Low–Impact Development Design: A New Paradigm for Stormwater Management Mimicking and Restoring the Natural Hydrologic Regime An Alternative Stormwater Management Technology

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Abstract

Whether complying with federal or state regulations or addressing local vital watershed protection/restoration objectives, local jurisdictions are confronted with the daunting task of developing, administering and funding complex effective multi-objective stormwater management programs, Today's comprehensive stormwater program not only has to deal with runoff quantity and quality control but, may also have to address such complicated issues as ecosystem restoration, combined sewer overflow reduction, fisheries protection, potable surface/ground water source protection, and wetland, riparian buffer and stream protection. As our understanding of the technical and practical limitations of conventional stormwater management technology has increased over the past two decades, and as watershed protection objectives have changed, many jurisdictions have begun to question the efficacy and cost-effectiveness of conventional stormwater approaches in meeting today's complex environmental/water resources objectives. Older communities with existing extensive stormwater management infrastructures are also struggling with the economic reality of funding the high costs of maintenance, inspection, enforcement and public outreach necessary to support an expanding and aging infrastructure. Still more challenging are the exceptionally high costs of retrofitting existing urban development using conventional stormwater management end-of-pipe practices to restore and protect receiving waters and living resources.

With growing concerns about the limitations of conventional technology and to address the changing objectives of watershed protection, in 1990 Prince George's County's Department of Environmental Resources (PGDER) began exploring alternative stormwater management practices and strategies. The development of bioretention or "Rain Gardens" (using the green space to manage runoff within small depressed landscaped areas) led to an understanding of how to optimize and engineer the landscape to restore hydrologic functions by uniformly integrating micro-scale management practices and impact-minimization measures into the development landscape. In 1997 PGDER released the Low Impact Development (LID) Design Manual demonstrating the principles and practices of LID to create a hydrologically functional landscape (PGDER, 1997).

LID stormwater management technology can maintain or restore a watershed's hydrologic regime by fundamentally changing conventional site design to create an environmentally and hydrologically functional landscape that mimics natural hydrologic functions (volume, frequency, recharge and discharge). This is accomplished in four ways. First: minimizing impacts to the extent practicable by reducing imperviousness, conserving natural resources and ecosystems, maintaining natural drainage courses, and reducing the use of pipes and minimizing clearing/grading. Second: recreating detention and retention storage dispersed and evenly distributed throughout a site with the use of open swales, flatter slopes, depression storage, rain gardens (bioretention), water use (rain barrels), etc. Third: maintaining the predevelopment "time of concentration" by strategically routing flows to maintain travel time. Fourth: providing effective public education and socioeconomic incentives to ensure property owners use effective pollution prevention measures and maintain management measures. With LID, every site feature is multifunctional (green space, landscaping, grading, streetscapes, roads and parking lots) and helps to reduce stormwater impacts or provide/maintain beneficial hydrologic functions. The cumulative beneficial impact of using the wide array of distributed LID techniques allows the site designer to maintain or restore watershed's natural relationship between rainfall, runoff, infiltration and evaporation.

The effective use of LID site design techniques can significantly reduce the cost of providing stormwater management. Savings are achieved by eliminating the use of stormwater management ponds, using less pipe, inlet structures, curbs

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and gutters, less roadway paving, less grading and clearing. Where LID techniques are applicable, and depending on the type of development and site constraints, stormwater and site development design construction and maintenance costs can be reduced by 25 % to 30% compared to conventional approaches.

The creation of LID's wide array of micro-scale management principles and practices has led to the development of new tools to retrofit existing urban development. Micro-scale management practices that filter, retain and detain runoff can be easily integrated into the existing green space and streetscapes as part of the routine maintenance and repair of urban infrastructure. LID retrofit techniques may lead to drastic reductions in the cost of retrofitting existing urban development. Reducing urban retrofit costs will increase the ability of cities to implement effective retrofit programs to reduce the frequency and improve the quality of CSOs and improve the quality of urban runoff to protect receiving waters. LID represents a radically different approach to controlling stormwater runoff that provides effective tools to restore or maintain a watershed's hydrologic functions for new or existing development.

In 1998 EPA provided grant funding to assist PGDER in their efforts to develop a general manual describing LID principles and practices, and share this technology with other local governments throughout the nation. Efforts are currently underway with EPA to further advance LID technology by improving the sensitivity of current hydrology and hydraulic analytical models for application with small watersheds and sites and to develop new micro-scale control approaches and practices for urban retrofit. Additional efforts are also underway to demonstrate how LID micro-scale management and multifunctional infrastructure principles and practices can be used to control highway runoff within existing rights-of-way. It is hoped that the LID national manual will help to stimulate debate on the state of current stormwater, watershed protection and restoration technology and its future direction. The lessons learned about LID planning, principles, practices and research are described in detail in the reference documents listed at the end of this paper. Copies of these reference documents can be obtained by calling the Prince George's County's Department of Environmental Resources at (301) 883-5832.

Background

Typically, adverse stormwater impacts are mitigated through conservation of natural resources (forests, streams, floodplains and wetlands); zoning restrictions to direct densities and increase open space; and the use of structural or non-structural control technologies (best management practices - BMP's) to treat and manage runoff quantity and quality. Many conventional stormwater mitigation approaches, such as management ponds, exhibit a number of inherent practical, environmental and economic limitations including inability to replicate predevelopment watershed hydrology, elevated water temperatures, costly maintenance burdens, and accelerated stream erosion due to the increased duration and frequency of runoff events. Furthermore, because current mitigation practices only lessen development impacts, there is concern about the cumulative impacts of the widespread use of conventional mitigation practices that may fundamentally alter a watershed's hydrologic regime and water quality, adversely affecting receiving waters and the integrity of their ecosystems. Many highly urbanized jurisdictions are beginning to question the efficacy of current technology and are finding it harder to ensure, enforce or fund stormwater programs and maintain the massive infrastructure created by conventional approaches.

Currently every site is designed with one basic overriding goal - to achieve good drainage. As we develop a site reshaping the landscape inch by inch, its hydrologicfunctionsare altered on a micro-scale level. The cumulative impacts of micro-scale changes to the landscape drastically alter watershed hydrology. If sites can be designed to achieve good drainage, destroying natural hydrologic functions, why not design sites with the opposite objective to maintain predevelopment hydrologic functions? If inch by inch, sites are carefully and intelligently engineered to maintain hydrologic functions, would the cumulative beneficial affects result in the preservation of a watershed's hydrology? Can a site be designed in a way to remain as a functional part of a watershed's hydrological regime? To achieve a hydrologically functional development there must be a radical change in our thinking. We must not think in terms of impact mitigation as the stormwater management objective, but rather preservation of hydrologic and environmental functions. We should design sites to maintain hydrologic functions not just to mitigate impacts. Can our current stormwater management technology adequately meet our regulatory objectives and water resources/ecosystem protection needs? No one can answer that question for sure. However, it has not been shown that conventional ponds replicate predevelopment hydrology nor is there any evidence to suggest that conventional technology can ensure the ecological integrity of

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ecosystems. In fact, recent studies suggest that conventional approaches can not meet our water/natural resources and ecological objectives.

Introduction

With growing concerns about the economicsand efficacy of conventional technology, in 1990 Prince George's County Maryland's Department of Environmental Resources began exploring alternative stormwater management practices. The success that was achieved through the development and use of bioretention (filtering or infiltration runoff in small depressed landscaped areas) led us to understand that perhaps changing the form and function of the developed landscape could be important in mitigating urban stormwater impacts. Later it was realized that through intelligent site design and uniform distribution of LID micro-scale management controls it was possible to maintain or restore hydrologic functions in a developed watershed. What is not known is how much of a watershed's hydrologic functions can be maintained or restored within a given development type (residential, commercial or industrial)? The one limiting factor to maintaining/restoring the hydrologic regime for highly urbanized development is the lack of available micro-management tools. Much of the current research underway is to expand the number of practices applicable in highly urbanized areas.

LID's objective is to preserve the natural predevelopment hydrologic regime. If predevelopment hydrology and water quality can be maintained, this would provide the best level of protection possible to receiving waters and aquatic living resources. Experience over the last 20 years has demonstrated that maximizing the efficiency of conventional conservation measures and the use of conventional end-of-pipe stormwater management practices can not reasonably be used to restore watershed functions. What is needed is a new philosophical approach to site development, an approach that will allow the designer to retain a site's hydrologic functions.

The approach used in LID designs is really an old one. LID borrows its basic principles from nature - uniform distribution of micro-management controls. In a natural setting, stormwater is controlled by a variety of mechanisms (interception by vegetation, small depression storage, channel storage, infiltration and evaporation) uniformly distributed throughout the landscape. LID mimics these mechanisms by uniformly distributing small infiltration, storage, and retention and detention measures throughout the developed landscape. What we soon began to see is that every development feature (green space, landscaping, grading, streetscapes, roads, and parking lots) can be designed to provide some type of beneficial hydrologic function.

Low - Impact Development General

LID controls stormwater at the source creating a hydrologically functional landscape that mimics natural watershed hydrology. Low impact development (LID) achieves stormwater management controls by fundamentally changing conventional site design to create an environmentally functional landscape that mimics natural watershed hydrologic functions (volume, frequency, recharge and discharge). LID uses four basic management planning and design principles. First: minimize impacts to the extent practicable by reducing imperviousness, conserving natural resources/ecosystems, maintaining natural drainage courses, reducing use of pipes and minimizing clearing and grading. Second: provide runoff storage measures dispersed uniformly throughout the landscape with the use of a variety of small decentralized detention, retention and runoff practices such as bioretention, open swales and flatter grades. Third: maintain the predevelopment time of concentration by strategically routing flows to maintain travel time and control discharge. Fourth: implement effective public education and incentive programs to encourage property owners to use pollution prevention measures and maintain on-lot landscape management practices. A developed site can be designed to become a hydrologically functional part of the watershed with comprehensive and intelligent use of LID practices and principles.

LID Basic Site Planning Strategies

The goal of LID is to design the site in a way that mimics hydrologic functions. The first step is to minimize the generation of runoff (reduce the change in the runoff curve number (CN)). In many respects, this step is very similar to traditional techniques of maximizing natural resource conservation, limiting disturbance and reducing impervious areas. The major difference with LID is you must carefully consider how best to make use of the hydrologic soil groups and site topography to help reduce and control runoff. These considerations would include how to:

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1. maintain natural drainage patterns, topography and depressions,

2. preserve as much existing vegetation as possible in pervious soils; hydrologic soil groups A and B,

3. locate BMP's in pervious soils; hydrologic soil groups A and B,

4. where feasible construct impervious areas on less pervious soil groups C and D,

5. disconnect impervious surfaces,

6. direct and disburse runoff to soil groups A and B,

7. flatten slopes within cleared areas to facilitate on-lot storage and infiltration and

8. re-vegetate cleared and graded areas.

Where ground water recharge is particularly important (to protect well, spring, stream and wetland flows) it is important to understand the source and mechanisms for ground water recharge. When using the LID design concepts to mimic the hydrologic regime you must determine how and where ground water on the site is recharged and where necessary, protect and utilize the recharge areas in the site.

LID Hydrologic Analysis/Response

The objective of LID site design is to minimize, detain and retain the post development runoff volumes uniformly throughout the site close to the source to simulate predevelopment hydrologic functions. Widespread use and uniform dispersion of on-lot small retention and/or detention practices to control both runoff discharge volume and rate is key to better replicating predevelopment hydrology. Using LID practices also produces runoff frequencies that are much closer to existing conditions than can be achieved by typical application of conventional BMP's. Management of both runoff volume and peak runoff rate is included in the design. This is in contrast to conventional end-of-pipe treatment that completely alters the watershed hydrology regime.

The LID site analysis and design approach focuses on four major hydrologically based planning elements. These fundamental factors affect hydrologic and are introduced below.

1. Curve Number (CN) - A factor that accounts for the effects of soils and land cover on amount of runoff generated. Minimizing the change in the post development CN by reducing impervious areas and preserving more trees and meadows to reduce runoff storage requirements, all to maintain the predevelopment runoff volume.

2. Time of Concentration (Tc) - This is related to the time runoff travels through the watershed. Maintaining the predevelopment Tc reduces peak runoff rates after development by lengthening flow paths and reducing the use of pipe conveyance systems.

3. Permanent storage areas (Retention) - Retention storage is needed for volume and peak control, water quality control and to maintain the same CN as the predevelopment condition.

4. Temporary storage areas (Detention) - Detention storage may be needed to maintain the peak runoff rate and/or prevent flooding.

Minimizing the Change in CN

Reducing the change in CN will reduce both the post development peak discharge rate and volume. Calculation of the LID CN is based on a detailed evaluation of the existing and proposed land cover so that an accurate representation of the potential for runoff can be obtained. This calculation requires the engineer/planner to investigate the following key parameters associated with LID including:

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1. land cover type,
2. percentage of and connectivity of impervious cover,
3. hydrologic soils group (HSG), and
4. hydrologic conditions (average moisture or runoff conditions).

The following are some of the LID site planning practices that can be utilized to achieve a substantial reduction in the change of the calculated CN:

1. narrower driveways and roads (minimizing impervious areas),
2. maximized tree preservation and/or afforestation,
3. site finger-printing (carefully siting lots/roadways to avoid disturbance of streams, wetlands and other resources), greater use of open drainage swales,
4. preservation of soils with high infiltration rates to reduce CN,
5. location of BMP's on high-infiltration soils and,
6. construction of impervious features on soils with low infiltration rates.

Maintaining the Predevelopment Time of Concentration Tc

The LID hydrologic evaluation requires that the post development Tc be close to the predevelopment Tc. Minimizing the change in pre and post Tc will help maintain the same frequency of runoff discharges, assuming there is uniform distributed micro-scale retention and detention of LID practices. The following are some of the site planning techniques can be used to maintain the existing Tc:

1. maintain predevelopment flow path length by dispersing and redirecting flows using open swales and vegetated drainage patterns,
2. increase surface roughness (e.g., preserving woodlands, vegetated swales),
3. detain flows (e.g., open swales, rain gardens, rain barrels etc.),
4. minimize disturbances (minimizing soil compaction and changes to existing vegetation /drainage patterns),
5. flatten grades in impacted areas,
6. disconnect impervious areas (e.g., eliminating curb/gutter and redirecting down spouts) and,
7. connect pervious areas to vegetated areas (e.g., reforestation, afforestation).

The combined use of all these techniques results in cumulative impacts that modify runoff characteristics to effectively shift the post development peak runoff time and frequencies to that of the predevelopment condition, and lower the peak runoff rate.

Maintaining the Redevelopment Curve Number and Runoff Volume

Once the post development Tc is maintained at the predevelopment conditions and the impact of CN is minimized, any additional reductions in runoff volume must be accomplished through distributed micro-scale on-site stormwater management techniques. The goal is to select the appropriate combination of management techniques that simulate the hydrologic functions of the predevelopment condition to maintain the existing CN and corresponding runoff volume. The target design volume is equal to the initial abstraction of rainfall that would have occurred in the predevelopment condition.

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LID site designs maximize the use of small retention practices distributed throughout the site at the source to provide the required volume storage. The required storage volume will be reduced when the change in the pre and post CN is minimized.

Retention storage allows for a reduction in the post development volume and the peak runoff rate. The increased storage and infiltration capacity of retention LID BMP's allow the predevelopment volume to be maintained. The most appropriate retention BMP's include:

1. bioretention cells (rain gardens),
2. infiltration trenches,
3. water use storage (rain barrels and gray water uses) and,
4. roof top storage.

Other possible retention BMP's include retention ponds, cisterns and irrigation ponds but it may be difficult to distribute these types of controls throughout a development site.

As retention storage volume is increased there is a corresponding decrease in the peak runoff rate, in addition to runoff volume reduction. If a sufficient amount of runoff is stored, the peak runoff rate may be reduced to a level at or below the predevelopment runoff rate. This storage may be all that is necessary to control the peak runoff rate when there is a small change in CN. However, when there is a large change in CN, it may be less practical to achieve flow control using volume control only.

Potential Requirement for Additional Detention Storage

In cases where very large changes in CN cannot be avoided, retention storage practices alone may be either insufficient to maintain the predevelopment runoff volume or peakdischarge rates or require too much space to represent a viable solution. In these cases, additional detention storage will be needed to maintain the predevelopment peak runoff rates. A number of traditional detention storage techniques are available that can be integrated into the site planning and design process for a LID site. These techniques include:

1. swales with check dams, restricted drainage pipes, and inlet/entrance controls,
2. wide, low gradient swales,
3. rain barrels/cisterns,
4. rooftop storage and
5. shallow parking lot/road storage.

Determination of Design Storm Event

The hydrologic approach of LID is to retain the same amount of rainfall within the development site as was retained prior to any development (e.g., woods or meadow in good condition) and then release runoff as the woods or meadow would have. By doing so, it is possible to mimic, to the greatest extent practical, the predevelopment hydrologic regime to maximize protection of receiving waters, aquatic ecosystems and ground water recharge. This approach allows the determination of a design storm volume that is tailored to the unique soils, vegetation and topographic characteristics of the watershed. This approach is particularly important in watersheds that are critical for ground water recharge to protect stream/wetland base flow and ground or surface water supplies.

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LID BMP's

Site design techniques and BMP's can be organized into three major categories as follows; 1) runoff prevention measures designed to minimize impacts and changes in predevelopment CN and Tc, 2) retention facilities that store runoff for infiltration, exfiltration or evaporation and 3) detention facilities that temporarily store runoff and release through a measured outlet. Table 1, below, lists some of a wide array of LID BMP's and their primary functions. Placing these BMP's in series and uniformly dispersing them throughout the site provides the maximum benefits for hydrologic controls.

Table 1. Examples of LID BMP's and Primary Functions

BMP	Runoff Prevention	Detention	Retention	Conveyance	Water Quality
Bioretention		X	X		X
Infiltration Trench			X		X
Dry Wells		X	X		
Roof Top Storage		X	X		X
Vegetative Filter Strips				X	X
Rain Barrels		X	X		
Swale and Small Culverts		X		X	X
Swales		X		X	X
Infiltration Swale		X	X	X	X
Reduce Imperviousness	X				
Strategic Clearing / Grading	X				
Engineered Landscape	X				
Eliminate Curb and Gutter	X				X
Vegetative Buffers	X				X

Water Quality

LID maximizes the use of the developed landscape to treat stormwater runoff. Not only can the landscape be used to store, infiltrate and detain runoff, the unique physical, chemical and biological pollutant removal/ transformation/immobilization/detoxification capabilities of the soil, soil microbes and plants can be used to remove pollutants from runoff. For example, bioretention basins or rain gardens are designed to use the upland soil/microbe/plant complex to remove pollutants from runoff. Rain gardens which look and function like any other garden except they treat runoff are designed with a layer of 2-3 inches of mulch, 2-3 feet of planting soil and vegetation (trees shrubs and flowers). Figure 1 shows a parking lot landscape island rain garden (bioretention practice) that uses a high rate filter media with plants to filter and treat 90% of the annual volume of runoff from the parking lot.



Figure 1. Parking Lot Rain Garden.

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Studies conducted by the University of Maryland have shown rain gardens to be very effective in removing pollutants. The percent pollutant removal of various contaminants is shown below in Table 2. The results shown represent the average removal rates under a wide variety of flow rates and pollutant concentrations.

Table 2. Percent Pollutant Removal by Rain Gardens

cu	Pb	Zn	P	TKN	NH4+	NO3-	TN*
%	%	%	%	%	%	%	%
93	99	99	81	68	79	23	43

. Removal varied as a function of depth in the soil. Percent removal shown is at a depth of approximately 3 feet.
Testing Conducted by the University of Maryland, Department of Engineering

The variety of physical, chemical and biological pollutant removal mechanisms available in the complex rain garden system is staggering. A description or explanation in any detail of these mechanisms is beyond the scope of this paper. A more detailed description can be found in the 1998 “Optimization of Bioretention Design” study conducted by the University of Maryland. Mulch has been found to be very effective in removing heavy metals through organic complexing with the hydroxyl and carboxyl sites on the organic molecules. Soil bacteria can metabolize (use as a carbon energy source) oil, grease and gasoline into CO2 and water in the presence of adequate nutrients and oxygen. Soil bacteria have been used for years for the remediation of contaminated soils. Plants are known to uptake, transpire, accumulate and detoxify heavy metals and many other toxic compounds. The physiologic and metabolic processes of plants are used to clean contaminated soils through phytoremediation. A goal of LID is to maximize the use of upland landscape with its soil/ microbes/ plant complex to treat runoff. Using upland systems to trap and remove pollutants allows one to more easily control the fate of contaminants and prevent them from entering the water column where they are almost impossible to contain and remove.

Public Outreach and Pollution Prevention

Pollution prevention and maintenance of on-lot LID BMP’s are two key elements in a comprehensive approach. Effective pollution prevention measures can reduce the introduction of pollutants to the environment and extend the life of LID treatment BMP’s. Public education is essential to successful pollution prevention and BMP maintenance. Not only will effective public education complement and enhance BMP effectiveness, it can also be used as a marketing tool to attract environmentally conscious buyers, promote citizen stewardship, awareness and participation in environmental protection programs and help to build a greater sense of community based on common environmental objectives and the unique character of LID designs.

Costs

LID case studies and pilot programs show that at least a 25% reduction in both site development and maintenance costs can be achieved by reducing grading and the use of pipes, ponds, curbs and paving. In one subdivision called Somerset which used the rain garden LID technique for water quality controls, the developer saved $4,500 per lot or a total of $900,000 by eliminating the need for curbs, ponds and drainage structures. Maintenance costs are also reduced in scale and magnitude by using the small LID practices. LID site designs require only routine landscape care and maintenance of the vegetation, This eliminates the high costs of pond maintenance associated with dam repairs and dredging.

Road Blocks to LID

In the development and acceptance of the LID site planning approach, a number of roadblocks had to be overcome. Regulating agencies, the development community and the public all had concerns about the use of new technology. The

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LID design manual represents the culmination of four years of work to address all of these concerns and issues. Some of the major components of the LID approach, which addressed the many concerns, include:

1. develop an hydrologic analytical methodology to demonstrates the equivalence of LID to conventional approaches,
2. develop new road standards which allow for narrow roads, open drainage and cluster techniques,
3. streamline the review process for innovative LID designs which allow easy modification of site, subdivision, road and stormwater requirements,
4. develop a public education process which informs property owners on how to prevent pollution and maintain on lot BMP,
5. develop legal and educational mechanisms to ensure BMP's are maintained,
6. demonstrate the marketability of green development,
7. demonstrate the cost benefits of the LID approach,
8. provide training for regulators, consultants, public and political leaders and,
9. conduct research to demonstrate the effectiveness of bioretention BMP's.

Summary

LID is a viable economically sustainable alternative approach to stormwater management and the protection of natural resources. LID provides tangible incentives to a developer to save natural areas and reduce stormwater and roadway infrastructure costs. LID can achieve greater natural conservation by using conservation as a stormwater BMP to reduce the change in CN. As more natural areas are saved, less runoff is generated and stormwater management costs are reduced. This allows multiple use and benefits (environmental and economical) of the resource.

Additionally, developers have incentives to reduce infrastructure costs by reducing impervious areas, and eliminating curbs/gutters and stormwater ponds to achieve LID stormwater controls. Reduction of the infrastructure also reduces infrastructure maintenance burdens making LID designs more economically sustainable. Superior protection of aquatic and riparian ecosystems can be achieved since a LID developed watershed functions in a hydrologically similar manner as the predevelopment conditions. Recreating the predevelopment hydrological regime is a better way to protect the receiving waters than the conventional end-of-pipe mitigation approaches.

LID promotes public awareness, education and participation in environmental protection. As every property owner's landscape functions as part of the watershed, they must be educated on the benefits and the need for maintenance of the landscape and pollution prevention. LID developments can be designed in a very environmentally sensitive manner to protect streams, wetlands, forest habitat, save energy, etc. The unique character of a LID green development can create a greater sense of community pride based on environmental stewardship.

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MASSACHUSETTS LOW IMPACT DEVELOPMENT TOOLKIT homepage

Welcome to the Massachusetts Low Impact Development Toolkit homepage.



Low Impact Development (LID) strategies use careful site design and decentralized stormwater management to reduce the environmental footprint of new growth.



This approach improves water quality, minimizes the need for expensive pipe-and-pond stormwater systems, and creates more attractive developments.

The Massachusetts Low Impact Development Toolkit is a set of materials designed to help citizens, public officials and developers implement LID.



We are continually adding new material to this site, so please check back frequently. For more information or to order hard copies of our materials, please email: lid@mapc.org.

Explore the Toolkit:

- An introduction to LID—for public officials, advocates, & citizens
- An introduction to LID—for developers and property owners
- An introduction to LID—for engineers, planners, and landscape architects
- Low Impact Development FAQs
- Stormwater Bylaws and Low Impact Development
- LID Local Codes Checklist
- Low Impact Development Slide Show
- Internet Links and Resources

LID Fact Sheets

- Low Impact Site Design
- Roadways and Parking Areas
- Permeable Paving
- Bioretention
- Vegetated Swales
- Filter Strips
- Infiltration Trenches and Dry Wells
- Cisterns and Rain Barrels

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- Green Roofs

Credits:

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Outer Bank Hydrology Management Committee

Report of Findings

November 3rd, 2005

1.0 INTRODUCTION

When there were live dune fields and windswept beaches, rainwater quickly infiltrated into the landscape and replenished fresh water lenses that lay under the sand. In some places this freshwater supply was suspended in the soil, perched upon a shallow clay layer; in others, it floated under the sand upon the denser salt water. These waters eventually move out to the ocean or estuary by underground seepage.

Away from the burning coastal winds, in protected areas, forested wetlands and pocosins grew between dune ridges pocketed with ponds and swamps. In these systems, the majority of rainwater was processed by evapotranspiration (ET) (Daniel, 1983). ET occurs when plants take up water and nutrients to grow. The excess water is off–gassed into the atmosphere through their leaves. As a result, coastal ponds can be full of water in the winter and, once leaves emerge in the spring, the plants consume the water, often drying out the ponds completely.

Historic documents and local stories portray visions of the Outer Banks with abundant fish stocks, healthy waters, thriving wildlife, and lots of insects! However, with all ecosystems, much changes with time. On the Outer Banks, the landscape has changed considerably within the last two generations. The catalyst for this change has been both man and nature-driven, but regardless of the cause, in every sector of our community, there are sincere concerns about the health of our natural and human ecosystems. Much of this concern is focused on the impacts related to stormwater. Research has demonstrated that even in low density urbanized areas, the majority of rainwater that falls on the landscape rapidly drains to create excess surficial ground, storm and flood water (White et. al., 1999). This water can often be highly polluted (White et al., 1999). Rain itself is not typically considered a pollutant, but when it contacts the landscape and picks up nutrients, organic matter, pathogens, sediment, metals or volatile organic carbons (VOCs), then the water becomes a pollutant too. The extent of the threat can vary, but the fact that polluted water has the potential to do harm, cannot.

Impacts associated with polluted runoff water have also been found in watersheds with farming and forestry activities (White and Line, 2004). This can be attributed to the fundamental way that grading, soil compaction, ditching, draining and vegetation removal — not just pavement -- alter watershed hydrology. These facts demonstrate that sustainability will require a new management paradigm.

Watershed hydrology, water budget, and hydrologic cycle are all expressions referring to various processes that comprise the mechanisms and vectors involved in cycling water through the landscape and atmosphere. That is, when it rains, some portion of water runs off (some is normal), some infiltrates to ground water (both surficial and deep), and some returns to the atmosphere via evapotranspiration or ET from plants or ground surfaces. What is normal? It

varies by watershed. Studies conducted in coastal forested pocosin systems document that as much as 70-80% of the water that falls on the landscape is processed by plant-driven ET (Daniel, 1983). Conversely, empirically collected data also provide documentation that as much as 70% of the total volume of rainfall falling on developed land leaves the system as runoff twice as fast as in a vegetated landscape (Line and White, 2004). Simply put, developed landscapes do not store as much water as long as natural landscapes.

Stormwater runoff problems are further complicated on the coast by the seasonally high ground water levels. Areas that are paved or built upon are no longer available to process rainfall so the remaining landscapes can become over-saturated and flood. Another complicating factor is that plant removal reduces the amount of water removed from the landscape by evapotranspiration. Plants can consume a tremendous amount of water, and tree losses can significantly affect stormwater runoff volume levels costing communities millions of dollars to build stormwater management infrastructure to replace the services trees once provided for free((American Forests, 2005).

The dynamics and impacts vary from street to street, neighborhood to neighborhood, but these are the basic mechanisms contributing to excessive stormwater and flooding on the Outer Banks. These problems have created a multitude of negative consequences from "posted" beaches and closed shellfish waters to damaged property--leaving no segment of our coastal community and aquatic ecosystems free from the effects.

Senator Basnight challenged us to work on this problem when a series of large and frequent rainfall events in July and August of 2004 exhibited the extent of the problem. The Senator noted in his letter to the committee members that, "First and foremost, I see this problem as needing a multi-governmental solution. Indeed, there are problems that are being caused by inadequate management of road drainage, but there are also many problems being caused as a result of less than friendly development practices. To that end, I would propose that a group be established to study this issue and develop recommendations for adoption that will get at these problems." (See Appendix for complete version of Senator Basnight's letter).

The Outer Banks Hydrology Committee, made up of representatives from Dare and Currituck county governments, all the towns in northern Dare, the NC Division of Water Quality, NC Division of Environmental Health, NC Department of Transportation, NC Homebuilders and Realtors Associations, Dare and Currituck Natural Resource Conservation Districts, Dare County Water System, NC Department of Transportation, and NC Coastal Federation convened on September 21. The committee held 11 meetings, participated in over 45 hours of contact time, heard 15 speakers on topics such as coastal hydrogeology, water reuse, drinking water, transportation, low impact development and green building (See Appendices for meeting notes). After the generous contributions of time by many expert speakers as well as by committee members sharing their expertise with each other, the members realized that the Outer Banks water budget is grossly out of balance. They also agreed that water resource management on the Outer Banks needs (for both problem identification as well as solution development) a holistic approach addressing the entire hydrologic water budget and working across government and agency jurisdictions. The committee agreed that we cannot "restore" the hydrology of the Outer

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Banks, but we need to reconstruct and manage the system in a manner that we hope will "do no harm".

The rainfall events which occurred in July and August, 2004 dumped an excessive amount of water on the Outer Banks, overloading the landscape and stormwater management systems--ditches, creeks, yards, and pipes filled spilling over to flood roads and homes during a year when extreme and frequent rainfall events had saturated the groundwater table. Were the problems witnessed during the summer of 2004 primarily attributable to excessive rainfall? Or is it attributable to increased runoff from all the development which has occurred on the Outer Banks in the last 15 years? Yes and no to both. The committee realized that these events afforded us an opportunity to see the consequences if we do not take action. Outer Banks communities have an opportunity to improve as well as reduce potential future problems through proactive management.

To develop the recommendations in this report, the committee reviewed how we develop and manage three distinct areas of the Outer Banks: 1) the landscape; i.e. the land area of the watershed that we use for our homes, businesses; 2) the streets, roads and associated rights of ways (ROW's); and one fairly unique feature, 3) the ocean and sound outfalls. Their findings are organized into a review of the causes of the problems, solutions, and closing with implementation strategies.

2.0 CAUSES

2.1 Landscape Issues:

Losses in vegetation associated with land development--lot clearing, filling, and grading—have significantly reduced the mechanisms by which water is removed from the landscape via evapotranspiration (ET). The problem has accrued incrementally, stem by stem, lot by lot.

Land development has caused incremental reductions in small wetland areas resulting in lost storage and assimilative capacity throughout the watersheds. Further compounding lack of storage capacity is the increased areas of impervious surfaces (compacted gravel, clay, paving, rooftop, patio or driveway). These areas cannot infiltrate water and generate more runoff. The cumulative effects are too much water for too few places, and during large rainfall events, flooding.

Runoff water overwhelms ditches and swales as well as vacant lots, which act as coincidental storage, because they weren't designed to handle the increased volume of water associated with the activities and impacts noted above. Additionally, many swales on state, town, and private subdivision roads have been filled and planted with sod by adjacent property owners. Property owners also tend to grade their lots and driveways to drain to the street—adding an unknown quantity of water to the system which it is also not designed to handle. Furthermore, many existing ditches and swales need maintenance. In most cases, the responsible agency is unaware of the problems or does not have the resources to maintain them. Lastly, but not the least of the causative factors, is that many projects add fill material to their lots to accommodate septic systems, facilitate views, and reduce risk of flooding — independent of its affect on adjacent landscapes or the capacity of stormwater systems.

Another exacerbating factor is irrigation. Property owners unwittingly contribute to the saturation and flooding problem by irrigating without any management. Sprinklers are regularly observed operating irrespective of rainfall and even during storm events.

The complexity of managing stormwater effectively is compounded by the myriad of regulatory and governmental agencies whose responsibilities are co-mingled, but not coordinated or understood by each other. Stormwater –related development impacts occur at the parcel scale, which are largely unregulated. Neither the Coastal Area Management Act program nor the NC-DENR stormwater program require stormwater management practices if the individual parcel is built under the low density option (less than 30% total impervious surface area per lot). The sediment and erosion control program administered by the NC Division of Land Quality only regulates stormwater if more than one (1) acre is to be disturbed.

2.2 Roads, Highways, ROW's, and the Outfalls:

Roads and highways generate but predominantly collect and transport stormwater. DOT and town roads also suffer from similar impacts resulting from uncoordinated and unplanned stormwater management. For example, portions of US Highway 158 were originally elevated, but over the years, filling to accommodate adjacent development has made it difficult for the road to drain properly. Additionally, the number of pipe connections to the road side drainage system has increased so the increased volume of water frequently causes flooded roads and ditches. Stormwater management is currently not coordinated between local government and North Carolina Department of Transportation (NCDOT) because the resources to review every property and site plan do not currently exist.

Ocean and sound outfalls were installed to prevent flooding on the highways, and work as designed. However, stormwater carries a wide variety of pollutants, and the discharge reduces water quality and poses an unknown level of threat to public health. It is the recommendation and goal of this committee that if at all possible, the necessary assessment and mitigation activities be implemented to remove the outfalls, or at a minimum, that the frequency of discharging events be greatly reduced.

3.0 SOLUTIONS

There is no single magic bullet to solve the stormwater and flooding problems. The causative factors for the problems evidenced on the Outer Banks in the summer of 2004 were generated incrementally with changes in land use associated with the development process. To "fix" the flooding problems without compromising water quality in the ocean and the estuary, there will need to be a long term commitment to find ways to integrate jurisdictional responsibilities and foster implementation of flexible strategies that can be applied at a variety of scales and jurisdictions to sustain both the human and environmental ecosystems.

3.1 Landscape Issues

Hydrologic conditions need to be quantified for all the watersheds on the Outer Banks. One approach was recommended by an expert hydrogeologist, Ed Andrews of Andrews and Associates at one of the early meetings. It involves mapping the location and distribution of the perched ground water layers, developing a 3-D map of the water table, and intersecting that data with the spatial map of the complaints. This would identify areas with both systemic and functional commonalities. This approach facilitates developing strategies for problem repair.

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However, in the short term, and as a first step, communities need to reclaim their roadside drainage ditches. This will greatly improve storage and infiltration capacity, and a targeted effort to address chronic problem areas is advisable. Also, in the short term, because damage caused by lost vegetation is long term, communities should enact a vegetation protection ordinance or protection review process. Some communities, which have done this, have appointed a local committee specifically to review site plans to implement the ordinance or to make sure provisions of the ordinances are followed. However, other communities have found that they can be effective using existing site plan review procedures.

Water conservation and landscape guidelines are needed. These programs can help to reduce plant losses caused by unnecessary land disturbance, guide landscaping choices towards natives, which need less water and fertilizer, as well as establish good irrigation practices to reduce ground water saturation problems, and reduce incidences of activities that drain additional water to the streets. Good housekeeping guidelines can be included that reduce pollutant load associated with fertilizer use and improperly managed pet wastes.

Water conservation guidelines and landscape ordinances are commonly practiced in many parts of North Carolina, so guidelines for these programs are readily available.

3.2 Low Impact Development (LID) Guidelines:
One promising approach that may offer some solutions for managing stormwater is using the strategies suggested in Low Impact Development (LID).
The Five goals of LID are as follows:
1. To conserve native landscapes
2. To minimize impacted areas.
3. To increase time of concentration and retention of rainwater in the landscape.
4. To implement stormwater management methods which reconstruct predevelopment hydrology.
5. To prevent and minimize pollution sources.

The philosophy of LID is to implement best management practices so that the post-development hydrology of a land unit mimics its predevelopment condition. Sounds simple, but there are two critical components to the implementation of LID that must be quantified in order for it to work successfully. First is the determination of each land unit's pre-development hydrologic condition, that is, how much water infiltrates, runs off, or evaporates. As recommended above, areas having similar conditions such as seasonal ground water levels, soil type and land cover are delineated, grouped, and these water budget functions are quantified. The second step involves determining the management practices that can be used to maintain the hydrology for a given development project and its impacts. These practices can take a variety of forms: conservation, constructed features, green building techniques and so forth. Ideally, a menu of treatments could be compiled and rated for the functional service each provides allowing each development project to choose how they wish to maintain pre-development hydrologic conditions. One note of caution, because LID assessment and implementation methods are new; there are essential analyses which need to be conducted to understand how to integrate it into current development, planning, and stormwater management programs. However, LID, may offer Outer Banks

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communities more flexibility to increase densities in some areas as well as incentives to protect landscapes that are near sensitive resources. This should increase opportunities for economic development, habitat protection, and conservation.

2.3 Highways, Roads, ROWs, and Outfalls:
Ocean and sound outfalls are problematic because they are needed to keep highways and homes from flooding, but the discharge from them is polluted to an unknown extent. Given the data collected in other locations, the EPA considers the discharge water to be a public health threat; so any time there is water flowing through the system connected to the outfalls, the beaches, in the vicinity of the discharge, are posted with warnings.

A short term issue is that maintenance is presently needed for the outfalls to function and remove water efficiently from the road ways and connected drainage structure. Funding and resources within NCDOT need to be directed specifically for outfall drainage maintenance—both to address compromised roadside infrastructure and outfall pipes.

However, the committee agreed that the outfalls are not an ecological or water quality asset. An important and desirable goal is to remove the outfalls if possible, but at a minimum to reduce the events during which there is discharge. To begin this process, we need to know more about the watershed areas contributing water to discharge from the pipes. How much water flows during typical events? How much water flows during catastrophic events? How polluted is the water? How much water is contributed from various parts of the landscape? To know the extent of water quality treatment and volume control practices needed, these outfall drainage areas need to be assessed.

In addition, management practices to treat and reduce the volume of water coming into the system need to be identified, designed, and built. The reinstatement of the roadside ditches by both the towns and DOT on their state roads to increase retention and infiltration functions has been noted and is much needed. There may be potential using water control structures to reduce the number of discharge events.

The committee also recommends that DOT investigate redesigning flood-prone highway areas for treatment and storage opportunities that may be integrated with the highway infrastructure. For example, the median could potentially be made into a rain garden or constructed wetland—storing and treating excess rainfall. Another option would be to install an underground water storage facility. The stored water could be made available through bulk hauling for fires, washing, or other non-potable application.

Flooding may also be alleviated by raising the elevation of the existing roadway. It was also suggested that excess water accumulating on US 158 could be pumped to an artificial wetland island in the sound created from dredge spoil—thereby recreating habitat that has been lost due to shoreline hardening and erosion—however, concerns about environmental impacts were strongly expressed, and this idea was not discussed fully.

The committee strongly recommended that coordination on planning, design, review and permit process between DOT and local jurisdictions regarding curb cuts, driveways, pipe sizes, and road

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side storage is needed. Communication is also needed to address cross jurisdictional management of drainage from individual lots and subdivisions, discharge into and the maintenance of road side swales and ditches, and size and frequency of driveway connections. However, in order for these recommendations to be implemented, the mandate for NCDOT needs to be expanded. They need to have the authority to coordinate with the localities within which they work. NCDOT staffing will need to be increased and dedicated to focus specifically on permit coordination and review.

4.0 IMPLEMENTATION ISSUES

A tremendous amount of work needs to be done, and the committee agreed that an Outer Banks Hydrology Management Consortium should be established, made up of representatives from each community, to foster and guide the initiatives recommended in this report. The consortium can provide coordination and consistency between communities. It can also provide a forum by which communities can share and help each other.

Cost is a concern with regard to implementing these recommendations. Local governments should commit funding to support this consortium and to help initiate these efforts more quickly. The consortium can work together to find, manage and focus funding as well as help coordinate and direct educational efforts . Communities may need to implement stormwater utility districts to enact one time fees, develop incentives, or charge recurring fees to help generate the needed funds. To develop the needed information to implement these programs, consultants will need to be hired to conduct the assessments, develop guidelines and procedures. In the interim however, efforts to reduce wetland impacts, conserve and maintain open space, and limit fill are needed to minimize additional problems.

The consortium can also provide a venue for coordination with Dare County agencies which currently have no stormwater responsibilities. In particular, there are incongruities between the goals of this report and day to day implementation strategies utilized by the Department of Health. For example, the Department routinely recommends fill as a standard practice to permit new septic systems, and this can contribute to stormwater management local problems. Their participation in the consortium would assist with coordination of the Health Department's permitting process with the towns' and counties' stormwater management strategies.

Other activities which could be coordinated by an Outer Banks Hydrology Management Consortium would be to help develop consistent incentive-based or cost share programs that would encourage communities to use these ideas—particularly with regards to the implementation of LID. Critically, an effort is needed to facilitate the use of hydrologic curve numbers, end the exemptions for filling wetlands, increase buffer and native vegetation protection under CAMA, but conversely allow communities to increase densities through density trading (conservation areas traded for increased density to protect habitat).

The consortium could help garner the involvement of the watershed's citizens as well as provide a venue for partnering with other agencies such as the NC Department of Transportation (NCDOT) and NC Ecological Enhancement Program (EEP). The consortium could also assist with the delivery of watershed education programs, which will be needed to successfully implement these initiatives.

5.0 Additional comments regarding reuse:
While the committee initially had a strong interest in the potential for water reuse as a solution to excess stormwater, but there are several road blocks to implementing this idea on a regional scale. First and foremost, because the Outer Banks has no community wide sewer system, there is no infrastructure in place to collect and redistribute the water. It cannot be collected off the ground because becomes too dirty and difficult to treat for any type of reuse. However, LID and green building both recommend the use of cisterns. Decentralized cistern use on individual buildings has great potential to address many water –related problems. Cisterns can reduce the demand on potable water supplies. Since the Outer Banks invests substantially in water infrastructure to meet summer water demands, the use of cisterns could alleviate pressure on the supply during the summer peak season. Cisterns, properly designed, are also an effective stormwater reduction and treatment device. Reuse of the rainwater at a later date, redistributes the volume of water to reduce storm event-related impacts.

6.0 SUMMARY
The problems manifested on the Outer Banks late in the summer of 2004 are not unique to this region. Across the state of North Carolina, hydrologic management addressing both quantity and quality is coming to the forefront as one of the preeminent environmental issues of our time. Changes in watershed hydrology affect groundwater recharge rate, stream base flows, and aquatic habitat structure in ways that affect water quality, fisheries, and overall stream ecosystem function. Increases in polluted runoff into stream systems add to damages caused by hydrologic impacts. Scientists struggle with developing research fast enough to provide relevant data that will assist public policy makers in their decisions, but indicators such as fisheries losses, algal blooms, shellfish closures, and increasing property damage to homes and roads mean we what we have been doing is not sustainable.

The members of the Outer Banks Hydrology Management Committee include a diverse array of interests, from municipal and county governments to representatives of the real estate industry and conservation community. We submit these recommendations with the belief that they provide a solid framework for conducting a truly innovative and sustainable stormwater management and hydrologic reconstruction program for the Outer Banks.

Respectfully yours,

Committee Members and Participants:

Wayne Mobley/ NC DEH
Tricia Huffman/ Town of Kitty Hawk
Tom Reeder/ NC DWQ
Ted Sampson/ NC DCM
Steven Shriver/ Dare County
Rufus Croom/ NRCS – Dare SWCD
Robert Tankard/ NC SWD
Randy Metzger/ Town of Kill Devil Hills
Nancy White/ UNC Coastal Studies Institute

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Mike Hejduk/ Town of Southern Shores
Mike Doxey/ Currituck Soil and Water
Kevin Schwartz/ Outer Banks Homebuilders Assoc/Outer Banks Assoc. Realtors
Jim Rivera/ Martin's Point Homeowner's Assn
Jim Butz/ Walnut Island Assn
JD Potts/ NC DEH Recreational Waters Program
Jan DeBlieu/ NCCF
J. Webb Fuller/ Town of Nags Head
Gil Falasco/ Currituck County
Gary McGee/ Town of Kitty Hawk
Erin Burke/ Town of Manteo
Ed Sampson/ NC DCM
Dwane Hinson/ Albemarle RCD
Debbie Diaz/ Town of Kill Devil Hills
Dave Clark/ Nags Head Public Works
Darrell Merrell/ Town of Kill Devil Hills
Dan Shields/ Southern Shores Town Council
Dan Scanlon/ Currituck County
Chris Layton/ Town of Duck
Bob Oreskovith/ Dare County Water
Allen Russell/ NC DOT
Alan Saunders/NC Shellfish

Guest Speakers:
Ed Andrews, Andrews and Associates
Joe Anlauf, Quibel and Associates
Larry Coffman, LID Strategies, Associate Director, Dept of Natural Resources, Prince George's County, Maryland
Mary Tod Winchester, Chesapeake Bay Foundation
Bill Hunt, Stormwater NCSU Extension Specialist
Barbara Doll, Sea Grant Water Quality Specialist
Christy Perrin, Program Coordinator, NCSU Watershed Education For Communities &Officials.
Jennifer Plat, Town of Cary
Betsy Pearce, Town of Cary
Dave Henderson, NC DOT
Allen Russell, NC DOT
Anthony Roper, NC DOT

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APPENDICES

Letter from Senator Basnight

September 8, 2004

Dear :

Thank you so much for your participation in the stormwater summit last week. I was very pleased with the interest in this most important subject and the willingness to address this critical situation in our area. I have given much thought to those things that we should be doing to correct this problem and am ready to make a few recommendations that I believe will get us on the path of resolution.

First and foremost, I see this problem as needing a multi-governmental solution. Indeed, there are problems that are being caused by inadequate management of road drainage, but there are also many problems being caused as a result of less than friendly development practices. To that end, I would propose that a group be established to study this issue and develop recommendations for adoption that will get at these problems.

In structuring this working group, I would propose that Nancy White, director of the Coastal Studies Institute, chair this working group. In addition to Nancy, I believe a representative from each municipality and each county should serve on the group. These individuals should be appointed by each of the respective boards and should be an individual that will be willing and available to devote a serious amount of time to the task, perhaps the town or county manager or the town or county engineer. Finally, I believe that it is important that representatives from various agencies of the state join in this discussion from the perspective of technical practicality and permissibility under state laws and regulations. Specifically representatives of the Divisions of Environmental Health, Water Resources, Water Quality, Coastal Management in the Department of Environment and Natural Resource and the Department of Transportation should be invited to attend.

After a cursory review of the situation and based on my site visits I believe that a myriad of solutions could be implemented. First on the acute issues, I believe the drainage problems at Gooseander are best remedied by elevating the properties and I will be sharing my thoughts with the homeowners there. Although I believe that DOT is contributing some portion of the stormwater standing on the properties, our efforts to correct the DOT problem will not resolve all their needs.

On the long-term front, I believe that we must develop a phased approach to stormwater that applies the concepts of retention, collection, treatment, reuse, and discharge. Under retention, we must examine the various ways that we can accept stormwater on our properties and retain them for personal use including irrigation, fire suppression and individual plumbing needs.

After maximizing our retention efforts, we must find a way to collect the stormwater presently generated in a comprehensive and efficient collection system. Indeed our current

collection mechanism is grossly inadequate to meet the needs of chronic everyday rainfall events, not to mention those catastrophic events that occur. An efficient collection system would have at its core the ability to taken a given amount of rainfall, for instance the first 3 inches in a fashion that water does not stand on property.

Upon reaching an efficient collection strategy, we should target our efforts at ensuring that any water taken in by the collection system be treated. My limited research indicates that there are numerous treatment strategies available on the private market. These strategies should be investigated for their feasibility of use in our area. Indeed, the working group may decide to develop an RFP for the engineering community to consider that would join our collection and treatment goals. This RFP could be reviewed by the working group and then proposed for adoption by the various governmental entities.

Once treated, I personally believe that we should examine the goal of reuse. As I stated in my discussions with you earlier, my impressions of the facilities at Walt Disney World in Florida are the wave of the future and are examples of exactly what we ought to be doing to protect the environment. As mentioned earlier, reuse strategies such as irrigation, fire suppression and alternative plumbing system seem to be very practical and easily implemented solutions for this problem. I would encourage this group to look very closely at the ideas and I would offer my office up to assist in making contacts with the folks at Disney for presentation.

Finally, that water that cannot be reused but is still treated should be allowed for discharge into adjacent water bodies so long as there is no degradation to the surrounding water body as a result of the discharge. Discharge should be viewed as a last resort. Indeed with the water needs that I am certain our area will be facing in the near future, the promise of using stormwater to help address these needs will provide us all just the resolution that we need to help "kill two birds with one stone." However, I am also cognizant of the need to be prepared in the event that we are unable to take all the water on. To that end, ensuring that the resultant discharge is clean is of paramount concern to me.

These strategies will all involve some additional cost to us. I believe the working group should look at these costs in addition the strategies that they set out. In many areas, the availability of a stormwater fee would help finance these costs. For instance, the City of Raleigh currently has enacted a fee to help maintain and repair their existing stormwater drainage system. All parties in the city are assessed a flat amount commensurate with the type of development they are in – commercial, residential, etc. Some thought should be given to such a fee in our area to help field the costs of this system. Perhaps the localities may choose to establish a stormwater drainage district in a given area and assess the residents of the district. This would allow for stormwater problems to be targeted to a specific area of need with those folks in the district bearing the cost.

These ideas that I share with you are but one way to address the issue of stormwater in our area. I encourage you to give careful thought as well to this problem. It is an issue that I am confident that we can address if we put our minds to it. In order to begin the work of the committee I have asked Nancy White to convene the first meeting of the work group on Tuesday, September 21, 2004 at 10 A.M. at 108 Budleigh Street, Manteo, North Carolina.

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Thereafter, I would propose that the group meet every other Tuesday through the end of the year with periodic progress reports for the various elected officials. It is my hope that the working group will bring forth recommendations during this time period to address the issues as outlined above and any legislative proposals that the collective bodies deem appropriate prior to the convening of the 2005 Session of the General Assembly. I look forward to hearing from you your thoughts on this proposed process and your appointments to the working group. Please contact Anne Kenny at 252-475-3663, x. 24, to let her know of your appointments and attendance at this meeting.

Again, thank you for your strong interest in this issue and please let me know how I can continue to help facilitate a resolution. It is a pleasure to serve you.

Sincerely,

Marc Basnight

MB/rb

Meeting Notes

Outer Banks Hydrology Management Committee Meeting
Tuesday, Sept. 21, 2004
10:00 a.m.
108 Budleigh Street, Manteo, NC

Present: See attached Sign - In Sheet

Convened by Nancy M. White, Director, UNC Coastal Studies Institute.

Dr. White presented asked the group to consider how they would like to proceed with the tasks they have been asked to address, and noted that committee has a unique opportunity to contribute to the development of policy that will affect development and land management on the Outer Banks.

Those present introduced themselves, stated which agency/ town they represented, and their primary issues and concerns.

Chris Layton, Town Manager from Duck, said he is learning about and concerned with stormwater flooding problems especially on NC 12. He says that issues related to minimizing flooding and keeping the road open are complex. He noted that Duck does not have ocean outfalls, possibly one sound outfall, and no stormwater infrastructure. Duck has hired a consulting engineer on staff from Quibel. They also have the Council's the commitment to share the cost of a study. Layton will be working on the study and with this group concurrently.

Erin Burke is the Town Planner from Manteo. She noted that the town has just gotten a grant to work on water quality issues. The town currently has six (6) outfalls. They have already hired a consultant. The grant is to for planning not implementation.

Steve Shriver is the Dare County Engineer. As such his responsibilities cover the unincorporated parts of the County which has a wide range of land use types many of which are unique. The basic stormwater management strategy has been roadside and lot-side drainage ditches. The County does not have any roadway responsibilities.

Alan Russell is the Dare & Currituck Counties Maintenance Engineer for NC DOT. Dave Henderson couldn't make it today, but he will also be attending in the future. Alan commented that he feels like he knows where the problems are today, but that could change tomorrow. Their policy on when to pump during storm events is when they are requested to do so by NC Emergency Management.

Dan Scanlon is the County Manager for Currituck County. He noted that the County does not have a stormwater management plan, but has hired an engineer to study the problem. He noted that they have created a stormwater district at Whalehead. Dan expressed concern about how store the volume of water needed to alleviate flooding and where/how to discharge? They have one permitted discharge into the ocean for county water system. He expressed interest in studying deep acquifer storage as an possible alternative.

J.D. Potts from DENR Shellfish Sanitation stated that his program monitors recreational waters and use EPA guidelines whether or not to post swimming and contact advisories. They have found that runoff is responsible for 90% of water problems.

Wayne Mobley, Section Chief for DENR Shellfish Sanitation stated that their responsibility is to monitor and advise recreational waters and shellfish harvesting areas. He also noted that they have a LOT of data and the obvious trend is that development equals increased bacteria levels which lead to increased closures. They want to find a solution and are very willing to work. Solutions will be good for everyone.

Debbie Diaz from the Town Kill Devil Hills stated that they have a Stormwater Management Plan. They do not have an engineer on staff, but have a consultant. Over the past 10 years the Town has made a lot of street and drainage improvements including management of nuisance flooding. At a recent meeting on storm water issues, Dave Clark, with the Town of Nags Head, made a point that some of the lots that were now being developed were some of the less desirable ones and she felt Kill Devil Hills was experiencing this, also. Some of these properties require a lot of fill, creating a much higher elevation than the adjoining lots.

Debbie said they have a Street Improvements Subcommittee that is currently reviewing drainage-only projects and will be making a recommendation to the Board of Commissioners. At a recent meeting the Kill Devil Hills Board of Commissioners requested staff review the funding ratio between street improvements and drainage only improvements. A concern was voiced that

funding for drainage improvements tends to affect very specific areas rather than generally as streets improvement do. In Kill Devil Hills commercial development is required to have an engineered storm water plan while residential development is not. This may be reviewed by the Board of Commissioners again in the future.

Dan Shields from the Southern Shores Town Council said they do not have a plan. They have asked an engineer to study and recommend an approach for developing a plan. The Town never had this problem before.

James Butz from the Walnut Island Association said they have some road problems. They are trying to figure out what permits they might need and where to send the excess water. They are looking for direction on where to go and what to do about it.

Dave Clark is the Public Works Director for the Town of Nags Head. Dave said Nags Head developed their Stormwater Management Plan in 1980 and revised it in 1995. This year with all the rain, many problems have been caused by individuals compromising the approved system(s) within their subdivision. They are planning on using LIDAR maps to determine factors that may be contributing to problems with stormwater and groundwater management, and as an aid in solving those problems. They are cautious that engineered solutions may not necessarily work in all cases. They have five (5) outfalls (four in town and one just south of town). He expressed a need to look at it in a coordinated fashion.

Webb Fuller, the Town of Nags Head Manager, said that Dave Clark is their official representative, but he wants to be active and involved in the process also. They want to make sure that some of the $15M set aside in most recent State budget for DOT drainage work in the coastal area gets to the Whalebone Junction project.

Dan Shields noted that some solutions will need to be looked at regardless of existing rules and regulations. A lot of the problems start with development and that possibly part of solution is to change the building codes.

Webb noted that public education and public involvement have to play a big part in the solution. The government can be responsible for people who make bad decisions.

The guests at the meeting inlcuded Mike Muglia from the UNC Coastal Studies Institute, Anne Kenny from the UNC Coastal Studies Insitute, Kevin Schwartz from the Outer Banks Home Builders Association, a reporter from the Sentinal, Jan DeBlieu of the NC Coastal Federation, and Ted Sampson of the NC Division of Coastal Management.

Dr. White invited Ted to join in the discussion. Ted stated that development within CAMA areas of concern (AECs) is a growing problem. DCM doesn't control permitting of development. He also noted that there has been a large incremental loss of wetlands as areas are developed and those areas are where runoff used to go. We need to keep the eco-system working when determining solutions.

A open discussion followed.

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It noted that this committee will concern itself with this district of the NE region of NC.

Dan Shields noted that for those that are not entirely familiar with the reason/causes of the problem having a presentation/s by an engineer would be helpful. He further noted that once folks have a basic understanding of the problem might be better able to make decisions.

It was recommended to contact Joe Anlauf from Quibel might be appropriate to come speak to the group as he has done a lot of work on the OBX. .

Other local experts familiar with problems are Richard Spruill, Bob Oreskovich, Ed Andrews.

It was discussed by the group we need to understand the volume of water generated by storms and the total water budget. How high is the ground water table? Are all the changes making a difference? Is there a trend?

Concern for water storage capabilities were discussed. Will we need to consider sending it offshore? How far would be far enough? Would this be an option only for catastrophic events?

Should localities continue to use septic drain fields? Should we consider central wastewater treatment? Properly installed and maintained septic systems work very well vs. a central wastewater treatment facility.

Does there need to be a land use plan for the entire Outer Banks? Could land use density transfers, conservation, and transfer of development rights be used successfully for mitigation?

It was decided that the next meeting will have two invited speakers to talk about the causes of stormwater. It will be held October 5, 2004 at the Nags Head municipal building. It will be planned for 10-2 with a working lunch.

Dr. White's office will transcribe and distribute the minutes from this meeting along with the attendance list.

Meeting adjourned at noon.

Respectfully submitted,
Anne R. Kenny
Admin. Sec.
UNC Coastal Studies Institute

October 5 Commissioner's Meeting Room Nags Head
OBX Hydrology Management Group Meeting
October 5, 2004
10-2PM
Nags Head Town Board Room

Attending
Rufus Croom, NRCS – Dare SWCD
Dan Shields, Southern Shores Town Council
Kevin Schwartz, OBHBA/ OBAR
Robert Tankard, DENR-DWQ
Tom Reeder, DWQ
JD Potts, NC RWQ
Dwane Hinson, Albemarle RCD
Debbie Diaz, KDH
Dave Clark, Nags Head
Dan Scanlon, Currituck Co
Jim Butz, Walnut Island Assn
Jim Rivera, Martin's Point Homeowner's Assn
Mike Doxey, Currituck S&W
Allen Russell, NC DOT
Tricia Huffman, Kitty Hawk
Erin Burke, Manteo
Steve Shriver, Dare Co
Chris Layton, Duck
Gary McGee, Kitty Haw
Jan DeBlieu, NCCF

Sincere thanks to the Town of Nags Head for hosting this meeting as well as to Joe Anlauf and Ed Andrews for taking the time to come and help us.

Meeting Notes Summary:

Joe Anlauf, a consulting engineer with Quibel Associates, explained the hydrologic cycle as it pertains to the OBX, how groundwater is distributed and factors affecting that distribution. Several important points made during his presentation include: 1) The ground water table is the primary factor controlling flooding, and 2) we have had a tremendous amount of rainfall over the last year that has elevated groundwater levels. He also noted that losses in vegetation affect the rate of evapotranspiration, which, prior to clearing is a significant vector for the removal of groundwater. Additionally, incremental losses of wetlands results in lost storage capacity. Our challenge will be how to manage groundwater -- the budget of which varies by location in the landscape. He emphasized that stormwater management goals are focused on the surface water component using the regional design storm curves, which does not address groundwater or total water budget management issues.

Ed Andrews, also a private consultant, concurred with Anlauf in that the management of ground water is key to managing flooding problems on the Outer Banks. He also emphasized that we are dealing with a tremendous volume of water which in the past has been either utilized by vegetation and/ or has flowed to either the sound / ocean via surficial ground water flows in deep sand. An extended discussion followed regarding factors contributing to perched groundwater, how it contributes to flooding, where it occurs and the possible strategies for dealing with it. Ed

mentioned that he has worked on projects where they "punched" through the clay layer to drain excess water to the sand underneath thus allowing the water to be treated, which addresses the committees concerns about water quality, and before it goes from the site to the sound. Ed also noted that the volume of water taken from the deep aquifer for drinking water (and being used for irrigation, car washing, and discharged as waste water) is an addition to the total water volume having to be managed as part of the surficial management strategies—this could be as much as 3-12% of the total water volume "in the system". Ed suggested that the problems and strategies varied by location in the landscape—he emphasized that the maritime ridge and swale areas in particular need to be reviewed. A good strategy for the committee would be to identify the location and distribution of the perching layers, develop a 3-D map of the water table, and intersect that data with the spatial map of the complaints. This would help to identify areas with problems, commonalities in the types of problems in those locations, the underlying system functions which may be contributing to those problems and this would in turn help to identify the categories of water management strategies which may work in those locations.

An effort to independently list the factors contributing to stormwater and flooding problems generated the following list:

Removal of vegetation
Impervious surfaces
Planning deficiencies
High groundwater
Inappropriate irrigation
Regulatory limitations at all levels and scales / permitting gaps
Soils, topography, hydrology
Inadequate and / or compromised stormwater systems
Inter-aquifer transfers
Development
Grade/ cut/ fill
Density management
Incremental management
Growth rate
Roads
Loss of storage (wetlands)
Water quality = good stormwater management
Unmanaged changes in land use
Public ignorance of the problems
Lack of incentives
Undefined goals
Cost prohibitive
Lack of coordination between jurisdictions and agencies

Suggested Sorting for the development of management strategies:

Natural Systems
High groundwater

Soils, topography, hydrology
Inter-aquifer transfers
Grade/ cut/ fill

Local Gov't
Removal of vegetation
Planning deficiencies
Inappropriate irrigation
Inadequate and / or compromised stormwater systems
Development
Grade/ cut/ fill
Density management
Incremental management
Loss of storage (wetlands)
Unmanaged changes in land use
Water quality = good stormwater management

State Govt/ Regional
Regulatory limitations at all levels and scales / permitting gaps
Inter-aquifer transfers
Density management
Growth rate
Roads
Loss of storage (wetlands)
Lack of incentives
Undefined goals
Lack of coordination between jurisdictions and agencies
Cost prohibitive
Public ignorance of the problems
Water quality = good stormwater management

Data or Information needed to develop management strategies/ committee action:
Identification of spatial distribution of the problem areas from the "customer standpoint" each town and county will compile and forward to County to be mapped. One single map of both Dare and Currituck Co will be produced for the next meeting with the problem areas mapped on it.
Delineate areas of hydrologic functions/ natural factors—Nancy will determine who can do this, the information they need, then coordinate with the counties to have the information delineated on the map noted above.

Determine how much of the OBX water budget is from aquifers – Nancy and DWR

Determine how much of the OBX aquifer derived water is used for non-potable applications- Nancy and DWR.

Determine local ordinances or other local conditions (incongruities between towns, development review process, post construction compromises, "upstream development", subdivision covenants, etc) which are facilitating or exacerbating the problems—Each Town and County will compile and bring a list to the next meeting.

Identify jurisdictional gaps—Each Town and County will list and bring to the next meeting.

Approach for meeting on Oct 19:

1) Review the overlay of natural systems delineation with areas of complaint on the two - county map.
2) Using the information provided regarding the type of complaint and the natural system functions -- link problems to causes, look for commonalities for causes (both natural, managerial and jurisdictional as indicated above.
3) Generate draft list of potential solutions.
4) Next steps.

As suggested by Joe Anlauf and Ed Andrews this approach would help identify areas with problems, commonalities in the types of problems in those locations, the underlying system functions which may be contributing to those problems and this would in turn help to identify the categories of water management strategies which may work in those locations.

Next Meeting: October 20, Town Hall, Kill Devil Hills 10am-2PM.

Outer Banks Hydrology Management Committee Meeting
Tuesday, Oct. 20, 2004
10:00 a.m.
Kill Devil Hills Town Hall, 102 Town Hall Drive, Kill Devil Hills

Present: Tricia Huffman/Town of Kitty Hawk, Robert Tankard/Division of Water Quality, Tom Reeder/Division of Water Quality, Kevin Schwartz/Outer Banks Homebuilders Assoc/Outer Banks Assoc. Realtors, Darrell Merrell/Town of Kill Devil Hills, Randy Metzger/Town of Kill Devil Hills, Debbie Diaz/Town of Kill Devil Hills, Rufus Croom/NRCS-SWCD, Dave Clark/Nags Head Public Works, Ted Sampson/NC DCM, Gary McGee/Kitty Hawk, Mike Hejduk/Southern Shores, Chris Layton/Duck, Dan Scanlon/Currituck, J.W. Fuller/Nags Head, Jim Rivera/Martins Point, Wayne Mobley/Shellfish Sanitation, JD Potts/ Shellfish Sanitation, Erin Burke/Manteo, Nancy White/UNC Coastal Studies Institute

This meeting was devoted to a discussion of the issues on a community by community basis.

There was consistency in the issues reported by communities with some variability related to whether the community had outfalls (Nags Head, KDH, Manteo) versus those without outfalls (Currituck, Duck, SS, Kitty Hawk).

Towns with outfalls reported that most of the problems are fixable with local drainage solutions. Most of the problems are related to areas where systems were installed but property owners compromised them. A second type of problem area is generally NOT a town issue, but the land is simply just too low-lying.

All communities felt that an important component is public education so that people don't compromise the drainage systems, don't increase imperviousness, and improve their water conservation and landscape practices.

Communities without outfalls also have problem related to people elevating ground levels and the increased development on marginal lots.

However, there are problems related to lack of control over road and lot management in private developments.

It was noted by the group that cooperation and coordination with DOT is needed to enforcing and preserving the right-of-way ditches for NC 12.

Also, DOT has accepted the drainage from subdivision developments (commercial and residential) which by design had their stormwater/drainage running out to NC 12, which now floods.

Comments Provided by KDH:
The single greatest positive impact DOT could provide for the town of the Kill Devil Hills storm water quality and management system would be the reclamation of the roadside swales and ditches along the entire length of US 158.

Many areas that previously were areas of storm water storage or management have been filled with landscaping or other uses, which has resulted in the loss of valuable storm water storage and retention from their system. Culverts under roadways have also been covered thereby blocking flow resulting in flooding of these areas.

The loss of this huge storage area has severely impacted our storm water management system. In many areas, storm water from the highway dumps directly into our storm water management system, overloading our system and thereby greatly reducing water quality as it exits into our sound and ocean.

If DOT would reestablish these drainage management features within its right of way, it would help our efforts tremendously.

NC 12 - Establishment of a drainage system along the length of this corridor would help remove a great deal of standing water issues on this roadway. At the present time, only a few areas have drainage infrastructure installed.

Drainage right of way areas OUTSIDE of US 158- continue reclamation efforts in these areas with mowing, mucking and the cleaning of culverts and ditches: Starting at the Dare Center on

US 158 to the connection at the Wright Memorial -- The entire length of the ditch within the US Park Service Wright Memorial

Ocean Outfalls
DOT and the town are very dependent on these outfalls as they are the only avenue for drainage in the southern half of the town. Items that could be done to improve these outfalls:
Install anti back flow devises on ends of all existing pipes. We are constantly having problems with them closing up due to wave action.

Upgrade sizes or possibly adding a tandem/adjacent pipe beside each existing one.

Questions provided by Currituck:
What is DOTs position/coordination with local jurisdictions regarding curb cuts/driveway permits?

What is their position regard the numerous subdivisions that, as part of their stormwater plan, include discharging into road side swales and ditches; does NC DOT permit this and are they going to maintain the swales and ditches?

What is NC DOT's position regarding standing water on public streets?
Language provided by Tom Reeder, DWQ regarding DOT and Phase Two:

SECTION 8. Petition Process. - A petition may be submitted to the Commission to request that an owner or operator of a municipal separate storm sewer system (MS4) or a person who discharges stormwater be required to obtain a Phase II National Pollutant Discharge Elimination System (NPDES) permit for stormwater management as follows:

(1) Connected discharge petition. - An owner or operator of a permitted municipal separate storm sewer system (MS4) may submit a petition to the Commission to request that a person who discharges into the permitted municipal separate storm sewer system (MS4) be required to obtain a separate Phase II National Pollutant Discharge Elimination System (NPDES) permit for stormwater management. The Commission shall grant the petition and require the person to obtain a separate Phase II National Pollutant Discharge Elimination System (NPDES) permit for stormwater management if the petitioner shows that the person's discharge flows or will flow into the permitted municipal separate storm sewer system (MS4).

Most notably, while the outfalls manage the drainage given the caveats noted above, the question remains as to how do we treat the discharge water, reduce the volume, or combo of reducing, treating, managing and not making the problem worse? What do the communities do that don't have outfalls? Manteo is an example of a community that obtained a grant because it is proposing to remove outfalls by investigating a land-based treatment solution, but what do communities do that have flood/ stormwater problems that DON'T have outfalls??? Or those that don't that don't have the option of removing them?

A discussion of possible strategies for solutions and speakers to discuss them followed.

Community education strategies could be addressed by Barbara Doll and Bill Hunt.

Would like to investigate / know more about the programs at Wrightsville Beach and the Town of Cary where they are regulating imperviousness have water conservation and water reuse programs.

The Southern Watershed Area Municipal Planning District in Hampton Roads has created a regional watershed management program that could provide a model for the Outer Banks.

Nancy offered to construct a matrix of issues and solutions for the group to consider.

The next meeting will be November 2nd at 10 a.m. at the Outer Banks Assoc. of Realtors office off West 8th Street in Nags Head. Turn between the Eckerd's and the ABC store, turn Left, building is on the Right. (105 West Airstrip Road, KDH)

Meeting adjourned at 2:00 p.m.

Outer Banks Hydrology Management Committee Meeting
Tuesday, Nov. 2, 2004
10:00 a.m.
Outer Banks Association of Realtors Offices, Kitty Hawk

Present: Dan Shields/Southern Shores, Tom Reeder/NC DWQ, Gil Falasco/Currituck County, Erin Burke/Town of Manteo, Robert Tankard/NC SWQ, Dave Clark/Town of Nags Head, Steven Shriver/Dare County, Tricia Huffman/Town of Kitty Hawk, Bob Oreskovith/Dare County Water, Jim Rivera/Martins Point, Kevin Schwartz/OBAR/OBHBA, Webb Fuller/Town of Nags Head, Debbie Diaz/Kill Devil Hills, Ted Sampson/NC DCM, Chris Layton/Town of Duck, Jan DeBlieu/NCCF, Nancy White/UNC Coastal Studies Institute, Dan Scanlon and Mike Doxey/ Currituck Co.

Given that there are only five (5) more meetings the group discussed that it needs to focus its efforts to be able to produce a report by January, 2005.

It was noted that it is extremely important that DOT attend and participate since they are a significant developer of land, as well as producer and manager of storm/ flood water.

The group discussed areas needing information in order to move forward. A significant point of discussion pertained to the costs of the drinking water system for Dare County—the reality of the situation is that in order to serve the tourism peak, the system needs significant infrastructure which is difficult to support during the rest of the year when water use is reduced—so water conservation would not help "pay" for the water system.

Topics needing attention are an understanding how to implement and maintain innovative stormwater management techniques, the realities of water reuse, how to implement stormwater districts (to help pay for the infrastructure), DOT processes, procedures for implementing a public education program, and sustainable development and planning strategies.

It was decided that after the Town of Cary's water reuse, conservation and stormwater management presentation that Mike Doxey and Dan Scalon would present the stormwater management districts being developed in Currituck County on November 30. DOT would be invited to present how they plan, permit and maintain roads so the committee could better understand how to coordinate with them. Other speakers suggested were Larry Coffman, an expert on Low Impact Development, someone from King Co, Washington, someone from the Chesapeake Bay Foundation, David Mayes from Wilmington, Barbara Doll and Bill Hunt from NCSU, and someone from the SWAMP.

Nancy noted that she will start drafting the preliminary report.

Each committee representative needs to send to Nancy recommendations for immediate, short-term, and long-term solutions for their community by Dec 21st (via e-mail Word document).

Each committee member also planned to present the preliminary findings to their councils and Boards before Christmas and forward any recommendations to Nancy.

The group will also meet January 11th and then schedule another meeting in Raleigh to be able to present the final report to Senator Basnight.

The group also decided to plan a field trip on Dec 7 to see examples of problem areas and sites that have engineered solutions. CSI will arrange for vans or some other type of transportation so the group can go together. The sites will be decided at the Nov. 30th meeting.

Steve from Dare County noted that he would provide maps with problem areas noted to each community to facilitate the site identification process.

The next meeting, Nov. 17th, will be at the Kitty Hawk Town Hall, with the Nov. 30th meeting at Southern Shores. Locations for the December 14th and 21st meetings are TBA.

Meeting adjourned at 12:45 p.m.

Outer Banks Hydrology Management Committee Meeting
Tuesday, Nov. 16, 2004
10:00 a.m.
Kitty Hawk Town Hall, Kitty Hawk

Present: Robert Tankard/NC DWQ, Rufus Croom/NRCS, Mike Doxey/Currituck Soil and Water, Steven Shriver/Dare County, J.D.Potts/NC Shellfish, Jim Rivera/Marrtins Point Homeowners, Ted Samson/NC DCM, Jan DeBlieu/NCCF, Wayne Mobley/NC DEH/Shellfish, Tricia Huffman/Town of Kitty Hawk, Chris Layton/Town of Duck, Dan Scanlon/Currituck County, Bob Oreskovich/Dare County, Gary McGee/Kitty Hawk, Dan Shields/Southern Shores, Webb Fuller/Nags Head, Debbie Diaz/Kill Devil Hills, Dave Clark/Nags Head Public Works, Kevin Schwartz/OB Assoc Realtors-OB Homebuilders Assoc, Erin Burke/Manteo, Nancy White/Coastal Studies Institute

SARB_006106

Below are the proposed speakers and dates:

Nov 30 – Eric Walberg, AICP Principal Planner, Hampton Roads Planning Dist. Comm.? Districts, Dan Scanlon and Mike Doxey, Currituck County Stormwater Management
Location: Southern Shores Pitt Center adjacent to Town Hall.
Dec 7 – NC DOT
Dec 14 – Bob Oreskovich
Dec 21 – Larry Coffman, LID Strategies, Associate Director, Dept of Natural Resources, Prince George's County, Maryland
Evening lecture for the public
Dec 28 – NO MEETING
Jan 10, 2005 – Mary Tod Winchester, Chesapeake Bay Foundation
Jan 11, 2005 –
Bill Hunt, Stormwater Extension Specialist
Barbara Doll, Sea Grant Water Quality Specialist
Christy Perrin, Prog. Coord. For Watershed Educ. For Communities &Officials.

To be considered, whether to schedule a session to discuss plan with Senator Basnight and his staff.

Jennifer Platt, water conservation manager from the Town of Cary, addressed the committee on water conservation and reuse followed by Betsy Pearce, Stormwater Specialist to present the Town's stormwater management program.

Ms. Platt's presentation is attached.

Tricia has a copy of Betsy's presentation that we will pass along with the next set of minutes. NOTE: At the end her presentation Ms. Pearce recommended the group talk to folks at Wilmington since they have already addressed this problem there and it is a similar landscape to the Outer Banks (NOTE Dave Mayes declined to come because he was anticipating a new baby in the house during the time period we needed him to come.).

I thought I would note a couple of points that seemed significant to me that we can use for discussion.

A water conservation program can achieve a 15-30% reduction in water use, which can save costs for new infrastructure and expansion. Their rate structure ramps up quickly, increasing after 4,000 gals/ mo for a residence. They charge and extra fee for the irrigation meter. Collected water for the reuse program can be moved by pumping and through bulk hauling, not just underground infrastructure, then used for street cleaning, fire protection etc. Stormwater treatments are required to be put on private property with required bonds and maintenance plan by the homeowners association. The Town involved the community in a stakeholder input process to get their involvement in the solutions and implementation strategies.

The next meeting is November 30th in Southern at the Pitt Center which is adjacent to the Town Hall, the building on the far Right off the parking lot.

Outer Banks Hydrology Management Committee Meeting
Tuesday, Nov. 30, 2004
10:00 a.m.
Southern Shores Town Hall/Pitt Center

Present: Dan Shields/Southern Shores, Ed Sampson/NC DCM, Steve Shriver/Dare County, Gary McGee/Kitty Hawk, Tricia Huffman/Kitty Hawk, Jan DeBlieu/NCCF, Erin Burke/Manteo, Randy Metzger/Kill Devil Hills, Alan Saunders/NC Shellfish, Jim Rivera/Martins Point, Chris Layton/Duck, Robert Tankard/DWQ, Gil Falasco/Currituck DPW, Tom Reeder/DWQ, Mike Doxey/Currituck Soil & Water, Kevin Schwartz/OBHBA/OBAR, Dave Clark/Town of Nags Head, Nancy White/Coastal Studies Institute

The meeting convened at 10:05. Mike Doxey from Currituck Soil & Water presented a very informative program on setting up Stormwater Service District. He provided handouts.

Mr. Doxey explained the different types of water districts, how to form a service district, what Currituck County is doing and how to service once set up.

He stressed that finding a way to make developments manage and maintain compliance prior to building is best solution because retro-fitting existing development is a challenge. An important point made is that it is nearly impossible to retrofit developments based on a routine fee assessment. A special assessment is generally necessary to generate the funds needed to "fix" a development once it is built and has the problems. It is also important that sufficient funds are generated so that DWQ and the county/ towns can provide necessary monitoring and management.

This discussion led the group to question what solutions would work and how they should proceed with develop specific solutions to specific problems.

The fact is that there is no magic bullet. There will need to be an integrated approach that is implemented at a variety of scales and jurisdictions and some of them may require some innovation. For example, some ideas suggested are 1) Pump excess water to an artificial island in the sound; 2) use natural wetlands for treatment and storage; 3) Put a storage pipe beneath the roadway? 4) Put in a median and plant as bioretention? 5) Adjust rate and fee structure of providing water to pay for infrastructure needed to deal with impacts related to tourism? 6) Use special service districts to do special assessments to generate the funds to implement BMPs needing to reduce runoff? 7) Use the districts to assess fees to pay for management and maintenance? 8) Require that all new development be low impact? 9) Assess fees to monitoring that the LID strategies are maintained?

A discussion followed about how to move forward to develop recommendations…

The group discussed breaking out recommendations into short, medium and long term recommendations; as well as at a variety of scale, individual, community, regional etc.

Table of Contents
Industry Sources

	Author/Agency/Organization	Title	Date	URL
1	American Society of Civil Engineers	Stormwater Management	2004	www.asce.org/pressroom/news/policy_details.cfm?hdlid=160
2	Boston Business Journal (Giangrande, D.)	A Low-Impact Approach to Storm Water Management	8/27/2004	http://www.bizjournals.com/boston/stories/2004/08/30/focus6.html
3	California Builder: the Magazine of the California Building Industry Association (Frith, J.)	Building Green: It's Good for the Environment - and the Bottom Line	03-04/02	www.californiabuildermagazine.com/internal.asp?pid=32&spid
4	California Builder: the Magazine of the California Building Industry Association (Grillo, T.)	Concrete Evidence: Age-Old Material Continues to Reinvent Itself		http://www.californiabuildermagazine.com/internal.asp?pid=194
5	Carter & Burgess	Low Impact Development: 'Green' Approaches to Storm Water Management Preserve Natural Systems and Improve Water Quality	2004	http://www.c-b.com/information%20center/land%20development/ic.asp?tID=17&pID=282
6	Environmental Water Resources Institute of the American Society of Civil Engineers	International Stormwater Best Management Practices Database		www.bmpdatabase.org
7	National Association of Home Builders	Green Home Building Guidelines	2006	http://www.nahbrc.org/greenguidelines/complete_guidelines.pdf
8	National Association of Home Builders Research Center	Builder's Guide to Low Impact Development	2003	http://www.toolbase.org/PDF/DesignGuides/Builder_LID.pdf
9	National Association of Home Builders Research Center	Guides to Low Impact Development	2003	http://www.toolbase.org/Design-Construction-Guides/Land-Use/low-impact-development-guides
10	National Association of Home Builders Research Center	Low Impact Development (LID) Practices for Storm Water Management		http://www.toolbase.org/Techinventory/TechDetails.aspx?ContentDetailID=909&BucketID=6&CategoryID=11
11	National Association of Home Builders Research Center	Municipal Guide to Low Impact Development	2003	http://www.toolbase.org/PDF/DesignGuides/Municipal_LID.pdf
12	National Association of Home Builders, Partnership for Advancing Technology in Housing (PATH)	The Practice of Low Impact Development	07/03	http://www.huduser.org/Publications/PDF/practLowImpctDevel.pdf
13	National Association of Home Builders, Partnership for Advancing Technology in Housing (PATH)	Permeable Pavement		http://www.toolbase.org/techinv/techDetails.aspx?technologyID=98
14	ToolBase Services	Environmentally Green... Economically Green: Tools for a Green Land Development Program	2001	http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=18&DocumentID=3475
15	ToolBase Services	Low Impact Development Offers Some Solutions for Groundwater Issues	2001	
16	Urban Land Institute, American Society of Civil Engineers, & National Association of Home Builders	Residential Storm Water Management	1975	http://www.toolbase.org/PDF/DesignGuides/storm_water_management.pdf
17	Western Region Builder News	A Growing Trend in Stormwater Management	03/07	http://www.buildernewsmag.com/viewnews.pl?id=614

Stormwater Management

Approved by the National Energy and Environmental Policy Committee on February 19, 2004
Approved by the National Water Policy Committee on March 9, 2004
Approved by the Policy Review Committee on March 12, 2004
Adopted by the Board of Direction on May 14, 2004

Policy

The American Society of Civil Engineers (ASCE) supports and encourages coordinated local, state and regional programs to manage the quantity of and improve the quality of stormwater entering streams, lakes and estuaries.

ASCE supports stormwater management techniques that prevent and mitigate the effects of urbanization and other land use changes on surface runoff, including detention and retention methods, innovative stormwater drainage systems and other techniques needed to reduce, to the maximum extent practicable, the impact on ecosystems and stability of receiving water.

ASCE supports increased funding, the required level of control, the guidance for developing control options and strategies, the need for consideration of cost versus performance, and the flexibility afforded to the states to adapt local and regional water quality standards to reflect site specific conditions.

Issue

Failure to effectively manage stormwater runoff from urbanization and other land use changes increases downstream runoff and erosion, stream degradation, loss of and changes in aquatic habitat and water-quality deterioration. This growing problem, including jurisdiction conflicts, can be overcome by the development and implementation of practical stormwater management methods and technology consistent with the principles of sustainable development.

ASCE Policy Statement 395, Control of Combined Sewer Discharges, supports the Environmental Protection Agency's (EPA) national policy statement for combined sewer overflows which represents the consensus of states, environmental groups, municipalities and other interested parties.

Rationale

Civil engineers are typically the lead professionals involved in the design, construction, operation and maintenance of stormwater systems. The availability and the development of stormwater system evaluation and design technology can lead to improved systems that manage the quantity and quality of stormwater runoff and meet the goals to minimize its impacts on receiving waters.

ASCE has in the past developed guidelines for the design, construction and operation of urban stormwater management systems. These guidelines are contained in the joint ASCE Manual of Professional Practice Number 77 and Water Environment Federation Manual of Practice FD-20, entitled "Design and Construction of Urban Stormwater Management Systems" and the joint ASCE Manual and Report on Engineering Practice Number 87 and Water Environment Federation Manual of Practice Number 23 entitled "Urban Runoff Quality Management."

Best Management Practices for the control of storm water can enhance the built environment. These practices should be included in any design of new stormwater facilities or rehabilitation of existing facilities. They include: preventative soil erosion measures on disturbed areas, reasonable recharge of storm runoff into the groundwater where soil infiltration rates permit, adequate storage of excess stormwater to minimize impacts downstream, use of grass filter strips and other natural filter areas including wetlands to minimize pollution, adequate sizing of pipes and culverts to minimize flooding and other measures.

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Boston Business Journal - August 30, 2004
http://boston.bizjournals.com/boston/stories/2004/08/30/focus6.html

Boston Business Journal



From Beginners to Bigshots: Going and Growing with the SBA

Sponsored by MasterCard

BUSINESS PULSE SURVEY: If you don't have an iPhone, do you plan to buy one? Why or why not?

Insider view

A low-impact approach to storm water management

LID seen as a way to improve water quality, but local hurdles exist

Boston Business Journal - August 27, 2004 by David Giangrande

Low-impact development (LID) makes so much sense as a planning and storm water management technique, it's a wonder that it is the exception rather than the rule. Improved water quality, increased water supply, lower storm water infrastructure costs, and more vegetation and open space -- these are just some of the key benefits of LID.

According to some studies, LID has saved more than 20 percent in construction costs for housing developments elsewhere. The practice also helps preserve open space, reduce the size of storm pond structures and eliminate catchments and piped storm conveyances.

But as is often the case with real estate development, the issue isn't as simple as it seems.

State and local regulations can discourage developers from even trying LID. Density is a big issue, for example. The principles of LID often call for a greater concentration of the built environment and less disturbance of the natural landscape. This runs head-on into the zoning regulation trend of acre-plus lot minimums in most suburban communities.

Also, some principles of low-impact development -- for instance, narrower-than-normal streets -- can bring opposition from fire officials concerned that rescue equipment may not have the room or access needed in an emergency situation. And finally, developers may shy away from even proposing LID techniques in a project because it often requires an extensive effort to educate officials and residents about what this atypical method entails.

But attitudes are starting to change, according to the Massachusetts Department of Conservation and Recreation. While most of the principles of LID have been around for some time, only recently have development, planning and engineering professionals begun to group these principles together in a coherent approach to planning and storm water management.

What is low-impact development?

The National Association of Home Builders defines low-impact development as "an ecologically friendly approach to site development and storm water management that aims to mitigate development impacts to land, water and air. The approach emphasizes the integration of site design and planning techniques that conserve natural systems and hydrologic functions on a site."

Basic components of LID include reduced impervious surfaces -- including narrower roads and fewer cement sidewalks -- keeping or planting native vegetation, retaining the natural grade of the site and creating bioretention areas and grassed swales to help filter ground water and allow it to seep into the ground.

Instead of forcing storm water to collect in one or more central locations and then directing it off-site via a system of storm drains and pipes, LID uses the natural topography and vegetation, as well as strategic bioretention areas such as rain barrels and rain gardens, to decentralize the dispersion of storm water. This keeps more of the storm water in the local aquifer, instead of shipping it to a body of water far away from where it falls.

A local example

Like many growing communities in the Boston area, the town of Franklin grapples with the ever-increasing demand for clean drinking water. The town has taken several steps to ensure adequate water supply, including mandatory water bans, curbing water use for maintenance of town property, and searching for new water sources.

Town officials hope to add low-impact development to that list of water conservation efforts. In April, Bill Fitzgerald, Franklin's public works director, submitted a grant application to the Massachusetts Department of Environmental Protection (DEP) that would provide $109,200 in federal money to assess how LID techniques could be implemented on more than 50 existing and proposed streets in Franklin. To ensure that the benefit would be state wide, the study would also provide a road map to help other municipalities implement LID techniques under existing state and local regulations.

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According to Sara Cohen of the Mass. Department of Conservation and Recreation, a lot of the resistance to LID comes legitimately from developers who understand that before a LID project has a chance of being accepted, they have to go through a process of educating officials and boards, who in turn face state laws that may work at cross-purposes to LID.

Even if developers acknowledge the upside, they know that it might cost them time and money to help the community understand the benefits.

Despite the hurdles, LID is likely to pick up steam relatively quickly over the next decade. As parts of Massachusetts run into water-supply difficulties, regulations will begin to support this type of development as a requirement for accessing the water supply. And secondly, as a few case studies spring up, developers and town officials will begin to propagate it based purely on its own merits. Lastly, obstacles to LID posed by state laws will start to become better understood, resulting in necessary revisions to these laws.

David Giangrande is president of Design Consultants Inc. in Somerville.

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March/April 2002

Building Green
It's Good for the Environment - and the Bottom Line

By John Frith

Mike Dwight, vice president of sales and marketing for Forecast Homes, is not a card-carrying environmentalist. Yet Dwight is among a small but growing number of California homebuilders who thinks the future is tinged green - green as in environmentally friendly and green as in profitable.

Forecast, Premier Homes, Pardee Homes, and Shea Homes are among the industry leaders in exploring ways of making a home green. But if their efforts prove successful, other builders are expected to join the tide. Not only are there money-saving advantages available, but initial consumer response is proving favorable at both the entry-level and executive home levels.

"Forecast primarily does entry-level homes. It has a very significant impact if we can show prospective homebuyers how our homes will cost less to operate. It makes them more attractive and more available because of energy-efficient mortgages," Dwight said. The mortgages allow homebuyers to count their energy savings as income, helping them qualify for loans.

"To take it further, many jurisdictions offer incentives in fast-tracking (permit approvals), that sort of thing. We're given preference because the project itself is putting less waste into landfills, it's being clean, and it's recycling construction waste. That benefits the community. There are a variety of reasons for doing it, other than that it's the right thing to do," he added.

Dwight said all of Forecast's future projects will be certified green by standards developed by the Building Industry Institute, an affiliate of CBIA. (See sidebar, page 10.)

Many new homes already environmentally friendly
In fact, many builders are already using environmentally friendly techniques, said John Blue, a green building specialist for the California Integrated Waste Management Board, the State's primary recycling agency. For example, engineered wood used to reduce warping of trusses and joists also results in less construction waste.

"One thing that's really easy for production homebuilders is recovery of materials on

site. Builders have a specific waste stream, and it's all pretty clean and easy to collect. They're paying a lot in hauling fees, and cardboard, drywall, wood, and concrete all have established markets (for recycling)," he said.

The state's energy crisis provided a major push for green building in 2001. The threat of rolling blackouts -- and the certainty of skyrocketing utility rates -- first surfaced in San Diego in 2000 as the area's utility became fully deregulated as part of the State's unsuccessful plan to establish a market- based system.

As area consumers increasingly complained about rising energy costs, builders took notice. In January 2001, Shea Homes unveiled its High Performance Home at a San Diego development, combining energy-efficient design, solar electric power, and solar-heated hot water.

Builders around the state quickly followed suit. And at the same time, California adopted new energy- efficiency standards requiring that all new homes be 15 percent more efficient than before -- 30 percent above the national Model Energy Code. (See "The New Energy Standards Are Here" in the May-June 2001 issue of California Builder at www.cbia.org.)

Builders found that energy- efficiency is a good marketing tool

"The average consumer's not terribly concerned that we recycle concrete," Dwight noted. "They think, 'That's laudable, but it's not a reason to buy.' But if the home costs $40 a month less in utility costs, that is a reason to buy."

In the past few months, Premier Homes and Pardee Homes took environmentally friendly to the next level.

Going green in Corona
Joe Killinger, Premier Homes' purchasing manager, said the impetus for his company moving green started with company CEO Jim Previti last August.

"We had our quarterly senior management retreat and Previti usually has comments about his goals. One goal he wanted was to be a green homebuilder and energy-efficient. I took it as a direction so I started working on making our newest project green at the beginning," he said.

In planning the Belcourt Estates development in Corona, Killinger met with consultants from ConSol, the Stockton-based firm that operates the ComfortWise program, and penciled in more efficient heating systems, improved insulation, spectrally selective glass (windows that reduce solar heat gain in the summer and reduce heat loss in the winter), and Energy Star-certified appliances that use less

energy.

Killinger also directed landscape architects to design front yards that contain more shrubs and less lawn area to reduce water consumption and told the clean-up contractor to recycle most construction waste.

As a result, Premier became the first California Green Builder under BII's standards. Forecast, then also owned by Previti, quickly became the second.

Salespeople at the $400,000 executive-home development are trained to emphasize the money-saving and green features, and signage is prominently placed to remind buyers. Killinger said sales average three or four a week and that the green features, especially energy savings, are a major draw.

Although the extra features cost nearly $1,000 per home, incentives such as rebates from Southern California Edison bring down the final cost. The use of the high-end windows and other efficiency features allows lower-tonnage air conditioner compressors to be used. Premier also participates in the ComfortWise program, which includes third-party inspections of the energy features, improving quality control. Because Premier builds over code and has third-party inspections, the city of Corona reduced plan-check times, which saved $130 per home. In all, Killinger estimated his net cost to build green is about $300 per home. He hopes more builders will take a closer look.

"Ultimately, it makes builders look better. It shows we're conscientious about what's going on in our environment. The industry is slow to change, but if we do, people might look at us differently. I know I'd love it if my home was a green one," he said.

Going green in San Diego

Pardee Homes is taking building green another step forward at its Santa Barbara development in San Diego by including extensive use of engineered wood, carpets made from recycled soda bottles, and pavers in the driveway that allow water to percolate back into the ground, reducing runoff. The development also features such options as fluorescent lights, tankless water heaters, and low-VOC paint.

Joyce Mason, Pardee's vice president of marketing, said the development's Living Smart design was one of a number of features required to gain voter approval to open up the Pacific Highlands area to development in 1998. Pardee worked closely with environmental organizations to fashion the project, which includes habitat conservation and restoration of natural vegetation. As a result, the local chapter of the Sierra Club supported the project.

Other standard features include the use of certified wood -- lumber from trees grown

and harvested in a way that ensures sustainable forests -- and sealed HVAC ducts. Among some 30 options are solar power panels on backyard trellises; bamboo flooring (a sustainable material that looks like hardwood); fiberglass entry doors; and Energy Star-rated refrigerators, dishwashers, and front-loading washing machines that also use less water.

The development opened in mid-January and the initial reaction was extremely positive, Mason said, with more than 1,000 people visiting the models during the first weekend. The first 10 homes released, priced between $600,000 and $800,000, sold out immediately. Mason said at press time that buyers were still choosing options but that the company was receiving positive feedback on several options, especially the solar trellises and indoor air quality features.

Beneficial in the long and short term

Forecast and Premier plan to have all future developments meet the Green Builder Standards, while Pardee plans to be completely Energy Star-compliant. Among other builders, Centex Homes is working with the Alameda County Waste Management Authority, to develop green standards, and Citation Homes recently achieved an 86 percent recycling rate at a project in Union City.

Forecast's Dwight said being on the ground floor of this growing movement will help the industry.

"We as an industry are heading in that direction. It's going to be imposed on us anyway so we might as well act first. That way, when the State is looking at new regulations, we will have pro- active experience and will be able to offer insights as to what's realistic and practical at a cost that won't damage homebuyers' chances to buy a home," he said.

Meanwhile, he said it's good for the bottom line.

"It also gives us a marketing advantage. But the most you ever get in our business is a head start. If it works, others will adopt it," he said.

BII Program Ensures Substance, Practicality

California's Green Builder effort got under way in 1999 when the Building Industry Institute, at the direction of CBIA, began work on developing standards. Mike Hodgson, a principal in ConSol, an energy consulting firm, and CBIA's energy chairman, said BII assembled a group of industry officials, experts from environmental agencies, and representatives from the environmental community to begin the tough task of cobbling together standards.

"We wanted a green building program in California, but we didn't know what it should be," Hodgson recalled. "All we knew is it couldn't be 'greenwashing' and that we wanted to develop a program that resulted in verifiable savings."

Energy consultant George Burmeister surveyed the largest existing green builder programs. "His conclusion was that most weren't very successful -- they didn't save much energy or prevent much pollution. The programs were often confusing to the builder, and not simple or clearly defined," Hodgson recalled.

So BII decided to first focus on energy standards, which were quantifiable, environmentally friendly -- and a potential sales tool. The Community Energy Efficiency Program (CEEP) is now in place in more than 40 jurisdictions around the state. In exchange for building homes that are 15 percent more energy-efficient than the Title 24 requirements, communities agree to expedite energy-related plan checks, deliver quicker inspections, and some may reduce fees and give local recognition.

Meanwhile, the group kept meeting to flesh out a comprehensive voluntary program. Ultimately, the following protocols were adopted:

• Air Quality: Reduce air emissions by meeting the energy standards.

• Waste Recycling: Divert at least 50 percent of job-site waste from landfills to help local jurisdictions comply with State waste diversion laws. Where recycling and diversion are not available, the builder agrees to adopt the BII Waste Recycling Guidelines and work with local jurisdictions to overcome market barriers

• Water Conservation: 25 percent decrease in water use compared to typical 1980s home, using such techniques as reducing lawn area to no more than 75 percent and irrigating shrubs with a drip system.

Hodgson said the BII standards are good for everyone concerned. "George Burmeister is now working with Tom Ingram, Riverside County's Chief Building Official, to go even further. Tom's saying if we go green, maybe he can expedite everything (not just energy-related plan checks) because it is consistent with the wishes of his Board of Supervisors. That would really get builders' attention," Hodgson said.

Web links
California Green Builder Program information

ComfortWise program

Job-site recycling information

Alameda County Waste Management Authority

Concrete Evidence
Age-Old Material Continues to Reinvent Itself

By Terry Grillo

"There is a species of sand which naturally possesses extraordinary qualities. It is found about Baiae and the territory in the neighborhood of Mount Vesuvius; if mixed with lime and rubble, it hardens as well under water as in ordinary buildings. This seems to arise from the hotness of the earth under these mountains…"
-- Marcus Vitruvius Pollio, from De architectura (The Ten Books of Architecture), circa 80-70 B.C.

Roman engineers and architects were the first to master the art of building with concrete. Using a material they called pozzolana—cement fired by the volcanoes in southern Italy—they formed the concrete that has held together structures like the Appian Way, the Roman baths, the Coliseum and the Pantheon for nearly 2,000 years.

Today, concrete has become much more than the foundation material for other, traditionally more attractive materials. Now, builders can make concrete look just like marble, without all that sweat and bother—and cost—of carving up the Italian landscape.

The same goes for brickwork, flagstone, interior and exterior tile, kitchen countertops, and fancy fireplace surrounds. Before it dries, concrete can be molded, stretched, poured, and colored to create just about any space and surface a builder or architect can imagine.

And with concrete leading the construction industry as the most commonly-used product in the world – 7 billion yards of concrete are laid each year – new and innovative products are surfacing each day, redefining the industry as we know it.

Mind the Gap

One of the main concerns typically associated with concrete is drainage. As the urban landscape grows, acres and acres of pavement grow along with it, and anything dropped on it gets washed away into storm drains. Gasoline, oil, chemicals from brake pads, and even the flow of water create environmental concerns.

Pavement is starting to cover up areas that have served to filter and clean rainwater and runoff flows before they reach rivers, lakes, and oceans. Big money is now required to trap, filter, and move runoff from weather that pours down on solid pavement. Some experts are calling storm water runoff one of the largest pollution problems the country is currently facing.
According to Andy Youngs of the California Nevada Concrete Promotion Council, a

new type of concrete could be the best solution for storm water runoff and other drainage problems the industry has seen yet.

“Pervious concrete is our newest product in California, and I think it’s going to be one of our most prevalent ones,” Youngs said. “It solves the problem of toxic rainwater runoff by permitting natural runoff and by developing bacteria in its structure that breaks down toxic chemicals.”
With 15 to 25 percent of pervious concrete consisting of empty space, or “void structure,” three to eight gallons per minute are allowed to pass through each square foot. Youngs said that this rate accounts for more flow than is generated during most rainstorms.

It looks like tightly packed gravel, feels rougher than regular concrete underfoot, and drains water from a gushing hose like a sieve. Water flows right through so storm drains are not needed, in many cases saving homebuilders and owners the time and expense of installing a separate system.
“Pervious concrete provides hardscape without altering the land’s hydrology,” Youngs said.

There’s a growing concern in many parts of the state—particularly critical in Southern California—of water table depletion. Groundwater is not recharged by natural runoff flows that are now channeled to the sea. Pervious concrete pavements let the natural scheme of things take over, and the natural percolation and filtering effect of the soil go to work to do what dirt has done forever—clean the water.

While pervious concrete pavements have been used in Florida and other southeastern states since the 1970s, the idea has been slow to grow in the West. Communities in California are beginning to favorably review the material for its ability to restore groundwater supplies and reduce pollution in waterways and offshore.
“Right now we’re pretty small, probably 1 percent of the market, but that’s a big jump from zero percent four years ago,” said Youngs.

Framework for Success
While pervious concrete is making headlines in the industry for its drainage capabilities, another unique concrete product is quietly coming to the forefront of the construction scene: insulated concrete forms (ICF). The latest in framing construction, ICF work is slowly but surely gaining popularity around the state, and for good reason – ICF houses are cooler, stronger, and more energy-efficient than traditional wood-frame homes.

Like many good ideas, the process is simple. Stay-in-place foam segments sandwich a vertical concrete pour. Drywall is added to the inside and nearly any exterior treatment goes on



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the outside, resulting in homes that are stronger, quieter, and more energy-efficient that anything currently available. And they don't look like vertical concrete slabs or Roman temples – unless that's what the client wants.

"Poured concrete walls are not new," said Randy Daniels, southwest regional manager for Arxx Walls and Foundations. "What's new is the form work—it stays in place." Daniels said the process is very builder-friendly and once contractors use it, they "really enjoy the whole concept. They'd much rather work with ICF than bang on boards or haul around cinder blocks."

According to Daniels, interest in ICF has traveled, often by word-of-mouth, from the East Coast, down through the southern U.S. and finally out West. Demand for the product represents a relatively small part of the California market, but it is steadily growing.

"Five years ago the response was, 'What's that?' and now people are starting to understand," he said.

For Sam Gallego, manager of business development for Cemex in Ontario, ICF homes are becoming more and more attractive to clients because just about anything can be done with them. "We've done a tremendous amount of custom homes in Southern California," Gallego said. "These are fire-safe buildings, which is very important throughout California."

In early 2006, Cemex had more than 160 homes under construction in the Palm Springs market. The blistering hot summers were costing owners with wood-frame homes more than $700 a month in electricity for air conditioning. "We were able to reduce that to between $240 and $400 a month," he said.

While ICF construction has been used in Europe since the 1950s, it didn't take hold in the U.S. until in the early 1980s. In part, growth in ICF construction was limited by a slightly higher cost. The process also ran smack into the traditional method of wood frame construction.

However, Jim Niehoff, manager of residential programs at the Portland Cement Association, believes it is only a matter of time before those impressions change for good.

"ICF is ideal for California," Niefhoff said. "It's energy efficient, fire safe, and ICF homes are surprisingly quiet. Property constructed, ICF homes offer superior protection against disasters like hurricanes and earthquakes."

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Low Impact Development

'Green' Approaches to Storm Water Management Preserve Natural Systems and Improve Water Quality

While the green building movement is having a significant impact on many high profile projects, only a limited number of residential, retail and commercial developments have gone green-but that could soon change. Environmental awareness around the United States is increasing and consumers are starting to seek out green products. The hybrid car market, for example, while still a small percentage of overall new car sales, is expected to grow from 40,000 cars a year in 2003 to 350,000 in 2008, according to J.D. Powers and Associates.



However, one of the most powerful reasons for developers to build environmentally conscious projects is that they can actually save money both in development and in long-term maintenance. In particular, Low Impact Development strategies and green site planning can lessen the environmental impact of new developments by reducing storm water runoff and improving water quality. These approaches can also meet new regulations regarding storm water, save money and set the project apart in the marketplace. These strategies, therefore, are not just good for the planet-they're good for developer's, too.

What is low-impact development?

Traditional development practices take a straightforward approach to water: grab it and get it off the site. Paved surfaces slope to the drainage system, which shuttles water to river and lakes. The problem is that the water picks up junk along the way: oil, pesticides and sediment.

Awareness of these problems first grew out of the environmental movement of the 1960s and early 1970s. In 1972, the National Pollutant Discharge Elimination System (NPDES) was created under the Clean Water Act to regulate the discharge of pollutants into the nation's waters.

If we want to maintain our quality of life, we need to make the best use of our water.New development

"Once the major water quality problem in the United States was point-source pollution,

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such as factories dumping toxic substances into rivers," said Steve Veal, a Carter & Burgess Public Works Unit Manager.

strategies are a good place to start.

Heather Kinkade-Levario
Carter & Burgess

"Today, the problem is more likely to be non-point source pollution-the pollution that comes from everywhere and nowhere."

The Clean Water Act specifically regulates storm water management during construction: projects greater than one acre in size must carefully control runoff. Federal law is less specific concerning post-construction, and many completed projects largely ignore storm water quality issues. The exception is found in cities like Austin and Seattle where permanent pollution prevention practices are proscribed by strict storm water ordinances.

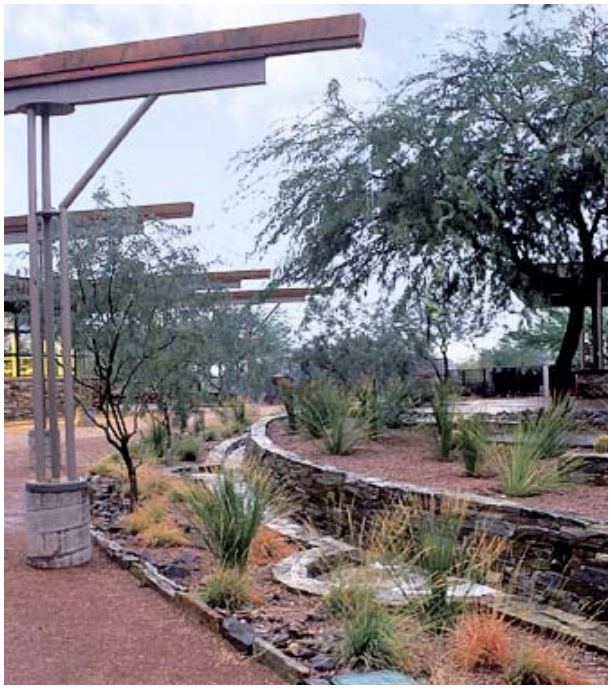
Meanwhile, in the 1990s, the green building movement began to pick up steam. Landscape architects and engineers involved in these projects, as well as those wrestling with traditional approaches to site planning, realized that significant savings in water usage could be achieved by approaching storm water in a new way.

"Why stop with the building itself?" said Heather Kinkade-Levario, a Planning Studio Leader in Carter & Burgess' Urban Design & Planning Unit. "Why not make the site as environmentally friendly as possible? These big basins and pipes are expensive. There is a better way!"

The result was a collection of new strategies and techniques grouped under the category Low Impact Development. They can generally be divided into two categories: active and passive.

Passive storm water management

Passive approaches use natural, gravity-driven processes to slow and filter water. "As water flows through the site, it should meander along so it has time to sink in. Compare that to sheet flow across a parking lot, where all sorts of oils and particles are picked up," Kinkade-Levario said.



Passive strategies start by considering each site as its own watershed. Designers get a sense of natural drainage basins and existing vegetation so the site can be designed to take advantage of as many of these features as possible. Low Impact developers will also work to preserve open space, sometimes choosing to "cluster" homes.

"When you cluster a development, rather than spreading homes throughout the entire site, you group them together, perhaps with smaller lot

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sizes," said Kinkade-Levario. "Now you don't have to add infrastructure to the remaining open land. You've preserved trees, wetlands, meadows and other natural amenities that the residents can enjoy, and you've enabled that portion of your site to continue to filter storm water in a natural way."

A further approach is to reduce the width of streets within residential developments. Many projects today have streets of up to 32 feet wide. Streets account for 40 to 50 percent of the impervious cover in residential areas and generate the largest amount of storm water pollution, according to researchers at the University of Connecticut. However, streets can be narrowed to between 26 and 20 feet and still provide enough room for traffic, reducing overall impervious area by 5 to 20 percent. Emergency responders, particularly fire departments, however need to be involved in the design of these streets; often driveways need to be widened and on-street parking limited to allow easy access for fire trucks.

Narrower streets have other advantages as well: they are cheaper to build and maintain, and traffic naturally travels more slowly and safely.

The next step is to divide the site into micro-watersheds that can be managed individually. Specific strategies include the following:

- Micro-basins, French drains and swales
- Sidewalks, driveways and parking lots sloped towards open space
- Depressed islands (rather than raised planters) in and along parking lots
- Pervious paving surfaces such as pavers, gravel-crete, porous concrete and porous asphalt
- Rain gardens, where specifically selected vegetation is planted in low areas so water will naturally flow at the end of a downspout

"Consider a tree in a raised island in a parking lot," Kinkade-Levario said. "The tree's roots can't extend beyond the edge of the island, not only because they can't get water but also because the surrounding pavement gets too hot. The tree never grows very big and its weak roots make it vulnerable in wind."

However, if a tree is planted in a depressed island surrounded by lightcolored, porous pavers, the tree's roots can extend under the paved surface so it can grow taller and stronger.

"Natural irrigation will keep it healthy, and the tree will contribute toward shading the paved surface and filtering runoff," said Kinkade-Levario. "Now you've contributed to both the aesthetics and the function of your site."



Active storm water management

Active Low Impact Development techniques generally involve systems of pumps, pipes and storage tanks to capture, store and reuse rainwater. Rainwater harvesting involves gathering relatively clean water from rooftops, while storm water reuse captures water at ground level where it can pick up pollutants. This water can then be stored (either underground or in above grade cisterns) and used for any purpose for which nonpotable water is appropriate, including the following:

- Landscape irrigation
- Fountains or water features
- Car washes
- Cooling towers
- Firework pre-wetting

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- Sewer cleaning
- Dust control
- Snow making
- Restrooms (Innovative systems pump water to toilets through separate piping systems. Rainwater can be supplemented with treated water when necessary.)

"There are thousands of innovative examples out there where communities are reusing water," said Carter & Burgess Senior Project Manager Bart Hines, a member of the board of directors for the Water Reuse Association. "Many golf courses have extensive water reuse strategies. So do power plants. The entire state of Florida reuses 52 percent of their wastewater effluent for non-potable purposes, which saves the potable water resources for the highest and best uses. Reuse of all waters is a great cost-saving strategy, regardless of the size of the community."



How is low-impact development good for developers?
The stakes are high in development projects, and few developers are willing to gamble their projects on new techniques solely for environmental reasons-particularly if they fear those techniques will cost more. However, Low Impact Development can provide significant benefits to developers and doesn't have to cost more. Three benefits-in addition to preserving water quality-can be obtained:

Meet legal requirements. Today, the primary enforcement mechanism for storm water pollution prevention is the EPA's National Pollutant Discharge Elimination Systems (NPDES) program. A storm water pollution prevention plan is required for all construction projects of more than one acre in size. However, most developers need to do little to reduce pollution after their project is complete.

That could change, however, as storm water pollution prevention becomes a priority for more local communities. This is driven by increased environmental concerns as well as by the municipal provisions of the Clean Water Act. Under Phase I of the NPDES program, cities with populations greater than 100,000 were required to develop storm water management plans and implement Best Management Practices (BMPs); Phase II, effective since March 2003, extended the same requirements to most smaller communities.

Cities are likely to turn to new developments to find improvements in storm water control. The Dallas/Fort Worth metroplex, for example, is developing a new Integrated Storm Water Management program that will regulate storm water pollution prevention across the region and encourage low-impact strategies. Communities across the United States, wrestling with poor water quality, eroded streams and creeks and increased flooding, as well as NPDES requirements, are likely to follow North Texas' lead.

Save Money. Low Impact Development strategies don't necessarily cost more-indeed, they often cost less. Passive Low Impact Development techniques such as swales, French drains and rain gardens cost less than the retention ponds and below ground storm water tanks used in typical storm water management and do a better job filtering water.

"And developers get back land on their site," said Kinkade-Levario. "Low Impact Development techniques take up less space than big retention ponds. They're spread out across and are integral to the entire site. The developer then has more property available for their project."

Infrastructure costs can be lower, particularly when considered over the long term. For example, a parking lot paved with asphalt may cost only $2 per square foot to install;

however, basins, storm drains, curbs and gutters must be built alongside the lot. Striping must be updated regularly, and the pavement itself must be sealed or even replaced every 10 years. On the other hand, pervious pavers cost $5 per square foot, but parking lots with pavers don't need the same curbs, gutters, basins, etc. Pavers last 25 years and require very little maintenance.

More active strategies such as rainwater harvesting have more extensive upfront costs but long-term water bills go down significantly. For sites requiring extensive irrigation, rainwater reuse can either eliminate or dramatically reduce water utility costs.

"Green site planning also doesn't necessarily add time to project schedules," said Kinkade-Levario. "If considered up front by knowledgeable landscape architects and engineers, low-impact strategies can be implemented without any time lost."

Differentiates the project. As environmental awareness becomes widespread, consumers are becoming more attracted to ecologically friendly developments. Savvy developers can use low impact development strategies as a selling point.

Furthermore, green site planning dovetails with several other development trends, including Smart Growth and New Urbanism. Narrower, more efficient street layouts, for example, encourage pedestrian activity, promote connectivity and reduce impervious cover. These projects can foster a "sense of community" in part on environmental responsibility and stewardship.

"Home buyers who are looking for a certain type of lifestyle are drawn to these projects," said Kinkade-Levario. Even if the developer doesn't choose to promote a project as green, low-impact techniques bring benefits to the look and feel of a project.

"Open space is highly prized in developments, particularly high-end residential projects," said Veal. "Low Impact Development provides a way to offer an amenity while promoting water quality and makes storm water pollution prevention a priority." Ultimately, the greatest benefit of low-impact development is to the entire community. Environmentally sensitive design reduces the consumption of potable water, decreases pollution to rivers and lakes, and increases ground water infiltration and aquifer replenishment.

"If we want to maintain our quality of life, we need to make the best use of our water," Kinkade-Levario said. "New development strategies are a good place to start."



North Central Texas Develops
Regional Storm Water Pollution Prevention Policies

The North Central Texas Council of Governments (NCTCOG) is working on a new Integrated Storm Water Management (iSWM) program that would provide a single set of guidelines for all municipalities in the D/FW Metroplex. “We’re being driven by several purposes,” said NCTCOG Director of Environment and Development John Promise. “We need to do a better job of managing flood risks, preventing pollution and controlling the erosion and degradation of streams and drainageways.”

iSWM emphasizes analysis, evaluation and site-specific planning early in the development process. Developers will draw up plans that identify preservation areas, buffers and BMPs to prevent pollution as well as identify continuing operation, maintenance and inspection strategies.

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The draft guidelines do not strictly dictate Low Impact Development techniques, but they do encourage reducing impervious cover. Developers would get credits for designing with the land, retaining natural drainageways and preserving open space. If developers choose to bulldoze their site, grade the land and design using conventional techniques, they would be required to build extensive (and expensive) structural BMPs to mitigate storm water pollution impact.

The iSWM program is still under development. “In our first phase, we asked, can we really come up with a design approach that addresses flooding, water quality and stream-bank erosion? The answer was yes,” said Promise. “In the second phase, where we are now, we’re asking, do we understand costs and benefits? Are we prepared to implement this plan? In the third phase, we’ll develop a tool box of materials, training programs and implementation mechanisms.”

To evaluate costs and benefits, NCTCOG selected seven recent projects in the area developed using conventional means. A consulting team is redesigning these projects using the draft design manual and estimating the costs of building the redesigns. NCTCOG deliberately selected a wide range of development and redevelopment projects, including single-family, multi-family, retail, office, etc., with a range of design challenges for the study.

“What we’re trying to learn is how these strategies work with different types of development examples—what works and what doesn’t,” said Promise.

The results of this study will be released in the fall of 2004. Then the design guidelines and study results will go out for public review and comment.

“The timing is right for this project,” said Promise. “We’ve got communities across the region involved—more than 55 local governments are actively supporting us with 100 percent cost-sharing. Storm water doesn’t respect city limits. We’re going to do this together.”



This article originally appeared in Carter & Burgess's Quarterly, Issue Four, 2004.

International Stormwater Best Management Practices (BMP) Database

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New Link! November 29, 2006 Center for Transportation and Environment Telecast

Welcome to the International Stormwater Best Management Practices (BMP) Database project web site, which features technical documents, software and database developed over the past decade. The overall purpose of the project is to provide scientifically sound information to improve the design, selection and performance of BMPs. To accomplish this goal, the Project Team has developed tools to promote scientifically-based collection and management of the data needed to evaluate the effectiveness of stormwater runoff BMPs. These tools include standardized BMP monitoring and reporting protocols, a stormwater BMP database, BMP performance evaluation protocols, and BMP monitoring guidance. Continued population of the database and assessment of its data will ultimately lead to a better understanding of factors influencing BMP performance and help to promote improvements in BMP design, selection and implementation.

The project, which began in 1996 under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the U.S. Environmental Protection Agency (USEPA), now has support and funding from a broad coalition of partners including the Water Environment Research Foundation (WERF), ASCE Environmental and Water Resources Institute (EWRI), USEPA, Federal Highway Administration (FHWA) and the American Public Works Association (APWA). Wright Water Engineers, Inc. and GeoSyntec Consultants are the entities maintaining and operating the database clearinghouse and web page, answering questions, conducting analyses of newly submitted BMP data, conducting updated performance evaluations of the overall data set, disseminating project findings, and expanding the database to include other approaches such as Low Impact Development techniques. The database itself is downloadable to any individual or organization that would like to conduct its own assessments.

On this web site, you can obtain:

- the minimum protocols for submitting BMP monitoring studies for

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inclusion into the database;

- guidance for monitoring stormwater BMPs to meet these protocols;
- data entry software to store and report BMP monitoring study data;
- performance summaries for individual BMPs through the on-line searchable database containing roughly 200 BMPs;
- statistical summaries of the overall BMP database;
- statistical summaries of performance by BMP types (e.g., wet ponds);
- technical reports describing the statistical techniques recommended for analyzing BMP performance and the results of performance evaluations;
- published papers from conference proceedings and journals on the BMP database; and
- other useful information.

This site is updated regularly with the latest findings and links to materials produced by the Project Team. The underlying data for this project is the result of dedicated efforts of the stormwater research community, and its continued success is predicated on the cooperative efforts of researchers and professionals around the world. The Project Team continuously pursues new BMP data for inclusion in the database and uploads new studies approximately semi-annually. If you have data that you are interested in submitting, please Contact Us.

Summary of the Number of BMPs in the BMP Database

BMP Database Disclaimer

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DISCLAIMER

This publication contains guidance for builders engaged in or interested in green building products and practices for residential design, development and construction. This publication is not intended to be exhaustive and all-inclusive and the enclosed guidelines are not to be considered the only method of green building. These guidelines for green building originate from the collective experience of leading personnel in the green building movement (marketplace), but must, due to the nature of the responsibilities involved, be presented only as a guide for the use of a qualified developer, builder, remodeler, or design professional.

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These guidelines could not have become a reality without the time and effort of numerous people. For example, input from the Stakeholder Group provided the necessary information to modify and finalize the guidelines. These organizations and individuals helped move green home building techniques and technologies further into mainstream home building.

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INTRODUCTION



The process of green building incorporates environmental considerations into every phase of the home building process. That means that during the design, construction, and operation of a home, energy and water efficiency, lot development, resource efficient building design and materials, indoor environmental quality, homeowner maintenance, and the home's overall impact on the environment are all taken into account.

Now to answer the question, **"Why should we care about green building?"** There are many compelling reasons for changing the way we build and operate homes. Although we cannot avoid affecting the environment when we build a house, green building can work toward minimizing that environmental impact.

These guidelines were designed with the mainstream home builder in mind. We recognize that many home building companies already incorporate some elements of green building into their current practices. However, the purpose of these guidelines is to highlight ways in which a mainstream home builder can effectively and holistically weave environmental concerns into a new home and to provide a tool for local associations to create a green home building program.

At the time these guidelines were created, there were 28 green home building programs in operation throughout the United States. These programs have done a great job of spreading the word about green home building. However, there are numerous other locales that are interested in green home building but have not had the resources to create a program from scratch. These guidelines are intended to serve as a tool kit for home builder associations to create new programs and to help those programs expand and flourish.

GUIDING PRINCIPLES

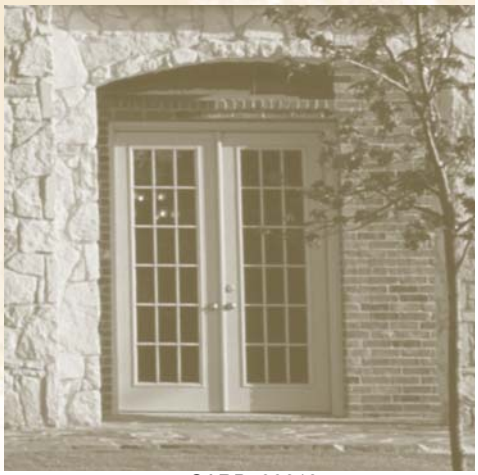
As noted above, during the process of building a green home, a builder takes numerous considerations into account simultaneously and consciously incorporates environmental issues into all decisions. These model green home building guidelines consist of a variety of distinct line items that a builder can choose from in creating a green home. For organizational purposes, we have grouped the line items into overarching sections, or guiding principles. Below are the guiding principles addressed in green home building:

Guiding Principle—LOT DESIGN, PREPARATION, AND DEVELOPMENT

Resource-efficient site design and development practices help reduce the environmental impacts and improve the energy performance of new housing. For instance, site design principles such as saving trees, constructing onsite storm water retention/infiltration features, and orienting houses to maximize passive solar heating and cooling are basic processes used in the design and construction of green homes.

Guiding Principle—RESOURCE EFFICIENCY

Most successful green homes started with the consideration of the environment at the design phase—the time at which material selection occurs. Creating resource-efficient designs and using resource efficient materials can maximize function while optimizing the use of natural resources. For instance, engineered-wood products can help optimize resources by using materials in which



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more than 50% more of the log is converted into structural lumber than conventional dimensional lumber.

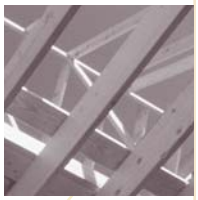
Resource efficiency is also about reducing job-site waste. Invariably, there are leftover materials from the construction process. Developing and implementing a construction waste management plan helps to reduce the quantity of landfill material. The average single-family home in the United States, at 2,320 ft^2 (NAHB, 2003), is estimated to generate between 6,960 and 12,064 lbs. of construction waste. Thus, by creating an effective construction waste management plan and taking advantage of available recycling facilities and markets for recyclable materials, construction waste can be reduced by at least two-thirds, creating potential cost savings for builders and reducing the burden on landfill space.

Lastly, basing the selection of building materials on their environmental impact can be tricky. For instance, a product might be renewable, but on the other hand it takes a relatively great amount of energy to transport the product to a project's job site. One way to compare products is to look at a product's or a home's life-cycle environmental impacts through a process called life-cycle analysis (LCA). An LCA of a building product covers its environmental impacts "cradle to grave" through six basic steps: 1) Raw material acquisition, 2) Product manufacturing process, 3) Home building process, 4) Home maintenance and operation, 5) Home demolition, and 6) Product reuse, recycling, or disposal. There are numerous reasons why building products are not commonly selected via LCAs. One of the issues is the availability of data—there is a lack of data to feed into tools that allow for an LCA on a product or system.

One such tool created by the National Institute of Standards and Technology (NIST) is the Building for Environmental and Economic Sustainability (BEES) software program. BEES has 10 impact categories: acid rain, ecological toxicity, eutrophication, global warming, human toxicity, indoor air quality, ozone depletion, resource depletion, smog, and solid waste. Since information is not available to conduct full LCAs on all available building products, we have instead included an LCA mind-set in creating the list of line items in the Resource Efficiency section. Our hope is that in the future the prescriptive line items in the guidelines will eventually be replaced with a full LCA approach for the home as a system and the components therein.

Guiding Principle—ENERGY EFFICIENCY

Energy consumption has far-reaching environmental impacts: from the mining of fossil-fuel energy sources to the environmental emissions from burning non-renewable energy sources. And each home consumes energy year after year, meaning that the environmental impacts associated with that use accrue over time. Therefore, energy efficiency is weighted heavily in a green building program.



Energy consumption occurs not only during the operation of a home but also during the construction of a home and, indirectly, in the production of the materials that go into the home. Although the energy used to heat and cool a home over its life far outweighs that to manufacture the materials and construct it, the large number of homes built (currently about 1.85 million per year) renders the energy used during the construction phase significant.

On average, a home built between 1990 and 2001 consumed about 12,800 kWh per year for space and water heating, cooling, and lights and appliances. Where natural gas is used, consumption averages 69,000 cubic feet per household annually. Total energy expenditures during a year cost these homeowners about $1,600. Energy-efficiency improvements that make a home 20% more efficient—a conservative estimate for many green homes—could significantly reduce a homeowner's annual utility expenses.

No matter what the climate, energy efficiency is considered a priority in most existing green building guidelines/programs. Moreover, as the cost to heat and cool a home becomes more unpredictable, it is advantageous to every homeowner to be "insulated" from inevitable utility bill increases. As with all aspects of these guidelines, the greatest improvements result from a "whole systems" approach. Energy performance does not end with increased R-values, the use of renewable energy, and/or more efficient HVAC equipment. Rather, there needs to be a balance between these features and careful window

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selection, building envelope air sealing, duct sealing, and proper placement of air and vapor barriers from foundation to attic to create a truly high-performance, energy-efficient home that is less expensive to operate and more comfortable to live in than a conventionally constructed home.

Guiding Principle—WATER EFFICIENCY

The mean per capita indoor daily water use in today's homes is slightly over 64 gallons. Implementing water conservation measures can reduce usage to fewer than 45 gallons. For this reason, green homes are especially welcomed in areas affected by long- and short-term drought conditions.

The importance of water resources is becoming increasingly recognized, especially in the western third of the country. Choices between sending water to growing urban areas and making water available for irrigation highlight the issues surrounding the scarcity of this valuable resource.

Green homes often conserve water both indoors and out. More efficient water delivery systems indoors and native and drought-resistant landscaping choices outdoors can help prevent unnecessary waste of valuable water resources. Communities can obtain additional benefits when builders effectively use native species in landscaping. Current research and practice have shown that natural processes can be a successful means of filtering and removing contaminants from storm water and wastewater.



Guiding Principle—INDOOR ENVIRONMENTAL QUALITY

Healthy indoor environments attract many people to green building. After energy efficiency, the quality of a home's indoor air is often cited as the most important feature of green homes. Pam Sessions, president of Hedgewood Properties in Atlanta, said during the 2002 National Green Building Conference that the majority of people interested in green homes in the Atlanta market indicated that indoor air quality was their top issue of interest.

An increase in reported allergies and respiratory ailments and the use of chemicals that can off-gas from building materials have contributed to a heightened awareness of the air we breathe inside our homes. Even though there is no authoritative definition of healthy indoor air, there are measures that can mitigate the effects of potential contaminants including controlling the source, diluting the source, and capturing the source through filtration.

Guiding Principle—OPERATION, MAINTENANCE, AND HOMEOWNER EDUCATION

Improper or inadequate maintenance can defeat the designer's and builder's best efforts to create a resource-efficient home. For example, homeowners often fail to change air filters regularly or neglect to operate bath and kitchen exhaust fans to remove moist air. Many homeowners are unaware of the indoor environmental quality impact of using common substances in and around the house such as pesticides, fertilizers, and common cleaning agents. ***By providing homeowners with a manual that explains proper operation and maintenance procedures, offers alternatives to toxic cleaning substances and lawn and garden chemicals, and points out water-saving practices, a builder can help assure that the green home that was so carefully built will also be operated in an environmentally responsible manner.***

Guiding Principle—GLOBAL IMPACT

There are some issues related to home building and land development that do not fit neatly into the context of the aforementioned guiding principles. ***For these items that are a by-product of home construction, we have added a separate principle—global impact.*** One example of an issue having global impact is the selection of paints that contain relatively low or no volatile organic compounds (VOCs). Although the VOC content of paint is often considered for indoor environmental reasons, the vast majority of VOCs are released by the time the paint is dry.

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However, the release of VOCs from wet paint helps form ground-level ozone pollution. Therefore, the use of low- or no-VOC paints falls under the global impact principle because the environmental impact of using paints with relatively high VOC levels is greater on the global scale than it is on the indoor environment.

Guiding Principle—SITE PLANNING AND LAND DEVELOPMENT

The process of green home building should not stop at the house. If a builder is also involved in the development of the community, site planning and land development can be part of the process. Therefore, information about low-impact site planning and land development is included in Appendix A. Considering the entire community and existing infrastructure in addition to the individual building(s) can amplify the benefits of green home building. For example, by improving a subdivision's storm water management plan and preserving natural resources through careful design and construction practices, ***a builder can influence not only the resource efficiency of each particular house but also the entire subdivision's overall environmental impact.*** Low-impact development (LID), which uses various land planning and design practices and technologies to simultaneously conserve and protect natural resources and reduce infrastructure costs, is one way to approach green development.

HOW HOMEOWNERS CAN BENEFIT FROM GREEN BUILDING

The previous section highlighted the environmental benefits of green building practices. However, green building is much more than just reducing a home's environmental footprint. Homeowners can also realize direct benefits by owning a green home. Here are some of the primary benefits that owners of green homes have experienced compared with owners of conventional homes:

- **Lower operating costs—**Homeowners receive less expensive utility bills because of energy and water efficiency measures.
- **Increased comfort—**Green homes have relatively even temperatures throughout the home, with fewer drafts and better humidity control.
- **Improved environmental quality—**By following these guidelines, builders pay extra attention to construction details that control moisture, choose materials that contain fewer chemicals, and design air exchange/filtration systems that can contribute to a healthier indoor environment.



- **Enhanced durability and less maintenance—**Green homes incorporate building materials and construction details that strive to increase the useful life of the individual components and the whole house. Longer-lasting materials not only require fewer resources for replacement but also reduce maintenance and repair costs. Green homes have lawns that require less weeding and watering, building elements that require less maintenance, and more durable building components that reduce the time needed for upkeep.

It is important to note that a builder can do only so much when it comes to how the home will perform. Homeowners play a big role in the house performance and, therefore, should be instructed on how to operate the green home as it was intended.

GUIDELINES DEVELOPMENT PROCESS

The NAHB Model Green Home Building Guidelines were developed through a public process that included the following major steps:

1. An extensive review of the existing local green home builder programs—primarily home builder association programs, but also including several public sector and non-profit programs. All but three of the 28 existing programs are voluntary and market-driven.
2. A review of the voluntary energy-efficiency programs endorsed by NAHB.

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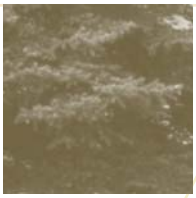
3. A review of the leading life-cycle analysis (LCA) tools available for use by residential design and construction professionals in North America (e.g., BEES, ATHENA).
4. Input through an open process from numerous individuals in the NAHB Advisory Group and the Stakeholder Group.
5. Applying certain criteria to each line item in order to give the line items point values.

Each line item in the guidelines has a point value attributed to it. Once the Stakeholder Group members finalized the list of line items for inclusion in the guidelines, the NAHB team looked at each line item through three different lenses: 1) environmental impact, 2) building science and best building practices, and 3) ease of Implementation. The team used publicly available information, experiential data, and other data inputs to assign each line item points via these three criteria. Each line item's final point total was calculated by weighting the criteria. Environmental impact received the greatest weight, followed by building science and best building practices, with ease of implementation receiving the least weight.

Environmental Impact—The main purpose of these guidelines is to provide a framework for builders to reduce a home's environmental impact. We assessed how each line item helped make a home more energy efficient, improved indoor environmental quality, and so on. Assigning a value to each line item is an inexact science since all of the necessary data are not available. In addition, some line items had impacts that spanned multiple principles, and, in some cases, the impact was positive for one guiding principle while negative for another. With that as background, the NAHB team took into account all of the above considerations and available data to assess the environmental impact of implementing each line item. Using qualitative and quantitative information, the team assigned value to each line item based on the positive impact to the environment.

Building Science and Best Building Practices—Certain green building practices dramatically affect how a house operates. For example, the sealing of a home's building envelope has an impact on the home's HVAC system. In addition, some measures such as proper flashing details and installation of weather barriers enhance durability, minimize the possibility of indoor environmental problems, and are considered "best building practices." Line



items that help a home perform effectively as a system for the long term were assigned a higher point value.

Ease of Implementation—Some line items are easier to implement than others. The NAHB team compared each line item with current home building practices and estimated how difficult it would be for a builder to implement the line item relative to cost and time. For instance, would it take longer to install a new technology? Would subcontractors need to be educated on the use of a new product? Would a new technology cost more to buy? A line item will have a positive environmental impact only if it is implemented. Line items that were relatively easy to implement (and therefore more likely to be implemented) were assigned a greater point value than the items that are more difficult to implement.

Green Programs and Homes Differ Across the Country

When assigning points to the line items, NAHB assumed the home would be built in Baltimore, which is in Zone 4 of DOE's proposed climate zone map. The map can be viewed at the following web site:
www.energycodes.gov/implement/pdfs/color_map_climate_zones_Mar03.pdf

For associations located outside of Zone 4 that are interested in creating a green building program, point values can be customized for some line items most affected by climate conditions. For example, an association in Florida will likely want to increase the point values attributed to installing an energy efficient-air conditioning



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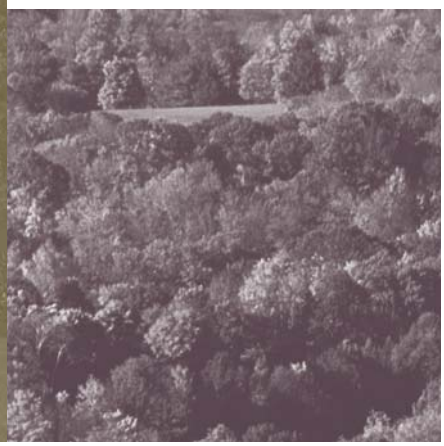

system and decrease the point value associated with installing a high-efficiency heating system. Similarly, in the southwestern United States, associations would probably place higher value on water efficiency measures. A thermometer symbol in the User Guide identifies line items that most likely will see point value changes due to climatic differences across the country.

Additional factors can lead to the decision to alter point values for a certain location, such as the availability of materials, the recycling marketplace, and the existence of rebate programs. A line item's point value is determined by consensus among the members of the green home building program's development committee. This is primarily a qualitative process, and some acknowledgment of the decision-making process should be clearly stated in the program.

Various Levels of Green

Homebuilders differ in their relative knowledge and comfort level with green building concepts. Some builders have been building green for years, while others are being introduced to the ideas for the first time. Recognizing this broad range of knowledge, the NAHB team established various thresholds to delineate different levels of green building effort.

The first step was to identify practices that should be part of any home building project. The first level of green building, Bronze, includes additional line items that in the end show that a builder paid special attention to a project's environmental impact. The next two levels of green home building, Silver and Gold, include additional line items that place increasingly greater emphasis on the home's environmental impact. The "How to Use the Guidelines" section of this document outlines how to score a home to determine if it meets or exceeds any of the green home building levels noted above.

The Uncertainties of Green Building

It should be noted that although many green building programs have been in existence for 10 years or more, the concept and practice of green building is not clearly defined and straightforward. Many gray areas remain in identifying and quantifying the precise environmental impact for each particular line item. For example, there is very little publicly available information regarding manufacturing processes that document energy consumption, impact on natural resources, or CO_2 emissions for each building material.

In addition, a particular guideline may contain trade-offs and carry with it contradictory characteristics. For example, a recirculating hot water system can help conserve water but may use a relatively large amount of energy in its operation. Although the guidelines in their current form are based on experiential evidence and the latest independent scientific research available, they still may leave many questions unanswered due to the lack of scientific and quantitative data.

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Finally, assigning a particular degree of importance to different criteria undoubtedly involves a certain amount of personal or local value judgment. Life-cycle assessment (LCA) tools are beginning to sort out such questions, but the tools still remain in their infancy. Therefore, this set of green home building guidelines should be viewed as a dynamic document that will change and evolve as new information becomes available, improvements are made to existing techniques and technologies, and new research tools are developed.

HOW TO USE THE GUIDELINES

The guidelines are organized by the guiding principles listed above. However, there are two underlying ideas that everyone should keep in mind before undertaking a green home project. First, environmental considerations should be incorporated into the project from the very beginning. It is much harder to weave green home concepts into a project after the house plans are finished. Second, the house should be looked at as a whole as the builder determines which of the green home guideline items to put into the house. For example, making a home's building envelope tighter through air sealing and quality building techniques can affect the way in which the builder designs the home's ventilation system. It is through such a forward-thinking process that builders can gain cost efficiencies.

PART ONE—Green Home-Building Checklist

Part One of these guidelines contains the checklist of line items. Each entry includes the line item title, the point value, and the items that should be provided by the builder to verify that the line item was implemented. The verification column assumes there is a green building program coordinator or other third party. However, the guidelines and point system can be used independently even if a formal green building program does not exist in a particular region.

It is again recommended that a builder first become familiar with the line items prior to designing a home to help introduce concepts that a builder can incorporate into the home's design, construction, and operation.

To help a builder holistically incorporate green building into homes, the NAHB team established different point levels to achieve for each guiding principle at each level of green building. The point system is described below.

POINT SYSTEM

There are three different levels of green building available to builders wishing to use these guidelines to rate their projects—Bronze, Silver, and Gold. At all levels, there are a minimum number of points required for each of the seven guiding principles to assure that all aspects of green building are addressed and that there is a balanced, whole-systems approach. After reaching the thresholds, an additional 100 points must be achieved by implementing any of the remaining line items. The table below outlines the various green building level thresholds.

Points Required for the Three Different Levels of Green Building

	Bronze	Silver	Gold
Lot Design, Preparation, and Development	8	10	12
Resource Efficiency	44	60	77
Energy Efficiency	37	62	100
Water Efficiency	6	13	19
Indoor Environmental Quality	32	54	72
Operation, Maintenance, and Homeowner Education	7	7	9
Global Impact	3	5	6
Additional Points From Sections of Your Choice	100	100	100

** If the home does not have a ducted distribution system for space heating and cooling, deduct 15 points from the number required in the Energy Efficiency section.*

A reduction in the required points for a home without ductwork for the space heating and cooling systems reflects the fact that there are more points available for homes that do have ductwork. It is not intended as an indication of preference for one type of system over another.

To determine point values for each guiding principle, a builder simply adds the points for each line item applied to the home for each guiding principle. Comparing the project's points for the individual guiding principles with the chart above will determine whether the project is deemed a Bronze-, Silver-, or Gold-level green home.



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PART TWO—User Guide

Recognizing that some of the line items need more than a one- or two-sentence explanation, the User Guide further explains each concept. For each line item, the User Guide contains an entry with the following subheadings:

Intent—Explains the general reasons for including each line item in the guidelines and the impact that implementing the line item will have on the environment.

Additional Information / How to Implement—Contains text, pictures, and formulas to help facilitate the line item's implementation.

Resources—References to books, web sites, articles, and technical guides for further in-depth information related to the line item. Please note that the URLs were active and current at the time this document was created. With the significant changes occurring on the Internet and in the home building industry products and services markets, location and availability of resources will likely change over time.

As noted earlier, Appendix A provides additional ideas to consider for builders and developers who can effect change at the subdivision level, i.e., multiple home levels.

If a local green home building program does not exist, a builder can use the checklist and User Guide to self-certify a home. However, if a local association has used this document to create a local green building program, the builder can use the checklist and system from that program to show a home's relative green value.

Final Thoughts

We hope you find this tool useful and that it helps further advance green home building practices into mainstream construction. We wish you well in your endeavors and encourage you to share this information with your friends and family, customers, and product suppliers and distributors.



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SECTION 1 LOT DESIGN, PREPARATION, AND DEVELOPMENT



		PTS	HOW TO VERIFY
1.1 SELECT THE SITE			
	Select the site to minimize environmental impact.		
1.1.1	Avoid environmentally sensitive areas as identified through site footprinting process or existing third-party data.	7	Any one of the following: • Comprehensive plan • Wetland institute • Local jurisdiction's guidelines • Site footprinting process results • Set of site plans
1.1.2	Choose an infill site.	**9**	
1.1.3	Choose a greyfield site.	**7**	
1.1.4	Choose an EPA-recognized brownfield.	**7**	Confirmation from a federal, state, or local brownfields site inventory list or representative that the site is a brownfield
1.2 IDENTIFY GOALS WITH YOUR TEAM			
1.2.1	Establish a knowledgeable team. A. Identify team member roles and how they relate to various phases of green lot design, prep, and development. B. Create a mission statement that includes the project's goals and objectives.	**6**	Written project mission statement, goals, and team member roles
1.3 DESIGN THE SITE			
	Minimize environmental impacts; protect, restore, and enhance the natural features and environmental quality of the site (points for each guideline are only rewarded upon implementation of these plans).		
1.3.1	Conserve natural resources. A. Complete a natural resources inventory used to drive and create the site plan. B. Create a protection and maintenance plan for priority natural resources and areas during construction. See Section 1.4 for guidance in forming the plan. C. Participate in a natural resources conservation program, e.g., *Building With Trees.* D. Provide basic training in tree and other natural resource protection to onsite supervisor.	**6**	Pre- and post-development natural resources inventory Protection and maintenance plan Certificate or letter indicating participation in a natural resources conservation program

		PTS	HOW TO VERIFY
1.3.2	Site the home and other built features to optimize solar resource (refer to Energy Efficiency module for guidance on solar resource optimization).	6	House plans
1.3.3	Minimize slope disturbance. **A.** Limit development footprint on steep slopes (slopes greater than or equal to 25%). **B.** Complete a hydrological/soil stability study for steep slopes, and use this study to guide the design of all structures onsite. **C.** Align road or extended driveway with natural topography to minimize its grade and reduce cut and fill. **D.** Reduce long-term erosion effects through the design and implementation of terracing, retaining walls, landscaping, and restabilization techniques.	5	Hydrological/soil stability study results Topographical map with contour lines
1.3.4	Minimize soil disturbance and erosion. *See Section 1.4 for further guidance.* **A.** Schedule construction activities to minimize exposed soils. **B.** Use alternative means to install utilities, such as tunneling instead of trenching, use of smaller equipment, shared trenches or easements, and placement of utilities under streets instead of yards. **C.** Demarcate limits of clearing and grading.	6	Sediment and erosion control plans
1.3.5	Manage storm water using low-impact development when possible. **A.** Preserve and use natural water and drainage features. **B.** Develop and implement storm water management plans that minimize concentrated flows and seek to mimic natural hydrology. **C.** Minimize impervious surfaces, and use permeable materials for driveways, parking areas, walkways, and patios.	8	Storm water management plan
1.3.6	Devise landscape plans to limit water and energy demand while preserving or enhancing the natural environment. **A.** Formulate a plan to restore or enhance natural vegetation that is cleared during development. Within this plan, phase landscaping to ensure denuded areas are quickly vegetated. **B.** Select turf grass and other vegetation that are native or regionally appropriate species. **C.** Limit turf areas of landscaped area, selecting native and regionally appropriate trees and vegetation in a way that complements the natural setting. **D.** Group plants with similar watering needs (hydrozoning). **E.** Specify planting of trees to increase site shading and moderate temperatures (see also Energy Efficiency Guideline 3.4.1.c specifying siting of trees to reduce the energy consumption of the home). **F.** Design vegetative windbreaks or channels as appropriate to local conditions.	8	Landscape plan



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		PTS	HOW TO VERIFY
	G. Require onsite tree trimmings or waste of regionally appropriate trees to be used as protective mulch during construction or as a base for walking trails. **H.** Establish an integrated pest management plan to minimize chemical use of pesticides and fertilizers.		
1.3.7	Maintain wildlife habitat.	**5**	Set of site plans (Extra points) Present a certificate or letter indicating participation in a wildlife conservation program.
1.4 DEVELOP THE SITE **Minimize environmental intrusion during onsite construction.**			
1.4.1	Provide onsite supervision and coordination during clearing, grading, trenching, paving, and installation of utilities to ensure that targeted green development practices are implemented (see 1.3.4).	**5**	Protection and maintenance plan
1.4.2	Conserve existing onsite vegetation. **A.** Minimize disturbance of and damage to trees and other vegetation designated for protection through installation of fencing and avoidance of trenching, significant changes in grade, and compaction of soil and critical root zones. **B.** Prepare designated existing trees and vegetation for the impact of construction by pruning, root pruning, fertilizing, and watering.	**5**	Protection and maintenance plan and/or set of site plans
1.4.3	Minimize onsite soil disturbance and erosion. **A.** Demarcate limits of clearing and grading. **B.** Create construction "no disturbance" zones using fencing or flagging to protect vegetation and sensitive areas from construction vehicles, material storage, and washout. **C.** Install and maintain sediment and erosion controls. **D.** Stockpile and cover good soil for later use. **E.** Reduce soil compaction from construction equipment through laying mulch, chipped wood, or plywood sheets. **F.** Stabilize disturbed areas within the EPA-recommended 14-day period. **G.** Improve the soil with organic amendments and mulch.	**6**	Sediment and erosion control plans
1.5 INNOVATIVE OPTIONS **Seek to obtain waivers or variances from local development regulations to enhance green building.**			
1.5.1	Share driveways or parking.	**6**	Waiver or variance for the plan
1.5.2	Other (specify).		Waiver or variance for the item(s)



		PTS	HOW TO VERIFY
2.1 REDUCE QUANTITY OF MATERIALS AND WASTE			
2.1.1	Create an efficient floor plan that maintains a home's functionality.	**9**	House plans
2.1.2	Use advanced framing techniques that reduce the amount of building material while maintaining the structural integrity of the home (see User Guide for examples).	**8**	House plans
2.1.3	Use building dimensions and layouts that maximize the use of the resources by minimizing material cuts.	**6**	House plans
2.1.4	Create a detailed framing plan and detailed material takeoffs. Provide an onsite cut list for all framing and sheathing material.	**7**	Framing plan Cut list
2.1.5	Use building materials that require no additional finish resources to complete application onsite.	**4**	Product literature Installer, manufacturer, or builder certified
2.1.6	Use pre-cut or pre-assembled building systems or methods.		Framing plan
	A. Provide a pre-cut (joist) or pre-manufactured (truss) floor and roof framing package—points provided for a flooring or a roof framing package—additional points provided if both packages are used.	**3** per	
	B. Provide a panelized wall framing system.	**6**	
	C. Provide a panelized roof system.	**6**	
	D. Provide modular construction for the entire house.	**7**	
2.1.7	Use a frost-protected shallow foundation (FPSF).	**4**	
2.2 ENHANCE DURABILITY AND REDUCE MAINTENANCE			
	Building design minimizes degradation, and weathering of materials and enhances life expectancy. Features and details are to be specified on architectural plans.		
2.2.1	Provide a covered entry (e.g., awning, covered porch) at exterior doors to prevent water intrusion and subsequent rotting of joists, sills, and finishes.	**6**	House plans
2.2.2	Use recommended-sized roof overhangs for the climate.	**7**	House plans
2.2.3	Install perimeter drain for all basement footings sloped to discharge to daylight, dry well, or sump pit.	**7**	House plans
2.2.4	Install drip edge at eave and gable roof edges.	**6**	House plans
2.2.5	Install gutter and downspout system to divert water five feet away from foundation and into the overall onsite drainage area.	**6**	

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		PTS	HOW TO VERIFY
2.2.6	Divert surface water from all sides of building. Slope top of backfill to achieve settled slope of at least six inches of fall within 10 feet of the foundation walls.	7	Set of site plans
2.2.7	Install continuous and physical foundation termite barrier in areas where subterranean termite infestation is a problem.	7	
2.2.8	Use termite-resistant materials for walls, floor joists, trusses, exterior decks, etc., in areas known to be termite infested.	7	
2.2.9	Provide a water-resistant barrier (WRB) or a drainage plane system behind the exterior veneer system or the exterior siding.	8	
2.2.10	Install ice flashing at roofs edge.	5	
2.2.11	Install enhanced foundation waterproofing.	7	House plans
2.2.12	Employ and show on plans the following flashing details: **A.** Around windows and doors **B.** Valleys **C.** Deck/house juncture **D.** Roof/wall junctures, chimneys step flashing **E.** Drip cap above windows and doors.	9	House plans
2.3 REUSE MATERIALS			
2.3.1	Disassemble existing buildings (deconstruction) instead of demolishing.	6	
2.3.2	Reuse salvaged materials where possible.	5	List of components
2.3.3	Dedicate and provide onsite bins and/or space to facilitate the sorting and reuse of scrap building materials.	6	C & D waste management plan
2.4 USE RECYCLED CONTENT MATERIALS			
2.4.1	Use recycled-content building materials.	3	List of components used
2.5 RECYCLE WASTE MATERIALS DURING CONSTRUCTION			
2.5.1	Develop and implement a construction and demolition (C & D) waste management plan that is posted at job site.	7	Copy of C & D waste management plan
2.5.2	Conduct onsite recycling efforts, e.g., use grinder and apply materials onsite, thus reducing transportation-related costs.	5	Copy of C & D waste management plan including information on what materials are going to be ground for the project
2.5.3	Recycle construction waste offsite, e.g., wood, cardboard, metals, drywall, plastics, asphalt roofing shingles, concrete, block, other.	6	Contractual agreement between the recycling firm and the builder Documentation on materials that have been recycled List of components recycled

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		PTS	HOW TO VERIFY
2.6 USE RENEWABLE MATERIALS			
2.6.1	Use materials manufactured from renewable resources or agricultural byproducts such as soy-based insulation, bamboo, or wood-based products	3	List of components used
2.6.2	Use certified wood for wood and wood-based materials and products from all credible third-party-certified sources, including **A.** The Sustainable Forestry Initiative® Program **B.** The American Tree Farm System® **C.** The Canadian Standards Association's Sustainable Forest Management System Standards (CAN/CSA Z809) **D.** Forest Stewardship Council (FSC) **E.** Program for the Endorsement of Forest Certification Systems (PEFC), and **F.** Other such credible programs as they are developed and implemented.	4	Certification document—points given per component
2.7 USE RESOURCE-EFFICIENT MATERIALS			
2.7.1	Use products that contain fewer resources than traditional products.	3	List of components used
2.8 INNOVATIVE OPTIONS			
2.8.1	Use locally available, indigenous materials.	5	List of components used
2.8.2	Use a life-cycle assessment (LCA) tool to compare the environmental burden of building materials and, based on the analysis, use the most environmentally preferable product for that building component.	8	Provide BEES or ATHENA output to show use of an environmentally preferable product

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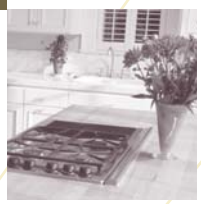

3.1 IMPLEMENT AN INTEGRATED AND COMPREHENSIVE APPROACH TO ENERGY-EFFICIENT DESIGN OF BUILDING SITE, BUILDING ENVELOPE, AND MECHANICAL SPACE CONDITIONING SYSTEMS

REQUIREMENTS—The home must meet the following conditions listed in 3.1.1 through 3.1.3 below.

The home must also achieve the equivalent of at least 37 points (Bronze level) from the optional guidelines in the performance path (Section 3.2) or the prescriptive path (Section 3.3).

GUIDELINE		PTS	HOW TO VERIFY
3.1.1	Home is equivalent to the IECC 2003 or local energy code, whichever is more stringent. Conformance shall be based on plan analysis using software such as ResCheck or other as approved by green building program administrator.	**Req.**	ResCheck Analysis (only necessary if the local energy code does not at least meet the IECC 2003 requirements)
3.1.2	Size space heating and cooling system/equipment according to building heating and cooling loads calculated using ANSI/ACCA Manual J 8th Edition or equivalent. Computerized software recognized by ACCA as being in compliance with Manual J 8th Edition may be used.	**Req.**	Manual J load calculations
3.1.3	Conduct third-party plan review to verify design and compliance with the Energy Efficiency section. When multiple homes of the same model are to be built by the same builder, a representative sample (15%) of homes may be reviewed subject to a sampling protocol.	**Req.**	Plan review may be completed by Green Building Program administrator, energy program administrators, architect/engineer, consultant, or other party outside of the builder's company and acceptable to the Green Building Program administrator.

3.2 PERFORMANCE PATH

An energy-efficiency line item with a "(PP)" preceding it is a line item likely to be used to calculate X% above IECC 2003. If a builder chooses to use the performance path—line item 3.2.1—to meet the guideline's energy-efficiency requirements, then those measures with a "(PP)" cannot be used to obtain the 100 additional points from sections of your choice.

3.2.1	Home is X% above IECC 2003		ResCheck Analysis
	A. 15% (Bronze)	**37**	
	B. 30% (Silver)	**62**	
	C. 40% (Gold)	**100**	

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GUIDELINE		PTS	HOW TO VERIFY
3.3 PRESCRIPTIVE PATH			
3.3.1	Building envelope		Builder certified
	(PP)A. Increase effective R-value of building envelope using advanced framing techniques, continuous insulation, and/or, integrated structural insulating system. Measures may include but are not limited to:		Approved by local program administrator Builder spec sheet
	• SIPS*, or	8	
	• ICFS*, or	8	
	• Advanced framing, or	6	
	Insulated corners and interior/exterior wall intersections*		
	Insulated headers on exterior walls		
	• Raised heel trusses	2	
	• Continuous insulation on exterior wall	4	
	• Continuous insulation on cathedral ceiling	4	
	** This line item also has a resource-efficiency benefit.*		
	(PP)B. Incorporate air sealing package to reduce infiltration. *(All measures that apply to project must be performed.)*	10	Builder certified
	1. Sill sealer between foundation and sill plate.		
	2. Caulk bottom plate of exterior walls.		
	3. Air seal band joist cavities between floors.		
	4. Ensure air barrier continuity at all framed cavities such as air chases, soffits, coffered or dropped ceilings, and behind tub/shower units on exterior walls. Use either an interior or exterior air barrier as per local practice.		
	5. Caulk/foam all electrical, plumbing, heating penetrations between floors (including attic, basement, crawl space, and garage) and to exterior		
	6. Block and seal cantilevered floors and kneewalls.		
	7. Weatherstrip attic hatches, kneewall doors.		
	8. Insulate, caulk, or foam between window and door jambs and framing.		
	9. If installing recessed lights in ceilings adjacent to unconditioned space, use rated, airtight Type IC housings.		
	10. Caulk/foam HVAC register boots that penetrate the building envelope to subfloor or drywall.		
	11. If a fireplace is requested, install a sealed combustion gas fireplace or a wood-burning fireplace with gasketed doors.		



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GUIDELINE	PTS	HOW TO VERIFY
(PP)C. Use ENERGY STAR®—rated windows appropriate for local climate.	8	Recommendation for local climate by Energy Efficient Windows Collaborative, www.efficientwindows.org
3.3.2 HVAC design, equipment, and installation		
A. Size, design, and install duct system using ANSI/ACCA Manual D® or equivalent.	8	Manual D calculation
B. Design radiant or hydronic space heating systems using industry-approved guidelines, e.g., Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melting Systems by the Radiant Panel Association, Heat Loss Guide (H-22), by the Hydronics Institute Division of GAMA or accredited design professionals and manufacturer's recommendations.	8	Documentation of design or design signed by professional
C. Use ANSI/ACCA Manual S® or equivalent to select heating and/or cooling equipment.	8	Manual S documentation
D. Verify performance of the heating/cooling system. HVAC contractor to perform the following: • Start-up procedure according to manufacturer's instructions • Refrigerant charge verified by super-heat and/or sub-cooling method • Burner set to fire at nameplate input • Air handler setting/fan speed • Total airflow within 10% of design flow • Total external system static should not exceed equipment capability at rated airflow.	8	Certification by HVAC contractor
E. Use HVAC installer and service technician certified by a nationally or regionally recognized program such as NATE, BPI, RPA, or manufacturers' training.	6	HVAC certification
(PP)F. Fuel-fired space heating equipment efficiency (AFUE):		Certification by HVAC contractor
Gas Furnace ≥81%	4	
≥88% (ENERGY STAR)	6	
≥94%	8	
Oil Furnace: ≥83%	2	
Gas or Oil Boiler: ≥85%% (ENERGY STAR)	2	
>90%	6	

Note: Add three points if Manuals S and D and start-up procedures are followed when one of the space heating units noted above is installed.

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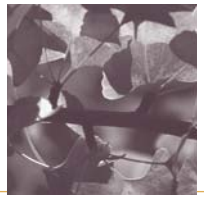
GUIDELINE	PTS	HOW TO VERIFY
(PP)G. Heat pump efficiency (cooling mode)		Certification by HVAC contractor
1. SEER 11-12*	4	
2. SEER 13-14	6	
3. SEER 15-18	6	
4. SEER 19+	7	
5. Staged air conditioning equipment	9	
Note: Split systems must be ARI-tested as a matched set.		
**SEER 13 will be federal minimum as of January 2006.*		
Note: Add three points if Manuals S and D and start-up procedures are followed when one of the ground source heat pumps noted above has been installed. Do not take these points again in 3.3.2.H.		
(PP)H. Heat pump efficiency (heating mode)		Certification by HVAC contractor
7. 2-7.9 HSPF	6	
8. 0-8.9HSPF	7	
9. 0-10.5HSPF	9	
>10.5 HSPF	10	
Note: Split systems must be ARI-tested as a matched set.		
(PP)I. Ground source heat pump installed by a certified geothermal service contractor (cooling mode).		Certification by HVAC contractor
EER = 13-14	5	
EER = 15-18	6	The equipment supplier and the contractor shall furnish, in writing, a "geothermal loop performance guarantee" stating that the heat rejection and absorption of the equipment will not exceed the geothermal loop design submitted and will consistently perform at or above specified efficiencies (taking into account water flow, airflow and entering water temperature).
EER = 19-24	8	
EER = >25	10	
Note: Add three points if Manuals S and D and start-up procedures are followed when one of the ground source heat pumps noted above has been installed. Do not take these points again in 3.3.2.J.		
(PP)J. Ground source heat pump installed by a Certified Geothermal Service Contractor (heating mode).		Certification by HVAC contractor
1. COP 2.4 - 2.6	6	
2. COP 2.7 - 2.9	8	
3. COP ≥3.0	10	
K. Seal ducts, plenums, and equipment to reduce leakage. Use UL 181 foil tapes and/or mastic.	6	Certification by HVAC contractor



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GUIDELINE		PTS	HOW TO VERIFY
L.	When installing ductwork: 1. No building cavities used as ductwork, e.g., panning joist or stud cavities. 2. Install all heating and cooling ducts and mechanical equipment within the conditioned building envelope. 3. No ductwork installed in exterior walls.	**8**	Certification by HVAC contractor
M.	Install return ducts or transfer grilles in every room having a door except baths, kitchens, closets, pantries, and laundry rooms.	**6**	Certification by HVAC contractor
N.	Install ENERGY STAR ceiling fans. (Points per fan)	**1**	Builder certified
O.	Install whole-house fan with insulated louvers.	**4**	Builder certified
P.	Install ENERGY STAR-labeled mechanical exhaust in every bathroom ducted to the outside.	**8**	Builder certified
3.3.3	Water heating design, equipment, and installation		
A.	Water heater energy factor (EF) equal to or greater than those listed in the following table.	**4**	Installer certified

GAS	
Size (gallons)	**Energy Factor**
30	0.64
40	0.62
50	0.60
65	0.58
75	0.56
ELECTRIC	
30	0.95
40	0.94
50	0.92
65	0.90
80	0.88
100	0.86
OIL	
30	0.59
50	0.55



B.	Install whole-house instantaneous (tankless) water heater. (Water heater complies with DOE Standard 10CFR430)	**4**	Installer certified
C.	Insulate all hot water lines with a minimum of one inch insulation.	**4**	Installer certified

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GUIDELINE		PTS	HOW TO VERIFY
D.	Install heat trap on cold and hot water lines to and from the water heater (if not integral to the water heater).	3	Installer certified
E.	Install manifold plumbing system with parallel piping configuration (aka "home run") using smallest diameter piping allowed by code.	5	Installer certified
3.3.4	Lighting and appliances		
	A. Use an ENERGY STAR Advanced Lighting Package (ALP) in home.	7	Builder certified
	B. Install all recessed lighting fixtures within the conditioned envelope of the building, e.g., housing does not penetrate insulated ceiling.	7	Builder certified
	C. Install motion sensors on outdoor lighting (if not credited under 3.3.4.a).	7	Builder certified
	D. Install tubular skylights in rooms without windows.	2	Builder certified
	E. Install ENERGY STAR-labeled appliances:		Builder certified
	• Refrigerator	3	
	• Dishwasher	3	
	• Washing machine.	5	
3.3.5	Renewable energy/solar heating and cooling	10	Builder spec sheet
	3.3.5.1 Solar space heating and cooling		
	A. Use sun-tempered design: building orientation, sizing of glazing, design of overhangs to provide shading are in accordance with guidelines below:		
	• Long side of the home faces within 30° of south		
	• Glazing area < 7% of finished floor area (FFA) on south face (Low-E)		
	• Glazing area < 2% of FFA on west face (Low-E, Low SHGC)		
	• Glazing area < 4% of FFA on east face (Low-E, Low SHGC)		
	• Glazing area < 4% of FFA on north face (Low-E)		
	• Skylights less than 2% of finished ceiling area, with shades and insulated wells		
	• Overhangs designed to provide shading on south-facing glass (at a minimum), or adjustable canopies or awnings. *(See User Guide for charts that indicate length of overhang, amount and period of shading according to latitude.)*		



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GUIDELINE	PTS	HOW TO VERIFY
B. Use passive solar design: sun-tempered design as above plus additional south-facing glazing, appropriately designed thermal mass to prevent overheating, and provision for airflow to adjoining rooms. • Sun-tempered design as outlined above except additional glazing permitted on south wall *plus* • For any room with south-facing glazing > 7% of FFA, properly sized thermal mass, and • Provision for forced airflow to adjoining areas as needed • (SBIC Passive Solar Design Guidelines for your climate should be referenced to size thermal mass.) *Note: 3.3.5.1.A must also be done in order to receive points for 3.3.5.1.B.*	**10**	Builder spec sheet identifying passive solar design features Documentation of design process
C. Use passive cooling. • Exterior shading on east and west windows, e.g., shade trees, moveable awnings or louvers, covered porches • Overhangs designed to provide shading on south-facing glazing. Use supplied charts that indicate length of overhang, amount and period of shading according to latitude. (Not to be double-counted if credited in 3.3.5.1.A above.) • Windows located to facilitate cross ventilation • Solar-reflective roof or radiant barrier in hot climates. *Note: All of the above must be done in order to receive points for this line item.*	**8**	Builder spec sheet Documentation of design process Builder certified
3.3.5.2 Solar water heating		Installer certified
A. Install solar water heating system. Must use SRCC-rated system. Solar fraction:		Manufacturers' specifications
1. 0.3	**8**	
2. ≥ 0.5	**10**	
3.3.5.3 Additional renewable energy options		Installer certified
A. Supply electricity needs by onsite renewable energy source such as photovoltaics, wind, or hydro whereby the system is estimated to produce the following kWh per year:		Manufacturers' specifications
2,000 to 3,999	**8**	
4,000 to 5,999	**10**	
6,000 +	**12**	
(Equipment should carry all applicable IEEE and UL certifications. Installation shall be in accordance with local utility and electrical code requirements.)		

GUIDELINE	PTS	HOW TO VERIFY
B. Provide clear and unshaded roof area (+/-30°of south or flat) for future solar collector or photovoltaics. Minimum area of 200 sf. Provide a rough-in of piping from the roof to the utility area:		Builder certified
• Conduit	3	
• Insulated piping	5	
C. Provide homeowner with information and enrollment materials about options to purchase green power from the local electric utility.	2	Builder certified
(Not to duplicate points for homeowner manual in IEQ section below.)		
3.3.6 Verification		
3.3.6.1 Conduct onsite third-party inspection to verify installation of energy-related features such as:	8	Inspection may be performed by Green Building Program administrator, energy program administrator, architect, engineer, or other party outside of the builder's company and acceptable to the Green Building Program administrator.
A. Duct installation and sealing		At least two onsite inspections should be done: one after insulation is installed and the second upon completion of the project.
B. Building envelope air sealing details		
C. Proper installation of insulation including no gaps, voids, or compression		
D. Insulation cut accurately to fit cavity		
E. Windows and doors flashed, caulked, and sealed properly.		
(When at least 100 homes of the same model are to be built by the same builder, a representative sample [15%] of homes may be inspected.)		
3.3.6.2 Conduct third-party testing to verify performance, e.g., blower door, duct leakage testing, flow hood testing (per test).	8 per test	Report showing results of testing
A. Building envelope leakage: blower door test results < 0.35 ACHnat		Examples of those who would be qualified to perform testing include but are not limited to energy program technicians, weatherization program technicians, HVAC contractors, and energy efficiency/building science consultants.
B. Central HVAC duct leakage: duct leakage test results:		
• Leakage to unconditioned space < 5% of rated blower capacity		
• Total leakage < 10% of rated blower capacity		
C. Balanced HVAC airflows: flow hood test results:		
• Measured flow at each supply and return register within 25% of design flow.		
• Total airflow within 10% of design flow.		
(When multiple homes of the same model are to be built by the same builder, a representative sample of homes may be tested subject to the sampling protocol.)		

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GUIDELINE		PTS	HOW TO VERIFY
3.3.7	Innovative options		
	A. Install drain water heat-recovery system.	2	Installer certified
	B. Install desuperheater in conjunction with ground source heat pump.	6	Installer certified
	C. Install heat pump water heater. Must be rated according to the current US DOE test standard and shall have an EF > 1.7.	6	Installer certified
	D. Install occupancy sensors for lighting control. (Points per sensor)	4	Builder certified

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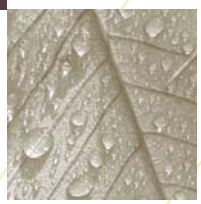

		PTS	HOW TO VERIFY
4.1 INDOOR/OUTDOOR WATER USE			
4.1.1	Hot water delivery to remote locations aided by installation of: **A.** On-demand water heater at point of use served by cold water only. (Points per unit installed) **B.** Control-activated recirculation system.	**6**	Installer certified
4.1.2	Water heater located within 30 feet of pipe run of all bathrooms and kitchen.	**9**	Installer certified
4.1.3	ENERGY STAR® water-conserving appliances installed, e.g., dishwasher, washing machine	**7 per appl.**	Installer certified
4.1.4	Water-efficient showerhead using conventional aerator or venturi technology for flow rate < 2.5 gpm	**2 per fixture**	Installer certified
4.1.5	Water-efficient sink faucets/aerators < 2.2 gallons/minute	**2 per fixture**	Installer certified
4.1.6	Ultra low flow (< 1.6 gpm/flush) toilets installed: **A.** Power-assist **B.** Dual-flush.	 **4** **6**	Installer certified
4.1.7	Low-volume, non-spray irrigation system installed, e.g., drip irrigation, bubblers, drip emitters, soaker hose, stream-rotator spray heads	**7**	Installer certified
4.1.8	Irrigation system zoned separately for turf and bedding areas	**6**	Installer certified
4.1.9	Weather-based irrigation controllers, e.g., computer-based weather record	**7**	Installer certified
4.1.10	Collect and use rainwater as permitted by local code. (Additional credit for distribution system that uses a renewable energy source or gravity)	**9**	Builder certified
4.1.11	Innovative wastewater technology as permitted by local code, e.g., constructed wetland, sand filter, and aerobic system	**7**	Submit plan approved by local code or health department official
4.2 INNOVATIVE OPTIONS			
4.2.1	Shut-off valve, motion sensor, or pedal-activated faucet to enable intermittent on/off operation	**6**	Installer certified
4.2.2	Separate and re-use greywater as permitted by local code	**6**	Installer certified
4.2.3	Composting or waterless toilet as permitted by local code	**6**	Installer certified

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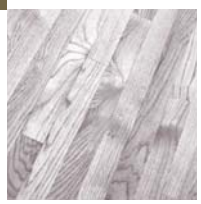

		PTS	HOW TO VERIFY
5.1 MINIMIZE POTENTIAL SOURCES OF POLLUTANTS			
5.1.1	For vented space heating and water heating equipment: **A.** Install direct vent equipment or **B.** Install induced/mechanical draft combustion equipment.	**8**	Builder spec sheet
5.1.2	Install space heating and water heating equipment in isolated mechanical room or closet with an outdoor source of combustion and ventilation air.	**6**	Builder spec sheet
5.1.3	Install direct-vent, sealed-combustion gas fireplace, sealed wood fireplace, or sealed woodstove. or Do not install fireplace or woodstove.	**6**	Builder spec sheet
5.1.4	Ensure a tightly-sealed door between the garage and living area, and provide continuous air barrier between garage and living areas including air sealing penetrations, walls, ceilings, and floors.	**9**	Builder spec sheet
5.1.5	Ensure particleboard, medium-density fiberboard (MDF) and hardwood plywood substrates are certified to low formaldehyde emission standards ANSI A208.1, ANSI A208.2, and ANSI/HPVA HP1, respectively. Composite wood/agrifiber panel products must either contain no added urea-formaldehyde resins or must be third-party certified for low formaldehyde emissions.	**6**	Manufacturer's spec sheet Third-party listing
5.1.6	Install carpet, carpet pad, and floor covering adhesives that hold "Green Label" from Carpet and Rug Institute's indoor air quality testing program or meet equivalent thresholds verified by a third party.	**6**	Manufacturer's spec sheet Third-party listing
5.1.7	Mask HVAC outlets during construction and vacuum ducts, boots, and grilles before turning on central heating/cooling system.	**5**	
5.1.8	Use low-VOC-emitting wallpaper.	**3**	Builder's spec sheet
5.2 MANAGE POTENTIAL POLLUTANTS GENERATED IN THE HOME			
5.2.1	Vent kitchen range exhaust to the outside.	**7**	Builder spec sheet Use guidance in homeowner's manual

		PTS	HOW TO VERIFY
5.2.2	Provide mechanical ventilation at a rate of 7.5 cfm per bedroom + 7.5 cfm and controlled automatically or continuous with manual override. The ventilation equipment may be:		Builder spec sheet Use guidance in homeowner's manual
	A. Exhaust or supply fan(s), or	7	
	B. Balanced exhaust and supply fans, or	9	
	C. Heat-recovery ventilator, or	10	
	D. Energy-recovery ventilator.	10	
5.2.3	Install MERV 9 filters on central air or ventilation systems.	3	Use guidance in homeowner's manual
5.2.4	Install humidistat to control whole-house humidification system.	4	Use guidance in homeowner's manual
5.2.5	Install sub-slab de-pressurization system or infrastructure to facilitate future installation of radon mitigation system. *The more stringent requirement between a local building code and this provision shall apply.	6	Builder spec sheet
5.2.6	Verify all exhaust flows meet design specifications.	9	
5.3 MOISTURE MANAGEMENT (VAPOR, RAINWATER, PLUMBING, HVAC)			
5.3.1	Control bathroom exhaust fan with a timer or humidistat.	6	Builder spec sheet
5.3.2	Install moisture-resistant backerboard—not paper-faced sheathing—under tiled surfaces in wet areas.	6	Builder spec sheet
5.3.3	Install vapor retarder directly under slab (6-mil) or on crawl space floor (8-mil). In crawl spaces, extend poly up wall and affix with glue and furring strips, or damp-proof wall below grade. Joints lapped 12 inches.	9	Builder spec sheet
5.3.4	Protect unused moisture-sensitive materials from water damage through just-in-time delivery, storing unused materials in a dry area, or tenting materials and storing on a raised platform.	6	Builder's moisture management practice or plan
5.3.5	Keep plumbing supply lines out of exterior walls.	5	
5.3.6	Insulate cold water pipes in unconditioned spaces with one-half-inch insulation or other coating that comparably prevents condensation.	4	Builder spec sheet
5.3.7	Insulate HVAC ducts, plenums, and trunks in unconditioned basements and crawl spaces to avoid condensation.	4	Builder spec sheet
5.3.8	Check moisture content of wood before it is enclosed on both sides. Ensure moisture content of subfloor/substrate meets the appropriate industry standard for the finish flooring material to be installed.	4	Builder's moisture management practice or plan
5.4 INNOVATIVE OPTIONS			

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OPERATION, MAINTENANCE, AND HOMEOWNER EDUCATION



	PTS	HOW TO VERIFY
6.1 PROVIDE MANUAL TO OWNERS/OCCUPANTS ON THE USE AND CARE OF THE HOME. MANUAL MUST INCLUDE ALL ITEMS BELOW:		
A. Narrative detailing the importance of maintenance and operation to keep a green-built home green	9	Copy of the home manual
B. Local green building program certificate		
C. Warranty, operation, and maintenance instructions for equipment and appliances		
D. Household recycling opportunities		
E. Information on how to enroll in a program so that the home receives energy from a renewable energy provider		
F. Explanation of the benefits of using compact fluorescent light bulbs in high-usage areas		
G. A list of habits or actions to optimize water and energy use		
H. Local public transportation options (if applicable)		
I. Clearly labeled diagram showing safety valves and controls for major house systems.		
6.2 OPTIONAL INFORMATION TO INCLUDE IN THE HOME MANUAL		
(Choose at least five.)		
A. A list of local service providers that focus on regularly scheduled maintenance and proper operation of equipment and the structure (sealants, caulks, gutter and downspout system; shower/tub surrounds, irrigation systems, etc.)	2	
B. A photo record of framing with utilities installed. Photos should be taken prior to installing insulation, clearly marked, and provided in homeowner's manual.		
C. List of Green Home Building Guidelines items included in the home		
D. User-friendly maintenance checklist		
E. Instructions for proper handling and disposal of hazardous materials		
F. Information on organic pest control, fertilizers, de-icers, and cleaning products		
G. Information about native or low-water landscape		

	PTS	HOW TO VERIFY
H. Information on how to keep a home's relative humidity in the range of 30%-60%		
I. Instructions for checking crawl space for termite tubes periodically		
J. Instructions for keeping gutters clean. Instructions should note that downspouts should divert water at least five feet away from foundation		
6.3 PROVIDE EDUCATION TO OWNERS/OCCUPANTS IN THE USE AND CARE OF THEIR DWELLINGS.		
A. Instruct homeowners/occupants about the building's goals and strategies and occupant's impacts on costs of operating the building. Provide training to owners/occupants for all control systems in the house.	7	
6.4 SOLID WASTE		
A. Encourage homeowners/occupants to recycle by providing built-in space in the home's design (e.g., kitchen, garage, covered outdoor space) for recycling containers.	1	
6.5 INNOVATIVE OPTIONS		



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GLOBAL IMPACT



		PTS	HOW TO VERIFY
7.1 PRODUCTS			
7.1.1	Product manufacturer's operations and business practices include environmental management system concepts (the product line, plant, or company must be ISO 14001 certified).	**3**	ISO 14001 certification
7.1.2	Choose low- or no-VOC indoor paints. VOC concentrations (grams/liter) of interior paints should be equal to or less than those specified by the EPA's Environmentally Preferable Purchasing Program: • Interior latex coatings: Flat: 100 grams/liter; Non-flat: 150 grams/liter • Interior oil-based paints: 380 grams/liter	**6**	Builder spec sheet Manufacturer's spec or third-party listing
7.1.3	Use low-VOC sealants. VOC concentrations for construction adhesives and sealants should meet the limits specified in the California Air Resources Board Regulation for Reducing Volatile Organic Compound Emissions from Consumer Products: • Construction adhesives: the greater of 15% by weight or 200 grams/liter • Sealants and caulks: the greater of 4% by weight or 60 grams/liter • Contact adhesives: the greater of 80% by weight or 650 grams/liter	**5**	Manufacturer's spec or third-party listing
7.2 INNOVATIVE OPTIONS			
7.2.1	Builder's operations and business practices include environmental management system concepts (the builder must be ISO 14001 certified).	**4**	ISO 14001 certification

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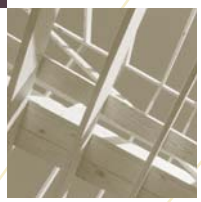
APPENDIX A—SITE PLANNING AND LAND DEVELOPMENT



	PTS	HOW TO VERIFY
1.0 IDENTIFY GOALS WITH YOUR TEAM		
• Establish a knowledgeable team and communicate in writing.		Written list of team members
• Establish a "green development" mission statement.		Written project mission statement
• Identify goals and objectives.		Written project goals
• Identify team member roles and how they relate to various phases of development.		Written project team member roles
• Provide training to onsite supervisors and team members on the green development practices that will be instituted onsite.		Training materials information
• Create a checklist to be filled out onsite that contains only those targeted green development practices that will be implemented in this project *(see Guideline 4a for execution of this checklist).*		Checklist of green development practices that will be implemented
2.0 SELECT THE SITE		
Select the site to minimize environmental impact.		
• Avoid environmentally "sensitive areas" as identified through site footprinting process or third party.		Any one of the following: • Comprehensive plan • Wetland Institute • Local jurisdiction's guidelines • Site footprinting process results • Set of site plans
• Choose an EPA-recognized brownfield *(see User Guide for definition).*		Confirmation from a federal, state, or local brownfield site inventory list or representative that the site is a brownfield
• Choose a greyfield site *(see User Guide for definition).*		
• Choose an infill site *(see User Guide for definition).*		

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	PTS	HOW TO VERIFY
3.0 DESIGN THE SITE		
Minimize environmental impact; protect, enhance, and restore the natural features and environmental quality of the site (points for each guideline are only rewarded upon execution of these plans).		
• Conserve natural resources.		
• Complete a natural resources inventory that is used to drive and create the site plan.		Pre- and post-development natural resources inventory
• Create a protection and maintenance plan for priority natural resources/areas during construction. *(See Section 4 for guidance in forming the plan.)*		Protection and maintenance plan
• Locate roads, buildings, and other built features to conserve high-priority vegetation.		Certificate or letter indicating participation in a natural resources conservation program
• Participate in a natural resource conservation program.		
• Orient streets and configure lots to allow for the majority of homes to optimize solar potential *(see the Energy Efficiency module for guidance on solar resource optimization)*		House plans
• Minimize slope disturbance.		
• Limit development footprint on steep slopes (slopes greater than or equal to 25%).		Hydrological/soil stability study results
• Complete a hydrological/soil stability study for steep slopes, and use this study to guide the design of all structures onsite.		Topographical map with contour lines
• Align roads with natural topography to minimize grade to reduce cut and fill.		
• Reduce long-term erosion effects through the design and implementation of terracing, retaining walls, landscaping, and restabilization techniques.		
• Minimize soil disturbance and erosion.		
• Phase development to minimize exposed soils.		Sediment and erosion control plans
• Use alternative means to install utilities, such as tunneling instead of trenching, use of smaller equipment, shared trenches or easements, and placement of utilities under streets instead of yards.		
• Manage storm water properly.		Storm water management plan
• Direct storm water to a locally approved regional storm water management and treatment facility that has been designed to address water quality.		
• Preserve and utilize natural water and drainage features.		
• Develop and implement storm water management plans that minimize concentrated flows and seek to mimic natural hydrology.		

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	PTS	HOW TO VERIFY

• Minimize impervious surfaces, and utilize permeable materials for
  • Parking areas
  • Walkways
  • Streets—minimize street widths and rights-of-way as per recommendations in either local code or in *Residential Streets, 3rd Edition:*
  a. No on-street parking: 18 feet
  b. Parking on one side: 22–24 feet
  c. Parking on both sides: 24–26 feet		

• Use an advanced wastewater system as an alternative to the conventional septic system and drain field, where municipal sewage is not available. Examples include sand/media filters, aerobic treatment units, and community package plants.		System specifications
• Devise landscape plans to limit water demand while preserving or enhancing the natural environment.		Landscape plan
• Formulate a plan to restore or enhance natural vegetation that is cleared during construction or development. Within this plan, phase landscaping to ensure denuded areas are quickly vegetated.		
• Select turf grass and other vegetation that are native or regionally appropriate species.		
• Limit turf areas of landscaped area, selecting native and regionally appropriate trees and vegetation in a way that complements the natural setting.		
• Group plants with similar watering needs (hydrozoning).		
• Specify planting of trees to increase site shading and moderate temperatures *(see also Energy Efficiency Guideline 3.3.5.1 specifying siting of trees to reduce the energy consumption of the home).*		
• Require onsite tree trimmings of regionally appropriate species to be used as protective mulch during construction or as a base for walking trails.		
• Establish an integrated pest management plan to minimize chemical use in pesticides and fertilizers.		
• Maintain wildlife habitat.		Certificate or letter indicating participation in a wildlife conservation plan
• Preserve open space as wildlife corridors where possible.		
• Institute wildlife habitat measures		
• Participate in a wildlife conservation program.		
• Prepare operation and maintenance plan (manual) for transfer of common open spaces, utilities (storm water, wastewater), and environmental management.		Copy of the manual
• Disassemble existing buildings, and reuse or recycle the building materials (deconstruction) instead of demolishing.		Catalogue reused or recycled building materials

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	PTS	HOW TO VERIFY
4.0 DEVELOP THE SITE		
Minimize environmental intrusion during onsite construction.		
• Provide onsite supervision and coordination during clearing, grading, trenching, paving, and installation of utilities to ensure that targeted green development practices are implemented.		Protection and maintenance plan
• Conserve existing onsite vegetation.		
• Provide basic training in tree and other natural resource protection to onsite supervisor.		Protection and maintenance plan and/or set of site plans
• Minimize disturbance of and damage to trees and other vegetation designated for protection through installation of fencing and avoidance of trenching, significant changes in grade, and compaction of soil and critical root zones.		
• Prepare designated existing trees and vegetation for the impacts of construction through pruning, root pruning, fertilizing, and watering.		
• Improve the soil with organic amendments and mulch.		
• Minimize onsite soil disturbance and erosion.		Sediment and erosion control plans
• Demarcate limits of clearing and grading.		
• Create construction "no disturbance" zones using fencing or flagging to protect vegetation and sensitive areas from construction vehicles, material storage, and washout.		
• Install and maintain sediment and erosion controls.		
• Stockpile and cover good soil for later use.		
• Reduce soil compaction from construction equipment through laying mulch, chipped wood, or plywood sheets.		
• Stabilize disturbed areas within the EPA-recommended 14-day period.		
5.0 INNOVATIVE OPTIONS		
Seek to obtain waivers or variances from local development regulations to enhance green building.		
• Cluster development to preserve meaningful open space.		Set of site plans
• Reduce street widths.		Set of site plans
• Share driveways or parking.		Set of site plans
• Other (specify).		



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DISCLAIMER

This publication contains guidance for builders engaged in or interested in green building products and practices for residential design, development, and construction. This publication is not intended to be exhaustive and all-inclusive, and the enclosed guidelines are not to be considered the only method of green building. These guidelines for green building originate from the collective experience of leading personnel in the green building movement (marketplace) but must, due to the nature of the responsibilities involved, be presented only as a guide for the use of a qualified developer, builder, remodeler, or design professional.

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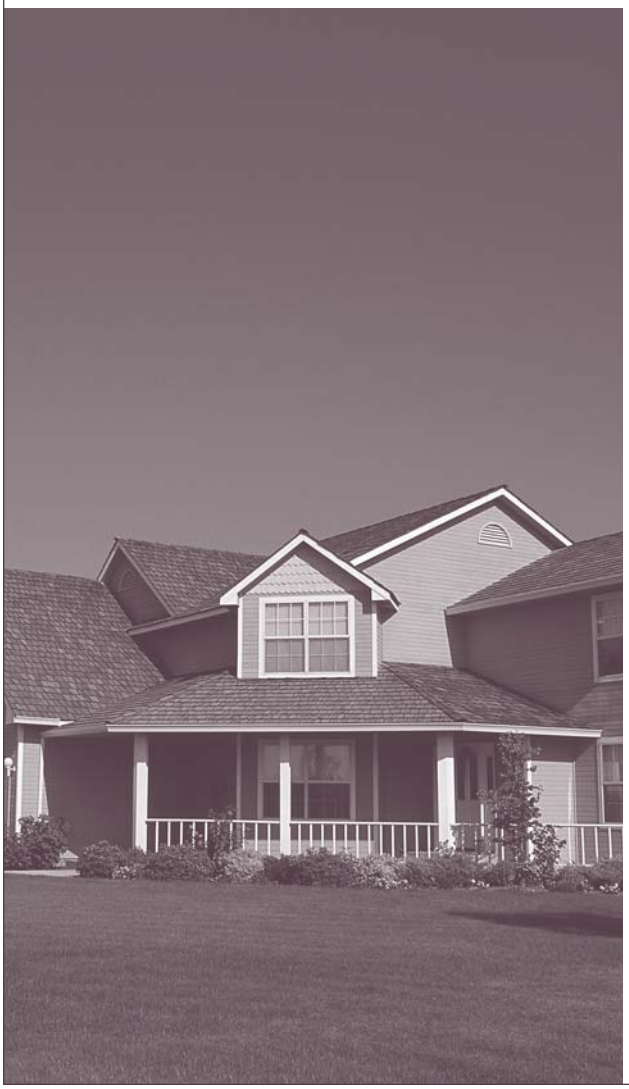

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1.1 SELECT THE SITE

1.1.1 Avoid environmentally "sensitive areas" as identified through site footprinting process or existing third-party data.

Intent:
Thoughtful site selection can be the first step in building a green home. By avoiding environmentally sensitive areas, a builder can help preserve land that might function as a corridor for wildlife, recreational open space, or habitat sanctuary. By selecting a site that has at any time been identified as an environmentally sensitive area, a builder will receive no credit for this line item, regardless of the site's classification at the time of construction.

Information / How to Implement:
"Sensitive areas" may be identified within a comprehensive plan, by a wetland institute, or by the local jurisdiction. Other excellent sources of detailed environmental information about a site are professionals such as arborists, landscape architects, ecologists, and wildlife biologists. These experts can provide assistance in identifying a potential site's natural resources and environmentally sensitive areas.

Resources:
- American Society of Consulting Arborists, www.asca-consultants.org/why.html
- American Society of Landscape Architects, www.asla.org/members/pigroups.cfm
- International Society of Arboriculture, www.isa-arbor.com/home.asp
- Society of American Foresters, www.safnet.org/certifiedforester/
- The Ecological Society of America, www.esa.org/

1.1.2 Choose an infill site.

Intent:
Building on an infill site can effectively conserve resources (e.g., infrastructure) and preserve open space that could be lost from "green field" development.

Information / How to Implement:
Infill areas are vacant or underutilized lots of land served by existing physical installations such as roads, power lines, sewer and water, and other infrastructure.

Resources:
- Policy Link, Equitable Development Toolkit, Infill Incentives, www.policylink.org/EDTK/Infill/.
- Northeast-Midwest Institute and Congress for the New Urbanism, *Strategies for Successful Infill Development* (2001), www.nemw.org/infillbook.htm.

1.1.3 Choose a greyfield site.

Intent:
Redevelopment of a greyfield site can provide an efficient use of land and infrastructure. Greyfield redevelopment allows for the preservation of open space and wildlife habitat in the midst of growth.

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Information / How to Implement:
Within these guidelines, a greyfield is defined as "any site previously developed with at least 50% of the surface area covered with impervious material." The development of a greyfield site can be daunting, but local or national incentives may exist to reward those builders who go through the process. Incentives may include the elimination of development-related fees, contribution from the local government in the development of offsite improvements, and tax breaks. For more information, contact the Congress for the New Urbanism, Urban Land Institute, American Planning Association, or the International Council of Shopping Centers.

Resources:
- Congress for the New Urbanism, www.cnu.org
- Urban Land Institute, www.uli.org
- American Planning Association, www.planning.org
- International Council of Shopping Centers, www.icsc.org
- Congress for the New Urbanism and PricewaterhouseCoopers, *Greyfields into Goldfields: From Falling Shopping Centers to Great Neighborhoods* (February 2001), www.cnu.org/cnu_reports/Executive_summary.pdf
- Congress for the New Urbanism and PricewaterhouseCoopers, *Greyfield Regional Mall* Study (January 2001), www.cnu.org/cnu_reports/Greyfield_Feb_01.pdf

1.1.4 Choose an EPA-recognized brownfield.

Intent:
Remediation of a brownfield results in the environmental restoration of a polluted site, a transformation that makes an abandoned site habitable. Like greyfield and infill development, brownfield development provides an efficient use of land and infrastructure while allowing for the preservation of open space and wildlife habitat in the midst of growth.

Information / How to Implement:
The U.S. Environmental Protection Agency (EPA) characterizes brownfields as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." The EPA estimates that there are 450,000 such sites around the country. Grants, loans, and training are available through the EPA's Brownfield Initiative to assist builders and developers in the remediation and development of brownfield sites.

Resources:
- U.S. Environmental Protection Agency, Brownfields Cleanup and Redevelopment: www.epa.gov/Brownfields/index.html
- The EPA has introduced two Web-based tools to give the public additional access to information about brownfield properties and cleanup efforts. The tools allow residents to locate brownfields in their area and provide access to information about cleanup grants. Go to www.epa.gov/Brownfields/bfwhere.htm

1.2 IDENTIFY GOALS WITH YOUR TEAM

1.2.1 Establish a knowledgeable team.

A. Identify team member roles and how they relate to various phases of green lot design, prep, and development.

B. Create a mission statement that includes the project's goals and objectives.

Intent:
One of the earliest challenges for a builder in developing a green lot is assembling an effective team to help the builder implement best green practices throughout the process. Those involved in the development phase must understand what the mission of the site is, what it means to be a green lot, and why green practices should be followed. Once this baseline is established, coordination and communication with and among the various team members is essential to successful development.

Information / How to Implement:
Before ground is broken, all parties that will be involved in lot development (i.e., the team) should understand that the lot will be developed as a green site. Team members may include staff, site superintendents, utilities, excavators, landscape architects, wildlife biologists, ecologists, and arborists. Once the green intent of the builder is communicated to the lot development team, the builder should work with the team throughout the development process to identify and delegate responsibilities of team members, as well as facilitate coordination between the members to achieve best green practices.

Resources:
- American Society of Consulting Arborists, www.asca-consultants.org/why.html
- American Society of Landscape Architects, www.asla.org/members/pigroups.cfm
- International Society of Arboriculture, www.isa-arbor.com/home.asp
- Society of American Foresters, www.safnet.org/certifiedforester/
- The Ecological Society of America, www.esa.org/

1.3 DESIGN THE SITE

Minimize environmental impacts; protect, restore, and enhance the natural features and environmental quality of the site.

1.3.1 Conserve natural resources.

A. Complete a natural resources inventory used to drive/create the site plan.

B. Create a protection and maintenance plan for priority natural resources/areas during construction. *(See Section 1.4 for guidance in forming the plan.)*

C. Participate in a natural resources conservation program, e.g., Building with Trees.

D. Provide basic training in tree and other natural resource protection to onsite supervisor.

Intent:
Onsite natural resources concern such features as solar energy availability, flora, fauna, water, soil, and geological formations. A natural resources inventory should be completed to identify the site's environmental attributes. A builder can then identify high-priority resources for conservation (e.g., trees, waterway, snags, and micro-habitats) and plan for the conservation of those resources during each stage of site development.

Information / How to Implement:
On complex sites, a natural resources inventory may be performed by a qualified professional such as an arborist, wildlife biologist, or landscape architect. Simpler sites, such as previously developed sites or farmland, might be adequately inventoried by knowledgeable, but less qualified, individuals. Whoever ultimately conducts the inventory should be able to discern between invasive and regionally appropriate vegetation, understand how to site a house to achieve maximum solar energy potential, be able to identify areas important to wildlife habitat, and understand how natural features can be used in managing storm water onsite.

A protection and maintenance plan should be drafted to detail how resources identified through the inventory will be protected throughout development. Section 4 of this module describes how to protect existing onsite vegetation and minimize soil disturbance and erosion through such means as installation of fencing, identification of specified washout and material storage areas, laying of mulch to reduce soil compaction, etc. In addition to protecting priority areas from intrusion during development, a maintenance plan should be created to ensure that priority vegetation survives development. Within the maintenance plan, include plans and information on fertilizing and watering trees as needed before, during, and after development.

One way to verify that the plan is implemented as planned is to create construction documents that explain how to implement the plan at each phase.

Resources:

- American Society of Consulting Arborists, www.asca-consultants.org/why.html
- American Society of Landscape Architects, www.asla.org/members/pigroups.cfm
- International Society of Arboriculture, www.isa-arbor.com/home.asp
- Society of American Foresters, www.safnet.org/certifiedforester/
- Article on preserving trees during construction: www.umass.edu/bmatwt/publications/articles/preserving_trees_during_construction.html

1.3.2 Site the home and other built features to optimize solar resources (refer to Energy Efficiency module for guidance on solar resource optimization). (Note—do not include these points if you get points from 3.3.5.1.a or 3.3.5.1.b in the Energy Efficiency section.)

Intent:
Thoughtful orientation of a home can maximize solar heating potential in the heating season and minimize solar gains in the cooling season. Orienting a home to optimize its solar resource reduces energy use and, therefore, reduces the pollution caused by a home during its life.

Information / How to Implement:
A builder should consider such issues such as slope, storm water management, local solar angles, and high-priority vegetation when determining the optimum site for each home. The final decision in siting generally involves a compromise among these many factors.

Resources:

- See Sections 3.3.5.1.a or 3.3.5.1.b of this User Guide for resources.

1.3.3 Minimize slope disturbance.

A. Limit development footprint on steep slopes (slopes greater than or equal to 25%).

B. Complete a hydrological/soil stability study for steep slopes, and use this study to guide the design of all structures onsite.

C. Align road or extended driveway with natural topography to minimize its grade and reduce cut and fill.

D. Reduce long-term erosion effects through the design and implementation of terracing, retaining walls, and restabilization techniques.

Intent:
Leaving a slope undisturbed reduces the risk of disturbing natural hydrological drainage and causing long- and short-term erosion on the site, which can pollute water sources and damage local ecology.

Information / How to Implement:
Within these guidelines, steep slopes are defined as those slopes that are greater than or equal to 25%. Note: Points should be awarded only if there are developable steep slopes in the area.

Reduce cut-and-fill practices to help prevent unnecessary stripping of vegetation and loss of soils and reduce the need for additional resources to be brought in from offsite.

Resources:
- Prince George's County, Maryland, Department of Environmental Resources, Low-Impact Development Design Strategies: An Integrated Design Approach (EPA 841-B-00-003) (Largo, MD: June 1999), www.epa.gov/owow/nps/lid/lidnatl.pdf

1.3.4 Minimize soil disturbance and erosion. See Section 1.4 for further guidance.

A. Schedule construction activities to minimize time that soil is exposed.

B. Use alternative means to install utilities, such as tunneling instead of trenching, use of smaller equipment, shared trenches or easements, and placement of utilities under streets instead of yards.

C. Demarcate limits of clearing and grading.

Intent:
Sediment and the pollutants contained in it are recognized sources of water quality problems. Exposed soils should be minimized to reduce erosion, promote water quality, and reduce damage caused to native vegetation. Heavy equipment and excessive digging can result in compaction or loss of topsoil along with the introduction of invasive and problematic flora. Minimizing soil disturbance and erosion both reduces stressors on downstream water bodies and saves valuable topsoil for the site.

Information / How to Implement:
NAHB's *Storm Water Permitting: A Guide for Builders and Developers* contains information about the federal Phase I and II storm water permitting program and the equivalent requirements for state storm water permits (see Resources section). *Storm Water Permitting* also contains technical information, including recommendations for use and cost estimates, on over 50 of the most commonly used Best Management Practices; sample Storm Water Pollution Prevention Plans; and tips on compliance, including how to handle visits from inspectors.

Methods for preventing erosion include silt fences, sediment traps, vegetated buffer areas, and mulching. More permanent solutions include biomechanical devices such as swales and vegetated buffers. Another highly effective, environmentally responsible method for preventing erosion is to use compost filter berms, compost erosion socks, and/or surface application of compost erosion control. The compost should be from organic sources like bioshields, yard waste, and wood chips. Turf and plant material—which help to facilitate the re-establishment of a natural environment—are established more quickly when organic compost is used.

Resources:
- National Association of Home Builders (NAHB), *Storm Water Permitting: A Guide for Builders and Developers*, 2005, store.builderbooks.com or 800-368-5242 x8163
- King County Department of Natural Resources, King County, Washington Surface Water Design Manual Appendix D: Erosion and Sediment Control Standards (Seattle: September 1998), ftp://ftp.metrokc.gov/ddes/acrobat/esa/kcswdm-d.pdf
- Dr. James R. Fazio, National Arbor Day Foundation, Trenching and Tunneling: A Pocket Guide for Qualified Utility Workers (Nebraska City, Nebraska: 1998), www.arborday.org/shopping/merchandise/merchdetail.cfm?id=62

1.3.5 Manage storm water using low-impact development when possible.

A. Preserve and utilize natural water and drainage features.

B. Develop and implement storm water management plans that minimize concentrated flows and seek to mimic natural hydrology.

C. Minimize impervious surfaces and use permeable materials for driveways, parking areas, walkways, and patios.

Intent:
Percolation through soil is one of the most effective means for filtering pollutants carried by storm water. By using natural water and drainage features, minimizing impervious surfaces, and distributing storm water flows, builders can reduce harmful pollutants carried off-site while safely and effectively managing much of their storm water load onsite.

Information / How to Implement:
Use open space and natural systems such as vegetative swales, french drains, wetlands, dry wells, and rain gardens that promote water quality and infiltration.

Resources:
- The Practice of Low Impact Development, U.S. Department of Housing and Urban Development (HUD); www.huduser.org/publications/destech/lowimpactdevl.html
- Tom Schueler, Center for Watershed Protection, Site Planning for Urban Stream Protection, Ellicott City, MD, 1995, www.cwp.org/SPSP/TOC.htm
- Lisa Austin, Washington State Department of Ecology Water Quality Program, Stormwater Management Manual for Western Washington (Publication 99-12), September 2001, www.ecy.wa.gov/pubs/9912.pdf
- Betty Rushton, Southwest Florida Water Management District, *Low Impact Parking Lot Design Reduces Runoff and Pollutant Loads: Annual Report # 1*, Brooksville, Florida, 1999

1.3.6 Devise landscape plans to limit water and energy demand while preserving or enhancing the natural environment.

A. Formulate a plan to restore or enhance natural vegetation that is cleared during development. Within this plan, phase landscaping to ensure denuded areas are quickly vegetated.

B. Select turf grass and other vegetation that are native or regionally appropriate species.

C. Limit turf areas of landscaped area, selecting native and regionally appropriate trees and vegetation in a way that complements the natural setting.

D. Group plants with similar watering needs (hydrozoning).

E. Specify planting of trees to increase site shading and moderate temperatures (see also Energy Efficiency Guideline 3.4.1.c specifying siting of trees to reduce the energy consumption of the home).

F. Design vegetative windbreaks or channels as appropriate to local conditions.

G. Require onsite tree trimmings or waste of regionally appropriate trees to be used as protective mulch during construction or as a base for walking trails.

H. Establish an integrated pest management plan to minimize chemical use in pesticides and fertilizers.

Intent:
Landscaping water use accounts for approximately 50% of a home's total water needs. Conservation of this valuable resource through such techniques as hydrozoning, reducing turf area, and selecting regionally appropriate plants is a key component to responsible building. Thoughtful selection and placement of plants can also reduce heating/cooling loads of a home, provide habitat for native fauna, and minimize the heat-island effect of developments.

Information / How to Implement:
Select landscaping materials and vegetation to fit site conditions. Regionally appropriate plants are hardy plants that can withstand local water and temperature conditions such as freeze, heat, drought, and rain. Regionally appropriate plants will also not be overly prolific or invasive, and will be able to coexist with other native plants over time.

Other benefits of landscaping with native plants: minimizes maintenance (reduces emissions of equipment), fosters wildlife habitat. See EPA's Mid-Atlantic Region Green Landscaping www.epa.gov/reg3esd1/garden/what.htm for more information.

When planning for the revegetation of a site, consider the multiple services that natural areas can provide: natural habitat, storm water processing, shading, windbreak, etc. Trees that shade the streets can keep a neighborhood cool while also increasing the neighborhood's attractiveness. Properly selected plants can be grouped to serve as a bioretention zone. Deciduous trees allow the sun's rays through in winter and provide shade in the summer. Evergreens can provide an effective windbreak. Careful selection and integration of trees and vegetation can reduce a developer's initial costs while providing value to a development or neighborhood later. When planting trees, several factors should be taken into account such as the value of shading (trees shading asphalt will mitigate a site's temperature more than trees shading landscaped areas), maintaining a safe distance from the house (especially in areas prone to natural disasters), ultimate tree size, etc.

Developers may wish to consider enforcing guidelines for the protection of onsite vegetation. Some developers even fine builders for damage to areas designated for protection.

If grinding and scattering cleared plants, care should be taken to grind only regionally appropriate plants. Grinding of invasive species can increase their propagation and result in the ultimate destruction of native species.

One of the best ways to reduce energy consumption is through passive solar design of a home—using orientation, overhangs, fenestration, etc. Landscaping to reduce energy consumption is only part of the whole effort.

It is good practice to limit ratio of turf area to total landscaped area due to maintenance requirements of turf versus native plants and regionally appropriate trees and vegetation. In some areas, there may be restrictions on the percentage of turf that the front yard must contain. Research has shown that homeowners are comfortable with having as little as 50% of the front yard composed of turf. Fewer regulations are imposed on turf-to-landscaping ratio in the backyard, so good gains might be made more easily there. For research on turf and landscape of front yard with native species, see *Nassauer, Joan. 1995. Messy Ecosystems, Orderly Frames. Landscape Journal, 14 (2), 161-170.*
In areas with low annual rainfall, one way to account for water usage is through the development and implementation of a water budget. Below is Built Green Colorado's water budgeting information.

Water Budgeting

Description
Calculate the water needs of irrigated landscapes based on plant types, land area, and irrigation system efficiency. Use the calculated water budget to apply water according to the needs of the plants and manage irrigation. Overall property water budgets can be developed to include both indoor and outdoor water requirements.

Basic Practice Guidelines
A. The landscape design process should incorporate a general outdoor annual water budget as a guideline for irrigation design and long-term landscape management. The water budget should be developed by the landscape architect or designer as part of the plant selection and grouping process (turf, trees, shrubs, ground covers, etc.).

B. The irrigation maintenance process should be based on calculation of a monthly and annual water budget for exist-

ing sites.

C. Calculate the site landscape water budget by summing the water requirements calculated for each hydrozone of the landscape using either of these general formulas:

Approach #1, when Reference ET is known:

$$\text{Water Budget} = \frac{(ETo)(Kc)(LA)(0.623)}{E}$$

Where:

Water Budget = Water Needed for Plants (gallons per year)

ETo = Reference evapotranspiration (inches per year) for bluegrass in your area

Kc = Crop coefficient for plant type (See Appendix E for more information.)

LA = Landscaped Area (square feet)

0.623 = Conversion Factor (to gallons per square foot)

IE = Irrigation Efficiency (varies based on irrigation system)

Approach #2, when Reference ET is not known:

Water Budget = Land Area (sq. ft.) x Estimated Plant Water Use (gallons/sq. ft.)

Where:

Estimated Plant Water Use = Estimated water use in gallons/sq. ft. for the metro-Denver Front Range area. For other areas, water use estimates may need to be increased or decreased based on climate and location characteristics. Water use estimates may also be reduced when more efficient irrigation systems such as drip irrigation are used.

D. The water budget provides the annual irrigation that the site needs in order to thrive in addition to natural precipitation. The annual water budget assumes a normal year of natural precipitation (14 inches of annual precipitation for the Front Range area). In either wetter or drier years, the water budget will need to be adjusted.

E. The rate at which plants lose water to the surrounding air is called evapotranspiration (ET). Temperature, humidity, wind, and light all influence the ET rate. When watering, it is only necessary to replace the amount of water that has been lost due to ET.

F. In order for water budgets to be accurate, it is necessary to provide accurate information on factors such as crop coefficients. See the GreenCO Web site www.greenco.org and Appendix E for recommended crop coefficients to be used in calculating water budgets.

G. It should be noted that the ET0 (reference ET) in the water budget equation does not reflect that Kentucky bluegrass can be attractive and viable at much lower ET rates and can be very drought tolerant. For properly established turf, the actual irrigation water needs of turf can vary, depending on desired appearance.

H. The water budget does not apply to the initial establishment period for plantings, which can vary from two to four weeks for annuals to several growing seasons, depending on plant type and the timing of planting. One year is typical for many perennials and shrubs to become established.

I. Water features, outdoor pool(s), and/or any other outdoor water uses should be included in the water budget.

J. If a property manager/landscaper knows the water budget for each month, he/she can compare actual use to the site water budget and adjust irrigation practices accordingly. Excessive water use may also be attributed to irrigation system deficiencies, which should be corrected.

K. Evapotranspiration (ET) or "smart" irrigation controllers can facilitate landscape irrigation according to the needs of the plants (and therefore the water budget).

1. Low-water-use plants don't automatically save water (they are easily, and frequently, over-watered). Using a "smart" controller can ensure the proper irrigation is applied to low-water-use plants.
2. High-water-use plants (such as turf) don't automatically waste water. They are also often over-watered. Using a "smart" controller can ensure the proper irrigation is applied to high-water-use plants.

L. Often the retrofitting of poor irrigation systems and the use of "smart" controllers will provide a payback in saved water. To calculate the payback time, use the water budget to measure how much water is actually needed, versus how much has historically been used, along with local water rates and irrigation system cost.

M. GreenCO provides a simple water budget calculator on its Web site www.greenco.org. Green industry professionals can use this calculator with customers to demonstrate that water budgeting is a manageable approach to understanding water needs for a given property and adjusting watering practices accordingly.

Regional or Industry Considerations/Adaptations

A. Water budgets can be used by water utilities to determine how much water is needed versus how much the utility sells or has.

B. Water budgets can be used by water utilities to determine how much water they need versus how much they sell or have. The difference is how much water could be saved, or how much more water needs to be purchased.

C. Water budgeting approaches adopted by utilities typically include ET-based irrigation scheduling combined with tiered pricing for increasing water usage. Tiered pricing, by gradually increasing the price of water as consumption rises, provides incentive to conserve. At the time of this manual's publication, this approach had been adopted in other water-limited states such as California and Arizona. See Centennial Water and Sanitation District in Highlands Ranch, Colorado, for information on their program http://www.highlandsranch.org/6/6-1a.html.

D. Colorado's Water Efficient Landscape Design Model Ordinance (see www.dola.state.co.us/smartgrowth/) is based on water budgeting with a goal of 15 gallons/square foot/year of water required for a landscaped area.

E. Check the GreenCO Web site (www.greenco.org) for more information on water budgeting techniques.

Key References

Ash, T. 1998. *Landscape Management for Water Savings: How to Profit from a Water-Efficient Future*. Orange County, CA: Municipal Water District of Orange County.

California Department of Water Resources. 1993. Model Water Efficient Landscape Ordinance. www.owue.water.ca.gov/landscape/ord/ord.cfm.

Centennial Water and Sanitation District. 2004. Water Conservation Program. www.highlandsranch.org/06_wsan/06_3watercons.html. Highlands Ranch, CO: Centennial Water and Sanitation District.

Colorado Department of Local Affairs. 2004. Water Efficient Landscape Design Model Ordinance. www.dola.state.co.us/smartgrowth/. Denver, CO: Colorado Department of Local Affairs, Office of Smart Growth.

Colorado State University Cooperative Extension Drought Task Force. 2004. www.drought.colostate.edu/.

Design Studios West, Inc.; J.M. Knopf; HydroSystems KDI, Inc.; The Restoration Group, Inc.; and G. A. White. 2004. *WaterWise Landscaping Best Practice Manual: A Companion Guide to Water Efficient Landscape Design*. www.dola.state.co.us/smartgrowth/. Denver, CO: Colorado Department of Local Affairs, Office of Smart Growth.

GreenCO. 2004. Water Budget Calculator at www.greenco.org.

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McStain Neighborhoods. 2003. *Water Conservation Standards for Common Areas and Open Space Landscapes*. Boulder, CO: McStain Neighborhoods.

Mecham, B. 2004. Scheduling Methods Using ET as a Management Tool. www.ncwcd.org/ims/ims_info/scheduli.pdf. Loveland, CO: Northern Colorado Water Conservancy District.

Northern Colorado Water Conservancy District. 2004. Turfgrass Irrigation Management Program. www.ncwcd.org/ims/scheduler.asp. Loveland, CO: Northern Colorado Water Conservancy District.

Slack, E. 2001. Case History: Irrigation on a Water Budget, *Irrigation Business and Technology*, March/April. (www.irrigation.org).

Resources:

- Center for Plant Conservation, www.mobot.org/CPC/
- Lady Bird Johnson Wildflower Center, Native Plant Information Network National Suppliers Directory, www.wildflower2.org/NPIN/Suppliers/suppliers.html
- New England Wildflower Society, Native Plant Societies of the United States and Canada, www.newfs.org/nps.htm
- NAHB Research Center Inc., *Onsite Grinding of Residential Construction Debris: The Indiana Grinder Pilot*, February 1999

1.3.7 Maintain wildlife habitat.

Intent:
As the frontier of home building continues to expand, sharing the land with wildlife becomes an increasing challenge to builders. Through individual initiative or participation in a wildlife conservation program, home builders can work to create a habitat where both wildlife and humans can thrive—whether in an urban, suburban, or rural setting.

Information / How to Implement:
(Extra points) Participate in a wildlife conservation program.

Examples of programs: USDA National Resources Conservation Service's Backyard Conservation Plan, the Audubon Cooperative Sanctuary System's Treasuring Home Initiative, or the National Wildlife Federation's Backyard Wildlife Habitat Program.

Enhance quality of habitat, including food sources, diversity of habitat, and protective areas, through selective plantings and site design.

Leave snags (dead tree or portion that's left for habitat). Provide birdhouses.

Resources:

- Audubon International, Audubon Cooperative Sanctuary System, www.audubonintl.org/programs/acss/. Audubon Cooperative Sanctuary System's Treasuring Home Initiative.
- Become a certified participant in the National Wildlife Federation's Backyard Wildlife Habitat Program.

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secure.nwf.org/backyardwildlifehabitat/certify/page1.cfm

1.4 DEVELOP THE SITE

Minimize environmental intrusion during onsite construction.

1.4.1 Provide onsite supervision and coordination during clearing, grading, trenching, paving, and installation of utilities to ensure that targeted green development practices are implemented (see 1.3.4).

Intent:
The noblest intentions when designing a site are practically achieved through onsite supervision during the lot development phase. A qualified member(s) of the builder's team should be onsite as these activities progress to ensure that each objective is achieved according to targeted green lot specifications.

Information / How to Implement:
See documents line item 1.3.4.

Resources:
Information will be added in Version 2.

1.4.2 Conserve existing onsite vegetation.

A. Minimize disturbance of and damage to trees and other vegetation designated for protection through installation of fencing and avoidance of trenching, significant changes in grade, and compaction of soil and critical root zones.

B. Prepare designated existing trees and vegetation for the impact of construction by pruning, root pruning, fertilizing, and watering.

Intent:
After a builder has identified (during the planning stage) the existing vegetation that will be conserved onsite, practical steps must be taken during the development stage to achieve the intended conservation. Such steps include pre-development preparation of the vegetation and protection of the foliage, soil, and root system of designated vegetation.

Resources:
- National Arbor Foundation, Building With Trees, www.arborday.org/programs/Buildingwithtrees/index.cfm
- Phillip A. Pratt and Michael W. Schnelle, Oklahoma State University, Oklahoma Cooperative Extension Service, Site Disturbance and Tree Decline (OSU Extension Facts F-6429), September 2003, http://osuextra.com/pdfs/F-6429web.pdf

1.4.3 Minimize onsite soil disturbance and erosion.

A. Demarcate limits of clearing and grading.

B. Create construction "no disturbance" zones using fencing or flagging to protect vegetation and sensitive areas from construction vehicles, material storage, and washout.

C. Install and maintain sediment and erosion controls.

D. Stockpile and cover good soil for later use.

E. Reduce soil compaction from construction equipment by laying mulch, chipped wood, or plywood sheets.

F. Stabilize disturbed areas within the 14-day period recommended by the EPA.

G. Improve the soil with organic amendments and mulch.

Intent:
This guideline seeks to ensure the field implementation of conservation plans. Each measure identifies a practical way to foster water quality and conserve onsite ecological habitat by reducing soil disturbance and erosion.

Information / How to Implement:
Soil stabilization may be temporary or permanent.

Keep in mind that, while the use of stockpiled onsite soil is a preferred method, excavation, stockpiling, grinding, and screening destroy the ecological microsystem of the soil. Rejuvenation of the unimproved soil to its original form will take several years. To offset this phenomenon, the incorporation of compost and sand is an effective method for more rapidly rebuilding the structure and ecosystem of the topsoil and allowing turf and plants to establish more quickly. As indicated above, compost is recommended for this purpose.

When additional soil must be brought in, there are environmental advantages of using industrial by-products as ingredients in topsoil including foundry sand, biosolids compost, and other EPA-approved by-products. In addition to keeping these materials out of community landfills, processing techniques produce superior topsoil.

The use of organic mulch is an excellent way to conserve water in landscape beds and to build soil quality. Ideally, use mulch that results from onsite recycling efforts such as yard waste, processed pallets, and other clean wood from construction waste.

Resources:
- King County Department of Natural Resources, King County, *Washington Surface Water Design Manual Appendix D: Erosion and Sediment Control Standards* (Seattle: September 1998), ftp://ftp.metrokc.gov/ddes/acrobat/esa/kcswdm-d.pdf

1.5 INNOVATIVE OPTIONS

Seek to obtain waivers or variances from local development regulations to enhance green building.

1.5.1 Share driveways or parking.

Intent:
Sharing driveways or parking can reduce the amount of impervious material on a lot, thereby decreasing storm water and pollution runoff.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

1.5.2 Other (specify).

Information will be added in Version 2.

(A note regarding defining "low maintenance" materials: For certain types of building products, the buyer should be on the lookout for materials that have below-average maintenance needs compared with other products in that same material category (e.g., composite decking or treated lumber). Although existing green builder programs provide good information for builders to emphasize the long-term advantages and savings of more durable, lower-maintenance products, there is no standardized method to assess the durability of residential construction materials or systems or to define "low maintenance. " A possible approach that green home building program administrators can use at this time is to give credit for extended warranties on materials and workmanship. The person choosing the building product should consider using manufacturer claims, warranty duration, third-party certifications, and sources such as GreenSpec Directory, and Life-Cycle Assessment (LCA) tools that are under development as proxies to identify "low maintenance" or "durable" materials during the purchasing process.)

2.1 REDUCE QUANTITY OF MATERIALS AND WASTE

2.1.1. Create an efficient floor plan that maintains a home's functionality

Intent:
Use the local data regarding the average size of homes built (taking bedrooms into account), and get credit for building a home with the same number of bedrooms but with fewer square feet than an average-sized house.

Size homes, rooms, and wall heights based on available material sizes. Two-foot modules work well for floor plans. Wall height should be based on availability of structural framing members in pre-cut lengths (i.e., precut stud lengths).

Use designs that incorporate efficient mechanical systems layout, like stacked "wet walls" for efficient plumbing layout, minimized pipe runs, and rapid hot water delivery. Dedicate one "wet wall" per floor, i.e., kitchen sink and powder room or master and guest baths with back-to-back layouts that share a plumbing wall. Locate walls that contain drain/waste/vent and supply pipes on interior walls. (Section 5.3.5, Indoor Environmental Quality, also covers the design practice of installing water supply lines on interior walls.)

When homes require forced-air space conditioning, incorporate the HVAC duct layout in the architectural plan and design the ducts into the conditioned space of the building to maximize system efficiency.

Information / How to Implement:
NAHB Research Center national survey data regarding average size of homes:

- 2 BR = 1,382 sq. ft.
- 3 BR = 1,890 sq. ft.
- 4 BR = 2,648 sq. ft.
- 5+ BR = 3,424 sq. ft.

In the table below, note that the square footage of a 2 BR house must be reduced by 50 square feet to obtain an additional point. In order to determine how much the homes with 3, 4, and 5+ bedrooms must be reduced, we referenced the national data (see above). The average 3 BR house is 37% larger than the average 2 BR; the average 4 BR is 40% larger than the average 3 BR; the average 5+ BR home is 29% larger than the average 4 BR. These percentages were used in the table below to determine the house size thresholds.

For example,

- a 1,825 sf. home is 37% larger than a 1,332 sf. home;
- a 2,555 sf. home is 40% larger than a 1,825 sf. home;
- a 3,296 sf. home is 29% larger than a 2,555 sf. home.

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GUIDELINES FOR EFFICIENT FLOOR PLAN DESIGN

Area of Home (Square Feet) (Based on ANSI Z765-2003)	# of Bedrooms				
	2	3	4	5+	Points
	1382	1890	2648	3424	0
	1332	1825	2555	3296	1
	1282	1756	2459	3172	2
	1232	1688	2363	3048	3
	1182	1619	2267	2925	4
	1132	1551	2171	2801	5
	1082	1482	2075	2677	6
	1032	1414	1979	2553	7
	982	1345	1883	2430	8
	932	1277	1788	2306	9

Resources:

- Use the newly modified American National Standards Institute (ANSI) Z765-2003 to calculate square footage. Available from the NAHB Research Center Bookstore— www.nahbrc.org/tertiaryR.asp?TrackID=&CategoryID=1652&DocumentID=2636
- Oikos®, Small, Efficient and Beautiful, 17 Space Design Tips. http://oikos.com/esb/52/smallefficient.html
- There are many resources available to help a builder create efficient home floor plans. For example, Sarah Susanka's *Not So Big House* series of books can assist in home design. *The Not So Big House* (The Taunton Press, 1998); *Creating the Not So Big House* (The Taunton Press, 2000)
- GreenBuilder, Sustainable Building Sourcebook, www.greenbuilder.com/sourcebook/
- Environmental Building News and BuildingGreen.com, GreenSpec Directory www.greensage.com/BOOKS/GreenSpecs.html

2.1.2. Use advanced framing techniques that reduce the amount of material used to build a home while maintaining the structural integrity of the home.

Intent:

Advanced Framing or Optimum Value Engineering refer to framing techniques that reduce the amount of materials used to build a home while maintaining its structural integrity. An optimum value-engineered assembly tends to use less energy for space conditioning because the omitted (and redundant) structural components can be displaced with insulation. Accordingly, the user will note that some advanced framing techniques receive points for both Resource Efficiency and Energy Efficiency.

Information / How to Implement:

Advanced framing elements can be applied independently, or adopted in their entirety, depending upon the specific requirement(s) of the project. Framers unfamiliar with the techniques may need training, and the initial use of these techniques may temporarily slow down framing operations. In general, more planning is needed to implement these elements.

In addition to the advanced framing techniques described below for wood, homes with steel framing can incorporate advanced framing techniques, including 24-inch on-center spacing for steel floors and walls, described in the HUDUSER's Prescriptive Method for Residential Cold-Formed Steel Framing *(see Resources section of this line item for additional information).*

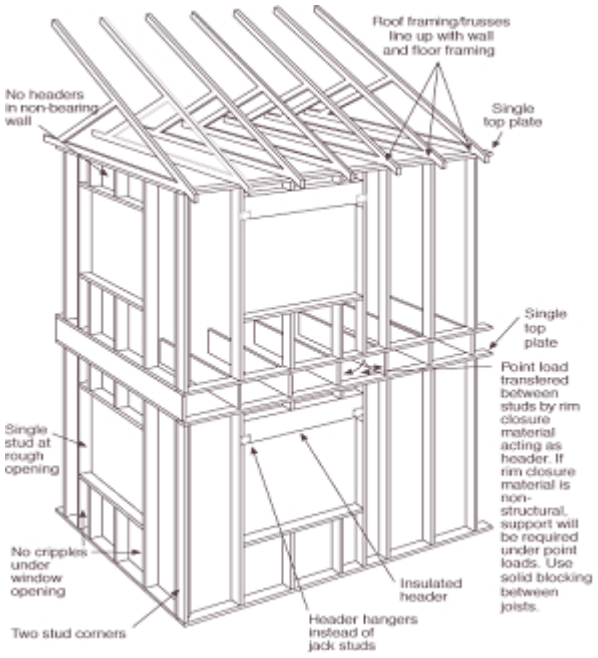
Some of the benefits of advanced framing include:

- Reduced first cost (3% to 5% of framing cost)
- Improved energy efficiency (2% to 5% per year)
- Improved resource efficiency (less wood consumption and waste).

Advanced framing uses engineering principles to minimize material usage while meeting model building code structural performance requirements.

The following list covers different principles that form an advanced framing system:

- 19.2-inch or 24-inch on-center framing, floor systems
- 19.2-inch or 24-inch on-center framing, bearing walls
- 24-inch on-center framing, roof systems
- 24-inch on-center interior partitions
- Single top plate walls
- Right-sized headers or insulated (box) headers (where required)
- Eliminate headers in non-bearing walls
- Doubling the rim joist in lieu of header (2x6 or deeper wall framing)
- Ladders blocking at interior-wall-to-exterior-wall intersections
- Two-stud corner framing



Builders need to employ at least two of the items above in order to get four points for this line item. An additional point may be added for each additional technique employed to a maximum of eight points.

19.2-inch and 24-inch ON-CENTER FRAMING

Details: Wall and floor framing spacing can often be engineered for 19.2-inch (one-fifth of an eight-foot sheet) or 24-inch on center (one-fourth of an 8-foot sheet). Roof framing that utilizes trusses is most frequently spaced at 24-inches. This strategy can be combined with modular layout and single top plate for added economy but can also be used independently.

Installation: Installation should be in accordance with manufacturer's specifications and model building code prescriptive methods. Bracing and fastening schedules and sheathing thickness requirements increase with framing spacing.

Careful spacing of window and door openings will maximize the economy of wider spacing. Designs that are built repeatedly should include wall framing layout drawings to guide the framing crew. When first implementing advanced framing elements, crews are likely to be slowed down until they become more familiar with the method.

Benefits/Cost: Approximately one-third of the lumber can be eliminated from the wall and floor framing of a value-engineered house, over walls and floors spaced 16 inches on center. Floor joists may need to be deeper for wider spans, but the reduction in lumber required for the building usually offsets the price increase from having larger floor joists. The need for thicker deck sheathing will also offset a portion of the savings. A careful analysis or a trial prototype is needed to determine whether the wider spans make economic sense for a particular plan. In general, simpler plans designed on a two-foot module are much more likely to result in savings with 24-inches on center framing than are complex plans with odd dimensions and many small offsets. However, resource savings will occur regardless of economic savings.

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Wider stud spacing contributes to energy efficiency by reducing the amount of lumber in a wall cavity. Since more insulation and less lumber is used, and since insulation has a higher R-value than lumber, increasing stud spacing increases the overall R-value of the wall system. Limitations: Floor decking, wall cladding, roof sheathing, and interior finish material (such as gypsum wallboard) need to be sized to span the added dimension without undesirable deflection. If floor joists are chosen that have wide flanges, this will reduce the clear span of the floor decking. Material fastening schedules and sheathing thicknesses become more stringent when wider spans are employed, which may affect quantities, installation time, and cost of accessories.

One-half-inch-thick gypsum board will deflect somewhat more over 24-inch framing than 16-inch framing, although it is commonly used. An alternative would be to use half-inch "anti-sag" or five-eighths-inch" gypsum board.

Some manufacturers do not make insulation batts for 19.2 inches on center framing. Therefore, using this spacing in an insulated wall assembly may require changing type or brand of insulation.

In some markets, there is a perception that wide-spaced framing is a mark of inferior construction. Attention to all of the details of assembly, including fastening and bracing schedules, will assure that the system performs well.

Code/Regulatory: Model codes allow bearing walls framed with 2x4 studs spaced 24 inches on center or single top plates on bearing walls within defined structural guidelines. Designs in high-wind zones or with tall walls may not allow 24-inch on-center spacing.

SINGLE TOP PLATE—EXTERIOR AND BEARING WALLS

Details: Single top plates are typically incorporated with advanced framing designs that include 24 inch on center framing. By stacking the wall and roof framing, it is possible to use a single top plate because the top plate merely transfers compressive vertical loads to the stud below. Steel plates or straps are used to maintain continuity of the plate in the absence of a second, overlapping plate.

Installation: Temporary bracing is needed to steady and plumb newly erected walls. As with all light frame structures, temporary bracing should be left in place until the floor and/or roof is completed to permanently brace the structure.

Benefits/Costs: In a 28-foot x 40-foot two-story house, the savings from eliminating second top plates in bearing and non-bearing walls is equivalent to eliminating about 35 studs. Because one plate is omitted, the amount of wall insulation is increased, slightly improving energy performance.

Limitations: May not work on homes in high-wind or earthquake zones. Requires purchasing a longer stud.

Code/Regulatory: Meets model codes in some designs, but is more likely than other OVE practices to raise questions from building officials.

SINGLE TOP PLATE—INTERIOR NON-BEARING PARTITIONS

Details: Any non-bearing partition can be built with a single top plate.

Installation: Bracing is needed to steady and plumb recently erected walls. This bracing should be left in place until the floor or roof above the walls is completed, tying the structure together.

Benefits/Costs: Savings depend on the design's linear feet of non-bearing walls. In a 2,200-sq. ft. home, the equivalent of two or three dozen studs is likely to be saved on interior walls.

Limitations: If used along with a normal double plate on bearing and exterior walls, two lengths of wall studs are required on the job, which could be confusing.

Code/Regulatory: Meets codes but is more likely than other OVE techniques to inspire questions from the building official.

RIGHT-SIZED HEADERS or INSULATED BOX HEADERS

Details: Instead of sizing all headers in bearing walls to accommodate the greatest load case, size each header for its actual load and span using the appropriate wood species. Also consider the benefit of using a deeper, single-ply, and engineered wood header.

If the tedium of framing different header depths to uniform head heights at openings is daunting, use insulated box headers that facilitate load transfer above openings and use fewer resources than two-ply solid sawn members. Typically, a boxed header design consists of a top and bottom 2x4 on the flat, some end and interior cripples, and a plywood face on one or two sides. The hollows in the header interior allow insulation to be added.

Installation: Headers of various sizes require framers to pay attention to plans and customize openings. An alternative would be to site-fabricate and insulate box headers of a consistent depth and install these in lieu of dimensional or engineered wood headers.

Benefits/Costs: Material cost and usage economies must be balanced against the chance of installing the wrong-sized header and slowing down the framing process by making opening head framing inconsistent. Similarly, material economies associated with fabricating box headers of consistent depth will be offset by labor involved with fabricating these onsite. The need to have an additional material, insulation, on hand at the rough frame stage makes the bill of materials more complex.

Reducing the use of large-dimensioned lumber is environmentally desirable.

Limitations: Without thoughtful implementation, right-sizing headers could result in uneven window and door head heights. The practice requires cutting different-sized cripples over headers.

Code/Regulatory: Model building codes include prescriptive methods for sizing headers and girders, as well as sizing and constructing box headers.

NO HEADERS IN NON-BEARING PARTITIONS

Details: Although it is obvious that headers are not needed in non-bearing partitions, it is not always obvious which partitions are load bearing and which are not. Thus, framers often put headers over every opening to be safe. Eliminating these headers saves both material and labor.

Installation: If a method of identifying bearing walls versus non-bearing partitions is included on the plans, the layout framer can determine which openings need headers. For instance, solid blue walls can denote bearing and uncolored walls can be non-bearing.

Benefits/Costs: Saves material and labor cost, and conserves resources by reducing the use of wide-dimension lumber.

Limitations: None.

Code/Regulatory: Model codes do not prescribe headers in non-bearing locations, although it may be necessary to demonstrate to the inspector that a partition is non-bearing.

LADDERS AT PERPENDICULAR WALL INTERSECTIONS

Details: Use flat horizontal blocking between studs to secure a perpendicular wall rather than solid vertical framing. (With 24 inches on center wall framing, three 22-1/2-inch scrap pieces are set at 24 inches on center vertically to replace two studs.)

Installation: Cutting and nailing three pieces of blocking requires approximately the same labor as installing two studs.

Benefits/Costs: Less lumber is used, and scrap pieces can be used for blocking. The horizontal blocking stiffens the wall junction. Most important, insulation in the exterior wall can be installed continuously behind the ladder frame.

Limitations: Blocking should be set so that it does not conflict with light switches and outlets.

Code/Regulatory: The system has no impact on model codes.

TWO-STUD EXTERIOR CORNER FRAMING

Details: Only two studs are needed at an outside building corner, one at the end of each intersecting wall end. Any additional framing is needed only to support the gypsum board at the inside corner. Gypsum can be supported either with a flat stud, to leave an open-ended cavity at the corner; or with drywall clips, thus eliminating the need for a third stud.

Installation: If using a third stud for gypsum board backing, the extra stud can be a 2x4, even if the wall is composed of 2x6 studs.

Benefits/Costs: With a two-stud corner, one stud is eliminated. In all cases, the open cavity at the corner can be insulated along with the wall, eliminating the need for the framer to insulate a closed cavity before the sheathing goes on.

Limitations: Drywall clips are unfamiliar to some builders and subcontractors. Exterior corner trim or cladding may result in being secured to the sheathing only and not to the stud.

Code/Regulatory: More studs may be required at corners in high-wind or earthquake zone construction.

Availability: Drywall clips are readily available.

DOUBLING THE RIM JOIST IN LIEU OF HEADER (2x6 or wider wall construction)

Details: In thick wall construction, 5 1/2-inch or greater actual wall dimension, it is possible to have the floor system rim board act as the header, or one member of a two-ply girder or header assembly, at the door or window openings located below that member.

Installation: The joists that frame into this structural member will be shorter than other joists if the design requires a two-ply member to carry the span across the opening. Multiple-member headers should be properly fastened to assure load sharing.

Benefits/Costs: Some labor may be saved in framing the header, but extra labor and thought are involved in fitting perpendicular joists inside the two-ply assembly and framing the opening height down. The concept works best for long spans where the extra depth of the member or additional height of the opening is needed. The design is also an efficient method for use above openings in foundations.

Limitations: If the rim joist is intended to act along with the extra member (or by itself), it must be continuous across the opening.

Code/Regulatory: This is an unusual technique and may inspire questions from the inspector.

Resources:

- NAHB Research Center, *Advanced Framing Techniques: Optimum Value Engineering*, www.nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=2021&CategoryID=70
- HUDUSER, *Prescriptive Method for Residential Cold-Formed Steel Framing*, www.huduser.org/publications/destech/pm2.html
- Building American, DOE, *Optimum Value Engineering Best Practices*, (September, 2002), www.ibacos.com/pubs/OptimumValueEngineering.pdf
- DOE, *Advanced Framing for Walls and Ceilings*, www.energy.state.or.us/code/respub/res10.pdf
- International Code Conference, *2003 International Residential Code®*, Panel Box Headers, Table R602.7.2, pg. 123, and Fig. R602.7.2, pg. 124

2.1.3 Use building dimensions and layouts that maximize the use of the resources without the need to cut materials.

Intent:
Use of standard or modular dimensions in layout will reduce waste by not having to cut materials.

Information / How to Implement:
Modular dimensioning was adopted in the late 1960s and is widely used. Adherence to modular dimensioning can reduce waste of material on the job site.

- One side of a door and window opening located at regular 16-inch or 24-inch stud positions.
- Modular window sizes used, with both side studs located at normal 16-inch or 24-inch stud positions.
- Building dimension in the direction parallel to the primary joist span is evenly divisible by four feet.
- Building dimension in the direction perpendicular to the primary joist span is evenly divisible by two feet.

Building to a 2-foot module and using 24-inch on-center wall and floor framing will maximize framing material resource efficiency and cost savings. Few homes can be entirely confined to a rigid module because typical dimensions such as the width of a tub or corridor are not in two-foot modules. To maximize savings, window sizes and placement should be coordinated with the two-foot module.

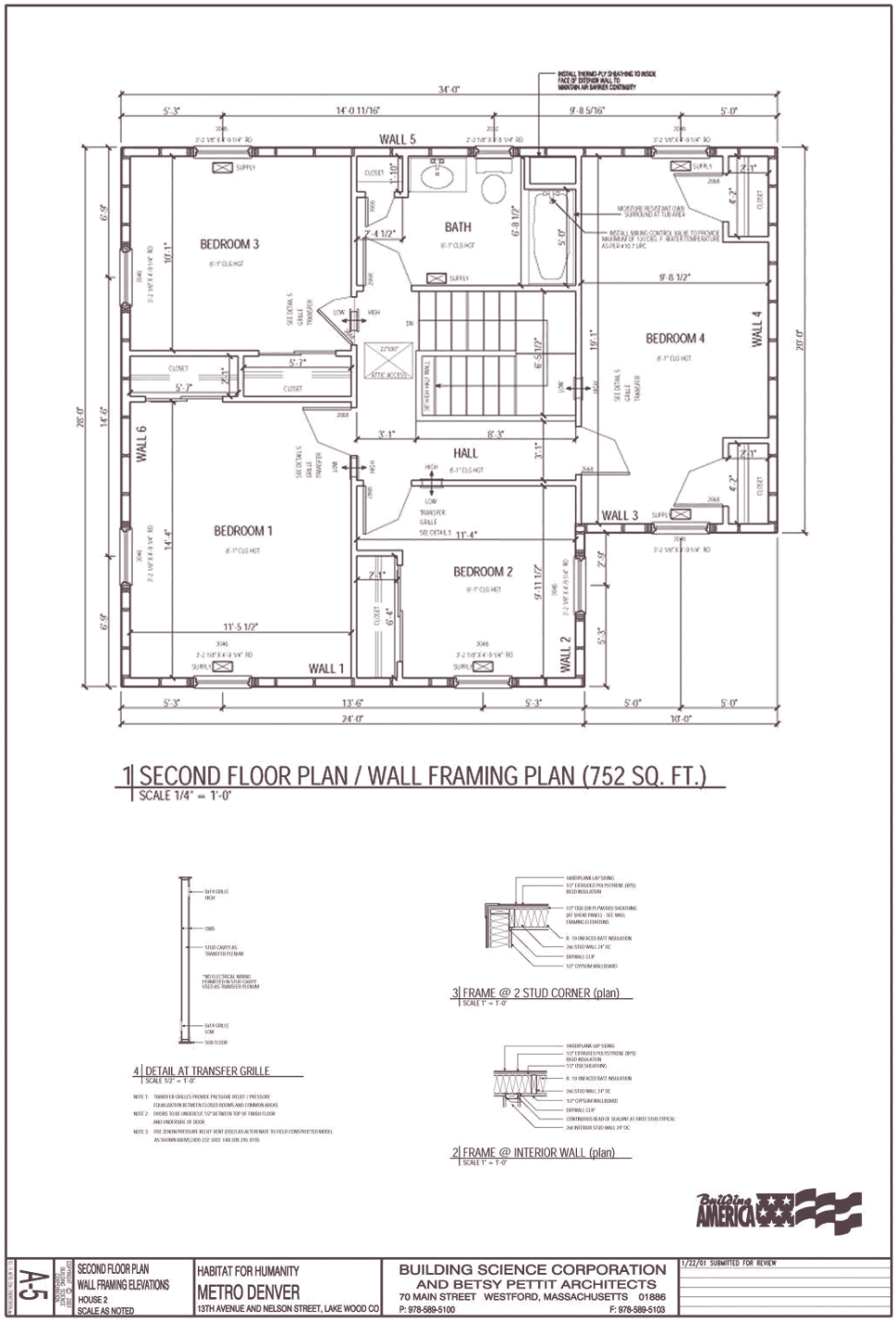
Resources:
NAHB Research Center, PATH technology list, *Advanced Framing Techniques: Optimum Value Engineering (OVE)*, www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2021&CategoryID=70

2.1.4 Create a detailed framing plan and detailed material takeoffs. Provide an onsite cut list for all framing and sheathing material.

Intent:
Recognize the benefits of careful planning in the design, purchase, and installation phases. A framing plan provides a blueprint for the layout of each piece of lumber. A plan eliminates redundant (off-layout) studs at window openings or joists at stair and mechanical chase openings that can act as thermal bridges. The layout provides an accurate count for generating a bill of materials that reduces job-site waste.

Information / How to Implement:

A detailed framing plan can be as complex as a three-dimensional perspective generated in a computer-assisted-design (CAD) program or as simple as a one-eighth-inch scale drawing detailing the floor, wall, roof, lumber, or component layout, dimensions for rough opening(s), headers and girders, and blocking locations. The following pages show examples of a wall framing plan using advanced framing techniques.




WALL 1
WALL 2
WALL 3
WALL 4
WALL 5
WALL 6
A-5
SECOND FLOOR PLAN
WALL FRAMING ELEVATIONS
HOUSE 2
SCALE AS NOTED
HABITAT FOR HUMANITY
METRO DENVER
13TH AVENUE AND NELSON STREET, LAKE WOOD CO
BUILDING SCIENCE CORPORATION
AND BETSY PETTIT ARCHITECTS
70 MAIN STREET WESTFORD, MASSACHUSETTS 01886
P: 978-589-5100
F: 978-589-5103

2.1.5. Use building materials that require no additional finish resources to complete application onsite.

Intent:
Materials that do not require additional finish resources save on priming, painting, and/or additional resources at the installation stage. Additionally, fewer resources are needed for recurring maintenance.

Information / How to Implement:
Ask manufacturer or installer whether a product requires any additional finish.

Examples (not an exhaustive list):

- Pigmented and stamped concrete-surfaced interior floors (of a slab-on-grade foundation).
- Exterior trim not requiring paint or stain.
- Windows with finished surfaces not requiring paint or stain.
- Siding not requiring paint or stain.

Resources:
Information will be added in Version 2.

2.1.6 Use pre-cut or pre-assembled building systems or methods.

A. Provide a pre-cut (joist) or pre-manufactured (truss) floor and roof framing package (points provided for a flooring or roof framing package—additional points provided if both packages are done).

B. Provide a panelized wall framing system.

C. Provide a panelized roof system.

D. Provide modular construction for the entire house.

Intent:
Utilizing materials that do not require additional resources and/or onsite assembly optimizes plant manufacturing efficiencies and offers protection from the elements. Less time (site impact) and resources are spent onsite.

Information / How to Implement:
For Option A, the builder would receive three points for using a flooring package, three points for a roof framing package, or six points for using both.

Pre-cut material packages—A pre-cut floor or roof package can be bundled and shipped for sequencing of use in layout and covered to minimize exposure to the elements. Pieces are marked by location on a layout plan that is provided on the blueprint or with the package. Package delivery can be scheduled for just-in-time delivery to minimize site disturbance. Not having to cut or calculate the position of the components of the floor system speeds assembly, eliminates onsite waste, and saves labor. Contractor-focused lumberyards and component manufacturers that supply engineered wood will have the resources to provide this value-added service. Another resource is building material supply dealers that supply steel stud framing packages.

Pre-manufactured component packages—Open-web floor or roof truss packages also benefit from the efficiencies listed above for pre-cut material packages. Because building components can be engineered with 2x4 and 2x6 lumber to perform as capably as wide-dimension lumber, components present an opportunity to reduce the resources in a home. Often, the reduced amount of board feet of lumber in the component facilitates easier handling because of the reduced weight.

Panelized construction—Open wall panels manufactured in a factory benefit from efficient purchasing and use of materials, automated cutting and fastening methods, and assembly in an environment that is protected from the elements. Panels are custom manufactured and delivered to meet the builder's schedule. A layout plan aids the carpenter in assembling the walls onsite. Using panels can save several days in the critical path of assembly and speed the process of "closing in" the home.

Modular construction—Entire sections of the home are constructed and transported to the site. Modular housing goes further in reducing waste onsite, since the unit is delivered to the site 70 to 85% finished. Modules are moved onto a site-built foundation, connected, repaired at common junctions, and tied in to utilities. Homes can be made ready for move-in within one week.

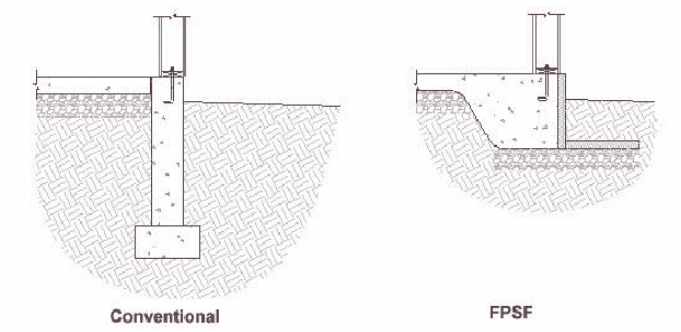
Resources:

- NAHB, Building Systems Council, Fast Facts: Systems-Built Housing, www.nahb.org/generic.aspx?sectionID=455&genericContentID=10216 and www.buildingsystems.org
- U.S. HUD, Builders' *Guide to Residential Steel Floors*, www.huduser.org/Publications/PDF/steelfloor.pdf

2.1.7 Install a frost-protected shallow foundation (FPSF).

Intent:
Minimize the excavation and site disturbance for foundations. Frost-protected shallow foundations use fewer materials than conventional foundations.

Information / How to Implement:
An FPSF incorporates strategically placed insulation to raise soil temperature and the frost depth around a building, thereby allowing foundation depths as shallow as 16 inches for almost all areas of the continental United States Model codes have recognized frost-protected shallow foundation design principles since 1995. Performance has been proven in cold climates like Scandinavia, where FPSFs have been installed for the past 75 years.



Resources:

- NAHB Research Center, Revised Guide to Frost-Protected Shallow Foundations www.toolbase.org/docs/SubsystemNav/Foundations/4495_RevisedFPSFGuide.pdf

2.2 ENHANCE DURABILITY AND REDUCE MAINTENANCE

Intent:
Building designs, material choices, and installation techniques should seek to minimize the effects of degradation and weathering, enhance life expectancy of the assembly, and lessen maintenance needs.

Information / How to Implement:
Durability may be defined as the ability of a material, product, or building to maintain its intended function for its intended life expectancy with intended levels of maintenance in intended conditions of use.

Fortunately, many of the best practices meant to improve durability require little more than good judgment and a basic knowledge of the factors that affect building durability. A thorough review of resource publications will provide a solid foundation.

Resources:

- NAHB Research Center for PATH, Durability by Design, www.huduser.org/publications/destech/durdesign.html
- Canadian Architect, *Measures of Sustainability*, www.cdnarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_durability.htm
- The Residential Moisture Management Network is working on addressing issues related to moisture management in homes, www.rmmn.org/
- Installation details for wood framed construction that will minimize moisture intrusion into the building envelope can be found at www.buildabetterhome.org. Publications on foundations, roofs, and walls can be downloaded by going to each of those sections under the "builder tips" and then clicking on "get the brochure."

2.2.1 Provide a covered entry (e.g., awning, covered porch) at exterior doors to prevent water intrusion and subsequent rotting of joists, sills, and finishes.

Intent:
A roof over an entry to a home sheds precipitation and keeps sunlight from the opening, protecting the door finish and penetration of moisture around jambs, trim and threshold, minimizing the need for maintenance of these areas. Roofs over entries also are convenient for the occupant during foul weather and are an architectural feature that can enhance a home's visual appeal and provide an outdoor living space.

Information / How to Implement:
Designs should include a roof or recessed front opening of a depth equal to or greater than the recommended roof overhang for the region.

Resources:
Information will be added in Version 2.

2.2.2. Use recommended-sized roof overhangs for the climate.

Intent:
Protect the building envelope and enhance the home's durability through the use of overhangs. Use overhangs to shade windows from summer heat gain.

Information / How to Implement:
The following table presents the recommended roof eave and rake overhangs for varying the climates:

RECOMMENDED MINIMUM ROOF OVERHANG WIDTHS FOR ONE- AND TWO-STORY WOOD FRAME BUILDINGS*

Climate Index (see map below)	Eave Overhang (inches)	Rake Overhang (inches)
Less than 20	N/A	N/A
21 to 40	12	12
41 to 70	18	12
More than 70	24 or more	12 or more

Source: Modification of Prevention and Control of Decay in Homes by Arthur F. Verrall and Terry L. Amburgey, prepared for the U.S. Department of Agriculture and U.S. Department of Housing and Urban Development, Washington, DC, 1978.

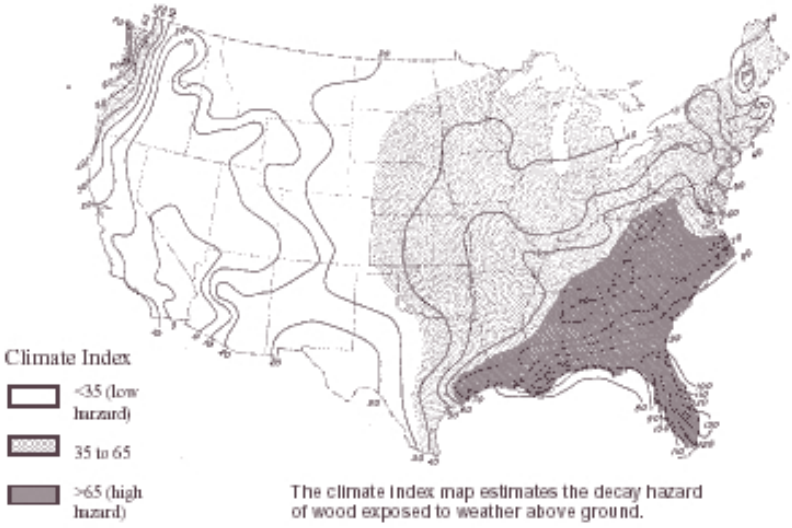
* Table based on typical two-story home with vinyl or similar lap siding. Larger overhangs should be considered for taller buildings or wall systems susceptible to water penetration and rot.

Resources:
- NAHB Research Center for PATH, Durability by Design, www.huduser.org/publications/destech/durdesign.html

2.2.3. Install perimeter drain for all basement footings sloped to discharge to daylight, dry well, or sump pit.

Intent:
Divert surface and subsurface water away from the house, and limit water seepage through the foundation walls and basement slab.

Information / How to Implement:
A perimeter footing drain system of perforated pipe should be installed below the level of the basement slab on the inside and outside of the foundation wall and interconnected. Pipe should be wrapped with filter fabric and surrounded with a prescribed minimum of (IRC® 12 inches x 6 inches, exterior) clean gravel or crushed stone. If the outfall is to a sump pit, and the pit requires mechanical removal, pipe should be installed for outfall 10 feet away from foundation wall that does not cause localized erosion.



The climate index map estimates the decay hazard of wood exposed to weather above ground.

Resources:
Information will be added in Version 2.

2.2.4. Install drip edge at eave and gable roof edges.

Intent:
The drip edge directs roof runoff water into the gutters and away from the fascia and roof sheathing.

Information / How to Implement:
Drip edge is an inexpensive accessory that can be included in the roofer's scope of work and roofing material package.

Resources:
- Truini, Joseph, This Old House, Roof Runoff Remedy, www.thisoldhouse.com/toh/knowhow/solutions/article/0,16417,193154,00.html

2.2.5. Install gutter and downspout system to divert water at least five feet away from foundation and into the overall onsite drainage area.

Intent:
Moisture intrusion of foundations is avoided by moving runoff water beyond the foundation.

Information / How to Implement:
Storm water can be diverted from the roof and into a rain garden. Such a technique can help beautify the yard, reduce the amount of mowing needed, and reduce the need to use potable water for watering.

Resources:
Information will be added in Version 2.

2.2.6 Divert surface water from all sides of building. Slope top of backfill to achieve settled slope of at least six inches of fall within 10 feet of the foundation walls.

Intent:
Moisture intrusion of foundations is avoided by moving runoff water beyond the foundation.

Resources:
Steven Winter Assoc., Inc. for HUD, Volume 1 Rehab Guide: Foundations, Chapter 4, www.toolbase.org/docs/SubsystemNav/Foundations/4406_rehab1_found.pdf

2.2.7. Install a continuous and physical foundation termite barrier in areas where subterranean termite infestation is a problem.

Intent:
Providing a non-chemical termite obstruction offers a long-term solution to termite infestation avoidance.

Information / How to Implement:
IRC Fig. R 301.2(6) has a Termite Infestation Probability Map of the United States dividing the country into different zones of infestation levels; heavy, moderate to heavy, etc. The local HBA may offer information on the regional probability of termite infestation in consultation with the cooperative extension service and other termite experts.
Using a foundation termite shield is only one way a builder can effectively combat infestation. Following is a breakdown of the home building process and a list of the tactics that can be used in an environmentally aware fashion to accomplish termite resistance.

I. Site.

A. Selection—termites dislike dry conditions. Choose a site that is well-drained and ventilated.

B. Sanitation—the majority of termites that infest homes live underground, and food (cellulose in the form of wood, paper, leaves, etc.) stored underground may lead termites to a house. When preparing a site for construction, don't bury vegetation and construction debris. After the foundation is built, don't include wood scraps in the backfill.

C. Landscaping—Keep homes dry. Slope finish grade away from the house. Keep plantings well away from homes. Roots act as underground bridges through chemical or physical termite barriers. Plants such as shrubs and trees can prevent ventilation to the home and prevent drying after precipitation events.

II. Design

A. Layout—Keep houses dry. Ensure that wood elements are stopped at least eight inches above finish grade. Termites can form hills or tubes that extend from the soil to food. Greater clearance between ground and wood elements prevents this situation and allows more time for detection should termites use tubes to reach above-ground food sources. Keep untreated wood away from contact with concrete. Concrete is a good conductor of water, and untreated wood in contact with concrete may decay or attract termites.

B. Thermal—Termites love moisture and moisture comes from many sources. Proper design of the exterior envelope will prevent condensation from occurring.

C. Materials—Areas of the home that are particularly susceptible to moisture, like shower and bath surrounds, should not be detailed with cellulose materials. Penetrations through the foundation, walls, and roof are all vulnerable to moisture intrusion, and care should be taken to minimize them. To protect against foundation penetrations, consider using one of new physical barriers in the marketplace. Termiticides bonded between a polymer fabric and a stainless-steel mesh small enough to keep out termites are some of the innovations available.

III. Construction Process

A. Material Storage—Keep moisture-sensitive materials dry, and don't incorporate compromised products into the house. Arrange to have materials delivered as close to the time of installation as practical.

B. Flashing—Penetrations through the exterior envelope are particularly vulnerable to moisture intrusion. Properly flash and seal all penetrations to prevent moisture accumulation.

IV. Post Construction

A. Owner Education—Inform homeowners about the value of dry homes and practices they can perform to keep the house free of termites and decay. Describe prevention features of the home and how these features can become compromised.

B. Termite Control—Should termites need subsequent control, consider targeted poisons such as baits.

Resources:

- Canadian Wood Council, Termite Control and Wood-Frame Buildings: Slab and Foundation Details, www.cwc.ca/publications/building_performance/termites/structural.php
- NAHB Research Center, Termite Baiting www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1402&DocumentID=2153
- University of Kentucky Entomology, Termite Baits: A Guide for Homeowners, www.uky.edu/Agriculture/Entomology/entfacts/struct/ef639.htm
- Termiticide fabric and mesh manufacturers, www.impasse.com/ and http://www.termi-mesh.com/

2.2.8. Use termite-resistant materials for walls, floor joists, trusses, exterior decks, and other exterior wood in regions known to be termite infested.

Intent:

By eliminating the cellulose food source for termites or by repelling termites, the home's durability is enhanced.

Information / How to Implement:

Use the IRC® infestation map referenced in Section 2.2.7 to determine the probability of infestation for the region. Termite-resistant materials include naturally pest-resistant species of wood (e.g., redwood, cedar, white oak, black locust), treated wood (borate or ground contact solutions), masonry, steel, and concrete.

Reduce humidity in crawl spaces. Keep shrubs, vines, and other vegetation from growing over ventilation openings. Never bury wood scraps or waste lumber in the yard. Remove old tree stumps and roots around and beneath the building. Inform the homeowner to keep firewood piles away from the house, raised off the ground, and covered.

Resources:

- Durable-Wood.com, Forintek Canada Corp., Termite Control and Wood-Frame Buildings durable-wood.com/termites/termitecontrol-e.pdf
- Western Wood Preservers Institute, www.wwpinstitute.org
- *Terminate the Termites*, www.steelframingalliance.com

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2.2.9 Provide a weather-resistant barrier (WRB) or a drainage plane system behind the exterior veneer system or the exterior siding.

Intent:
To protect the building envelope from water intrusion by installing a secondary, exterior-wall water management system.

Information / How to Implement:
Wind-driven rain and air pressure differentials allow water intrusion into and behind most exterior claddings and veneers. A comprehensive approach to water management prevents water from reaching the sheathing or framing. Primary water management strategies include water-shedding architectural features such as overhangs and exterior claddings. Secondary (redundant) water management to protect the sheathing and framing from moisture damage can be in the form of a weather-resistive barrier, a distinct drainage plane, or both.

As part of a whole-wall design, weather-resistant barriers need to be integrated with other wall system components, including structure, insulation, vapor retarder, air retarder (if separate), and flashing systems.

Resources:
- NAHB Research Center, Weather-Resistant Barriers, www.toolbase.org/docs/MainNav/MoistureandLeaks/3950_weatherresistantbarriers.pdf

2.2.10. Install ice flashing at roof edge.

Intent:
The eave edges of a roof are particularly susceptible to water intrusion from wind-driven rain, clogged gutter backup, and freeze-thaw cycles after winter snowfalls. Ice barrier or flashing is a redundant barrier that protects the sheathing near the roof edges and keeps water out of the attic and walls.

Information / How to Implement:
The IRC® requires that, in areas where the average daily temperature in January is 25°F or less, an ice barrier consisting of at least two layers of underlayment cemented together or a self-adhering polymer modified bitumen sheet that extends from the edge of the eave to a point at least 24 inches inside the exterior wall line of the building be installed. It is recommended that the ice barrier approach be used for green home construction because the redundant protection provided by an ice-barrier is efffective against many weather phenomena such as rain storms with high winds and winter snow.

Resources:
- University of Minnesota Extension Service, Ice Dams, www.extension.umn.edu/distribution/housingandclothing/DK1068.html

2.2.11 Install enhanced foundation waterproofing.

Intent:
To keep moisture out of the foundation by providing a waterproof exterior coating or engineered exterior drainage plane.

Information / How to Implement:
Foundation coatings that are required by the model building codes help prevent moisture from penetrating the foundation. A number of products are available to provide a more permanent barrier to moisture at the exterior of the foundation.

Resources:
- ToolBase Services, Foundation Drainage Panels, www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2063&CategoryID=1010

2.2.12 Employ and show on plans the following flashing details:

- Around windows and doors,
- Valleys,
- Deck/house juncture,
- Roof/wall junctures, chimney step flashing, and
- Drip cap above windows and doors.

Intent:
To specify and call out the details of systems integration on the blueprints rather than leaving them to the half dozen or so specialists who perform installation of adjacent materials on the jobsite. All junctions of dissimilar material and flashing details are to be shown on plans.

Information / How to Implement:
Product manufacturer's installation guides and association best practices details are good sources for the correct detailing of systems.

Resources:
- Brick, www.gobrick.com/html/frmset_thnt.htm
- Masonry products, www.ncma.org
- Various, http://pix.nrel.gov:8020/BASIS/nich/www/bapublic/SDF
- Windows and doors, http://pix.nrel.gov:8020/BASIS/nich/www/bapublic/SDF
- Wood, http://apacad.org/
- *EEBA Water Management Guide*—www.eeba.org/mall/water.asp—This guide presents a variety of ways to minimize water intrusion into homes. These recommendations are not intended to apply to every conceivable situation but are intended to illustrate principles.

2.3 REUSE MATERIALS

2.3.1 Disassemble existing buildings (deconstruction) instead of demolishing.

Intent:
Construction activities may comprise as much as 40% of all raw materials extracted from the earth. At the same time, construction, remodeling, and deconstruction are blamed for generating 136 million tons of waste annually. Some waste material can easily be refitted into a structure. The action decreases both material use and waste. In addition, unneeded transportation costs associated with hauling can be eliminated.

Information / How to Implement:
Develop and implement a plan to use materials prudently, regardless of their origination.

Resources:

- Inform, Inc., Community *Waste Prevention Toolkit: Construction and Demolition Fact Sheet*, www.informinc.org/fact_CWPconstruction.php#basics
- Government of Hawaii, *Minimizing Construction and Demolition Waste*, www.hawaii.gov/health/environmental/waste/sw/pdf/constdem.pdf
- California Integrated Waste Management Board (CIWMB), www.ciwmb.ca.gov
- CIWMB, *Recycled-Content Product Directory*, www.ciwmb.ca.gov/RCP/Product.asp?VW=CSI&CATID=269
- NAHB Research Center, ToolBase Services, Construction Waste Management, www.toolbase.org/secondaryT.asp?TrackID=&CategoryID=34
- Whole Building Design Guide, *Construction Waste Management Database*, www.wbdg.org/ccbref/cwm.php
- Washington State Department of General Administration, Construction Waste Management Guide, www.ga.wa.gov/EAS/CWM/ContractorsGuide.doc

2.3.2 Reuse salvaged materials, where possible.

Intent:
To minimize the waste stream by reusing materials. Ideally, salvaged materials should be reclaimed from a nearby or onsite demolition or remodeling project to minimize transportation.

Information / How to Implement:
Note: Building materials can come from the deconstructed building in 2.3.1 or from another source.
Note—The word "component" is used in certain line items in this section (2.3.2; 2.4.1; 2.5.3; 2.6.1; 2.6.2; 2.7.1; and 2.8.1). A component is defined as part of an entire building system, such as:

- footing
- foundation walls
- slab
- floor framing
- interior partitions
- wall framing
- roof framing
- wall sheathing
- roof sheathing
- wall insulation
- attic insulation
- windows
- interior doors
- exterior doors
- interior trim
- flooring trim
- finish trim
- siding
- other.

Salvaged materials can be used for fill material, base for paved areas, or within building(s). Materials include crushed concrete, salvaged wood, steel, brick, and architectural materials such as windows, doors, paneling, and cabinets.

Salvaged windows and exterior doors should not be used at the expense of energy efficiency.

Disclaimer—Salvaged materials must meet minimum standards where applicable. Be careful of lead paint and other potentially hazardous finishes that could be part of existing materials.

Points can be provided if the total cost of the salvaged materials (including material costs and labor costs, i.e., installed costs) is equal to or greater than 1% of construction costs.

Resources:

- Jennifer Corson, *The Resourceful Renovator: A Gallery of Ideas for Reusing Building Materials* (Chelsea Green Publishing Company, December 2000)

- Greater Vancouver Regional District Policy and Planning Department, *Old to New Design Guide Salvaged Building Materials in New Construction* 3rd Edition (January 2002), www.buildsmart.ca/pdfs/DesignGuideMaster.pdf
- Used Building Materials Association, http://bcn.boulder.co.us/environment/ubma/index.html

2.3.3 Dedicate and provide onsite bins and/or space to facilitate the sorting and reuse of scrap building materials.

Intent:
This practice will establish a central storage area to encourage maximizing usage of all materials on the site. Workers are less likely to waste material that will be subject to future inspection. Those same workers are more likely to seek and use scraps if they know where to find them quickly and the remnants that were not incorporated into the job are already sorted for grinding or recycling.

Information / How to Implement:
Information will be added in Version 2.

Resources
Scopes of work should include the removal of remnants to a designated central area. The reuse area should be conveniently located and marked or delineated for the size, type, and quantity of material expected.

2.4 USE RECYCLED-CONTENT MATERIALS

2.4.1 Use recycled-content building materials.

Intent:
To minimize the impact of home building on the environment.

Information / How to Implement:
Points: To obtain the three points, the project must have a minimum of two types of recycled-content materials. Each type of recycled-content material used thereafter would give the project another point each, to a maximum of six points.

A builder can obtain three points by incorporating at least two different types of recycled-content building materials into the home's construction. An additional point is awarded for each additional type of material for a maximum point total of five points.

Post-consumer means that the materials have been used by a consumer. Post-industrial can include waste materials from within a manufacturing site that are fed back into the manufacturing process as feedstock *and* materials from outside the plant that are waste elsewhere, have not gone to a landfill or consumer yet, but are incorporated into a product's manufacturing process (e.g., fly ash for concrete).

The results of a California Integrated Waste Management Board (CIWMB) study on building material emissions indicate that recycled-content products perform about the same as standard products. Both alternative and standard products have the potential to emit chemicals of concern. For a copy of the study, see www.ciwmb.ca.gov/Publications/GreenBuilding/43303015.doc.

Here are some typical ranges of recycled content found in various construction materials:

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Clay brick is manufactured with a variety of recycled materials. Examples include contaminated soils, scrap soils from excavations, inclusion of bottom ash from coal-fired generators, and production scrap from other ceramic products. The amount of recycled materials in clay brick depends on the type of material added, but typical values range up to 7% by weight.

Through the Composite Panel Association's Environmentally Preferable Product (EPP) Specification CPA 1-02, composite panels (particleboard, medium-density fiberboard [MDF], and hardboard) can be certified to have 100% recycled or recovered fiber. See the Resources section of this line item for further information.

Cellulose insulation can contain as much as 85% recycled paper stock (wood-based) content. Additionally, it is certified in accordance with ASTM 739 and the Cellulose Insulation Manufacturers Association.

Fiberglass insulation: 25% combination post- and pre-consumer recyclables

Steel framing: 25% of which no less than 10% should be post-consumer recycled

Carpeting: Recycled-content carpet is available for residential construction 

Fly ash or slag: Fly ash or slag, by-products of the steel production process, can be used in concrete as a replacement for some of the cement. In some cases, as much as 40% of the cement can be substituted while maintaining required strength and durability. Many concrete suppliers are familiar with recycled-content options, and some have reported that the use of fly ash or slag is standard practice. Several contractors have reported that the fly ash-content concrete sets up more slowly, and adjustments must be made in the timing of finishing. Also, fly ash- or slag-content concrete may have some dark streaking and therefore, may not be suitable for exposed flatwork or poured walls. Check with your local concrete supplier.

Road and paver base, gravel: In many parts of the country, efforts are underway to recycle concrete waste. Concrete is ground into usable materials for temporary construction roads, a base for pavers or bricks, or other possible uses in place of limestone or gravel. In some cases, concrete suppliers have developed and tested mixes in which some recycled concrete is used. Check with local concrete suppliers or landfills to see if recycled concrete aggregate is available.

Check with local jurisdictions regarding recycling programs. The use of recyclable materials is also recommended. Products that are either recycled or recyclable will display the triangle logo (see above). The product literature must note the recycled content, if any. The reference section contains additional information on this.

Resources:

- King County (WA), *Environmentally Responsible Carpet Choices*, www.metrokc.gov/procure/green/carpet.htm
- U.S. Environmental Protection Agency (EPA), *Comprehensive Procurement Guidelines*, www.epa.gov/cpg/
- EPA, *Environmentally Preferable Purchasing*. www.epa.gov/oppt/epp/tools/toolsuite.htm
- Green Building Source, *Green Product Information* http://oikos.com/products/index.lasso
- California Integrated Waste Management Board, *Recycled Product Directory*; *Products Category*: Construction, can provide a baseline for total recycled content (TRC) that is achievable with some products, www.ciwmb.ca.gov/RCP/Product.asp?VW=CAT&CATID=257
- Details on the Composite Panel Association's Environmentally Preferable Product (EPP) Specification CPA 1-02 and a list of certified manufacturers, www.pbmdf.com/AboutCPA/EPP.asp
- Carpet America Recovery EffortSM, www.carpetrecovery.org/
- Steel Recycling Institute, www.recycle-steel.org/construction.html

Excerpt from the Federal Trade Commission's Part 260 —*GUIDES FOR THE USE OF ENVIRONMENTAL MARKETING CLAIMS*…(d) Recyclable: "It is deceptive to misrepresent, directly or by implication, that a product or package is recyclable. A product or package should not be marketed as recyclable unless it can be collected, separated or otherwise recovered from the solid waste stream for reuse, or in the manufacture or assembly of another package or product, through an established recycling program. Unqualified claims of recyclability for a product or package may be made if the entire product or package, excluding minor incidental components, is recyclable. For products or packages that are made of both recyclable and non-recyclable components, the recyclable claim should be adequately qualified to avoid consumer deception about which portions or components of the product or package are recyclable. Claims of recyclability should be qualified to the extent necessary to avoid consumer deception about any limited availability of recycling programs and collection sites. If an incidental component significantly limits the ability to recycle a product or package, a claim of recyclability would be deceptive. A product or package that is made from recyclable material, but, because of its shape, size or some other attribute, is not accepted in recycling programs for such material, should not be marketed as recyclable…"

Source: Federal Trade Commission, Part 260–Guides for the Use of Environmental Marketing Claims, www.ftc.gov/bcp/grnrule/guides980427.htm

2.5 RECYCLE WASTE MATERIALS DURING CONSTRUCTION

Recycling waste materials is driven by market conditions at the local level. Recycling markets and tipping fees vary greatly.

2.5.1 Develop and implement a construction and demolition (C & D) waste management plan that is posted at job site.

Intent:
Create a C & D waste management plan that sets goals to recycle or salvage a minimum of 50% (by weight) of construction, demolition, and land-clearing waste.

Information / How to Implement:
A C & D plan can be a simple spreadsheet that covers the materials used or deconstructed on site and the plan for reusing them onsite or recycling them. If recycling, include the name of the hauler, the destination, and approximate quantities. A sample plan can be obtained from the City of Oxnard, CA, in the Resources.

Resources:
- City of Oxnard (CA), C & D *Solid Waste Management and Recycling Plan*, www.ci.oxnard.ca.us/pubworks/refuse/worksheets/c_dplan.pdf
- NAHB Research Center, Inc., Residential Construction Waste information, www.epa.gov/epaoswer/non-hw/debris/mgmt.htm
- U.S. Environmental Protection Agency Solid Waste and Emergency Response, Building Savings, Strategies for Waste Reduction of Construction and Demolition Debris from Buildings (EPA-530-F-00-001) (June 2000), www.epa.gov/osw
- Institute for Local Self-Reliance. www.ilsr.org/recycling/buildingdebris.pdf

2.5.2. Conduct onsite recycling efforts, e.g., use grinder and apply materials onsite, thus reducing transportation-related costs.

Intent:
Through grinding, divert from the landfill a minimum of 50% (by weight) of construction, demolition, and land-clearing waste. Reduce transportation-related environmental costs.

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Information / How to Implement:
This task may also be part of the builder C & D plan. Grinding and other methods of onsite processing and reuse of waste require an economic analysis. Large home builders have reported successful integration of a grinder into field operations. (See Waste Handling Equipment news article in References.) For small-volume builders, it not likely be cost effective to own or rent grinding equipment. There may, however, be a local business that could efficiently perform this service for a small job.

Resources:
- Waste Handling Equipment News, Major Home Builders Benefit from On-site Recycling, www.wastehandling.com/july/major.html
- NAHB Research Center, ToolBase Services, RESIDENTIAL CONSTRUCTION WASTE: FROM DISPOSAL TO MANAGEMENT, www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=34&DocumentID=2301

2.5.3 Recycle construction waste offsite, e.g., wood, cardboard, metals, drywall, plastics, asphalt roofing shingles, concrete, block, other.

Intent:
Through a recycling program, divert from the landfill a minimum of 50% (by weight) of construction, demolition, and land clearing waste.

Information / How to Implement:
At least two types of materials must be recycled to obtain the six points. Each type of material recycled thereafter yields two points each to a maximum of 12 points.

This task may also be part of the builder C & D plan.

Resources:
- The U.S. General Services Administration (GSA) has recently updated its online Construction Waste Management Database to assist the building industry in reducing construction and demolition waste. Recyclers of construction and demolition waste may advertise their services free on this site. Access the database at http://cwm.wbdg.org.
- American Forest and Paper Association, National Wood Recycling Directory, www.afandpa.org/Content/NavigationMenu/Environment_and_Recycling/Recycling/Wood_Recovery1/Wood_Recycling_Directory1/Wood_Recycling_Directory_Intro.htm
- California Integrated Waste Management Board, www.ciwmb.ca.gov/
- Corrugated Packaging Council, How to Recycle Corrugated, http://cpc.corrugated.org/Recycle/RecyHowTo.aspx
- U.S. Environmental Protection Agency Municipal and Industrial Solid Waste Division Office of Solid Waste, Characterization of Building-Related Construction and Demolition Debris in the United States (EPA530-R-98-010) (June 1998), www.epa.gov/epaoswer/hazwaste/sqg/c&d-rpt.pdf
- Steel Recycling Database, www.recycle-steel.org/database/main.html

2.6 USE RENEWABLE MATERIALS

2.6.1 Use materials manufactured from renewable resources or agricultural by-products such as soy-based insulation, bamboo, or wood-based products.

Intent:
Use building products that use carbon sequestration, i.e., that are made from plants that take carbon from the atmosphere and store it as fiber.

Information / How to Implement:
A builder can obtain three points for this line item by incorporating at least two different types of renewable resources into the home's construction. An additional point can be obtained for each additional type of material for a maximum total for this line item not to exceed five points.

Careful review of the material manufacturer's claims and material specifications is required for this task. Points should be given for each material specified and used.

Note: Products used should also comply with the Indoor Environmental Quality section of the User Guide. For example, composite wood or agrifiber panel products should not contain process-added urea-formaldehyde resins or must be third-party certified for low formaldehyde emissions. Particleboard, medium-density fiberboard (MDF), and hardwood plywood substrates must be certified to low formaldehyde emission standards ANSI A208.1, ANSI A208.2 and ANSI/HPVA HP1, respectively (see Section 5.1.5). Similarly, bamboo flooring manufacturers should produce a copy of the lab test results, by an American laboratory, for their products. The results should include a formaldehyde test and a hardness and stability (expansion/contraction) test.

Resources:
Information will be added in Version 2.

2.6.2 Use certified wood for wood and wood-based materials and products from all credible third-party-certified sources.

Intent:
Preserving our natural resources includes the commitment to best practices in forest management, like practices that maintain and restore their health and ecosystems. Forest certification systems help identify producers that assure a reliable supply without damaging forests.

Information / How to Implement:
A comparison list of the North American certifiers is provided by the Forest Certification Resource Center in the Resources section.

Below is a list of the third-party-certified wood sources.
- The Sustainable Forestry Initiative® Program
- The American Tree Farm System®
- The Canadian Standards Association's Sustainable Forest Management System Standards (CAN/CSA Z809)
- Forest Stewardship Council (FSC)
- Program for the Endorsement of Forest Certification Systems (PEFC), and
- Other such credible programs as they are developed and implemented.

Resources:
- Forest Certification Resource Center, *Comparison of Forest Certification Systems*, www.certifiedwood.org/search-modules/compare-systems/comparison-of-systems/comparison-of_systems.htm
- The Sustainable Forestry Initiative® Program, www.aboutsfi.org/
- The American Tree Farm System® www.treefarmsystem.org/
- The Canadian Standards Association's Sustainable Forest Management System Standards (CAN/CSA Z809) www.sfms.com/welcome.htm
- Forest Stewardship Council (FSC) www.fsc.org/fsc
- Program for the Endorsement of Forest Certification Systems (PEFC) www.pefc.org/internet/html

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2.7 USE RESOURCE-EFFICIENT MATERIALS

2.7.1 Use products that contain fewer resources than traditional products.

Intent:
Minimize the resources consumed by and the environmental impact of building a house.

Information / How to Implement:
A project must use resource-efficient materials for at least two different types of components to receive the three points.

When specifying materials, consider the amount of resources going into the product and whether alternatives are available. Examples are specifying hollow brick that meets the requirements of ASTM C 652 and is made from less material than face brick meeting ASTM C 216. Appearance and durability requirements are identical. Or, specifying engineered-wood products, e.g., I-joists that use 35% less fiber material than solid-sawn products.
Caveat: Even though engineered products can reduce the amount of feedstock used in a product, e.g., wood fiber in I-joists, more energy or binders may be needed to create the final product. While this may be the case, our intent is to reduce the core source of material going into the product's creation.

Resources:
- DOE's Energy Efficiency and Renewable Energy, Energy and Environmental Guidelines for Construction, www.eere.energy.gov/buildings/info/design/construction.html#construction

2.8 INNOVATIVE OPTIONS

2.8.1 Use locally available, indigenous materials.

Intent:
To make the home building process more environmentally acceptable by minimizing transportation and processing costs and using materials that are common to the local region.

Information / How to Implement:
A builder can obtain three points for this line item by incorporating at least one type of locally available, indigenous material into the home's construction. An additional point can be obtained for each additional type of material for a maximum point total of five points.

Guidance to program administrators: Points should be awarded in this section based on criteria such as 10% of the building materials are extracted, processed, and manufactured within a 300-mile radius or within a 1000-mile radius if shipped by rail, or a combination of the two distances.

Resources:
Information will be added in Version 2.

2.8.2 Use a life-cycle assessment (LCA) to compare the environmental burden/effects of building materials. Based on the analysis, choose the most environmentally preferable product for that building component.

Intent:
To highlight the best use of resources, including cost, to assure that all of the guiding principles have been considered.

Information / How to Implement:
A life cycle assessment (LCA) is a reliable way to calculate and compare the cradle-to-grave environmental effects and costs of common building materials. Designers can use modeling tools such as Athena™ to examine the life-cycle environmental effects of a complete structure or of individual assemblies, and can experiment with alternative designs and material mixes to arrive at the best environmental footprint. A software tool such as BEES (www.bfrl.nist.gov/oae/software/bees.html) can also identify the life-cycle costs of select building components.
The objective of the modeling is to aid the designer in selecting building assemblies and/or materials with the lowest reported impact in terms of energy consumption, air and water toxicity index, GWP, ecologically weighted resource use, and solid-waste emissions.

Suggested course of action:
1. Develop building design using materials with a low environmental impact. Evaluate building materials for each life-cycle phase using either the manufacturer's data or a reputable LCA.
2. Establish a process to compare and assess similar building materials in similar categories.
3. Survey manufacturers to analyze the environmental impacts at each phase of a product's life, making it possible to explore the environmental effects of design options or material mixes in order to arrive at the best green design.
4. Use the Athena™ tool to assess building assemblies.

Another suggested two-step process:
1. Conduct preliminary research and an evaluation of building materials generically, such as concrete, steel, and wood. Explore the environmental effects of different design options or material mixes.
2. Provide evidence that the selection of the foundations and floor assembly materials, structural system (column and beam, or post and beam combinations), roof and envelope assembly materials (cladding, windows etc.) included a life-cycle assessment.

Resources:
- National Institute of Standards and Technology, *Building for Environmental and Economic Sustainability software*, www.bfrl.nist.gov/oae/software/bees.html
- The Athena™ Sustainable Materials Institute, www.athenasmi.ca/news/down/LCI_Database_Project_News_1.pdf

SARB_006210

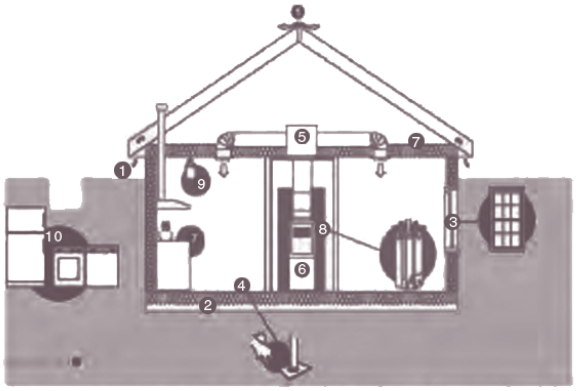
3.1 IMPLEMENT AN INTEGRATED AND COMPREHENSIVE APPROACH TO ENERGY-EFFICIENT DESIGN OF BUILDING SITE, BUILDING ENVELOPE, AND MECHANICAL SPACE CONDITIONING SYSTEMS

Intent:
To use a whole-systems approach in designing and building an energy-efficient home. Key concepts are integrated and comprehensive.

Information / How to Implement:
Pay attention to multiple facets related to energy efficiency during the design and construction process. For instance, rather than simply focusing on individual decisions related to energy efficiency, such as the R-value of attic insulation, consider the implications of each choice on the performance of the whole house. Balance the cost and performance of each component of the home system, such as a well-insulated building envelope (foundation, walls, and attic); windows recommended for the climate by experts such as the Efficient Windows Collaborative, the Department of Energy, and/or local energy professionals; a thorough and carefully implemented air sealing package; climate-appropriate heating and cooling equipment that balances efficiency with cost-effectiveness; sealed ductwork kept within the conditioned space; and efficient water heating equipment and distribution. Moisture and indoor environmental quality are closely related factors that are affected by energy-efficiency measures.

For more detailed information and explanation about the sizing and design of space heating and cooling, refer to "Understanding HVAC System Design Issues" at the end of this Energy Efficiency section.

Resources:
- *Home Energy Checklist* (EEBA) www.eeba.org/technology/publications/hec/default.htm
- *Whole House Energy Checklist* (U.S. DOE fact sheet), www.southface.org/web/resources&services/publications/technical_bulletins/WH-Energy%20Checklist%20GO-10099-766.pdf
- *Energy Efficiency Pays* (U.S. DOE fact sheet), www.southface.org/web/resources&services/publications/technical_bulletins/EEP-Efficiency_pays%2099-746.pdf
- *Considerations for Building a More Energy Efficient Home*, NAHB Research Center fact sheet. Available at www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1809&DocumentID=4168



Improve Energy Efficiency Throughout the House

1. Provide roof/attic ventilation
2. Install adequate insulation with no gaps or compressed areas.
3. Specify efficient windows; consider window orientation.
4. Seal all penetrations.
5. Locate all ducts within conditioned space; ensure all ducts are sealed with mastic.
6. Size heating and cooling equipment; choose efficient models.
7. Provide controlled ventilation.
8. Install efficient water heating.
9. Specifly efficient lighting for fixtures used more than 4 hours per day.
10. Choose efficient appliances.

Courtesy of Southface Institute: developed with funding from the U.S. Department of Energy

SARB_006211

Requirements:

3.1.1 Home is equivalent to the IECC 2003 or local energy code whichever, is more stringent. Conformance shall be based on plan analysis using software such as REScheck or other as approved by green building program administrator or NAHB.

3.1.2 Space heating and cooling system/equipment shall be sized according to building heating and cooling loads calculated using ANSI/ACCA Manual J 8th Edition or equivalent. Computerized software recognized by ACCA as being in compliance with Manual J 8th Edition may be used.

3.1.3 Conduct third-party plan review to verify design and compliance with Section 3. When multiple homes of the same model are to be built by the same builder, a representative sample of homes (15%) may be reviewed subject to a sampling protocol.

Intent:
To establish a minimum energy threshold for all NAHB-certified green homes

Information / How to Implement:
If you are building under the jurisdiction of the 2003 International Energy Conservation Code (IECC), your home will meet this requirement. If you do not follow the IECC 2003, you can determine if your project meets this energy code by using REScheck, a free, easy-to-use software package.

Resources:
- ***REScheck*** is a free software tool that can be downloaded at www.energycodes.gov/rescheck/.
- ***Manual J 8th Edition*** is available through the Air Conditioning Contractors of America and can be purchased online at www.accaconference.com/Merchant2/merchant.mv?Screen=SFNT&Store_Code=ACCOA. Also, see www.acca.org for additional approved third-party software providers.
- *Heat Loss Calculation Guide H-22*, Hydronics Institute Division of GAMA, 2001
- *International Energy Conservation Code* (IECC) 2003. Available from the International Code Council, www.iccsafe.org
- Third-party plan review: A Certified Home Energy Rating System (HERS) rater. A directory of Home Energy Raters can be found on the ENERGY STAR® website at www.energystar.gov.

3.2 PERFORMANCE MEASURES

Optional guidelines—At least 37 points must be obtained from the line items under the Energy Efficiency section to qualify your project as a green home at the Bronze level. The Silver level requires 62 points and the Gold level 100 points.

3.2.1 Home is X % above IECC 2003:

A. 15%

B. 30%

C. 40%

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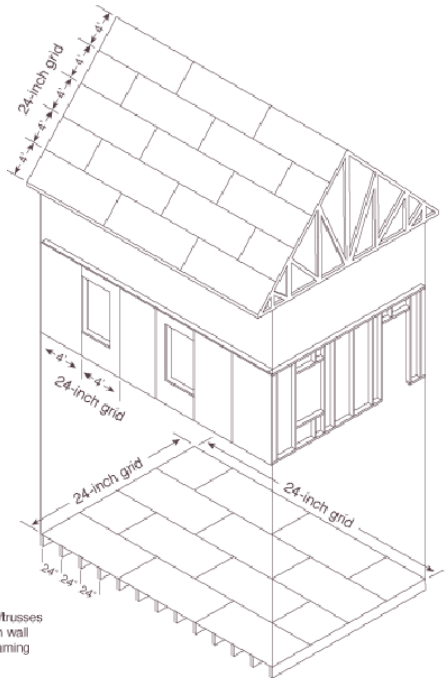
Intent:
To offer builders a flexible, performance-based means of achieving higher levels of energy performance than the IECC 2003. An ENERGY STAR home is approximately 15% more energy efficient than a home that meets the IECC 2003. Some builders are now achieving a 40% or 50% improvement.

Information / How to Implement:
Use REScheck to examine the effect of different levels of insulation, window U-values and SHGC factors, and space conditioning equipment efficiencies to identify a cost-effective system for your project. The appropriate level of energy performance above IECC 2003 will vary depending upon the severity of the climate, but building to the equivalent of ENERGY STAR is usually cost-effective for consumers in most regions of the country.

Resources:
- REScheck—REScheck, available for free download at: www.energycodes.gov/rescheck/
- International Energy Conservation Code (IECC) 2003. Available from the International Code Council, www.iccsafe.org

3.3 PRESCRIPTIVE PATH

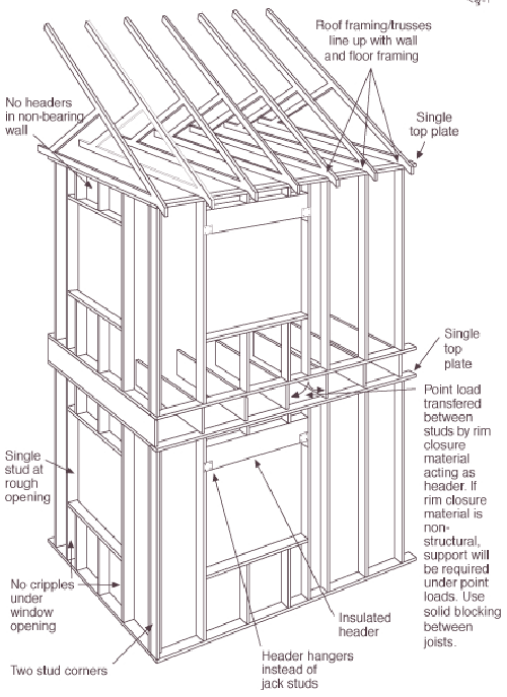
Alternate method for gaining points for energy efficiency



3.3.1 BUILDING ENVELOPE

A. Increased effective R-value of building envelope using advanced framing techniques, continuous insulation, and/or integrated structural insulating system. Measures may include but are not limited to:
   - SIPS*
   - ICFs*
   - Advanced framing
   - Insulated corners and interior/exterior wall intersections*
   - Insulated headers on exterior walls
   - Raised heel trusses
   - Continuous insulation on exterior walls, cathedral ceiling, attics

   * This line item also has a resource-efficiency benefit

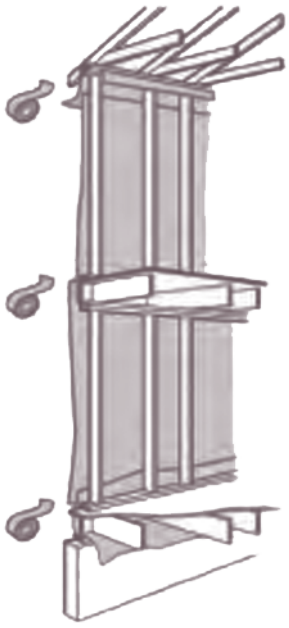


Intent:
To enhance the insulating value of the building envelope by selecting an efficient and cost-effective framing package or alternative structural wall system. Framing details such as two-stud corner framing, ladder blocking at wall intersections, and raised heel roof trusses can eliminate thermal bridges, i.e., areas where there is no room for insulation.

Information / How to Implement:
The Resources listed below will help identify methods for insulating walls to the fullest extent and avoiding thermal bridging.

Resources:
- *Reduce Framing Costs with Advanced Framing Techniques*, U.S. EPA: www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide3D.pdf
- *Advanced Framing Fact Sheet*, U.S. DOE: www.toolbase.org/docs/MainNav/WoodFrameConstruction/3949_advancedwallframing1.pdf
- Advanced framing: www.buildingscience.com/housesthatwork/advancedframing/default.htm
- *Cost Effective Homebuilding: A Design and Construction Handbook*, 1994, NAHB Research Center, available for purchase at www.nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=2584&CategoryID=917

B. Incorporate air sealing package to reduce infiltration. (All measures that apply to project must be performed.)
- Use sill sealer between foundation and sill plate.
- Caulk bottom plate of exterior walls.
- Air seal band joist cavities between floors.
- Ensure air barrier continuity at all framed cavities such as air chases, soffits, coffered or dropped ceilings, and behind tub/shower units on exterior walls.
- Caulk/foam all electrical, plumbing, heating penetrations between floors (including attic, basement, crawl space, and garage) and to exterior.
- Block and seal cantilevered floors and kneewalls.
- Weatherstrip attic hatches, kneewall doors.
- Insulate, caulk, or foam between window/door jambs and framing.
- If installing recessed lights in ceilings adjacent to unconditioned space, use rated, air-tight Type IC housings.
- Caulk/foam HVAC register boots to subfloor or drywall that penetrate the building envelope.
- If a fireplace is installed, install a sealed-combustion gas fireplace that is sealed combustion or a wood-burning fireplace with gasketed doors.



Housewrap Installation

Intent:
When building an energy-efficient home, it is equally or more important to prevent air infiltration as it is to provide a high R-value wall system. Air can pass through very small cracks, resulting in energy loss and condensation, so it is necessary to be very detail-oriented when it comes to air sealing.

Information / How to Implement:
See also Section 5.2.2, Indoor Environmental Quality section for more information about mechanical ventilation options.

Air leakage can account for as much as 20%-30% of energy loss through the building envelope. Although insulation reduces energy loss, air infiltration can compromise the efficiency of a building because it brings conditioned air directly outdoors (or outdoor air inside), bypassing the insulation. In addition, it not only carries heated (or cooled) air to the outdoors, but may also create moisture problems as water vapor in the air moves from a warmer to colder location and condenses. Use the list above to make sure that you seal the nooks and crannies where air may escape.

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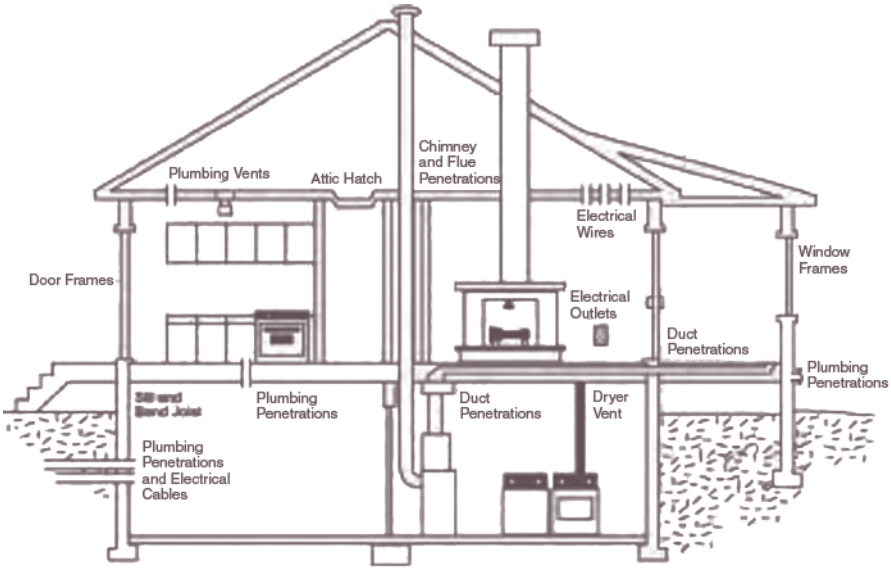
To perform air sealing, use a variety of materials such as caulk, foam, and gasket materials. It has been proven that "chinking" with fiberglass insulation does not prevent airflow. Low-expanding foams should be used around windows and doors so that the frame doesn't bind—a common complaint with first-generation, high-expanding foam products.



Typical Locations of Air Leakage

In conjunction with implementing an air sealing package, consider a means of providing fresh air to the home. This may be operable windows if the homeowner will use them, but often an automatic mechanical means of introducing fresh air may be the most reliable way to ensure adequate ventilation. Controlled ventilation that is carefully designed and installed provides a more consistent rate of air exchange compared with simply building a leaky structure. A tight building envelope with an intentional means of introducing outdoor air enhances energy efficiency, comfort, and indoor air quality. See the Indoor Environmental Quality section for additional information about mechanical ventilation.

Resources:

- *Advanced Air Sealing* (book available for viewing online): http://oikos.com/library/airsealing/index.html
- U.S. DOE's fact sheet, *Airtight Drywall Approach* (no diagrams), www.eere.energy.gov/consumerinfo/fact sheets/bd8.html
- Southface Energy Institute's fact sheet, *Airtight Drywall Approach* (contains diagrams), www.southface.org/web/resources&services/publications/fact sheets/24ada_drywal.pdf

C. Use ENERGY STAR-rated windows appropriate for local climate.

Intent:

To assure optimum building envelope performance. Window area often comprises a substantial portion of the wall area in new homes. Compared with an opaque insulated wall, windows offer only about 15% to 25% of the R-value. In addition, they are a source of direct solar gains in the summer, which can add to the cooling load.

Information / How to Implement:

Select windows featuring the ENERGY STAR label. Alternately, visit the Efficient Windows Collaborative Web site to see which type of glazing is recommended for your climate. Low-E coatings for windows are recommended for almost all regions of the United States. Generally, look for windows with as low a U-value as is affordable—they offer the best insulating value (U-value is the inverse of R-value). In cooling-dominated climates, use a window that has a low SHGC. Always choose a frame that provides a thermal break, e.g., wood, composite, vinyl, or aluminum with a thermal break. Using high-efficiency windows can not only enhance thermal performance but also reduce the risk of condensation on windows. For passive solar designs and homes that are constructed with large amounts of glazing in a specific orientation, use windows selected for each orientation (e.g., high SHGC on south face for direct solar gain). Refer to the Resources for a more detailed understanding of how window technologies perform in various climates.

Resources:

- www.efficientwindows.org
- *Improve Energy Efficiency with High Performance Windows*, ENERGY STAR fact sheet, www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide3E.pdf

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- Efficient Windows Collaborative, www.efficientwindows.org. Recommends U-value and solar heat gain coefficient (SHGC) by climate region.
- ENERGY STAR website www.energystar.gov for list of stores that sell ENERGY STAR-labeled windows
- The National Fenestration Rating Council (NFRC) labels windows for U-value and solar heat gain coefficient and has searchable directory of windows meeting specific criteria on its web site at www.nfrc.org.

3.3.2 HVAC DESIGN, EQUIPMENT, AND INSTALLATION

A. Size, design, and install duct system using ANSI/ACCA Manual D® or equivalent.

Intent:
Getting the proper amount of airflow to and from each room is as important to comfort and efficiency as the equipment itself. Careful sizing and layout according to recognized industry standards is essential.

Information / How to Implement:
Ask your HVAC contractor to use ACCA Manual D to size and lay out supply and return ductwork to each area of the home. Manual D recommends duct diameter to fit the load in each room, taking into account the length of the duct run and the type of duct being used. Request a copy of the Manual D printout. After the system has been installed, examine it to verify that it is in accord with the design and that there are no sharp bends or poor connections.

Resources:
- *ACCA Manual D®*, Residential Duct Systems (available for purchase at www.acca.org)
- *Air Distribution System Design* (U.S. DOE fact sheet) www.toolbase.org/docs/MainNav/Energy/4074_doe_airdistributionsystemdesign.pdf
- *A Builder's Guide to Placement of Ducts and HVAC Equipment in Conditioned Spaces*, 2000, NAHB Research Center. Available for $5 from NAHB Research Center bookstore at http://nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=2570&CategoryID=110
- *Design and Construction of Interior Duct System*, Florida Solar Energy Center, (2002) www.fsec.ucf.edu/bldg/baihp/pubs/Papers/interior_ducts.pdf

B. Design radiant or hydronic space heating systems using industry-approved guidelines, e.g., *Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melting Systems by the Radiant Panel Association*, *Heat Loss Guide (H-22)*, by the Hydronics Institute Division of GAMA or accredited design professionals and manufacturer's recommendations.

Intent:
To ensure proper design of hydronic and radiant space heating systems by using industry expertise. Hydronic and radiant systems require the same attention to detail as forced air systems. Components such as piping and pumps must be properly sized and matched according to the equipment being used.

Information / How to Implement:
Ask your HVAC contractor to use the Radiant Panel Association design guidelines when designing a hydronic system. There are training and certification programs through the Radiant Panel Association for HVAC contractors

Resources:
- *Quick Reference to RPA Guidelines for Hydronic Radiant Floor Heating*, *Radiant Panel Association (RPA)*, www.radiantpanelassociation.org/files/public/GdlnQuick.htm. (Entire guidelines available to download for $15 at www.radiantpanelassociation.org/i4a/store/category.cfm?category_id=8)

- List of RPA certified contractors, available at www.radiantpanelassociation.org

C. Use ANSI/ACCA Manual S® or equivalent to select heating and/or cooling equipment.

Intent:
Manual S is the second step in assuring proper design of a space heating and/or cooling system. After using Manual J to calculate the building's heating and cooling load, use Manual S to help select and size equipment that will satisfy the latent and sensible heating and cooling loads.

Information / How to Implement:
Ask your HVAC contractor to use ACCA Manual S in selecting the heating or cooling equipment for the home. By reviewing this process, you can better understand some of the issues involved and help guide customers' decisions about their heating and cooling system. Very efficient homes that require less energy for heating and cooling are much more sensitive to proper HVAC equipment sizing.

Resources:
- ACCA Manual S®, *Equipment Selection*, available for purchase at www.acca.org
- U.S. DOE fact sheet, Right Size Heating and Cooling Equipment, www.toolbase.org/docs/MainNav/Energy/4073_doe_hvacsizing.pdf

D. Verify performance of the heating/cooling system. The HVAC contractor should perform the following:
- Start-up procedure according to manufacturer's instructions
- Refrigerant charge verified by super-heat and/or sub-cooling method
- Burner set to fire at nameplate input
- Air handler setting/fan speed
- Total airflow within 10% of design flow
- Total external system static should not exceed equipment capability at rated airflow.

Intent:
Verification of performance provides a final assurance that the system has been designed, installed, and commissioned as intended. Items can easily be overlooked during a busy construction schedule, even given the most conscientious approach.

Information / How to Implement:
Ask your HVAC contractor to carefully follow the start-up procedure outlined in the equipment literature. Ask for a checklist of the recommended start-up procedure.

Resources:
- North American Technician Excellence. Operates a certification program for HVAC technicians. Maintains a database of certified technicians at www.natex.org/ or by calling 877-420-NATE.
- Manufacturer's Web site or printed installation instructions

E. Use HVAC installer and/or service technician who are certified under a nationally or regionally recognized program such as NATE, BPI, RPA, or manufacturers' training.

Intent:
The programs citied above are the equivalent of a "technical degree" for an HVAC contractor. With an HVAC trade contractor who has completed a certification, you and your customer can have added assurance that the HVAC system in the home is designed and installed in accordance with the industry's best recommended practices.

Information / How to Implement:
Encourage your contractor to investigate the local availability of HVAC training and certification programs. Ask for certifications when seeking proposals. Some agencies maintain a database of certified contractors; consider using HVAC contractors in your area that have been certified.

At the time of the printing of this document, the Air Conditioning Contractors of America (ACCA) is in the process of establishing a contractor accreditation program that will ensure contractors perform quality installations.

Resources:
- NATEX Business Locator, available at www.natex.org or by calling 877-420-NATE. A searchable database of contractors certified by the National Association for Technician Excellence (NATE).
- The Building Performance Institute. Certifies whole-house performance contractors and provides a searchable database of certified contractors at www.bpi.org.
- List of Radiant Panel Association members that are certified by RPA (for hydronic heating) www.radiantpanelassociation.org
- Manufacturers' website for directory of contractors trained for proprietary equipment
- The Air Conditioning Contractors of America Web site at www.acca.org

F. Fuel-fired space heating equipment efficiency (AFUE):

		% Improvement above Federal minimum
Gas Furnace	≥81%	3%
	≥88% (ENERGY STAR	10%
	≥94%	6%
Oil Furnace	≥83%	5%
Gas or Oil Boiler	≥85%	5%
	> 90%	10%

Note: Add three points associated with increasing AFUE if Manuals S and D and start-up procedure are followed when one of the space heating units noted above is installed.

Intent:
As with cooling equipment, higher-efficiency equipment will satisfy space heating requirements using less fuel.

Information / How to Implement:
Select equipment bearing the ENERGY STAR label, or check manufacturer's literature for efficiency information. The American Council for an Energy-Efficient Economy (ACEEE) lists the highest-efficiency equipment available (see Resources). The measure of furnace efficiency, annual fuel utilization efficiency (AFUE), is the ratio of heat produced per unit of fuel consumed over the course of a heating season. Depending upon the fuel used, ask your HVAC contractor about pricing higher-efficiency furnaces or boilers. Typically, 81%-83% of AFUE furnaces carry little cost increase over those meeting federal minimum efficiency standards (currently 78%). Higher-efficiency gas furnaces or boilers (greater than 90% AFUE) are usually direct vent, sealed combustion units and, because the flue gases are cooler, PVC pipe can often be used for venting, eliminating the need for a chimney. Through-the-wall venting may offset the higher cost of the equipment.

Keep in mind that sealed combustion equipment not only offers an energy-efficiency benefit but may also be advantageous with respect to indoor environmental quality as well. The sealed combustion chamber eliminates any possibility of backdrafting or spillage of combustion gases into the home.

It is usually a good idea to invest in high-AFUE heating equipment in climates that have a significant heating load or high fuel costs. Energy-efficiency investment dollars may be better spent elsewhere in cooling-dominated climates.

Resources:

- American Council for an Energy-Efficient Economy's list of most energy efficient appliances www.aceee.org/consumerguide/mostenef.htm
- www.energystar.gov for a list of equipment meeting ENERGY STAR standards
- *Gas Appliance Manufacturer's Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment.* www.gamanet.org
- Manufacturers' Web sites.

G. Heat pump efficiency (cooling mode)

1. SEER 11-12*—(9%-17% improvement above SEER 10 air conditioner)
2. SEER 13-14—(23%-29% improvement above SEER 10 air conditioner)
3. SEER 15-18—(33% -44% improvement above SEER 10 air conditioner)
4. SEER 19+—(47%+ improvement above SEER 10 air conditioner)
5. Staged air conditioning equipment

Split systems must be ARI-tested as a matched set.

*SEER 13 is the federal minimum as of January 2006.

NOTE: Additional three points given if Manuals S and D have been used and start-up procedures are followed when one of the A/C units noted above is installed.

Intent:

High-efficiency equipment uses less energy to accomplish the same task. The intent of this guideline is to reduce the electrical energy necessary to cool the home.

Information / How to Implement:

Select equipment that carries the ENERGY STAR label, or check manufacturer's literature for information on SEER. The ACEEE lists the highest-efficiency equipment available (see Resources). Several issues to consider:

As of January 2006, the federal minimum efficiency for air conditioning units is SEER 13.

It is often more beneficial to concentrate on improving design, installation, and commissioning procedures before simply installing equipment with a higher SEER rating. For instance, proper sizing, insulating, and sealing of ductwork can reduce the amount of energy loss and increase occupant comfort as well. Even the most efficient equipment cannot make up for deficiencies in a distribution system or inadequate sizing and commissioning. Before investing in more efficient cooling equipment, invest in proper sizing, design, installation, and commissioning of the entire system.

To encourage such practices, the guidelines award double points for increasing SEER if Manuals S and D and start-up procedures are followed.

For cooling-dominated climates, it often makes sense to invest energy-efficiency dollars in high-SEER equipment. For climates with little cooling load, investments in efficiency may be better spent elsewhere.

Resources:

- List of most energy efficient appliances
- www.aceee.org/consumerguide/mostenef.htm
- www.energystar.gov for a list of equipment meeting ENERGY STAR standards

H. Heat pump efficiency (heating mode)

1. 7.2-7.9 HSPF (6%-16% increase in efficiency)
2. 8.0-8.9 HSPF (18%-31% increase in efficiency)
3. 9.0-10.5 HSPF (32%-54%% increase in efficiency)
4. >10.5 HSPF (>54% increase in efficiency)

Intent:
To reduce the amount of nonrenewable energy used to meet the space heating requirements of a home.

Information / How to Implement:
Select equipment that carries the ENERGY STAR label, or check manufacturer's literature for HSPF data. The ACEEE lists the highest-efficiency equipment available (see Resources). The current federal minimum heating season performance factor (HSPF), the standard measure of heat pump efficiency in the heating mode, is 6.8. Heat pumps are often the cost-effective solution for space conditioning equipment in climates where outdoor temperatures are moderate and there is a need for both heating and cooling. Air-to-air heat pumps are not recommended if winter temperatures often drop below 35° F. If heating is the predominant load, consider a heat pump with an HSPF of 8.0 or higher.

Resources:

- American Council for an Energy-Efficient Economy's list of most energy efficient appliances www.aceee.org/consumerguide/mostenef.htm
- www.energystar.gov for a list of equipment meeting ENERGY STAR standards

I. Ground source heat pump installed by a Certified Geothermal Service Contractor. (cooling mode)

1. EER = 13-14
2. EER = 15-18
3. EER = 19-24
4. EER = > 25

Note: An additional three points are given if Manuals S and D and start-up procedures are followed when one of the ground source heat pumps noted above has been installed. Do not duplicate points if these additional points have been taken in Guidelines 3.3.2.f and 3.3.2.h above.

Intent:
To reduce consumption of non-renewable energy for space heating and cooling requirements and ensure that design and installation are conducted according to industry standards.

Information / How to Implement:
Select ENERGY STAR-labeled equipment, or check manufacturer's literature for EER information. Use a contractor that has been certified in design and installation of geothermal systems by the International Ground Source Heat Pump Association (see Resources)—proper sizing of geothermal systems is crucial for efficiency and to reduce first cost. Ground source heat pumps are often more efficient than air-to-air heat pumps because they take advantage of the constant and more moderate temperature of the ground which is an advantage for space heating in the winter and cooling in the summer. Ground source heat pumps are more expensive to install than air-to-air heat pumps due to the added

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cost of drilling wells or trenching for the ground loop. However, they may be cost competitive when compared with very high efficiency furnaces and central air conditioning systems. Geothermal systems may also include a desuperheater, a device that uses some of the waste energy from the heat pump to pre-heat water for domestic use.

Because the selection of equipment, design of ductwork, and commissioning are integral to efficient performance of the system, additional points will be given if these measures have also been completed.

Resources:

- American Council for an Energy-Efficient Economy's list of most energy efficient appliances www.aceee.org/consumerguide/mostenef.htm
- www.energystar.gov for a list of equipment meeting ENERGY STAR standards
- International Ground Source Heat Pump Association (IGSHPA), database of accredited installers and designers of geothermal heat pump systems: www.igshpa.okstate.edu/business_directory/home.html
- J. Ground Source Heat Pump installed by a Certified Geothermal Service Contractor (heating mode)
  1. COP = 2.4-2.6
  2. COP = 2.7-2.9
  3. COP > 3.0

  (See Section 3.3.2.I above for more information.)

K. Seal ducts, plenums, and equipment to reduce leakage. Use UL 181 foil tapes and/or mastic.

Intent:
To assure optimum performance of the forced-air space conditioning system by reducing duct leakage.

Information / How to Implement:
Leaking Ducts can reduce the heating and cooling efficiency of a forced-air system by as much as 30%. While duct leakage to the conditioned space does not compromise energy performance as does leakage into unconditioned spaces, it may result in a less comfortable space due to insufficient air delivery. Best industry practice is to seal all ductwork with a foil tape meeting UL 181 requirements or with mastic. It is also important to seal plenum connections at the equipment as well as holes in the fan cabinet. Gasketed cabinet doors allow for a tight seal without compromising ease of maintenance. An achievable goal is to strive for less than 5% leakage (as a share of the air handler capacity) to unconditioned space.

Resources:

- Air Distribution System Installation and Sealing, (U.S. DOE fact sheet), www.toolbase.org/docs/MainNav/Energy/4071_doe_airdistributionsysteminstallation.pdf
- Source of supply for duct mastic: Oikos.com has a list of manufacturers of Duct Mastic (category 15816)
- Advanced Air Sealing (book available for viewing online): http://oikos.com/library/airsealing/index.html
- Overview of sealing ductwork: http://energyoutlet.com/res/ducts/index.html

L. When installing ductwork:

1. No building cavities used as ductwork, e.g., panning joist or stud cavities.
2. Installation of all heating and cooling ducts and mechanical equipment within the conditioned building envelope.
3. No ductwork installed in exterior walls.

Intent:
The possibility of duct leakage to unconditioned space is significantly reduced by avoiding placement of ducts in areas listed.

Information / How to Implement:
Panned joists or stud cavities should be avoided because they can rarely be effectively sealed. When cavities are used as returns, air may be pulled from unintended locations in the home and create unwanted pressure imbalances that may compound energy loss. When cavities are used as supplies, the volume of delivered air may be inadequate, and, because these areas may be dusty and dirty, indoor environmental quality issues may result.

Methods for keeping ductwork in the conditioned envelope include extending the thermal boundary by insulating the foundation walls, insulating the attic at the roof, or installing ductwork beneath an insulated ceiling and enclosing it with bulkheads.

With improved window technology and air sealing practices, there is less need to supply warm air along exterior walls—a common practice in older homes that needed airflow near windows to prevent condensation on poorly insulating windows and to keep occupants warm near drafty windows. In tightly sealed and well-insulated homes, heating or cooling registers can be located near the interior, thereby minimizing duct length and eliminating any need to run ductwork in outside walls. This not only reduces leaking to the exterior but also eliminates the need to reduce insulation in those wall cavities.

Resources:
- *A Builder's Guide to Placement of Ducts and HVAC Equipment in Conditioned Space*, 2000, NAHB Research Center. Available for purchase at www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2570&CategoryID=110

M. Install return ducts or transfer grilles in every room having a door except baths, kitchens, closets, pantries, and laundry rooms.

Intent:
To prevent pressure imbalances that may occur when there are central return(s) and interior doors are closed. Pressure imbalances can lead to inadequate airflow to a room, which can create uncomfortable conditions.

Information / How to Implement:
Supply and return registers located in every room and sized according to industry standards provide the best assurance that airflow to each room is balanced. However, having supply and return vents in each room increases the installation cost of a forced-air heating or cooling system. Common practice is to locate a single central return on each floor of the home. This method pulls return air from all areas of the home in most cases, but return airflow is restricted when doors are closed. Doors cannot be undercut sufficiently to provide an adequate path for airflow. When return air flow is restricted from a particular room, that area becomes pressurized and air leakage to the outdoors increases. Other areas of the home may become depressurized causing the opposite effect, i.e., outdoor air is drawn through cracks and crevices. Transfer grilles in interior walls are a cost-effective compromise to ensuring that all rooms have adequate supply and return airflow.

Resources:
- ACCA Manual D® Residential Duct Systems

N. Install ENERGY STAR ceiling fans. (Points per fan)

Intent:
To reduce energy use for space cooling while maintaining comfort.

Information / How to Implement:
A ceiling fan helps occupants feel cooler without lowering a thermostat because it provides convective cooling from the breeze created. Under many conditions, ceiling fans, which use less energy than most light bulbs, will be all that is

required to keep occupants cool, thereby reducing the need for compressor cooling. ENERGY STAR fans produce more airflow per watt than standard ceiling fans due to improved blade design and more efficient motors.

Resources:

- List of ENERGY STAR-labeled ceiling fans (fan only)
  www.energystar.gov/ia/products/prod_lists/ceiling_fans_only_prod_list.pdf
- List of ENERGY STAR-labeled ceiling fans (fan and light)
  www.energystar.gov/ia/products/prod_lists/ceiling_fans_with_lighting_prod_list.pdf
- List of ENERGY STAR-labeled ceiling fan (light kits only)
  www.energystar.gov/ia/products/prod_lists/ceiling_fans_lightkit_prod_list.pdf



O. Install whole-house fan with insulated louvers.

Intent:
To reduce energy use for space cooling while maintaining comfort.

Information / How to Implement:
A whole-house fan can draw outdoor air inside quickly, providing cooling at night and at other times when the outdoor air is cooler than indoors. A whole-house fan can reduce the energy needed for cooling by taking advantage of the "free" cooling from outside air. Usually placed in the ceiling of the top floor of a home, whole-house fans use less energy than a compressor and air handler. One disadvantage of whole-house fans is that they can be difficult to seal off when not in use. Care must be taken in selecting equipment that has an effective insulating enclosure and in designing and installing a custom insulating and weather stripping system for the enclosure.

Resources:

- Home Energy Magazine article http://hem.dis.anl.gov/eehem/99/990511.html
- Whole-House Fan: How to install and use a whole-house fan,
  www.southface.org/web/resources&services/publications/technical_bulletins/WHF-Wholehousefan%2099-745.pdf

P. Install ENERGY STAR-labeled mechanical exhaust from every bathroom ducted to the outside.

Intent:
To achieve spot exhaust ventilation using highly efficient ventilation equipment.

Information / How to Implement:
ENERGY STAR-labeled fans provide more ventilation capacity at a lower wattage than a standard bath fan. They are also quieter than most standard fans and therefore are more likely to be used. Because of their more efficient blade design and motors, they are more durable and carry longer warranties than standard fans. Most major manufacturers offer an ENERGY STAR model, but in some areas, it may be a special order item.

This guideline also has an indoor environmental quality benefit in that local removal of moisture and humidity is achieved in a more effective and efficient manner.

Resources:

- List of products meeting ENERGY STAR criteria: www.energystar.gov/ia/products/prod_lists/vent_fans_prod_list.pdf
- Spot Ventilation: Source control to improve indoor air quality (U.S. DOE fact sheet),
  www.toolbase.org/docs/MainNav/Energy/3947_spotventilation1.pdf

3.3.3 WATER HEATING DESIGN, EQUIPMENT, AND INSTALLATION

A. Water heater energy factor equal to or greater than those listed in the following table.

Size (gallons)	Energy Factor
30	0.64
40	0.62
50	0.60
65	0.58
75	0.56

Size (gallons)	Energy Factor
30	0.95
40	0.94
50	0.92
65	0.90
80	0.88
100	0.86

Size (gallons)	Energy Factor
30	0.59
50	0.55

Intent:
To increase the efficiency of water heating by installing equipment that provides the same amount of hot water for less energy than standard water heating equipment.

Information / How to Implement:
The hot water heater energy rating that is used to compare different water heaters is the energy factor (EF). EF represents the percentage of purchased fuel (electricity, gas, propane or oil) that is used for heating water; it includes losses through the tank as well as flue losses. Electric tanks have a higher EF than fuel-fired heaters since they do not have flue losses. However, electric tanks can be more expensive to operate than fuel-fired tanks.

To select high-efficiency water heating equipment, compare the yellow Energy Guide labels of similar equipment. Review manufacturer's literature for energy factor information—the EF is not usually prominently displayed on the unit. Alternately, the ACEEE maintains a list of the highest-efficiency water heating equipment (see Resources).

Resources:
- *The Most Energy Efficient Appliances*, (list from Consumer's Guide to Home Energy Savings), American Council for an Energy Efficient Economy, www.aceee.org/consumerguide/mostenef.htm
- *Gas Appliance Manufacturer's Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment.* www.gamanet.org
- *Water Heating: Energy-Efficient Strategies for Supplying Hot Water in the Home* (U.S. DOE fact sheet), www.toolbase.org/docs/SubsystemNav/Plumbing/3946_waterheating.pdf

B. Install whole-house instantaneous (tankless) water heater. (Water heater complies with DOE Standard 10CFR430)

Intent:
To reduce energy use associated with water heating by eliminating standby losses that occur with tank heaters.

Information / How to Implement:
Even though newer tank water heaters are better insulated than their predecessors, heat lost from the tank can account for a large portion of hot water energy consumption, especially in homes that use relatively little hot water. By having no reservoir of hot water, tankless water heaters eliminate these standby losses. For gas tankless water heaters, there are similar flue losses to gas tanks. Both electric and gas tankless water heaters have higher energy factors (EF = 0.62 minimum) than most tank water heaters.

Gas, propane, and electric instantaneous water heaters are available. Typically, gas water heaters can heat a larger volume of water each minute than electric heaters and can provide a greater temperature rise for a given flow rate. This can be an important consideration when coincident hot water uses are expected or when high flow rates at hot temperatures are desired. Electric tankless units can achieve about a 77°F temperature rise at 2.5 gallons per minute–which is plenty for a hot shower but it does not leave a lot of extra capacity for simultaneous hot water usage. Gas units will provide greater capacity to allow for simultaneous multiple uses.

All tankless water heaters use large amounts of energy at higher flow rates. These large draws often require a larger-than-normal service entrance for electric units or larger pipe diameter for gas units. Evaluate these differences when comparing installed costs. Although peak demand for space heating and water heating usually do not occur at similar times, your local utility may offer helpful advice regarding peak demand and selection of whole-house water heating appliances.

Resources:
- *The Most Energy Efficient Appliances*, (list from Consumer's Guide to Home Energy Savings), American Council for an Energy Efficient Economy, www.aceee.org/consumerguide/mostenef.htm

C. Insulate all hot water lines with a minimum of one-inch insulation.

Intent:
To reduce energy losses from hot water piping.

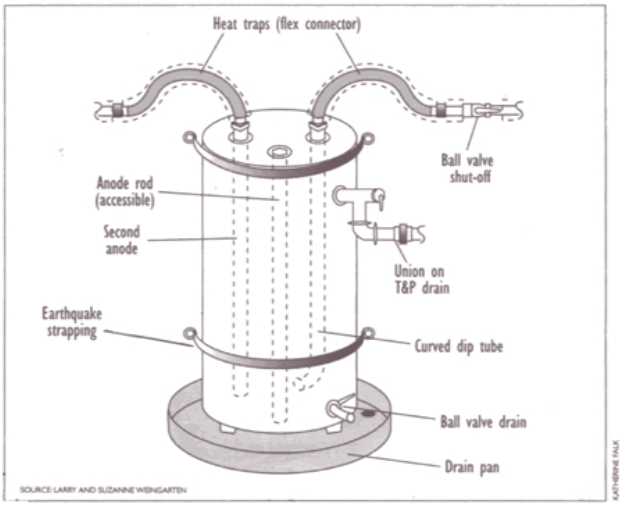
Information / How to Implement:
Insulating hot water piping can be beneficial in two ways: 1) losses are reduced as hot water moves through the lines to the point of use, and 2) losses are slowed and may be reduced when hot water sits in the lines between draws. Foam pipe insulation is relatively inexpensive and easy to install. In addition to offering some energy savings, insulating the hot water lines is also likely to add convenience, comfort, and water savings. Hot water will get to the tap more quickly—meaning there is less potential for water to run down the drain while the user waits for it to get hot.

Resources:
- *Water Heating: Energy-Efficient Strategies for Supplying Hot Water in the Home* (U.S. DOE fact sheet), www.toolbase.org/docs/SubsystemNav/Plumbing/3946_waterheating.pdf

D. Install heat trap on cold and hot water lines to and from the water heater (if not integral to the water heater).

Intent:
To minimize energy loss associated with thermo siphoning action from a water heater.

Information / How to Implement:
In the same way that warm air moves toward cooler air and warm air rises, hot water will rise and displace cooler water in the lines leading to and from the heater tank. This thermo siphoning action contributes to heat loss from the tank, and, once the water temperature in the tank has cooled below the thermostat set point, the elements or burner will need to activate to bring the water back up to temperature, even when there is no demand for hot water. Heat traps prevent thermo siphoning. Many new water heaters have integral heat traps; ask your plumber or plumbing materials supplier or check manufacturers' literature. If heat traps are not integral to the water heater, install them on the inlet and outlet to the water heater.



Resources:
- *Water Heating: Energy-Efficient Strategies for Supplying Hot Water in the Home* (U.S. DOE fact sheet)

E. Install manifold plumbing system with parallel piping configuration (aka "home run") using smallest diameter piping allowed by code.

Intent:
Reduce energy use associated with waiting for hot water at taps and with hot water left standing in pipes after a hot water draw.

Information / How to Implement:
A manifold plumbing system in which dedicated "home run" hot and cold water piping services each fixture allows the most direct (and therefore shortest) pipe run and smaller diameter piping than a "tree" type piping configuration. Reduced pipe diameter means hot water is delivered faster to a faucet and there is less water left in a pipe after a hot water draw—and therefore less energy waste from hot water left to cool in pipes. Most manifold piping is cross-linked polyethylene (PEX) pipe rather than copper or CPVC. Because PEX allows for gentle bends, fittings are reduced, which saves installation time and minimizes the possibility of leaks. Often, three-eighths-inch diameter pipe can be used. PEX also has better insulating value than copper piping. In order to maximize the benefits of a manifold system, baths and kitchens should be located in close proximity to one another and to the water heater.

Resources:
Information will be added in Version 2.

3.3.4 LIGHTING AND APPLIANCES

A. Use an ENERGY STAR Advanced Lighting Package (ALP).

Intent:
To use high-quality, aesthetically pleasing electric light using less energy than conventional incandescent lighting.

Information / How to Implement:
ENERGY STAR fixtures use about two-thirds less electricity than standard fixtures to provide equal light. Although on average, an ENERGY STAR fixture may cost about $30 more than a comparable standard fixture, the fluorescent bulbs will last longer (about seven years) and cost less to operate over their lifetime than incandescent bulbs. Placing 20

ENERGY STAR fixtures in a home in which electricity costs are 10.5 cents per kWh will reap almost $100 in annual savings to the homeowner in energy and bulb replacement costs, after accounting for the increase in the mortgage due to higher initial cost. Today's fluorescent bulbs are dramatically improved over the old technology: Not only are a wide variety of styles available, but the light quality is high and there is no flicker, hum, or delayed start. ENERGY STAR fixtures also carry a two-year warranty.

High-Use Rooms	Kitchen, Dining Room, Living Room, Family Room, Bathroom(s), Halls/Stairway(s)	50% of Total Number of Fixtures
Med/Low-Use Rooms	Bedroom, Den, Office, Basement, Laundry Room, Garage, Closet(s), and All Other Rooms	25% of Total Number of Fixtures
Outdoors	Outdoor Lighting Affixed to Home or Free-Standing Pole(s) Except for Landscape and Solar Lighting	50% of Total Number of Fixtures Including All Flood Lighting

Resources:

- Tool to estimate lighting energy savings of advanced lighting package: www.energystar.gov/ia/partners/manuf_res/Savings_Look-up_ChartsLR.pdf
- ENERGY STAR program information for builders: www.energystar.gov/index.cfm?c=bldrs_lenders_raters.ALP_Builder

B. Install all recessed lighting fixtures within the conditioned envelope of the building, e.g., fixture housing does not penetrate insulated ceiling.

Intent:
To eliminate energy losses associated with inadequate insulation above, and air infiltration through, light fixtures in insulated ceilings.

Information / How to Implement:
Although there are recessed light fixtures rated for insulation contact, they still carry an energy penalty because of reduced insulation thickness in the ceiling above the fixture and/or air leakage around the housing. To completely avoid this energy penalty, do not install recessed lights in an insulated ceiling. Bulkheads or dropped soffits can permit the installation of recessed lights in insulated ceilings. Be sure that there is a continuous air barrier at the top of the bulkhead or the original ceiling. The preferred method is to install drywall (or other finish material) on the ceiling prior to constructing the bulkhead.

Resources:
Information will be added in Version 2.

C. Install motion sensors on outdoor lighting (if not credited under 3.3.4.a).

Intent:
To minimize outdoor lighting energy use by activating outdoor lighting when needed, rather than operating it continuously.

Information / How to Implement:
Motion sensors activate outdoor lighting only when it is needed: to light an entry as one returns home after dark or to maintain security by illuminating outdoor areas when motion is detected. Many fixtures come with motion sensors, but they can also be installed separately. Not all outdoor ENERGY STAR fixtures have built-in motion sensors.

Resources:
Information will be added in Version 2.

D. Install tubular skylights in rooms without windows.

Intent:
To reduce the need for artificial lighting by providing natural light when available.

Information / How to Implement:
Tubular skylights provide natural lighting to interior spaces while minimizing the inherent energy losses of standard skylights. Tubular skylights have a smaller diameter roof penetration than most skylights and have an additional layer of insulating glazing at the ceiling level.

Resources:
- Tubular Skylights (NAHB Research Center technology fact sheet)
  www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1282&DocumentID=2024

E. Install ENERGY STAR labeled appliance: Refrigerator, dishwasher, washing machine. (Points per appliance)

Intent:
To reduce energy use in the home for appliances.

Information / How to Implement:
On average, ENERGY STAR-labeled appliances use at least 20% less energy than standard appliances to perform the same duties. ENERGY STAR-labeled dishwashers and washing machines also use less water, which contributes to added resource efficiency. Look for the ENERGY STAR label when selecting major appliances or use the yellow Energy Guide label to compare efficiency of similar appliances.

If you are not directly responsible for the purchase and installation of appliances, you can help customers learn about ENERGY STAR options. It is recommended that points be awarded only if ENERGY STAR appliances are actually installed in the home at the time a project is certified.

Resources:
- www.energystar.gov for list of appliances meeting ENERGY STAR criteria and list of local stores that sell ENERGY STAR appliances. The Web site also includes a calculator to show prospective homeowners how much they will save and how fast the upgraded appliance will pay for itself over time.

3.3.5 RENEWABLE ENERGY/SOLAR HEATING AND COOLING

3.3.5.1 Solar Space Heating and Cooling

More detailed design guidance for climate-specific passive solar design is available from the Sustainable Building Industry Council , 1331 H Street NW, Suite 1000, Washington, DC 20005; Phone: (202) 628-7400; www.sbicouncil.org.

A. Use sun-tempered design: Building orientation, sizing of glazing, design of overhangs to provide shading are in accordance with guidelines below:
- Long side of the home faces within 30° of south;
- Glazing area < 7% of finished floor area (FFA) on south face (Low-E);
- Glazing area < 2% of FFA on west face (Low-E, Low SHGC);
- Glazing area < 4% of FFA on east face (Low-E, Low SHGC);

- Glazing area < 4% of FFA on north face (Low-E);
- Skylights less than 2% of finished ceiling area, with shades and insulated wells;
- Overhangs designed to provide shading on south-facing glass (at a minimum), or adjustable canopies or awnings. *(See User Guide for charts that indicate length of overhang, amount and period of shading according to latitude.)*

Intent:
To reduce the amount of non-renewable energy required to heat and cool a home through design features that permit solar heat gains and minimize the potential for overheating.

Information / How to Implement:
The Sustainable Buildings Industry Council provides the most concise and clear-cut guidance on sun-tempered design. The design rules of thumb cited above will provide some solar benefit and prevent overheating in most climates.

Resources:
- *Green Building Guidelines—Meeting the Demand for Low-Energy, Resource-Efficient Homes*, Chapter 2A: Renewable Energy: Solar and Other Renewables, Sustainable Buildings Industry Council
- *Passive Solar Design Strategies, Guidelines for Home Building*, Sustainable Building Industries Council, www.psic.org
- *Passive Solar Design* (NAHB Research Center fact sheet) www.toolbase.org/docs/MainNav/Energy/3944_passivesolardesign.pdf

B. Use passive solar design: Sun-tempered design as above plus additional south-facing glazing, appropriately designed thermal mass to prevent overheating, and provision for airflow to adjoining rooms.

- Sun-tempered design as outlined in Section 3.3.5.1a except additional glazing permitted on south wall PLUS
- For any room with south-facing glazing > 7% of FFA, properly sized thermal mass, and
- Provision for forced air flow to adjoining areas as needed.
- SBIC Passive Solar Design Guidelines for your climate should be referenced to size thermal mass.

Intent:
To reduce the amount of non-renewable energy required to heat and cool a home by taking advantage of the sun's energy through passive design features that collect desirable solar heat gain and mitigate unwanted solar heat gain.

Information / How to Implement:
Note: 3.3.5.1.A must also be implemented to receive points for 3.3.5.1.B.

In most regions of the country having a winter heating load, homes can be designed so a portion of this load is satisfied by solar gains. As south-facing glass is increased to obtain greater solar benefit, thermal mass must be provided to store excess heat gain, prevent overheating, and moderate heat delivery to the home. Properly sized thermal mass (typically in the form of masonry materials such as tile floors and brick walls, or water) absorbs heat while the sun strikes it and releases that heat slowly once the sun has gone down. Designing a truly passive solar home requires careful calculation of solar gain, thermal storage capacity, and hourly outdoor winter conditions. Obtain the passive solar design guidelines (see Resource) for your climate as well as the other references cited below. It is also advisable to consult a design professional with background and experience in passive solar design.

Resources:
- *Green Building Guidelines*—Meeting the Demand for Low-Energy, Resource-Efficient Homes, Chapter 2A: Renewable Energy: Solar and Other Renewables, Sustainable Buildings Industry Council
- Sustainable Building Industry Council Passive Solar Design Guidelines, available at www.sbicouncil.org

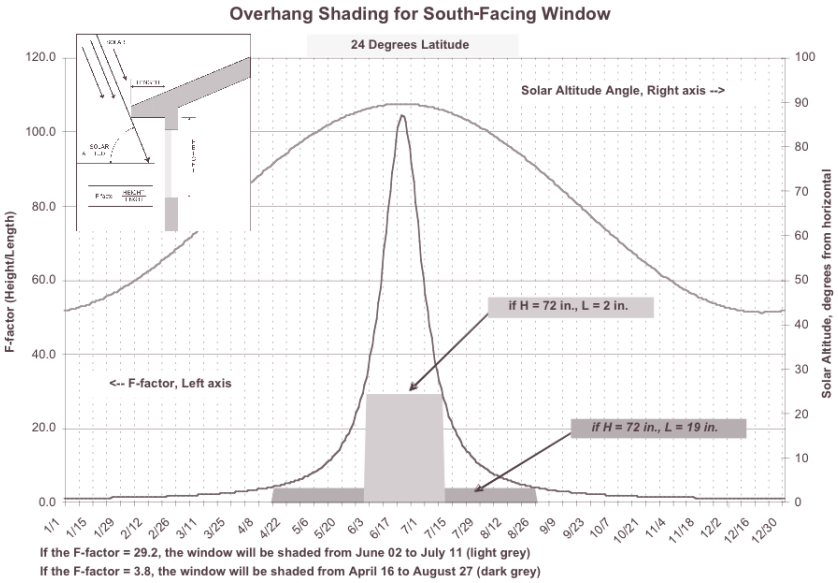
C. Use passive cooling.

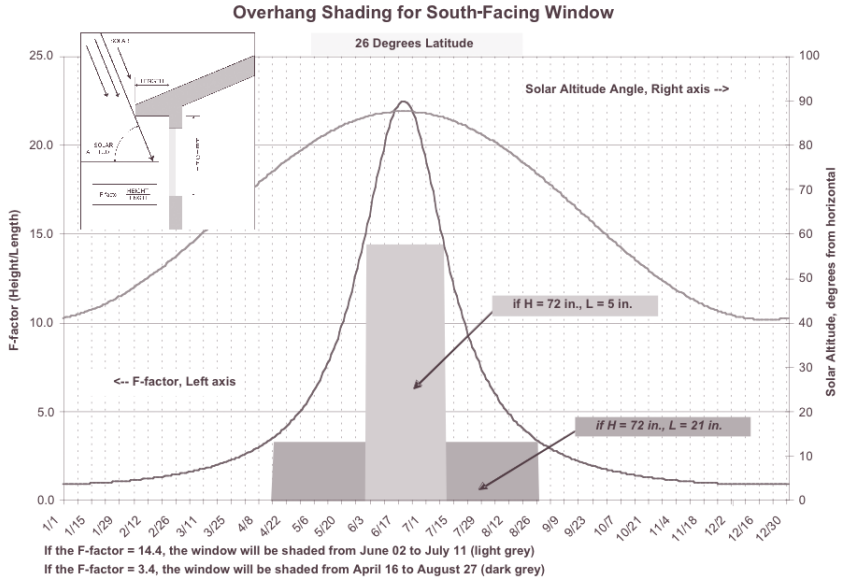
- Exterior shading on east and west windows, e.g., shade trees, moveable awnings or louvers, covered porches
- Overhangs designed to provide shading on south-facing glazing. (Use supplied charts that indicate length of overhang and amount and period of shading according to latitude. Not to be double-counted if credited in 3.4.1.a above)
- Windows located to facilitate cross ventilation.
- Solar reflective roof or radiant barrier in hot climate.

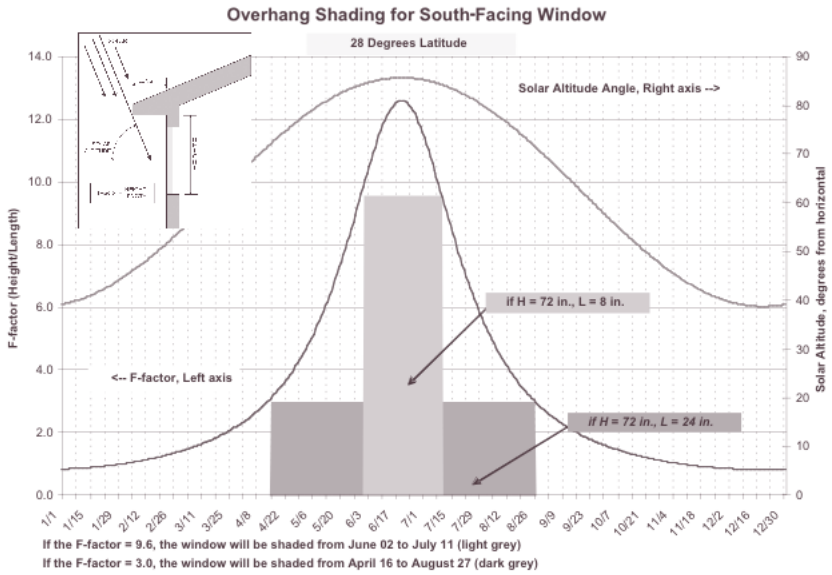
Intent:
To reduce non-renewable energy required for space cooling in the home by mitigating solar heat gain and using design features that promote natural ventilation.

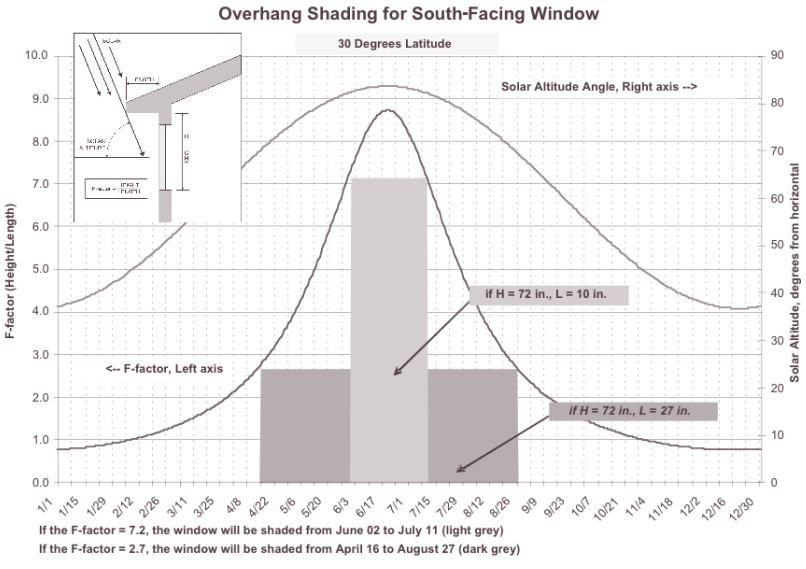
Information / How to Implement:
Natural features, landscaping, and architectural features can help cool a home naturally and/or reduce unwanted solar gains that increase cooling load. The charts below provide guidance on the length of overhangs to achieve desired shading of south-facing glass for different latitudes in the country.

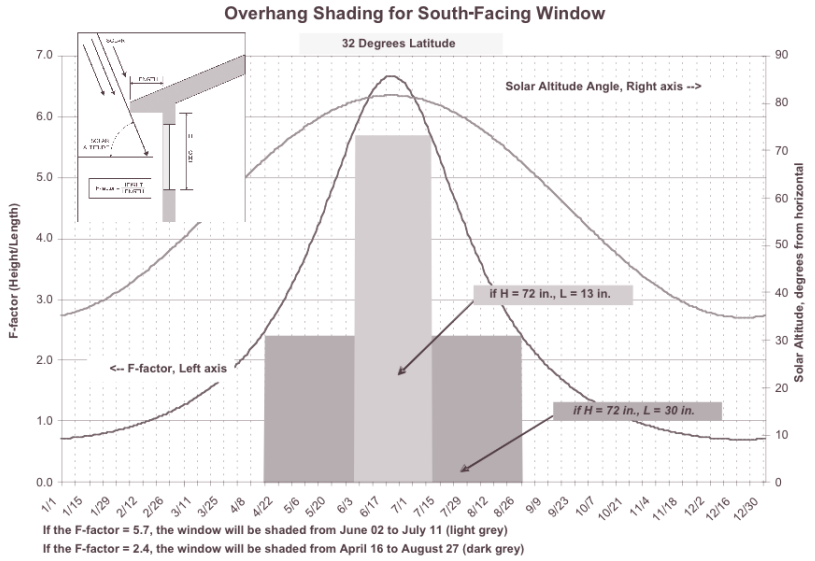
Shading of east and west windows is difficult to achieve with a fixed overhang because the sun is low in the sky when shading is typically desired. Moveable awnings or louvers allow the flexibility to shade windows during certain times of the day or year. In cooling-dominated climates, a covered porch may be a good solution on the west side of the home to mitigate unwanted solar heat gain.

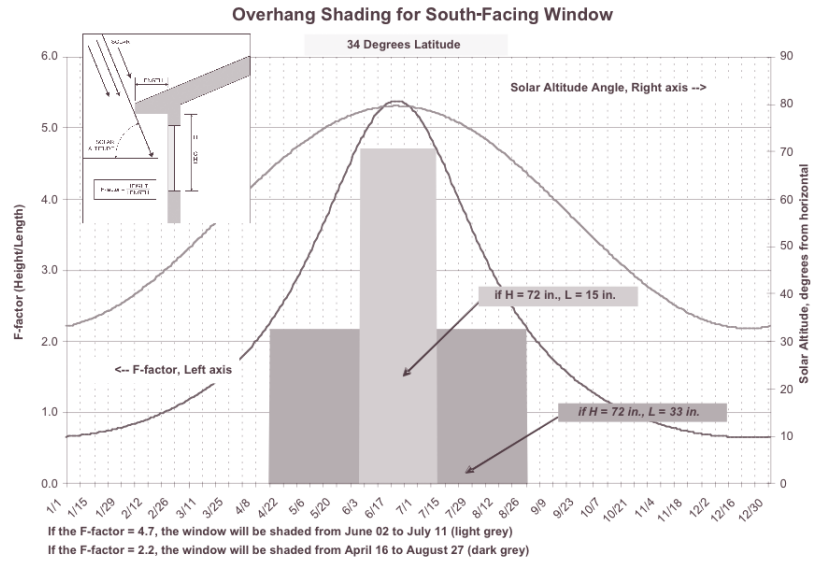


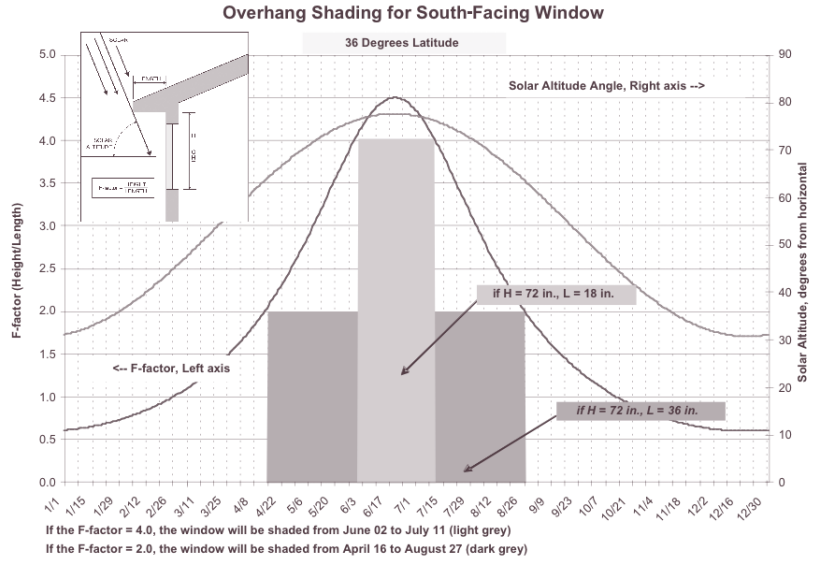

Overhang Shading for South-Facing Window
26 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 5 in.
if H = 72 in., L = 21 in.
If the F-factor = 14.4, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 3.4, the window will be shaded from April 16 to August 27 (dark grey)

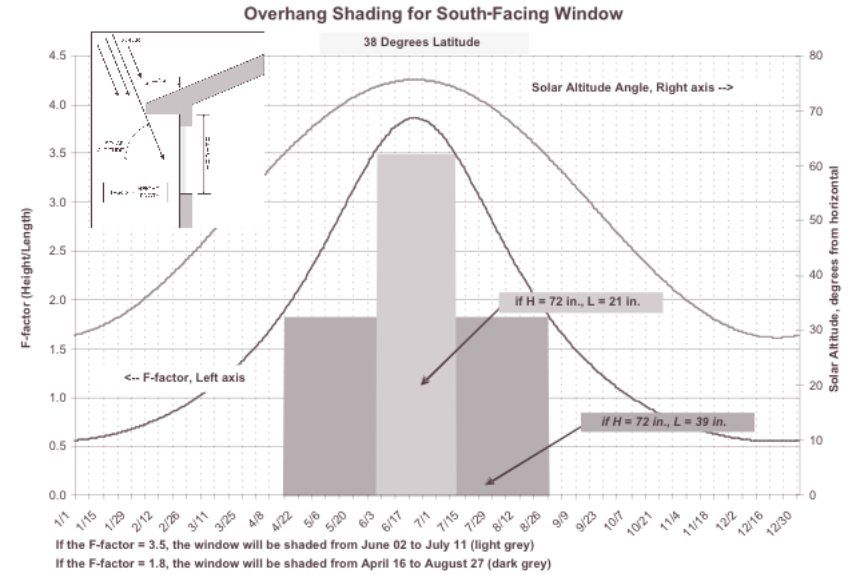

Overhang Shading for South-Facing Window
28 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 8 in.
if H = 72 in., L = 24 in.
If the F-factor = 9.6, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 3.0, the window will be shaded from April 16 to August 27 (dark grey)

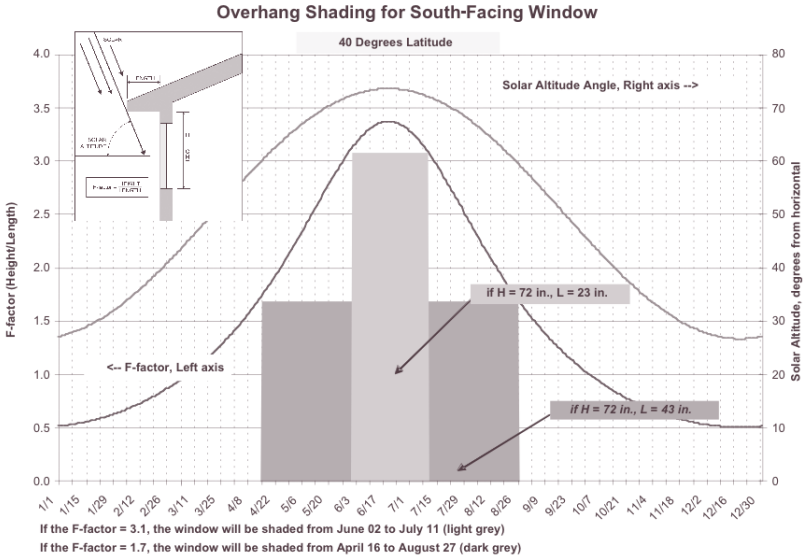

Overhang Shading for South-Facing Window
30 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 10 in.
if H = 72 in., L = 27 in.
If the F-factor = 7.2, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 2.7, the window will be shaded from April 16 to August 27 (dark grey)

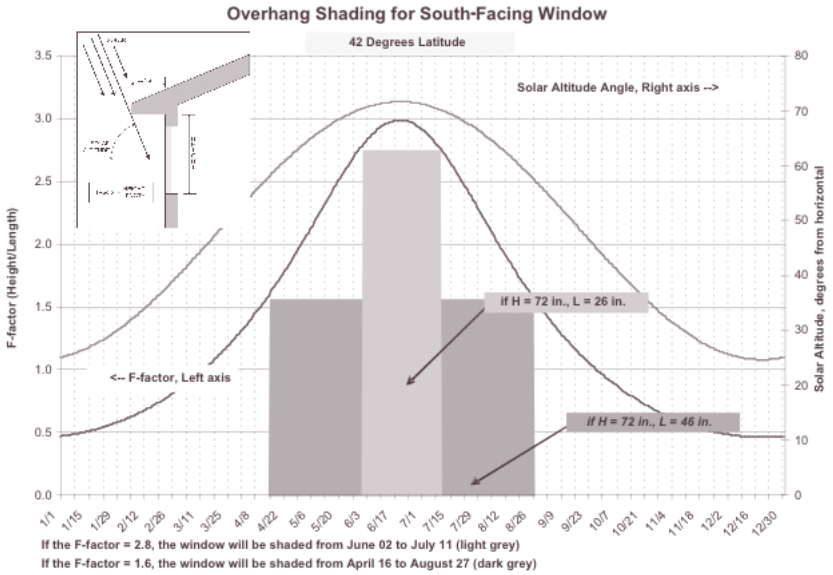

Overhang Shading for South-Facing Window
32 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 13 in.
if H = 72 in., L = 30 in.
If the F-factor = 5.7, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 2.4, the window will be shaded from April 16 to August 27 (dark grey)

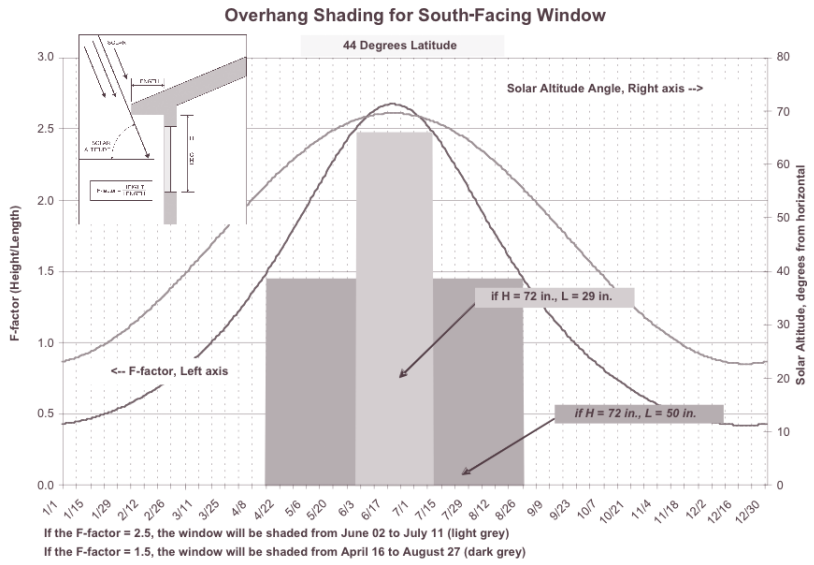

Overhang Shading for South-Facing Window
34 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 15 in.
if H = 72 in., L = 33 in.
If the F-factor = 4.7, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 2.2, the window will be shaded from April 16 to August 27 (dark grey)

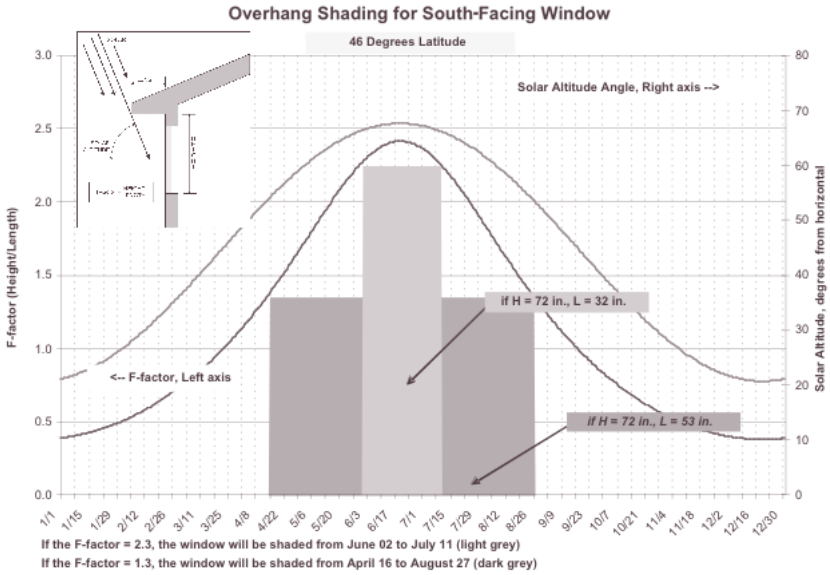

Overhang Shading for South-Facing Window
36 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 18 in.
if H = 72 in., L = 36 in.
If the F-factor = 4.0, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 2.0, the window will be shaded from April 16 to August 27 (dark grey)

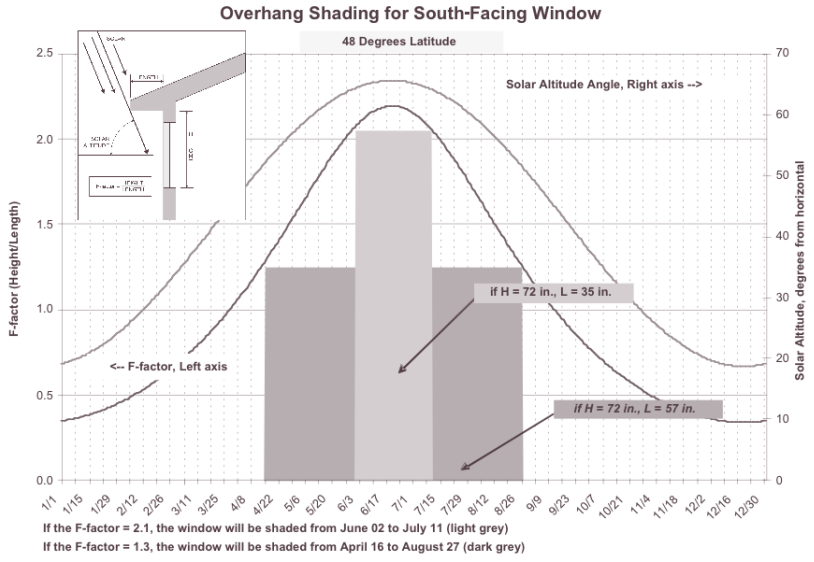

Overhang Shading for South-Facing Window
38 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
if H = 72 in., L = 21 in.
<-- F-factor, Left axis
if H = 72 in., L = 39 in.
If the F-factor = 3.5, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.8, the window will be shaded from April 16 to August 27 (dark grey)

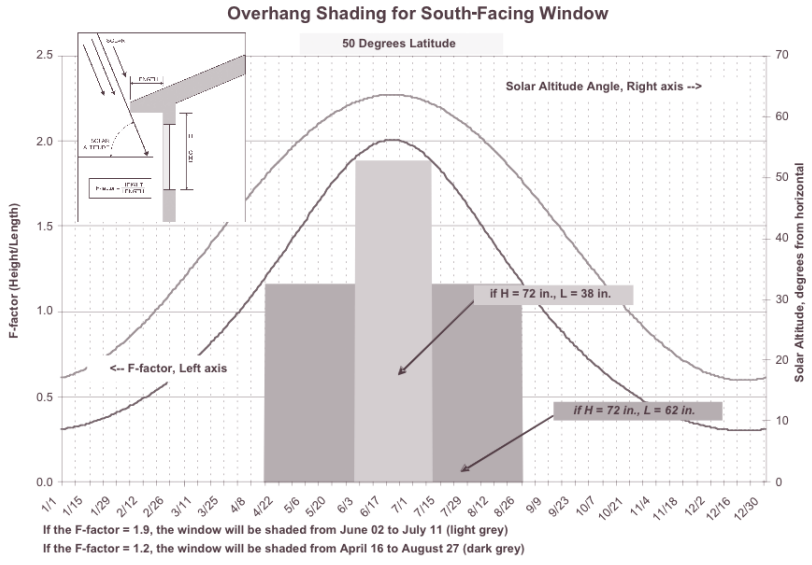

Overhang Shading for South-Facing Window
40 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
if H = 72 in., L = 23 in.
<-- F-factor, Left axis
if H = 72 in., L = 43 in.
If the F-factor = 3.1, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.7, the window will be shaded from April 16 to August 27 (dark grey)


Overhang Shading for South-Facing Window
42 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
if H = 72 in., L = 26 in.
<-- F-factor, Left axis
if H = 72 in., L = 46 in.
If the F-factor = 2.8, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.6, the window will be shaded from April 16 to August 27 (dark grey)


Overhang Shading for South-Facing Window
44 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 29 in.
if H = 72 in., L = 50 in.
If the F-factor = 2.5, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.5, the window will be shaded from April 16 to August 27 (dark grey)


Overhang Shading for South-Facing Window
46 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 32 in.
if H = 72 in., L = 53 in.
If the F-factor = 2.3, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.3, the window will be shaded from April 16 to August 27 (dark grey)


Overhang Shading for South-Facing Window
48 Degrees Latitude
Solar Altitude Angle, Right axis -->
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
<-- F-factor, Left axis
if H = 72 in., L = 35 in.
if H = 72 in., L = 57 in.
If the F-factor = 2.1, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.3, the window will be shaded from April 16 to August 27 (dark grey)



Resources:

- *Passive Solar Heating and Cooling: Natural Cooling*, Arizona Solar Center fact sheet, www.azsolarcenter.com/technology/pas-3.html
- Cooling Your Home Naturally, (U.S. DOE fact sheet) www.eere.energy.gov/consumerinfo/pdfs/coolhome.pdf
- *Passive Solar Design Strategies*, Guidelines for Home Building, Sustainable Building Industries Council, www.psic.org

3.3.5.2 Solar Water Heating

A. Install solar water heating system. Must use Solar Rating and Certification Corporation (SRCC)-rated system. Solar fraction:

1. 0.3
2. >0.5

Intent:
To reduce non-renewable energy use for domestic water heating.

Information / How to Implement:
Solar collectors that preheat water for domestic use are often cost-effective. However, solar water heaters must be designed and installed properly to operate to their maximum potential for many years. Solar water heater designs are generally climate specific, primarily with regard to freeze protection. Consult a knowledgeable local installer to design the system, select equipment, and carefully install the system. Use the references below for a basic understanding of the types of systems available and the estimated performance in your climate. Use the ratings published by the SRCC (see Resources) to determine the solar fraction provided by the system you select.

Resources:

- For a list of Solar Rating and Certification Corporation's certified solar water heating systems, see www.solar-rating.org
- Solar Water Heaters (NAHB Research Center technology fact sheet), www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2136&CategoryID=68
- Database of State Incentives for Renewable Energy, www.dsireusa.org

3.3.5.3 Additional Renewable Energy Options

A. Supply electricity needs via onsite renewable energy source such as photovoltaic, wind, or hydro whereby the system is estimated to produce the following kWh per year:

1. 2,000 to 3,999
2. 4,000 to 5,999
3. 6,000 +

(Equipment should carry all applicable IEEE and UL certifications. Installation shall be in accordance with local utility and electrical code requirements.)

Intent:
To supply a portion of a household's electricity needs with renewable energy sources, reducing peak electricity demand of the home. Peak electricity demand can necessitate power companies to operate peak generation equipment, which, because it is operated for a short time, generally is less efficient.

Information / How to Implement:
As demand for electricity increases and costs to build additional generating capacity continue to escalate, renewable energy sources such as photovoltaics and wind power become more attractive and more cost effective to consumers and utilities. Local generation of electricity by the sun and wind is a viable option in most regions of the country. Costs of smaller (2 kW to 8 kW) photovoltaic systems are about $8-$9 per watt, and in some states like New York, California, and New Jersey, incentives are available that bring the cost even lower. Net metering—in which excess electricity produced at a residence causes the electric meter to spin backwards—may also be available in your area. Net metering effectively credits the customer full retail value for electricity sent back to the utility and greatly improves the economics of residential solar electric power production.

Resources:
- www.dsireusa.org—provides information about areas offering incentives that promote renewable energy and information about net metering rules.

B. Provide clear and unshaded roof area (+/-30° of south or flat) for future solar collector or photovoltaics. Minimum area of 200 sf. Provide a rough-in of piping from the roof to the utility area for:

1. Conduit
2. Insulated piping

Intent:
To encourage and facilitate installation of renewable energy systems for space and water heating needs.

Information / How to Implement:
By providing the infrastructure for the installation of a solar thermal collector or photovoltaic system, you can increase the likelihood that the homeowner will install a renewable energy system in the future. Given the uncertainties of the cost of electricity as well as the possibility of eventual incentives, it makes sense to build this flexibility into the home. It is relatively simple and inexpensive to run electrical conduit or water piping to the attic or roof area while the home is under construction but can be disruptive and costly when retrofitted at a later date. This measure contributes to the cost-effectiveness of the installation of a future renewable energy system.

Resources:
Information will be added in Version 2.

C. Provide homeowner with information and enrollment materials about options to purchase green power from the local electric utility. *(Not to duplicate points for Homeowner Manual in IEQ section below.)*

Intent:
To increase the possibility that the homeowner will select green power when available from the local utility.

Information / How to Implement:
Many utilities across the country purchase or produce at least some power from renewable sources such as wind or hydro. Some utilities offer this power to their customers through green pricing programs, in which a customer can choose to purchase a certain amount of electricity generated by renewable sources. While this electricity is usually more expensive than the utility's standard rates, green pricing programs enable customers to indicate their support for renewable energy sources.

Resources:
- www.eere.energy.gov/greenpower/markets/pricing.shtml?page=0
- Database of State Incentives for Renewable Energy, www.dsireusa.org
- State Energy Office—directory of state energy offices at www.naseo.org/members/states.htm
- Photovoltaics, U.S. DOE fact sheet, www.eere.energy.gov/RE/solar_photovoltaics.html

3.3.6 VERIFICATION

3.3.6.1 Conduct onsite third-party inspection to verify installation of energy related features such as:

A. Duct installation and sealing

B. Building envelope air sealing details

C. Proper installation of insulation including: no gaps, voids, or compression

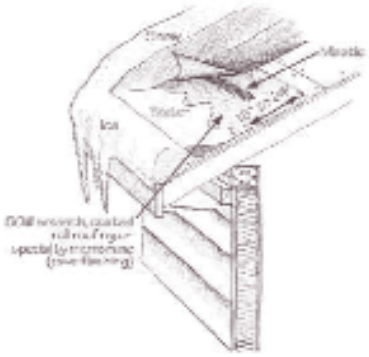
D. Batt insulation cut accurately to fit cavity

E. Windows and doors flashed, caulked, and sealed properly.

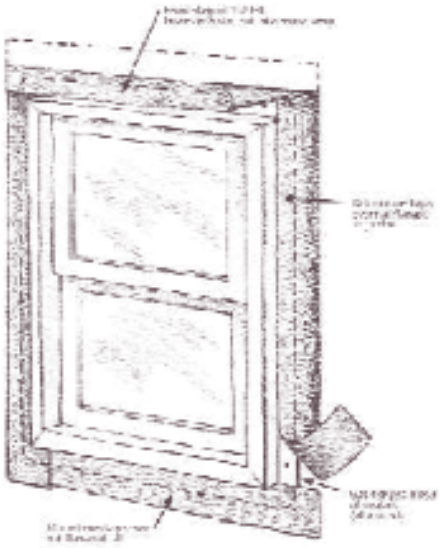
(When at least 100 homes of the same model are to be built by the same builder, a representative sample [15%] of homes may be inspected.)

Intent:
The third-party verification of materials and features that enhance energy efficiency offers customers an added level of assurance that the home will perform as designed. Most builders that have used third-party inspections say it is worth the extra cost because it provides proof to potential clients that the home has higher-quality energy features than competitors' homes.

Information / How to Implement:
A third-party inspection can be performed by any objective, experienced, outside party such as a green building program coordinator, a code enforcement official, an architect or engineer, an energy consultant or specialist, a Home Energy Rating System professional (HERS rater), or an energy program coordinator. Photographs taken by the builder during construction have often been used to defray costs associated with onsite inspections.



Ice Flashing Detail



Window Flashing Detail

Resources:

- Third-party plan review using a Certified HERS rater. A directory of home energy raters can be found on the ENERGY STAR website at www.energystar.gov.
- Local utility, if it offers a new-home energy-efficiency program.

3.3.6.2 Conduct third-party testing to verify performance, e.g., blower door, duct leakage, and flow hood testing (points given per test).

A. Building envelope leakage: blower door test results < 0.35 ACHnat

B. Central HVAC duct leakage: Duct leakage test results:

- Leakage to unconditioned space < 5% of rated blower capacity.
- Total leakage < 10% of rated blower capacity.

C. Balanced HVAC airflows: Flow hood test results:

- Measured flow at each supply and return register within 25% of design flow.
- Total airflow within 10% of design flow

  (When multiple homes of the same model are to be built by the same builder, a representative sample of homes may be tested subject to the sampling protocol.)

Intent:
Testing of the installed systems of a home such as envelope or duct tightness or airflows of HVAC systems provides an added level of assurance to the customer as well as to the builder that energy features were installed properly and will perform to expected levels.

Information / How to Implement:
Keep in mind that proper design and installation are the key ingredients; testing provides confirmation, assurance, and possibly education. With respect to blower door and duct blaster testing, the builder is able not only to gain an idea of the relative tightness of the envelope or the ductwork but also to identify potential problem areas that need correction. Duct blaster testing is less important when all ducts are located within conditioned space; under these conditions, the test may identify comfort or installation issues rather than energy lost to the outdoors.
Third-party testing is conducted by professionals who have specialized equipment for blower door and duct pressure testing. See Resources for information on finding energy specialists who can conduct testing.

Resources:

- Third-party plan review by a certified Home Energy Rating System (HERS) rater. A directory of HERS raters can be found on the ENERGY STAR website at www.energystar.gov.
- Building Performance Institute (www.bpi.org) certifies whole-house building performance contractors.
- Manufacturers of testing equipment offer databases of contractors trained on proprietary equipment (e.g., The Energy Conservatory)
- Local utility
- Yellow pages for "energy," "energy efficiency," or "weatherization"

3.3.7 Innovative options

A. Install drain water heat recovery system.

Intent:
To reduce energy required for heating domestic hot water.

Information / How to Implement:
Drain water heat recovery (DHR) systems recover some of the energy from hot water going down the drain. DHR systems are available from several manufacturers. One type of DHR system, the GFX, consists of flexible copper piping coiled around a copper drainpipe that is fitted into the DWV line with rubber couplings. In a typical GFX configuration, cold water running through the outer flexible copper tubing is preheated by hot water running down the drain from the main shower. The preheated water is then supplied to both the hot water tank and the cold side of the main shower—which reduces the volume and flow of hot water needed. A similar configuration can be designed for the whole house but must be more carefully designed.

Resources:
- Department of Energy—www.eere.energy.gov/consumerinfo/energy_savers/virtualhome/508/shower.html
- Drainwater Heat Recovery, NAHB Research Center technology fact sheet, www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2134&CategoryID=947

B. Install a desuperheater in conjunction with ground source heat pump.

Intent:
Increase the efficiency of a ground source heat pump operating in cooling mode while providing "free" hot water for domestic use. Also provide hot water while heat pump is in heating mode at high efficiency.

Information / How to Implement:
A desuperheater recovers heat that is rejected from a ground source heat pump (GSHP) operating in cooling mode, increasing the cooling efficiency of the heat pump and providing "free" hot water. In heating mode, hot water is produced by the GSHP and, therefore, is produced at a high efficiency. Desuperheaters should be installed by an experience installer or come pre-installed from the factory.

Desuperheaters can be an addition to any split system A/C unit but are most commonly found on ground-source heat pump units.

Resources:
- www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide3E.pdf
- Improve Energy Efficiency with Desuperheaters, U.S. EPA fact sheet, www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide3E.pdf
- Geothermal heat pump manufacturer websites

C. Install heat pump water heater. Must be rated according to the current U.S. DOE test standard and shall have an Energy Factor > 1.7.

Intent:
Reduce the energy needs for electric water heating.

Information / How to Implement:
Heat pump water heaters (HPWH) operate in a similar way to space conditioning heat pumps—they use the energy in the surrounding air to preheat water. HPWH technology has been under development for many years and is now reaching the marketplace with a number of manufacturers offering products. HPWHs operate best in hot climates where the resultant cooling of the air around the heat pump can provide additional energy savings during most of the year. HPWHs can as much as double the efficiency of electric water heating, not including any additional energy savings from space conditioning.

Careful design of the heat pump water heater system is necessary to ensure adequate performance in all seasons.

Resources:

- www.toolbase.org/tertiaryT.asp?DocumentID=2100&CategoryID=946
- Heat Pump Water Heaters, Federal Technology Alert, List of heat pump water heater manufacturers at ACEEE's Web site: www.aceee.org/consumerguide/topwater.htm

D. Install occupancy sensors for lighting control. (Points per sensor)

Intent:
Reduce the electricity consumption associated with lighting in unoccupied rooms.

Information / How to Implement:
Purchase lighting controls from a supplier of energy-efficient products or your local lighting supply store.

Resources:

- Retail outlet of energy-efficient products, e.g., www.EFI.org, www.positive-energy.com, www.sheltersupply.com

UNDERSTANDING HVAC SYSTEM DESIGN ISSUES

When designing a comfort system, it is not adequate to merely produce a heat loss and heat gain estimate. Heat loss and heat gain estimates are part of a design procedure that flows from system selection decisions and the actual load calculations to equipment selection procedures, placement and selection of air distribution hardware, duct routing and airway sizing.

Documents such as ACCA Manual RS provide valuable information about zoning, system concepts, equipment capability, and design procedures. It is strongly recommended that system designers be familiar with the material in Manual RS.

Manual J or equivalent load calculations affect every aspect of the system design procedure. The calculations must be as accurate as possible.

- Equipment capacity that matches the size of the applied heating and cooling loads will deliver comfort, efficiency, and reliability over the entire range of operating conditions.
- Heating and cooling loads determine the total air delivery requirement (blower CFM) and the airflow requirement for each room (room CFM). This airflow information is then used to select supply air outlets and to size the duct runs.
- Load information also is used to estimate purchased energy requirements and to estimate annual operating cost. In this regard, the energy and operating cost estimates will only be as accurate as the load estimate.
- The design concept must be suitable for the application:
  - Contemporary architecture tends to produce dwellings that require a zoned system and/or variable capacity equipment.
  - Custom homes that feature a large amount of architectural glass that provides a panoramic view or architectural theme may not have internal shade, or the shading device may be completely open when the room is occupied. In such cases, the performance of the glass (U-value and solar heat gain coefficient) has a significant effect on comfort, equipment size, and energy use. If there is a large amount of south glass, cooling may be required during cold weather. These dwellings must be carefully zoned and may require year-round cooling.
  - People may be uncomfortable when bathed by sunlight pouring through a window. During cold nights or cold overcast days, radiation from the occupant's skin to cold glass surfaces may cause discomfort.
- External overhangs or some type of internal shading device are desirable because they provide comfort for the occupants (overhangs provide shade without interfering with the view).

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***Manual S* (or Equivalent) and Manufacturer's Data to Select Equipment**

In general, the effective capacity of heating and cooling equipment shall, as closely as possible, match the load when the equipment is subjected to design conditions. For instance, Manual S explains how to use Manual J output and manufacturer performance data to obtain this result. Manual S also provides guidelines pertaining to the acceptable amount of excess capacity and manipulating heat pump balance points.

***ACCA Manual T* (or Equivalent) and Manufacturer's Data to Select Supply Outlets and Return Grilles**

Supply outlets (grilles and registers) shall be the appropriate style and size for the application and shall be in an appropriate location for the application.

- Supply outlets shall not produce objectionable noise. Design guides and manufacturers' information establish limits for face velocity.
- Supply outlets shall provide the appropriate throw for the installed location. Floor outlets shall throw the supply air to the ceiling; ceiling outlets shall throw the supply air to the wall, etc. Size depends on product performance, the supply CFM value, and the face velocity limitation.
- Never blow supply air directly into the occupied zone. Occupants will complain about drafts.
- Floor outlets that blow air straight up the exposed wall are best for cold-climate heating and, if properly selected, adequate for cooling.
- Ceiling outlets are best for cooling but will not warm slab or exposed floors during the winter.
- If high sidewall outlets are used for cooling, supply air shall not drop into the occupied zone during cooling. These devices will not warm slab or exposed floors during the winter.
- The relation between supply CFM, throw, face velocity, and drop is established by manufacturer performance data. Performance is very sensitive to size, and devices that appear to be generally similar can have substantially different performance characteristics.
- A low-resistance return path shall be provided for every room that receives supply air—a wall opening with no door, a transfer grille, or a ducted return. Door undercuts are not acceptable.
- Return grilles shall be the correct size for the grille flow rate. Filter grilles have a lower face velocity than plain grilles.
- The location of the return grille does not affect room air patterns, which are controlled by the supply outlets and will not have a significant effect on pockets of stagnant air. Low returns do pull warm air down to the floor, and high returns do not pull cool air up into the occupied zone.

***Manual D* (or Equivalent) to Size the Duct Runs**

The resistance (inches water gauge of static pressure) of the longest circulation path (longest supply run plus longest return run) shall be compatible with the performance of the blower that is supplied with the heating-cooling equipment. Airway sizes that are compatible with the blower performance shall be increased if airflow velocity creates a potential noise problem. All systems shall have adequate provision for balancing airflow.

- The length of the longest circulation path and the available static pressure determine the friction rate used for airway sizing.
- The length of the circulation path includes the straight runs and the equivalent length of the fittings along the path. One fitting can add from 5 feet to more than 60 feet to the length of the path.
- External static pressure is determined from the equipment manufacturer's blower performance data, preferably for medium-speed operation.
- The available static pressure equals the external static pressure minus the pressure drop through all the air-side devices in the circulation path. Refer to blower table footnotes and manufacturer pressure drop data for devices that were not in place when blower performance was laboratory-tested by the equipment manufacturer.

- Accessory or after-market filters (or any device) that produce a substantial increase in system resistance shall not be installed if the blower cannot accommodate the increased resistance by speed change. An arbitrary increase in system resistance may cause low airflow to rooms, a high temperature rise across a furnace heat exchanger, or low suction pressure at the cooling coil.
- The room heat loss and heat gain estimate (Manual J or equivalent) and the heating and cooling factors (Manual D or equivalent) determine the design value for room airflow.
- Airway size is determined by sectional flow rate and the design friction rate value.
- The friction chart or duct slide rule used for airway sizing shall be technically correct for the type of duct material.
- Airway velocities shall not exceed specified design limits.
- Branch (runout) ducts shall be equipped with a hand damper (for balancing).

Related Comfort Conditioning System Design Considerations

Impact of Incorrectly Sized Heating and Cooling Equipment

- The obvious problem with significantly undersized equipment is that it will not maintain the desired set-point temperature when a passing weather system imposes a design load on it. However, slightly undersized cooling equipment—by a margin of 10 percent or less—may actually provide more comfort at a lower cost.
- Oversized equipment causes short cycles, marginalizes part-load temperature control, creates pockets of stagnant air (unless the blower operates continuously) and degrades humidity control during the cooling season (more information on this subject is provided below). Oversized equipment also requires larger duct runs, increases installed cost, increases operating cost, increases the installed load on the utility grid, and causes unnecessary stress on the machinery.

Humidity Control During the Cooling Season

- Sensible and latent cooling loads are imposed on dwellings in climates that have a substantial amount of moisture in the outdoor air during the cooling season (wet-coil climates). When the summer design condition occurs, properly sized equipment will operate continuously or almost continuously, both loads will be completely neutralized, and the occupants will be comfortable. But, the design condition occurs for only a few dozen hours per season.
- Reduced latent capacity at part load will cause the indoor humidity to drift above the design value, which is acceptable, providing the relative humidity stays below 60 percent. The possibility for experiencing comfort problems at part-load conditions is minimized by using the default indoor and outdoor design conditions recommended by the design manual, providing a code or regulation does not specify a different set of conditions.
- Some climates are too dry to produce a latent load on the indoor coil. In this case, the indoor humidity depends on the moisture content of the outdoor air, the infiltration rate, and the amount of moisture generated by the occupants. If the outdoor air is very dry, these factors will combine to produce an indoor relative humidity of less than 50 percent and could even be lower than 40 percent. But if the relative humidity stays above 30 percent, the indoor air condition will be in the comfort zone.

Humidity Control During the Heating Season

During the heating season, dry air causes a sensation of coolness, a desire to increase the thermostat set point, problems with static electricity, and dry sinuses. Adding a humidifier to the heating system moderates these problems, but if a humidifier is installed, it must not produce a visible or concealed condensation problem. (See the unabridged version of Manual J for more information on this subject.)

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Part-Load Days More Important than Design-Load Days

As a group, homeowners are overly concerned with extreme weather conditions that occur for a few hours per season and uninformed about the significance of the part-load conditions that occur for thousands of hours per season. This lack of understanding pressures contractors to install oversized equipment and results in systems that are more expensive to install, less efficient, less comfortable for a majority of the season, and less reliable. In addition, the oversized equipment produces an unnecessary load on the electric and gas distribution systems. The solution to this problem is consumer education.

4.1 INDOOR/OUTDOOR WATER USE

General Resources:
All aspects of water conservation:
www.awwa.org/waterwiser/

Water Resources of the United States:
http://water.usgs.gov/

4.1.1 Hot water delivery to remote locations aided by installation of:

A. On-demand water heater at point of use served by cold water only. (Points per unit installed)

B. Control-activated recirculation system.

Intent:
Reduce water waste by using technologies that provide hot water at the tap with a minimal wait time.

Information / How to Implement:
Install a water heater at the point of use, or a hot water recirculation device that is controlled by the user or an automatic device (e.g., timer or thermostat) to minimize or eliminate the waiting period for hot water at faucets. To save both energy and water, recirculating systems should be controlled by the user at the time of use rather than circulating hot water through the piping system continuously. Typically, in this type of controlled system, a switch or a button located near a fixture activates a small pump that begins circulating hot water when there is demand for it.

Resources:
- Demand Hot Water Heater fact sheet:
  www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1318&DocumentID=3206
- Hot Water Recirculation Systems fact sheet:
  www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1436&DocumentID=2130
- "An Energy-Saving Product That's Actually Convenient?" Energy Design Update, July, 1997, pg. 8. This article reviews one hot water recirculation product.

4.1.2 Water heater located within 30 feet pipe run of all bathrooms and kitchen.

Intent:
Minimizing the distance between the water heater and major hot water uses reduces the total amount of plumbing pipe installed. This helps reduce the amount of conductive heat loss from the pipe, the amount of time it takes for hot water to reach baths, the laundry area, and the kitchen (helping to conserve water), and the amount of hot water left standing in pipes after a draw (which helps save energy). It has an added benefit of resource efficiency from using less piping material.

Information / How to Implement:
This line item is closely related to the efficient design of the home discussed under the Resource Efficiency section. The first step in minimizing the distance between the water heater and bathrooms and kitchens is to locate those areas in close proximity to one another when designing a home. Once baths, kitchens, and laundry rooms are "clustered" or "stacked," the water heater can be placed to maximize efficient delivery. The effective implementation of this line item offers material and labor savings during construction as well as water and energy savings throughout the life of the home.

Resources:
- DOE Technology Fact Sheet—Water Heating www.eere.energy.gov/buildings/info/documents/pdfs/26465.pdf

4.1.3 ENERGY STAR water-conserving appliances installed, e.g., dishwasher, washing machine.

Intent:
Reduce water consumption by selecting water-efficient major household appliances.

Information / How to Implement:
The ENERGY STAR label identifies appliances that are at least 20% more energy efficient than other appliances of similar size and model and use less water than their standard counterparts. An ENERGY STAR washing machine uses approximately 20 gallons of water per load compared with 40 gallons for standard models. The machine also removes more water during the spin cycle, reducing drying time. ENERGY STAR washing machines are available in both top- and front-loading models. An ENERGY STAR dishwasher uses about 40% less water than conventional models. The ENERGY STAR label takes much of the guesswork out of selecting energy efficient appliances and equipment, making the selection process easier for builders and homeowners.

Resources:
- List of ENERGY STAR-rated appliances: www.energystar.gov/index.cfm?c=appliances.pr_appliances
- Vertical Axis (Top Loading) Energy-Saving Clothes Washers: www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1280&DocumentID=2004
- Energy Efficient Appliances, DOE Technology Factsheet: www.toolbase.org/Docs/MainNav/Energy/4070_doe_energyefficientappliances.pdf?TrackID=&CategoryID=1280&DocumentID=4070
- "*Dishing Out Dollars*," *Consumer Reports*, March, 1998, pg. 37. A comprehensive review of energy- and water-efficient dishwashers.

4.1.4 Water-efficient showerhead using conventional aerator or venturi technology for flow rate < 2.5 gpm

Intent:
Save water by installing low-flow showerheads.

Information / How to Implement:
Low-flow showerheads conserve water by cutting water flow to levels below the federal minimum standards for showerhead flow rate.

Resources:
- PATH Technology Inventory: Low Flow Plumbing Fixtures
  www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1316&DocumentID=2135
- Plumbing materials and supplies: www.plumbingworld.com

4.1.5 Water-efficient sink faucets/aerators < 2.2 gallons/minute

Intent:
Save water by installing aerators that cut flow to levels below the federal minimum standards for faucet flow rate.

Information / How to Implement:
Aerators are a water saving device. Installing aerators in faucets conserves water by restricting the water flow at the faucet outlet. Aerators can be simply screwed into most conventional faucets.

Resources:
- PATH Technology Inventory: Low Flow Plumbing Fixtures
  www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1316&DocumentID=2135

4.1.6 Ultra-low-flow, (< 1.6 gpm/flush) toilets installed:

A. Power-assist

B. Dual flush.

Intent:
Reduce water use associated with toilet flushing.

Information / How to Implement:
Several manufacturers offer toilets that use even less water than the federally mandated 1.6 gallons per flush while still performing reliably. Power-assist toilets with a small, electrically powered pump use either 1.0 or 1.4 gallons per flush depending upon liquid or solid waste. These models require a receptacle near the toilet and have a button on top that allows the user to select the desired flow. One manufacturer estimates water savings of about 2,000 gallons per year. Other new gravity-fed models use as little as 0.8 to 1.4 gallons per flush and maintain quiet operation. Most of these models are set to a particular flow rate at installation, but this setting can be adjusted.

Resources:
- EPA, Low Flow Toilets: www.epa.gov/owm/water-efficiency/toilets.htm
- Arizona Cooperative Extension: www.sahra.arizona.edu/programs/water_cons/home/bathroom_toilet.htm#3

4.1.7 Low-volume, non-spray irrigation system installed, e.g., drip irrigation, bubblers, drip emitters, soaker hose, stream-rotator spray heads.

Intent:
Minimize outdoor water use by installing irrigation systems that offer the most effective and efficient delivery method.

Information / How to Implement:
Drip irrigation systems provide water directly to root systems where it is most needed, making it more efficient than spray systems. Water runoff and evaporation are minimized with drip irrigation systems. Drip systems are the preferred irrigation method in the desert regions of the United States, but are also recommended in any region where lawns and bedding areas require supplemental watering during the growing season.

Resources:
- *Turf and Landscape Irrigation Best Management Practices*, Irrigation Association, www.irrigation.org/PDF/IA_BMP_FEB_2004.pdf
- *Landscaping Irrigation Systems*, H2ouse.org., the California Urban Water Conservation Council, www.h2ouse.org/tour/details/element_action_contents.cfm?elementID=68BAD0B5-0C95-4AE8-8EC6EC8D76A4CBE1&actionID=BD9DA9D3-0CFA-4F05-B3CBFEC63E2EEE57&roomID=F80B1F87-C00D-498C-9C1F1E5BE9D04637

4.1.8 Irrigation system zoned separately for turf and bedding areas.

Intent:
Control irrigation to individual areas.

Information / How to Implement:
Turf and bedding areas have different irrigation needs based on the various types of grasses and vegetation planted. Zoned irrigation systems allow for distributed control of the flow of water to each individual turf or bedding area. Zoned systems can conserve water by providing irrigation on a selective basis since most plants require 25% to 50% less water than lawns.

Resources:
- *Turf and Landscape Irrigation Best Management Practices*, Irrigation Association, www.irrigation.org/PDF/IA_BMP_FEB_2004.pdf
- *Landscaping Irrigation Systems*, H2ouse.org., the California Urban Water Conservation Council, www.h2ouse.org/tour/details/element_action_contents.cfm?elementID=68BAD0B5-0C95-4AE8-8EC6EC8D76A4CBE1&actionID=BD9DA9D3-0CFA-4F05-B3CBFEC63E2EEE57&roomID=F80B1F87-C00D-498C-9C1F1E5BE9D04637

4.1.9 Weather-based irrigation controls, e.g., moisture-sensor, computer-based weather record.

Intent:
Conserve water by providing irrigation on an "as needed" basis.

Information / How to Implement:
The portion of household water used outdoors varies by climate but can be up to 60% of all household water use. Currently, most irrigation systems are controlled by automatic timers. The systems operate at a particular time each day regardless of whether it has rained recently. Often, assessing the need for watering by visual observation or surface conditions can be difficult since watering needs are based on conditions at the roots. The recommended method for irri-

gation control is to use sensors that activate irrigation based on soil moisture content. This not only saves water but also provides the optimum conditions for the turf grass or plants in question since over-watering can be as detrimental to healthy plant growth as insufficient water.

Computer-based controls use historical local weather data to project anticipated weather patterns and time outdoor watering accordingly.

Resources:

- *Turf and Landscape Irrigation Best Management Practices*, Irrigation Association, www.irrigation.org/PDF/IA_BMP_FEB_2004.pdf
- University of Nebraska drought monitoring site by U.S. state, http://drought.unl.edu/dm/monitor.html
- Soil type and classification, Association of American State Geologists, www.kgs.ukans.edu/AASG/AASG.html

4.1.10 Collect and use rainwater as permitted by local code. (Additional credit for distribution systems that use a renewable energy source or gravity.)

Intent:
Reduce water needs for irrigation by collecting and using rainwater.

Information / How to Implement:
Rainwater collection systems store rainwater for future watering and irrigation needs. Collecting rainwater keeps rainwater onsite, thus lowering the impact on storm water collection and conveyance systems and helping to replenish aquifers. See Resources for information about how to construct a rainwater harvesting system and related code issues. Many types of rainwater collection systems are also available commercially.

Resources:

- PATH Technology Inventory, *Rainwater Harvesting*: www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1315&DocumentID=2129
- Harvesting Rainwater for Landscape Use: *http://ag.arizona.edu/pubs/water/az1052/harvest.html*
- Garden supply houses

4.1.11 Innovative wastewater technology as permitted by local code, e.g., constructed wetland, sand filter, and aerobic system.

Intent:
Communities often rely on municipal sewage treatment systems rather than onsite wastewater systems because of the generally higher level of supervision and control. However, if onsite processing is the only option for a builder on a lot, the builder will be rewarded for using advanced measures that more effectively process waste and reduce constituents such as nitrogen, which, if in plentiful supply, can be harmful to water bodies.

Information / How to Implement:
Innovative wastewater systems are a technological advancement over conventional septic systems. These technologies treat wastewater to higher levels, resulting in cleaner effluent discharge, improved system operation, and lower impact on the environment.

Resources:

- United States Environmental Protection Agency, Office of Water, Office of Research and Development, *Onsite Wastewater Treatment Systems Manual*, EPA/625/R-00/008, February 2002, www.epa.gov/ORD/NRMRL/Pubs/625R00008/html/625R00008.htm
- University of Minnesota Extension Service: www.extension.umn.edu/distribution/naturalresources/DD7734.html
- Alternative Individual Wastewater Systems fact sheet: www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1325&DocumentID=2258
- Onsite Sewage Disposal Systems fact sheet: www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1291&DocumentID=4063

4.2 INNOVATIVE OPTIONS

4.2.1 Shut-off valve or pedal-activated faucet to enable intermittent on/off operation.

Intent:
Reduce water waste by installing a faucet control that allows the user, via a (typically) hands-free method, to turn water on and off without changing the temperature.

Information / How to Implement:
Motion-sensor devices automatically control on/off operation of the faucet. Pedal-activated faucets allow individuals to use their feet to control the faucet. Both systems conserve water by reducing the duration of a water flow event.

Resources:

- U.S. DOE, Greening Federal Facilities, Showers, Faucets and Drinking Fountains www.eere.energy.gov/femp/pdfs/29267-6.3.pdf

4.2.2 Separate and reuse greywater as permitted by local code.

Intent:
Reduce total household water consumption by reusing greywater, i.e., water generated from the laundry, showers, and sinks.

Information / How to Implement:
Greywater reuse is the process of recycling laundry, shower, and sink water for non-potable uses. Greywater is typically used to irrigate lawns, trees, shrubs, and vegetation and can also be used to flush toilets. Reusing greywater can significantly reduce total household water consumption.

Resources:

- PATH Technology Inventory: www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2137&CategoryID=1002
- Greywater: www.greywater.com
- Arizona Department of Environmental Quality, Using Gray Water at Home: www.deq.co.pima.az.us/water/Water%20PDFs/graywater.pdf

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4.2.3 Composting or waterless toilet installed as permitted by local code.

Intent:
Eliminate water use associated with toilet flushing by installing composting or waterless toilets.

Information / How to Implement:
Composting or waterless toilets do not use water.

Resources
- EPA, Technology Fact Sheet, Composting Toilets: www.epa.gov/owm/mtb/comp.pdf
- Sustainable Building Sourcebook, Composting Toilets: www.greenbuilder.com/sourcebook/CompostToilet.html
- What is a composting toilet? www.oikos.com/library/compostingtoilet/
- Composting Toilets: www.compostingtoilet.org/

GENERAL RESOURCES

- The Sustainable Building Sourcebook, www.greenbuilder.com
- The Healthy House Institute, www.hhinst.com
- For Volatile Organic Compounds, www.concretenetwork.com/concrete/finished_basements/a_word_about_vocs.htm
- For Building Material Emissions Study, www.ciwmb.ca.gov/Publications/GreenBuilding/43303015.doc
- For spot ventilation, see the fact sheet *Spot Ventilation—source control to improve indoor air quality* www.toolbase.org/Docs/MainNav/Energy/3947_spotventilation1.pdf?TrackID=&CategoryID=1004&DocumentID=3947 (Sept 2004)
- EPA. *A Guide to Indoor Air Quality*; www.epa.gov/iaq/pubs/insidest.html (Sept 2004)
- *Mold in Residential Buildings*, www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1554&DocumentID=2944 (Sept 2004)

5.1 MINIMIZE POTENTIAL SOURCES OF POLLUTANTS.

5.1.1 For vented space heating and water heating equipment:

A. Install direct vent equipment.

Or

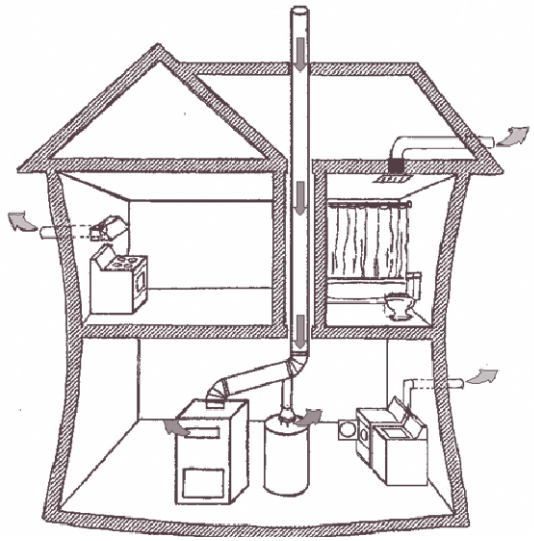
B. Install induced/mechanical draft combustion equipment.

Intent:
There are concerns that exhaust vents (bathroom, kitchen, etc.) can depressurize a tight home and cause the byproducts of combustion from appliances to be drawn into the home. If installing combustion space and water heating appliances, minimize the back-drafting potential by choosing direct-vent (sealed combustion) or mechanical/induced-draft (power-vented) equipment. All space and water heating appliances must meet these criteria to receive points.

Note: Points can be obtained for this guideline by mixing equipment types. For instance, direct-vent space heating equipment and an induced-draft water heater can be installed and receive credit.

Information / How to Implement:
Combustion appliance manufacturers offer equipment with various means of exhausting by-products:

1) Unvented equipment (aka, ventless, vent-free) where byproducts are exhausted into the home;
2) Natural draft equipment (aka, atmospherically vented) where environmental pressure and temperature differences cause by-products to be drawn up a chimney which is directly connected to the equipment;
3) Mechanical draft equipment (aka, induced draft, power vented) where by-products are exhausted through a vent due to pressure differences created by a fan, blower, or ejector located in the vent, or



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4) Direct-vent equipment where all combustion takes place in a sealed chamber. Combustion air is drawn directly from the outdoors into the chamber. Products of combustion are then vented directly outdoors. Direct-vent space heating equipment also has an energy benefit as compared with natural draft or mechanical draft equipment. The Annual Fuel Utilization Efficiency (AFUE) of direct-vent equipment is typically above 85%.

Direct-vent water heaters remain quite expensive. Mechanically vented or electric water heaters may be the most practical option for many builders wishing to comply with this guideline. Some local codes may require an outdoor source of combustion air for mechanical draft equipment.

An alternative to direct vent equipment includes isolating combustion equipment from the conditioned space, such as constructing a combustion closet (see 5.1.2).

Resources:

- Koontz, M.D., N.L. Nagda. *Depressurization-Induced Backdrafting and Spillage: Implications of Results from North American Field Studies.* ASHRAE Winter Meeting; January 12–16, 2002, Atlantic City, New Jersey. AC-02-3-2. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 2002
- National Fire Protection Association, *American Gas Association. National Fuel Gas Code*. 2002 Edition. NFPA 54-2002. ANSI Z2223.1-2002. Section G2406 (303) Appliance Location
- American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. *ASHRAE Standard 62-1989*
- Lstiburek, J., *Builder's Guide: Hot-Dry & Mixed-Dry Climates*. Westford, MA: Building Science Corporation, September 2000
- Lstiburek, J., *Builder's Guide: Hot-Humid Climates*. Westford, MA: Building Science Corporation, January 2002
- Lstiburek, J., *Builder's Guide: Hot-Humid Climates*. Westford, MA: Building Science Corporation, February 2002
- www.epa.gov/iaq/homes/ Search for "Preventing Problems with Combustion Equipment" and "What You Should Know About Combustion Appliances and Indoor Air Pollution"

5.1.2 Install space heating and water heating equipment in an isolated mechanical room or closet with an outdoor source of combustion and ventilation air.

Intent:
Installing combustion appliances in an isolated space, such as in a combustion closet, can minimize the concern that combustion byproducts could be drawn into the home.

Information / How to Implement:
A combustion closet is an area sealed off from the conditioned space. Insulate and seal all walls and the ceiling, install a solid door with weather stripping and a sufficient threshold, and extend ducts outside the building envelope to provide combustion and ventilation air.

Alternatives include installing direct-vent or mechanical/induced-draft equipment (see 5.1.a-b) or installing electric equipment.

Resources:

- Efficiency and Renewable Energy, U.S. Department of Energy. *Combustion Equipment Safety: Provide Safe Installation for Combustion Appliances*. Page 3, Combustion Closet Design chapter

5.1.3 Install direct-vent sealed combustion gas fireplace, sealed wood fireplace, or sealed woodstove.

Or

No fireplace or woodstove installed.

Intent:
Direct-vent sealed combustion gas fireplaces, or sealed wood burning fireplaces, and sealed woodstoves minimize the risk of smoke and combustion byproducts back-drafting into the home. Outdoor air is also supplied directly to the combustion chamber so that indoor air is not required for combustion.

Information / How to Implement:
Fireplaces typically come in:

- Wood burning (uses room air for combustion, and exhausts up a chimney)
- Vented gas (uses room air for combustion, exhausts through vent or chimney),
- Directvent gas (aka, "sealed combustion," outdoor combustion air provided directly to sealed combustion chamber, exhausts through vent or chimney), or
- Vent-free gas (uses room air for combustion and exhausts to room).

When installing a wood-burning stove or fireplace, make sure it is sealed with a gasketed door. Recognize that a wood-burning fireplace is only about 10 to 30% efficient. Consider specifying an EPA-certified wood stove, which has efficiencies of around 69 to 78 percent. EPA-certified woodstoves and gas appliances minimize outdoor air pollution.

Direct-vent fireplaces (aka, sealed combustion) are more energy efficient than wood fireplaces and atmospherically-vented gas fireplaces. They use outside air for combustion and exhaust directly to the outside. Like vented gas fireplaces, they typically use a heat exchanger to circulate warm air through the room but keep combustion air separate from room air.

Resources:

- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Consumer Energy Information: EREC Reference Briefs. *Air Pollution from Wood-Burning Appliances and Fireplaces* www.eere.energy.gov/consumerinfo/factsheets/ja3.html.
- Hearth, Patio, and Barbecue Association (HPBA). http://hpba.org
- HPBA fact sheet on EPA-certified wood burning www.hpba.org/communications/FactSheets/Fact03-EPAWoodBurn3.pdf
- HPBA fact sheet *Wood Burning Fireplaces* www.hpba.org/communications/FactSheets/WoodBurningFireplace.pdf
- HPBA fact sheet, Gas Fireplaces www.hpba.org/communications/FactSheets/GasFireplace.pdf
- National Fireplace Institute. nficertified.org. Find a certified installer. NFI Certification identifies those individuals who have passed an exam based on the knowledge needed to properly plan and install hearth products and their venting systems.
- U.S. EPA Compliance Monitoring, *Woodstoves:* www.epa.gov/compliance/monitoring/programs/woodstoves
- For fireplace venting options, www.fireplacenow.com/_content_/VentingOptions.htm (Sept 2004)

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5.1.4 Ensure a tightly-sealed door between the garage and living area and provide continuous air barrier between garage and living areas including air-sealing penetrations, walls, ceilings, and floors.

Intent:
Walls and ceilings between a garage and the living space should be tightly sealed to prevent car exhaust and other fumes from entering the living space. Pressure differences can cause fumes to be drawn into the living space through common walls and ceilings. Providing a continuous, sealed air barrier along this wall and sealing all penetrations will greatly reduce the potential for contaminants to enter the home from the garage.

Automated mechanical ventilation is sometimes used to exhaust air from the garage to the outdoors. Because this type of system creates negative pressure in the garage, pollutants are less likely to be drawn into the home. However, mechanical ventilation is not a substitute for air sealing because wind speed and direction affect its performance. An alternative to providing a continuous air barrier is to construct a detached garage. However, this option requires more construction materials and therefore has a somewhat negative impact on resource efficiency.

Information / How to Implement:
A continuous air barrier, which decouples garage air from living space air, can be accomplished in many ways. Before the framed wall is enclosed, seal or caulk all penetrations, gasket or seal sills, caulk inside edges of top and bottom plate, install cavity insulation, and install an air barrier such as rigid foam or a sheet barrier (not a vapor retarder) overlapped and taped at joints and corners and attached to the bottom plate, drywall walls and ceiling, tape and spackle all seams. Gasketed drywall or the airtight drywall approach may also be used.

At a minimum, caulk the drywall to the bottom plate, tape and spackle all drywall seams, and seal all penetrations. Only sealing the plates is not enough; air can enter between the drywall and the bottom plate, move through the stud bays, and out of the corresponding gap on the inside wall.

Resources:
- Super Good Cents Builders Field Guide—Chapter 9, Air Tightening Specialist
- Building Science Corporation: Figure 19. www.buildingscience.com/housesthatwork/hotdry/tucson.htm
- http://oikos.com/library/airsealing/rim_joists.html
- Wilber, M.W. and S.R. Klossner. 1997. A Study of Undiagnosed Carbon Monoxide Complaints. Healthy Buildings/IAQ '97: Global Issues and Regional Solutions, Vol. 3, Bethesda, Maryland, Sept 27-Oct, 1997
- Bohac, D.L. and T. H. Brown. 1997. Results from IAQ Evaluations on Cold Climate Single Family Houses Undergoing Sound Insulation. Healthy Buildings/IAQ '97: Global Issues and Regional Solutions, Vol. 3, Bethesda, Maryland, Sept 27-Oct, 1997

5.1.5 Ensure particleboard, medium-density fiberboard (MDF), and hardwood plywood substrates are certified to low formaldehyde emission standards ANSI A208.1, ANSI A208.2, and ANSI/HPVA HP1, respectively. Composite wood/agrifiber panel products must either contain no added urea-formaldehyde resins or must be third-party certified for low formaldehyde emissions.

Intent:
Products certified as having low formaldehyde emissions have less detrimental effect on indoor air quality than uncertified products. In June 2004, the International Agency for Research on Cancer (IARC) declared formaldehyde a known human carcinogen. The glue used to bind materials in wooden board products often contains formaldehyde. Over time, Formaldehyde can leach out of these materials and into the home.

Information / How to Implement:
When purchasing wood panel products, look for materials certified as having low formaldehyde emissions.
The Composite Panel Association's Environmentally Preferable Product Certification Program certifies that composite panels at least meet the appropriate ANSI product criteria. Particleboard should be in conformance with ANSI A208.1-1993. For particleboard flooring, look for ANSI grades "PBU," "D2," or "D3" stamped on the panel. MDF should be in conformance with ANSI A208.2-1994 and hardwood plywood with ANSI/HPVA HP-1-1994.

Resources:
- IARC Monographs on the Evaluation of Carcinogenic Risks to Humans—monographs.iarc.fr/htdocs/announcements/vol88.htm
- www.buildinggreen.com—GreenSpec Directory
- The Composite Panel Association (CPA) Environmentally Preferable Product (EPP) Certification Program, www.pbmdf.com/AboutCPA/EPP.asp
- www.eppbuildingproducts.org/specifications/draftspecs/RevisedCP.attachment/30/EPPD_Composite_Panels_052405.pdf This work is currently underway and may not be completed as of the printing of these guidelines.
- GreenGuard certifies products for low emissions. As of September 2004, only one engineered wood product was listed. www.Greenguard.org
- For formaldehyde-free MDF, check www.advancedbuildings.org/main_t_finishes_formaldehyde.htm, Sept 2004.

5.1.6 Install carpet, carpet pad, and floor covering adhesives that hold the "Green Label" from Carpet and Rug Institute's indoor air quality testing program or meet equivalent thresholds verified by a third party.

Intent:
Reduce VOC emissions from carpets by installing carpets certified by a third-party testing agency as low emitting.

Information / How to Implement:
The Carpet and Rug Institute administers a testing program to identify low-emitting carpets, carpet pads, and floor covering adhesives. Look for the "Green Label" when purchasing carpets. Natural fiber carpets are also good alternative floor coverings.

Resources:
- www.carpet-rug.com/drill_down_2.cfm?page=8&sub=4&requesttimeout=350
- Wargocki, P., D.P. Wyon, Y.K. Balk, G. Clausen and P.O. Fanger. 1999. Perceived Air Quality, Sick Building Syndrome Symptoms and Productivity in an Office with Two Different Pollution Loads. Indoor Air 1999, vol. 9: 165-179.
- Environmental Protection Agency. www.epa.gov/iaq/formalde.html. (Sept 2004)

5.1.7 Mask HVAC outlets during construction and vacuum ducts, boots, and grilles before turning on central heating/cooling system.

Intent:
When possible, do not operate ducted HVAC equipment during construction.
Remove dust and dirt from supply and return ducts before putting the equipment into operation to minimize airborne pollutants.

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Information / How to Implement:
Tightly cover openings with materials such as cardboard and tape, especially during tasks that create significant dust such as drywall or floor sanding. It is not necessary to professionally clean ducts to comply with this guideline. Rather, use a shop vacuum to remove dust and debris close to the openings.

Resources:
- Information will be added in Version 2.

5.1.8 Use low-VOC-emitting wallpaper.

Intent:
Use low-VOC-emitting wallpaper to reduce potentially harmful VOCs from being emitted into the indoor air.

Information / How to Implement:
Use materials certified by a third party as having low VOC emissions.
The reason this line item is in the IEQ guiding principle and the low VOC paints line item is in the "Global Impacts" guiding principle is because once the homeowner moves into a new home, the vast majority of VOCs in paints have already been released to the atmosphere and are thus do not have a significant impact on indoor environmental quality. However, wallpaper releases VOCs more slowly. Thus, there is still a relatively good amount of VOCs remaining in wallpaper after a homeowner moves into a new home.

Resources:
- www.greenguard.org
- *Green from Wall to Wall* by Environmental Design+Construction, www.edcmag.com/CDA/ArticleInformation/coverstory/BNPCoverStoryItem/0,4118,128601,00.html (Sept 2004)
- *Paints and Wall Coverings* by DOE, Energy Efficiency and Renewable Energy. www.eere.energy.gov/femp/pdfs/29267-7.1.6.pdf (Sept 2004)

5.2 MANAGE POTENTIAL POLLUTANTS GENERATED IN THE HOME.

5.2.1 Vent kitchen range exhaust to the outside.

Intent:
Remove moisture, odors, and combustion byproducts.

Information / How to Implement:
Install a range hood that is vented to the outside. Because a vented hood requires another puncture in the building envelope, be sure to tightly seal around the penetration. Take caution not to over-ventilate. Large kitchen exhaust fans can increase the potential for back-drafting if there are other combustion appliances in the home. (See 5.1.1 above.) The Home Ventilating Institute recommends a range hood with a minimum rate of 40 CFM per lineal foot of range top for wall-mounted hoods and 50 CFM per lineal foot for island hoods. For cooking that generates heavier steam or smoke, HVI recommends 100 CFM per lineal foot for wall-mounted hoods and 150 CFM per lineal foot for island hoods. Duct length and routing can affect flow rates; be sure to verify the flow rate is as designed.

Resources:
- Home Ventilating Institute, www.hvi.org
- American Society of Heating, Refrigeration and Air-Conditioning Engineers, ASHRAE Standard 62-1989
- 2003 IRC, Page 302, Section M1506.3 Ventilation Rate

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- State of California. Reducing Indoor Air Pollution, www.arb.ca.gov/research/indoor/rediap.htm (Sept 2004)
- Doiron, Jacques, Cleaner cooking. www.canadianhomeworkshop.com/quickfix/kitchen_vent.shtml (Sept 2004)
- Miltner, Karen, Keeping Kitchen Smells Fresh. www.democratandchronicle.com/homes/buyersguide/1010G221OKH_HOODS11_Homes.shtml (Sept 2004)

5.2.2 Provide mechanical ventilation at a rate of 7.5 cfm per bedroom +7.5 cfm and controlled automatically or continuous with manual override. The ventilation equipment may be:

A. Exhaust or supply fan(s)

B. Balanced exhaust and supply fans

C. Heat recovery ventilator

D. Energy recovery ventilator.

Intent:
Provide small amount of background ventilation to ensure that indoor air is exchanged at a consistent and adequate rate.

Information / How to Implement:
It is advantageous from an indoor environmental quality perspective and for energy-efficiency purposes and comfort to construct a tight building envelope. Air infiltration not only contributes to energy loss but can also cause mold problems if warmer air condenses when it reaches a cooler surface as it moves through a wall cavity. However, a very tight building shell can create the need for an intentional means of introducing fresh air into the living space. Introducing outdoor air into the home in a controlled manner has both an energy and IEQ advantage.

Exhaust or Supply Fan: Kitchen or bath exhaust fans can be part of a whole-house ventilation strategy in cold climates if fans are controlled with timers or humidistats. As air is exhausted from the home, the negative pressure created pulls in outdoor air from nooks and crannies in the building envelope. The practice is not recommended in warm, humid climates because humid, outdoor air traveling through a wall cavity can create moisture problems. In these climates, supply-only ventilation is preferable. For supply-only ventilation, locate the ducts carefully since cold or hot outdoor air can create comfort issues.

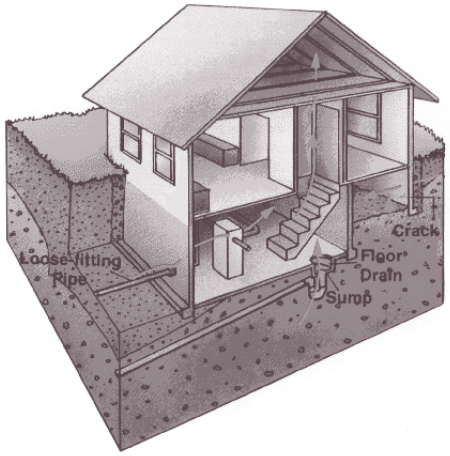
Balanced Exhaust and Supply Fan: Balanced ventilation does not contribute to pressure imbalances between indoors and out. As air is exhausted by one (or more) fans, fresh air is introduced by another. One option for balanced ventilation is to use bath fans for the exhaust and to install a small duct from outside to the return side of the air handler on a central heating or cooling system. Controls and timers are then used to operate the fans and air handler simultaneously or as desired. Outdoor air can also be supplied directly to the home with a separate fan, but take care in locating the ducts so that comfort is not compromised.

Heat or Energy Recovery Ventilators: These systems are also a form of balanced ventilation. In addition to supplying fresh air and exhausting stale air, they precondition the incoming air to some degree. Heat recovery ventilators exchange sensible heat while energy recovery ventilators transfer moisture to some extent as well. Thus, in a humid climate, some moisture from the incoming air is transferred to the exhaust stream. Energy recovery ventilators are not dehumidifiers; they transfer moisture from one air stream to another. For severely humid climates, one should consider a dehumidifying ventilator. Typically, heat recovery ventilators are recommended for cold climates and energy recovery ventilators for hot climates. However, if dry indoor air is a potential issue in a heating-dominated climate, an energy-recovery ventilator may be preferred.

See also Section 3.3.1B under the Energy Efficiency section.

Resources:
American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. ASHRAE Standard 62-1989

5.2.3 Install MERV 9 filters on central air or ventilation systems.



Radon can enter a house through many paths.

Intent:
Reduce the amount of airborne particulates.

Information / How to Implement:
MERV 9 filters remove particles larger than 3 microns and are more effective than standard spun fiber filters. MERV 9 filters capture dust but not contaminants such as molds and bacteria that are in the 1-micron range. Some studies have shown that 97% of airborne particles are 1 micron or less. Filters with a greater efficiency are often not recommended for space heating and cooling equipment because they may restrict airflow too much. More efficient filters such as MERV 9 also have a resource efficiency benefit from the standpoint that more dust is captured by the filter and is not deposited on the air handler.

Resources:
- National Institute for Occupational Safety and Health. Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks. www.cdc.gov/niosh/docs/2003-136/2003-136c.html (Sept. 2004)
- CHMC " What a Furnace Filter Can Do For You" www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_ce22.cfm (Sept. 2004)

5.2.4 Install humidistat to control whole-house humidification system.

Intent:
Control excessive humidification, which can result in moisture damage.

Information / How to Implement:
Indoor humidity should be between 30 and 60 percent. Indoor humidity below 30 percent causes dry eyes, nose, and throat, which are not only uncomfortable but also an invitation for bacteria and viruses. At the other extreme, indoor humidity above about 60% can contribute to the potential for mold growth. Given temperatures between 40 and 80 degrees Fahrenheit and a food source (wood, paint, dirt, dust), mold will grow within 24 to 48 hours. Therefore, if a whole-house humidification system is installed, it should have an adjustable humidistat control to avoid excessive humidification.

Resources:
- ToolBase Website. Humidity-Sensing Control Device www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2096&CategoryID=960 (Sept. 2004)

5.2.5 Install sub-slab depressurization system or infrastructure to facilitate future installation of radon mitigation system. When applicable, the more stringent requirement of local building code and this provision shall apply.

Intent:
Prevent radon gas from entering the home.

Information / How to Implement:
Radon is a naturally occurring gas spontaneously produced from the decay of radium. Radon levels can vary in outdoor air, indoor air, soil, and ground water. Radon is a carcinogen that can enter through voids in a home's foundation and become trapped inside. Radon gas can easily be directed outside with a few basic construction designs.

Text and graphic from www.epa.gov/radon/construc.html

A. Gas-Permeable Layer

This layer is placed beneath the slab or flooring system to allow the soil gas to move freely underneath the house. In many cases, the material used is a four-inch layer of clean gravel.

B. Plastic Sheeting

Plastic sheeting is placed on top of the gas-permeable layer and under the slab to help prevent the soil gas from entering the home. In crawl spaces, the sheeting is placed over the crawl space floor.

C. Sealing and Caulking

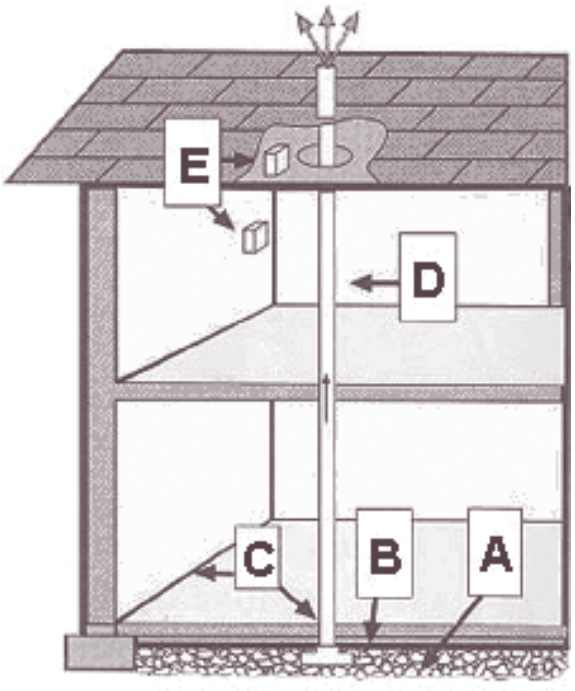
All openings in the concrete foundation floor are sealed to reduce soil gas entry into the home.

D. Vent Pipe

A three- or four-inch gas-tight or PVC pipe (commonly used for plumbing) runs from the gas-permeable layer through the house to the roof to safely vent radon and other soil gases above the house.

E. Junction Box

An electrical junction box is installed in case an electric venting fan is needed later.



Note that in high radon areas, special consideration should be taken to treat well water. Simple water treatments are available. For more information, call EPA's Drinking Water Hotline at (800) 426-4791, visit www.epa.gov/safewater/radon.html, or contact the state radon office.

Resources:
- 2003 IRC, Page 559
- HBA: Use radioactivity maps from USGS, state geological surveys, colleges/universities to better know the dangerous radon zones in your area. http://energy.cr.usgs.gov/radon/georadon/4.html
- Radon map for Prince George's and Montgomery counties from USGS http://energy.cr.usgs.gov/radon/georadon/4.html



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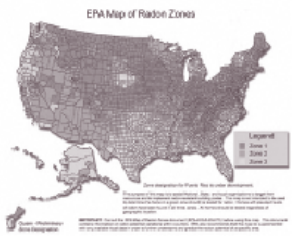


- EPA's map of radon zones by county www.epa.gov/radon/zonemap.html
- HBA: EPA also recommends contacting your state radon representative. EPA has a list of contacts on its website at www.epa.gov/iaq/whereyoulive.html
- www.epa.gov/radon
- *Radon Resistant New Construction*—www.epa.gov/radon/construc.html
- 2000 IRC, Page 564, *Radon-resistant construction details for four foundation types*
- For Radon remediation, check www.toolbase.org/secondaryT.asp?TrackID=&CategoryID=1174

5.2.6 Verify all exhaust flows meet design specifications.

Intent:
Ensure all exhaust flows are operating as designed.

Information / How to Implement:
If ductwork is not properly sized and installed, fan flow may be restricted and not exhaust air at its rated capacity. For example, a fan rated at 50 CFM may exhaust only 35 CFM if duct runs are extremely long or if ductwork is kinked during installation. Without adequate fan capacity, moisture may not be properly removed. Size ducts according to the manufacturer's recommendation for diameter and maximum length. Fans should perform within 10% of their rated capacity. After installation, visually inspect the duct length, look for crimped or damaged ducts, check for missing parts, and ensure that connections are secure. A more accurate method of checking fan airflow is to use a flow hood or pitot tube and manometer. Ask the installer about methods of checking airflow.

Resources:
- ACCA Manual D www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_ce17.cfm
- Flow hood equipment—www.energyconservatory.com/products/products1.htm

5.3 MOISTURE MANAGEMENT (VAPOR, RAINWATER, PLUMBING, HVAC)

Intent:
Reduce risk of moisture accumulation, which can lead to deterioration of building products and potential mold problems.

Information / How to Implement:
See Resources section.

Resources:
- Lstiburek J., and J. Carmody, *Moisture Control Handbook*, *Principles and Practices for Residential and Small Commercial Buildings*, Wiley, 1996

5.3.1 Control bathroom exhaust fan with a timer or humidistat.

Intent:
Ensure that fans are operated in a manner that removes moisture without relying on input from the homeowner, and remove residual moisture from bathrooms after use.

Information / How to Implement:
Often, bath fans are used infrequently because of their noise, a lack of understanding of their importance by the homeowner, or simply because the homeowner is not in the habit of doing so. Installing controllers on fans, especially timers or humidistats that remove residual humidity after a person leaves the bathroom, is an effective method for removing interior generated moisture at its source. Timers can also prevent unnecessary fan energy use that occurs when a fan is inadvertently left on.

Timers and humidistats are basically upgraded switches. They are wired in and mounted like a typical switch. Timers can typically be set to run from 10 to 60 minutes. Homeowners should be instructed to run bathroom exhaust fans for 20 minutes after a bath or shower. Humidistats will automatically cycle the fan on and off to maintain proper humidity levels; they can be adjusted to operate between 20% and 80% relative humidity. Timers and humidistats cost about $25 and up. Bath fans are also available with integral humidistats and timers.

See Section 3.3.2 for information about energy-efficient exhaust fans.

Resources:
- http://energyoutlet.com/res/fan/
- www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_ce17.cfm
- *Moisture Control in Bathrooms* by Home Energy Magazine Online. http://hem.dis.anl.gov/eehem/98/980310.html (Sept 2004)
- *Spot ventilation—source control to improve indoor air quality*. www.toolbase.org/docs/MainNav/Energy/3947_spotventilation1.pdf (Sept 2004)

5.3.2 Install moisture resistant backerboard, not paper-faced sheathing, under tiled surfaces in wet areas.

Intent:
Reduce the risk of problems if water penetrates tile surfaces in kitchens and baths.

Information / How to Implement:
A cement-based backerboard does not contain organic paper that can deteriorate, swell (potentially causing cracking in the grout), and be a substrate for mold growth when wet. Cement backerboard is resistant to the deleterious effects of moisture.

Resources:
Backerboard manufacturer Web sites for installation information (e.g., WonderBoard, Durock)
Tile Council of America, 2003-2004 Handbook for the Installation of Ceramic Tile, www.tileusa.com

5.3.3 Install vapor retarder directly under slab (6 mil) or on crawl-space floor (8 mil). In crawl spaces, extend poly up wall and affix with glue and furring strips, or damp-proof wall below grade. Joints should be lapped 12 inches.

Intent:
Prevent moisture migration from the ground through wicking action (through slab) or by vapor movement (in crawl space).

Information / How to Implement:
A vapor retarder should be continuous with joints lapped 12 inches and taped, if possible. Any penetrations or other areas where the vapor retarder has been compromised should be sealed with tape or caulk.

Resources:

- Carter, Tim. *Vapor Retarders Will Stop Odors and Moisture*. www.askthebuilder.com/printer_279_Vapor_Retarders_Will_Stop_Odors_and_Moisture.shtml (Sept 2004)
- Makela, Eric, et al. *How to construct unventilated crawlspace to meet the provisions.* USDOE. www.holtonhomes.com/webcast_04_crawlspaces.pdf (Sept 2004)
- *Crawlspace Moisture Control*, fact sheet by Dominion Power, www.dom.com/customer/efficiency/res/answers/pdf/crawlspaces.pdf%20
- *EEBA Builders' Guides (for Cold, Mixed-Humid, Hot-Dry/Mixed-Dry, and Hot-Humid Climates)*, available from the Energy and Environmental Building Association's Web site at www.eeba.org/mall/builder_guides.asp

5.3.4 Protect unused moisture-sensitive materials from water damage through just-in-time delivery, storing unused materials in a dry area, or tenting materials and storing them on a raised platform.

Intent:
Prevent wetting of building materials through proper storage techniques during construction. Wetting of building materials can lead to dimensional instability, deterioration, and mold growth.

Information / How to Implement:
Lumber should be inspected upon delivery for moisture and mold. Delivery should be scheduled so that lumber is used soon after it is received at the site. Lumber should not be stored in direct contact with the ground: It should be elevated to allow air circulation and to prevent absorption of ground moisture. Lumber that is stored outside should be covered in an open area in a way that will protect the wood from rain and snow but will also allow water vapor to escape, such as by covering it with house-wrap (plastic sheeting can trap moisture). Interior architectural items such as flooring, trim, and cabinets should be stored indoors until they reach equilibrium with interior moisture levels. This guideline is also a cost-effective measure—by protecting materials from the weather, waste from warping, shrinking, and swelling can be avoided.

Resources:

- *Panel Selection, Handling, Storage.* OSB Design and Construction Guide. March 2000. PFS Research Foundation. Madison, WI
- Forest Products Laboratory. 1999. *Wood handbook—Wood as an engineering material.* Gen. Tech. Rep. FPL-GTR-113. Madison, WI. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463 p. see Section 12, Page 18. Design Factors Affecting Dimensional Change.
- ToolBase. www.toolbase.org/docs/ToolBaseTop/Research/3464_HelpingHomebuyeresUnderstandMold.pdf (Sept 2004)
- *Proper Lumber Storage*, Southern Pine Council, www.southernpine.com/lumberstorage.shtml
- *Proper Storage and Handling of Glulam Beams*, APA—The Engineered Wood Association, www.apawood.org/pdfs/managed/R540.pdf
- *Storage and Handling of APA Trademarked Panels*, APA—The Engineered Wood Association, www.apawood.org/pdfs/managed/U450.pdf
- *Storage, Handling, and Safety Recommendations for APA Performance Rated I-Joists*, www.apawood.org/pdfs/managed/Z735.pdf
- (Just-in-Time Delivery) *Industrializing the Residential Construction Site*, 2000. Center for Housing Research, VPI. Available from the U.S. Department of Housing and Urban Development

5.3.5 Keep plumbing supply lines out of the exterior walls.

Intent:
Reduce the potential for condensation by keeping supply pipes in conditioned space, where pipes are not exposed to large temperature and humidity differentials. Also reduce the consequences of a potential plumbing leak, which could lead to wetting of structural members, insulation, and interior finishes.

Information / How to Implement:
Try to cluster bathrooms and other hot water uses, e.g., "stacked" bathrooms, to minimize the need for running supply lines on exterior walls. Water supply lines can be run through duct chases (designed for keeping ducts in conditioned space). When piping must be located in exterior walls, insulation should be placed between the exterior sheathing and the pipe but not between the pipe and the interior wall (to prevent freezing).

Resources:
- *Builder's Guide to Placement of Ducts and HVAC Equipment in Conditioned Space*, 2000, NAHB Research Center. Available at www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2570&CategoryID=110
- Lewis, Bill. *Preventing Frozen Water Pipes.* http://homerepair.about.com/cs/plumbing/a/frozen_pipes_b3.htm (Sept 2004)

5.3.6 Insulate cold water pipes in unconditioned spaces with insulation or other coating that comparably prevents condensation.

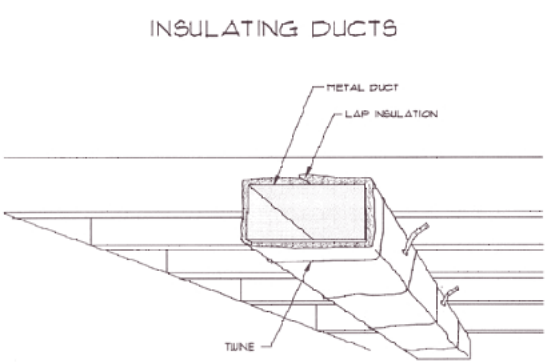
Intent:
Reduce the potential for condensation on cold water supply pipes located in unconditioned space by insulating the pipes. This guideline has more relevance in hot, humid climates where piping is more likely to be located in an unconditioned area. Cold water piping installed in crawl spaces can pose a condensation problem in colder regions during the summer months.

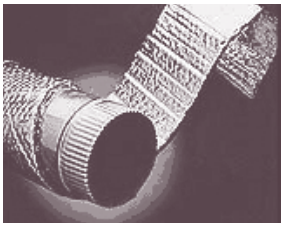
Information / How to Implement:
Foam insulation for insulating pipes is readily available and easy to install.

Resources:
- *Preventing and Thawing Frozen Pipes*. www.prepare.org/basic/frozen.htm (Sept 2004)
- Do It Yourself. www.diynet.com/diy/diy_kits/article/0,2019,DIY_13787_2275412,00.html (Sept 2004)

5.3.7 Insulate HVAC ducts, plenums, and trunks in unconditioned basements and crawl spaces to avoid condensation.

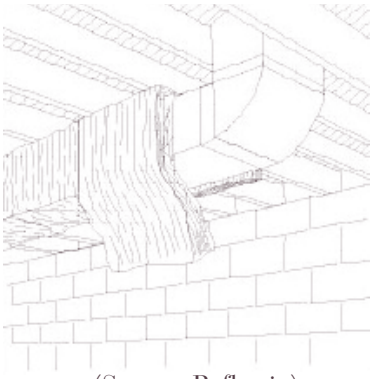
Intent:
Prevent condensation on the outside of cold HVAC ducts located in unconditioned basements and crawl spaces that can lead to moisture problems in those areas.





Information / How to Implement:
www.mme.state.va.us/de/energybook/hbchap5.html

After sealing ductwork, use spray foam or wrap a flexible insulation product (e.g., reflective insulation, fiberglass batts) around metal supply ducts, plenums, and trunks in basements and crawl spaces. Do not use flexible ductwork in crawl spaces, as it can be an entry point into the home for vermin.



(Source: Reflectix)

Resources:
- Energy Outlet information on duct sealing, available at www.energyoutlet.com/res/ducts/insulating.html
- *Crawlspace Condensation* by Home Energy Magazine Online http://hem.dis.anl.gov/eehem/01/010304.html (Sept 2004)
- *Insulating Ducts for Efficiency*. www.bobvila.com/ArticleLibrary/Subject/HVAC/Insulation/InsulatingDucts.html (Sept 2004)

5.3.8 Check moisture content of wood before enclosing on both sides. Ensure moisture content of subfloor/substrate meets the appropriate industry standard for the finish flooring material to be installed.

Intent:
Because wood's ability to dry is compromised when it is not subject to free airflow, moisture content should be acceptable before the wood is enclosed in a wall or floor joist cavity. Reduce the risk of shrinkage and mold on lumber by ensuring the moisture content of dimensional lumber is below 19% before enclosure.

Information / How to Implement:
Use a moisture meter (preferably a probe-type meter, which is more accurate than the scanning type) to measure the moisture content in the wood and wood subfloor. A sample of wood materials can be checked relatively quickly before installing finish materials.

For hardwood flooring over a truss or joist system, the average moisture content of framing members and subflooring should be below 12% to 14% before delivery of the flooring.

When installing flooring over a concrete slab, testing a concrete slab requires use of a calcium chloride test; the test should show a moisture content of three pounds or less (if no moisture retarder is installed) and four to seven pounds (if a moisture retarder is installed). Per the National Wood Flooring Association's guidelines, wood flooring should not be installed over concrete with readings exceeding seven pounds calcium chloride. Use a surface moisture meter, and perform a calcium chloride test to measure moisture in a concrete slab/subfloor.

Resources:
- National Wood Flooring Association, Hardwood Flooring Installation Guidelines, www.nwfa.org.
- The Wood Flooring Manufacturer's Association, Installing Hardwood Flooring, www.nofma.org/installation1.htm
- Electric Moisture Meters, ToolBase Services fact sheet, available at www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2120&CategoryID=1013Golden, J.A., 1998, Moisture Testing Guide for Wood Frame Construction Clad with Exterior Insulation and Finish Systems, p. 7-8. Available at www.toolbase.org/docs/MainNav/MoistureandLeaks/876_protocol5A.pdf
- Computing Moisture Content of Wood. www.woodbin.com/ref/wood/emc.htm (Sept 2004)
- EPA Moisture Content Calculation. www.epa.gov/athens/learn2model/part-two/onsite/mc.htm (Sept 2004)

5.4 INNOVATIVE OPTIONS

Information will be added in Version 2.

Ensure that homeowners are aware of the green features of their new home, know how to operate and maintain the home to achieve the highest level of environmental performance, and have a resource for warranty issues.

6.1 PROVIDE MANUAL TO OWNERS/OCCUPANTS ON THE USE AND CARE OF THE HOME THAT INCLUDES ALL OF THE ITEMS BELOW

A. Narrative detailing the importance of maintenance and operation to keep a green-built home green.

B. Local Green Building Program's certificate.

C. Warranty, operation, and maintenance instructions for equipment and appliances.

D. Household recycling opportunities.

E. Information on how to enroll in a program for purchasing energy from a renewable energy provider.

F. Explanation of the benefits of using compact fluorescent light bulbs in high usage areas.

G. List of habits/actions to optimize water and energy use.

H. Local transportation options.

I. Clear labeling of safety valves and controls for major house systems.

Intent:
Help homeowners to "live green" in their green-built home.

Information / How to Implement:
Gather information for homeowners from local and national resources (see Resources). Include information about the green features of the home as well as tips for living in the home with less impact on the environment. Ask whether the local Green Building Program offers a sample Green Homeowner's Manual.

Resources:

- Fannie Mae, *Home Performance Power: Fannie Mae's Guide to Buying and Maintaining a Green Home*. For a copy, call Fannie Mae's Consumer Resource Center at 1-800-7FANNIE (1-800-732-6643).
- NAHB's *Your New Home and How To Take Care of It*
- *The National Home Maintenance Manual*, by California Building Standards
- Your local HBA's Green Building Program office. List of local Green Building Programs at www.toolbase.org (click on "Green Building").
- Various manufacturers
- City, county, or township recycling information
- U.S. DOE's Green Power Network: www.eere.energy.gov/greenpower/
- Lighting energy savings calculator at www.goodmart.com/light_bulb_energy_saving_calculator.aspx
- Water-saving tips at www.h2ouse.org. Energy-Saving tips: www.eere.energy.gov/consumerinfo/energy_savers/ and www.aceee.org/consumerguide/chklst.htm
- Metropolitan-area, city, county, township, or private public transit information (usually listed in the front of the phone book)
- *Homeowner's Manual—At last, an owner's manual for your new home*. By CMHC. www.cmhc-schl.gc.ca/en/bureho/buho/buho_002.cfm (Sept 2004)
- National Environmental Services Center, www.nesc.wvu.edu/nsfc/NewReleases/nsfc_NR_11_14_03.htm (Sept 2004)

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- Community Associations Institute, www.caionline.org/about/homeowner_education.cfm (Sept 2004)
- Massachusetts Housing Partnership, www.mhp.net/homeownership/education.php (Sept 2004)
- How-To Publications by Family Resource Management, College of Agriculture & Home Economics. www.cahe.nmsu.edu/pubs/_g/ (Sept 2004)
- Papolos, Janice. *The Virgin Homeowner: The Essential Guide to Owning, Maintaining, and Surviving Your Home*, Penguin Books. ISBN: 0140274766
- For earthquake safety: www.seismic.ca.gov/pub/CSSC_2002-04_HOG.pdf (Sept 2004)
- For fire prevention: www.ofm.gov.on.ca/english/FirePrevention/FireSmart%20Communities/pdf/User%20guide.pdf (Sept 2004)
- For soil-lead hazard: www.epa.gov/region01/leadsafe/pdf/chapter8.pdf (Sept 2004)
- For septic system by University of Minnesota Extension Service: www.extension.umn.edu/distribution/naturalresources/DD6651.html (Sept 2004)
- For pest control and pesticide safety: http://pep.wsu.edu/psp/scripts/documents.asp?qryType=new, and http://scholar.lib.vt.edu/ejournals/JPSE/v5/v5hipkinsra2.pdf (Sept 2004)
- For HVAC: www.healthgoods.com/Education/Healthy_Home_Information/Space_Heating_and_Cooling/sizing_heat_and_ac.htm (Sept 2004)

6.2 OPTIONAL ITEMS TO INCLUDE IN THE HOME MANUAL (CHOOSE AT LEAST FIVE)

A. List of local service providers that focus on regularly scheduled maintenance and proper operation of equipment and the structure (sealants, caulks, gutter and downspout system; shower/tub surrounds, irrigation systems, etc.).

B. Photo record of framing showing utilities installed. Photos should be taken prior to installing insulation, clearly marked, and provided in homeowner's manual.

C. List of the Green Building Guideline items that are included in the home.

D. User-friendly maintenance checklist.

E. Instructions for proper handling and disposal of hazardous materials.

F. Information on organic pest control, fertilizers, de-icers, and environmental cleaning products.

G. Maintenance instructions for native or low-water landscape.

H. Information on how to keep a home's relative humidity in the range of 30% to 60%.

I. Information about checking crawl space for termite tubes periodically.

J. Instructions for keeping gutters clean. Information should note that downspouts should divert water at least five feet away from foundation.

Intent:
Provide further information about maintenance and operation of a green home and the surrounding site.

Information / How to Implement:
Provide above information in the homeowner's manual.

Resources:
- Home*a*Syst, An Environmental Risk-Assessment Guide for the Home, Healthy Home Tool, available at www.uwex.edu/homeasyst

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- Local Green Building Checklist or other documents
- EPA document: www.epa.gov/epaoswer/non-hw/househld/hhw.htm
- Check with the local or state environmental or solid-waste agency to see if there is a hazardous waste drop-off day. Local recycling information may cover hazardous wastes. The county or state may have Cooperative Extension fact sheets geared toward your municipality (see, for example, www.epa.gov/grtlakes/seahome/housewaste/src/open.htm).
- Local Cooperative Extension office should have printed information. Also, organic-based lawn services, such as NaturaLawn, usually have printed information.
- County or state Cooperative Extension publications
- Cooperative Extension publications for information about termite tubes, where to look for them, and what they look like. See, for example, www.uky.edu/Agriculture/Entomology/entfacts/struct/ef604.htm.

6.3 PROVIDE EDUCATION TO OWNERS/OCCUPANTS IN THE USE AND CARE OF THEIR DWELLINGS

A. Instruct homeowners/occupants about the building's goals and strategies and occupant impacts on costs of operating the building. Provide training to owners/occupants for all control systems in the house.

Intent:
During the walk-through, demonstrate how to control all the mechanical systems in the home. Demonstrate how to use all controls such as thermostats, lighting controls, and fan controls.

Resources:
- National Association of Home Builders, *Your New Home and How to Take Care of It*. Washington, DC: BuilderBooks, 2001, 60 pages Provide homeowners tips on maintenance to help keep their new home performing at its peak. In the back there are pages on which to note maintenance dates and remarks.
- www.builderbooks.com, 800-223-2665
- Manuals from manufacturers for reference.

6.4 SOLID WASTE

A. Encourage homeowners/occupants to recycle by providing built-in space in the home's design for recycling containers.

Intent:
Make it convenient to recycle.

Information / How to Implement:
Include a recycling center in or near the kitchen under the sink, in an island near the sink, or in a pantry. Credit is also given in this line item for an in-counter compost bin.

Hardware is available for recycling bins to rest on slides. Most under-sink recycling systems can fit two bins under one side of the sink, allowing plenty of room for other typical under-sink items.

Resources:
- www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1280&DocumentID=2001

6.5 INNOVATIVE OPTIONS

Information will be added in Version 2.

7.1 PRODUCTS

7.1.1 Manufacturers' operations and business practices include environmental management system concepts (the product line, plant, or company must be ISO 14001 certified).

Intent:
Use products that come from organizations that have taken the time and resources to create an environmental management system (EMS) that conforms to the ISO 14001 standard.

Information / How to Implement:
See Resources section.

Resources:
- U.S. EPA Position Statement on Environmental Management Systems (EMS), www.mswg.org/USEPAPS/EMSposState.pdf

7.1.2 Choose low- or no-VOC indoor paints. VOC concentrations (grams/liter) of interior paints should be equal to or less than those specified by the EPA's Environmentally Preferable Purchasing Program as follows:

A. Interior latex coatings: Flat: 100 grams/liter

B. Non-flat: 150 grams/liter

C. Interior oil-based paints: 380 grams/liter

Intent:
Reduce the amount of volatile organic compounds (VOCs) released to the outdoors and to reduce the formation of ground-level ozone.

Information / How to Implement:
VOC content of paints is categorized under Global Impacts rather than Indoor Environmental Quality because, once a homeowner moves into a new home, the vast majority of VOCs in paints have been released to the atmosphere and are thus not a significant impact on indoor environmental quality.

Although emissions of VOCs from paints can negatively affect indoor air, the half-life of VOCs in paints is usually shorter than the time between painting and homeowner occupancy. For example, paints cure and finish off-gassing in approximately four days; a home buyer typically occupies a home two to four weeks after painting.

Although the builder's paint isn't a big indoor pollutant, homeowners can be informed about the use of low-VOC-emitting paints when repainting the home in the future. There are paints certified as low-VOC emitting that are certified through GREENGUARD—an independent air-quality certification organization.

Note that low-VOC-content paints are not the same as low-VOC-emitting paints. The U.S. EPA established low-VOC-content standards based on a set of ozone-forming chemicals; these standards do not take into account the many other potentially hazardous chemicals found in indoor paint.

Low-VOC-content paints are widely available; by choosing them you contribute to a healthier environment. Check the label on the paint can for the VOC content.

Resources:



- Green Seal certifies low-content paints: www.greenseal.org/certproducts.htm#paints
- The GREENGUARD Environmental Institute (GEI) provides a guide to third-party-certified low-VOC-emitting interior products and building materials, www.greenguard.org
- Master Painters Institute, www.paintinfo.com
- National Paints and Coatings Association (NPCA), www.paint.org
- EPA's Environmentally Preferable Purchasing Guide, www.epa.gov/oppt/epp/documents/pfs.htm_(Sept 2004)

7.1.3 Use low-VOC sealants. VOC concentrations for construction adhesives and sealants should meet the limits specified in the California Air Resources Board Regulation for Reducing Volatile Organic Compound Emissions from Consumer Products as outlined below.

A. Construction adhesives: the greater of 15% by weight or 200 grams/liter

B. Sealants and caulks: the greater of 4% by weight or 60 grams/liter

C. Contact adhesives: the greater of 80% by weight or 650 grams/liter

Intent:
Use low-VOC sealants to reduce potentially harmful VOCs from being emitted into the environment.

Information / How to Implement:
Note that, like low-VOC-content paints, low-VOC-content sealants are not the same as low-VOC-emissions. The California Air and Resources Board created low-VOC-content standards based on a set of ozone-causing chemicals. Also, VOC content does not directly equate to VOC emissions. In addition, VOC emission rates and times are greatly affected by temperature, humidity, age, and other factors.

Resources:
- www.arb.ca.gov/consprod/consprod.htm
- California Air Resources Board, www.arb.ca.gov/consprod/regs/Cpreg.doc (Sept 2004)

7.2 INNOVATIVE OPTIONS

7.2.1 Builder's operations and business practices include environmental management system concepts (the builder must be ISO 14001 certified)

Intent:
Institutionalize and consistently apply the concept of incorporating environmental considerations into all phases of the company's operations.

Information / How to Implement:
At the time this document was created, there was only one ISO 14001 certified builder in the United States: Skanska USA.

You may be familiar with the 9000 series of international standards regarding quality management systems (QMS). As a continuation of this standardization process, the ISO 14000 series of international standards have been developed for environmental management systems (EMS).

In September 1996, the International Organization for Standardization (ISO) finalized the ISO 14001 standard for environmental management systems.

Similar to the QMS implemented for ISO 9001, the ISO14001 requires implementation of an EMS in accordance with defined, internationally recognized standards as set forth in the ISO14001 specification. The standard specifies requirements for establishing an environmental policy, determining environmental aspects and impacts of products/activities/services, planning environmental objectives and measurable targets, implementation and operation of programs to meet objectives and targets, checking and corrective action, and management review.

ISO14001 standards require a company to document and make this policy available to the public. In addition, the company must review the environmental aspects and impacts of products and then create and implement procedures to reduce them. The process of creating an EMS can help a company better understand how it affects the environment through all of its business processes.

Resources:

- Skanska USA's EMS information can be found at its website under Management Systems, www.skanska.com/
- The ISO 14001 Information Center provides information on the EMS at http://www.iso14000.com.

1.0 IDENTIFY GOALS WITH YOUR TEAM

Establish a knowledgeable team, and communicate in writing.

Intent:
One of the earliest challenges for a builder in developing a green lot is assembling an effective team to help implement best green practices throughout the process. Those involved in the development phase must understand the mission of the site, what it means to be a green lot, and why green practices should be followed. Once this baseline is established, coordination and communication with and among the various team members are essential to successful development.

Information / How to Implement:
Before ground is broken, all parties involved in lot development (the team) should understand that the lot will be developed as a green site. Team members can include staff, site superintendents, utilities, excavators, landscape architects, wildlife biologists, ecologists, and arborists. Once the green intent of the builder is communicated to the lot development team, the builder should work with the team throughout the development process to identify and delegate responsibilities of team members, as well as facilitate coordination between the members to achieve best green practices.

Resources:
- American Society of Consulting Arborists, www.asca-consultants.org/why.html
- American Society of Landscape Architects, www.asla.org/members/pigroups.cfm
- International Society of Arboriculture, www.isa-arbor.com/home.asp
- Society of American Foresters, www.safnet.org/certifiedforester
- The Ecological Society of America, www.esa.org

Establish a green development mission statement.

Intent:
Communicate relevant, streamlined green goals into the field to ensure that they are put into practice

Information / How to Implement:
Post the mission statement for all project personnel to see.

Resources:
Information will be added in Version 2.

Identify goals and objectives.

Intent:
Those involved in the development phase must understand the site's goals and objectives, what it means to be a green development, and why they should follow green practices.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

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Identify team member roles and how they relate to various phases of development.

Intent:
Before ground is broken, all parties involved in lot development (the team) should understand that the lot will be developed as a green site.

Information / How to Implement:
Examples of possible team members include staff, site superintendents, utilities, excavators, landscape architects, wildlife biologists, ecologists, and arborists.

Resources:
Information will be added in Version 2.

Provide training to onsite supervisors and team members on the green development practices that will be instituted onsite.

Intent:
The noblest intentions pursued in designing a site are practically achieved through onsite supervision during the lot development phase. A qualified member(s) of the builder's team should be onsite as these activities progress to ensure that each objective is achieved according to targeted green lot specifications.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

Create a checklist to be completed onsite that contains only those targeted green development practices that will be implemented in the project.

Intent:
A qualified member(s) of the builder's team should be onsite as these activities progress to ensure that each objective is achieved according to targeted green lot specifications. A checklist will facilitate the process of tracking progress.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

2.0 SELECT THE SITE

Select the site to minimize environmental impact.

Avoid environmentally sensitive areas as identified through site footprinting process or third party.

Intent:
Thoughtful site selection can be the first step in building a green home. By avoiding environmentally sensitive areas, a

builder can help preserve land that might function as a wildlife corridor, recreational open space, or habitat sanctuary. If a site is selected that at any time has been identified as an environmentally sensitive area, no credit will be given for this line item, regardless of the site's classification at the time of construction.

Information / How to Implement:
"Sensitive areas" may be identified within a comprehensive plan, by a wetland institute, or by the local jurisdiction. Other excellent sources of detailed environmental information about a site are professionals such as arborists, landscape architects, ecologists, and wildlife biologists. These experts can provide assistance in identifying a potential site's natural resources and environmentally sensitive areas.

Resources:
- American Society of Consulting Arborists, www.asca-consultants.org/why.html
- American Society of Landscape Architects, www.asla.org/members/pigroups.cfm
- International Society of Arboriculture, www.isa-arbor.com/home.asp
- Society of American Foresters, www.safnet.org/certifiedforester
- The Ecological Society of America, www.esa.org
- Choose an EPA-recognized Brownfield.

Choose an infill site.

Intent:
Remediation of a brownfield results in the environmental restoration of a polluted site, a transformation that makes an abandoned site habitable. Like greyfield and infill development, brownfield development provides an efficient use of land and infrastructure while allowing for the preservation of open space and wildlife habitat in the midst of growth.

Information / How to Implement:
The U.S. Environmental Protection Agency (EPA) characterizes brownfields as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." The EPA estimates that there are 450,000 brownfield sites around the country. Grants, loans, and training are available through the EPA's Brownfield Initiative to assist builders and developers in the remediation and development of Brownfield sites.

Resources:
- U.S. EPA, *Brownfields Cleanup and Redevelopment:* www.epa.gov/Brownfields/index.html
- U.S. EPA has introduced two Web-based tools to give the public additional access to information about brownfield properties and cleanup efforts. The tools allow residents to locate brownfields and provide access to information about cleanup grants—www.epa.gov/Brownfields/bfwhere.htm

Choose a Greyfield site.

Intent:
Redevelopment of a greyfield site can provide an efficient use of land and infrastructure. Greyfield redevelopment allows for the preservation of open space and wildlife habitat in the midst of growth.

Information / How to Implement:
Within these guidelines, a greyfield is defined as "any site previously developed with at least 50% of the surface area covered with impervious material." The development of a greyfield site can be daunting, but local or national incentives

may exist to reward builders who go through the process. Incentives may include the elimination of development-related fees, contribution from the local government in the development of offsite improvements, and tax breaks. For more information, see Resources.

Resources:

- Congress for the New Urbanism, www.cnu.org
- Urban Land Institute, www.uli.org
- American Planning Association, www.planning.org
- International Council of Shopping Centers, www.icsc.org
- Congress for the New Urbanism and PricewaterhouseCoopers, *Greyfields into Goldfields: from falling shopping centers to great neighborhoods* (February 2001), www.cnu.org/cnu_reports/Executive_summary.pdf
- Congress for the New Urbanism and PricewaterhouseCoopers, *Greyfield Regional Mall Study* (January 2001), www.cnu.org/cnu_reports/Greyfield_Feb_01.pdf

Choose an infill site.

Intent:
Building on an infill site can effectively conserve resources (e.g., infrastructure) and preserve open space that could be lost from "green field" development.

Information / How to Implement:
Infill areas are vacant or underutilized lots of land, served by existing physical installations such as roads, power lines, sewer and water, and other infrastructure.

Resources:

- Policy Link, Equitable Development Toolkit, Infill Incentives, www.policylink.org/EDTK/Infill
- Northeast-Midwest Institute and Congress for the New Urbanism, *Strategies for Successful Infill Development* (2001), www.nemw.org/infillbook.htm

3.0 DESIGN THE SITE

Minimize environmental impacts; protect, enhance, and restore the natural features and environmental quality of the site.

Conserve natural resources.

1. Complete a natural resources inventory that is used to drive/create the site plan.
2. Create a protection and maintenance plan for priority natural resources/areas during construction. *(See Section 4 for guidance in forming the plan.)*
3. Locate roads, buildings, and other built features to conserve high-priority vegetation.
4. Participate in a natural resources conservation program.

Intent:
Onsite natural resources concern features such as solar energy availability, flora, fauna, water, soil, and geological formations. A natural resources inventory should be completed to identify the site's environmental attributes. A builder can identify high-priority resources for conservation (e.g., trees, waterways, snags, micro-habitats) and plan for the conservation of those resources during each stage of site development.

Information / How To Implement:
On complex sites, a natural resources inventory may be performed by a qualified professional such as an arborist, wildlife biologist, or landscape architect. Simpler sites, such as previously developed sites or farmland, might be adequately inventoried by knowledgeable but less qualified individuals. Whoever ultimately conducts the inventory should be able to discern invasive from regionally appropriate vegetation, understand how to site a house to take advantage of solar energy, be able to identify areas important to wildlife habitat, and understand how natural features can be used in managing storm water onsite.

A protection and maintenance plan should be drafted to detail how resources identified through the inventory will be protected throughout development. Section 4 of this module provides details on how to protect existing onsite vegetation and minimize soil disturbance and erosion through installation of fencing, identification of specified washout and material storage areas, laying of mulch to reduce soil compaction, and other means. In addition to protecting priority areas from invasive species intrusion during development, a maintenance plan should be created to ensure that priority vegetation survives development. Within the maintenance plan, include plans and information on fertilizing and watering trees as needed before, during, and after development.

One way to verify that the plan is implemented as planned is to create construction documents that explain how to implement the plan during construction.

Resources:
- American Society of Consulting Arborists, www.asca-consultants.org/why.html
- American Society of Landscape Architects, www.asla.org/members/pigroups.cfm
- International Society of Arboriculture, www.isa-arbor.com/home.asp
- Society of American Foresters, www.safnet.org/certifiedforester

Orient streets and configure lots to allow for the majority of homes to optimize solar potential (see the Energy Efficiency module for guidance on solar resource optimization).

Intent:
Thoughtful orientation of a home can maximize solar heating potential in the heating season and minimize solar gains in the cooling season. By reducing non-renewable energy needs, orienting a home to optimize the solar resource reduces the life-cycle pollution caused by a home.

Information / How to Implement:
A builder should consider such issues such as slope, storm water management, local solar angles, and high-priority vegetation in determining the optimum site for each home. The final decision in siting a home will generally involve a compromise between these many factors.

Resources:
See Section 3.4 of this User Guide for resources.

Minimize slope disturbance.

1. Limit development footprint on steep slopes (slopes greater than or equal to 25%).
2. Complete a hydrological/soil stability study for steep slopes, and use this study to guide the design of all structures onsite.
3. Align roads with natural topography to minimize grade to reduce cut and fill.
4. Reduce long-term erosion effects through the design and implementation of terracing, retaining walls, and re-stabilization techniques.

Intent:
Leaving a slope undisturbed when siting a home reduces the chances of disturbing natural hydrological drainage and causing long- and short-term erosion, thereby reducing the potential to pollute water sources and damage local ecology.

Information / How to Implement:
Within these guidelines, steep slopes are defined as being greater than or equal to 25%. Note: Points should be awarded only if there are developable steep slopes in the area.

Reducing cut and fill practices can prevent unnecessary stripping of vegetation and loss of soils and reduce the need for additional resources to be brought in from offsite.

Resources:
- Prince George's County, Maryland, Department of Environmental Resources, *Low-Impact Development Design Strategies: An Integrated Design Approach* (EPA 841-B-00-003) (Largo, MD: June 1999), www.epa.gov/owow/nps/lid/lidnatl.pdf

Minimize soil disturbance and erosion.

1. Phase development in order to minimize exposed soils.
2. Use alternative means to install utilities, such as tunneling instead of trenching. Use smaller equipment, shared trenches or easements, and place utilities under streets instead of yards.

Intent:
Sediment and pollutants contained in the sediment are recognized as a reason that water bodies do not meet their intended uses. Exposed soils should be minimized to reduce erosion, promote water quality, and reduce damage caused to native vegetation. Heavy equipment and excessive digging can result in compaction or loss of topsoil along with the introduction of invasive and problematic flora. Minimizing soil disturbance and erosion can both reduce stressors on downstream water bodies and save valuable topsoil for the site.

Information / How to Implement:
NAHB's *Storm Water Permitting: A Guide for Builders and Developers* contains information about the federal Phase I and II storm water permitting program and the equivalent requirements for state storm water permits (see Resources section). *Storm Water Permitting* also contains technical information, including recommendations for use and cost estimates, on over 50 of the most commonly used best management practices; sample storm water pollution prevention plans; and tips on compliance, including how to handle visits from inspectors.

Methods for preventing erosion include silt fences, sediment traps, vegetated buffer areas, and mulching. More permanent solutions include biomechanical devices such as swales and vegetated buffers. Another highly effective, environmentally responsible method to prevent erosion is to use compost filter berms, compost erosion socks, and/or surface application of compost erosion control. The compost should be from organic sources like bioshields, yard waste, and wood chips. Turf and plant material—which help to facilitate the reestablishment of a natural environment—are established more quickly when organic compost is used.

Resources:
- National Association of Home Builders (NAHB), *Storm Water Permitting: A Guide for Builders and Developers*, 2005, store.builderbooks.com or 800-368-5242 x8163
- King County Department of Natural Resources, King County, Washington *Surface Water Design Manual Appendix D: Erosion and Sediment Control Standards* (Seattle: September 1998), ftp://ftp.metrokc.gov/ddes/acrobat/esa/kcswdm-d.pdf

- Dr. James R. Fazio, National Arbor Day Foundation, *Trenching and Tunneling: A Pocket Guide for Qualified Utility Workers* (Nebraska City, Nebraska: 1998), www.arborday.org/shopping/merchandise/merchdetail.cfm?id=62

Manage storm water properly.

1. Direct storm water to a locally approved regional storm water management and treatment facility that has been designed to address water quality.
2. Preserve and utilize natural water and drainage features.
3. Develop and implement storm water management plans that minimize concentrated flows and seek to mimic natural hydrology.
4. Minimize impervious surfaces, and utilize permeable materials for
    a. Parking areas
    b. Walkways
5. Minimize street widths and rights-of-way as per recommendations in either local code or in Residential Streets, 3rd Edition:
    a. No on-street parking: 18 feet
    b. Parking on one side: 22 to 24 feet
    c. Parking on both sides: 24 to 26 feet

Intent:
Percolation through soil is one of the most effective means for filtering pollutants carried by storm water. By using natural water and drainage features, minimizing impervious surfaces, and distributing storm water flows, builders can reduce harmful pollutants carried offsite while safely and effectively managing much of their storm water load onsite.

Information / How to Implement:
Use open space and natural systems such as vegetative swales, french drains, wetlands, dry wells, and rain gardens that promote water quality and infiltration.

Resources:
- The Practice of Low Impact Development, U.S. Department of Housing and Urban Development (HUD); www.huduser.org/publications/destech/lowimpactdevl.html
- Tom Schueler, Center for Watershed Protection, *Site Planning for Urban Stream Protection*, Ellicott City, MD, 1995, www.cwp.org/SPSP/TOC.htm
- Lisa Austin, Washington State Department of Ecology Water Quality Program, *Stormwater Management Manual for Western Washington* (Publication 99-12), September 2001, www.ecy.wa.gov/pubs/9912.pdf
- Betty Rushton, Southwest Florida Water Management District, *Low Impact Parking Lot Design Reduces Runoff and Pollutant Loads: Annual Report # 1.*, Brooksville, Florida, 1999

Where municipal sewage is not available, use an advanced wastewater system as an alternative to the conventional septic system and drain field. Examples include sand/media filters and aerobic treatment units.

Intent:
Refer to the Water Efficiency section of the User Guide for details on this topic.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

Devise landscape plans to limit water demand while preserving or enhancing the natural environment.

1. Formulate a plan to restore or enhance natural vegetation that is cleared during construction or development. Within this plan, phase landscaping to ensure denuded areas are quickly vegetated.
2. Select turf grass and other vegetation that are native or regionally appropriate species.
3. Limit turf areas of landscaped area, selecting native and regionally appropriate trees and vegetation in a way that complements the natural setting.
4. Group plants with similar watering needs (hydrozoning).
5. Specify planting of trees to increase site shading and moderate temperatures (see also Energy Efficiency Guideline 3.3.5.1 specifying siting of trees to reduce the energy consumption of the home).
6. Require onsite tree trimmings of regionally appropriate species to be used as protective mulch during construction or as a base for walking trails.
7. Establish an integrated pest management plan to minimize chemical use in pesticides and fertilizers.

Intent:
Landscaping water use accounts for approximately 50% of a home's total water needs. Conservation of this valuable resource through such techniques as hydrozoning, reducing turf area, and selecting regionally appropriate plants is a key component to responsible building. Thoughtful selection and placement of plants can also reduce heating/cooling loads of a home, provide habitat for native fauna, and minimize the heat-island effect of developments.

Information / How to Implement:
Select landscaping materials and vegetation to fit site conditions. Regionally appropriate plants are hardy plants that can withstand local water and temperature conditions such as freeze, heat, drought, and rain. Regionally appropriate plants will also not be overly prolific or invasive, and will be able to coexist with other native plants over time.
Other benefits of landscaping with native plants: minimizes maintenance (reduces emissions of equipment); fosters wildlife habitat. See EPA's Mid-Atlantic Region Green Landscaping http://www.epa.gov/reg3esd1/garden/what.htm for more information.

When planning for the revegetation of a site, consider the multiple services that natural areas can provide: natural habitat, storm water processing, shading, windbreak, etc. Trees that shade the streets can keep a neighborhood cool while also increasing the neighborhood's attractiveness. Properly selected plants can be grouped to serve as a bioretention zone. Deciduous trees allow the sun's rays through in winter and provide shade in the summer. Evergreens can provide an effective windbreak. Careful selection and integration of trees and vegetation can reduce a developer's initial costs while providing value to a development/neighborhood later. When planting trees, several factors should be taken into account such as the value of shading (trees shading asphalt will mitigate a site's temperature more than trees shading landscaped areas), maintaining a safe distance from the house (especially in areas prone to natural disasters), ultimate tree size, etc.

Developers may wish to consider enforcing guidelines for the protection of onsite vegetation. Some developers even fine builders for damage to areas designated for protection.

If grinding and scattering cleared plants, care should be taken to grind only regionally appropriate plants. Grinding of invasive species can increase their propagation and result in the ultimate destruction of native species.

One of the best ways to reduce energy consumption is through passive solar design of a home—using orientation, overhangs, fenestration, etc. Landscaping to reduce energy consumption is only part of the whole effort.
It is good practice to limit the ratio of turf area to total landscaped area due to maintenance requirements of turf versus native plants and regionally appropriate vegetation. In some areas, there may be restrictions on the percentage of turf that the front yard must contain. Research has shown that homeowners are comfortable with having as little as 50% of the front yard composed of turf. Fewer regulations are imposed on turf-to-landscaping ratio in the backyard, so good gains might be made more easily there. For research on turf and landscape of front yards with native species, see Nassauer, Joan, 1995. Messy Ecosystems, Orderly Frames. Landscape Journal, 14 (2), 161-170.

In areas with low annual rainfall, one way to account for water usage is through the development and implementation of a water budget.

Resources:
- Center for Plant Conservation, www.mobot.org/CPC
- Lady Bird Johnson Wildflower Center, Native Plant Information Network National Suppliers Directory, www.wildflower2.org/NPIN/Suppliers/suppliers.html
- New England Wildflower Society, *Native Plant Societies of the United States and Canada*, www.newfs.org/nps.htm
- NAHB Research Center Inc., Onsite Grinding of Residential Construction Debris: The Indiana Grinder Pilot, February 1999

Maintain wildlife habitat.

1. Preserve open space as wildlife corridors where possible.
2. Submit evidence of wildlife habitat preservation and improvements to the green development guidelines' administrator for review.
3. Participate in a wildlife conservation program.

Intent:
As the frontier of home building continues to expand, sharing the land with wildlife becomes an increasing challenge to builders. Through individual initiative or participation in a wildlife conservation program, home builders can work to create a habitat where both wildlife and humans can thrive—whether in an urban, suburban, or rural setting.

Information / How to Implement:
Examples of programs: USDA National Resources Conservation Service's Backyard Conservation Plan, the Audubon Cooperative Sanctuary System's Treasuring Home Initiative, or the National Wildlife Federation's Backyard Wildlife Habitat Program

Enhance quality of habitat, including food sources, diversity of habitat, and protective areas, through selective plantings and site design.

Leave snags (dead tree or portion that's left for habitat). Birdhouses.

Resources:
- Audubon International, *Audubon Cooperative Sanctuary System*, www.audubonintl.org/programs/acss. Audubon Cooperative Sanctuary System's Treasuring Home Initiative.
- Become a certified participant in the National Wildlife Federation's Backyard Wildlife Habitat Program. https://secure.nwf.org/backyardwildlifehabitat/certify/page1.cfm

Prepare operation and maintenance plan (manual) for transfer of common open spaces, utilities (storm water, wastewater), and environmental management.

Intent:
Green land use features often require ongoing maintenance so that they can continue to function as designed. Planning for such operations and maintenance prior to implementing the features is important and can help the long-term viability of such features.

Information / How to Implement:
Many manufacturers and distributors of green land use features and technologies also sell annual and/or long-term maintenance plans. Ask the manufacturers and/or distributors of the particular technology you're planning on implementing for such a service plan.

Resources:
Information will be added in Version 2.

Disassemble existing buildings, and reuse or recycle the building materials (deconstruction) instead of demolishing.

Intent:
See the Resource Efficiency section for details on this topic.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

4.0 DEVELOP THE SITE

Minimize environmental intrusion during onsite construction.

Provide onsite supervision and coordination during clearing, grading, trenching, paving, and installation of utilities to ensure that targeted green development practices are implemented.

Intent:
The noblest intentions when designing a green site are practically achieved through onsite supervision during the lot development phase. A qualified member(s) of the builder's team should be onsite as these activities progress to ensure that each objective is achieved according to targeted green lot specifications.

Information / How to Implement:
The information for this line item should link to the plans and any documents produced in line item 1.3.5.

Resources:
Information will be added in Version 2.

Conserve existing onsite vegetation.

1. Provide basic training in tree and other natural resource protection to onsite supervisor.
2. Minimize disturbance of and damage to trees and other vegetation designated for protection through installation of fencing and avoidance of trenching, significant changes in grade, and compaction of soil and critical root zones.

3. Prepare designated existing trees and vegetation for the impacts of construction through pruning, root pruning, fertilizing, and watering.
4. Improve the soil with organic amendments and mulch.

Intent:
After a builder has identified (during the planning stage) the existing vegetation that will be conserved onsite, practical steps must be taken during the development stage to achieve the intended conservation. Such steps include pre-development preparation of the vegetation and protection of the foliage, soil, and root system of designated vegetation.

Information / How to Implement:
See Resources section.

Resources:
- National Arbor Foundation, *Building With Trees,* www.arborday.org/programs/Buildingwithtrees/index.cfm
- Phillip A. Pratt and Michael W. Schnelle, Oklahoma State University, Oklahoma Cooperative Extension Service, *Site Disturbance and Tree Decline* (OSU Extension Facts F-6429), September 2003, http://osuextra.com/pdfs/F-6429web.pdf

Minimize onsite soil disturbance and erosion.

1. Demarcate limits of clearing and grading.
2. Create construction "no disturbance" zones using fencing or flagging to protect vegetation and sensitive areas from construction vehicles, material storage, and washout.
3. Install and maintain sediment and erosion controls.
4. Stockpile and cover good soil for later use.
5. Reduce soil compaction from construction equipment by laying mulch, chipped wood, or plywood sheets.
6. Stabilize disturbed areas within the 14-day period recommended by EPA.

Intent:
This guideline seeks to ensure the field implementation of conservation plans. Each measure identifies a practical way to foster water quality and conserve onsite ecological habitat through reducing soil disturbance and erosion.

Information / How to Implement:
Soil stabilization may be temporary or permanent.

Keep in mind that while the use of stockpiled onsite soil is a preferred method, excavation, stockpiling, grinding, and screening destroy the ecological microsystem of the soil. Rejuvenation of the unimproved soil to its original form will take several years. To offset this phenomenon, the incorporation of compost and sand is an effective method for more rapidly rebuilding the structure and ecosystem of the topsoil and allowing turf and plants to establish more quickly. As indicated above, compost is recommended for this purpose.

When additional soil must be brought in, there are environmental advantages of using industrial by-products as ingredients in topsoil including foundry sand, biosolids compost, and other EPA-approved by-products. In addition to keeping these materials out of community landfills, processing techniques produce superior topsoil.

The use of organic mulch is an excellent way to conserve water in landscape beds and build soil quality. Ideally, use mulch that results from onsite recycling efforts such as yard waste, processed pallets, and other clean wood from construction waste.

Resources:

- King County Department of Natural Resources, King County, Washington *Surface Water Design Manual Appendix D: Erosion and Sediment Control Standards* (Seattle: September 1998), ftp://ftp.metrokc.gov/ddes/acrobat/esa/kcswdm-d.pdf

5.0 INNOVATIVE OPTIONS

Seek to obtain waivers or variances from local development regulations to enhance green building.

Cluster development to preserve meaningful open space.

Intent:
Preserve meaningful open space, and reduce infrastructure and long-term maintenance costs.

Information / How to Implement:
During the past 50 years, a steady migration from urban to suburban areas and into the countryside has constituted a significant trend throughout much of the United States. In response to this phenomenon, planners, developers, and elected officials have created a number of tools designed to balance growth with the preservation of community environmental and financial assets. One tool that has received an increasing amount of attention lately is cluster development. This approach may be termed open-space development, conservation development, hamlet style, farm village, or other unique names coined by proponents and developers. Regardless of the title used to describe it, cluster development is an important tool community planners should consider as they look to the future. The purpose of this fact sheet is to describe cluster development, its history, potential, and limitations.

Resources:

- U.S. Environmental Protection Agency, Development, Community, and Environment Division, *Our Built and Natural Environments* (EPA 231-R-01-002) (Washington, DC: 2001), www.epa.gov/smartgrowth/pdf/built.pdf
- Urban Land Institute, www.uli.org/DK/index.cfm?CFID=526893&CFTOKEN=67483350

Reduce street widths.

Intent:
Reduce the amount of impervious surface and storm water runoff in the development.

Information / How to Implement:
Street widths have the largest impact on runoff and on costs. Unfortunately, most communities have ordinances requiring excessively wide streets. Developers may be able to negotiate changes for a particular development but will likely have to seek changes to local land development standards to change street-width requirements more generally.
The publication, Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation (HUD and NAHB Research Center, 1993), includes recommendations for minimum street widths that recognize the cost and environmental benefits of narrower versus wider streets (see below) and other cost-effective development strategies. It also includes recommendations for turnarounds, another location where the pavement area can be reduced.

Recommendations for Minimum Street Widths

Widths of Traveled Way
Minimum Width of Traveled Way (ft.)

Street Type	Both On- and Off-Street Parking (1)	One-Way Street (2
Major Collector	20 (3)	10
Collector	36 (4)	26
Subcollector	26–28 (4, 5)	26
Access	18–22 (5)</SUP< p>	18

Where no off-street parking is provided, the minimum width of traveled way for collector streets shall be 36 feet, and 34 feet for subcollector and access streets (two 9- or 10-foot travel lanes and two 8-foot parking lanes). Major collectors do not typically accommodate on-street parking. Access street width can be reduced to 26 feet if parking needs are met on one side of the street and restricted to that side only.

Where on-street parking is not permitted, the one-way street width may be reduced to 10 feet.

Parking is not allowed on major collector streets. Travel lanes may be added in accordance with traffic requirements.
Width can be reduced to 20 feet if on-street parking is not permitted.

Minimum street width shall be selected by taking into consideration the size of fire and emergency equipment that will serve the development.

Resources:

- Better Site Design Fact Sheet: Narrower Residential Streets, www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/narrow_streets.htm

Install an advanced wastewater treatment system.

Intent:
See the Water Efficiency section of the User Guide for more details on this topic.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

Install an advanced storm water treatment system.

Intent:
Percolation through soil is one of the most effective means for filtering pollutants carried by storm water. By using natural water and drainage features, minimizing impervious surfaces, and distributing storm water flows, builders can reduce harmful pollutants carried offsite while safely and effectively managing much of their storm water load onsite.

Information / How to Implement:
This line item would be over and above what is done for line item 1.3.5. Use open space and natural systems such as vegetative swales, french drains, wetlands, dry wells, and rain gardens that promote water quality and infiltration.

Resources:
- *The Practice of Low Impact Development*, U.S. Department of Housing and Urban Development (HUD); www.huduser.org/publications/destech/lowimpactdevl.html
- Tom Schueler, Center for Watershed Protection, *Site Planning for Urban Stream Protection* (Ellicott City, MD: 1995), www.cwp.org/SPSP/TOC.htm
- Lisa Austin, Washington State Department of Ecology Water Quality Program, *Stormwater Management Manual for Western Washington* (Publication 99-12) (September 2001), http://www.ecy.wa.gov/pubs/9912.pdf
- Betty Rushton, Southwest Florida Water Management District, *Low Impact Parking Lot Design Reduces Runoff and Pollutant Loads: Annual Report # 1.* (Brooksville, Florida: 1999)

Institute wildlife habitat measures.

Intent:
As the frontier of home building continues to expand, sharing the land with wildlife becomes an increasing challenge to builders. Through individual initiative or participation in a wildlife conservation program, home builders can work to create a habitat where both wildlife and humans can thrive—whether in an urban, suburban, or rural setting.

Information / How to Implement:
Examples of programs include the USDA National Resources Conservation Services Backyard Conservation Plan, the Audubon Cooperative Sanctuary System,s Treasuring Home Initiative, and the National Wildlife Federations Backyard Wildlife Habitat Program.

Enhance quality of habitat, including food sources, diversity of habitat, and protective areas, through selective plantings and site design.

Leave snags (dead tree or portion thats left for habitat).

Resources:
- Audubon International, *Audubon Cooperative Sanctuary System*, www.audubonintl.org/programs/acss. Audubon Cooperative Sanctuary System,s Treasuring Home Initiative.
- Become a certified participant in the National Wildlife Federation,s Backyard Wildlife Habitat Program. https://secure.nwf.org/backyardwildlifehabitat/certify/page1.cfm

Minimize grading.

Intent:
Excessive grading can disturb a site's natural drainage, vegetation, and ecological habitat. If topsoil removed during grading is not replaced, the health of the site's future ecological system may be compromised as well.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

Share driveways or parking

Intent:
Sharing driveways or parking can reduce the amount of impervious material on a lot, thereby decreasing storm water and pollution runoff.

Information / How to Implement:
Information will be added in Version 2.

Resources:
Information will be added in Version 2.

Other (specify).
Information will be added in Version 2.

SARB_006286

What is Low Impact Development (LID)?

Ever wish you could simultaneously lower your site infrastructure costs, protect the environment, and increase your project's marketability? With LID techniques, you can. LID is an ecologically friendly approach to site development and storm water management that aims to mitigate development impacts to land, water, and air. The approach emphasizes the integration of site design and planning techniques that conserve the natural systems and hydrologic functions of a site.



Source: Prince George's County, DER

Residential Lot with Bioretention

Somerset Development
Prince George's County, MD

LID Benefits

In addition to the practice just making good sense, LID techniques can offer many benefits to a variety of stakeholders.

Developers
- Reduce land clearing and grading costs
- Potentially reduce infrastructure costs (streets, curbs, gutters, sidewalks)
- Reduce storm water management costs
- Potentially reduce impact fees and increase lot yield
- Increase lot and community marketability

Municipalities
- Protect regional flora and fauna
- Balance growth needs with environmental protection
- Reduces municipal infrastructure and utility maintenance costs (streets, curbs, gutters, sidewalks, storm sewer)
- Increase collaborative public/private partnerships

Environment
- Preserve integrity of ecological and biological systems
- Protect site and regional water quality by reducing sediment, nutrient, and toxic loads to water bodies
- Reduce impacts to local terrestrial and aquatic plants and animals
- Preserve trees and natural vegetation

Cover Photo: R. Arendt

Case Study

Kensington Estates is a conventional development on 24 acres consisting of 103 single-family homes in Pierce County, WA. A study was conducted to redesign the site using a new state storm water model and to illustrate the full range of LID practices and technologies available to developers.

Overall, the redesigned LID site could have:
- Resulted in construction cost savings of over 20%;
- Preserved 62% of the site in open space;
- Maintained the project density of 103 lots;
- Reduced the size of storm pond structures and eliminated catchments and piped storm conveyances; and
- Achieved "zero" effective impervious surfaces.



Source: AHBL, Inc.

Cost Comparison: LID vs. Conventional Development

For More Information

- Low Impact Development Center
  http://www.lowimpactdevelopment.org
- Prince George's County, Maryland
  http://www.goprincegeorgescounty.com
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Builder's Guide to Low Impact Development

Would you be interested in saving upwards of $70,000* per mile in street infrastructure costs by eliminating one lane of on-street parking on residential streets?

Did you know that communities designed to maximize open space and preserve mature vegetation are highly marketable and command higher lot prices?

Are you aware that most homeowners perceive Low Impact Development practices, such as bioretention, as favorable since such practices are viewed as additional builder landscaping?

Did you know that by reducing impervious surfaces, disconnecting runoff pathways, and using on-site infiltration techniques, you can reduce or eliminate the need for costly storm water ponds?

SARB_006287

LID Site Planning and Design Concepts

Successful LID projects simultaneously reduce land development and infrastructure costs while protecting a property's natural resources and functions. During the development process, the designer, developer, and reviewing agency should work together to identify solutions that integrate the following concepts:

- Preserve Open Space and Minimize Land Disturbance;
- Protect and Incorporate Natural Systems (wetlands, stream/wildlife corridors, mature forests) as Design Elements;
- Utilize Neo-Traditional Street and Lot Layouts and Designs; and
- Decentralize and Micromanage Storm Water at its Source Using LID Storm Water Management Practices.

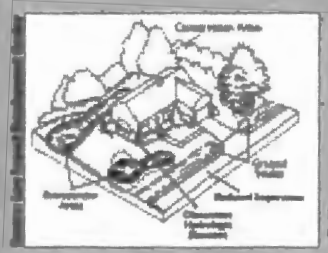
LID and Storm Water Management

LID aims to mimic natural hydrology and processes by using small-scale, decentralized practices that infiltrate, evaporate, and transpire rainwater. Specifically, LID aims to:

- Minimize impervious surfaces;
- Disconnect hydrologic elements (roofs, downspouts, parking areas);
- Maintain/increase flow paths and times; and
- Utilize decentralized treatment practices.

Bioretention Areas
Storm water directed to these shallow topographic depressions in the landscape is filtered, stored, and infiltrated into the ground using specialized vegetation and engineered soils.

Grassed Swales
Water moving through these systems is slowed, filtered, and percolated into the ground. These systems can act as low cost alternatives to curbs, gutters, and pipes.



LID Lot Level Source Controls

Preserve Open Space and Minimize Land Disturbance



Source: Bielinski Homes

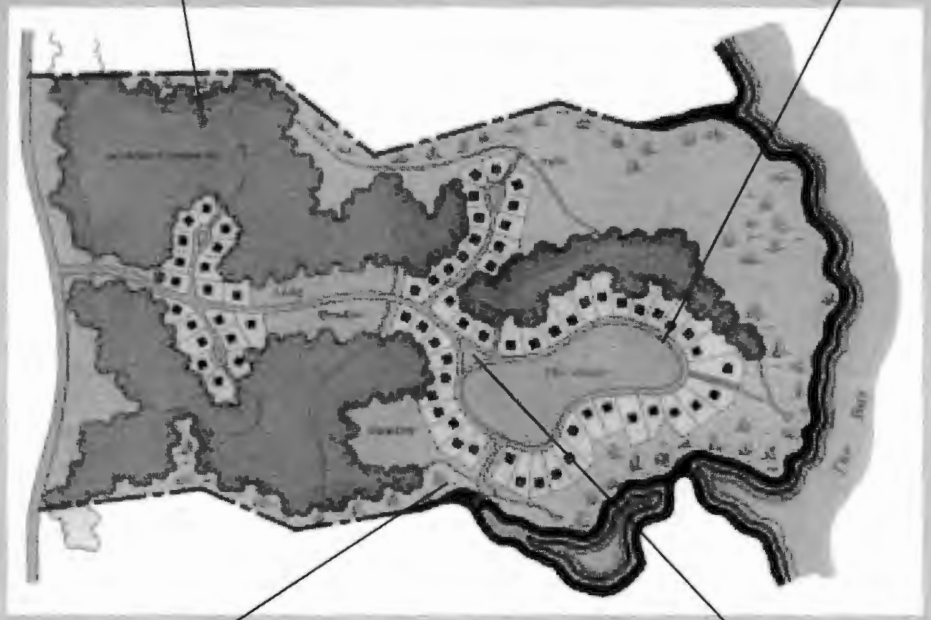
Community Open Space
Bielinski Homes
Waukesha, WI

Decentralize and Micromanage Storm Water at its Source using LID Storm Water Management Practices



Source: Low Impact Development Center

Grassed Swales
Somerset Development
Prince George's County, MD



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Protect and Incorporate Natural Systems as Design Elements



Source: Applied Ecological Services, Inc.

Wetland System
Prairie Crossing
Grayslake, IL

Utilize Neo-Traditional Street and Lot Layouts and Designs



Source: OPT & Co.

Bowman Park
Vermillion Community
Vermillion, NC

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Electrical/Electronics
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Foundations
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Guides to Low Impact Development

Builder's Guide to Low Impact Development 94 KB /PDF
Municipal Guide to Low Impact Development 92 KB /PDF

March 2003

Ever wish you could simultaneously lower your site infrastructure costs, protect the environment, and increase your project's marketability? Using Low Impact Development (LID) techniques you can. LID is an ecologically friendly approach to site development and storm water management that aims to mitigate development impacts to land, water, and air. The approach emphasizes the integration of site design and planning techniques that conserve natural systems and hydrologic functions on a site.

LID has a variety of benefits to Builders, Municipalities, and the Environment such as:

- The reduction of land clearing and grading costs;
- Balancing the need for growth and environmental protection;
- The protection of local land and water resources.

LID utilizes a system of source controls and small-scale, decentralized treatment practices to help maintain a hydrologically functional landscape. The conservation of open space, the reduction of impervious surfaces, and the use of small-scale storm water controls, such as bioretention, are just a few of the LID practices that can help maintain predevelopment hydrological conditions.

SARB_006289

Featured case study

Somerset is an 80-acre development in suburban Maryland consisting of 199 homes on 10,000 square foot lots. During Somerset's creation, the developer used LID practices to reduce its storm water management costs. By using LID, the developer:

- Eliminated the need for storm water ponds by using bioretention techniques saving approximately $300,000;
- Gained 6 additional lots and their associated revenues;
- Reduced finished lot cost by approximately $4,000.

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SARB_006290

Low Impact Development (LID) Practices for Storm Water Management

A cost effective way to address storm water management through site design modifications and "Best Management Practices"

Summary



Water quality concerns have intensified, and storm water management practices have come under scrutiny, as development occurs on an increasing percentage of the available land area in the United States. With more stringent design requirements, costs for traditional collection and conveyance systems have risen sharply. Organizations from community groups, to regional watershed authorities, to state and federal agencies have become involved in this issue. Subsequent changes in storm water regulations could strongly impact builders and communities as more new regulations and practices are implemented. Low Impact Development (LID) techniques can offer developers a more cost effective way to address storm water management through site design modifications and "Best Management Practices" (BMPs). These strategies allow land to be developed in an environmentally responsible manner, and create a more "Hydrologically Functional" landscape.

In 1998, a report on Stream Corridor Restoration was produced by the Federal Interagency Stream Restoration Working Group (FISRWG) documenting the impact of human activities on the stream systems forming the backbone of watersheds throughout the United States. This group represents 15 Federal agencies from the Departments of Agriculture, Commerce, Interior, Defense, Housing and Urban Development (HUD), Environmental Protection Agency (EPA), Federal Emergency Management Agency (FEMA), and Tennessee Valley Authority (TVA). The following illustration from the report shows how development affects water infiltration into soils and runoff.

Less developed land areas allow a larger portion of storm water to seep gradually into soils, remove contaminants, replenish soil moisture, and recharge groundwater aquifers. As areas become developed, a much larger percentage of rainwater hits impervious surfaces including roofs, sidewalks, parking lots, driveways, and

SARB_006291

streets, and must be controlled through storm water management techniques. Traditional approaches have focused on collection and conveyance to prevent property damage. Local building code requirements often require developers to take an "end of pipe" approach, using gutters and piping systems to carry rainwater into ponds or detention basins. As new requirements have attempted to address water quality, erosion, flow volume, and other problems created by common conveyance methods, the cost and complexity of these engineered systems has increased.

Low Impact Development (LID) strategies strive to allow natural infiltration to occur as close as possible to the original area of rainfall. By engineering terrain, vegetation, and soil features to perform this function, costly conveyance systems can be avoided, and the landscape can retain more of its natural hydrological function. Low Impact Development practices dovetail with "green" building practices that incorporate environmental considerations into all phases of the development process. Builders can often use green building and LID to lower actual development costs. Although most effective when implemented on a community-wide basis, using LID practices on a smaller scale, i.e., on individual lots, can also have an impact.

Pollution from storm water runoff can also be a major concern, especially in urban areas. Rainwater washing across streets and sidewalks can pick up spilled oil, detergents, solvents, de-icing salt, pesticides, fertilizer, and bacteria from pet waste. Storm water drains do not typically channel water to treatment facilities, but carry runoff directly into streams, rivers, and lakes. Most surface pollutants are collected during the first one-half inch of rainfall in any "storm event". This is the period when the majority of pathogens, sediment, waste and debris are picked up by flow across lawns and roadways. Carried untreated into streams and waterways, these materials become "non-point source pollutants" which can increase algae content, reduce aquatic life, and require additional costly treatment to make the water potable for downstream water systems. LID design principles can be used as buffers to filter these pollutants before they reach aquifers. For traditional conveyance systems, specially designed catchbasins may be required to perform a "first flush" filtering function using various technologies for collection of sediment and contaminants. Some units are designed to retrofit existing storm water inlets. Manufacturers include AquaShield, Stormtreat Systems, Inc, Stormceptor, and Stormwater Management Co.

On September 21-23, 2004 the first national Low Impact Development (LID) Conference, called Putting the LID on Stormwater Management, took place in College Park, Maryland. It highlighted innovative LID techniques designed to minimize the effect of development on watersheds. Presenters of over 85 papers provided insight into a variety of Low Impact Development projects conducted nationwide.

The Future of LID

During the Conference's closing session, Future Vision of LID and Storm Water Management, a panel of experts reflected upon the current state of LID and the direction in which LID is headed. One common theme was that LID is a concept where residential developers, local public planners, engineers, citizens, and environmental groups all can support the idea of using water as a resource, reducing stream erosion, and pretreating storm water before it enterways waterways and recharges groundwater aquifers.

LID should be more than just new storm water technologies for single

lots. LID should be about looking at water resources in a holistic, watershed-based manner, and effectively managing such resources. Such an approach involves conserving water inside and outside a house, using decentralized storm water management BMPs for single lots and larger-scale developments, and identifying the best ways to handle wastewater. The HUD publication, The Practice of Low Impact Development, provides ways to help public and private sectors meet the goal of creating a comprehensive approach to water resources management.

Low Impact Design Strategies:

The strategies fall under the two broad categories of **practices** and **site design**. The most common concepts are summarized below:

Practices:

Basic LID strategy for handling runoff is to: 1) reduce the volume of runoff and 2) decentralize flows. This is usually best accomplished by creating a series of smaller retention/detention areas that allow localized filtration rather than carrying runoff to a remote collection area. For the practices noted below, special attention should be paid to the composition of existing soils, as well as new soils or amended soils used, and underlying topography. For instance, a locale with karst topography may react differently to introduction of LID practices than a site that does not have underground channels. Common methods include:

- **Bio-retention cells** typically consist of grass buffers, sand beds, a ponding area for excess runoff storage, organic layers, planting soil and vegetation. Their purpose is to provide a storage area, away from buildings and roadways, where storm water collects and filters into the soil. Permanent ponds can be incorporated into the cell design as landscaping features. Temporary storage areas without ponds may be called detention cells. Bioretention areas have also been called rain gardens since they are typically landscaped with native plants and grasses, selected according to their moisture requirements and ability to tolerate pollutants. Annual maintenance of bioretention cells must be planned in order to replace mulching materials, remove accumulated silt, or revitalize soils as required.
- **Grass swales** function as alternatives to curb and gutter systems, usually along residential streets or highways. They use grasses or other vegetation to reduce runoff velocity and allow filtration, while high volume flows are channeled away safely. Features like plantings and checkdams may be incorporated to further reduce water velocity and encourage filtration. Walkways are either separated from roadways by swales, or relocated to other areas. In areas where salts are commonly used for winter de-icing, careful attention must be paid to selecting plant species which are salt tolerant.
- **Filter strips** can be designed as landscape features within parking lots or other areas, to collect flow from large impervious surfaces. They may direct water into vegetated detention areas or special sand filters that capture pollutants and gradually discharge water over a period of time.
- **Disconnected impervious areas** direct water flows collected from structures, driveways, or street sections, into separate localized detention cells instead of combining it in drainpipes with other runoff. Disconnecting the flow limits the velocity and overall amount of conveyed water that must be handled by end-of-pipe facilities.
- **Cistern collection systems** can be designed to store rainwater for dry-period irrigation, rather than channeling it to streams. Smaller tanks that collect residential roof drainage are often called "rain barrels" and may be installed by individual homeowners. Some collection systems are designed to be

installed directly under permeable pavement areas, allowing maximum water storage capacity while eliminating the need for gravel beds. Other innovative systems incorporate graywater collection for additional water conservation (see separate PATH Technology Inventory article on Graywater Reuse).

Site Design:

Decreasing Impervious Surfaces can be a simple strategy to avoid problems from storm water runoff and water table depletion, by reducing surfaces that prevent natural filtration. Methods may include:

- **Reducing Roadway Surfaces** can retain more permeable land area. In some cases, planners have reduced pavement needs by up to 40% by using longer, undulating roads that create more available lot frontage, instead of wide shorter streets with more intersections. Other options may include shared driveways, "flag" lots with reduced street frontage, landscaped detention islands within cul-de-sacs, or alternate designs for turn-around areas.
- **Permeable Pavement Surfaces** can be constructed from a variety of materials, including traditional asphalt and concrete, gravel or pavers. Permeable roadway or parking areas allow water to flow through, replenishing soil areas directly beneath. However, the sub-base underneath permeable pavements must be engineered to accommodate temporary water storage and filtration. In many cases, permeable surfaces can reduce or eliminate the need for traditional storm water structures. Further information is available in a separate PATH Technology Inventory article titled "Permeable Pavement."
- **Vegetative Roof Systems** create a lightweight, permeable vegetative surface on an impervious roof area. Moss, grass, herbs, wildflowers, and native plants can be used, creating an aesthetically pleasing roof landscape. The systems start with a high strength rubber membrane placed over the base roof structure. Various layers above the rubber may contain insulation, filter and drainage media, separation fabrics, lightweight growth media, vegetation, and wind erosion fabric. Some systems even incorporate rainbarrel runoff collection, pumping, and irrigation equipment. These systems are more costly than standard roofs, and have not been used on a large scale for residential development in the U.S.

Planning site layout and grading to natural land contours can minimize grading costs and retain a greater percentage of the land's natural hydrology. Contours which function as filtration basins can be retained or enhanced, and incorporated into the landscaping design.

- **Natural Resource Preservation and Xeriscaping** can be used to minimize the need for irrigation systems and enhance property values. Riparian, or stream bank, areas are particularly crucial to water quality, and in most areas, subject to Federal or State regulations. Preserving existing wooded areas, mature trees, and natural terrain, can give new developments a premium "mature landscape" appearance and provide residents with additional recreational amenities. Both of these features can improve marketability. Xeriscaping refers to landscaping with plants native to area climate and soil conditions. These plants thrive naturally, requiring less maintenance and irrigation than most hybrid or imported varieties. For more information, refer to the separate PATH Technology Inventory article on this subject. XeriscapeTM is a registered trademark of Denver Water, Denver, CO.
- **Clustering Homes** on slightly smaller lot areas can allow more preserved open space to be used for recreation, visual aesthetics, and wildlife habitat. Clustering can reduce infrastructure costs to the builder, since fewer feet of pipe, cable, and pavement are needed, and maintenance costs are reduced for homeowners. Builders in many areas have been able to charge a premium price for "view lots" facing undisturbed natural

vistas, or pond areas that also function as bioretention cells.

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PATH Attributes

It has been shown in side to side comparison that careful integration of LID Practices can be less espensive than actually integrating drainage and piping for retention basins, etc. This lowers costs for the developers while alowwing for environmentla performance.

Because natural filtration methods are used, run-off polution is reduced, resulting in less polution of waterways and other vegetation. In addition, the vegetation used for filtering still thrives and provides oxygen.

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Ease of Implementation



Consultation with environmental planners and engineers is critical for determining how to integrate LID practices. In some situations, they may not be practical or useful at all. However, once planned, such systems may be easier to install than their conveyance method counterparts.

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Initial Cost NA

If planned correctly, LID practices can be installed for a lower cost than other storm and water management options. Though vegetative roof systems and cisterns may be expensive initially, they can provide for energy and utility savings in the future

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Operational Cost NA

Proper maintenance and groundskeeping must be employed for the system to perform properly, but this is no more expensive than typical landscaping.

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U.S.Code Acceptance

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Statutes mandating the implementation of storm water management plans include: The Clean Water Act (Wetlands, Section 404; Storm water, Section 402), the National Pollutant Discharge Elimination System (NPDES) regulations, and in some cases, State Pollutant Discharge Elimination Systems (SPDES). State, local, or subdivision codes and zoning requirements may dictate designs or systems which are sometimes not consistent with current LID strategies. Especially in largely developed areas, however, the trend is for land-use or water-basin management authorities to mandate more stringent storm water management planning and practices.

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Field Evaluations

Not Applicable

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Installation

Low Impact Development requires more precise engineering for soil characteristics, filtration rates, water tables, native vegetation, and other site features. Participation of environmental consultants and planners is critical from the earliest planning phases for residential development.

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Warranty

Not Applicable

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Benefits/Costs

Cost benefits to builders and developers utilizing LID strategies can be significant. According to the Center for Watershed Protection, traditional curbs, gutters, storm drain inlets, piping and detention basins can cost two to three times more than engineered grass swales and other techniques to handle roadway runoff. Other LID strategies can have similar impact. Choosing permeable pavement for a parking area may remove the need for a catchbasin and conveyance piping. Small distributed filtration areas on individual lots can reduce site requirements for larger detention ponds that take up valuable land area.

Not all sites can effectively utilize LID techniques. Soil permeability, slope, and water table characteristics may limit the potential for local infiltration. Urban areas and locations with existing high contaminant levels may be precluded from using LID filtration techniques.

Many existing local codes, zoning regulations, parking requirements and street standards were developed prior to the emergence of water quality and storm water management concerns, and may prohibit or inhibit implementing LID practices.

Established practices can be difficult to modify, although cost factors may help drive change. Additionally, there may be negative perceptions among homebuyers. Even though many buyers welcome naturalistic features proscribed by LID, others may prefer large flat lots with wide curbed streets. While traffic studies have not borne out the theory, some consumers perceive curbs to be a safety feature for pedestrians. Others fear that the lack of conventional storm water systems will result in basement flooding or structural damage.

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What is Low Impact Development (LID)?

LID is an ecologically friendly approach to site development and storm water management that aims to mitigate development impacts to land, water, and air. The approach emphasizes the integration of site design and planning techniques that conserve natural systems and hydrologic functions on a site. The practice has been successfully integrated into many municipal development codes and storm water management ordinances throughout the United States. Specifically, LID aims to:

- Preserve Open Space and Minimize Land Disturbance;
- Protect Natural Systems and Processes (drainage ways, vegetation, soils, sensitive areas);
- Reexamine the Use and Sizing of Traditional Site Infrastructure (lots, streets, curbs, gutters, sidewalks) and Customize Site Design to Each Site;
- Incorporate Natural Site Elements (wetlands, stream corridors, mature forests) as Design Elements; and
- Decentralize and Micromanage Storm Water at its Source.



Source: City of Portland, OR

Courtyard with Bioretention Areas

Buckman Heights Community
Portland, OR

Cover Photo: R. Arendt

Questions and Answers

Information on the most frequently asked low impact development questions.

Public Safety

Q. I am aware that in some instances, LID advocates the reduction of street widths and the reduced use of sidewalks to decrease impervious surfaces. Isn't this a threat to public safety?

A. No. Studies have shown that reduced street widths still provide all the functions of access, parking, and circulation for residents and emergency vehicles alike. Depending on density, minimizing the use of sidewalks may help to reduce development costs, increase housing affordability, and reduce impervious surfaces.

Q. Don't LID storm water management practices increase the likelihood of flooding?

A. No. LID designs provide adequate conveyance of storm water by using designs that maintain predevelopment volumes and rates of runoff. Since bioretention areas are designed to completely drain within a specified period of time, they do not provide breeding grounds for mosquitos. Overflow controls within bioretention areas control the risk of flooding.

Public Perception

Q. Aren't homeowners concerned about maintaining storm water controls on their properties?

A. Environmental stewardship is everyone's responsibility. Most homeowners view these systems as additional landscaping and once they are aware of the benefits that these systems provide to local hydrology, few remain opposed.

Maintenance

Q. LID practices sound great, but who maintains all of the open space and various storm water controls?

A. Communities designed using LID practices often rely on a combination of homeowner stewardship and maintenance agreements. When designed correctly, most homeowners perceive these systems as value-added builder amenities and actively provide for their maintenance.

For More Information

- Low Impact Development Center
  http://www.lowimpactdevelopment.org
- Prince George's County, Maryland
  http://www.goprincegeorgescounty.com
- NAHB Research Center Toolbase Services
  http://www.toolbase.org
- U.S. EPA
  http://www.epa.gov/owow/nps/urban.html

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*Assumes paving costs of $15/sq. yd.



Municipal Guide to Low Impact Development

Would you be interested in saving upwards of $70,000* per mile in street infrastructure costs by eliminating one lane of on-street parking on residential streets?

Did you know that communities designed to maximize open space and preserve mature vegetation are highly marketable and command higher lot prices?

Are you aware that most homeowners perceive Low Impact Development practices, such as bioretention, as favorable since such practices are viewed as additional builder landscaping?

Did you know that by reducing impervious surfaces, disconnecting runoff pathways, and using on-site infiltration techniques, you can reduce or eliminate the need for costly storm water ponds?

SARB_006298



Source: Low Impact Development Center

Grassed Swale and Narrow Street

Montgomery County, MD



Source: Applied Ecological Services, Inc.

Bioretention with Native Vegetation

Prairie Crossing
Grayslake, IL

LID Benefits

In addition to the practice just making good sense, low impact development techniques can offer many benefits to a variety of stakeholders.

Municipalities

- Protect regional flora and fauna
- Balance growth needs with environmental protection
- Reduce municipal infrastructure and utility maintenance costs (streets, curbs, gutters, sidewalks, storm sewer)
- Increase collaborative public/private partnerships

Developers

- Reduce land clearing and grading costs
- Potentially reduce infrastructure costs (streets, curbs, gutters, sidewalks)
- Reduce storm water management costs
- Potentially reduce impact fees and increases lot yields
- Increase lot and community marketability

Environment

- Preserve integrity of ecological and biological systems
- Protect site and regional water quality by reducing sediment, nutrient, and toxic loads to water bodies
- Reduce impacts to local terrestrial and aquatic plants and animals
- Preserve trees and natural vegetation

Case Study

Somerset is an 80-acre development in Prince George's County, Maryland consisting of 199 homes on 10,000-square-foot lots. During its creation, the developer used LID practices to reduce the storm water management burden. By using LID, the developer:

- Eliminated the need for storm water ponds by using bioretention techniques saving approximately $300,000;
- Gained six additional lots and their associated revenues; and
- Reduced finished lot cost by approximately $4,000.



Lot with Bioretention



Grassed Swale and Street without Curb and Gutter



Bioretention Area and Open Space

Photos: Low Impact Development Center

Description	Conventional Design	Bioretention System
Engineering Redesign	0	$110,000
Land Reclamation (6 lots x $40,000 Net)	0	<$240,000>
Total Costs	$2,457,843	$1,541,461
Total Costs (-Land Reclamation + Redesign Costs)	$2,457,843	$1,671,461
Total Cost Savings = $916,382		
Cost Savings Per Lot = $4,604		

Source: D. Winogradoff

Cost Comparison: Conventional Design vs. Bioretention



Aerial View of Somerset Development Site Plan, Prince George's County, MD

Hydrologic Comparison between Conventional Storm Water Management and LID

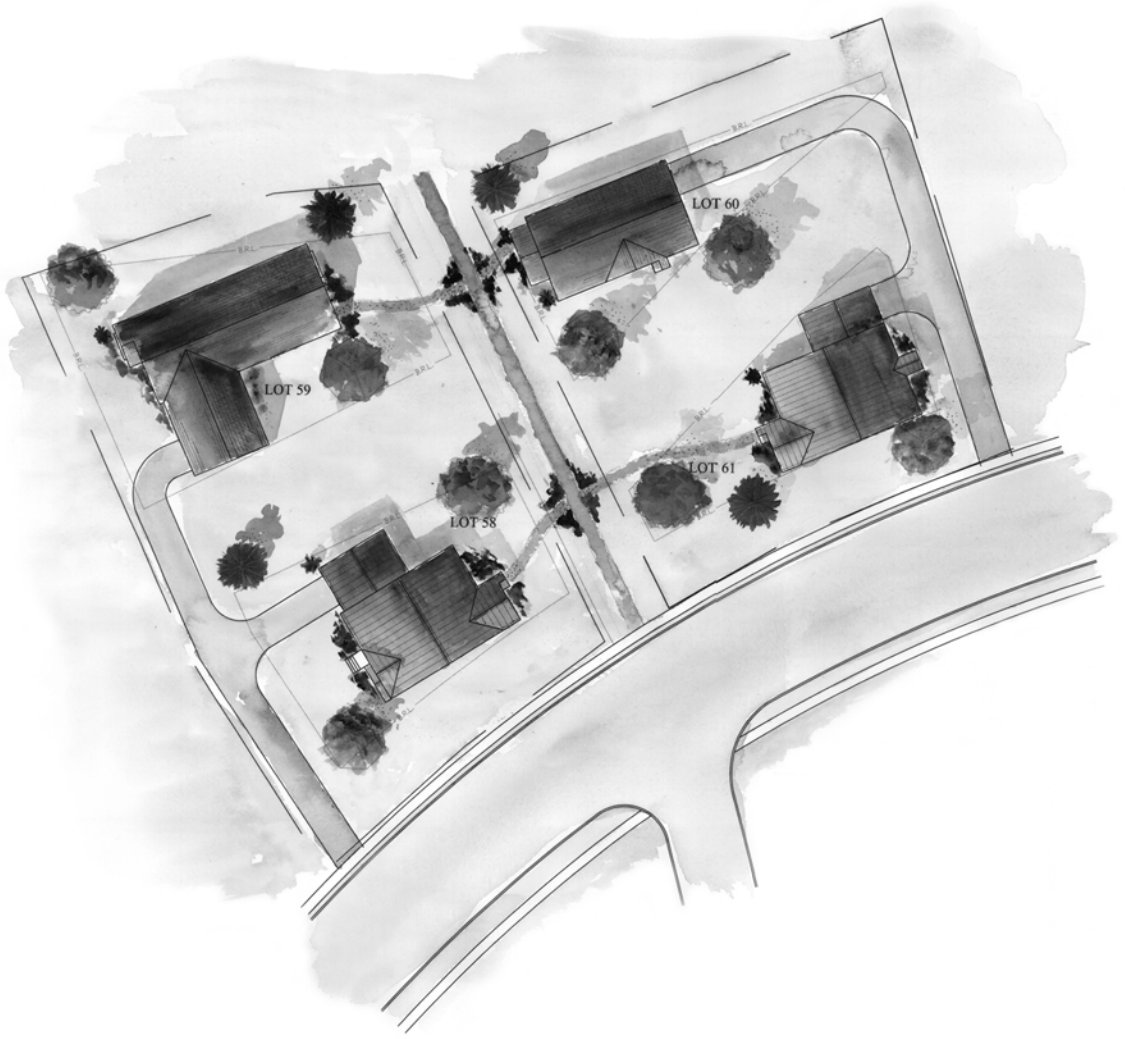
Hydrologic alterations within the landscape occur whenever land is developed. Conventional development approaches to storm water management have used practices to quickly and efficiently convey water away from developed areas. Usually these practices are designed to control the peak runoff rate for predetermined storm events, usually the 2 and 10-year storms. While these systems have worked to some degree, they still have not accounted for the increased runoff rates and volumes from smaller, more frequent storms, nor have they addressed the larger watershed functions of storage, filtration, and infiltration.

In contrast, LID utilizes a system of source controls and small-scale, decentralized treatment practices to help maintain a hydrologically functional landscape. The conservation of open space, the reduction of impervious surfaces, and the use of small-scale storm water controls, such as bioretention, are just a few of the LID practices that can help maintain predevelopment hydrological conditions.

SARB_006299

U.S. Department of Housing and Urban Development
Office of Policy Development and Research

The Practice of Low Impact Development



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PATH (Partnership for Advancing Technology in Housing) is a private/public effort to develop, demonstrate, and gain widespread market acceptance for the "Next Generation" of American housing. Through the use of new or innovative technologies, the goal of PATH is to improve the quality, durability, environmental efficiency, and affordability of tomorrow's homes.

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The Practice of Low Impact Development

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By:

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PREFACE

This U.S. Department of Housing and Urban Development (HUD) document, *The Practice of Low Impact Development (LID)*, is intended to assist the housing industry during the land development process. It complements the 1993 HUD publication *Model Land Development Standards and Accompanying Model State Enabling Legislation*, which simultaneously promoted safe, high-quality housing and eliminated needless requirements that add to a home's final cost.

The HUD Office of Policy Development and Research (PD&R) supports the Department's overall mission of helping to create affordable housing and assisting communities with meeting their development needs. In particular, PD&R is responsible for monitoring the nation's housing needs, conducting research on significant community development issues, and providing reliable and objective analysis to our nation's policymakers. This publication underscores PD&R's commitment to delivering timely and accurate research to our nation's housing professionals.

The document focuses specifically on technologies that affect both the cost impacts and environmental issues associated with land development. It provides a brief introduction to low impact development and discusses conventional and alternative techniques and technologies that developers can integrate into their existing land development practices. By continually examining the land development process, the home building industry can continue to provide America with built environments that enhance the natural environment.

EXECUTIVE SUMMARY

Building professionals and municipal planning officials each have numerous goals and try to satisfy many needs during land development. Private developers are interested in profitable business ventures that also effectively address environmental concerns and meet regulatory requirements. Public sector officials ensure that development projects mesh with applicable zoning ordinances and help improve the surrounding community. This publication is intended to assist these groups by 1) providing basic conventional and innovative land development technology information, and 2) encouraging the amendment of existing development codes to facilitate the use of those technologies.

In an effort to help meet both groups' needs, the publication provides ways to simultaneously incorporate economic and environmental considerations into the land development process. This approach to land development, called Low Impact Development (LID), uses various land planning and design practices and technologies to simultaneously conserve and protect natural resource systems and reduce infrastructure costs. LID still allows land to be developed, but in a cost-effective manner that helps mitigate potential environmental impacts. LID is best suited for new, suburban development.

Some developers are already using some LID technologies in their projects, however this publication can help building professionals and municipal officials who are interested in learning more about LID. Lastly, developers do not have to incorporate all of the LID technologies noted herein into every development, rather, it is suggested developers carefully select the technologies appropriate to a site's unique regulatory, climatic, and topographic conditions. Some of the key LID recommendations are presented below.

Project Planning & Design

While the LID approach can result in a myriad of benefits for the developer, the municipality, and the environment, the proposed use of LID is likely to spawn questions during the development process. However, careful project planning, close collaboration with the local municipality, and education programs can minimize the challenges and effectively answer the questions.

Developers who have used LID practices and technologies have indicated that one of the keys to a successful project is to invest additional time and money in the initial planning stages of development. While this idea may be unpopular because of increased up-front costs, the expenditures are often recouped in the form of rapid home sales, enhanced community marketability, and higher lot yields.

Storm Water Management

Conventional storm water management systems rely on collection and conveyance systems to remove water safely from developed areas and to protect life, property, and health. The systems are engineered and designed according to estimates of post-development storm water flows and volumes from pervious and impervious areas.

Low impact development storm water management systems can reduce development costs through the reduction or elimination of conventional storm water conveyance and collection systems. LID systems can reduce the need for paving, curb and gutter, piping, inlet structures, and storm water ponds by treating water at its source instead of at the end of the pipe. However, developers are not the only parties to benefit from the use of LID storm water management techniques. Municipalities also benefit in the long term through reduced maintenance costs.

Wastewater Management

Wastewater can affect natural resources; all wastewater coming from a home must be sent to an effective treatment site or public treatment system in order to limit adverse environmental and health impacts. Nitrogen and phosphorus are two nutrients in wastewater that, either in excess or through cumulative effect, can adversely affect receiving waterbodies. When septic systems fail to operate as designed, excess nutrients in untreated wastewater can enter the environment.

In most cases, either municipal sewer or private on-site wastewater treatment systems (i.e., septic systems) can handle wastewater treatment needs. However, there are exceptions. For instance, in some circumstances, sewer systems cannot be used because of cost considerations; it might be too costly to run pipes long distances to link a proposed development's wastewater system to existing municipal sewer connections. In other cases, a municipality might have specific health or environmental concerns that make the use of septic systems unacceptable. Via the LID approach, developers can consider a variety of on-site wastewater treatment system options either as alternatives or enhancements to conventional septic systems. Some on-site treatment alternatives to conventional systems, such as recirculating sand filters and evapotranspiration systems, are "add-ons" to a traditional septic tank system. The additional treatment unit is connected in-line with the septic tank and provides an extra level of treatment.

Circulation & Design

As the struggle to decrease nonpoint source pollution in our nation's waters continues, municipalities have begun to reexamine the connection between circulation design and storm water management practices. New designs for streets, sidewalks, and driveways can maintain the functions of circulation while helping to reduce expanses of impervious surfaces that can alter local hydrology and degrade water quality. In turn, new street designs can influence the layout of lots and help to increase the volume of open space in new residential developments.

When coupled with narrower, open-section streets, a well-designed street layout can eliminate hundreds of square feet of impervious surface. Depending on the density, location, and type of subdivision, different types of street layouts may easily lend themselves to a cluster arrangement, conserving natural features, maintaining open space, and protecting water quality.

INTRODUCTION

What if you could simultaneously reduce your residential development and infrastructure costs, conserve and protect the environment, increase the marketability of your projects, and improve housing affordability? It may sound too good to be true, but many developers throughout the nation have been able to meet these ambitious goals. How? By incorporating a growing collection of innovative practices and technologies into their existing land development processes and practices.

Low Impact Development (LID) is an approach to land development that uses various land planning and design practices and technologies to simultaneously conserve and protect natural resource systems and reduce infrastructure costs. LID still allows land to be developed, but in a cost-effective manner that helps mitigate potential environmental impacts.

There are numerous design practices and technologies developers can use through the LID approach. For instance, developers can work together with municipal officials and the general public during the initial planning stages of development to identify environmental protection opportunities. Examples of opportunities include saving trees on the site, not building on designated sensitive areas, orienting roads and lots to allow for passive solar orientation of homes, and enhancing the effectiveness of on-site wastewater treatment systems. Such efforts have resulted in rapid home sales, enhanced community marketability, and higher-than-average lot yields.

This publication often refers to "technologies." For the purposes of the discussion, an LID technology can be structural or nonstructural. Equipment such as a sand filter is an example of a structural technology used to treat wastewater. Nonstructural LID technologies often use natural features or are land use strategies. An example of a nonstructural technology is the disconnection of rain gutters from storm water drains and redirection of rainwater toward rain gardens or grass swales.

To developers, LID can offer both infrastructure savings and a way to respond to increasingly stringent environmental regulations. For municipalities, LID can help contain burgeoning street and storm water management costs. For community residents, LID can encourage local environmental stewardship. And, for the environment, the benefits speak for themselves.

Definition of LID

Low Impact Development (LID) is an approach to land development that uses various land planning and design practices and technologies to simultaneously conserve and protect natural resource systems and reduce infrastructure costs. LID still allows land to be developed, but in a cost-effective manner that helps mitigate potential environmental impacts.

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SCOPE

In 1993, the U.S. Department of Housing and Urban Development published *Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation* to support its mission of providing decent, safe, and suitable living environments for all Americans. This important publication focused on the identification and elimination of unnecessary land development practices that add to a home's final cost. Many of the standards also offered ancillary environmental benefits. As an indication of the publication's impact on land development, the volume led many states and municipalities to consider, and in the case of New Jersey directly adopt, some of the standards. Indeed, the publication's recommendations are as applicable today as they were in 1993. Appendix D contains the 1993 publication's Table of Contents. HUD USER (Telephone: 800-245-2691) can provide the entire 1993 publication to anyone interested in obtaining it.

1993 HUD Publication

In 1993, the U.S. Department of Housing and Urban Development published *Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation* to support its mission of providing decent, safe, and suitable living environments for all Americans. This important publication focused on the identification and elimination of unnecessary land development practices that add to a home's final cost.

This current effort by HUD's Office of Policy Development and Research is intended to complement and build on the information presented in the 1993 HUD document. It provides users with state-of-the-art information on relevant technologies that can help address both economic and environmental issues related to land development. Specifically, this document is designed to:

- Increase developer and public official awareness of LID opportunities;
- Discuss the alternative technologies available to developers;
- Encourage flexibility in local development codes;
- Continue to promote housing affordability; and
- Reduce land development's environmental impacts.

While LID may benefit all types of development, it is best suited for new, suburban residential development. Moreover, the LID practices and technologies are best integrated into a developer's existing land development process and practices. With some planning, the technologies described in this document can be integrated into today's land development projects. Based on a comprehensive site analysis (see Section 1.5.3), developers can decide which technology or combination of technologies will offer the best cost and environmental benefits taking into account the local ordinances. Developers do not have to incorporate all of the LID technologies noted herein into every development, rather, it is suggested developers carefully select the technologies appropriate to a site's unique regulatory, climatic, and topographic conditions.

HOW TO USE THIS DOCUMENT

This publication consists of two parts (see Table 1). Part I outlines the objectives of LID and explains how the approach can be easily integrated into a developer's project planning and design process. Part II presents the alternative practices and technologies that can be integrated into the land development process. In accordance with project objectives, site designers should explore the application of either an individual technology or a combination of technologies. For instance, planning for the conservation and protection of water resources on a project site may involve the integration of both storm water and wastewater management technologies. In sum, developers can first learn the objectives of LID (Part I) and then identify the practices and technologies (Part II) that can maximize the project's economic and environmental goals.

Part II of the document contains the following sections: Storm Water Management, Wastewater Treatment, and Circulation and Design, each of which was selected for its potential to offer the greatest LID benefits. Lastly, Appendix A contains a glossary, while Appendix B contains case studies that provide builders with real-world success stories of projects that used LID, Appendix C provides a list of references, and Appendix D provides the 1993 US HUD publication *Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation's* table of contents.

The Practice of Low Impact Development		
Introduction	Part I	Part II
Definition of LID Relationship to 1993 Publication	LID Objectives Project Planning and Site Design	Alternative Technologies • Storm Water Management • Wastewater Treatment • Circulation and Design

TABLE 1. OVERVIEW OF DOCUMENT

AUDIENCE

This document is intended primarily for residential building professionals as they work through the initial stages of project planning and design. In addition, municipal planning officials benefit as the document can help them during various stages of the project development process.

Building professionals such as builders/developers, engineers, planners, and landscape architects using the LID approach indicate that successful projects require meticulous planning and design. Consulting this document before initiating the planning process can help building professionals identify and implement a range of LID practices and technologies and thus maximize a project's potential.

Municipal planning officials can also benefit from the use of this document. Reference to the document during the review and permitting stages of development can help officials understand the use of LID practices and technologies. Municipal planning officials are often responsible for drafting and enforcing local development codes and reviewing and approving preliminary site plans. Therefore, in addition to helping to educate municipal officials on the LID approach, the document can help encourage the amendment of existing development codes to facilitate the use of LID practices and technologies.

Section 1.4 discusses the challenges involved in implementing LID. The success of developments such as the Somerset community in Prince George's County, Maryland, and the Kensington Estates community in Pierce County, Washington, proves that developers and public officials can work together to integrate LID practices and technologies into today's projects. These communities have received praise for reducing strains on land, water, air, and soil resources.

PART I:
PROJECT PLANNING AND DESIGN

SECTION 1. LOW IMPACT DEVELOPMENT (LID) PRIMER



The LID approach to land development uses various land planning and design practices and technologies to simultaneously conserve and protect natural resource systems and reduce infrastructure costs.

1.1 OVERVIEW

In the mid 1990s, the Prince George's County, Maryland, Department of Environmental Resources outlined an approach for addressing suburban storm water management. That approach, termed Low Impact Development (LID), uses certain technology-based practices to ensure that a site's post-development hydrologic functions mimic those in its pre-development state. These functions include groundwater recharge, infiltration, and frequency and volume of discharges.

For the purposes of this document, we have expanded the concept of LID to include site planning and design considerations as well as wastewater management considerations.

1.2 BENEFITS OF LOW IMPACT DEVELOPMENT

LID reexamines traditional development practices and technologies and focuses on identifying project-specific site solutions that benefit the municipality, the developer, the home buyer, and the environment. Elements of the approach are also known by other names, such as conservation design, environmentally friendly design, resource-efficient design, and better site design. In addition to the fact that LID makes good sense, low impact development techniques can offer many benefits to a variety of stakeholders (see Table 2).

1.3 GOALS OF LOW IMPACT DEVELOPMENT

Many developers are aware that incorporating low impact development into their existing practices helps them systematically balance environmental and cost issues. In particular, residential building professionals using the LID approach seek to do the following:

Preserve Open Space and Minimize Land Disturbances

Successful LID communities recognize the value of open space, mature landscapes, and native vegetation. Open-space tracts incorporated into community designs and planned as components of larger, contiguous areas are highly desirable; in fact, homeowners frequently seek assurances that their community enjoys easy access to undeveloped areas located nearby. Minimizing land disturbance helps dampen the impacts to ecological and biological processes both on and off the site.

Protect Sensitive Natural Features and Natural Processes

Protection of a site’s sensitive natural features and natural processes is paramount to planning for LID. Judicious application of information gained in a site analysis can help identify developable and nondevelopable areas of a site and minimize impacts to air, water, soil, and vegetation (see Section 1.5.3).

Identify and Link On- and Off-Site “Green Infrastructure”

Green infrastructure represents the planned and managed network of wilderness, parks, greenways, conservation easements, and working lands with conservation value that support native species, maintain natural ecological processes, and sustain air and water

resources. Site planners should strive to identify on-site opportunities to support and expand regional green infrastructure.

Developers
• Reduces land clearing and grading costs • Reduces infrastructure costs (streets, curbs, gutters, sidewalk) • Reduces storm water management costs • Increases lot yields and reduces impact fees • Increases lot and community marketability
Municipalities
• Protects regional flora and fauna • Balances growth needs with environmental protection • Reduces municipal infrastructure and utility maintenance costs (streets, curbs, gutters, sidewalks, storm sewers) • Fosters public/private partnerships
Home Buyer
• Protects site and regional water quality by reducing sediment, nutrient, and toxic loads to waterbodies • Preserves and protects amenities that can translate into more salable homes and communities • Provides shading for homes and properly orients homes to help decrease monthly utility bills
Environment
• Preserves integrity of ecological and biological systems • Protects site and regional water quality by reducing sediment, nutrient, and toxic loads to waterbodies • Reduces impacts to local terrestrial and aquatic plants and animals • Preserves trees and natural vegetation

TABLE 2. BENEFITS TO STAKEHOLDERS

Incorporate Natural Features (Wetlands, Riparian Corridors, Mature Forests) into Site Designs

LID takes advantage of natural resources for both their functional and aesthetic qualities. For instance, when designed correctly, wetlands and pond systems can provide storm water management solutions as well as aesthetic and recreational benefits for the entire community, thus increasing lot and community marketability.

Customize Site Design According to the Site Analysis

Planning for LID communities relies on the performance of a thorough site analysis. Site planners can use the information gathered during the site analysis to create the best balance between development and the conservation of natural resources. By identifying buildable and nonbuildable areas of a site, planners can direct development into areas that will experience the least impacts on air, soil, and water.

Decentralize and Micromanage Storm Water at Its Source

Understanding the difference between pre- and post-development hydrologic patterns is critical to LID. The use of best management practices to reduce the amount of impervious surfaces, disconnect flow paths (i.e., downspouts connected to storm sewers), and treat storm water at its source all help minimize the impacts to local hydrology. Attainment of these goals can lead to the protection of water quality, reduction of impervious surfaces, increased open space, protection of trees, reduced land disturbance, decrease in infrastructure costs, and reduced homeowner energy bills.

Associated Benefits of LID

Protection of Water Quality
Reduction of Impervious Surfaces
Increased Open Space
Protection of Trees
Reduced Land Disturbance
Decrease in Infrastructure Costs
Reduced Homeowner Energy Bills

1.4 CHALLENGES TO USING LOW IMPACT DEVELOPMENT

While the LID approach can result in a myriad of benefits for the developer, the municipality, and the environment, the proposed use of LID is likely to spawn questions during the development process. Two of the most frequent challenges facing developers who contemplate the use of LID center around restrictive local ordinances and local officials' and citizens' opposition to the approach. However, careful project planning, close collaboration with the local municipality, and education programs can reduce the challenges. Appendix B includes several case studies that developers can use to support their decisions to use LID.

Local ordinances guide the design and construction of new development. Often, a community drafted and adopted its ordinances years ago such that the regulations no longer reflect today's development practices, especially those of LID. In many cases, developers wishing to use LID may have to obtain some type of variance or waiver from their local planning agency until local codes are updated to reflect current practice. Unfortunately, variances can create delays in the approval and permitting process, and those delays often translate into more debt service on the loans secured for the original land purchase.

As a pure business decision, it usually does not make sense for a developer to go through the potentially time consuming steps of the variance process. One way to address this issue is to have municipalities reword their zoning ordinances in order to allow LID in residential land development projects. One thing that would help facilitate the ordinance revision process is the development of a nationwide database containing information on ordinances supporting the use of LID. This database would provide the entire development industry, including local planning officials, with a centralized resource that would provide examples of ordinances

Helping Communities Permit the Use of LID

Developers work within the local land development regulations. If a municipality would like developers use the LID approach in future projects, then the zoning ordinances should encourage such a change. However, municipal officials are looking for information on how to best provide flexibility in the local development regulations. Municipal officials have asked for a nationwide database containing information on sample zoning ordinances that support the use of LID. Since such a database does not currently exist, creating and updating an information clearinghouse would address one of the significant challenges in front of people interested in using the LID approach.

that encourage the LID approach.

Ideally, the time to obtain permit approval for an innovative land design should be at least equal to the time needed to develop that same parcel of land under the provisions of existing regulations. Developers incorporating LID practices and technologies into their projects should ask for expedited permitting or pre-development assurances that review and permitting times will not be extended. In fact, public officials that want developers to use LID technologies can tie incentives, such as expedited permitting process times, to developments incorporating those technologies. Until development ordinances are amended to allow innovative practices and technologies by-right, other incentives, such as density bonuses and reduced impact, application, or development fees can also be negotiated between developers and municipal officials to help offset additional costs. .

Local citizens may also show resistance to accepting the proposed use of LID within their communities. Misconceptions and minimal data regarding the safety and long-term viability of LID systems have led to questions concerning the practices' and technologies' efficacy, particularly in terms of flood control and public health and safety. To help homeowners, and sometimes even municipal officials, understand the benefits of LID techniques, developers may find it helpful to prepare brief educational presentations or publications on LID for both the general public and municipal officials. Studies have shown that once residents understand the benefits to local water quality, they are more likely to support and accept alternative technologies. Often, homeowners view practices such as bioretention cells as extra builder landscaping.

1.5 PLANNING FOR LOW IMPACT DEVELOPMENT

Proper team development and collaboration, (see Section 1.5.1), careful coordination with the public reviewing agency (see Section 1.5.2), and the performance of a thorough site analysis (see Section 1.5.3) are essential ingredients for successfully incorporating LID concepts into development plans.

Table 3 highlights some of the ways in which LID differs from conventional development. Developers who have used LID practices and technologies have indicated that one of the keys to a successful project is to invest additional time and money in the initial planning stages of development. While this idea may be unpopular, the expenditures are often recouped in the form of rapid home sales, enhanced community marketability, and higher lot yields.

Due to the iterative and phased nature of construction, both the collaboration and ordinance review/outreach phases should be conducted continuously from project commencement through completion. For example, changes to one aspect of the project (e.g., lot layout) can affect other aspects of the project (e.g., storm water management). During site construction, the site should be continuously monitored for potential impacts to vegetation, soils, or sensitive water features such that appropriate protective measures can be implemented.

	Collaboration	Ordinance Review/Outreach	Site Review and Analysis
Traditional Practice	• Often uses an engineering team and one or two other experts. • Uses experts sequentially, i.e., conducts one phase of development process and then passes project details to the next expert.	• Limits interaction with public officials to permitting meetings. • Does not actively seek out public's input on design options. • Meets existing ordinances. • Uses pre-development meetings to review preliminary site plans.	• Analyzes the land use ordinances to identify regulatory barriers. • Conducts review with the goal of developing one design plan. • Meets the regulatory requirements.
Low Impact Development Practice	• Uses experts such as landscape architects, engineers, hydrologists, geologists, and biologists to collaborate, perform site analysis, and identify innovative solutions. • Encourages collaborative effort among all site design professionals to maximize natural resource benefits.	• Proactively seeks public officials' input in pre-development meetings to identify project opportunities. • Works with the community to include its interests in project design. • Conducts resource analysis first to determine what the site offers. Reviews the ordinances to determine potential barriers to proposed designs. Design must meet ordinances or developer obtains a variance.	• Analyzes the land and ordinances to identify resource opportunities and constraints. • Reviews all inputs to create multiple land design options for consideration. • Works together with public officials to gain flexibility in the design phase.

TABLE 3. COMPARISON BETWEEN LOW IMPACT DEVELOPMENT AND TRADITIONAL LAND DEVELOPMENT PROCESSES

1.5.1 COLLABORATION

Historically, engineers have assumed primary responsibility for identifying a site's natural resources and integrating them into project designs. These professionals, however, may or may not have undergone the specialized training necessary to carry out their assigned tasks in the context of the LID approach. Engineers working on LID projects have benefited from the input of a variety of natural resource and land development professionals, including planners, architects, landscape architects, biologists, ecologists, and hydrologists.

Conducting the site planning process with the assistance of the above professionals increases the likelihood that the design process will disclose all opportunities for low

impact development. For instance, a site located in a headwaters area for sensitive wetlands may need the assistance of a hydrologist to identify strategies to protect local water resources. A landscape architect could help orient houses and lots to take advantage of passive solar heating. Section 1.6 discusses the process of incorporating these opportunities into project goals during the project design phase.

Developers' use of these professionals should obviously reflect a project's size and budget. In fact, the expertise offered by the above professionals may be available from several sources other than the professionals themselves. For instance, project engineers can consult the Internet, periodicals, and local governments to gain insights into efficient natural resource use and land planning practices.[1]

1.5.2 ORDINANCE REVIEW/OUTREACH

Before commencing work on any site design, developers committed to integrating LID practices and technologies into their designs should meet with local officials to review current development ordinances. Ordinance review meetings between developers and planning staff can help identify ways in which the public and private sectors can work together to build communities that minimize development impacts. Similar to the pre-development meetings that are now required in many municipalities throughout the country, ordinance review meetings should focus on the ways in which LID practices and technologies can further the intent of current ordinances. Developers should not view the meetings as opportunities for local municipalities to exert added regulatory control, but rather as forums in which the two parties can work together to identify mutually beneficial solutions.

Items to Consider During an Ordinance Review/Outreach Meeting
• Street Design and Parking Requirements
• Lot Layout and Setback Requirements
• Storm Water Management and Wastewater Treatment Practices and Technologies
• Bonus Densities or Other Development Incentives
• Options for Waivers or Variances

TABLE 4. ITEMS TO CONSIDER

Before the ordinance review meetings, developers should familiarize themselves with the relevant local regulations and the specific LID practices and technologies that they wish to implement. For instance, even though current zoning and storm water management regulations may prohibit the LID approach, a developer might be interested in integrating open-section roadways and grassed swales into a development. At the ordinance review meeting, the developer and the municipality might negotiate a compromise that will allow the developer to implement the practice on certain local streets in exchange for setting aside additional stream buffers elsewhere on the site. Developers can then apply for a variance that will likely be looked upon favorably by municipal officials since it was negotiated earlier between the developer and public official. This win-win situation

[1] Additional resources are listed at the end of each section in Part II.

reduces the developer's street construction costs and storm water management burden and increases municipal protections for riparian systems.

1.5.3 SITE ANALYSIS

Highly attractive and marketable developments begin with a thorough site analysis that takes into consideration a site's natural features. A site analysis is a process by which a developer or one or more members of the development team inventories a site's natural features and attributes to identify development opportunities and constraints. Soils, water resources, vegetative patterns, topography, microclimate, solar orientation, viewsheds, and access are just a few of the site attributes that go into a thorough analysis. Many may view the site analysis as a way to identify and plan for potential constraints that can sideline a project or increase development time or costs. However, as environmental awareness continues to increase, developers have realized that identifying and strengthening potential opportunities can be just as important. Table 5 provides some site analysis considerations that relate to Part II.

Storm Water Management
• Topography (low points, high points, ridgelines, swales)
• Hydrology (natural drainage patterns, surface and groundwater, wetlands, sensitive water resources)
• Vegetation (existing vegetation, tree-save areas, aquatic buffers)
Wastewater Management
• Soils (porosity, depth to bedrock, groundwater table)
• Topography (slopes conducive to drain fields)
• Natural Water Features/Sensitive Waterbodies
• Aesthetics (siting)
• Vegetation (sensitive areas)
Circulation and Design
• Hydrology (natural drainage)
• Topography (ridgelines/steep slopes)
• Natural Features (viewsheds, waterbodies, forested areas)
• Soils (hydric)

TABLE 5. SITE ANALYSIS CONSIDERATIONS FOR TECHNOLOGIES DISCUSSED IN PART II

Before even purchasing a piece of property, a developer usually conducts or commissions some type of feasibility study to identify possible physical, legal, or political barriers to developing the site. A feasibility study differs from a site analysis in that it is not usually conducted to assist in site design. In many instances, lending institutions may require an environmental assessment to identify any potential for site contamination that could increase liability for remediation and raise development costs. The data collected for a feasibility study should by no means be considered complete. Many other sources of public and private information are available (see Table 6). Information gathered from different sources should be synthesized into a single, usable map and taken to the site for

verification, especially given that many public maps do not accurately reflect current local site conditions.

However, a site analysis is about more than just preparing a base map and verifying site conditions. A good site analysis can help site designers integrate the built and natural environments into a functioning whole while ensuring identification of the processes, both natural and man-made, that occur on and off site. Armed with an understanding of a site's various attributes and functions, site designers can create developments that enhance the site's ecological integrity.

One of the first concepts to understand about the site analysis is that it can rarely be completed during one site visit. If time permits, the process should involve several site visits at different times to observe the effects of seasonal and climatologic changes on the property. For instance, site hydrology may change drastically from the spring to the summer or views may differ radically during the winter months when trees shed their leaves. Designers should also examine on- and off-site connections such as wildlife corridors, riparian areas, or valley systems. The value of these systems should be considered in terms of both their intrinsic value and their connection to their counterparts in the regional environment. Site analysis usually brings together three primary areas of interest: water, vegetation, and soils/topography as discussed below.

Possible Sources of Information for a LID Site Analysis
• City/County/State/Federal Maps
• National Flood Insurance Program (NFIP) Floodplain Maps
• Aerial Photographs
• National Wetlands Inventory (NWI) Maps
• Topography/Soils (U.S. Geological Survey/Soil Conservation Service / Natural Resources Conservation Service - USGS/SCS/NRCS)
• Local Tax/Plat Maps
• Seismic Maps
• Hazard Maps
• Coastal Zone Management Maps

TABLE 6. SOURCES OF INFORMATION

Water

Increasingly, public officials are evidencing concern over water quality and quantity. When properly protected and enhanced, water features can make a project highly marketable. Studies indicate that homebuyers will pay premiums not only for waterfront lots but also for lots with water views or lots in communities with desirable water features such as lakes or streams.

Many different water resources can exist on a given site, and all should be inventoried and their hydrologic relationships understood. It is important to keep in mind that the connectivity of hydrologic systems means that impacts to one resource may affect

another. For instance, sheetflow regime changes may affect a wetlands system, which may in turn affect both groundwater recharge rates and baseflows to streams.

In addition to surface water sources such as streams, rivers, and lakes, other less evident sources of water are equally important and must be identified and protected. Wetlands, seeps, and springs are groundwater-based sources that in most instances fall under the jurisdiction of the federal Clean Water Act. Since they are fed by groundwater, these features may ultimately determine the location of roads, lots, structures, and on-site storm water management or wastewater treatment systems.

Site designers should consider sheetflow characteristics and seasonally inundated areas. Sheetflow is the movement of rainwater across the surface of landscape or, in other words, how the site drains. Flow paths should be identified and natural channels inventoried and protected. Seasonally inundated areas, which are temporarily ponded shallow depressions that exist during rainy seasons, provide habitat for aquatic and migratory species and should be protected.

Vegetation

Tree-save areas are areas preserved on a development tract to meet tree ordinance requirements and/or to protect healthy vegetation from site development activities.

Trees can be valuable resources on project sites. They can significantly increase the value of individual lots by moderating temperatures within and outside structures, acting as wind buffers, and benefiting water quality. Vegetated riparian buffers and forested areas have the capacity to reduce storm water volumes, remove pollutants, and slow erosive flows. Current national trends indicate that buyers seek lots with mature vegetation. Builders now realize that the preservation of mature trees and stands of trees can mean more attractive communities. Viable tree areas should be inventoried and protected by a comprehensive tree preservation plan implemented before site clearing and grading. Most municipalities now mandate some form of tree protection and may offer credits for preservation of existing stands. Tree-save areas should be incorporated into both buildable and nonbuildable areas of a site.

Soils/Topography

Soils and topographic studies can help determine the placement of streets, lots, buildings, wells, drainfields, and other site amenities. A thorough analysis of all related soils information, including percolation and other geotechnical studies, is an essential component of the site analysis. Given that federal government soil surveys are highly generalized, planners should not rely on them for site-specific soils information. Hydric, or wetland soils, should be delineated by a certified wetlands professional and verified by the local U.S. Army Corps of Engineers field office.

1.6 SITE DESIGN FOR LOW IMPACT DEVELOPMENT

Once the planning phase is complete, the resultant information can be used in the formulation of the final site design. Often, standardized residential templates are overlaid on a site without regard to a site's natural features and environmental sensitivities. These "forced" patterns cause unnecessary impacts to local water, vegetation, and soils and can artificially inflate the infrastructure costs associated with clearing and grading.

Given that land development projects vary as widely as the parcels of land to be developed, it is difficult to prescribe an exact design process for every situation. The three topics discussed below, site area classification, circulation design, and infrastructure and natural resources design, are part of an LID approach that should embrace the various design determinants and variables identified in Figure 1. The list of design determinants and variables identified in the figure is by no means exhaustive. Site designers should identify a complete list of these items based on each site's characteristics.

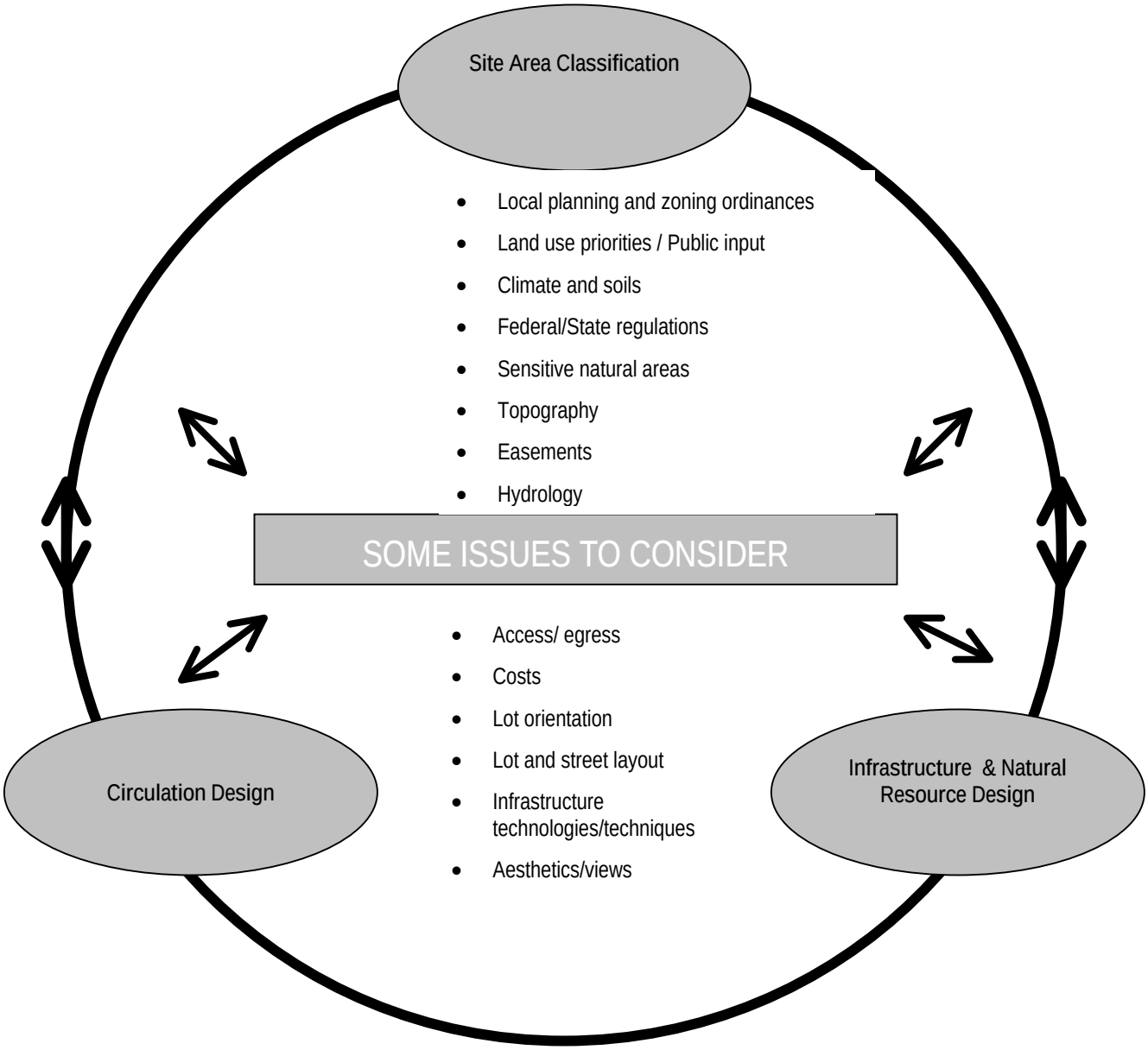


FIGURE 1. LOW IMPACT DEVELOPMENT SITE DESIGN

1.6.1 SITE AREA CLASSIFICATION

Once the site analysis is complete, site designers should analyze and classify areas of the site by suitability of use. During the process of site area classification, it is important to keep in mind that maximizing a site's development potential does not necessarily mean that the entire site needs to be developed. Compact forms of development make it possible to conserve open space and protect habitat and water quality while promoting housing affordability and a sense of community.

Even though open, nonvegetated areas are usually seen as prime development areas, site designers should remain flexible and take into account all natural resource information collected during the site analysis. For instance, a field might serve as a headwaters area for sensitive wetlands or be better developed into recreational fields for a park system.

Buildable Areas

Buildable areas of a site are the areas that are optimal for conversion into finished lots. Buildable areas usually have the fewest limitations in terms of access, regulatory restrictions, sensitive natural features, and zoning concerns. The process of identifying a site's buildable areas may point to the advisability of clustering development into several small areas rather than spreading it throughout one large area. While clustering can protect sensitive site features, it can contribute to infrastructure costs by increasing the excavation and construction costs for streets and utility lines. Yet, narrower streets and rights-of-way and smaller lot sizes mean that less land needs to be developed, permitting the achievement of lower development costs.

Nonbuildable Areas

Nonbuildable areas of a site should remain undeveloped in response to regulatory, natural resource, planning, or other development concerns. These areas can easily be incorporated into either community open space or larger regional systems. During site construction, nonbuildable areas should be protected with silt or tree protection fences, and equipment and materials should not be stored in them. Even though the areas are intended to remain undeveloped, site designers should examine opportunities to use the areas to accommodate the innovative technologies discussed in Part II (see Section 1.5.3 for additional information on the integration of infrastructure and natural resources).

1.6.2 CIRCULATION DESIGN

As discussed in Section 4 - Circulation and Design, a well-designed pedestrian and vehicular circulation system is critical to the success of a development project. The construction of roads is typically one of the largest infrastructure expenses for land development projects. It is estimated that the cost of paving a road averages $15 per square yard (The Center for Watershed Protection, 1999). The use of efficient road layouts, street types, and pavement treatments can significantly reduce the cost of roadway construction, decrease the quantity of runoff from a site, potentially increase lot yield and open space amounts, and protect natural resources.

After identifying buildable and nonbuildable areas, site designers should lay out an efficient circulation system that provides for access, parking, and circulation. To

minimize the amount of impervious surfaces, plans should maximize lot frontages and minimize pavement widths.

To minimize grading and to protect riparian channels, roadways should be located on topographic high points and should follow the natural contours of the land, within safe grade tolerances. Grade changes and curves in roadways can add visual interest to streets and communities and to help slow traffic. For additional road design standards, refer to AASHTO's *Green Book* (AASHTO, 1994).

1.6.3 INFRASTRUCTURE AND NATURAL RESOURCES DESIGN

The efficient blending of infrastructure and natural resources on a development site requires a thorough understanding of the natural processes that characterize the site and the infrastructure practices and technologies proposed as part of the land development process. Use of many of the practices and technologies discussed in Part II may allow for an entirely different set of site planning and design considerations. For instance, alternative wastewater treatment systems that use smaller drainfields may permit smaller lot sizes, which in turn can affect lot, road, and open-space layouts. All of the alternative practices and technologies discussed in this publication, whether related to storm water, wastewater, or circulation, affect water, soils, and vegetation. Site designers should use the best combination of systems based on individualized natural resource objectives for a given site.

PART II:
PROJECT TOOLS/REFERENCES

SECTION 2: STORM WATER MANAGEMENT



Implementing nontraditional, decentralized methods for handling storm water can significantly reduce site development costs, regional expenditures for storm water and planning, construction, and maintenance outlays while protecting the environment.

2.1 INTRODUCTION

Planning for storm water management in the initial stages of land development can yield significant cost and environmental benefits for developers, municipalities, and residents. Traditionally approached during site development as an obligation to satisfy state and federal regulatory requirements, storm water management has increasingly come under reexamination in light of its potential to function as a project opportunity and site design element. When correctly planned for and accommodated, storm water management systems can simultaneously satisfy regulatory requirements, act as site design elements, protect the environment, and reduce infrastructure costs—all the attributes of low-impact development.

The development of land, whenever and wherever it occurs, affects soils, vegetation, and water. After land is developed, rainwater that would have infiltrated into the ground, been absorbed by plant roots and transpired, or evaporated into the air instead becomes surface runoff. Runoff often picks up urban pollutants such as grease, oil, nutrients, metals, and debris and deposits them into local waterbodies. In addition to water quality impacts, post-development storm water runoff has other impacts, including changes to the peak flow characteristics of streams, degradation of habitat and aquatic species, and fluctuations in local groundwater tables.

Definition of LID

Low Impact Development (LID) is an approach to land development that uses various land planning and design practices and technologies to simultaneously conserve and protect natural resource systems and reduce infrastructure costs. LID still allows land to be developed, but in a cost-effective manner that helps mitigate potential environmental impacts.

Stricter federal water quality requirements under the Clean Water Act have caused both municipalities and developers to seek out more environmentally efficient, cost-effective storm water management alternatives that are compatible with hydrologic and watershed objectives. At the same time, traditional methods for addressing storm water management have brought to the fore other considerations such as cost and maintenance issues, liability issues, and the need for education and outreach programs for local officials and residents.

History of Low Impact Development

Initially developed and implemented by Prince George's County, Maryland, in the early 1990s as an innovative way to handle storm water runoff, LID techniques have rapidly spread across the country. The overall goal of LID storm water treatment is to mimic pre-development hydrologic conditions through the use of a variety of structural and nonstructural practices that detain, retain, percolate, and evaporate storm water. This publication is not intended as a comprehensive guide to LID storm water treatment strategies but merely aims at providing an overview of alternative storm water

Prince George's County, Maryland has pioneered several new tools and practices in LID. The Prince George's County Maryland Department of Environmental Resources Programs and Planning Division (PGDER) created two publications: 1) *Low-Impact Development Design Strategies An Integrated Design Approach* (EPA 841-B-00-003), and 2) *Low-Impact Development Hydrologic Analysis* (EPA 841-B-00-002). These publications describe how LID can achieve storm water control through the creation of a hydrologically functional landscape that mimics the natural hydrologic regime.

management practices and technologies. For a comprehensive look at the LID process, readers should consult the Prince George's County, Maryland, Department of Environmental Resources for copies of its LID publications (Telephone: 301-883-5810).

Cost Benefits

Low impact development storm water management systems can reduce development costs through the reduction or elimination of conventional storm water conveyance and collection systems. LID systems can reduce the need for paving, curb and gutter, piping, inlet structures, and storm water ponds by treating water at its source instead of at the end of the pipe. However, developers are not the only parties to benefit from the use of LID storm water management techniques. Although more data is needed on the maintenance of LID technologies, recent history has indicated that municipalities may also benefit in the long term through reduced maintenance costs.

Environmental Benefits

As storm water drains from urban areas, it picks up nutrients and pollutants such as nitrogen, phosphorus, oil, grease, heavy metals, and trash. These pollutants impair water quality and degrade the riparian systems that many plant and animal species depend on for survival. LID practices remove pollutants from storm water naturally and restore a site's pre-development hydrology. The alternative practices discussed later can recharge local groundwater tables, reduce domestic water use for lawns and vegetation, and provide habitat for a variety of species.

Storm Water Management Techniques

This section briefly discusses the different conventional and alternative storm water management techniques available to site designers, briefly highlighting the environmental and economic benefits that each can offer. It is important to keep in mind that regional differences in land characteristics, climatologic conditions, soils, and local ordinances will dictate the availability, type, and effectiveness of options for a given site. Regardless of the practices and technologies ultimately chosen, developers should ensure that they are consistent with the goals of regional storm water management plans. Table 7 lists objectives for alternative storm water management techniques.

LID Practices can Reduce Development Costs by:

Reducing the use of roadways, curbs and gutters, and sidewalks
Decreasing the use of traditional storm sewer appurtenances
Eliminating the use of or downsizing storm water ponds

Finally, designers should remember that an integrated site storm water management system can use several combinations of conventional and alternative techniques to meet site environmental and watershed objectives. Given that each development site has its own characteristics and constraints, the value of a thorough site analysis and conceptual design phase should not be underestimated. While the complete decentralization of storm water operations is the

Decentralizing Storm Water Management Involves:

Reducing storm water quantities
Disconnecting hydrologic elements, such as downspouts and storm drains
Treating storm water at its source by using alternative techniques

most desirable option for cost savings and environmental benefits, designers may still wish to rely on conventional systems such as wetlands or ponds to promote aesthetic or recreational opportunities.

Objective 1 Reduce the amount of impervious surfaces on the development site.
Objective 2 Manage storm water at the source instead of at centralized collection points.
Objective 3: Use "chains" of natural treatment systems to reduce storm water quantities and pollutant loadings.

TABLE 7. STORM WATER MANAGEMENT OBJECTIVES

2.2 CONVENTIONAL APPROACHES TO STORM WATER MANAGEMENT

Conventional storm water management systems rely on collection and conveyance systems to remove water safely from developed areas and to protect life, property, and health. The systems are engineered and designed according to estimates of post-development storm water flows and volumes from pervious and impervious areas.

Conveyance Systems

Conveyance systems comprise curbs and gutters, inlet and outlet structures, and buried concrete (or other) piping systems that move water from source areas to centralized control areas. Costs for installing a conventional drainage system extend to material, labor, planning, and design costs. Research has indicated that the cost of a conventional conveyance system typically ranges between $40 and $50 per linear foot (MNCBIA, 2001). Assuming $45 per linear foot as an average, the elimination of one mile of curb and gutter can decrease infrastructure and storm conveyance costs by approximately $230,000.

Collection Systems

Collection systems consist of wet and dry ponds that retain and detain storm flows until they can be safely discharged into local receiving waters. While these systems have functioned well, other strategies for managing storm water that use ecological approaches are gaining popularity. Moreover, traditional ponds are increasingly seen as expensive to design, construct, and maintain. In one residential community in Prince George's County, Maryland, one developer (and, ultimately, residents) saved nearly $300,000 when the use of individual-lot bioretention practices alleviated the need for a pond. Table 8 provides a summary of some of the current pond types used in residential developments.

It is estimated that storm water ponds in new, suburban developments consume approximately 10 percent of a project's developed land area (England et al, 2000). The elimination of ponds, however, can permit the preservation of additional land as permanent open space or allow for the platting of additional lots. In the example from Prince George's County, the developer was able to recover six lots that would have been lost to the area required for the storm water pond. Beyond the environmental benefits,

studies have indicated that residents are willing to pay premiums for the enjoyment of living next to permanent water bodies, even storm water ponds. At one condominium community in Virginia, the developer was able to receive premiums of up to $10,000 for waterfront lots (Friends of the Rappahannock, 2000).

Type of Pond	Cost	Advantages	Disadvantages
Dry Retention	Approximately $25,000 per acre of pond. Maintenance costs $100 to $500 per mowed acre.	High pollutant removal efficiencies. Groundwater recharge.	Proper design and construction critical to success. Periodic maintenance costs can be high.
Wet Detention	Approximately $90,000 per acre of pond. Maintenance costs variable.	Proper design can increase community and property values.	Large land areas needed to accommodate pond. Nitrogen and phosphorus removal capacities limited.
Wet Detention with Filtration	$100,000 per acre of pond. Maintenance costs variable.	Underdrain pipes with sand filters offer good removal of suspended solids and attached pollutants.	Significant maintenance required. Poor nitrogen and phosphorus removal.

Source: England et al, 2000.

TABLE 8. TYPES OF PONDS CURRENTLY USED IN RESIDENTIAL DEVELOPMENTS

2.3 ALTERNATIVES TO CONVENTIONAL SYSTEMS

Hydrologic alternatives to conventional storm water management systems can result in economic and environmental savings. Instead of piping the water to a central location, these alternatives try to treat the water at its source by infiltrating it into the ground. Some of the alternatives discussed include infiltration systems, filtering systems, alternate conveyance systems, and a few non-structural practices. Often used in support of site design principles that advocate the reduction of impervious surfaces, alternatives aim to mimic natural hydrologic cycles characteristic of forests and woodlands. In fact, hydrologic alternatives help decentralize storm water treatment thereby eliminating the need for expensive conveyance and collection systems such as pipes and ponds (see Table 9).

Hydrologic alternatives to conventional storm water management treat storm water at its source with small, cost-effective cells that use a combination of engineered soils and vegetation to evaporate, transpire, and percolate the storm water. Though significantly less costly to design, install, and maintain than conventional systems, the alternatives are also effective in filtering urban pollutants, recharging groundwater, and maintaining pre-development flows.

Description	Storm water Management Pond/Curb and Gutter Design	Bioretention System
Engineering Redesign	$0	$110,000
Land Reclamation (6 lots x $40,000 net)	$0	($240,000)
Total Costs	$2,457,843	$1,541,461
Total Costs--Land Reclamation *plus* Redesign Costs	$2,457,843	$1,671,461
Total Cost Savings = $916,382		
Cost Savings per Lot = $4,604		

Source: Derek Winogradoff, 2003.

TABLE 9. COST COMPARISON: CLOSED (CONVENTIONAL) SYSTEM VERSUS BIORETENTION

2.3.1 INFILTRATION SYSTEMS

Infiltration systems encourage the downward movement of water into the underlying soil to reduce the total quantity of overland runoff and pollutants from impervious surfaces. The systems discussed include trenches, drainfields, drywells, bioretention systems, and level spreaders. In comparison with conventional conveyance systems, infiltration systems are inexpensive to design and construct. Their use can reduce the amount and size of storm piping, inlet and outlet structures, and pond systems. However, as is the case with any LID technology, infiltration systems must be carefully engineered to the site's conditions. Table 10 provides a partial list of pollutant removal effectiveness. It is important to keep in mind that these systems are designed primarily for water infiltration and not necessarily for pollutant removal. For vegetated swales and filter/buffer strips there are situations where those systems are not always effective in removing pollutants, and can in fact increase the levels of phosphorus. In fact, a study conducted for the National Association of Home Builders (NAHB) indicates that those system's pollutant removal efficiencies are highly variable (NAHB, 2002b). Thus, building professionals should look at the site's climatic, soil, and other conditions to determine if a certain technology is right for the application.

"First flush" pollutants are higher-concentration pollutant loadings that initially run off impervious areas. As the duration of the rainfall event increases, pollutant loadings usually decrease as compared to the "first flush" levels.

Infiltration Trenches

Infiltration trenches are excavated trenches that are backfilled with an aggregate material to permit the filtration and percolation of water into subsoils. Storm water from impervious areas, including rooftops, parking areas, and driveways, is routed into the trenches for treatment (see Figure 2). Infiltration trenches are usually most effective at treating "first-flush" pollutant loadings in storm water and are extremely effective in recharging groundwater tables that contribute to stream baseflows. It is estimated that the trenches can remove between 80 and 100 percent of total suspended solids, zinc, and lead

from storm water as well as between 40 and 60 percent of total phosphorus and nitrogen. (Prince George's County, 2001). In areas with high concentrations of pollutants such as sediment, oil, grease, or grit, pretreatment mechanisms such as grassed filter strips should be installed upstream of the system to filter such pollutants before they enter the trench. This linked system concept is considered a "treatment train" approach to storm water management.

System	Total Suspended Solids (TSS)	Total Phosphorus (P)	Total Nitrogen (N)	Zinc	Lead
Bioretention	-	81	43	99	99
Dry Well	80–100	40–60	40–60	80–100	80–100
Infiltration Trench	80—100	40–60	40–60	80–100	80–100
Filter/Buffer Strip	20–100	0–60	0–60	20–200	20–200
Vegetated Swale	30-65	10–25	0–15	20–50	20–50
Infiltration Swale	90	65	50	80–90	80–90
Wet Swale	80	20	40	40–70	40-70
Rain Barrel	NA	NA	NA	NA	NA
Cistern	NA	NA	NA	NA	NA

Source: Prince George's County Bioretention Manual, 2001.

TABLE 10. REPORTED POLLUTANT REMOVAL EFFICIENCY OF BEST MANAGEMENT PRACTICE (BMP)

Infiltration Drainfields

An infiltration drainfield is generally the same as an infiltration trench except that it functions in a manner similar to a drainfield for a septic system. It consists of a pretreatment structure , a perforated manifold-type arrangement of drain lines, and a permeable drainfield. The drainfield itself consists of layers of topsoil, aggregate stone, sand, and filter fabric. An observation well is usually located in one corner of the system to permit the monitoring of flows. Infiltration drainfields are extremely effective in maintaining hydrologic functions such as infiltration and groundwater recharge and in improving water and stream quality by filtering pollutants and attenuating runoff volumes.

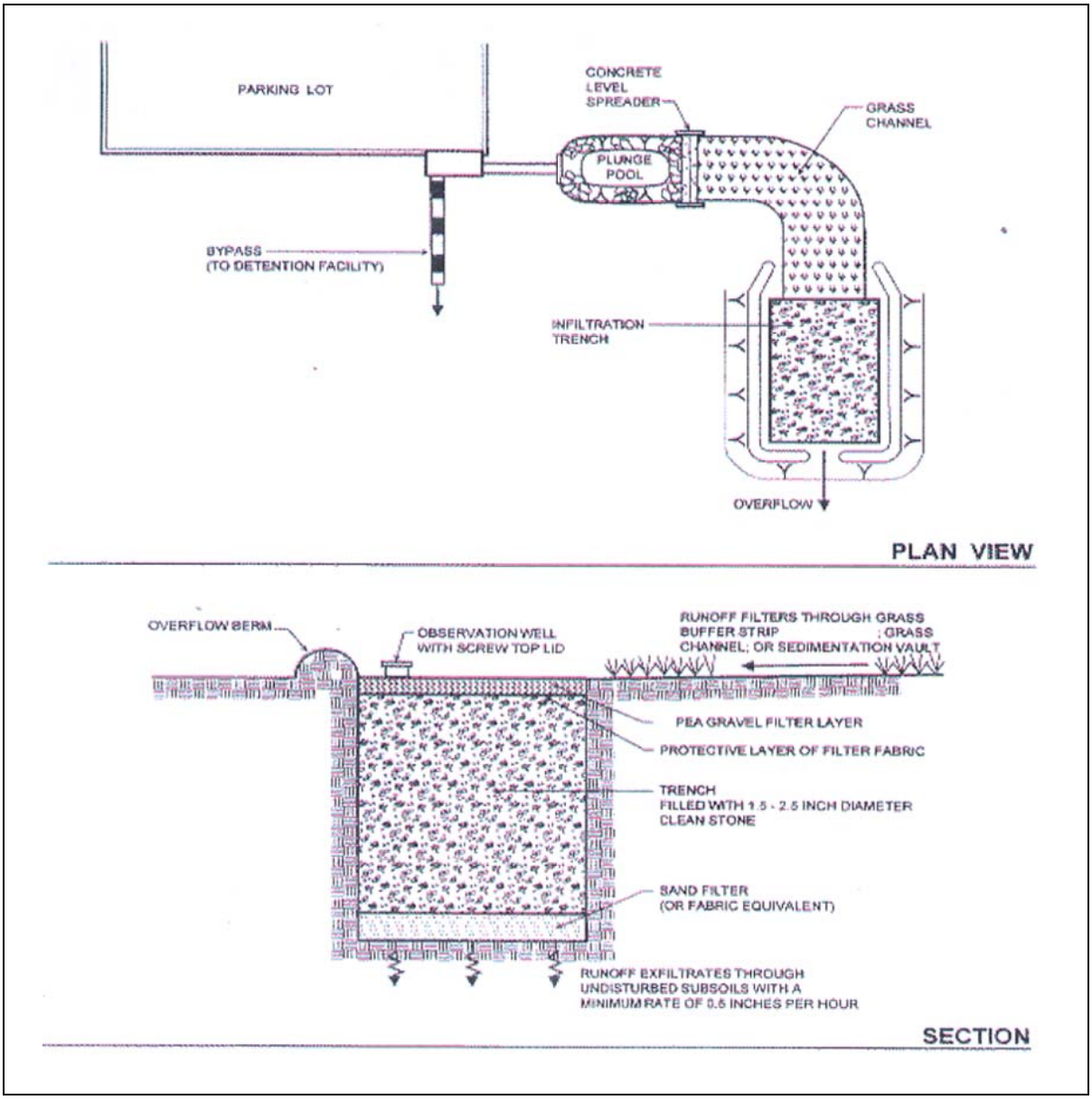


FIGURE 2. INFILTRATION TRENCH

Dry Wells

In residential communities, rooftops account for a significant source of runoff from impervious surfaces. Dry wells, sometimes referred to as "French drains," are usually sited near downspouts to manage rooftop runoff by infiltrating it into the ground (see Figure 3). Dry wells are excavated pits filled with aggregate stone to hold water until it can infiltrate into the ground. Similar to infiltration trenches, dry wells should be designed with emergency overflow structures that drain to public storm water conveyances to accommodate runoff from major storms. The drainage pathways should be well maintained and stabilized to prevent erosion.

Dry wells are extremely effective in removing sediment, zinc, and lead from storm water and mildly effective in reducing quantities of nitrogen and phosphorus. During construction, developers should take care to avoid excessive compaction of soils around the trenches and the accumulation of silt around the drainfield. Depending on the type of pollutants filtered, drainfields need to be maintained regularly for optimum performance.

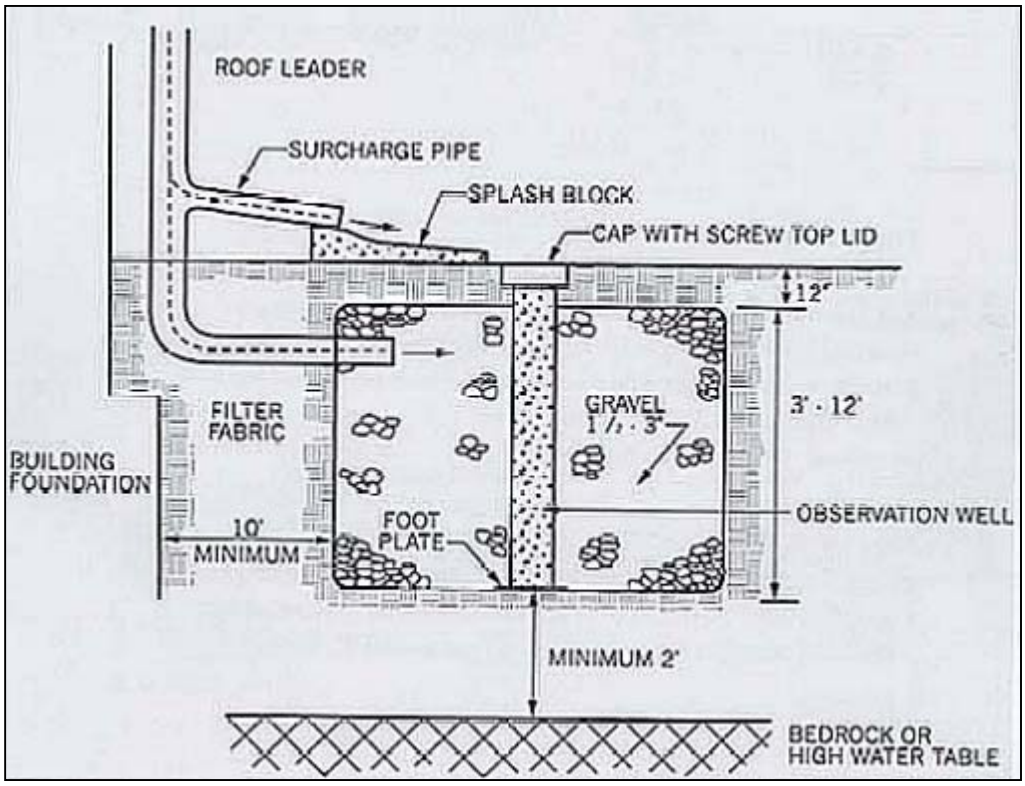


FIGURE 3. DRY WELL

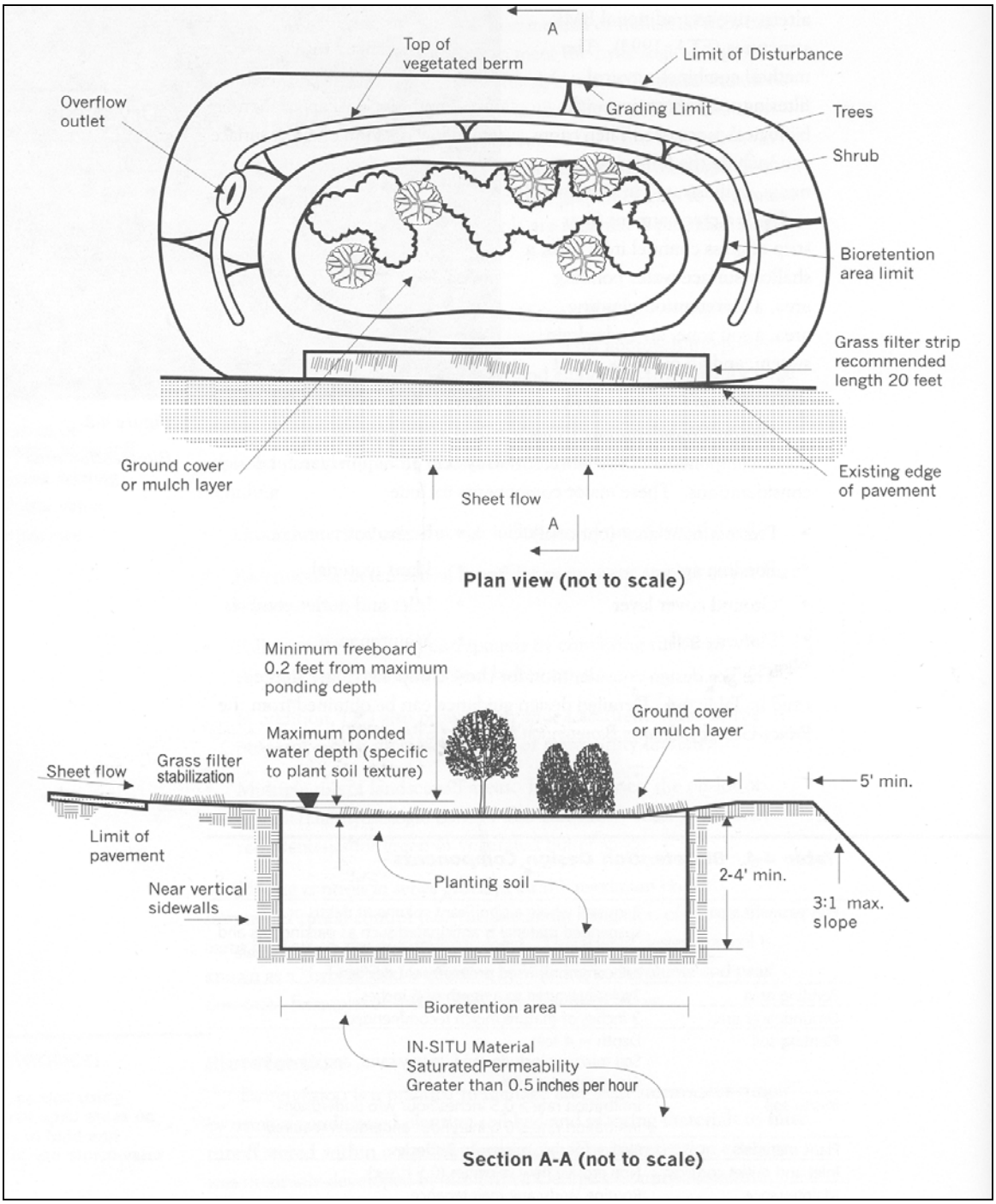
Bioretention

Bioretention is possibly one of the most recognized alternative storm water management practices. Used in residential, commercial, and certain industrial settings, bioretention has the potential to offer developers significant cost savings and environmental benefits over conventional storm water management systems. Bioretention areas are shallow, topographic depressions filled with engineered soils and vegetation that retain, treat, and infiltrate water. Figure 4 depicts a typical bioretention area.

Bioretention systems are designed for the temporary storage of rainwater. They successfully remove pollutants through increased contact time with soils and plant materials. As compared with conventional storm water management systems, bioretention areas more closely mimic the natural hydrologic cycle, allowing soils and plants to filter pollutants from storm water and permitting the processes of infiltration, evaporation, and transpiration to occur. The systems can also create wildlife habitat, minimize erosion, and recharge local groundwater supplies.

In parking lots, storm water should be conveyed directly to the bioretention area through a system of grassed swales. For residential applications, treatment areas are generally located some distance away from houses to increase flow paths and treat runoff from rooftops and driveways. In either case, bioretention systems route storm water to bioretention areas that are designed to accumulate water to depths not exceeding six to12 inches. In the event that storm water volumes exceed treatment capacities, bioretention areas are usually equipped with overflow drop inlets routed to municipal storm water systems. In certain industrial and commercial areas, pollutant loadings may be too concentrated for the successful use of bioretention areas. In such areas, termed "hotspots," the use of structural practices to infiltrate storm water may be deleterious to groundwater supplies. In these instances, designers are advised to use alternative practices, such as exfiltration trenches, to convey filtered water into a conventional storm water management system for proper treatment.

On average, bioretention costs approximately $3 to $4 per square foot of size, depending on the quantity of water to be treated and excavation costs. Plant materials are approximately $6.40 per cubic foot of storm water treated.



Source: Prince George's County Bioretention Manual, 2001.

FIGURE 4. TYPICAL BIORETENTION AREA

Level Spreaders

Level spreaders are mechanisms that convert concentrated runoff into sheetflow and slow the erosive velocities of storm water. Constructed by excavating a wide, shallow trench and filling it with crushed stone, a level spreader must be built with its lower edge

completely flat to ensure the even disbursement of water. Level spreaders are most effective in helping to convey sheetflow to bioretention areas. While not typically viewed as treatment mechanisms, level spreaders can help increase detention storage and time of concentrations and thus assist with pollutant and sediment removal functions. They should be used as part of an integrated, decentralized storm water management system.

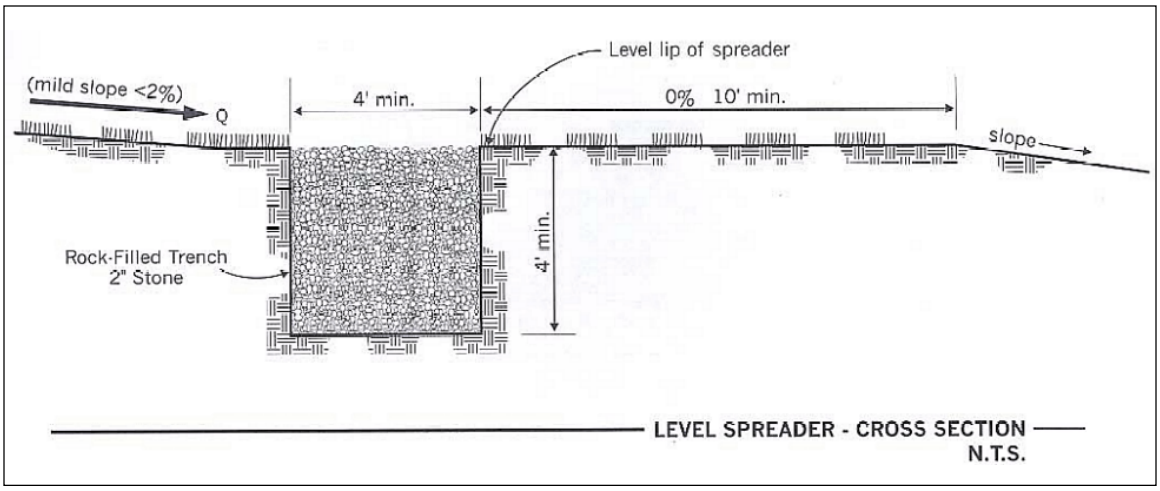


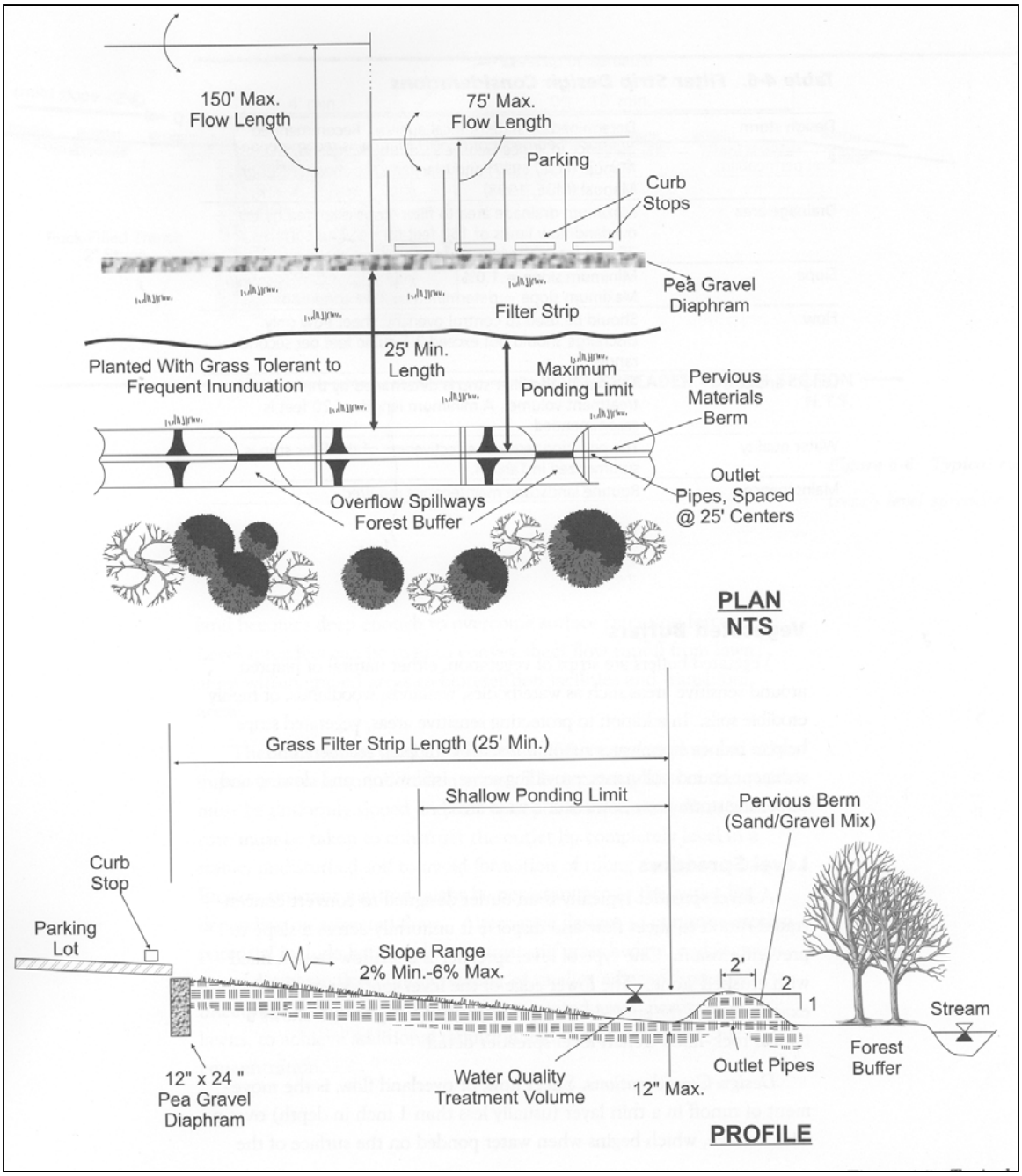
FIGURE 5. LEVEL SPREADER

2.3.2 FILTERING SYSTEMS

Filtering systems use soils and vegetation to remove pollutants from storm water. They function mainly as pre-treatment devices to remove sediment before water enters infiltration devices such as bioretention areas.

Filter Strips

Filter strips are low-grade vegetated areas that permit sediment deposition during sheetflow (see Figure 6). Usually used as one component of a storm water management system, filter strips are considered pre-treatment devices, meaning that water is routed through them before entering systems such as bioretention areas. For the systems to be fully effective, slopes should be minimal (0 to 2 percent), with channelized flows eliminated. Pollutant removal efficiency depends largely on the quantity of water treated, flow path and length, type of vegetation, and the soil infiltration rate. Depending on the amount and type of vegetation planted and the need for replacement or amendment of soils, filter strips can be inexpensive to construct and maintain.



Source: Prince George's County Bioretention Manual, 2001.

FIGURE 6. TYPICAL GRASS FILTER STRIP

Exfiltration Trench/Dry Swale

Exfiltration trenches function in a manner similar to infiltration trenches except for an underdrain system built into the bottom of the trench (see Figure 7). After water has percolated through the soil media and pollutants have been removed, the water enters perforated drain tile and is conveyed to a local storm water drain system.

Exfiltration trenches are low-cost, low-maintenance systems that are highly effective in removing pollutants, especially sediment, from storm water. The perforated underdrain in the system protects groundwater supplies from contamination in areas with high pollutant loadings. These areas, usually termed "storm water hotspots," are usually located in industrial or commercial areas dominated by vehicular traffic.

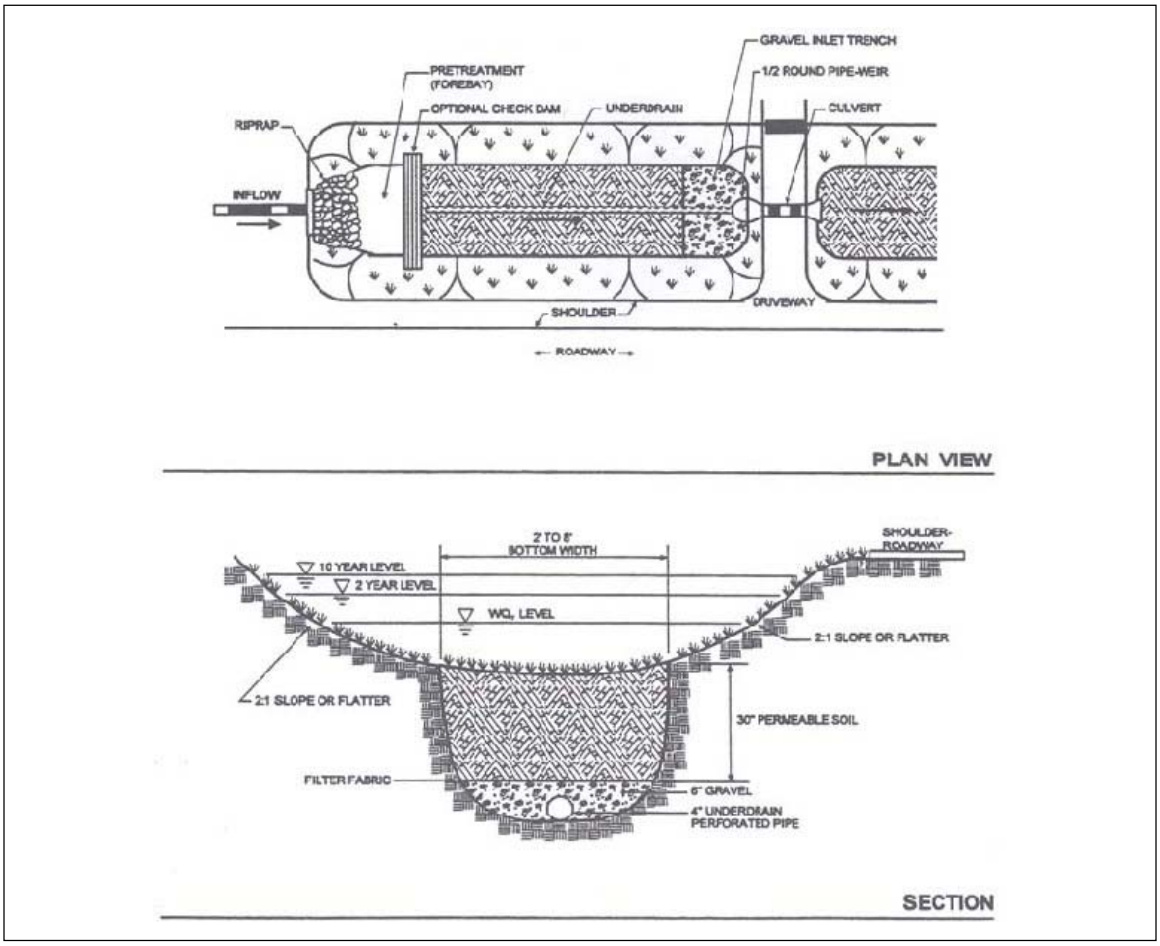


FIGURE 7. EXFILTRATION TRENCH/DRY SWALES

Wetlands

Constructed wetlands systems use soils, vegetation, and hydrology to remove pollutants from storm water. The systems are effective in attenuating flood flows, reducing pollutant loadings, and providing wildlife habitat (see Figure 8). From a community design standpoint, wetlands systems can create open space, offer improved aesthetics over traditional treatment systems, and provide recreational and educational opportunities.

Most natural and artificial wetlands systems are regulated by the Clean Water Act and fall under the jurisdictional authority of the U.S. Army Corps of Engineers (Corps). A recent U.S. Supreme Court decision concerning isolated wetlands has limited the jurisdiction of the Corps to navigable waters, their tributaries, and wetlands adjacent to these navigable waters and their tributaries.

Similar to their natural counterparts, constructed wetlands types can vary from seasonally inundated to year-round, open-water systems. To optimize pollutant removal capacities, design engineers usually aim to maximize flow paths through wetlands systems to prolong exposure to soils and vegetation, thereby facilitating nutrient and pollutant uptake, retention, and settling. Given the delicate hydrologic balance of wetlands systems, unmanaged storm water should never be discharged into jurisdictional wetlands, or wetlands under the direct control of the Corps. Therefore, constructed wetlands should be designed with water quality and quantity pre-treatment mechanisms, such as sediment forebays or gabion walls, which attenuate storm flows and protect sensitive wetlands vegetation.

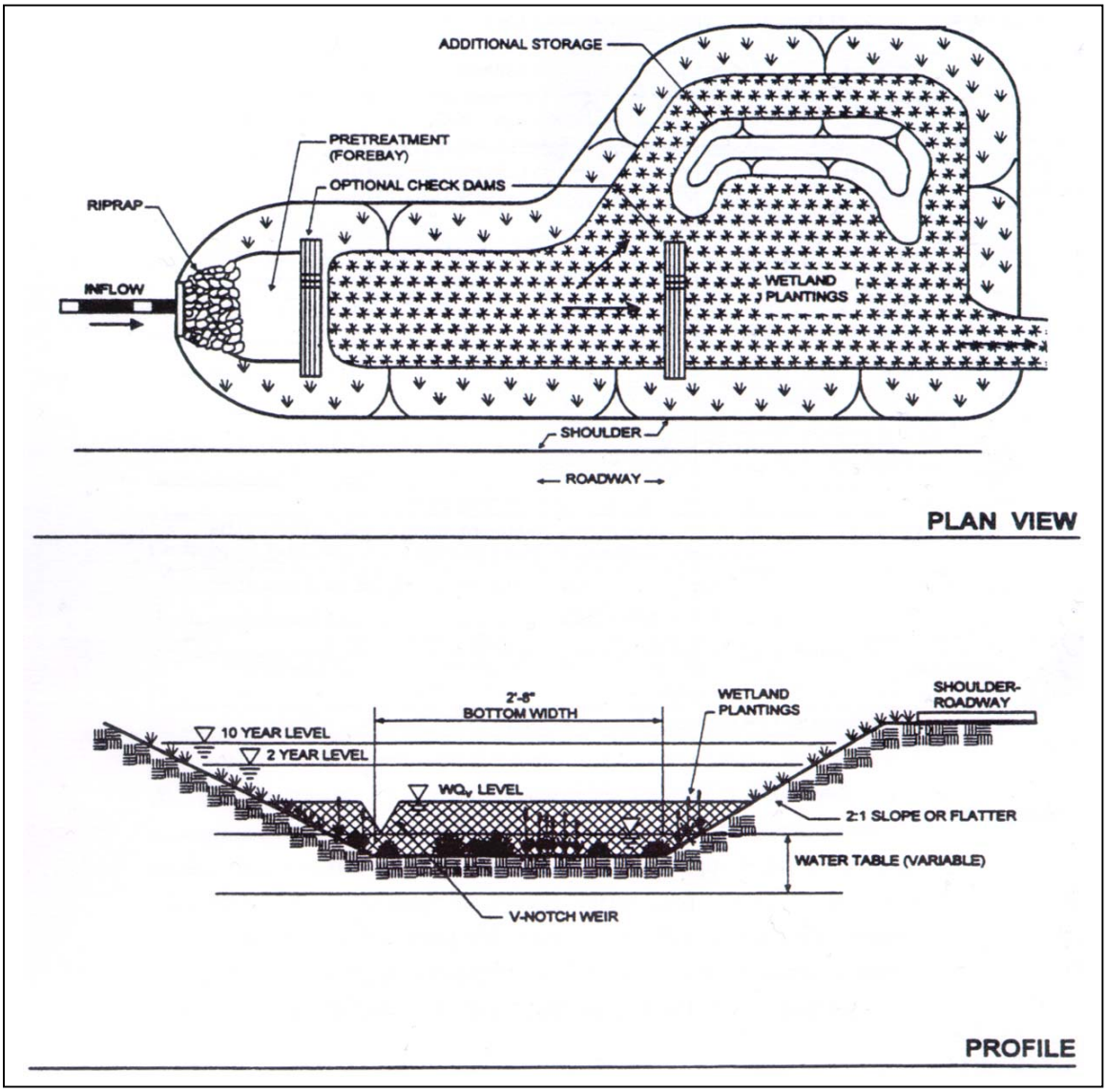


FIGURE 8. STORM WATER WETLANDS

As compared with other alternative systems, construction costs for wetlands systems may be high. The cost of a constructed storm water wetlands can exceed $300,000 per acre (JSPPOH, 2001), although shallow groundwater levels, shallow depth to bedrock, and

sloping topography can drive up construction costs further. In instances where the depth to groundwater is shallow, a clay liner should be used to prevent contamination of local aquifers. The quality and quantity of imported soils and plant material are also a factor when considering the total cost of built systems. However, while construction costs may be higher for constructed wetlands than for other BMP systems, operation and maintenance costs may be relatively low.

2.3.3 CONVEYANCE SYSTEMS

Alternate conveyance systems, such as vegetated channels and grassed swales, carry water to areas for treatment. Unlike conventional conveyance systems, such as curbs and gutters, these systems slow the erosive velocity of storm water, increase time of concentrating, and filter pollutants such as sediment.

Vegetated Channels/Grassed Swales

Curb and gutter can cost upwards of $12.50 per linear foot.

Source: Friends of the Rappahannock Study, 2000.

Vegetated channel systems and grassed swales are low-cost alternatives for conveying water away from streets, downspouts, and structures. They are low-cost alternatives to conventional conveyance systems, such as curbs or concrete channels. These alternatives reduce storm water velocities and allow sediment and pollutants contained within storm water to be filtered.

In residential settings, swales are an effective way to convey water to bioretention areas sited a short distance away from structures and foundations. When used in conjunction with bioretention areas, swales function as pre-treatment mechanisms that filter sediments from storm water. For health, safety, and maintenance reasons, minimum longitudinal slopes on swales should be 1 percent to avoid stagnation of water and to ensure proper drainage.

Wet swale systems are variants of dry swales and function similarly to a wetlands system. Slightly more expensive to construct than a vegetated channel or dry swale, wet swales are designed with a permanent pool structure and planted with wetlands vegetation for pollutant treatment. Due to health and safety concerns over potential mosquito breeding, wet swales have limited applicability in residential or commercial settings.

2.3.4 OTHER SYSTEMS

Rain Barrels

Rain barrels are low-cost retention devices placed below roof downspouts to collect water during storms (see Figure 9). Although rain barrels offer no primary pollutant removal benefits during collection times, they act as quantity controls and can help reduce the cumulative effects of storm water on downstream systems. As an example, one 42-gallon rain barrel can provide storage for 0.5 inch of runoff from a rooftop measuring 133 square feet (Prince George's County, 2001).

One inch of rain on a 1,000-square-foot roof yields approximately 623 gallons of water.

During dry periods, water from the barrels can be used to irrigate lawns and vegetation. Rain barrels should be equipped with some type of overflow device that routes overflow to a bioretention area for treatment during major storms. Rain barrels can be purchased online from a variety of municipal natural resources departments and environmental organizations. They are available in a variety of colors and sizes to match architectural styles.

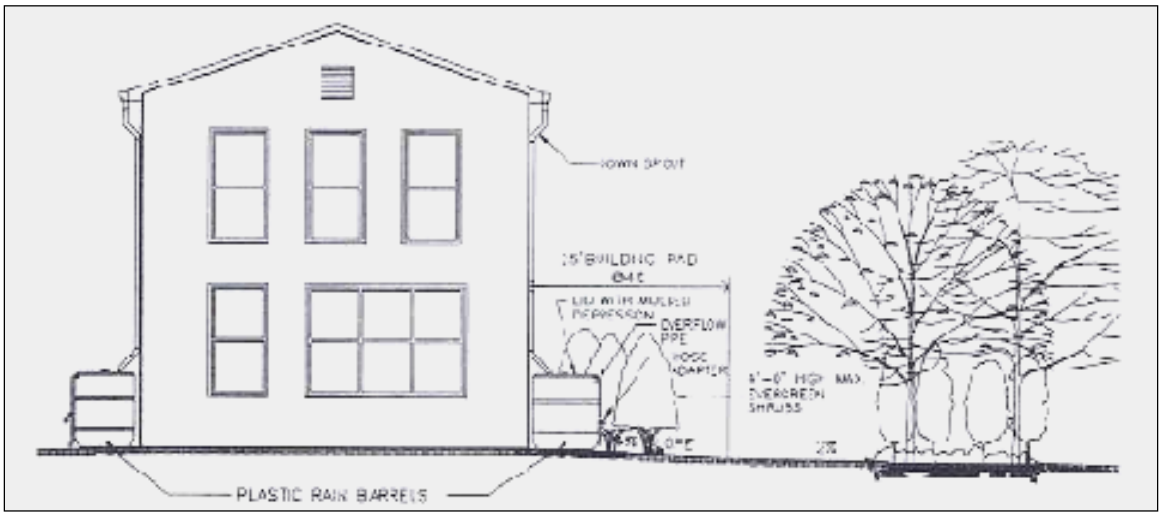


FIGURE 9. RAIN BARRELS

Cisterns

Cisterns are premolded plastic storage devices that are usually sited underground in proximity to rooftop downspouts. They function in a manner similar to rain barrels but offer storage capacities from 100 to 1,400 gallons. Water from cisterns is stored and released during dry periods, promoting water conservation for lawn and garden irrigation.

2.4 ADDITIONAL RESOURCES

Additional resources that provide detail on individual storm water management topics are listed below. The resources are not provided as endorsements, merely as educational and reference tools. Given regional variations in climate and land development needs, we have tried to include region- specific resources. It is important to note, however, that addresses, especially Internet links, are subject to change. This list contains the latest links and addresses as of the date of this publication.

Storm Water Management Manuals and Best Management Practices

City of Alexandria, Virginia
http://ci.alexandria.va.us/solidwaste/stormwater.html
Information on Virginia storm water ordinances and directions on acquiring publications such as *The Alexandria Supplement to the Northern Virginia BMP Handbook* and *The Virginia Storm Water Management Manual*.

City of Austin, Texas
http://www.ci.austin.tx.us/watercon/default.htm
Details of the city of Austin's Water Conservation Program as well as information about the city's rain barrel program (follow links to Single-family, Multi-family, and Commercial).

Friends of Bassett Creek, Minnesota
http://www.mninter.net/~stack/bassett/gardens.html
A comprehensive guide to the creation of rain gardens for runoff management, habitat creation, and aesthetic value is provided with design and construction information and recommendations on plant material.

F.X. Browne, Inc.
http://www.fxbrowne.com/html/gs-facts/gs_primers.htm
A fact sheet entitled *Bioretention Systems for Storm Water Management* is available for downloading at the homepage of the F.X. Browne environmental consulting firm.

National Association of Home Builders
http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1438&DocumentID=2007
An online report from the association's Technology Inventory entitled *Bioretention Sites for Storm Water Management* includes installation details, a short benefit/cost analysis, and a short list of bioretention links.

Pennsylvania Association of Conservation Districts
http://www.pacd.org/products/bmp/bioretention.htm
A Web site devoted to providing information on the bioretention BMPs for storm water pollution prevention.

Prince George's County, Maryland
http://www.epa.gov/nps/lid/index.html
The Prince George's County Maryland Department of Environmental Resources Programs and Planning Division (PGDER) created two publications with assistance from the U.S. Environmental Protection Agency (EPA): 1) *Low-Impact Development Design Strategies An Integrated Design Approach* (EPA 841-B-00-003), and 2) *Low-Impact Development Hydrologic Analysis* (EPA 841-B-00-002).

State of Maryland Department of Environment
http://www.mde.state.md.us/environment/wma/stormwatermanual/
This link provides updates on Maryland's Storm Water Management Program, including information on obtaining copies of *The 2000 Maryland Storm Water Design Manual (Vols. I & II).*

State of Massachusetts Bureau of Resource Protection
http://www.state.ma.us/dep/brp/ww/wwpubs.htm#storm
Downloadable versions of *Massachusetts Storm Water Policy Handbook*, *Storm Water Technical Handbook,* and *Storm water Management Policy*.

Storm Water Center
http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Storm

water_Practices/Filtering%20Practice/Bioretention.htm
A comprehensive document entitled *Storm Water Management Fact Sheet: Bioretention* provides detailed information on bioretention practices, including applicability, design considerations, and benefit/cost analysis.

Texas Natural Resources Conservation Service
http://www.txnpsbook.org
Texas Nonpoint Sourcebook, a site designed to provide storm water management information to public works professionals and other interested parties both in Texas and elsewhere, provides information ranging from basic to technical.

University of Washington Center for Urban Water Resources Management
http://depts.washington.edu/cuwrm/
A downloadable version of a publication from a research project investigating the use of permeable pavement entitled *The University of Washington Permeable Pavement Demonstration Project--Background and First-Year Results* is available under the Land Cover and Imperviousness section of the research link at the center's homepage.

U.S. Environmental Protection Agency
http://www.epa.gov/owm/mtbfact.htm
The Office of Wastewater Management in the Office of Water provides downloadable fact sheets on BMPs for urban storm water management, including bioretention, porous pavement, wet detention ponds, and more.

Washington State Department of Ecology
http://www.ecy.wa.gov/biblio/9911.html
The *Storm Water Management Manual for Western Washington* describes the storm water management standard for all new development and redevelopment projects in the Puget Sound area.

Organizations and Internet Resources

American Forests
http://www.americanforests.org/
The American Forests home page includes news, links, publications, and information on the use of trees to protect the environment. Included in the site is a link to the Trees, Cities and Sprawl section, which contains information and resources on urban forestry and resource protection.

American Society of Civil Engineers
http://www.bmpdatabase.org
The society and the U.S. Environmental Protection Agency provide an online, searchable database of over 90 studies evaluating the effectiveness of various storm water BMPs for surface water quality protection.

Center for Watershed Protection's Storm Water Center
http://www.stormwatercenter.net/
The Storm Water Center offers resources to assist decision makers and the public on storm water management issues. Resources include publications and manuals, slide shows, ordinance information, monitoring and assessment methods, and BMP fact sheets.

One publication, *Better Site Design: A Handbook for Changing Development Rules in Your Community*, could prove useful to municipal officials interested in revising their zoning ordinances.

Friends of the Rappahannock
http://for.communitypoint.org/pages/LID.htm
Friends of the Rappahannock, a nonprofit organization, highlights five existing commercial projects in the Fredericksburg, Virginia, area that were redesigned on paper to incorporate LID practices.

Low Impact Development Center, Inc.
http://www.lowimpactdevelopment.org
The Low Impact Development Center is a nonprofit water resources research group with a mission of conducting research and training on low impact development and sustainable storm water management. Publications, pictures, and other resources are available on the site.

Pennsylvania Housing Research/Resource Center
http://www.engr.psu.edu/phrc
Part of the Resource Center's work is in conducting research related to "smart growth" and sustainable site design. A workshop conducted March 2003 by Scott Brown entitled, "Understanding Management Practices for Post Construction Storm Water Control" provided information on the impact of development on runoff response.

Urban Land Institute
http://www.uli.org
The home page of the Urban Land Institute, an organization committed to providing responsible leadership in the use of land toward enhancing the environment, offers design resources for housing, retail, office, and transportation development.

U.S. Department of the Navy, Environmental Department
http://www.nfesc.navy.mil
A list of links to the Navy's pollution prevention program includes information about equipment, implementation, and planning. Also included is the Joint Service Pollution Prevention Library, a searchable database of prevention documents.

U.S. Environmental Protection Agency
http://www.epa.gov/OW/index.html
The Office of Water provides an immense amount of information on the protection and conservation of our nation's water resources.

Regional-Specific Resources

Northeastern United States

Cornell Cooperative Extension of Onondaga County
http://www.cce.cornell.edu/onondaga/fingerlakeslan/default.htm
The Web site presents information and design suggestions for landscaping property in a manner that reduces the risk of pollution to surface waters. The information is oriented to the Finger Lakes, New York region but is applicable to many other areas.

Minnesota Pollution Control Agency
http://www.mnerosion.org/tools.html
A comprehensive manual available online entitled *Protecting Water Quality in Urban Areas* highlights technical information about BMPs for protecting lakes, streams, and groundwater from storm water-related pollution.

New York State Department of Environmental Conservation
http://www.dec.state.ny.us/website/dow/swmanual/swmanual.html
The *New York State Storm Water Management Design Manual* provides designers with a general overview on how to size, design, select, and locate storm water management practices at a development site in compliance with state storm water performance standards.

Southeastern United States

Mississippi State University Agricultural and Biological Engineering Department
http://abe.msstate.edu/csd/NRCS-BMPs/pdf/water/quality/bioretentsys.pdf
A downloadable, two-page fact sheet providing descriptions and diagrams of a shallow-depression bioretention system.

Northern Virginia Regional Commission
http://www.novaregion.org/es_pubs.htm
A list of publications for purchase and downloading, including documents on BMPs such as *The Northern Virginia BMP Handbook* and *Nonstructural Urban BMP Handboo*k and publications on Virginia's watersheds.

NRDC's Storm Water Strategies: Strategies in the Southeast
http://www.main.nc.us/riverlink/content/07chap/chap07.htm
Case studies for addressing storm water management techniques in new development and redevelopment.

Western United States

Built Green Colorado
http://www.builtgreen.org/sites/green.htm
The Built Green Colorado Web page with links to many green building resources. Built Green Colorado is a public/private partnership created to encourage home builders to use technologies, products, and practices that enhance energy efficiency, reduce pollution, provide healthier indoor air, reduce water usage, preserve natural resources, improve durability, and reduce maintenance.

Caltrans Storm Water Management Program
http://www.dot.ca.gov/hq/env/stormwater/index.htm
Information on current monitoring studies, publications, conferences, and links are presented in the context of California's Storm Water Management Program. The site is oriented to reducing the impact of California roadways on aquatic resources.

City of Seattle
http://www.ci.seattle.wa.us/util/surfacewater/bmp/default.htm
Information on simple and effective BMPs for homeowners and businesses provided by

Seattle Public Utilities. The information includes everyday tips for protecting surface water.

U.S. Environmental Protection Agency Region 10
http://www.epa.gov/region10
The Region 10 home page provides general information on the region's resources as well as links to its programs. This site also includes regularly updated information on environmental issues in the local news.

Utah Association of Conservation Districts
http://www.ci.north-logan.ut.us/Information/Low%20Impact%20Report/Low%20Impact%20Report.html
The community of North Logan developed LID roadway design standards. The site includes documentation of the process, exhibits, standards, and specifications.

Southwestern United States

Arizona Department of Water Resources
http://www.adwr.state.az.us/
A variety of information on all aspects of water resources for the state of Arizona.

Pima County Department of Environmental Quality
http://www.deq.co.pima.az.us/water/storm.htm

Provides information on Tucson and the surrounding area's storm water management program and components.

Pima County Flood Control District
http://www.dot.co.pima.az.us/flood/wh/index.html
Methods for collecting, storing, and distributing rainwater to reduce residential runoff loads as well as information on harvesting system maintenance.

SECTION 3: WASTEWATER TREATMENT



Properly designed, installed, and maintained on-site wastewater treatment systems can cost effectively treat wastewater and protect the watershed from pollutant overloads.

3.1 INTRODUCTION

Section 2 addressed storm water management issues and explained how rainwater could be used as an asset instead of viewed as a liability in new developments. As we mentioned in Part I, we have expanded LID to include wastewater management. We now turn to the methods and systems that developers can use for effectively treating wastewater generated at residential sites.

It is becoming increasingly popular to protect the nation's surface water and groundwater and prevent further stress from a variety of pollution sources. Approximately 300,000 miles of rivers and shorelines and approximately 5 million acres of lakes are polluted by harmful microorganisms, sediment, and excess nutrients. (http://www.epa.gov/owow/tmdl/overviewfs.html). Wastewater can contain nutrients (e.g., nitrogen, phosphorus), pathogens (e.g., disease organisms), and chemicals (e.g., ammonia, medical byproducts). Thus, developers must ensure that equipment and management methods effectively treat wastewater before it is released into the environment.

Table 11 lists current conventional wastewater management practices and technologies and the alternative systems discussed in this chapter. The 1993 *HUD Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation* publication addressed some of the conventional technologies, which are briefly noted below. To put current technology use into perspective, Figure 10 shows that a vast majority of homes in the United States rely on municipal sewer systems.

Wastewater Management Options Discussed in Chapter	
Conventional	Alternative
Municipal Sewer Single Septic Community Septic Combined On-Site Systems and Sewer Storage and Removal	Aerobic Sand Filters Mound Trickling Filter Evapotranspiration Low-Pressure Pipe

TABLE 11. WASTEWATER MANAGEMENT OPTIONS

Although only 23 percent of homes in the United States are on individual septic systems, such systems can be a significant source of water pollution. Moreover, the average age of a home with a septic system exceeds 30 years. Further, of those homes on septic systems, an estimated 403,000 experienced system breakdowns in a three-month period in 1997 (Bureau of the Census, 1999).

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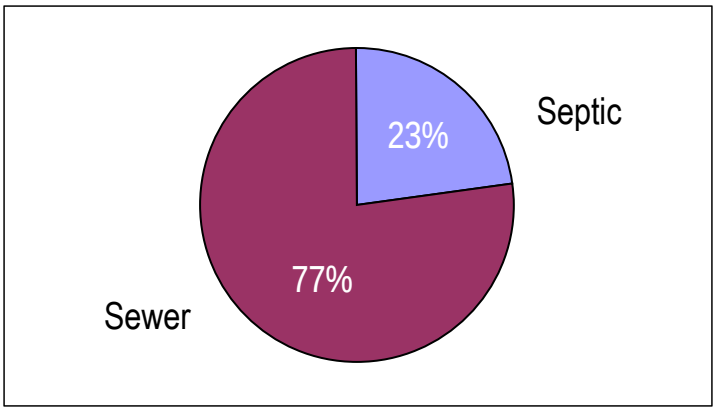

FIGURE 10. HOW HOMES HANDLE WASTEWATER

The management of residential wastewater is a process fraught with technological and regulatory issues. For instance, some communities limit the use of traditional septic systems because improperly maintained systems can release untreated effluent into the soils; in other instances, communities have experienced a number of system malfunctions. Effluent contains excess nutrients and harmful organisms that can adversely affect water quality. Regulatory officials respond to the need to protect our water by adopting progressively stringent wastewater treatment regulations. More specifically, in some cases, communities turn to rigorous regulation of conventional systems as a means of curtailing development, yet they fail to recognize that water quality issues can be addressed by using alternative wastewater management systems.

It is important to keep in mind that septic systems are still used effectively and approved throughout the country. However, in response to the problems noted above, private industry continues to develop alternative systems designed to overcome some of the issues that can plague the performance of conventional septic systems.

This chapter briefly describes the environmental, cost, and regulatory issues associated with wastewater treatment. It then explains how conventional residential developments deal with wastewater management. The last part of the chapter discusses some of the more common alternative means of wastewater management. Table 12 presents the chapter's overall objectives.

Objective 1:
Explain how the use of alternative systems and combinations of systems can reduce on-site infrastructure costs and loadings to municipal sewer systems.
Objective 2:
Demonstrate alternative lot and site layouts to accommodate a variety of system types.
Objective 3:
Show how the use of alternative systems and combinations of systems can reduce pollutant loadings to waterways.

TABLE 12. WASTEWATER MANAGEMENT OBJECTIVES

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3.1.1 ENVIRONMENTAL ISSUES

LID is an approach that uses technologies to simultaneously conserve and protect natural resource systems and reduce infrastructure costs. Wastewater can affect natural resources; all wastewater coming from a home must be sent to an effective treatment site or public treatment system in order to limit adverse environmental and health impacts. One of the reasons that public officials prefer to rely on municipal sewer systems for wastewater treatment is that many of the systems are operated by trained technicians who continuously monitor the treatment process to ensure that discharge waters meet local permit or other regulatory requirements.

- Heavy Equipment--Heavy-duty trucks and other equipment passing over a septic system or drainfield may damage the pipes or system parts.
- Clogging--Systems are designed to keep solids, e.g., sludge and scum, out of the final effluent. However, if those elements make it to the drainage field, they can cause premature soil clogging such that the effluent from the septic tank has trouble percolating into the soil and can pond.
- Roots--Tree and bush roots can enter the system. It is essential to keep large plants away from the septic system.
- Improper Sizing/Design--The system must be large enough for the load and installed in suitable soils as well as in as shallow a trench as possible so that it does not interfere with groundwater.
- Improper/Lack of Maintenance--Septic systems need routine maintenance, including tank pumping and cleaning and inspection by a licensed professional. Properly maintaining a tank keeps solids from accumulating and clogging the leach field.

TABLE 13. COMMON REASONS FOR SEPTIC SYSTEM FAILURE

In most cases, wastewater treatment can be handled by one of the four conventional methods noted in Table 11. However, there are exceptions. For instance, in some circumstances, sewer systems cannot be used because of cost considerations; it might be too costly to run pipes long distances to link a proposed development's wastewater system to existing municipal sewer connections. In other cases, a municipality might have specific health or environmental concerns that make the use of septic systems unacceptable.

Nitrogen and phosphorus are two nutrients in wastewater that, either in excess or through cumulative effect, can adversely affect receiving waterbodies. When septic systems fail to operate as designed, excess nutrients in untreated wastewater can enter the environment. Excess nitrogen in streams, lakes, and estuaries stimulates the growth of plants (algae and phytoplankton). Algae in turn consume oxygen, and the decomposition of dense algal blooms leads to anoxia (no oxygen) and hypoxia (low oxygen). Eventually, the aging process of the waterbody is accelerated through a complex chain of events known as eutrophication. Indicators of eutrophic conditions include odors, poor water clarity, stressed marine organisms, and, in severe cases, dead fish.

From a public health point of view, conventional septic system failure is one of the main reasons for increased interest in alternative on-site wastewater treatment systems. Table 13 lists some common causes of septic system failure. Conventional septic system failures potentially can contaminate groundwater and surface water with bacteria harmful

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to humans. Further, septic systems with poor nitrogen removal can overload nearby waterways, resulting in algal blooms and adverse impacts on aquatic life.

Numerous communities nationwide are attempting to address general water contamination and, in particular, nitrogen loading. For instance, when studies showed that septic systems were threatening groundwater supplies in the Los Angeles area, the Los Angeles Regional Water Quality Control Board voted in 1999 to prohibit the installation of any new septic systems in Ventura County and required the use of septic systems to cease by January 1, 2008 (California EPA Press Release, August 17, 1999). Studies showed that the prohibition was necessary to safeguard the public health and protect the local water supply; community drinking water is pumped from groundwater beneath the discharge area of the septic systems. As part of its overall water conservation plan, Milford, New Hampshire, prohibits septic system use near waterbodies (http://www.ci.milford.nh.us/conservation/streams.html). The Chesapeake Bay watershed is an area greatly affected by water pollutants. The Chesapeake Bay Program, which is designed to protect the bay, determined that between 55 and 85 percent of the nitrogen entering an on-site wastewater treatment system could be discharged into groundwater (U.S. Environmental Protection Agency, 1993). As noted in a U.S. Environmental Protection Agency (EPA) report, "Hydraulically functioning systems can create health and ecological risks when multiple treatment units are installed at densities that exceed the capacity of local soils to assimilate pollutant loads" (U.S. Environmental Protection Agency, 2002). Thus, the concern over septic systems extends to both the inability of septic systems to remove nitrogen and the increased number of septic tanks installed in any one area.

Phosphorus is another nutrient that, if discharged from septic systems, can lead to eutrophication of nearby waterbodies, although it is considered less of a threat than nitrogen to groundwater and surface contamination via conventional septic systems. Septic systems are generally effective in adequately removing phosphorus; furthermore, soil particles adequately adsorb soluble phosphorus and extract soluble phosphorus compounds from septic tank effluent as it leaches through the soil profile, thus limiting the movement of phosphorus through the soil.

3.1.2 COST ISSUES

Municipal Sewer Connection Fees

In addition to environmental issues, economic factors play a role in the selection of an appropriate wastewater treatment system. To connect a home or community to a municipal sewer system, developers must pay certain fees. A community that operates a municipal sewer system often combines the potable water tap fee with the sewer connection fee. In addition, communities sometimes charge developers impact fees to help offset new homeowner impacts on community resources.

Impact fees are not new; they have existed since enactment of the Standard Planning Enabling Act of 1922. However, both the number and dollar amount of impact and connection fees have risen dramatically since the early 1900s. In some communities, sewer connection fees have risen to help municipalities pay for system operation and maintenance costs and system expansions. Fees can range from $1,500 per house to over $14,000 per house. Fee increases have exacerbated the affordable housing problem

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currently plaguing portions of the United States. In a related matter, some communities report that their wastewater treatment facility is at or near capacity, hindering further residential development until facility expansion can accommodate additional growth. In response, HUD's Office of Policy Development and Research created the Regulatory Barriers Clearinghouse to examine how impact fees and other issues affect the creation and maintenance of affordable housing (http://www.huduser.org/rbc/).

Conventional Septic Installation and Maintenance Costs

The cost of installing septic systems depends on system size, treatment capacity, occupancy, and land issues such as the type of on-site soil. For example, in Minnesota, the costs of installing a septic system can range from $2,000 to $7,000. The average cost to pump the tank's sludge ranges from $75 to $150. Pumping the tank at the appropriate frequency is less costly than replacing the system's leach field, which would be needed if solids enter the field from an overloaded septic tank. If a septic system and corresponding leach field need to be replaced in Minnesota, the costs are equal to that of installing a new system - http://www.extension.unm.edu/distribution/naturalresources/components/DD6946c.html.

3.1.3 REGULATORY ISSUES

Currently, most local regulations are prescriptive and limit the introduction and use of alternative on-site wastewater treatment systems (OWTS). Public health officials, however, can facilitate the use of alternative OWTSs by revising the applicable codes.

The use of alternative systems can reduce the capacity strain on an existing wastewater treatment facility. In fact, some local officials may be willing to allow alternative OWTSs on some but not all lots within a parcel. For instance, some lots may have the appropriate soil composition for the use of conventional septic systems while the soils on other lots in the development may not lend themselves to such systems. Thus, a community that needs to increase the capacity of the local wastewater treatment system could allow a mix of alternative and traditional OWTSs on a single site instead of relying exclusively on alternative systems. This is an example of how LID is flexible in its application.

3.1.4 GENERAL PERFORMANCE STANDARDS

In general, wastewater treatment systems take in wastewater, treat it, and release it to the environment. It is difficult, however, for prescriptive codes to specify the full range of technological options appropriate for a given site and anticipate the different sensitivities of the site's water and land resources. Although the topic is beyond the scope of this publication, public officials could use performance codes to address site-specific natural resource needs while meeting health requirements.

In 2002, the National On-Site Wastewater Recycling Association (NOWRA) received a grant to develop draft national on-site performance standards (http://www.nowra.org/model_code.html). The underlying issue and impetus for the project is that local wastewater regulations are usually prescriptive. Although alternative OWTSs have worked elsewhere in the country, local code officials are often reluctant to approve the use of these systems in their jurisdiction when a site does not meet the

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prescriptive requirements. The goal of the NOWRA project is to create a set of national OWTS standards that local officials could use for approving the use of innovative systems (Small Flows Quarterly, Winter 2002).

The U.S. EPA states in a March 28, 2003 Federal Register notice regarding Voluntary National Guidelines for Management of On-site and Cluster (Decentralized) Wastewater Treatment Systems, "State agencies report that some of these systems have failed because of inappropriate siting or design or inadequate long-term maintenance. Historically high failure rates in some areas indicate a need for better management of these systems to protect public health and water quality." U.S. EPA has thus developed the Management Guidelines that are designed to enhance system performance through improving the quality of management programs (Federal Register, 2003). You may access this Federal Register notice electronically through the EPA Internet under the Federal Register listings at http://www.epa.gov/fedrgstr/T.

3.2 CONVENTIONAL APPROACHES TO WASTEWATER TREATMENT

Developers typically have four options regarding residential wastewater treatment systems: tying into a municipal or public sewer system, providing homeowners with an on-site septic system, using a community septic system, or using a combination of on-site systems and tying into the municipal system. Centralized municipal systems, often available in urban and many suburban areas, are often the most cost-effective option when municipal system connections are proximate to the land to be developed. Municipal systems consist of a series of pipes and pump stations leading to a wastewater treatment facility. The facility treats the water before releasing it to a body of water. In many instances, however, homes in a development cannot connect to a municipal treatment system. It may be cost-prohibitive to connect to a municipal system because of distance to conveyance pipes, or a municipal system already at capacity cannot treat additional effluent. In these cases, developers have traditionally turned to septic systems.

A conventional septic system normally treats a home's wastewater in an underground septic tank located on the property. The life of septic systems depends on the quality of the installation, correct usage, and the frequency of maintenance. With appropriate maintenance, many systems can last for 20 years or more.

Two primary factors in a septic system's successful operation include proper installation and appropriate operation and maintenance. Assuming proper installation, homeowners must ensure that the tank is pumped out as frequently as needed. In addition, given that the bacteria within the tank are sensitive to the wastewater inputs, homeowners should not use the system for the disposal of chemicals such as turpentine, alcohol, and bleach as well as for large volumes of grease and animal fats; such items can clog the system. Developers should provide homeowners with a list of "things to do and not to do". The National Small Flows Clearinghouse sells *The Homeowner On-Site System Recordkeeping Folder* (Item #WWBLPE37) and the *Homeowner Septic Tank Information Package* (Item #WWPKPE28) to help homeowners record and store information about their septic system and to educate homeowners on system care and system (http://www.nesc.wvu.edu/nsfc/nsfc_septicnews.htm#septic). In addition, the U.S. EPA has created a free, one-page Homeowner Septic System Checklist to highlight the homeowner's septic system maintenance needs (U.S. EPA, 2003).

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Another wastewater management option sometimes used by developers is a communitywide wastewater treatment system. Although the vast majority of today's homes either use single septic systems or are connected to public sewer, some developers have installed communitywide septic systems. The systems treat wastewater for a group of homes in a manner similar to a septic system for a single home. Small community cluster systems often try to take the best attributes of municipal sewers and septic systems and use them to reduce wastewater treatment system installation costs while meeting environmental goals. The systems transport wastewater from homes via sewer pipes to either a conventional treatment plant or a pre-treatment facility. The effluent is then discharged to soils similar to those required in the last stage of a single septic system's treatment process.

Some communities install a centrally located package wastewater treatment plant that connects each home in that community to the plant. The package system is similar to public wastewater treatment facility except that the effluent from the homes travels to a privately owned and operated treatment plant located in the community (sometimes referred to as "small community sewer" or "distributed sewer").

A small number of jurisdictions are using natural open spaces, golf courses, and soccer fields as areas for drip irrigation of semitreated effluent. Such uses of open space allow effluent to be effectively disposed of across large areas. Another benefit of is that the systems can be created as needed. The developer can calculate how much effluent the entire development will likely generate and then phase in the system as homes are built. The system's potential drawbacks include a perception that odor will be a problem or that public health will be compromised.

In several communities, community systems have proven themselves a feasible alternative. For example, in Warren Village, Vermont, nearby streams had become polluted in part because of a combination of dense development, small lot sizes, and failed single septic systems. When residents determined that a municipal sewer system was too expensive, the town used two parcels--a soccer field and a vacant lot-- as common leaching fields with a total capacity of 30,000 gallons per day. Homeowners whose lots lacked adequate wastewater disposal capacity could pay the newly formed wastewater management district $250 per user per year to discharge to the community system (http://www.daylor.com/projects/Gloucester/CommunityWastwater.htm).

Community systems can also facilitate the use of smaller house lots. Single septic systems need an adequate land area for the leach field. With community systems, the final treatment location is consolidated into one large leach field instead of relegated to several individual fields. Allowing for smaller lots can help the developer preserve open space, furthering the goals of low-impact development.

Some instances warrant a combination of sewer hook-up and septic system installation. . For example, a municipal sewer system may be able to serve only an additional 50 homes, yet a proposed development calls for 200 homes. Public officials and the developer might agree to hook up 50 of the new homes to the public system and serve the rest of the homes with an on-site septic tank system.

A combination system might also be warranted when soils on part of the development are not suitable for septic tank installation. In this instance, the lots that cannot accommodate

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septic systems could be connected to the municipal system while the rest of the lots could be served by septic systems or municipal connections.

Clearly, each parcel of land is often suited to a variety of options available to the developer. Developers can help create cost-effective developments by weighing all the wastewater management options and determining which will yield the best performance at the least cost. The LID approach helps increase the number of wastewater management system options available to the developer.

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3.3 ALTERNATIVES TO CONVENTIONAL SYSTEMS

Table 14 contains a brief description of the OWTSs highlighted in this chapter. Listed below are expanded explanations of the alternative systems that provide secondary treatment and that might allow for on-site wastewater treatment (U.S. Environmental Protection Agency, 2002).

OWTS Type	Key Components	Situations Where Its Use Might Be Appropriate
Sand Filters	• Septic tank, sand filter, and sometimes a recirculation tank	• Where soil conditions do not allow for percolative beds/trenches • High groundwater
Mound	• Pre-treatment unit(s), dosing (pumping) chamber, and elevated mound	• Slow- or fast-permeability soils • Shallow rock cover over creviced or porous bedrock • High groundwater
Trickling Filter	• Circular bed of coarse or plastic material and rotating distributor	• High concentrations of organic material in wastewater
Evapotranspiration	• Pre-treatment unit, evapotranspiration sand bed, bed liner, fill material, monitoring, overflow protection, and surface cover	• Annual evaporation rate exceeds annual rate of precipitation and wastewater applied
Low-Pressure Pipe	• Septic tank, pumping (dosing) chamber, and small-diameter pipes	• Where soils would become clogged as a result of localized overloading • High groundwater • Anaerobic conditions due to continuous saturation
Aerobic	• Aeration compartment, settling chamber, pre-treatment compartment (optional)	• Where septic systems have failed • Where lot size is not sufficiently large to accommodate a standard septic system drainfield
Proprietary Systems	• Varied	• Where conventional septic systems or sewer hook-ups are not feasible

TABLE 14. ON-SITE WASTEWATER TREATMENT SYSTEM ALTERNATIVES

Alternative systems can use anaerobic bacterial action, i.e., the bacteria decomposes waste in the absence of oxygen, while other systems need oxygen (i.e., aerobic) to operate properly. In addition, hybrid systems use a combination of aerobic and anaerobic processes.

Developers can consider a variety of on-site wastewater treatment system options either as alternatives or enhancements to conventional septic systems. By using the LID approach, developers often uncover information and options that can help facilitate the development approval process.

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While municipal sewer or on-site septic systems may be the most recognized wastewater treatment options, some sites might lack both sewer access *and* the ability to accommodate a septic system. Some of the limiting factors for septic systems include lot size (an ample soil absorption field is necessary), groundwater level, depth of bedrock, and on-site soil types. For example, dense clay or rocky soils can inhibit the use of septic systems. Recognition of various limitations has led to increased interest in and the development of alternative on-site wastewater treatment systems.

Alternative on-site wastewater treatment systems range from adding treatment steps (e.g., intermittent sand filter) to a conventional septic system to the reliance on proprietary systems that omit the use of traditional septic tanks. In fact, as technology grows more sophisticated, , it is often more important to establish an operation and maintenance plan for an alternative OWTSs than for an ordinary septic system.

Examples Where a Septic System May Not Be Allowed on a Lot

Lot size too small
Wrong types of soils
High groundwater level
Shallow soils/Depth of bedrock
Steep slopes
Soil does not percolate

When lots cannot be developed to take advantage of conventional wastewater management techniques (e.g., municipal sewer or on-site septic systems), the use of alternative OWTSs (discussed below) can make those lots suitable for development. Before using an alternative OWTS, however, developers are advised to familiarize themselves with the local public health criteria related to wastewater effluent and to recognize that, as opposed to municipal sewer systems, which are usually regulated by codes at the state level, local public health officials regulate on-site systems. The lack of information on the systems and absence of third-party verification of alternative system performance make public health officials reluctant to alternative OWTS. In general, public officials are most concerned with ensuring a certain level of public health, not with facilitating land development; therefore, officials often need to be educated about the efficacy of alternative systems.

On a related note, some public officials and environmental groups have expressed concern that the use of septic and/or alternative OWTSs will foster sprawl. The use of OWTSs by themselves does not lead to unchecked growth; indeed, the best way to manage growth effectively is through prudent zoning, not by eliminating potential wastewater treatment solutions or creating barriers for the adoption of alternative technologies related to development.

3.3.1 PROCESS FOR IDENTIFYING POTENTIAL ON-SITE WASTEWATER TREATMENT SYSTEM ALTERNATIVES

Each parcel of land is unique in terms of its size, shape, and soil types. If public health officials indicate that an alternative OWTS is a feasible option, then developers should consider several factors to identify the types of systems that might be used. For instance, OWTSs are more complex than septic systems and thus require a higher level of maintenance and supervision and may need additional excavation during installation to accommodate the various systems' several components. Table 15 briefly describes the various factors to be considered.

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Costs can vary for different OWTS options. For instance, community wastewater treatment systems that rely on gravity to transport wastewater can require deep and thus costly excavations, but the use of pressurized systems with small-diameter plastic pipes can minimize excavation costs.

Some OWTS alternatives to conventional systems, such as recirculating sand filters and evapotranspiration systems, are "add-ons" to a traditional septic tank system. The additional treatment unit is connected in-line with the septic tank and provides an extra level of treatment. Although it may seem more costly to add another layer of treatment, alternative treatment systems may be less costly if conventional wastewater management methods require the hauling of extra fill material or the construction of a retaining wall.

As for other cost issues, alternative OWTSs may need electricity to operate the pumps that are sometimes required as part of the treatment system itself and that are sometimes needed to move wastewater from the house to the treatment area. In addition, the inclusion of other features such as recirculation piping, aeration, and an increased need for cleaning/pumping may increase an alternative system's operation and maintenance costs.

Another economic issue associated with the use of an alternative OWTS is the long-term operation and maintenance (O&M) costs and related organizational framework required

- Aesthetics--Both the general public and public officials will be most aware of aesthetic concerns. In short, potential insect problems and odor issues must be addressed and mitigated.
- Capacity--The system must be able to handle the home's capacity; the approval process will consider both rate and volume of sewage flow. In addition, public officials may want the system to be able to handle more than the current load to accommodate changing uses of the home.
- Cost--The upfront costs of alternative OWTSs can often be higher than the costs of traditional septic systems. In addition, the complexity of alternative systems yield somewhat higher operation and maintenance costs (e.g., the alternative systems usually need electricity to treat waste).
- Efficiency and Reliability--The community at large will be interested in any third-party reports and data indicating how well the proposed systems treat or remove potentially harmful wastewater components. In addition, the system must have adequate safeguards to warn the occupant of system failure.
- Environmental and Public Health--A system must maintain or improve environmental quality and adequately address public health issues.
- Operation and Maintenance (O&M)--As an emerging issue in the on-site wastewater treatment field, OWTSs require more monitoring than standard septic systems; thus, the local jurisdiction or a third party must ensure the proper maintenance of equipment.
- Siting--Soil type and lot size are often determining factors when siting OWTSs. For instance, only about one-third of the land area in the United States has soils suitable for conventional subsurface soil absorption fields.

Source: U.S. EPA, 2002.

TABLE 15. FACTORS TO CONSIDER WHEN EVALUATING ON-SITE WASTEWATER TREATMENT SYSTEMS

with the systems. Given that innovative systems usually require more frequent and ongoing O&M than conventional systems, developers, public officials, and communities must work together to develop an O&M plan and establish an entity that will ensure

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effective system performance. Such an entity can oversee O&M activities, reduce liabilities, and establish service boundaries (Jones et al., 2001).

The following list offers criteria for determining situations in which an alternative OWTS could be most helpful:

- **When sewer is not located nearby.** If a given plot of land is not located close to existing infrastructure, thus making it costly to establish public sewer connections, then OWTS might be an effective option.
- **When the wastewater treatment facility is at capacity.** In some locales, the wastewater treatment facility is at capacity and cannot accept any more connections. In these instances, either a new facility will have to be built or the existing facility will have to be expanded. Either option will require the public's investment and time and will potentially delay land development.
- **When a lot is too small.** If local ordinances dictate that a lot is too small to accommodate a septic field, an alternative OWTS might help reduce the size of the required absorption field.
- **When a watershed requires higher-quality effluent.** In some instances, a watershed has effluent requirements that exceed the effluent characteristics normally produced by septic systems. Once again, the enhanced wastewater treatment available with some alternative OWTSs may help provide a solution.
- **When groundwater supply is limited.** Instead of pumping water off site through a sewer, an OWTS keeps water on the site; properly treated effluent from an alternative OWTS can help recharge the local groundwater aquifer.
- **When deep excavation is needed for a septic system.** Some alternative systems do not require as much excavation as septic systems, thus reducing initial costs.

Another way to look at the system selection process is through a variety of stakeholders' lenses. Figure 11 provides an overview of some of the groups interested in the process of selecting an appropriate OWTS and their relevant concerns (U.S. Environmental Protection Agency, 1997).

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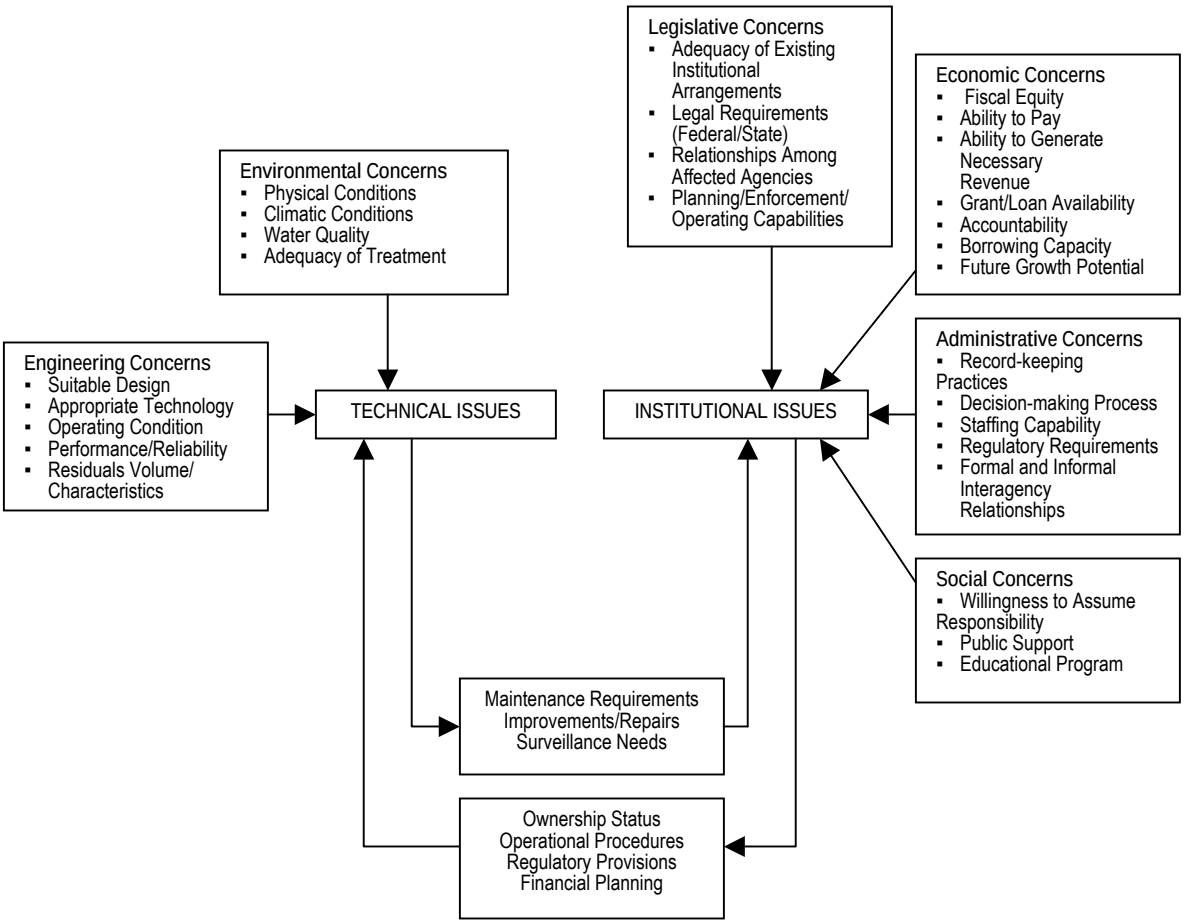

Source: Response to Congress On Use of Decentralized Wastewater Treatment Systems, http://www.epa.gov/owm/decent/response.

FIGURE 11. OVERVIEW OF PARTIES INTERESTED IN WASTEWATER TREATMENT DECISION MAKING

In some situations, conditions do not permit the installation of septic systems, particularly if soils are not appropriate or lot sizes are not sufficiently large to support a leach field. For example, the Floyd County, Kentucky, Plan Commission recently proposed a zoning ordinance amendment that would use soil conditions to dictate how many homes could be built per acre with septic systems (*The Courier-Journal*, Louisville, KY, May, 2002). In the worst soil and topographic conditions, the proposed amendment would limit development to one house with a septic system per 20 acres.

As previously noted, there are a variety of alternative systems available to developers. Below are descriptions of the different systems. Also included are considerations developers can take into account when deciding which systems to include in a new development.

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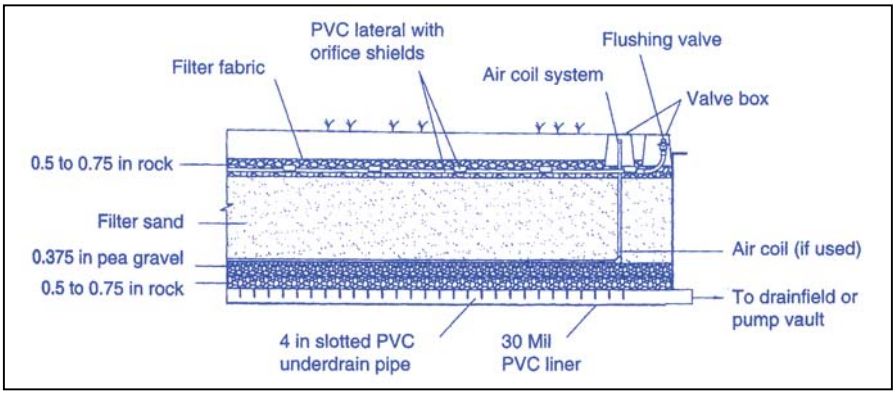
3.3.2 SAND FILTERS

Intermittent Sand Filters

Sand filter systems treat the effluent downstream from a conventional septic tank. Two of the more common sand filter systems are the single-pass system (i.e., intermittent) and the recirculating system. In the single-pass system, the wastewater first undergoes primary treatment in a septic tank. The effluent is then applied intermittently to the top of a bed of sand (or other suitable media) that sits on an impermeable liner and percolates through the sand into drains located at the bottom of the bed (see Figure 12). As the wastewater passes through the sand filter, both physical and chemical processes treat the effluent, although microorganisms attached to the fixed media primarily treat the effluent. The effluent is then piped to the leach field for further treatment and disposal. Bottomless systems have no impermeable liner and do not discharge to a drainfield but rather to the soil below the filter.



Source: National Small Flows Clearinghouse Fact Sheet, 1998.

FIGURE 12. TYPICAL CROSS-SECTION OF AN INTERMITTENT SAND FILTER

Intermittent sand filters produce a high-quality effluent by removing a high percentage of contaminants. The filter's ability to perform adequately depends on the filter's design and composition and, hence, the biodegradability of the wastewater and the environmental factors within the filter. The most important environmental factors include media re-aeration and temperature. Re-aeration makes oxygen available for the wastewater's aerobic decomposition. Temperature directly affects the rate of microbial growth, chemical reactions, and other factors that contribute to the stabilization of wastewater within the system.

System pumps and controls should be checked every three months while the sludge build-up in the septic tank should be checked as needed. Installation costs of intermittent sand filters, including labor and materials, generally range from $7,000 to $10,000. Daily energy costs for pumping the wastewater onto the filter bed run between $0.03 and $0.06.

Recirculating Sand Filters

In situations without sufficient land area for a single-pass filter system, recirculating sand filter systems are an option. In a recirculating system, wastewater first undergoes treatment in a septic tank. The pre-treated effluent then flows into a recirculation tank

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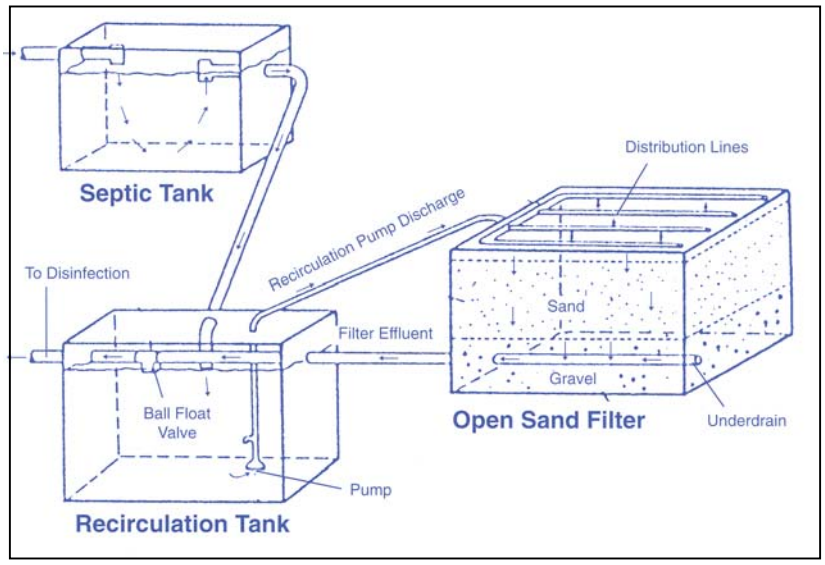
along with some of the water that has already passed through the sand filter. A pump transports the wastewater mixture from the tank to the sand filter, where microorganisms attached to the filter media carry out treatment. The treated effluent collects at the bottom of the filter; some of the effluent is sent back to the recirculation tank for further treatment and some is sent out for disposal or another type of treatment disinfection. In this type of system, the sand is periodically changed (see Figure 13).



Source: National Small Flows Clearinghouse Fact Sheet, 1998.

FIGURE 13. TYPICAL RECIRCULATING SAND FILTER SYSTEM

Recirculating sand filters are relatively low-maintenance systems whose operating costs are generally modest. Operation and maintenance costs were under $5,000 for a 135-home septic tank system in Elkton, Oregon, including $780 for electricity and 25 to 30 labor hours per month. The replacement of the media represents one of the system's most expensive maintenance items. Thus, it is prudent to use locally available materials. For example, the capital cost (land not included) for a 5,000 gallon per day system with black beauty™ sand media that was not locally available totaled about $68,600. That same system cost $36,000 with standard sand media.

- Peat Filters--Organic particles and suspended solids are removed by passing wastewater through a peat bed.
- Batch Reactors--To increase nitrogen-removal efficacy, batch reactors alternate between oxygen-rich and oxygen-poor cycles and treat one batch of wastewater at a time.
- Activated Sludge Systems and Aerobic Treatment--Biooxidation (aerating wastewater) and oxygen-poor settling areas improve treatment.

TABLE 16. SECONDARY TREATMENT

Other types of filters provide secondary wastewater treatment (see Table 16).

3.3.3 MOUND

On lots with high water tables or soils unsuited to septic systems, a mound of suitable soils is placed on top of the soils that do not permit the use of a septic system. The primary treatment takes place in the septic tank. The wastewater from the tank passes

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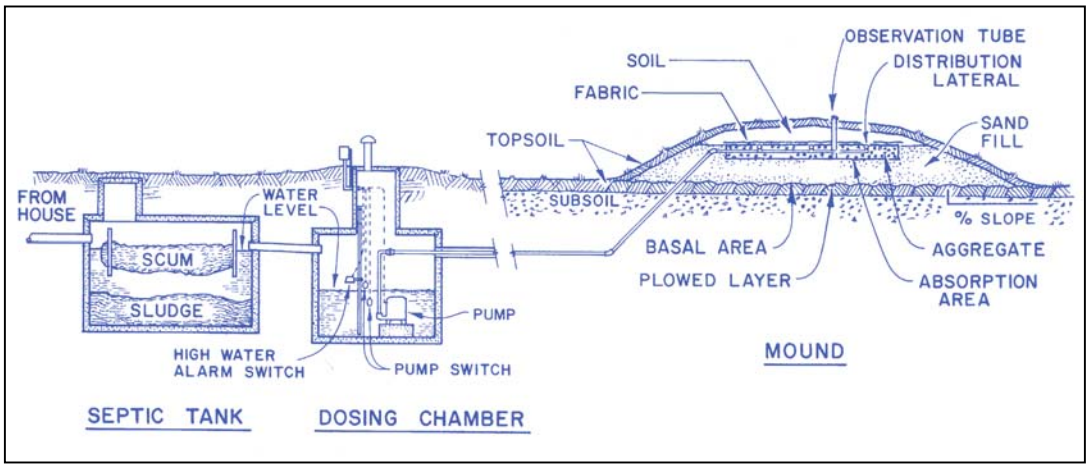
through a filter (to eliminate additional solids) and discharges to a dosing chamber. The effluent is then spread uniformly on the mound, which acts as an elevated or above-ground drain field. Typically, a mound system requires a pump that sends the effluent from the septic tank upward into perforated pipes that are located in the mound within a layer of fabric-covered coarse-gravel aggregate. The mound is often a soil cover that can support vegetation (see Figure 14).



Source: National Small Flows Clearinghouse Fact Sheet, 1998.

FIGURE 14. SCHEMATIC OF A WISCONSIN MOUND SYSTEM

The mound's height should be sufficient to treat the effluent effectively before it reaches the limiting soils, bedrock, or high water table. In general, codes require a mound height between one and four feet. Mound slopes can be up to 25 percent. Mounds should be sited well away from flood plains, drainage ways, or depressions unless flood protection is provided.

Sand suitable for a mound system should contain 20 percent or less material greater than 2.0 mm and 5 percent or less finer than 0.053 mm. Mound design depends on several additional factors, including the number of rooms in a home; up to 150 gallons per day per bedroom are allowed. In addition, to minimize the number of solids entering the mound filter, the septic tank and dosing chamber must be watertight. In Wisconsin, the mound system success rate is more than 95 percent.

A typical mound system in Wisconsin costs approximately $9,000 to construct, with another $750 in site evaluation, design, and permitting costs. The operation and maintenance costs range from $125 to $200 per year.

3.3.4 TRICKLING FILTER

Trickling filters are effective in removing nitrogen from wastewater. They trickle wastewater over a fixed medium (coarse stones or plastic material) covered with a bacterial mat that removes nitrogen from the effluent. A rotating distributor, which is a rotating pipe containing several holes, evenly distributes the wastewater from above the filter medium. Microorganisms on the medium break down the organic materials in the wastewater as it passes through the medium (see Figure 15).

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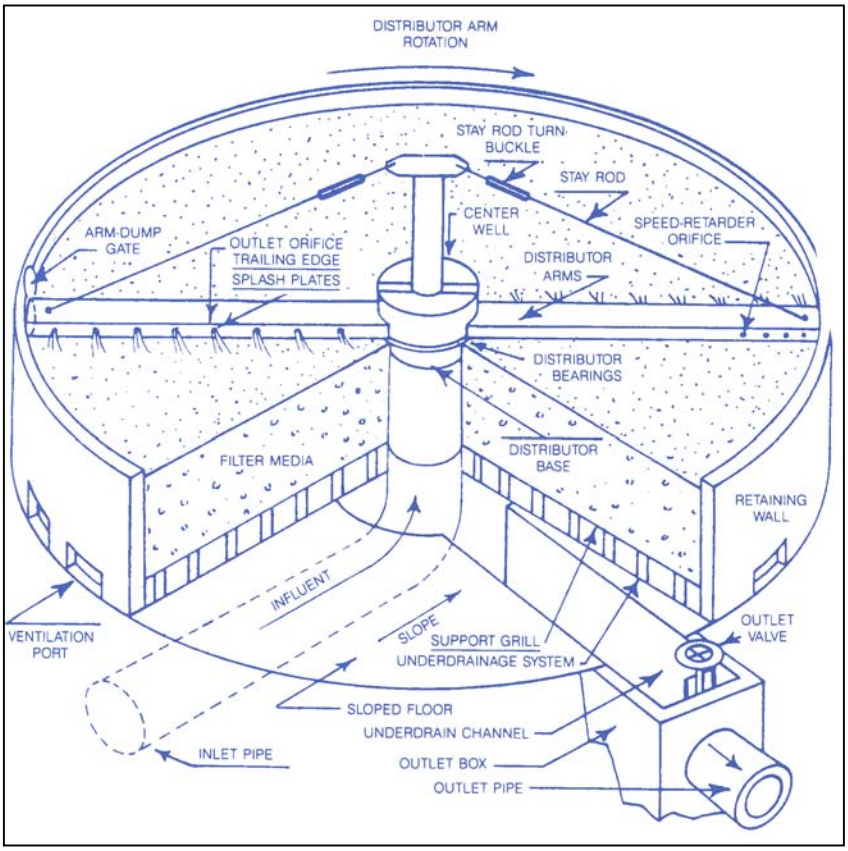

Source: National Small Flows Clearinghouse Fact Sheet, 1998.

FIGURE 15. SCHEMATIC OF A TRICKLING FILTER

Trickling filter systems are especially effective when the receiving waterbodies are highly sensitive to nitrogen loading. The filters successfully remove ammonia nitrogen by oxidizing it to nitrate nitrogen. The nitrate nitrogen is then converted into nitrogen gas that is vented to the atmosphere. The filters can accomplish ammonia nitrogen removal in one- or two-stage systems. In a single-stage unit, carbon oxidation (removal of organic material) and nitrification occur in the same unit. In two-stage systems, separate stages operate independently to complete the organic removal and nitrification steps. Trickling filters are highly sensitive to how much oxygen is available and to nitrogen loading rates.

3.3.5 EVAPOTRANSPIRATION

The two primary types of evapotranspiration (ET) systems are the standard ET system and an ET/absorption system (ETA). The more common is the ET system, which comprises a septic tank, an ET sand bed with wastewater distribution piping, a bed liner, fill material, monitoring wells, overflow protection, and a surface cover. Vegetation grows on the cover to facilitate the transpiration process.

Evapotranspiration systems are especially important on sites in need of surface and groundwater protection. An ET system can operate solely as a system that disposes of wastewater into the atmosphere through evaporation from the soil surface and/or transpiration by plants, or it can combine such treatment with seepage.

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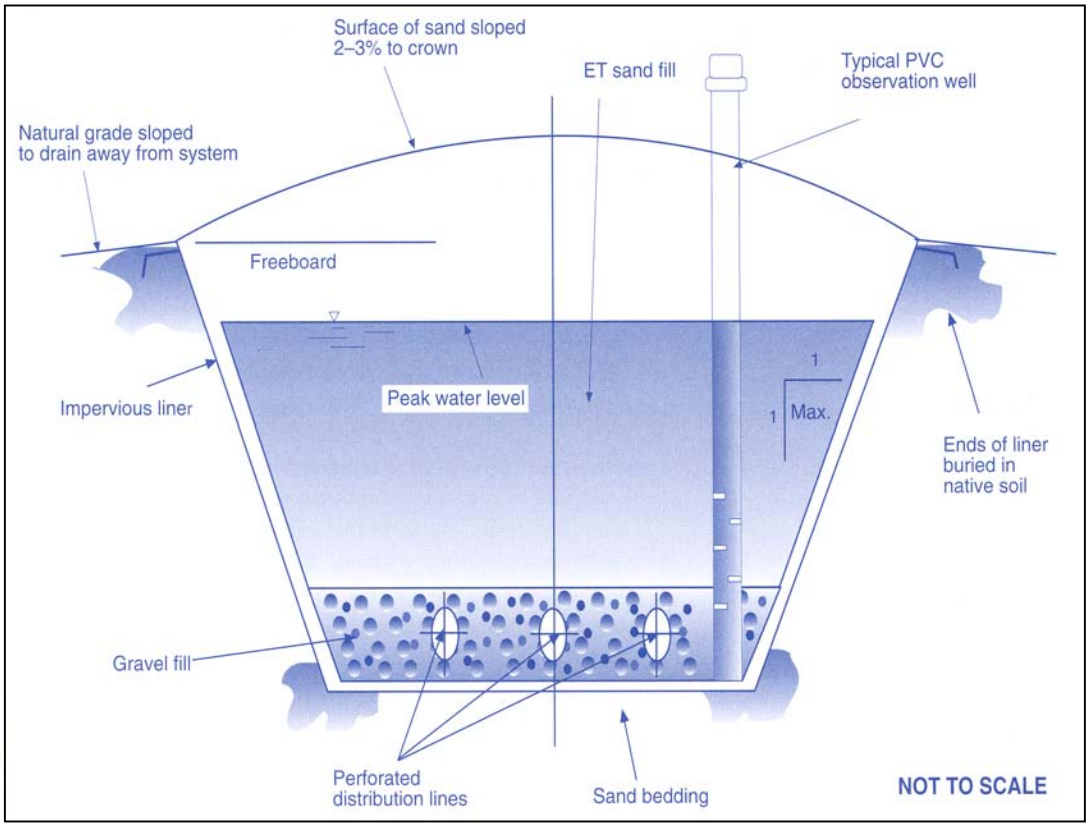

Source: National Small Flows Clearinghouse Fact Sheet, 1998.

FIGURE 16. CROSS-SECTION OF A TYPICAL EVAPOTRANSPIRATION BED

In a system that does not seep, the effluent flows from the septic tank into the lower portion of the sealed ET bed, which contains continuous impermeable liners and sand. Capillary action in the fine sand causes the wastewater to rise to the surface and escape into the atmosphere via evaporation. At the same time, vegetation brings wastewater from plant roots to the leaves, where it is transpired. An ET incorporates an unsealed bed, which allows for evaporation, transpiration, and percolation (see Figure 16).

To prevent overloading (with undersized systems) or excessive capital costs (with oversized systems), the design of ET systems requires accurate estimates of wastewater flow rates. The availability of land can limit the size of ET systems: up to 4,000 to 6,000 square feet of area is typically needed for a single-family home. However, the most important factor for ET systems is climate. Precipitation, humidity, wind speed, temperature, and the amount of solar radiation must are important considerations. For instance, system overloading can occur if large amounts of rainfall enter the system over a short period of time. Thus, ET systems are most suitable for use in arid to semi-arid locations such as the western and southwestern parts of the United States. The typical minimum cost for an ET system for a three-bedroom residence is $10,000.

3.3.6 LOW-PRESSURE PIPE

A low-pressure pipe (LPP) system is a shallow, pressure-dosed soil absorption system with a network of small-diameter perforated pipes placed in narrow trenches (see Figure

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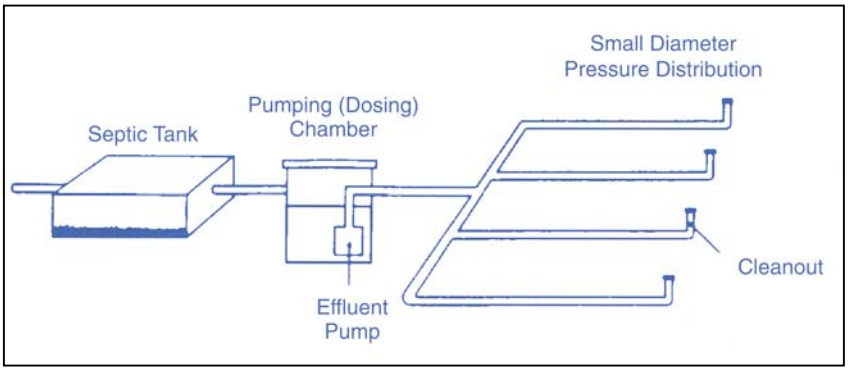
17). LPP systems can be used to address septic system issues such as soil clogging from localized overloading, mechanical sealing of the soil trench during construction, anaerobic conditions resulting from continuous saturation, and a high water table.

A typical LPP system consists of a septic tank for primary treatment. Partially treated effluent then flows by gravity to a pumping chamber, where it is stored until it reaches the level of the upper float control. Once the water reaches that level, the pump turns on and usually sends one to two batches of wastewater per day to the trenches via the distribution pipes. During each dosing cycle, the depth of wastewater in the trenches does not exceed two to three inches of the total trench depth.



Source: National Small Flows Clearinghouse Fact Sheet, 1998.

FIGURE 17. LOW-PRESSURE PIPE SYSTEM

Two critical factors affecting LLP system performance are the dosing and distribution of the effluent. The dosing must be correct to maintain aerobic conditions in the trench, and effluent must be evenly distributed to avoid localized overloading.

A properly designed and installed LPP system needs little maintenance. For instance, North Carolina requires LPP systems to be inspected at least once every six months. The septic tank and pumping chamber should be checked periodically for sludge and scum build-up as needed. Watertight pumping tanks are necessary to ensure that drainfields do not inadvertently become hydraulically overloaded.

In a 1989 study of LPP use in North Carolina, the average cost to install an LPP system for a three-bedroom home was $2,600. The more LPP systems used in a county, the less is the average cost per system. In counties with several systems, the cost was approximately $1,500 per system as compared with $5,000 per system in counties with few LPP systems.

3.3.7 AEROBIC SYSTEMS

Similar to conventional septic systems, aerobic systems also use natural processes to treat wastewater. However, septic treatment does not require oxygen (anaerobic), whereas aerobic treatment does need oxygen. Thus, aerobic units include a device that injects air into and circulates it inside the treatment tank.

According to U.S Environmental Protection Agency, aerobic treatment units can range in size from 400 to 1,500 gallons and usually include an aeration compartment and a settling

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chamber. Some units also include a pre-treatment compartment to remove garbage and grease (U.S. Environmental Protection Agency, 2000b). In addition, electrical service is required for the aeration equipment and pumps.

The two types of aerobic systems most often used for single-family homes are fixed-film and suspended-growth systems. Fixed-film systems are not available commercially and, as proprietary devices, are not described in detail here. Suspended-growth systems use microorganisms suspended in the waste stream to break down the wastes.

An aerobic system's application is limited primarily by soil conditions and topography. A site should have a percolation rate of less than 60 minutes per inch, its depth to the water table or bedrock should be two to four feet, and it should have level or slightly sloping topography.

Aerobic systems vary in cost, from $2,500 to $9,000 installed. In addition, the units must be maintained more frequently than a septic system. The recommended quarterly servicing costs about $350 per year.

3.3.8 PROPRIETARY SYSTEMS

Proprietary technologies are designed to provide turnkey solutions to developers' wastewater treatment needs.

Below are brief descriptions of the proprietary systems available today as well as the latest Web sites containing more information on the systems.

- Alascan--http://www.alascanofmn.com/

Alascan offers a variety of wastewater treatment options and systems to meet different needs, including source separation systems that separate blackwater from greywater and low-flush toilets that, according to the manufacturer, can reduce a home's water usage by 40 to 80 percent.

- Bio-Microbics, Inc.--http://www.biomicrobics.com/

Bio-Microbics, Inc., has created a Fixed Activated Sludge Treatment (FAST®) process. suited for use in single-family dwellings, clustered residential developments, and subdivisions. It can also be used to retrofit a failed conventional septic system.

- Cromaglass-- http://www.americanpump.com/croma3.htm

One of the more notable Cromaglass systems is the Cromaglass Batch Treat Process. The manufacturer claims that biological oxygen demand (BOD) and total suspended solid (TSS) removal rates exceed 90 percent and that independent laboratory research verifies system efficacy.

- E/One Sewer Systems--http://www.eone.com/sewer/intro/index.html

E/One offers several wastewater treatment systems sized to meet a customer's unique conditions. For instance, the GP 2010 is designed for single-family homes, whereas the GP 2016 is suited for multiple dwellings. The Web site provides brief case studies.

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- Global Water Systems-- http://www.globalwater.com/encampment.htm

Global's source separation systems treat greywater for reuse in toilet flushing or irrigation.

- Blackwater-- Toilet wastes in wastewater
- Greywater--Washwater excluding toilet wastes

- MicroSepTec, Inc.-- http://www.microseptec.com/

The MicroSepTec (MST) system is an on-site wastewater treatment system that can be used for residential applications. In addition, MicroSepTec, Inc., is a full-service septic solution provider and will assist with permits, engineering, project management, maintenance, and monitoring.

- Orenco Systems, Inc.--http://www.orenco.com/

Orenco Systems® offers on-site (decentralized) treatment solutions for many types of residential properties for small flows and large flows, household-strength waste and high-strength waste, poor soils, and high groundwater. The company provides a variety of package solutions.

- Waterloo Biofilter Systems, Inc.--http://www.waterloo-biofilter.com/

The Waterloo Biofilter ® is a patented trickle-filter–type treatment system that uses a filter medium to treat residential and industrial wastewater. Wastewater is sprayed intermittently onto the medium and allowed to drain through by gravity.

3.4 ADDITIONAL RESOURCES

Additional resources with more detail on wastewater treatment are included below. They are not provided as endorsements, merely as educational and reference tools. Given regional variations in climate and land development needs, we have tried to include region-specific resources. It is important to note, however, that addresses, especially Internet links, are subject to change. This list contains the latest links and addresses as of the printing of this publication.

Wastewater Manuals and Best Management Practices

National On-Site Demonstration Program
http://www.nesc.wvu.edu/nodp/nodp_index.htm
The National On-Site Demonstration Program (NODP), established in 1993, was developed to encourage the use of alternative on-site wastewater treatment technologies to protect the public health, ensure water quality, and sustain the environment in small and rural communities. Funded through the U.S. Environmental Protection Agency (EPA) and directed by the National Environmental Services Center of the National Research Center for Coal and Energy at West Virginia University, the NODP provides communities throughout the country with information on cost-effective alternatives to centralized wastewater treatment systems.

U.S. Environmental Protection Agency
http://www.epa.gov/ORD/NRMRL/Pubs/625R00008/625R00008.htm

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The 2002 *On-site Wastewater Treatment Systems Manual* is the U.S. Environmental Protection Agency's latest publication covering on-site wastewater technologies. As an update of the 1980 *On-Site Wastewater Treatment and Disposal Systems,* it provides supplemental and new information for wastewater treatment professionals in the public and private sectors. This manual is not intended to replace the previous manual but rather to explore further and discuss recent developments in treatment technologies, system design, and long-term system management.

Washington State Department of Ecology
http://www.ecy.wa.gov/biblio/9911.html
Washington's *Storm Water Management Manual for Western Washington* describes the storm water management standard for all new development and redevelopment projects in the Puget Sound region.

Organizations and Internet Resources

Canadian Housing Information Center (CHIC)
http://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/01-138-E.htm
Innovative On-Site Wastewater Treatment
The Canadian Housing Information Center has researched problems with residential septic systems across Canada and found surface breakouts, back-ups into houses, and contamination of groundwater supplies as evidence of system failures. Such problems arise from excessive water usage and lack of maintenance; inadequate site assessment, especially in marginal soils; outdated design practices; or poor construction.
http://www.cmhc-schl.gc.ca/en/imquaf/himu/wacon/wacon_001.cfm
Water conservation has been at the forefront of resource efficiency issues in Canada. In an effort to reduce water consumption, CMHC has conducted research into residential water reuse and innovative wastewater treatment technologies. Case Study of the Month presents water projects either supported by CMHC or undertaken by the private sector.

Hazen and Sawyer
http://www.co.sarasota.fl.us/environmental_services/pcssrp/pdfs/40075r048.pdf
Evaluation of On-site Wastewater Treatment and Wastewater Collection System Alternatives (TM No.7)
An assessment of available and applicable OWTS and collection system technologies determines the technologies' ability to improve current wastewater treatment and disposal practices in the Sarasota, Florida area.

NAHB Research Center
http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=3789&CategoryID=1843
On-site wastewater treatment systems can allow the construction of new homes on otherwise vacant infill lots in neighborhoods whose centralized wastewater treatment systems are beyond capacity. To find the best and most cost-effective aerobic treatment system, the Research Center is working with Anne Arundel County, Maryland, and will monitor the installation of several innovative on-site aerobic wastewater treatment systems on residential field sites. Approximately 25 percent of all homes in the county use on-site wastewater treatment systems, most of which are septic tanks.

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Rocky Mountain Institute
http://www.rmi.org/images/other/W-ComDecMakWstwtrSys.pdf
Case Studies of Economic Analysis and Community Decision Making for Decentralized Wastewater Systems
The Rocky Mountain Institute is conducting an 18-month project to increase understanding of how communities consider and value the benefits and costs of different-scale wastewater facility options (on-site, cluster, and centralized options) in dollar or other terms. The project also is examining the driving issues, motivations, thought processes, and decision-making methods of stakeholders relative to choices of wastewater system scale.

Small Flows Quarterly
http://www.nesc.wvu.edu/nsfc/nsfc_index.htm
The National Small Flows Clearinghouse (NSFC), funded by the U.S. Environmental Protection Agency, helps America's small communities and homeowners solve their wastewater problems and thereby protect the public health and the environment. The successful long-term operation of wastewater systems protects drinking water sources from contaminants and natural systems from pollutants. The NSFC assists in planning, operating, financing, and managing new or existing sewage systems, both for individual households and communities of less than 10,000 people. One of the *Small Flows Quarterly*'s most recent peer-reviewed articles, "Proposed National On-Site Standards: A Broad Assessment of Their Relative Benefits to Industry," proposes ideas about on-site wastewater treatment management in small communities. In most states, regulatory systems dominated by prescriptive codes restrict the activities of on-site wastewater treatment system manufacturers and suppliers.

The Home Inspection and Construction Information Website
http://www.inspect-ny.com/septic/lockwood.htm
Septic Systems--An Engineer's View
The Home Inspection and Construction Information Web site describes septic systems, their operation, and the reasons for system failure. Contributed by Lockwood, Dietershagen Associates Licensed Professional Engineers, Clifton Park, New York.

U.S. Environmental Protection Agency
http://www.epa.gov/OW/index.html
The Office of Water provides an immense amount of information on the protection and conservation of our nation's water resources.

Regional-Specific Resources

Northeastern United States

Cornell Local Government Program
http://www.cardi.cornell.edu/clgp/septics/Exec_Summ.PDF
Increasingly, rural communities, unsewered subdivisions, and responsible agencies are aware of issues and concerns associated with treating and managing human waste products with on-site wastewater treatment systems (OWTSs or septic systems). This guide provides an information framework for those seeking change.

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The New England Interstate Water Pollution Control Commission Regulatory Cooperation Project
http://www.neiwpcc.org/iatech.html
An interstate effort to evaluate innovative/alternative (I/A) on-site technologies capable of protecting the public health and the environment. The project provides states with an efficient review process for I/A technologies. By bringing together the interests of regulators and end users, the effort facilitates independent evaluation of environmental technology performance.

Southeastern United States

Commonwealth of Virginia State Board of Health
http://www.vdh.state.va.us/formfeed/VDH88.PDF
Regulations Governing Application Fees for Construction Permits for On-Site Sewage Disposal Systems and Private Wells

W*estern United States*

City of Oregon City--Development Services Department Engineering Division
http://www.orcity.org/public-works/design-standards/sewer/index.html
Sanitary Sewer Design Standards
Oregon City Development Services (Oregon) created sewer design standards to provide a consistent policy under which certain physical aspects of sanitary sewer design will be implemented.

Orenco Systems Incorporated
http://www.orenco.com/ccs/ccs_caseStudy.asp
Orenco Case Study--Diamond Lake, Washington: 12-Year-Old Effluent Sewer Requires Little Maintenance
The community of Diamond Lake, in northeast Washington, protected an 800-acre lake by replacing all the community's old, leaking septic tanks and inadequate disposal systems with watertight tanks and an Orenco effluent sewer system.

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SECTION 4: CIRCULATION AND DESIGN



Reconsidering traditional methods for planning and accommodating pedestrian and vehicular circulation is part of a cadre of better site design techniques that can simultaneously reduce development costs, protect the environment, and create win-win situations for builders, municipalities, and residents.

4.1 INTRODUCTION

As the struggle to decrease nonpoint source pollution in our nation's waters continues, municipalities have begun to reexamine the connection between circulation design and storm water management practices. New designs for streets, sidewalks, and driveways can maintain the functions of circulation while helping to reduce expanses of impervious surfaces that can alter local hydrology and degrade water quality. In turn, new street designs can influence the layout of lots and help to increase the volume of open space in new residential developments. These considerations all contribute to creating low impact developments. This section examines alternative street and lot layouts and their associated environmental and cost benefits.

Vehicular and pedestrian circulation systems have always played an important role in organizing and defining residential communities. Traditionally, residential or local streets have been designed with a focus on accommodating community access, circulation, and parking. In the years before World War II, older, close-in suburban neighborhoods were designed with narrow streets that were wide enough for one travel lane and parking on one side of the street.

- Mobility--A measure of long-distance travel at relatively higher speeds. Mobility usually characterizes highways.
- Access--A measure of service to origins and destinations. Access usually relates to local streets.

In the years after World War II, suburbanization and highway construction grew at a rapid pace. As reliance on the automobile increased, transportation planners identified the need for a hierarchy of safe and efficient transportation routes linking suburban residences with urban employment centers, retail concentrations, and recreation opportunities. They developed a hierarchy of highways, arterials, collectors, and local streets. The classification system sought to strike a balance between providing mobility and access.

Unfortunately, at some point during post-war suburban expansion, the classes within the hierarchy blurred. Communities started to design local streets according to standards more appropriate to arterial road and highway construction. Many areas of the country saw pavement widths widened to accommodate increased vehicle trips, ensure access for larger emergency vehicles, and provide parking spaces on both sides of the street (even though most neighborhoods accommodate off-street parking in driveways). The larger impervious areas created by wide streets have led to increased storm water runoff, reduced water quality, and riparian habitat and species degradation. They have also translated into increased design, construction, and maintenance costs for both developers and municipalities. Low impact development practices can help to alleviate these concerns.

What is the cost of an excessively wide street?		
Not only do excessive street widths affect the livability of a community, but they also give rise to additional costs that must be paid by homeowners. The figures cited here are for 2001 based on unit costs of contractor services for a project in northern California. For this project, a section of street 100 feet long would cost about $9,500 to build to a width of 24 feet compared with $13,500 for a 36-foot-wide street. Paving widths are 20 feet and 32 feet, respectively, with an additional two-foot gutter on each side. Moreover, in this area where lots sell for $300,00 per acre, land costs exceed street construction costs, even for narrower streets. Total land and construction costs for a 100-foot section of a 36-foot-wide street amount to almost $40,000 compared with $26,000 for a narrower 24-foot-wide street.		
Cost per 100 Feet of Street		
	24 Feet	36 Feet
5-Inch Asphalt Paving/6-Inch Base	$6,800	$10,880
6-Inch Curb and Gutter	$1,265	$1,265
4-Inch Sidewalk	$1,400	$1,400
Total Construction Costs	$9,465	$13,545
Land (at $300,000 per acre)	$16,800	$25,200
Total Cost	$26,265	$38,745

TABLE 17. TYPICAL STREET CONSTRUCTION COSTS

This chapter begins by providing a brief overview of the environmental and economic benefits of LID circulation and design. It briefly discusses conventional approaches to circulation and design and then concludes by considering some alternatives to conventional approaches. Table 18 provides some overall objectives of community circulation and design systems.

Objective 1:
Maximize open space by using alternative street and lot layouts.
Objective 2:
Reduce impervious surfaces by considering alternative street widths, types, and amenities.
Objective 3:
Site lots and houses to maximize solar orientation, reduce vehicular trips, and create a sense of community.

TABLE 18. CIRCULATION AND DESIGN OBJECTIVES

4.1.1 ENVIRONMENTAL BENEFITS

Properly designed and sited streets and street systems can conserve and protect site and regional environmental systems and resources. Most street standards are the result of compromises among engineers, planning staffs, and local emergency management professionals (police and fire and rescue services). To provide two travel lanes, access for emergency vehicles, and parking on both sides of the street, communities have long required streets that are much wider than necessary. However, research and experience show that compact street layouts, narrower street widths, and alternative pavement edge treatments can minimize clearing and grading, reduce storm water runoff, and protect

water quality while providing ample access for emergency vehicles, residential vehicles, and parking.

Paved streets create impervious surfaces that prevent storm water from infiltrating into the ground. As storm water travels across streets and other impervious areas, it picks up motor oils, grease, fuel residues, nutrients, and sediment, all of which are then carried to local receiving waterbodies where they adversely affect aquatic species and their habitats. Impervious areas are major contributors to the urban nonpoint source pollution problems that impair the nation's water quality.

4.1.2 ECONOMIC BENEFITS

Where density and zoning allow, redesigned vehicular and pedestrian circulation routes can reduce final infrastructure and development costs by limiting street lengths and the expanse of pavement. At the same time, reworked street types and layouts can mean reduced costs associated with planning and design, clearing and grading, and storm water management. Table 4-3 provides information on various subdivision development costs.

Subdivision Improvement	Unit Cost
Roads, Grading	$22.00 per linear foot
Roads, Paving (26-foot width)	$71.50 per linear foot
Roads, Curb and Gutter	$12.50 per linear foot
Total Cost of Road	$106.00 per linear foot
Sidewalks	$10.00 per linear foot
Storm Sewer (24 inches)	$23.50 per linear foot
Driveway Aprons	$500 per apron
Parking Spaces	$1,100 per parking space ($2.75 per square foot)
Clearing (forest)	$4,000 per acre
Sediment Control	$800 per acre
Storm water Management	$5,000 to $60,000 per impervious acre
Water/Sewer	$5,000 per lot (variable)
Well/Septic	$5,000 per lot (variable)

Source: Center for Watershed Protection, 1998.

TABLE 19. UNIT COST ESTIMATES OF TYPICAL SUBDIVISION DEVELOPMENT

4.2 CONVENTIONAL APPROACHES TO CIRCULATION AND DESIGN

4.2.1 RIGHTS-OF-WAY

A street right-of-way is a measure of the total width needed to accommodate the street pavement, sidewalk(s), drainage, street trees, and utility easements. Current street rights-of-way range from 30 feet to over of 60 feet to accommodate parking and sidewalks on both sides of the street. Excessive rights-of-way create wide and often visually uninteresting streets that promote speeding and undermine safety. Wider street rights-of-

way require land to be set aside to accommodate street systems, leaving less land available for lots and community open space. At the same time, given that safety and maintenance concerns require the removal of vegetation and trees within the right-of-way, road construction results in the removal of many mature trees and vegetation, potentially leading to soil erosion and siltation problems in local waterways.

Street rights-of-way should be the minimum width necessary to accommodate the pavement, sidewalk(s), street trees, and utilities. Where zoning and density allow, communities should permit open-section roadways with sidewalks on one side of the roadway only. Open-section roadways consist of a variable-width gravel shoulder, usually wide enough to accommodate a parked car, and an adjoining grassed swale that conveys storm water. Street pavements should be adjusted accordingly depending on off-street parking availability and shoulder requirements. To encourage the preservation of existing vegetation, only those trees within approximately five feet of the pavement edge should be cleared. Utilities should be located under street pavements to eliminate conflicts with tree roots, grassed swales, and bioretention areas. In northern climates, the right-of-way should be wide enough to accommodate snow storage.

4.2.2 STREETS

Besides rooftops and driveways, residential streets account for an enormous share of a community's impervious surfaces. A reevaluation of residential street standards to address the expanse of impervious surfaces and enhance the environment can also reduce infrastructure costs, improve pedestrian and vehicular safety, and increase community aesthetics. Many municipalities have already begun the difficult process of reevaluating their residential street standards. The process requires the involvement of many different stakeholders, including emergency personnel (police and fire and rescue services)(See Table 20), public works departments, school boards, homeowner associations, and safety advocates. Indeed, disagreements can be easily resolved by examining the current research on the use of narrower streets.

Width (feet)	Source
18 to 20	U.S. Fire Administration
24 (on-street parking) 16 (no on-street parking)	Baltimore County, Maryland
18 (minimum)	Virginia State Fire Marshal
20	Prince George's County, Maryland
18 (on-street parking on one side) 26 (parking both sides)	Portland, Oregon

Source: Center for Watershed Protection, 1998.

TABLE 20. MINIMUM STREET WIDTHS FOR FIRE VEHICLES

Most municipalities' standards for street pavement widths usually specify streets at least 36 feet wide—a width that usually accommodates two travel lanes and parking on both sides of the street (see Table 21). Given that most homes are built with either garages and/or driveways that accommodate up to three cars, municipalities should consider eliminating one or both of a street's seven-foot-wide parking lanes. Even a new street width of 22 feet can still accommodate parking on one side of the roadway and leave

ample room for a safe travel lane that is generous enough to accommodate most fire trucks, school buses, and garbage trucks. Consistent with low impact development practices, the new standards reduce infrastructure construction and maintenance costs while reducing impervious surfaces within the community (See Section 4.3.2 on queuing streets for additional information).

Local Streets	
No On-Street Parking	18 feet
Parking on One Side	22 to 24 feet
Parking on Both Sides	24 to 26 feet
Collector Streets	
	32 to 36 feet

Source: Residential Streets, NAHB, 2001.

TABLE 21. SUGGESTED PAVEMENT WIDTHS

Where density and zoning allow, open-section roadways can reduce the need for costly curb and gutter sections and encourage the filtering and infiltration of storm water. Open-section roadways consist of a variable-width gravel shoulder, usually wide enough to accommodate a parked car, and an adjoining grassed swale that conveys storm water. The grassed swales are usually pitched at a minimum of 1 percent to prevent standing water and end at a drop-inlet storm structure or waterbody. Historically, improperly designed swales posed health concerns because they served as breeding areas for insects and caused flooding. However, if communities follow current engineering standards for the design of swales, they no longer have to concern themselves with the associated health and flooding issues (see Section 2.3.3.1 for additional information on grassed swales).

4.2.3 INTERSECTIONS

A curb radius is the radius of the circle formed by the curve of the curb at the intersection corners.

Intersections create large areas of impervious surface within residential subdivisions. Reducing the overall size and width of intersections can decrease the volume of storm water runoff. Depending on the class of street entering the intersection, the number of travel lanes, and the dimensions of the curb radii, intersection diameters can become overly wide. The larger the curb radii, the larger the intersection. Recommended ranges for curb radii are contained in Table 22. Smaller, tighter radii can slow turning traffic and make the intersection safer for pedestrians while limiting the expanse of impervious surface.

Type of Intersections	Curb Radius (in feet)
Local/Local	10 to15
Local/Collector	15 to 20
Collector/Collector	15 to 25

Source: AASHTO.

TABLE 22: RECOMMENDED RANGES FOR CURB RADII

One of the best ways to reduce the impacts of impervious areas within intersections is to incorporate a traffic circle into the middle of the intersection. A traffic circle in the center of an intersection serves a variety of functions. First, it can slow traffic through the intersection and community, making the area safer for pedestrians and vehicles. Second, storm water generated by the impervious areas of the intersection can be routed to a bioretention area sited in the center of the traffic circle where it is detained and treated. Finally, traffic circles can add character to a neighborhood and create visual interest along the streetscape.

Traffic circles are usually smaller than their counterparts, the traffic roundabout. While traffic circles are more appropriate for lower-speed, smaller-volume residential intersections, roundabouts are better suited for collector streets that serve higher traffic volumes. Generally, traffic circles are 15 to 20 feet in diameter and require no additional street space than standard intersections. The center can be planted with a variety of native plants that are well suited for harsher street conditions and whose root structures will tolerate periodic inundation with water and provide superior nutrient uptake.

4.2.4 CUL-DE-SACS

Cul-de-sacs are dead-end streets that terminate in bulb-shaped paved areas, with lots cited around the perimeter of the street (see Figure 18). Given homebuyer preferences for residential cul-de-sac properties, many developers try to incorporate as many cul-de-sacs as possible into new developments. Depending on a subdivision's lot size and street frontage requirements, five to ten houses can usually be located around a standard cul-de-sac perimeter. The bulb shape allows vehicles up to a certain turning radius to navigate the circle. To allow emergency vehicles to turn around, cul-de-sac radii can vary from as narrow as 30 feet to upwards of 60 feet, with right-of-way widths usually extending ten feet beyond these lengths.

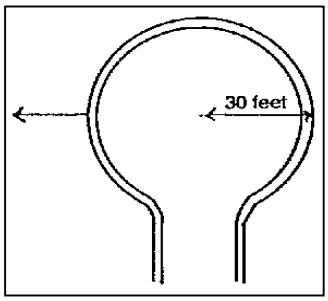


FIGURE 18. STANDARD CUL-DE-SAC

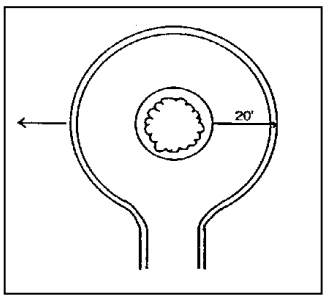


FIGURE 19. STANDARD BIORETENTION CUL-DE-SAC

Unfortunately, cul-de-sacs create excessive amounts of pavement that generate large volumes of storm water runoff. However, to reduce the expanse of paved surface and treat the runoff from the remaining pavement, cul-de-sacs can be designed with center vegetated islands (see Figure 19). As with intersections, the islands can be constructed as bioretention areas that detain storm water and filter urban pollutants such as grease, oils, hydrocarbons, and nutrients. For safety reasons, bioretention areas should be designed with underdrain and emergency overflow systems that safely convey peak flows into conventional storm drains.

Cul-de-sac designs with center bioretention islands should, at a minimum, retain 18-foot pavement widths around the island. To accommodate emergency vehicles, school buses, and sport utility vehicles, the portion of the travel way at the top of the island, which is directly opposite the entry, may be widened by several feet. Curb aprons can replace curb and gutter systems for the islands and allow water from the street to enter the system easily.

For dead-end streets serving fewer than ten houses, another option for reducing the expanse of impervious surface is "T-" or "Y-"turnarounds or auto courts (see Figure 20). These designs function much as cul-de-sacs but, due to a reduction in the area of paved surface, cannot accommodate bioretention areas in their centers. However, given that a standard 60-foot by 20-foot T- or Y-turnaround yields a paved area only 43 percent as large as the smallest (30-foot radius) circular turnaround, the turnaround generates much less storm water runoff (National Association of Home Builders, 2001) than that associated with traditional cul-de-sacs. Runoff could even undergo treatment in curbside swales located within the right-of-way.

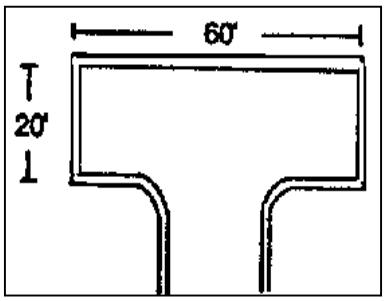


FIGURE 20. STANDARD "T-"TURNAROUND

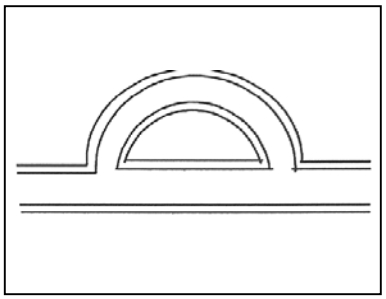


FIGURE 21. STANDARD LOOP TURNAROUND

An auto court is a functional automobile and pedestrian area that is surrounded by a cluster of homes and usually paved with decorative brick or stone pavers. Individual shortened driveways or garages are located immediately off the court. Auto courts use permeable paving systems, allowing runoff to percolate into and undergo filtration by the subsoil underlying the pavers. The systems help recharge local groundwater tables and reduce the need for conventional storm water management improvements. It should be noted, however, that the labor and material costs associated with the individually placed pavers exceed the cost of conventional asphalt paving. Costs may also be incurred for regular maintenance to remove any sediment and silt that accumulate in spaces between the pavers.

Looped turnarounds (see Figure 21) are another option for providing access to a small number of lots while limiting the expanse of impervious surface. Looped roads offer the same private and emergency vehicle access as standard cul-de-sacs, but without the added asphalt and construction costs. Similar to cul-de-sacs with center bioretention areas, the pavement width on a loop road should be no less than 18 feet to accommodate buses, emergency vehicles, and sport utility vehicles.

4.2.5 PARKING

No other decision can affect the final width of streets and ultimately the generation of storm water runoff as much as parking requirements. Most local ordinances require at

least 2 to 2.5 parking spaces per residence, either accommodated in a garage, in a driveway, or on the street. Current residential street standards tend to accommodate street parking on both sides of the street when in fact, the houses served by the street usually provide ample parking either in a driveway or garage. Most on-street parking spaces are 8 feet by 20 feet, resulting in long, underused street sections outside the general path of travel and excessively wide streets that are both expensive to construct and generate considerable quantities of storm water runoff. It is estimated that each seven- to eight-foot on-street parking lane can increase a street's impervious cover by 25 percent (Sykes, 1989). Given that most municipalities require post-development stormflows not to exceed pre-development flows, compliance with parking standards can translate into added costs for storm inlets, piping, and detention basin sizing.

From a water quality standpoint, water temperature can increase as storm water runoff moves across heated asphalt. As elevated-temperature water flows to a waterbody, it can damage sensitive aquatic environments, especially cold-water fisheries. The reduction of on-street parking, however, allows for narrower streets that can take advantage of the cooling effects of shade trees.

4.3 ALTERNATIVE APPROACHES TO CIRCULATION AND DESIGN

4.3.1 ALTERNATIVE DESIGN CONSIDERATIONS

Just as alternative street types and pavements can reduce infrastructure costs and environmental impacts, so, too, can alternative residential street layouts. When coupled with narrower, open-section streets, a well-designed street layout can eliminate hundreds of square feet of impervious surface. Depending on the density, location, and type of subdivision, different types of street layouts may easily lend themselves to a cluster arrangement, conserving natural features, maintaining open space, and protecting water quality.

Rethinking traditional circulation designs within residential subdivisions can result in:

- Decreased storm water quantities and nonpoint source pollution;
- Increased groundwater recharge; and
- Increases in community open space.

Traditional grid, curvilinear, and hybrid street patterns each have different characteristics that affect traffic movement, environmental values, and community aesthetics (see Figure 22). Grid patterns are typical of older, densely settled urban areas and are particularly effective in expediting traffic flow. Yet, research has indicated that they require 20 to 25 percent greater total street length than traditional, suburban curvilinear patterns and are most appropriate for flat sites with several access points. Given that densities in grid areas are often high, parking is generally needed on at least one side of the street.

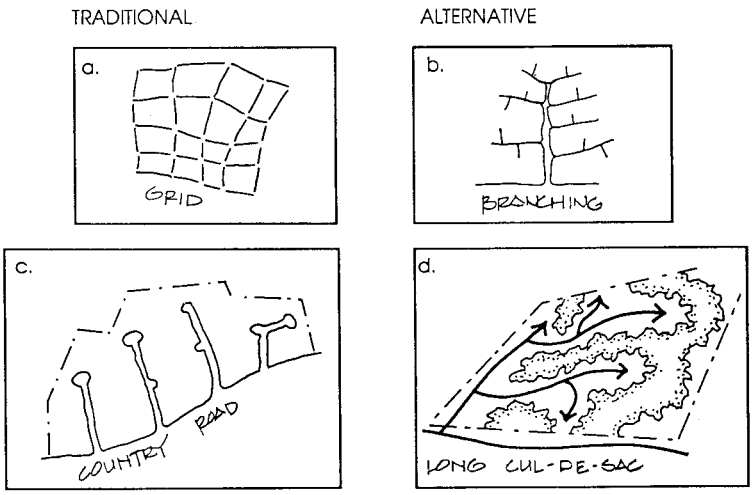


FIGURE 22. STREET LAYOUT EXAMPLES

Curvilinear patterns are best suited for larger-lot communities or communities with undulating topography. They are most popular in suburban settings and usually maximize the use of long cul-de-sacs that concentrate clusters of houses around natural resource areas, such as waterbodies. While the use of longer, winding streets and cul-de-sacs translates into greater expanses of impervious surface, communities can narrow their streets by limiting parking to only on one side of the street.

Possibly the best choice for suburban systems are hybrid layouts. Hybrid systems provide a balance between conventional grid and curvilinear patterns and are well suited to developments characterized by a mix of housing types and styles. They also permit the creation of open space. Hybrid systems can minimize the need for clearing and grading and help protect forests, wetlands, and trees.

Traffic Calming

Traffic calming refers to a set of measures designed to mitigate the effects of unmanaged traffic on urban and suburban roadways. While the use of traffic calming as a traffic mitigation strategy is beyond the scope of this publication, the practice is discussed here in terms of its relationship to low impact development and storm water management.

Certain traffic-calming measures, such as roundabouts or traffic islands, can be designed as vegetated bioretention islands that retain and treat street runoff. A traffic roundabout is a circle centered in an intersection; it slows traffic entering the intersection and directs it to exit points around the circle. Usually, a roundabout is raised and includes curbs and areas planted with grass or vegetation. Where street grades allow, roundabouts can be converted into bioretention areas.

Bioretention areas can be bordered by either curb cuts or flush-mount curbs that allow water to exit an intersection efficiently and enter the treatment system. Either treatment method allows for a transition between the street pavement and vegetated and mulched areas. As storm water enters the system, specially selected vegetation and engineered

soils retain and treat it. For reasons of safety, roundabouts designed for bioretention should incorporate underdrains and/or emergency overflow areas to prevent excessive ponding or flooding.

Clustering

With respect to lot layout, developers can turn to methods such as clustering to preserve open space, reduce infrastructure costs, and accommodate growth. This strategy concentrates small pockets of homes around the site in the least environmentally sensitive areas. In a clustered community, homes may be built on lots as small as 8,000 square feet, allowing developers to preserve unique land forms, trees, and vistas. Developers may need to work with local zoning officials to allow the use of clustering, if current zoning ordinances do not allow it. In addition, potential homeowners may need to be persuaded that cluster development creates a community that offers ample amounts of open space within walking distance of their homes.

More than half of the 1,350 real estate agents surveyed by Bank of America thought that trees have a positive impact on potential buyers' impressions of homes and neighborhoods. In addition, 84 percent of agents indicated that a home with trees would be as much as 20 percent more salable than a home without trees.
Source: Building Greener Neighborhoods.

Tree-Save Areas

Many parcels of land offer an array of natural resources that ingenious developers can capitalize on and transform into desirable design features. While most of this section of the publication has focused on ways to protect the water supply and thus enhance the environment, trees are a feature that homeowners value for their aesthetic and environmental benefits. Trees can shade homes, streets, parking areas, sidewalks, and paths, adding to the visual appeal of communities and helping to reduce heat island effects. Developers are beginning to recognize that lots with mature trees often sell for more than comparable lots without such trees.

Native trees should be identified during a project's planning stage. The Building *With* Trees (BWT) program offers more details on how best to preserve appropriate trees. The National Arbor Day Foundation, with support from the National Association of Home Builders, created the BWT program to help developers streamline the process of saving natural resources during land development. Program details can be found at http://www.arborday.org/programs/buildingwithtrees/

Solar Orientation

In an effort to maximize energy efficiency for homeowners, some developers are building resource-efficient communities by orienting streets and lots to take advantage of passive solar design. Passive solar design optimally uses the sun's energy for heating and cooling. During the design process, builders aim to orient as many lots as possible to take advantage of solar benefits. The optimum position for maximum passive solar orientation is to orient the façade of the house directly south, however, the axis can vary within 20 degrees of true south with minimal detrimental effect on solor gain. Streets should be oriented on an east-west axis.

4.3.2 ALTERNATIVE STREET TYPES

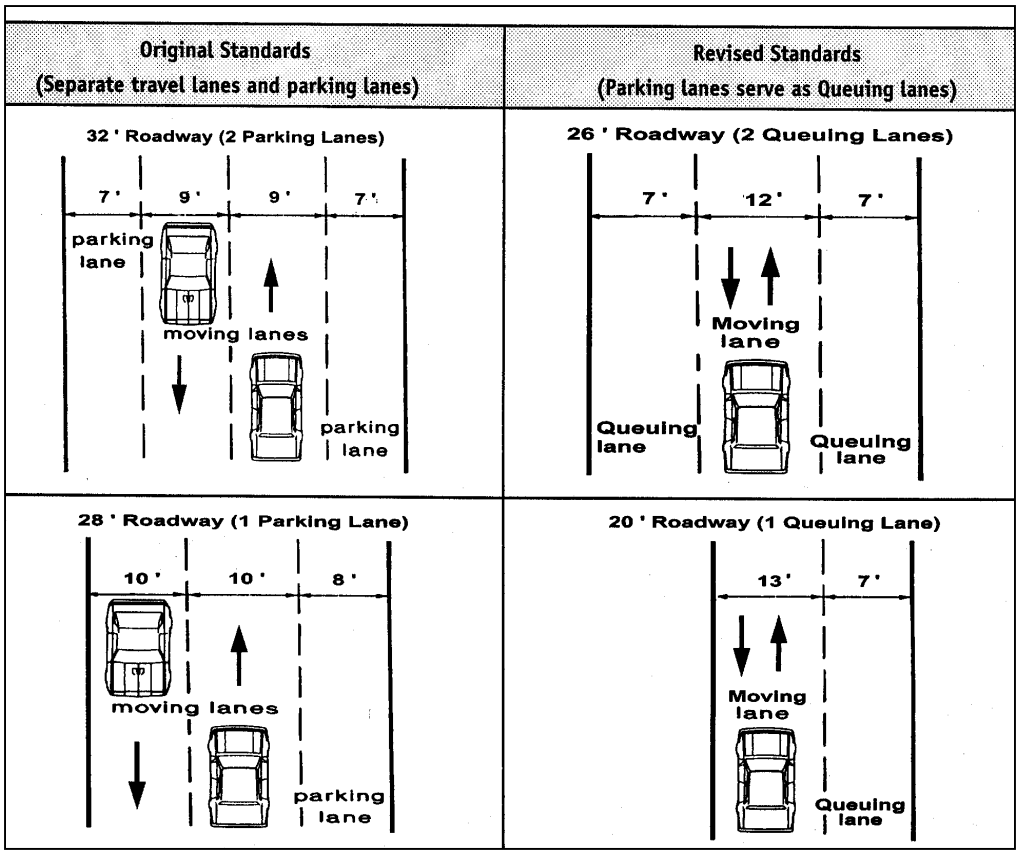
To meet the multiple and sometimes competing goals of creating affordable, environmentally friendly, and aesthetically pleasing communities, developers are incorporating alternative street designs into their plans. Each alternative street and path type has unique characteristics that help it fit into one part of the community, but not the other. One street type does not fit all situations.

Queuing Streets

Prairie Crossing, a development near Chicago, focused on creating a community that embraces environmental protection, a sense of place, and resource conservation. Sales for Prairie Crossing homes are at a 40 percent premium over comparable homes nearby.

Queuing streets are narrower street types that contain one parallel parking lane and a travel lane sufficiently wide to accommodate the passage of larger emergency and service vehicles. In instances where cars park along the roadway, queuing streets require one car to wait temporarily in "queue" until the oncoming car passes (see Figure 23). Traditionally used in older, closer-in suburban neighborhoods, queuing streets are enjoying a renaissance

Typically, queuing streets range between 20 and 26 feet wide, with a 12- to 13-foot travel lane and a seven-foot parallel parking lane. Compared to a typical 36-foot-wide street, queuing streets can reduce planning and design costs as well as other infrastructure costs, such as those associated with storm water management. It has been estimated that the elimination of parking on one side of the street can reduce storm water runoff by 25 percent (Center for Watershed Protection, 1998).



Source: Portland (OR) Office of Transportation, 1994.

FIGURE 23. A COMPARISON OF QUEUING STREETS VERSUS TRADITIONAL STREETS

From an environmental standpoint, narrower street rights-of-way can limit the amount of land areas subject to clearing and grading, make more land available for open space, and protect natural resource areas. Smaller streets also provide safer environments for pedestrians, which encourages walking and reduces dependence on the automobile.

Alleys

Alleys are considered a neotraditional design element that can be incorporated into residential designs to provide garage access and parking while accommodating functions such as utility maintenance and refuse collection. Alleys can also alleviate the need for on-street parking, which can increase street widths and the expanse of impervious surface. To limit the expanse of impervious surface, alleys should be no wider than 12 feet and constructed without curbs. An inverted crown that channels water to the center of the alley and then to either a storm drain or bioretention area can accommodate drainage.

Open-Section Streets

Instead of sending storm water to curbs and gutters, open-section roads drain storm water into grassed swales, where vegetation and soils treat pollutants. It has been estimated that, compared with any other residential design feature, streets contribute the highest volume of pollutants to urban storm water (Bannerman et al., 1993). Accordingly, where

density and traffic flow allow, streets with curb and gutter sections should be designed as open-section roadways.

For public works departments in most communities, maintenance concerns dictate a preference for curb and gutter roads in place of grassed swales. Grassed swales are more likely to be damaged by cars, erosion, and so forth while curb and gutter streets are easier to clean and provide a clear transition between pavement and lawn. However, in many localities, curbs and gutters drain directly to streams, lakes, and rivers, where they deposit harmful urban pollutants.

Open-section streets are less expensive to construct than curb and gutter systems. One study for a project in northern California in 2001 suggested that each linear foot of six-inch curb and gutter added approximately $12.65 to street construction costs (NAHB Residential Streets, 2001).

4.3.3 SHARED DRIVEWAYS

Shared driveways, sometimes referred to as pipestems, are another design tool that can help reduce the expanse of impervious surfaces. Driveways account for as much as 20 percent of the impervious cover in a residential subdivision (Center for Watershed Protection, 1995). Similar to a cul-de-sac, a shared driveway provides access to several houses from a single egress point off the local street. However, unlike cul-de-sacs, shared driveways terminate at the last house served instead of at a large impervious turnaround area. Table 23 provides several objectives for reducing impervious areas in driveways.

- Shorten driveway length through reduced front yard setback requirements.
- Reduce driveway widths or encourage driveway sharing between two or more homes.
- Use permeable pavements or a two-track surface with grass in between to facilitate water infiltration.

TABLE 23. DRIVEWAY CONSIDERATIONS FOR REDUCING IMPERVIOUS AREA

Where used in the appropriate situation and correctly designed, shared driveways can be functional, attractive, and environmentally friendly. In fact, alternative pavement materials such as bricks or pavers can further reduce a shared driveway's storm water runoff.

4.3.4 SIDEWALKS AND PATHS

While sidewalks and paths are an integral part of a community's transportation and circulation design, their impervious surface nonetheless contributes to the community's overall volume of storm water runoff (see Table 24). Depending on the density of the community and the type of street classification, sidewalks on only one side of the street might be appropriate; in the case of rural residential streets (250 average daily trips, sidewalks might not be needed at all. In rural residential instances, rights-of-way with a sufficiently wide gravel path can accommodate pedestrian and bicycle travel. Where used in combination with open-section roadways, sidewalks should be located several feet back from the outside crest of the grassed swale to allow for maintenance of the

swale and snow storage. Sidewalks should be horizontally sloped to drain toward roadside grassed swales and away from front yards.

- Shorten sidewalk length from the house to the street by reducing front yard setback requirements.
- Maximize sidewalk widths at four feet, depending on density.
- Increase the distance between the street and sidewalk to increase the likelihood that the grassy strip will be able to capture and absorb sheetflow from the sidewalk. Similarly, grade the sidewalk such that runoff drains toward the front yard and not the street.
- Place sidewalks in areas with pedestrian traffic.

TABLE 24. SIDEWALK CONSIDERATIONS FOR IMPERVIOUS AREAS

To reduce further the total expanse of a site's impervious surface, the use of pervious materials for sidewalks and paths might be considered in place of traditional concrete or asphalt. When properly maintained, alternative materials such as brick, compacted stone dust, and wood chips all accommodate safe passage of pedestrians and bicycles and, in most cases, still meet Americans with Disabilities Act (ADA) requirements. Permeable materials reduce the volume of slow runoff, allowing it to recharge groundwater.

4.3.5 ALTERNATIVE PAVEMENTS

Alternative pavements for streets, alleys, sidewalks, paths, and driveways should be considered along with traditional asphalt and concrete. Brick, block, concrete, and stone pavers reduce the percentage of site's impervious surface as well as the demand for conventional storm water management facilities. Unlike conventional pavements, pavers encourage groundwater recharge and reduce the runoff of pollutants such as oil, grease, hydrocarbons, and nutrients. A variety of alternative pavements can also meet different traffic, regulatory, climatologic, and aesthetic concerns. In addition to their environmental benefits, alternative pavements such as brick can add visual appeal and character to residential properties.

Material	Initial Cost	Maintenance Cost	Water Quality Benefits
Asphalt/Concrete	Medium	Low	Low
Pervious Concrete	High	High	High
Porous Asphalt	High	High	High
Turf Block	Medium	High	High
Brick	High	Medium	Medium
Natural Stone	High	Medium	Medium
Concrete Unit Paver	Medium	Medium	Medium
Gravel	Low	Medium	High
Wood Mulch	Low	Medium	High
Cobbles	Low	Medium	Medium

Source: Bay Area Storm Water Management Agencies Association (BASMAA), Start at the Source: Residential Site Planning & Design Guidance Manual for Storm Water Quality Protection*, 1997.*

TABLE 25. FUNCTIONAL COMPARISON OF VARIOUS TYPES OF ALTERNATIVE PAVEMENTS

Compared with conventional paving systems, material and installation costs can be higher for alternative paving systems (see Table 25). It is estimated that, while asphalt paving costs between $0.50 and $1.00 per square foot installed, interlocking concrete paving blocks can range anywhere from $5.00 to $10.00 per square foot. However, given that porous asphalts can help reduce overall storm water infrastructure costs, the total costs of site development can be significantly reduced, especially when considering the savings associated with potentially eliminating storm water management ponds. Clearly, any comparison of the costs of alternative versus traditional pavements should factor in total land development costs.

Some manufacturers are now producing pervious concrete products that decrease runoff and encourage infiltration. Pervious pavement such as porous asphalt or concrete can also decrease storm water conveyance costs and increase environmental quality. It is estimated that pervious pavements such as porous asphalt cost approximately 10 percent more that conventional nonporous asphalts. To maintain their efficiency and porosity, pervious pavements and pavers require regular maintenance to remove accumulated sediment and dirt.

4.3.6 ALTERNATIVE LOT SHAPES

Individual house lots are usually regularly shaped, that is, rectangular or square, and each lot has direct access to the street. In their attempt to conserve open space and reduce developed areas, low impact developments sometimes call for alternative lot shapes, including flag, zero-lot-line, Z- and angled Z-, or zipper lots. Figure 24 provides basic diagrams of alternative lot designs.

Flag lots, sometimes referred to as pipestem lots, mesh well with the concept of shared driveways. They accommodate a house or houses built behind another house, with one common driveway leading to the street. Flag lots are sometimes used to give developers

access to unused, landlocked spaces that are not preferred agricultural or conservation areas. The Center for Urban Policy Research defines a flag lot as a large lot not meeting minimum road frontage requirements and where access to the public road is by a narrow, private right-of-way or driveway. Zero-lot-line lots provide for greater usable yard space on each lot. The lots locate one side of the house on the lot line while the other side of the house faces the usable space. Interspersing various innovative lot types in a community can help developers incorporate passive solar design into house designs.

Z- or angled Z-lots are similar to zero-lot-line lots except that they are angled by about 30 to 40 degrees, allowing developers to alternate side- and front-loaded garages. In a zipper lot, the minimum rear setback is zero, and the rear yard depth varies to concentrate usable space on the side of the lot.

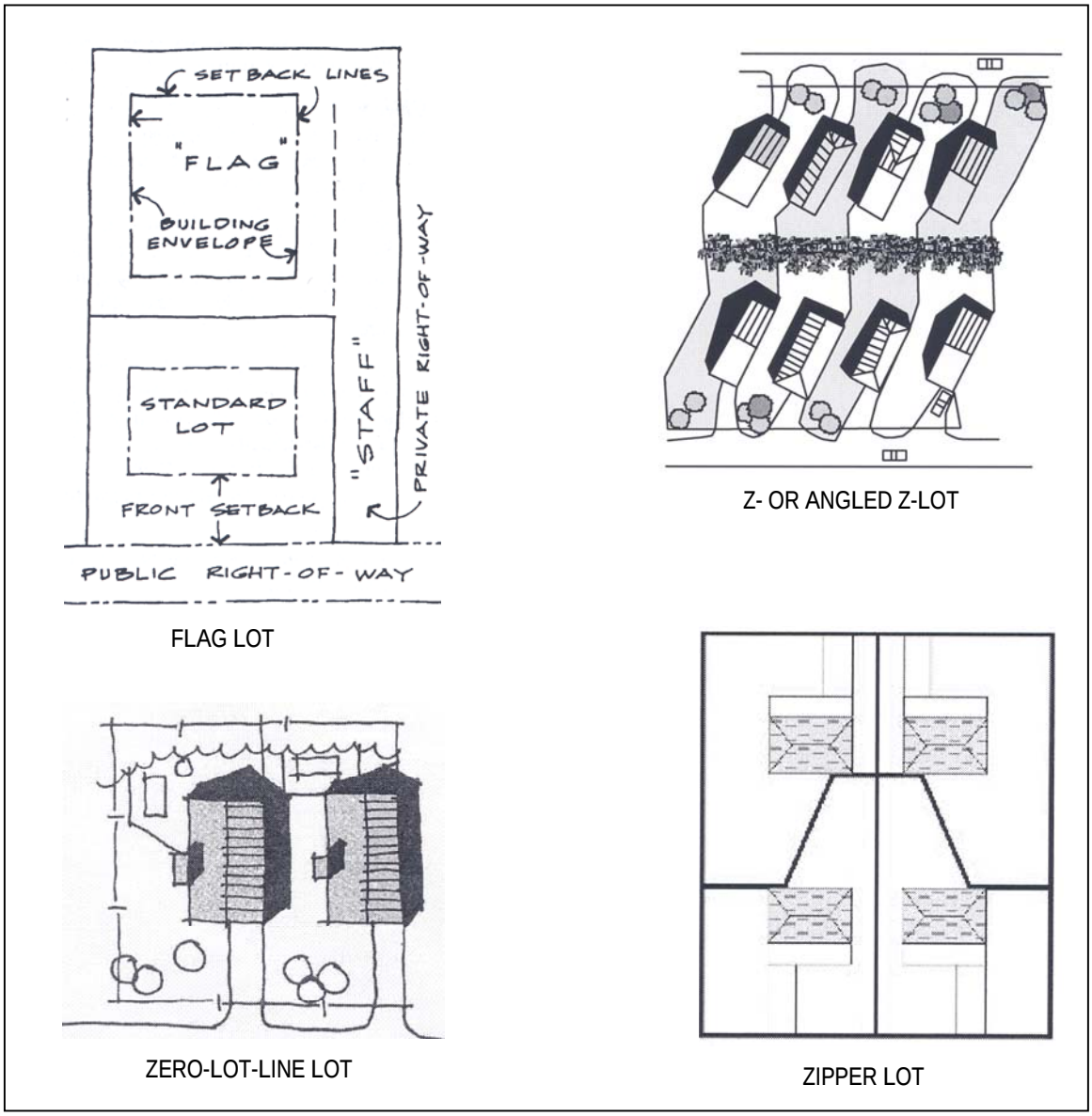


FIGURE 24. ALTERNATIVE LOT DESIGNS

4.4 ADDITIONAL RESOURCES

Additional resources that provide more detail on circulation and design are listed below. The resources are not provided as endorsements, merely as educational and reference tools. Given regional variations in climate and land development needs, we have included regional-specific resources. It is important to note, however, that addresses, especially Internet links, are subject to change. This list contains the latest links and addresses as of the printing of this publication.

Circulation Design and Resources

City of Portland Department of Transportation
http://www.trans.ci.portland.or.us/trafficcalming/devices/skinnystreets.
Information on Portland's Skinny Streets Program, including local traffic streets, queuing streets, and traffic-calming measures.

Geometric Design Practices for European Roads
http://international.fhwa.dot.gov/Pdfs/Geometric_Design.pdf
Practices and procedures in roadway geometric design and contextual design that seek a balance among safety, mobility, and community interests.

Sierra Club
http://www.sierraclub.org/sprawl/articles/narrow.asp
Web site discusses the value of narrow streets for slowing traffic, reducing vehicular crashes, and increasing neighborhood safety.

Organizations and Internet Resources

Center for Livable Communities
http://lgc.org/clc
Guidebook on how to implement designs for safe, efficient, and aesthetically pleasing streets.

Institute of Transportation Engineers
http://www.ite.org
Publications focusing on traditional neighborhood design and circulation patterns, including street space, connectivity, emergency access, parking, safety, and geometric design.

Local Government Commission
http://lgc.org/clc/
Publication on local communities' insight into how to implement local street.initiatives.

The Conservation Fund
http://www.conservationfund.org/
In partnership with the Urban Land Institute (http://www.uli.org), a workshop entitled "The Practice of Environmentally Sensitive Development" covers the full range of project planning, design, and construction.

Walkable Communities, Inc.
http://walkable.org
A nonprofit group that helps Florida communities become more walkable and pedestrian-friendly.

Publications

Longmont, Colorado, Street Study
A study by Swift and Associates correlating 20,000 accident reports over an eight-year period with 13 variables associated with the street. http://members.aol.com/phswi/swift-street.html

Residential Streets
A comprehensive design publication for residential streets published jointly by the National Association of Home Builders (NAHB), American Society of Civil Engineers (ASCE), and the Urban Land Institute (ULI). (800) 321-8050.
http://www.builderbooks.com

Roundabouts: An Informational Guide
A comprehensive source of information on modern roundabouts and their uses. (301) 577-0818.

Street Design Guidelines for Healthy Neighborhoods
http://lgc.org/clc
A publication of the Center for Liveable Communities to help communities implement guidelines for safe, efficient, and aesthetically pleasing streets for vehicular and pedestrian traffic.

Traditional Neighborhood Development Design Guidelines: Recommended Practice
A publication of the Institute of Transportation Engineers on neighborhood and street design, including sections on street space, connectivity, emergency access, parking, safety, and geometric design.

Regional-Specific Resources

Northeastern United States

Conservation Law Foundation
"Take Back Your Streets" focuses on the history of road design and its legal aspects in New England. (617) 350-0990.

Southeastern United States

Montgomery County, Maryland
Residential traffic-calming program to help reduce speeding and improve the residential environment.
http://www.dpwt.com/TraffPkgDiv/triage.htm

Walkable Communities
A 12-step program by the Florida Department of Transportation to encourage safe travel

for pedestrians and vehicles.
http://www.sustainable.doe.gov/pdf/walkable.pdf

Western United States

Citizens for Sensible Transportation
http://cfst.org/
A nonprofit group in Oregon that offers several publications on traffic calming and neighborhood livability.

Reclaiming Our Streets Task Force
http://www.trans.ci.portland.or.us/trafficcalming/reports/ArterialProgram/cover.htm
Community action plan to implement neighborhood transportation- calming techniques in the Portland, Oregon, area.

APPENDIX A - GLOSSARY

Aerobic--Having molecular oxygen as a part of the environment or growing or occurring only in the presence of molecular oxygen, as in aerobic microorganisms.

Anaerobic--Characterized by the absence of molecular oxygen or growing in the absence of molecular oxygen (as in anaerobic bacteria).

Best Management Practice (BMP)--A structural device or practice designed to mitigate the effects of storm water runoff to attenuate flooding, reduce erosion, and reduce pollution. BMPs include a variety of **Low impact development** practices such as bioretention, sand filters, and infiltration trenches.

Bioretention--A structural storm water practice that uses soils and vegetation to treat pollutants in urban runoff and to encourage infiltration of storm water into the ground.

Buffer--Area in its natural state left between development and a shoreline, wetlands, or stream to protect water quality. Development is restricted in a buffer zone.

Community Wastewater Treatment System--Term commonly used to describe an aerobic treatment unit serving multiple dwellings or an education, health care, or other large facility.

Cul-de-Sac--A residential street terminating in a closed, circular dead end that allows vehicles to turn around.

Curvilinear Street Pattern--A street layout that follows the natural contours of the site and relies on curving roadways and cul-de-sacs to reduce vehicle speeds and cut-through traffic.

Environmentally Sensitive Development--Development intended to conserve, protect, and enhance a site's natural resource systems through careful planning and design of site elements.

Eutrophication--A phenomenon caused by excessive plant nutrients in which waterbodies are deprived of oxygen and become uninhabitable for aquatic life. Streams and lakes receive excessive amounts of plant nutrients (primarily phosphorus, nitrogen, and carbon) in various ways. Runoff from agricultural fields, field lots, urban lawns, and golf courses are common sources of the nutrients. Untreated or partially treated domestic sewage is another major source.

Green Infrastructure--A strategically planned and managed network of wilderness, parks, greenways, conservation easements, and working lands with conservation value that supports native species, maintains natural ecological processes, sustains air and water resources, and contributes to the health and quality of life for America's communities and people (see http://www.greeninfrastructure.net/Intro/Definition.htm).

Groundwater--Water that is underground in cracks and spaces in soil, sand, and rocks. The layers of soil, sand, and rocks are also known as aquifers. Groundwater is used for drinking water by more than 50 percent of the U.S. population, including almost all residents of rural areas.

Hybrid Street Network--A street layout that is a mix between a traditional grid pattern and a curvilinear pattern. It can reduce a community's overall street length while still providing the functions of access, circulation, and parking.

Impervious Area--Any area in the landscape that cannot effectively allow the absorption and infiltration of rainwater into the ground.

Impervious Cover--Any surface in the built environment that prohibits the percolation and infiltration of rainwater into the ground.

Jurisdictional Wetlands--A wetlands or other water of the United States regulated under the Clean Water Act.

Low Impact Development (LID)--An approach to land development that uses various land planning and design practices and technologies for simultaneously conserving and protecting natural resource systems and reducing infrastructure costs.

Nonpoint Source Pollution--Water pollution caused by rainfall washing over and through land surfaces and carrying with it pollutants from the human environment. The Clean Water Act regulates nonpoint source pollution, which differs from point-source pollution.

Open-Section Roadway--A roadway that is constructed with gravel shoulders and grassed swale systems, instead of with curb and gutter systems, to convey storm water.

Open Space--Land set aside to remain undeveloped for a community's public use and enjoyment.

On-Site Wastewater Treatment System (OWTS)--A system that relies on natural processes and/or mechanical components to collect, treat, and disperse/discharge wastewater from individual dwellings or buildings.

Queuing Street--A street sufficiently wide for one travel lane and one parking lane that forces one of two passing automobiles to yield temporarily. These streets accommodate all the functions of normal streets, including emergency access, and reduce impervious areas and therefore storm water runoff.

Resource-Efficient Development (RED)--An innovative land development approach that incorporates environmental considerations into the land planning and design process to minimize impacts on local resources.

Right-of-Way--The width of the total land area required for street paving, curb and gutter, utilities, sidewalks, and street trees. Right-of-way widths should be the smallest measurement possible that accommodates these uses.

Riparian--Of or pertaining to stream systems or stream corridors. Riparian areas usually include a stream channel, its banks, the floodplain, and associated vegetated buffers.

Sand Filter--A packed-bed filter of sand or other granular material used to provide advanced secondary treatment of settled wastewater or septic tank effluent. Sand/media filters consist of a lined (e.g., impervious PVC liner on sand bedding) excavation or structure filled with uniform washed sand that is placed over an underdrain system. The wastewater is dosed onto the surface of the sand through a distribution network and allowed to percolate through the sand to the underdrain system, which collects the filter effluent for further processing or discharge.

Sedimentation--The transport, deposit, and accumulation of soil material by wind and water. Sedimentation is usually associated with the accumulation of soil material in waterbodies.

Septic Tank--A buried tank, designed to be watertight, that is constructed to receive and partially treat raw wastewater. The tank separates and retains settleable and floatable solids suspended in the raw wastewater. Settleable solids form a sludge layer at the tank bottom. Grease and other light materials float to the top to form a scum layer. The removed solids are stored in the tank, where they undergo liquefaction, which partially breaks down organic solids into dissolved fatty acids and gases. Gases generated during liquefaction are normally vented through a building's plumbing stack vent.

Setback--The minimum distance that design elements must be placed from other elements. For example, houses usually have front, side, and rear yard setbacks from streets and other buildings.

Sheetflow--The movement of rainwater across the surface of the landscape in response to topographic conditions.

Storm water Management--An integrated system of practices and techniques for managing the safe and efficient handling of post-development rainwater.

Subdivision--The process of dividing land into smaller parcels to accommodate housing, roads, open spaces, and utilities.

Swale--A small, linear topographic depression used to move water from one location to another.

Variance--A request to a zoning authority to deviate from the approved development ordinances of a particular area. For instance, a variance might be requested to waive a 40-foot front yard setback so that houses might be sited closer to the street.

Wastewater Treatment Facility--A wastewater treatment facility collects waste streams from residential, commercial, and industrial sources through sewer systems and treats the water to prescribed levels before release into a waterbody.

Zoning--Regulations governing the use, placement, spacing, and size of land and structures within a specific area.

APPENDIX B—CASE STUDIES

Appendix B contains the following case studies:

- Chancery on the Lake
- Duke Street Square
- Kensington Estates
- Phillippi Creek Septic System Replacement Program
- Ron Tyne and Associates
- Somerset Community

SARB_006414

CHANCERY ON THE LAKE

Chancery on the Lake is a condominium development centered around a 14-acre wet pond. The lake is marketed as a feature of the development, resulting in an increased sales pace relative to that of competitors. In fact, the developer realizes a premium of $7,000 to $10,000per lakefront unit.



VIEW OF THE WALKWAY, PICNIC AREA, AND LAKE

Specifics

- Seven-acre, 170-unit condominium development in Alexandria, Virginia, centered around a large urban runoff pond.
- Prices for the condominiums range from $129,990 to $139,990 (Frederick et al., 1995).
- 14-acre pond surrounded by picnic tables, a gazebo, and a walking trail, with a fishing pier planned for construction (Frederick et al., 1995).
- $7,000 to $10,000 premium for condominiums fronting on the lake (Flora, 1997).
- Above-average sales pace for the area and the condominium market; a significant number of sales from buyers who shopped around and then were attracted to Chancery because of the lake (Flora, 1997).
- Pond marketed as a selling point (Flora, 1997).
- Lake constructed by damming an existing creek, with some excavation of the surrounding area to achieve the desired shape and volume.
- No maintenance required other than mowing grassed areas, visual inspections of the dam and lake, and sediment removal from the rip-rap outfall structure (Scalia, 1997).

SARB_006415

References

- Debora Flora, Sales Manager, Chancery Associates Limited Partnership. Alexandria, VA. (703) 922-7171, personal communication.
- Vic Scalia, Halle Enterprises. Silver Spring, MD. (301) 495-1520, personal communication.

SARB_006416

DUKE STREET SQUARE

Duke Street Square uses a sand filter, which is a best management practice, to filter pollutants out of storm water runoff. At this urban site, buildable land was at a premium. An underground sand filter satisfied storm water management requirements without consuming buildable land area. The developer was able to add five to seven townhomes that would have been lost to land for a pond.



VIEW OF THE INSIDE OF A SAND FILTER SIMILAR TO THE ONE INSTALLED AT DUKE STREET SQUARE

Specifics

- 40-unit townhouse development in Alexandria, Virginia.
- Off-line sand filter system serves 1.38 impervious acres.
- Parking lot designed with grate inlets connected to underground pipes that carry storm water to the sand filter. Flows in excess of 0.5 inches of rainfall in a single event are diverted to the city sewer system.
- The filter's concrete chamber was cast in place (Keller, 1997).
- Underdrains transport filtered water to the city storm sewer system (Keller, 1997).
- Northern Virginia land prices of approximately $40 per square foot make it costly to install dry ponds, wet ponds, or storm water wetlands (Bell, 1997); the sand filter system uses no buildable area.
- Townhouse total includes between five and seven townhouses that normally would have been lost to land needed for a dry pond (Teets, 1997).

Cost Data

- Construction of the sand filter totaled $41,030, including the dry vault sand filter, two monitoring manholes, pipes with connections, and the sand filter itself ($35,197). The entire system cost $29,732 per impervious acre while the sand filter alone cost $25,505 per impervious acre.

SARB_006417

- Filter's sand bed will need replacement approximately every five years.
- System will need periodic inspection and removal of accumulated trash from grate inlets, pre-treatment structure, and filter bed.

Community Acceptance

- The homeowner association has set aside money for routine and nonroutine maintenance.

References

- Glenn Teets, Project Manager, Wills Company. Vienna, VA. (703) 760-9600.
- R.J. Keller, L.S. Project Manager, R.C. Fields, Jr., and Associates, P.C. Alexandria, VA. (703) 549-6422.
- Warren Bell, City Engineer, City of Alexandria. Alexandria, VA. (703) 838-4327.

SARB_006418

KENSINGTON ESTATES

At Kensington Estates the use of LID technologies in a conventional, 103-lot single-family development planned on 24 acres in unincorporated Pierce County were evaluated. The site was characterized by poor soils. The development took advantage of the new Western Washington Storm Hydrology Model (WWHM) to illustrate the full range of LID technologies in the site's redesign.

Specifics

- Maintained lot yield of 103 lots.
- Designed a roadway system adequate for emergency vehicles.
- Achieved "zero" effective impervious surfaces.
- Incorporated full range of LID techniques, including soil rehabilitation, rain gardens, bioretention, and pervious pavement;
- Provided adequate off-street parking.
- Reduced total project impervious pavement.
- Minimized piped conveyance.

Cost Data

A cost evaluation of the redesign further illustrated the potential benefits of LID. Overall, the LID project permitted construction cost savings of over 20 percent over the conventional project. It achieved the largest share of savings by reducing the size of the storm pond structures and eliminating catchments and piped storm conveyance. Excavation and erosion control costs were also significantly reduced.

Even though the LID design called for a roadway width of 20 feet, the proposed use of porous paving material and of "looped" cul-de-sac clusters designed for emergency vehicle access made the costs associated with roadways and utilities roughly equal to or slightly higher than the costs for conventional materials and design.

SARB_006419

PHILLIPPI CREEK SEPTIC SYSTEM REPLACEMENT PROGRAM

In Sarasota, Florida, available and applicable on-site wastewater treatment and collection technologies were evaluated (see Figure 25) to determine their potential for improving current wastewater treatment and disposal practices in Phillippi Creek.

Specifics

- Available technologies were grouped into three major categories for evaluation: natural systems (e.g., conventional septic tank and subsurface wastewater infiltration systems [SWIS] and septic tank and subsurface drip irrigation [SDI] systems); engineered biological systems (e.g., suspended growth systems, submerged biofilters, and unsaturated biofilters); and waste segregation systems (e.g., nonwater carriage toilets and on-site greywater treatment systems).
- Based on the number of connections, total flow, and available treatment plant and transmission capacities, the project area was previously divided into sixteen (16) manageable areas referred to as Wastewater Project Improvement Areas (WPIA).
- The cost analysis addressed natural systems and engineered biological systems but, because of a variety of implementation problems, including community acceptance, did not address waste segregation systems.



FIGURE 25. EVALUATION PROCESS FOR COMPARING COLLECTION AND ON-SITE WASTEWATER TREATMENT SYSTEM ALTERNATIVES

Cost Data

- The capital cost of a septic tank with a mound with 12-inch fill was $6,000.
- The capital cost of a septic tank with subsurface drip irrigation with 12-inch fill was $7,900.
- In terms of uniform annual cost, the septic tank with SWIS mound was the most cost-effective alternative in a low-density area. In medium- and high- density areas, the vacuum sewer system was the most cost-effective alternative.

RON TYNE AND ASSOCIATES

Terry Paff, president of Metropolitan Realty and Development in Sherwood, Arkansas, wanted to create a development that appealed to both the general public and permitting and review officials. He approached Ron Tyne of Tyne & Associates with his idea and hired the consultant to redesign a conventional site plan developed for a 130-acre parcel. The case study underscores two important points. First, at project inception, developers must formulate a vision of what they want to achieve. They then need to communicate that vision to everyone involved in and affected by the project. Second, by reducing infrastructure costs and collaborating with public officials, a developer can realize a net increase in a project's lot yield.

Specifics

- The new design worked with the land's features. For instance, streets flowed with the terrain, minimizing excavation needs; drainage areas were preserved and buffered by greenbelts.
- Existing drainage courses form a network of green spaces called greenbelts that are connected by neighborhood hiking trails.
- Maximizing the number of lots that backed up to the greenbelts addressed concerns about privacy.
- The original plan's collector street was changed to include green space buffers and traffic-calming circles, thus allowing the developer to reduce street widths from 36 to 27 feet. In addition, trees were allowed to stay close to the curb line.
- The site uses native vegetation such as buffalo grass. Cleared trees were transformed into mulch.
- The original plan preserved 1.5 acres of green space while the revised plan saved 23.5 acres.
- Some of the development cost savings went to fund a neighborhood park with picnic facilities, a pavilion, and ball fields.

Cost Data

- Overall, the developer made an additional profit of $2.2 million on the project by using the practices above.

References:

- "Bridging the Gap: Developers Can See Green," *Land Development Magazine*, Spring/Summer 2000, pp. 27-31.
- The ToolBase PATH Technology Inventory provides information on low impact development: http://www.toolbase.org/tertiaryT.asp?CategoryID=1008&DocumentID=2007

SOMERSET COMMUNITY

In a typical suburban development in Prince George's County, MD, the developer incorporated shallow landscaped depressions called bioretention areas, also known as rain gardens (see Figure 26), into each lot to control storm water quantity and quality. The bioretention areas eliminated the need for a storm water pond, allowed the development of six extra lots, and resulted in a cost savings of more than $4,000 per lot.



A TYPICAL BIORETENTION AREAIN SOMERSET

Specifics

- 80-acre site in Prince George's County, Maryland, undergoing development into 199 homes on 10,000-square-foot lots.
- Prices begin at $160,000.
- Bioretention areas range between 300 and 400 square feet, with one to two bioretention areas per lot (Daniels, 1995).
- Bioretention areas located at low points on lots (see Figure 27).
- Water allowed to pool to a depth of six inches in the bioretention areas after each rain event; complete infiltration of ponded water achieved within 48 hours (Daniels, 1995).
- Bioretention areas combined with grassed swales to replace curbs and-gutters.
- Total cost approximately $100,000 compared with nearly $400,000 for the storm water ponds originally planned (Daniels, 1995).
- Six more lots added to the development, thus increasing revenue (Daniels, 1995).
- Eliminated traditional curbs and gutters and storm water pond by using the less expensive alternative of bioretention areas and grassed swales.
- Development marketed as environmentally friendly. When told that they were helping preserve the Chesapeake Bay, homeowners and potential buyers became excited and interested in helping (Coffman, 1997).
- Bioretention areas perceived by homeowners as free landscaping (Coffman, 1997).
- Total cost for each bioretention area is $500 ($150 for excavation and $350 for plants) (Daniels, 1995).



INDIVIDUAL BIORETENTION AREA

Cost Data

Description	Storm water Management Pond/Curb and Gutter Design	Bioretention System
Engineering Redesign	$0	$110,000
Land Reclamation (6 lots x $40,000 net)	$0	<$240,000>
Total Costs	$2,457,843	$1,541,461
Total Costs--Land Reclamation *plus* Redesign Costs	$2,457,843	$1,671,461
Total Cost Savings = $916,382		
Cost Savings per Lot = $4,604		

Source: Winogradoff, 1997.

Table 26. Cost Comparison of Conventional Storm Water System versus Bioretention

Community Acceptance

Somerset residents have enthusiastically accepted their bioretention areas. Homeowners are actively maintaining them and have lodged few complaints. Only one bioretention area has experienced functional problems, which probably resulted from the diversion of too much water. Safety issues or mosquitoes have not been a problem.

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Permeable Pavement

Pavement system that allows water to seep through the surface, permitting natural filtration

Details Manufacturers Testimonials Resources CAD Details

Summary
Installation
Warranty
Benefits/Costs

PATH Attributes:

Ease of Implementation:

EASY DIFFICULT

Initial Cost:
Operational Cost:
Field Evaluations:
Code Acceptance

NA
N/A

View All Technologies

Symbol Legend

Summary



Just as drinking water can be filtered to remove impurities, the soil particles filters rainwater percolating through soil on its way to surface waters and to groundwater aquifers, This important step in the natural process of water purification is bypassed when rainwater falls on impermeable pavement surfaces or roofs and is carried directly through storm drainage systems into waterways. Since engineered curb and gutter storm drainage systems are costly to design and build, use of permeable pavement systems can also result in a reduction of construction costs for developers or municipalities. Pervious pavements are also denoted as porous or open-graded pavement.

Pollution carried in rainwater runoff is another concern, especially in urban areas. Storm water flowing across streets and sidewalks picks up contaminants associated with air pollution particles, spilled oil, detergents, solvents, de-icing salts during freezing conditions , dead leaves, pesticides, fertilizer, and bacteria from pet waste. Natural filtration of water through soil is the simplest way to control these pollutants, and is a direct advantage of permeable pavement.

There are many options for permeable pavement materials:

Porous Asphalt: A great advantage to porous asphalt is that the same mixing and application equipment is used as for impervious asphalt. Only the formula for the paving material changes with porous bituminous pavement. For more details on the various layers of materials see, the Pennsylvania Stormwater Management Manual Porous pavement specification used by the City of Seattle Washington Park Department. The amount of asphalt binder required is about 6% by weight which is somewhat higher than required for standard impermeable asphalt mixes.

Bituminous permeable paving is appropriate for pedestrian-only areas and for very low-volume, low-speed areas such as overflow parking areas, residential driveways, alleys, and parking stalls. Permeable

Other technologies to reduce impact of development

Rainwater Harvesting

Low Impact Development (LID) Practices for Storm Water Management

A PATH Top Ten Technology! See others at:

2007 PATH Top Ten Technologies

PDF documents require the free Adobe Reader.

All PDF documents open in a new browser window. Close the browser window to return to the site.

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paving is an excellent technique for dense urban areas because it does not require any additional land. With proper design, cold climates are not a major limitation.

Permeable paving is not ideal for high traffic/high speed areas because it has lower load-bearing capacity than conventional pavement. Nor should it be used on stormwater "hotspots" with high pollutant loads because stormwater cannot be pretreated prior to infiltration. Perkiomen Watershed Conservancy has an on line video presentation on Porous Pavement which requires the "Real Player" Media Player, to view.

Porous Concrete: Again, the same equipment may be used as for standard concrete. Larger pea gravel and a lower water-to-cement ratio is used to achieve a pebbled, open surface that is roller compacted. This material was recently used in a parking area in Fair oaks, California as a way to reduce solar heat-gain solar from absorption. Project costs were reduced because no retention pond or connection to the municipal storm drain system was required.

Plastic Grid Systems: High strength plastic grids (often made from recycled materials) are placed in roadway areas. Some are designed to be filled with gravel on top of an engineered aggregate material, while others are filled with a sand/soil mixture on top of an aggregate/topsoil mix that allow grass to be planted on the surface. The grids provide a support structure for heavy vehicles, and prevent erosion. After heavy rains, the grids act as mini holding-ponds, and allow water to gradually absorb into the soil below.

Block Pavers: This material can be used to create a porous surface with the aesthetic appeal of brick, stone, or other interlocking paving materials. They are most often used for driveways, entryways, walkways, or terraces to achieve a more traditional, formal appearance.

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PATH Attributes

Permeable pavements save open space for alternate use, as well as eliminate the cost of piping stormwater to an outfall.

Permeable pavement provides a reservoir and percolation field for surface water to re-enter ground aquifers.

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Ease of Implementation



Porous asphalt and concrete can be supplied by any qualified contractor.

Not all soils are absorptive enough to provide proper drainage under permeable surfaces. Permeable pavement may also have different

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maintenance requirements than conventional materials.

Because permeable pavements are not in wide use, they require special planning and expertise to install. It is not possible to retrofit paved areas with permeable surfaces without re-engineering all substrate and fill materials.

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Initial Cost

The costs for some of the permeable surfaces currently available are shown below, courtesy of the Center for Watershed Protection in Ellicott City MD:

Product	Manufacturer	Cost (Square Foot)
Asphalt	Various	$0.50 - $1.00
Geoweb®	Presto Products, Inc.	$1.00 - $2.00
Grasspave™, Gravelpave™	Invisible Structures, Inc	$1.00 - $2.00
Grassy™	Pavers RK Manufacturing	$1.00 - $2.00
Geoblock®	Presto Products, Inc	$2.00 - $3.00
Turfstone	Westcon Pavers	$2.00 - $3.00
UNI-Eco-stone	Uni-Group USA	$2.00 - $3.00
Checkerblock	Hastings Pavement Co.	$3.00 - $4.00

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Operational Cost

NA

Municipal governments are still collecting data on the maintenance costs associated with permeable pavements.

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U.S.Code Acceptance

All permeable materials must meet applicable material quality specifications, and requirements for compressive strength, water absorption, and freeze-thaw resistance. Mixes and/or installation methods should meet appropriate ASTM standards for public-use surfaces like parking lots and roads.

Concrete used in a slab for a carport or garage must meet minimum strength requirements.

Codes in many jurisdictions require the use of certain types of curbs, gutters, or stormwater piping that would prevent the possible cost savings from permeable surfaces to be fully realized.

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Field Evaluations

Not Applicable

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Installation

Installation techniques vary for the type of permeable material chosen, but in general are similar to requirements for the impervious materials they replace. Engineering of substrate material becomes more critical when porous surfaces are used, with special attention needed in hydraulic design for the overall system. In general the underlying soil must have a minimum infiltration rate of at least 0.3 inches/hour.

First step in installation is the excavation down to the design depth of the pavement /gravel reservoir system. The uncompacted base soil is covered with a geotextile fabric to reduce migration of soil fines into the gravel reservoir. The geotextile fabric is then covered with 12 to 36 inches crushed gravel (AASHTO no. 3 stone, median stone dimensions of one inch nominal). The thickness of the layer and the stone dimension of the crushed gravel storage reservoir vary with the specifying agency. A “choker course of 2-3 inch depth AASHTO no. 57 which fills the spacing in the underlying coarser aggregate is then placed followed by the hot mix asphalt layer 2.5-3.5 inches with the fine portion of the aggregate component removed.

The ability of systems to handle 10, 25, or 100 year storm events must be calculated and incorporated into designs as the application requires.

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Warranty

Parking and road surfaces generally do not carry warranties because of the use and harsh conditions they are subject to. Dutch researchers have predicted a ten year highway service life for open-graded friction course asphalt compared to a twelve year life for the impervious (dense-graded) alternative.

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Benefits/Costs

As discussed above, the main advantages to permeable pavement are cost savings compared to typical stormwater drainage systems. Permeable pavement may become an important element in finding solutions to water use challenges while still meeting roadway requirements for traffic load support, durability, and safety.

Permeable pavement also tends to be less reflective, causing less glare and allowing motorists to see pavement markings better.

Initial costs of permeable paving may be competitive with conventional materials, or somewhat higher. These costs are often offset when the need for other types of stormwater drainage is eliminated.

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Environmentally Green…Economically Green

Tools for a Green Land Development Program





NAHB Research Center, Inc.
400 Prince George's Boulevard
Upper Marlboro, MD 20774

with support from

U.S. Environmental Protection Agency
Innovative Transportation Programs & Partnerships
1200 Pennsylvania Avenue, NW
Washington, DC 20460

July 2001

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Disclaimer

This guidebook is based on information obtained during 1999 and 2000. Certain information, particularly Web site references and specifics of the green land development programs featured in the guide, is likely to change. Any references to costs or cost premiums should also be used with care.

Although the information in this guidebook is believed to be accurate, neither the U.S. Environmental Protection Agency, nor the NAHB Research Center, nor any of their employees or representatives make any warranty, express or implied, with respect to the accuracy, effectiveness, or usefulness of any information, method, or material in this guidebook, nor assumes any liability for the use of any information, methods, or materials disclosed herein, or for damages arising from such use.

Given the nature of any program that certifies or qualifies a particular product or technique under certain standards of content, operation, or performance, the NAHB Research Center strongly recommends that any home building association or other party seeking to use this guide in the development of a formal certification program seek legal counsel to protect the interests of both the association itself and its members.

COVER PAGE: Union Street Station by McGurn Investment Company, Gainesville, Florida (right) and Redmond Ridge, Seattle, WA.

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The NAHB Research Center, Inc. is the research and development leader in the home building industry. Federal, state, and local government agencies, manufacturers, builders, remodelers, and developers rely on the expertise and objectivity that are at the heart of the Research Center. Uniquely positioned to facilitate invaluable liaisons between builders and manufacturers, design professionals and housing researchers, and government and developers, the Research Center is dedicated to advancing housing and land development technology and techniques and enhancing housing affordability for the benefit of all Americans.

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PART I – GREEN LAND DEVELOPMENT OVERVIEW AND PROGRAM DEVELOPMENT

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OVERVIEW

Purpose Of The Guidebook

Environmentally Green...Economically Green is intended for local-level practitioners who want to incorporate green land development practices into their work. Part One of the guidebook contains a brief overview of green land development and information on how to create a local green land development program. Part One is geared primarily toward Home Builder Associations (HBA) that are considering developing a "green" program of their own. However, other organizations interested in developing a local program could also find the information useful. Part Two of the guidebook lists green land development principles and offers brief explanations for each principle. Although these principles are essential parts of a successful green land development program, they can also be used for many other purposes.

Developers can use Part Two to identify ways in which their companies can become more resource-efficient and save money. Local government officials will find the principles beneficial as they review local regulations, such as zoning ordinances, street standards, and stormwater management ordinances that govern land development. While current regulations may prohibit developers from implementing some of the action items contained in Part Two, the principles can nevertheless provide a centerpiece around which private industry representatives and public sector officials can discuss how affected parties can work together to address cost-effective, environmentally sensitive land development.

What Is Green Land Development?

Each year, the United States witnesses the construction of over 1 million new homes. Many of these homes are built in subdivisions, on land that was previously undeveloped. The goal of this guidebook is to help individuals incorporate environmental considerations into all phases of the land development process.

Green land development does not conform to a narrow definition. For this document, we define it as making improvements over current practice that produce a more environmentally-friendly development within reasonable economic limitations. To the extent possible, we focus on residential design and development that addresses both the cost and the environmental issues associated with development. The guidebook emphasizes improvements that developers can make at their discretion or improvements that require some minor or moderate institutional change by local regulatory agencies. For the most part, improvements are limited to items within a site's boundaries.

Current discussion about green development represent a push to foster land development practices that preserve open space and undeveloped land, limit stormwater runoff, reduce automobile traffic, decrease soil erosion, and increase aquifer recharge. These practices encourage more resource-efficient land use practices and residential environments while ensuring that development keeps pace with economic growth.

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The principles outlined in this guidebook can help the reader enhance a project's resource efficiency. The guidebook's goal is to explain the advantages of each principle and to discuss considerations in implementing a given action item.

Green Land Development Applied To Smart Growth

"Smart Growth" is a term often used by the media to characterize developments that are town-centered and transit- and pedestrian-oriented, that feature a wider-than-usual mix of housing types as well as on-site commercial and retail uses, and that optimize the use of open space. According to the National Association of Home Builders (NAHB), Smart Growth means meeting demand for housing by building political consensus and applying market-sensitive and innovative land use planning concepts. That translates into meeting housing demand through more intelligent means by planning and building to higher densities, preserving useful and valuable open space, and protecting environmentally sensitive areas. This guidebook does not focus on Smart Growth issues but instead demonstrates how green development principles can enhance developments within the context of Smart Growth.

Land development has become a national topic due to our population growth and the pressure for communities to provide better services. Within the premise that growth is inevitable is the desire among many to preserve farmland, parks, and other undeveloped areas.

One concern in the creation of a community is the replacement of natural pervious landscape with impervious surfaces that include rooftops, roads, parking areas, driveways, and sidewalks. A conceptual goal of sustainable development is to promote economic growth while also protecting the natural environment. At times, local codes and standards can work against that concept by promoting excessively wide streets, excessive parking requirements, and large-lot subdivisions. At the same time, there may be little in the local codes that conserve natural areas.

This guide attempts to highlight those and other areas where communities and developers can better work together to build environmentally-friendly neighborhoods.

Why Do We Need Green Land Development?

There are numerous reasons for an HBA to establish a green land development program:

- ***To acknowledge*** and promote *existing* land development practices that represent resource-efficient or environmentally friendly construction.
- ***To encourage*** and reward the use of *new* or *additional* land development practices that represent resource-efficient or environmentally friendly construction.
- ***To satisfy*** existing and/or ***create*** new market demand for resource-efficient or environmentally friendly construction.
- ***To improve*** existing or establish productive new relationships with key local and state government agencies.
- ***To educate*** developers, builders, and homebuyers with meaningful, comprehensive, and practical information about the impact of land development on the environment.
- ***To shape*** the public debate and regulatory agenda on local environmental issues.

Green land development can benefit the developer, the community, and the environment. The following is an example of one developer's project:

A Comparison of Two Different Land Plans

PROJECTED RESULTS FROM TOTAL DEVELOPMENT		
Total Site	**Conventional Plan**	**Revised (Green) Plan**
Lot Yield	358	375
Linear Feet--Street	21,770	21,125
Linear Feet–Collector Street	7,360	0
Linear Feet--Drainage Pipe	10,098	6,733
Drainage Sections--Inlets, Boxes, Headwalls	103	79
Estimated Total Cost	$ 4,620,600	$ 3,942,100
Estimated Cost per Lot	**$ 12,907**	**$ 10,512**

ACTUAL RESULTS FROM PHASE ONE		
	Conventional Plan (engineer's estimated figures)	**Revised (Green) Plan** (actual figures)
Lot Yield	63	72
Total Cost	$ 1,028,544	$ 828,523
Total Cost per Lot	**$ 16,326**	**$ 11,507**

ECONOMIC AND OTHER BENEFITS FROM LOW-IMPACT DEVELOPMENT	
Higher Lot Yield	17 additional lots
Higher Lot Value	$3,000 more per lot over competition
Lower Cost per Lot	$4,800 less per lot
Enhanced Marketability	80 percent of lots sold in the first year
Added Amenities	23.5 acres of green space/parks
Recognition	National, state, and professional groups
Total Economic Benefit	More than $2,200,000 in savings

(LAND DEVELOPMENT magazine, "Bridging the Gap: Developers Can See Green," Spring/Summer 2000, pp. 27–31.)

Some developers have already addressed the costs of green land development in comparison with conventional land development. For example, Ron Tyne of Tyne and Associates redesigned the site plan for a 130-ace parcel after the initial design failed to satisfy his environmental goals. The table to the left contains the cost comparison for the two designs. In addition to reducing the site's environmental impacts, the developer was able to reduce developments costs by over $2.2 million.

Green Development Tools

In 1993, the NAHB Research Center produced *Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation* for the U.S. Department of Housing and Urban Development. This was based on several decades of research into cost-effective development methods. The document discusses development methods, including the use of drainage swales, pathways and walkways, and resource conservation from an affordable housing perspective. Subsequently, other organizations have used the 1993 publication along with other materials to create documents that focus in greater depth on the environmental aspects of land development.

For example, the Center for Watershed Protection (CWP) has developed a concise, categorical organization of development principles to provide general design guidance. The 22 principles in the Center's *Better Site Design* are divided into three topic areas: residential streets and parking lots, lot development, and conservation of natural areas; the three areas are labeled, respectively, "Habitat for Cars," "Habitat for People," and "Habitat for Nature" . The publication is designed to help people identify areas where existing local codes and standards can be amended. In addition, CWP recognizes that each locale has different needs and that each principle must be locally adopted rather than nationally implemented to reflect the unique characteristics of a site and community.

Another organization, Sensible Transportation Options for People (STOP), addressed land use issues by setting forth a set of traffic-calming principles in its publication entitled *Traffic Calming: The Solution to Urban Traffic and a New Vision for Neighborhood Livability*. STOP defines traffic calming, which deals primarily with traffic and automobiles, as "environmentally compatible mobility management." The group contends that roads do not act solely as a corridor for traffic but also as an area of "social interaction, walking, cycling, and playing."

NATIONAL GREEN LAND DEVELOPMENT PRINCIPLES

Methodology

The process used to develop the list of green land development principles involved researching and using the information collected from existing green land development programs and publications. The step-by-step process for creating the list called for:

- Reviewing practices that are more environmentally friendly and cost-effective than conventional land development practices;
- Developing a list of best development practices based on the background literature and green land development program search;
- Reviewing a draft list of principles by a team of nationwide land development experts; and
- Pilot testing the list of principles through a local home builders association.

Green Land Development Programs

We analyzed three home builder association (HBA) programs that combined green building and green land development requirements. We reviewed the following programs to create a list of features that could be included in any community's green land development checklist:

- *Built-Green Program* of King and Snohomish Counties
- Clark County Home Builders Association *Build A Better Clark* Program
- *Evergreen Builders Guide* of Issaquah

Appendix A provides the green land development aspects of each program.

***Built-Green Program* Of King And Snohomish Counties, Washington**

The *Built-Green Program* of King and Snohomish Counties, Washington, uses a point system for awarding builders and developers Built-Green membership and project approval. The builder's point system is based on criteria in the "Health and Air Quality" section of the Built-Green Program while the developer's point system is based on criteria in the "Site and Water" section.

Overall, applicants are required to meet the Washington State Water Use Efficiency Code Standards and all applicable stormwater management and site development requirements. Additional points are awarded for building on an infill lot and building in a development that meets the Built-Green criteria on the builder and developer lists. For the purposes of this guidebook, we considered only those components in the developer list, including criteria in the areas of 1) Ecosystem Protection, 2) Pedestrian/Transit-Oriented Neighborhoods, and 3) Community Enhancement.

***Build A Better Clark* Program Of Clark County, Washington**

The Clark County Home Builders Association of Washington created the *Build a Better Clark Program* for both builders and developers. The program awards a development certificate and single-level *Build a Better Clark Program* membership, which a developer can earn by attending a program orientation and receiving a minimum 15 points from each of the two sections of a developer survey that outlines the green land development requirements. The developer survey requirements address the following issues: Building Pedestrian/Transit-Oriented Neighborhoods and Protecting Ecosystems and Conserving Natural Resources.

***Evergreen Builders Guide* Of Issaquah, Washington**

The *Evergreen Builder's Guide* of Issaquah, Washington, is based on what the guide calls the three "Es" of sustainable development: Environment, Economy, and Equity. Though it was designed largely for builders and homeowners, the guide also applies to the various trades and addresses site plan issues that should be considered in green development.

The Evergreen guide specifies criteria to reduce the environmental impacts of land development, ensure quality neighborhoods, and protect and enhance property values. The main elements of the guide include performance categories, performance improvement measures, and a priority ranking system.

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The guide's five performance categories include community enhancement, water quality and conservation, environmental quality, energy conservation, and resource management. Strategies that support category goals are intended to lead to choices for improving performance. To achieve performance improvements, strategies are translated into measures of preferred building components that are designed to improve performance. Measures are expressed as a fixed point value based on initial cost and environmental benefits. Points establish "star" levels, and participants must implement measures to at least the first star level.

Each of the local green building and development programs reviewed for this guidebook blend green building and green land development principles in each of their checklists. In addition, as noted later, the Home Builders Association of Metropolitan Denver used a draft of the Research Center's green development principles and created its own Built Green™ Communities Program. Appendix B presents the draft checklist for the Denver program.

Other Sources

In addition, we reviewed a variety of other green land development publications. The list of principles in Part Two of the guidebook contains elements from each source.

We recognize that green land development programs will most likely be voluntary and should include features that meet the needs of a particular community. Thus, our goal is to create a list of principles that can act as a foundation for local organizations interested in creating a local green land development program.

The principles located in Part Two of the guidebook focus on the subdivision level and are cost-effective resource-efficient land development methods. The principles are grouped into eight categories, listed below. We used these categories because they capture the essence of green land development currently in practice.

- Pedestrian system
- Layout/density/land use
- Streets and parking
- Stormwater
- Landscaping/grading
- Wastewater
- Site selection
- Other

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How To Use The National Green Land Development Principles

In its current state, the list of green land development principles is not to be used as a green land development checklist to certify a developer's handiwork. On the contrary, it is a list of principles to be used in helping to create a green land development program tailored to the issues most pertinent to a given community. For instance, communities in the Southwest might be particularly interested in reducing a development's water use. On the other hand, communities in the Pacific Northwest might be focused on reducing the effects of a development's increase in stormwater runoff. Either way, the guidebook can help satisfy existing market demand for resource-efficient construction or help communities prepare to respond to projected demand for such construction.

At the same time, developers interested in comparing their current projects to the latest green land development principles might find the guidebook useful. Similarly, developers, local organizations, and/or local government officials who are frustrated by opposition to innovative land development concepts can use the guidebook to focus discussions among various groups and to help build new relationships between different stakeholders in order to help reduce regulatory obstacles to green land development practices.

The action items are grouped under a list of eight overarching themes: 1) Pedestrian System, 2) Layout/Density/Land Use, 3) Streets and Parking, 4) Stormwater, 5) Landscaping/Grading, 6) Wastewater, 7) Site Selection and 8) Other. A developer can implement each action item to address the environmental and economic aspects of each respective theme.

Implementing one action item can influence a community in several ways. For example, by reducing the width of roads that wind through a development, a developer can limit a development's impervious surface, use fewer raw materials (e.g., asphalt) to build roads, and influence the design of the pathways along which emergency vehicles may travel. The matrix in Part Two of the guidebook shows how each principle affects the environment by denoting how each principle fits into one of three categories: 1) Reduce Pollutant Runoff, 2) Preserve and Conserve Natural Resources, and/or 3) Reduce Vehicle Use.

Reduce Pollutant Runoff

Communities can experience adverse impacts with stormwater runoff, particularly during heavy rains. Conventional development practices sometimes increase the amount and frequency of runoff, causing flooding, erosion, and water quality problems. Runoff is usually directed (either through pipes or above ground) to a water body or stormwater facility to protect property from damage. However, in so doing, runoff often collects pollutants from the land. Some of those pollutants include sediment, bacteria, garbage, chemicals, and nutrients. A green development should manage stormwater in a manner that better maintains natural runoff characteristics, reduces erosion and pollution, and deals with stormwater runoff as a resource instead of as a liability.

Preserve And Conserve Natural Resources

An overriding goal of most green development programs is to preserve open space and conserve natural resources. Through the use of clustering and other techniques, developers can provide open space, conserve resources, promote natural vegetation, provide wildlife corridors and

sanctuaries, create community recreational space, and promote watershed protection. Developers can also take into account environmental characteristics such as topsoil, hydrology, vegetation, wetlands, and habitat and balance market demand with site capacity. In addition, infill development can be used to preserve open space, make efficient use of existing buildings and infrastructure, and help spur social and economic revitalization.

Reduce Vehicle Use

Transportation planning should consider all forms of alternative transportation---- from public transit and ride sharing, to walking, bicycling, and programs such as telecommuting that reduce a community's dependence on the automobile. A well-designed transportation plan can yield several benefits, including the following:

- Reduced construction costs;
- Reduced maintenance costs;
- Alternative modes of transportation (e.g., walking, bicycling);
- Reduced vehicle miles traveled;
- Improved air quality;
- Within a development or pedestrian areas, slower traffic flow leading to potentially fewer accidents;
- More amenity space; and
- Connecting residential communities to services and shopping centers.

For each principle in Part Two of the guidebook, a check mark (✓) denotes to which of the three categories each principle best applies. *The lines of importance drawn here are gray since many of the action items carry over into more than one category.* If an action item equally affects more than one category, then multiple categories are checked. If a category is not checked, it means that the action item does not influence that category as much as a category with a check mark. These categories are in the guidebook to help local officials and members determine which action items have the greatest impact on stormwater management, transportation, and so forth. For instance, the principle "*Create a Street Network That Moves Vehicles at an Appropriate Rate of Speed*" is designed to help reduce vehicle speeds and thus encourage alternative forms of transportation (e.g., walking, bicycling). Therefore, a community that is focused on stormwater management may not benefit greatly from devoting a great amount of effort to such a principle.

Explanation Of One-Page Action Item Descriptions

Part Two of the guidebook contains roughly a page of details for each principle, including the principle's intent and the factors developers should take into account when determining whether they want to implement that particular item. In addition, real-world examples from the local and regional levels provide lessons in the success and failure of implementation. Some principles are harder to implement than others; however, an overarching theme among the examples is that coordination with local planning officials is often the key to efficient principle implementation.

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HOW TO CREATE YOUR OWN GREEN DEVELOPMENT PROGRAM

The steps suggested below are generally sequential, although some may occur simultaneously. Often, a newly conceived project suffers from the "chicken-and-egg" phenomenon; that is, attempts to address one issue have ramifications for other issues and generally blur important overall direction. For the steps below, the discussion highlights actions or issues that may be tied to other elements or features of an evolving program.

Program development from an HBA's perspective is broken down into 11 steps. Details for each step follow the summary list presented below. A similar list of steps has been used in *The Guide to Developing Green Builder Programs.*

STEP ONE	***Determine member and homebuyer interest in/basic knowledge of green land development***
STEP TWO	***Establish a development committee***
STEP THREE	***Set program objectives***
STEP FOUR	***Determine program partners***
STEP FIVE	***Determine program coverage***
STEP SIX	***Discuss first-year budget and structure of program fees***
STEP SEVEN	***Consider the role of existing programs***
STEP EIGHT	***Determine the certification or approval process***
STEP NINE	***Discuss and establish program resources and activities***
STEP TEN	***Establish key elements of program structure***
STEP ELEVEN	***Create program content items***

NOTE: These steps are the result of a review of existing local green building and land development programs.

STEP ONE: Determine member and homebuyer interest in/basic knowledge of green land development

You are probably investigating a green land development program in response to interest from members, the public, and/or a local government agency. You need to know the reason for interest in the program--whether it is based on economic growth, environmental protection, quality of life improvements, or a combination of these reasons. The feedback you will be looking for is a combination of the level of interest in, awareness of, and knowledge of green land development.

NOTE: It is important to recognize the difference among interest, awareness, and subject knowledge. Consumers often demonstrate interest in and awareness of environmental issues, but they fail to make the connection with the land development process. Accordingly, marketing campaigns need to become educational campaigns. Educational campaigns can be the shared responsibility of any number of entities, including industry groups, government agencies, foundations, and environmental organizations.

There are two basic mechanisms for soliciting feedback from developers and homebuyers—focus groups and surveys. Home builders associations have used each technique to test the advisability of launching new programs.

Focus Groups

A focus group is a qualitative market research tool used to gain information on and insight into the attitudes, motivations, perceptions, and decision-making processes of a particular group. The group normally consists of eight to ten people selected for certain attributes: occupation, expressed interest, level of education, and so forth.

The keys to a successful focus group are a clearly defined agenda and a professional moderator. Sessions can be audiotaped and videotaped for later review. The cost to set up, conduct, and analyze one two- to three-hour focus group can run from $4,000 to $10,000.

Even though the guidebook is intended primarily for use by home builders associations, it is potentially useful to other organizations interested in developing programs that promote resource-efficient land development. The important point to remember is that the most effective programs succeed by gaining both industry and local government buy-in from the outset. Organizations other than home builders associations that elect to use the guidebook should strive to include members of the land development industry from start to finish. As the steps below suggest, HBAs using this guide should determine, early in the process, the role that local government can play in program development. Partnerships, particularly with local government, can help HBAs overcome hurdles that may be encountered when the program calls for changes to local codes.

Developer Survey

HBAs have used general membership meetings, fax, mail, and telephone interviews as methods of obtaining completed surveys. General membership meeting surveys are by far the least expensive means of soliciting feedback, but they limit the range of responses to a group generally much smaller than the total membership. Fax and mail surveys cast a much wider net. In any case, care must be taken to keep the survey short enough to enable builders to complete it quickly but substantive enough to enable the organization to collect useful information. Telephone interviews can be the most useful survey tool because they encourage feedback that goes beyond the survey questions. Telephone interviews are, however, time-consuming for both developers and interviewers and confining because they often require scheduling of the interview.

Homebuyer Surveys

The key to a homebuyer survey is to identify a forum or vehicle that targets buyers as a consumer group. Two successful approaches include in-person interviews at home shows and a written survey run in the home section of a local newspaper.

The Home Builders Association of Central New Mexico used a home showcase to conduct in-person interviews with 250 potential homebuyers. Conducting an exit survey at a home show event effectively targeted the survey to potential homebuyers. A professional business information group developed, conducted, and analyzed the survey for a cost of approximately $1,100.

The Home Builder Associations of Kitsap and Clark counties also administered surveys at home show events. The program consultant developed the survey, and the HBA and local government volunteers administered it at HBA show booths.

The Greater Atlanta Home Builders Association made arrangements to run a full-page survey in the home section of the Sunday edition of the *Atlanta Constitution*. Respondents mailed or faxed the completed one-page survey back to the HBA.

Surveys of developers and homebuyers can yield two results. They provide valuable information, and they spread the word to individuals, firms, or agencies that might participate in the development of your program. Survey results can also provide the foundation for the development of marketing materials for the entire program

STEP TWO: Establish a development committee

Creating a green land development program involves considerable decision-making regarding program objectives, scope, financing, and structure. The composition of the committee (developers, associate members, outside organizations) needs to be broad enough to represent any and all directions the program might take. On the other hand, program development must maintain a focus that is reasonable in view of program objectives and available resources. It is easy to see how Step Two is closely linked to several other steps, particularly Steps Three and Four.

Consider the following for committee membership:

- **Developers.** Your committee should include a range of developers—from developers who specialize in small developments to those who tackle multifaceted sites. Differences in methods of land development, management, financing, product selection, and marketing can all have a significant impact on program structure and content.
- **HBA leaders.** HBA leaders must be directly involved through their membership on the development committee or indirectly involved through regular briefings. In this way, HBA leaders' commitment to the program will be cultivated or maintained.
- **Local government.** HBAs have long worked with local planning departments, safety officials, and stormwater management officials, taking advantage of both their financial and technical resources. As discussed below and in Step Four, the timing and level of local government involvement is often important to program success.
- **Lender(s).** Financial incentives for both homebuyer and developer participation in the program are a major part of the program—at least one lender should be involved in program development.
- **Real estate professionals.** The realty community can play an important role in the marketing of any program. Energy efficient mortgages can create incentives and additional buying power for homeowners and potential homeowners interested in buying a green home in a green land development.
- **Associate members.** Distributors, trade contractors, and local product manufacturers can be important sources of technical information and funding support.

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- **Environmental land development professionals.** Even with the assistance provided by the guidebook, nothing can replace local expertise in resource-efficient land use design and construction. Technical support to the committee is particularly important if the committee lacks developer members with field experience in green development practices.

There are two basic approaches to establishing a development committee. The first approach is to start with a core group of approximately six HBA members (primarily developers) and staff who will decide how and when to expand the land development committee to outside organizations. This early work will help ensure that the larger committee includes the appropriate mix of perspectives and resources. The start-up or core group should probably limit its role to establishing initial program objectives and scope before moving on to expand the committee.

The second approach is to include at least one outside organization at the outset. Such an organization can bring resources and a level of interest to the emergent committee. The establishment of a development committee raises the issue of partners in program development as discussed in Step Four.

STEP THREE: Set program objectives

HBAs with green land development programs have noted that one of the most important program benefits has been the good will generated with the public in general and with some local government offices in particular. A green land development program represents the opportunity for both private industry and government to demonstrate cooperation and consensus, building public support for both.

It is important for an HBA and its program development committee to discuss and establish program objectives during the early stages of program development because the objectives have a significant impact on everything that follows. It is also important to assign priorities to program objectives.

STEP FOUR: Determine program partners

The decision to include outside organizations in program development is often based on one or more of the following four factors: credibility, control, cooperation, and financial resources.

- **Credibility.** A stand-alone program, regardless of whether it is developed by an HBA, an environmental organization, or a government agency, faces the added challenge of convincing the public and interested outside parties that the program is substantive and objective. Generally, programs that contain an element of public/private partnership have greater credibility and receive more supportive media coverage than stand-alone programs.
- **Control**. The trade-off often made when a program involves two or more organizations is one of control. It is likely that the enhanced credibility of a partnership brings with it some compromise on or accommodation to program objectives or their priority. Accordingly, initial discussions regarding objectives can be important when seeking the appropriate partners in program development.

- **Cooperation.** Including outside organizations in the program development phase can help an HBA build bridges and, in the early stages of program development, identify potential/actual issues that may ultimately hinder program implementation.
- **Financial resources**. Although the costs of starting and running a program are discussed later, they usually include HBA staff time, production of educational and marketing materials, and consulting services (marketing, surveying, environmental consulting). The resources of each HBA and the goals of each program will determine the importance to the program of partners with financial resources. Step Six discusses in detail program development costs in detail.

Listed below are entities to consider when seeking partners.

- **Government agencies**. A variety of local or state government agencies or departments may be interested in contributing to the development of a local green land development program, including those in the following areas: planning, stormwater management, energy conservation, environmental quality, solid waste management, and building inspection. It is important to consider, however, that the participating entity may want to focus on the particular environmental issue that it champions. Another important consideration when working with government agencies is the substantial time and effort required if when seeking grants or other forms of financial support.
- **Product manufacturers**. While local distributors and suppliers often participate in local HBA programs as associate members, product manufacturers may be willing to be financial sponsors of a local green land development program. It is important to discuss with product manufacturers any expectations they may have for featuring particular products as a part of their sponsorship.
- **Non-profit organizations/foundations**. Nonprofit organizations with an investment in local environmental issues can make good partners in the creation of a green land development program. These organizations often enjoy strong relationships with both the media and environmentally related government agencies.

With the land development committee and program objectives established, information on member and homebuyer interest and attitudes collected, and initial financial resources identified, the committee can begin to address the details of program structure.

STEP FIVE: Determine program coverage

Land developers are the primary HBA constituency interested in a green land development program. Developing a land development program requires attention to issues such as local planning, zoning, stormwater management, infrastructure standards, and transportation systems. Addressing these issues may require significant changes in regulations, ordinances, and master plans as well as long-term political and educational efforts. Although the HBA programs noted earlier in the guidebook have formally introduced green land development into their programs, several existing green builder programs initially did not include elements or an entire section on land development for the simple reason that they would have required considerable legislative change. However, most HBAs plan to use the green builder program over the long term to address development issues.

The Home Builders Association of Metropolitan Denver Program includes a prerequisite that all homes in a green community must meet or exceed the Built Green™ Home certification. We recognize that multiple builders are often involved in the construction of a project and that the original developer will not have control over how each house is built once a lot is sold to a builder. Anyone trying to establish a local green land development program may want to discuss with developers the possibility of a "green home" prerequisite to determine if such a requirement would undermine program participation rates.

STEP SIX: Discuss first-year budget and structure of program fees

The first-year budget of a green land development program involves the costs of development and implementation. Most development costs are labor-related—staff, HBA members, and possibly consultant(s). Usually, implementation costs are largely the hard costs of printing materials, planning events, and promotion. The table below describes in broad categories the costs for one of the existing green builder/land development programs.

First -Year Budget for a Green Building/Land Development Program

Features	
Hard costs	**Kitsap**
Advertising	$ 4,400
Builder/consumer surveys/focus groups	$ 550
Marketing materials (logo, ad slicks, yard signs, certificates, plaques, and so forth.)	$7,650
Builder handbooks	$3,715
Hard Cost Subtotal	$16,315
Labor*	
Program development (HBA staff)	$ 6,775
Program development (consultant)	$26,770
Event planning (staff)	$0
Total	$49,860
Field checks (independent inspector)	N/A

****NOTE***: Labor figures are for existing programs that did not benefit from this guidebook. Use of the guidebook can result in significant savings in both staff and consultant labor.

Here are some general rules of thumb taken from the existing green land development programs:

- At least initially, the programs are not set up as revenue generators—the goal is to make the program revenue-neutral after the first or second year.
- Staff time to develop and administer the program is often not specifically allocated to the program budget. Staff are under direction as to the portion of their time to invest in development, implementation, and then ongoing administration of the program. The total

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staff investment during the first year of program development averaged around one-quarter- to one-half- time for one person.
- Program membership fees are often set up to cover only the hard costs of the program—printing materials, signs, and conducting spot checks. Excluding advertising and staff time, program hard costs average around $11,000.
- Advertising costs often are set up to be covered by project sponsorships as reflected in the wide range of advertising costs in the first year of the programs.
- It takes a substantial amount of time to gather and present background information on the program's content areas for compilation into an HBA library and/or builder's handbook. Before investing time and money in either, check with builder members likely to enroll in the program as to which vehicle they think will be more useful.

Even before specific features of the program have been established, however, answers to the following questions can help in determining program structure:

- Are developer enrollment fees assessed annually and/or per project?
- Are developer member fees tied in any way to the size of a developer's projects?
- Can a developer pay more to be a founding member and receive sponsor-level recognition?
- Can associate members (architects, subcontractors, building material suppliers, lenders) join, and how do their fees compare with those for developers?
- What is the cost of being a program sponsor or partner, and is there a limit to the number of sponsors or partners?

STEP SEVEN: Consider the role of existing programs

The land development committee should compile a list of existing local, regional, or national programs that may relate to the local green land development program. These programs may be HBA, NAHB, federal/state/local government, local environmental, or utility programs. One example includes the Building *With* Trees recognition program sponsored by the National Arbor Day Foundation in cooperation with the National Association of Home Builders. The program outlines tree protection practices and provides two opportunities for builders and developers to receive recognition for their efforts--one following the planning and design phase of a project and the other following construction. Another pertinent program is the Joint Center for Sustainable Communities, which is a collaboration between the U.S. Conference of Mayors (USCM) and the National Association of Counties (NACo). The Center helps local elected officials build sustainable communities by promoting community leadership initiatives, providing technical assistance and training, and conducting community policy and educational forums.

STEP EIGHT: Determine the certification or approval process

There can be two elements to the process of certifying participants in the program: an initial agreement and project-by-project certification. Some programs rely on a fairly formal contractual agreement for program members that states the rights and responsibilities of both the

member and the program administrator. Typical elements of these agreements include the following:

Developer Member

- Pay dues (annual and project)
- Enroll minimum number of development projects
- Permit use of developer name in program
- Assume responsibility for compliance
- Provide random access to projects for spot verification
- Limit use of program materials to enrolled projects
- Fairly represent and document compliance to lot buyer

Program Or Administrator

- Provide technical support/training
- Promote program to general public
- Promote program to real estate professionals/suppliers/developers
- Provide signage
- Establish grievance process
- Maintain records/process applications
- Provide program financial oversight

Most programs have begun with a self-certification process under an agreement that the program has the right to random checks of any project's compliance with program criteria.

STEP NINE: Discuss and establish program resources and activities

A wide range of resources and activities should be considered in the creation of a green land development program. The following list highlights the most significant resources that can be offered to developers:

Resources

- **Developer Handbook.** Most green land development programs develop a handbook that is distributed to developers when they enter the program. Handbooks usually take the form of a three-ring binder that easily accommodates changes and updates. Some handbooks are designed as a developer's introduction to the program; some are set up as a marketing tool for the developer to use with clients; and some are an extensive, detailed reference and educational tool for the developer. The most common elements of the handbooks are the following:
    - ***Summary checklist.*** This is a checklist all of the items described in one-line phrases on one or two pages. This summary sheet is often the same as the record of compliance that a builder will *complete for each qualifying home or project.*
    - ***Detailed action item descriptions.*** Although some or many of the items may require little elaboration for developers, others may require detailed examples or instructions. Details may be spelled out in the handbook or included in specific references that are part of the program resource library as discussed below.
    - ***Resources.*** The implementation of many program items requires contact or outlet information. Given that the resource portion of the program is that aspect of the

program most subject to change (e.g., add new companies, change contact personnel, update range of services), resource information is often kept in a separate section of the handbook.

NOTE: The elements listed above can be provided in a software package, thus facilitating easy updates.

- **HBA Resource Library.** A balance needs to be struck between the amount and level of information given to developers in the handbook and the materials retained for developer use in the HBA library. Some programs report that developers use little of the detailed information in the handbook and prefer to seek out information and guidance on specific items as needed. Others report that developers prefer a reference that is thorough enough to be used as an independent tool. The type, frequency, and level of education/training provided by the program may also affect the design and intent of the library and handbook.
- **Newsletter.** Several programs issue a one-page newsletter distributed to all members on a regular basis. The newsletter announces upcoming events, makes members aware of program updates, and provides tips to developers on green land development techniques.
- **Web site or listserv.** More and more developers and associate members enjoy computer access. As a result, the HBA Web site can be used in place of or in conjunction with the newsletter to communicate with program members.
- **Promotional materials.** The specific materials that programs provide to their developers include signs, ad slicks, logo stickers, brochures, certificates, and plaques.

Activities

- **Training.** Training can take the form of an initial orientation and/or an ongoing educational series. Several programs operate or are developing a training series to expose developers to the full range of options available within the program. While some of the techniques or actions suggested within the program may be straightforward or represent current practice for many developers, others may require both classroom and hands-on education. Developer training is generally a part of the program that is not well developed during the first year but evolves in subsequent years as developer needs are identified.
- **Community events.** Any existing community event that focuses either on housing or the environment provides an opportunity for the HBA to get the word out to potential homebuyers about the advantages of buying a home in a community developed in accordance with green land development practices. The Build a Better Kitsap program has a booth that features resource-efficient techniques and materials used by its participants. The booth is used at home shows and other local events. Any event that involves the creation of an exhibit involves the costs of construction as well as the costs of unit set-up, breakdown, and storage.

STEP TEN: Establish key elements of program structure

This step and Step Eleven are often considered together because of their impact on each other.

Five basic decisions guide the structure of the content areas and individual items in a green developer program: performance-based versus prescriptive standards, number of program levels, types of requirements, weighting of items by points, and organization of content areas.

Standards

Individual items in the program can be expressed as performance-based, prescriptive, or a combination of both.

Performance-based standards are expressed in terms of the end-product—the emphasis is on where you end up, not how you get there. An example is, "Percentage of common area open space to total area is 25 percent." The standard does not dictate *how* the developer preserves at least 25 percent of the land as open space but rather sets an end to be achieved.

Characteristics of performance-based standards include the following:

- The method and details of how a level of performance is achieved are left to the practitioners--the developers--giving them more flexibility and encouraging ingenuity.
- A baseline or conventional performance must be established for comparison purposes.
- Comparing individual performance with the baseline usually requires a calculation system or software program.
- If the current local zoning regulations are used as the baseline, then areas of the green land development program not addressed in the regulations may require the establishment of baselines for these areas.

Prescriptive standards are expressed in terms of the means used to achieve an end; the emphasis is on how the developer achieves a desired outcome. An example is, "Construct residential streets to 28 feet back of curb to back of curb."

Characteristics of prescriptive standards include the following:

- The method and details of compliance are explicitly stated.
- The system is generally simple and easy to use.
- There is no need for an explicitly stated baseline or conventional practice.
- There is no need for a system of calculation or a software program.

In general, a performance-based approach can require more time and/or investment in the compliance process than a prescriptive approach. A prescriptive approach requires carefully considered options and language so that the simplicity of the system does not come at the price of relevance, feasibility, or flexibility.

Some existing programs use a combination of both types of standards, and most provide a range of options that are prescriptive in nature but broad enough to provide developers with significant flexibility. In general, prescriptive standards that are carefully considered, clearly expressed, and

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generated by a developer committee have a good chance of finding acceptance among and proving useful to participating developers.

Levels

Programs can be either "all-or-nothing" single-level or multiple-level programs.

With single-level programs, developers earn either one point or satisfy an item total to qualify projects for the program; this is similar to a pass/fail approach. Single-level programs are generally set up for simplicity. The main idea is to set the bar high enough to make certification meaningful but not so high as to discourage developer participation. An example of a single-level program is the Home Builders Association of Metropolitan Denver Program (see Appendix B).

Multiple-level programs generally involve three or four levels under which builders can qualify their homes. Multiple-level programs are designed to accommodate and distinguish among a wider range of developer projects. They are often set up to motivate developers to adopt environmentally-sensible practices at the basic level and to provide opportunities for progression and education at the higher levels.

Requirements

Programs vary widely in both the extent and nature of their requirements. All of the green land development programs have sought a balance between flexibility and prescriptive standards. The best way to describe the various ways that requirements can be handled is by examples from existing programs. Appendix A provides program checklists for each of the programs discussed below.

Straight Item Count Versus Point-Weighting

Programs can either treat every listed item with equal weight or assign points to each item. The simplest approach is clearly to treat each item equally, in essence giving each program item a value of one.

Points can be assigned to each item based on the relative difficulty or cost of an action item, the relative significance of the environmental impact of an action item, or a combination of the two. In almost all cases, the determination of points for action items results from consensus among the members of the program development committee. .

Organization Of Content Areas

The number, listing order, and selection of content areas are all a part of how program items are organized. Content areas can be organized by environmental issue or by the approximate chronology in which environmental issues arise at the job site. Developers tend to be most comfortable with an organization that follows the order in which items need to be addressed on the job. To a greater or lesser degree, all of the programs reviewed here followed an organization based on environmental issues, not on the chronology of the issues.

In any case, the content areas should be numerous enough to create distinct topic areas but not disaggregated to a level that overwhelms the developer.

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STEP ELEVEN: Create program content items

The next section of this guidebook is dedicated to a review of the full spectrum of potential program action items. As individual action items are reviewed for inclusion in your local program, here are some basic issues to consider:

- **Avoid vague language.** Be as quantitative as possible so that meeting an item is clear-cut for the developer. *Example:* "85% of the lots have their front or rear facing within 15 degrees of solar south."
- **Avoid putting more than one action, technique, or material in one item.** For example, the phrase, "Use shared driveways to reduce impervious areas and construct streets to 32-34 foot PL (property line) to PL width" can be improved to "Use shared driveways to reduce impervious areas" or "Construct streets to 32-34 foot PL (property line) to PL width."
- **If your program uses points, avoid ranges for a single item whenever possible.** For example, the phrase, "Between 1 to 5 points will be given for recycling construction waste" can be improved to "___ (1-3 points) Take one point for each of the following materials that you recycle/reuse: scrap wood, cardboard, and soils."
- **Link items to resources, particularly items that may be new to builders.** For example, the phrase, "Select appropriate turf areas" can be improved to "Use native/drought tolerant grasses in turf areas exceeding 50%."
- **Leave room for items not considered, even the most thorough of program development efforts will not anticipate every developer's approach.** Include a write-in item in each content area. For example, instead of using the phrase, "Use this space to include a stormwater management technique that you employ but that is not included in this section—see program administrator for approval and credit," the developer could write in "Stormwater inlets will be labeled 'Stormwater Flows Directly to the River."
- Try to keep the same level of detail across topic areas and on individual items.

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PART II – GREEN LAND DEVELOPMENT PRINCIPLES

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OVERVIEW

As noted earlier in this document, Part II presents details of green land development principles. A matrix offers a quick glance at what developers can do to create green land developments. The matrix also presents the primary environmental benefits of each principle as well as the main effects of implementing the principles. The main effects under consideration include 1) Reduced Pollutant Runoff, 2) Preservation and Conservation, and 3) Reduced Vehicle Use.

A synopsis of each principle follows the matrix. The synopsis format is consistent across all principles and contains the following sections:

Intent

Certain objectives are associated with each principle. The "Intent" contains a description of what will most likely occur if the developer implements the principle.

Considerations And Examples

Each principle has its own set of considerations that developers should take into account before implementing the principle. For example, even though the principle will lead to numerous environmental benefits, the associated concept may be difficult to implement in communities where public officials are hesitant to endorse the principle. This section provides some items for consideration and offers examples where the principle has found application.

Cost Implications

The overall goal of the guidebook is to provide cost-effective land development solutions that also yield environmental benefits. The section on cost implications provides basic information on the main cost factors attributed to each principle. The cost implications are primarily qualitative in nature. They are intended to give a general understanding of cost implications, not actual costs.

The synopses are provided to help the reader understand more about each principle; however, the reader should not consider the guidebook an exhaustive source of information for the highlighted concepts. We encourage the reader to become familiar with the listed references or other sources of related information to gain a more thorough understanding of the nuances associated with a particular principle.

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Part Two of the guidebook references home builder association green land development programs, green land development publications, and other resources. You can reference one or more of these resources to obtain more information on specific principles. Below is a list of the sources of information used for Part Two of the guidebook:

Acronym/Descriptor Words Used in Part Two	Information Source
Best Development Practices	*Best Development Practices: A Primer for Smart Growth,* Reid Ewing
Build a Better Clark	Build a Better Clark Green Builder Program
CNU	*New Urbanism and Traditional Neighborhood Development – Comprehensive Report and Best Practices Guide*, New Urban News, 2000
CWP	*Better Site Design: A Handbook for Changing Development Rules in Your Community*, Center for Watershed Protection, August 1998
DTJ	Downing, Thorpe and James checklist
Denver HBA	Home Builders Association of Metropolitan Denver Built Green™ Communities Program
Evergreen	*Evergreen Builder's Guide,* Port Blakely Communities and the City of Issaquah (WA)
HUD	*Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation, 1993,* U.S. Department of Housing and Urban Development
International Dark Sky Organization	International Dark-Sky Association, Inc. 3225 N. First Avenue Tucson, Arizona 85719-2103 USA Phone: 520-293-3198 Fax: 520-293-3192
King-Snohomish	King-Snohomish Counties (WA) Built Green™ Program
STOP	*Traffic Calming: The Solution to Urban Traffic and a New Vision for Neighborhood Livability*, Citizens Advocating Responsible Transportation, 1993

COST-EFFECTIVE GREEN LAND DEVELOPMENT PRINCIPLES MATRIX

Green Land Development Principles	Environmental Benefits	Effects		
		Reduce Pollutant Runoff	Preserve & Conserve Natural Resources	Reduce Vehicle Use
1.0 Pedestrian System				
Include pedestrian pathways and bicycle paths to/from key areas	Encourages walking/biking over vehicle use			✓
Create safe and easily accessible pedestrian crossings	Encourages walking/biking over vehicle use			✓
Create a street network that moves vehicles at an appropriate rate of speed	Uses fewer materials; reduces impervious surfaces/stormwater runoff; encourages walking/biking over vehicle use	✓	✓	✓
2.0 Layout / Density / Land Use				
Optimize the average density of development	Preserves open space; reduces impervious surfaces/stormwater runoff	✓	✓	
Reduce the overall street area and utility runs (see also "Streets and Parking")	Preserves open space; reduces impervious surfaces/stormwater runoff; reduces utility runs/materials	✓	✓	
Connect amenities within the development and/or provide a pedestrian/bicycle pathway to existing external amenities	Encourages walking/biking over vehicle use			✓
Create a mixed-use development	Services within walking distance of homes reduce reliance on vehicle travel			✓
Optimize lot placement via clustering	Preserves open space; reduces impervious surfaces/stormwater runoff	✓	✓	
Optimize solar exposure and passive solar heating via appropriate lot orientation	Reduces use of natural resources		✓	
Preserve trees and other natural resources	Preserves open space; reduces impervious surfaces/stormwater runoff; reduces use of natural resources	✓	✓	
3.0 Streets and Parking				
Reduce street widths and lengths	Uses fewer materials; reduces impervious surfaces/stormwater runoff; encourages walking/biking over vehicle use	✓	✓	✓
Eliminate/reduce curbs and gutters	Uses fewer materials; reduces impervious surfaces/stormwater runoff	✓	✓	

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Green Land Development Principles	Environmental Benefits	Effects		
		Reduce Pollutant Runoff	Preserve & Conserve Natural Resources	Reduce Vehicle Use
Ensure sidewalk placement meshes with overall development design	Uses fewer materials; reduces impervious surfaces/stormwater runoff	✓	✓	
Reduce parking areas and requirements	Uses fewer materials; reduces impervious surfaces/stormwater runoff; treats stormwater; encourages walking/biking over vehicle use	✓	✓	✓
Use alternative street, driveway, walkway, and parking surfaces	Reduces impervious surfaces/stormwater runoff; replenishes groundwater supply	✓		✓
Use alternatives to large-diameter cul-de-sacs	Uses fewer materials; reduces impervious surfaces/stormwater runoff	✓	✓	
4.0 Stormwater				
Use swales and grassy channels in place of curbs and gutters	Uses fewer materials; reduces impervious surfaces/stormwater runoff	✓	✓	
Incorporate bioretention, infiltration, and retention/detention ponds into development design	Reduces impervious surfaces/stormwater runoff; treats stormwater; preserves open space	✓	✓	
Capture sheetflow from paved areas	Reduces impervious surfaces/stormwater runoff	✓		
Use porous pavements and other pervious materials to help recharge water table (see “Streets and Parking”)	Reduces impervious surfaces/stormwater runoff; replenishes groundwater supply	✓		✓
5.0 Landscaping / Grading				
Use sensible landscaping techniques (e.g., Xeriscaping)	Uses fewer natural resources; reduces impervious surfaces/stormwater runoff	✓	✓	
Use and/or create wind breaks	Helps reduce development’s energy needs		✓	
Use/plant street trees in urban areas	Helps reduce development’s energy needs; creates separation between traffic and pedestrians		✓	✓
Preserve trees and other natural areas (see “Layout/Density/Land Use”)	Preserves open space; reduces impervious surfaces/stormwater runoff; uses fewer natural resources	✓	✓	
Limit turf areas	Conserves natural areas; reduces need for chemicals; reduces impervious surfaces/stormwater runoff	✓	✓	
Use/preserve native plant species	Reduces stormwater runoff; replenishes groundwater supply; uses fewer natural resources; reduces need for chemicals	✓	✓	

Green Land Development Principles	Environmental Benefits	Effects		
		Reduce Pollutant Runoff	Preserve & Conserve Natural Resources	Reduce Vehicle Use
Use soils with increased organic materials and reuse topsoil	Reduces stormwater runoff; replenishes groundwater supply; uses fewer natural resources	✓	✓	
Grade site so that the slopes follow the natural contours as much as possible	Reduces stormwater runoff; preserves natural areas	✓	✓	
6.0 Wastewater				
Treatment of wastewater onsite for small communities	Reduces the land impacts (excavation, sediment runoff) that result from connecting a community to a municipal sewage system		✓	
Collection of wastewater effluent for offsite treatment with onsite solids collection	Reduces excavation and its impacts by using small-diameter effluent collection pipes		✓	
7.0 Site Selection				
Place new development in existing service and infrastructure areas	Encourages walking/biking over vehicle use; reduces the need to extend utilities and infrastructure		✓	✓
Conduct a site-suitability analysis	Identifies ecological and biological pros and cons to building on the site; aids in design layout by mapping site topography		✓	✓
Remediate Abandoned or Brownfield Properties Instead of Developing Open Space	Makes use of previously used site often located within existing infrastructure; remediates a potentially contaminated site and potentially limits development land impacts	✓	✓	✓
8.0 Other				
Educate homeowners on transportation options such as transit and ridesharing	Encourages walking/biking over vehicle use			✓
Involve public in site development process	Helps increase homebuyer awareness of development's environmental benefits and describes how to reduce environmental impacts	✓	✓	✓
Educate municipalities and homeowners on green land development	Helps increase homebuyer awareness of development's environmental benefits – describes how to reduce environmental impacts	✓	✓	✓
Educate public on wise water use and resource-efficient lawn care	Encourages the efficient use of water and helps improve water quality of stormwater runoff		✓	

Green Land Development Principles	Environmental Benefits	Effects		
		Reduce Pollutant Runoff	Preserve & Conserve Natural Resources	Reduce Vehicle Use
Promote green homes to lot buyers	Uses fewer materials and natural resources and improves site runoff characteristics	✓	✓	
Provide access to and incentives for public transportation	Encourages walking/biking over vehicle use			✓

GREEN LAND DEVELOPMENT PRINCIPLES

Pedestrian System Principles

1.1 Include Pedestrian Pathways and Bicycle Paths to/from Key Areas (also see Section 3.3: Ensure Sidewalk Placement Meshes with Overall Development Design)

Intent

Provide a convenient, safe, pleasant network of pedestrian paths that meander throughout neighborhoods and communities, thus encouraging walking, cycling, and reducing automobile use. The overall sidewalk and path network should be considered as part of an overall plan to move people to desired locations. For instance, due to the amount and frequency of pedestrian traffic in some suburban developments, some streets may warrant a sidewalk on only one side of the street. In other neighborhoods, pathways connecting local streets to one another may encourage pedestrian traffic more than automatically creating a sidewalk network parallel to all existing roadways. Create paths by which people can travel on foot or bicycle to gain access to basic services and amenities, thereby helping to reduce homeowners' automobile dependence. Reducing vehicle miles traveled results in fewer pollutants emitted into the air by automobiles.

Considerations And Examples

- Pedestrian linkages can reduce pedestrian and vehicular conflicts and link neighborhoods, basic services, and amenities.
- Pathways can be used to route community members along lakes, streams, and other natural amenities, adding value to the overall development. In addition, pedestrian and bicycle paths should be well designed and integrated into the community. The paths should link residents to the natural and man-made features (e.g., stores, sports fields, schools) they are most likely to frequent by foot or on bicycle.
- Provide access between different land use types.
- A community may want to determine if existing trails could connect to planned trails in the new development. Such connections help create longer trail systems for activities such as rollerblading, cycling, running, and walking.

Cost Implications

- Increased costs due to additional materials needed to create paths.
- Creates a strong selling point; helps to set the development apart from conventional developments.
- Sidewalks and their planting strip account for a two percent increase in the hard costs of housing. These costs can often be reduced or eliminated to help pay for additional pathways.

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1.2 Create Safe and Easily Accessible Pedestrian Crossings

Intent

Use different types of road surface materials at pedestrian crossings and integrate pedestrian walking paths and bicycle paths into street movement while providing a sense of safety and separation from automobile traffic. Design to decrease automobile speeds to allow pedestrians to become better integrated into the movement of a community and street. Enhance the visibility of drivers and pedestrians at road crossings. Provide an appropriate amount of high-quality street lighting that is directed toward the light's target. An efficient lighting system meets safety needs, guides vehicular movement, encourages pedestrians' and bicyclists' movement, and reduces night sky light pollution.

Considerations And Examples

- Install traffic-calming devices such as roundabouts and crosswalks to limit vehicle speed.
- Road design methods used to decrease traffic speed include narrowing traffic lanes, using paved or cobblestone strips across the road surface, installing paved speed tables, and installing neck-downs.
- Alter the color or type of paving material for pedestrian traffic, especially at pedestrian crossings where speed tables might be used.
- Place paved speed tables at pedestrian crossings. Raise whole intersections to the same level as footpaths or sidewalks.
- Provide proper street lighting. Keep lighting poles low; space them more closely. Specify "full-cutoff" luminaires to avoid uplight or glare (Note: full-cutoff luminaires differ from "cutoff" luminaires, which still allow some uplight). Avoid mercury vapor lamps; metal halide or high-pressure sodium lamps are preferable for most applications. "Fully shielded" lighting fixtures decrease glare and direct light to the intended target. Provide a strong sense of safety, but not light pollution that disturbs wildlife.

Cost Implications

- Additional pedestrian crossing features will carry some extra cost, but will offer a safer and more pedestrian-friendly environment in return.
- Additional and expensive lighting will obviously increase initial costs. However, inexpensive lighting fixtures often have inefficient lamps and a short lamp life and thus consume far more energy than needed. Paying for more electricity than needed is expensive, as is the maintenance cost associated with lower quality fixtures.

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1.3 Create a Street Network That Moves Vehicles at an Appropriate Rate of Speed

Intent

The farther that motorists can see ahead of their car, the greater the likelihood that they will increase their speed. Changing road direction and using roundabouts and "neck-downs" can cause drivers to slow down and increase their field of vision, facilitating increased awareness of pedestrians and cyclists. However, it is important to note that communities should not restrict sight lines and that they need to meet the minimum sight-distance requirements for intersections and curves.

TRAFFIC CALMING

Traffic calming relates to automobile traffic and its relationship to pedestrian movement and the community. These principles can reduce the significance of the automobile and makes the neighborhood more pedestrian-friendly.

Considerations And Examples

- Ensure that safety and rescue equipment can readily move through the area.
- Create 45-degree bends in roads, allowing back-in parking on alternating sides of the street.
- Incorporate tree lawns, detached walks, planting areas, lighting, signage, raised walkways, and crossings into design.
- Provide crosswalks and bicycle lanes, paths, or routes. Design streets to be shared with pedestrians and cyclists. Create and appropriately mark bicycle lanes, dedicated bicycle paths, crosswalks, and sidewalks to ensure safe travel. Ensure that routes are networked to encourage pedestrian travel. In Minnesota, planners have found that using a different color for the entire bicycle lane is effective at slowing vehicles by making the street appear narrower.
- A speed table differs from a speed bump in that it is a slightly raised section of road that is wide enough for both sets of tires to sit on top of the "table" at the same time.
- Roadways can appear to have been narrowed simply by building landscaped islands out from the footpath to provide protected parking bays.

Cost Implications

- Increased maintenance costs.

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Layout / Density / Land Use Principles

2.1 Optimize the Average Density of the Development

Intent

Increased density can preserve open-space and natural areas by providing more homes in a smaller area. This also gives the designer more flexibility in determining where to place homes, and allows the existing environment and natural features such as vegetation and water bodies to be functional parts of the development. Higher density can facilitate clustering (see later discussion of this topic).

LAND USE

This section encourages developments that allow for various uses and structures, creating a diverse community that allows people to work and shop where they live while minimizing commute and drive time. In addition, it allows for the creation of a diverse community by allowing numerous types of housing development that is available to all socioeconomic groups.

Considerations And Examples

- Consider incentives for developing land at higher gross residential densities.
- For multifamily housing, housing densities can be 20 units per acre or higher. This can be used as a target.
- Institutional changes, such as revised zoning designations that allow higher density, are often time-consuming to obtain.

Cost Implications

- Developing housing at higher densities can save the developer land and infrastructure costs on a per-unit basis. It may and create opportunities to "market" more green space or common areas. Smaller lots can also save maintenance costs for homeowners.

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2.2 Reduce the Overall Street Area and Utility Runs *(also see Section 3: Streets and Parking)*

Intent

By creatively placing the homes in a development, a developer can reduce the linear feet of street and utility runs. This can result in fewer materials used, reduced impervious surface, and reduced costs per lot.

Considerations And Examples

- Consider using hybrid street designs to help optimize land use and to make the community more functional. This also helps make the neighborhood amenities more accessible.
- By placing homes in closer proximity to one another, the developer can often increase the total number of homes built in the community.

Cost Implications

- Ron Tyne of Tyne and Associates redesigned the site plan for a 130-acre parcel after dissatisfaction with the initial design. On the following page is the cost comparison for the two designs.

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Comparing Two Different Land Plans

PROJECTED RESULTS FROM TOTAL DEVELOPMENT		
Total Site	**Conventional Plan**	**Revised (Green) Plan**
Lot Yield	358	375
Linear Feet - Street	21,770	21,125
Linear Feet–Collector Street	7,360	0
Linear Feet-Drainage Pipe	10,098	6,733
Drainage Sections: Inlets, Boxes, Headwalls	103	79
Estimated Total Cost	$ 4,620,600	$ 3,942,100
Estimated Cost Per Lot	**$ 12,907**	**$ 10,512**

ACTUAL RESULTS FROM PHASE ONE		
	Conventional Plan (Engineer's Estimated Figures)	**Revised (Green) Plan** (Actual Figures)
Lot Yield	63	72
Total Cost	$ 1,028,544	$ 828,523
Total Cost Per Lot	**$ 16,326**	**$ 11,507**

ECONOMIC AND OTHER BENEFITS FROM LOW IMPACT DEVELOPMENT	
Higher Lot Yield	17 additional lots
Higher Lot Value	$ 3,000 more per lot over competition
Lower cost per lot	$ 4,800 less cost per lot
Enhanced marketability	80 percent of lots were sold in the first year
Added amenities	23.5 acres of green space/parks
Recognition	National, state, and professional groups

TOTAL ECONOMIC BENEFIT: MORE THAN $ 2,200,000 ADDITIONAL PROFIT

(NAHB Land Development Magazine, "Bridging the gap: Developers can see green", Spring/Summer 2000, pp. 27-31.)

2.3 Connect Amenities within the Development and/or Provide a Pedestrian/Bicycle Pathway to Existing External Amenities

Intent

Developers can help reduce vehicle miles traveled by providing access to available services within walking/cycling distance and opportunities for employment and recreation. When available, neighborhoods can be connected to regional transit service and mesh logically with larger land use patterns.

Considerations And Examples

- Use open spaces, parks, and other community amenities to link various entities within the community to one another as well as to other communities.
- Consider developing parks and land uses for the benefit of the overall community as a way to market a development.
- Provide pedestrian/bicycle access to facilities such as recreation centers, pools, and schools.
- A low-cost approach for future amenities, such as planned bus or rail service, is to provide access easements for future paths/sidewalk construction.

Cost Implications

- Locating amenities within or close to a development can translate into higher property values, less time consumed in commuting, reduced dependence on the automobile, and reduced fuel costs. However, these features must be balanced against their initial cost.
- Typically, providing paths or other access to existing amenities can be done in an economic manner if it is part of an overall plan for moving people to desired locations.

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2.4 Create a Mixed-Use Development

Intent

A mixed-use development provides more than one use or purpose within the development area, which encourages less reliance on automobile trips. Gathering places and activity centers designed to accommodate civic and commercial functions encourage both social interaction and a sense of community. A mixed-use development with a variety of land uses and neighborhood gathering places and/or village centers within proximity to each other can minimize automobile trips, encourage walking, and increase social and economic vitality.

Considerations And Examples

- Potential uses for the community include single-family, owner-occupied housing; multifamily housing; rental housing; retail outlets; business enterprises; recreation centers and facilities; and educational and cultural establishments.
- In the Home Builders Association of Metropolitan Denver *Built Green™ Communities* Program, points are awarded to a developer that provides amenities that are located close to homes.
- Community-owned space within the development can provide some or all of the following features:
    - A place for community meetings and social events within the development
    - Play areas
    - A common laundry room
    - Office space
    - A community library or media room
    - A community swimming pool, tennis courts, exercise room or fitness course
    - Community tennis courts
- Provide commercial facilities that promote community interaction within the development, including any of the following:
    - A neighborhood coffee house or small restaurant
    - Small office spaces for rent to resident businesses
    - A daycare facility

Cost Implications

- Mixed-use developments may be more marketable in that you are helping reduce the amount of time residents have to spend on the road for their shopping or recreation trips.

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2.5 Optimize Lot Placement via Clustering

Intent

Decrease the total amount of developed property per development by clustering homes on smaller lots in exchange for more open space.

Considerations And Examples

- Develop land at a higher density and with clusters that preserve open space and sensitive natural areas.
- Cluster development to emphasize common space, open space to be used for recreation, visual aesthetics, and natural and wildlife habitats.
- Cluster housing a safe distance away from water bodies to reduce runoff pollution and to protect watersheds.
- Cluster homes on smaller lots in exchange for more public space.
- Reduced lot sizes will result in reduced maintenance for homeowners.

Cost Implications

- Clustering homes can reduce infrastructure costs. Fewer feet of pipe and cable need to be run with clustered homes.

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2.6 Optimize Solar Exposure and Passive Solar Heating through Appropriate Lot Orientation

Intent

Buildings and units should be oriented to make the best use of passive solar heating in appropriate climates. Encourage development solutions that use street, lot, and home designs to maximize passive solar exposure, collection, and use.

Considerations And Examples

- Promote energy conservation by maximizing solar exposure through access and building orientation
- Build first on the north area of a lot, retaining the south area for outdoor activities.
- Orient over 50 percent of lots to take advantage of passive solar heating. With the appropriate orientation determined for maximizing solar benefits, design the street layout to capitalize on passive solar energy.
- Install properly sized and angled overhangs on housing units to limit solar gain during summer, while still capturing passive solar heat during winter.
- Use natural daylight to reduce energy consumption for lighting.
- Overhangs, seasonal shading (trees), low-E windows, and window coverings can all be used to minimize solar gain during summer and maximize passive solar heating and lighting during other seasons.

Cost Implications

- Reduced energy costs for homebuyers.

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2.7 Preserve Trees and Other Natural Resources

Intent

To preserve and protect wetlands, shorelines, bluffs, and other critical areas during construction, portions of a site's natural vegetation may be left undisturbed. Trees, bushes, natural turf and wetlands act as a natural method of erosion and stormwater control, help shelter homes from the elements (e.g., extremes of weather, wind, precipitation), and enhance a site's aesthetic value. All of these benefits add value to lots and to the community as a whole.

NATURAL RESOURCE PRESERVATION

Erosion prevention and natural resource preservation help minimize the loss of essential land through runoff and construction. They also connect existing wildlife corridors within areas of new development.

Considerations And Examples

- Create a preservation program to save valuable trees and native vegetation. Protect trees during construction, particularly the root zone and tree dripline.
- Employ sensitive site grading practices, such as:
  - Creating terraces or forms that step with the existing slope
  - Following natural topography with roads, driveways, and on the lots themselves
  - Using retaining walls to protect sensitive areas
- Preserve existing native vegetation as landscaping.
- Integrate wetlands and landscape areas to promote infiltration of stormwater runoff.
- Enhance/create nonrequired wetlands.
- Create sediment traps in detention ponds to clarify water.
- Create natural alternative to conventional stormwater detention.
- Provide wildlife corridors. Set aside as much habitat as feasible, including a buffer zone or setbacks from high-use areas such as roadways.
- Phase construction activity to prevent adverse impacts on adjacent properties.
- Use compost to stabilize disturbed slopes.
- Grind land-cleared wood and stumps for reuse on construction site. Used wisely, mulch can renew the soil by improving water and nutrient retention.
- Replant or donate removed vegetation.

Cost Implications

- It may cost more in labor time in designating the natural resources to protect and in rerouting equipment to meet your goals. However, lots and communities that contain such amenities often sell at a premium compared to developments that do not preserve natural resources.

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Streets and Parking Principles

3.1 Reduce Street Widths and Lengths

Intent

Reducing the width and length of residential streets accomplishes two primary functions. First, it decreases the amount of impervious surface associated with development. By reducing the amount of pavement, the developer helps decrease the volume of stormwater runoff and allows more stormwater to recharge local aquifers. Second, wider streets encourage higher vehicle speeds. In a study of over 5,000 pedestrian and bicycle crashes, a narrow roadway was a factor in only two cases. Thus, reducing street widths can help improve pedestrian and cyclist safety.

STREET DESIGN

Street design relates to how streets are incorporated into the surrounding environment, what materials are used to construct streets, and how automobiles, bicyclists, and pedestrians use streets.

Considerations And Examples

- Use the minimum amount of pavement needed for travel lanes, on-street parking, and emergency and service vehicle access.
- Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length of a street. Street patterns that reduce both congestion and vehicle trips should also be considered.
- Provide narrower, slower-speed local streets. New guidelines from the Institute of Transportation argue for streets no wider than the minimum width needed to accommodate the "typical and usual vehicular mix"(e.g., garbage trucks, postal service trucks). Residential streets should be built at widths dependent on their function and hierarchy in the community street system.
- Several U.S. communities have implemented narrower street widths. For instance, Boulder, Colorado, reduced street widths to 20 to 26 feet, depending on traffic volume. The state of New Jersey allows 20-foot widths (no parking lanes) to 28-foot widths (parking on one side) for residential streets with a maximum average daily traffic flow of up to 3,500 trips.
- Reduce on-street parking. Housing density and the need for on-street parking help determine whether on-street parking should be allowed on both sides of the street, one side, or not at all (CWP).
- Connect to surrounding street network at 660- to 800-foot intervals. Such a measure reduces traffic congestion within and around neighborhoods and provides easier, safer routes for pedestrians and cyclists.
- Work with the site's topography to design the street layout. Adapt the street layout to natural contours to minimize excavation and expense.
- Maximize the number of homes with direct access to main streets.

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Cost Implications

- Reduced street lengths and widths permit a reduction in paved area, runs of cable and pipe for utilities, and the amount of storm sewer/curb and gutter or open channel construction. Each linear foot of street costs approximately $150; therefore, an overall reduction of 100 feet of road length yields a savings of $15,000 (CWP).
- Reduction of impervious area and thus storm water runoff may decrease cost of storm water management facilities.
- Reduced infrastructure maintenance costs will be realized.

SARB_006484

3.2 Eliminate/Reduce Curbs and Gutters

Intent

Many developments are required to install curb-and-gutter systems that move the stormwater, such as sheetflow runoff, to a system of pipes that in turn discharges the untreated water into nearby streams. For those developments not governed by such requirements, eliminate or reduce the use of curb and gutter. This will minimize stormwater's impact on the local stormwater management system, improve the filtering of pollutants from the stormwater, and help recharge the local groundwater system.

Considerations And Examples

- If curbs are eliminated on heavily-traveled streets, consider incorporating grass strips with planted trees between the street and any installed sidewalk. Mixed-use, high-density developments may particularly need a separation of this type. Consider the short-term and long-term context of the development if it is likely to change.
- Consider providing tree-lined planting strips along curbs to capture as much sheetflow runoff from streets and driveways as possible.
- Roadside swales can be used in place of curb and gutter systems to collect runoff, reduce downstream erosion and sedimentation, and improve the quality of storm water runoff.
- Cars are not more likely to hit pedestrians in the absence of curbing. In a Federal Highway Administration study of pedestrian and car crashes, only 0.2 percent of crashes were associated with low soft shoulders.
- If curbs are needed, use a small rising lip near facilities or curb cuts to allow runoff to enter retention areas or filters. Multiple curb cuts have a similar effect on runoff to having no curbs or gutters.

Cost Implications

- A curb and gutter system is typically two to three times more expensive ($40 to $50 per running foot) than an engineered swale.
- Stormwater management carried out at the source decreases downstream requirements for larger stormwater management facilities.
- The primary expenses for stormwater management are land acquisition, construction, and maintenance. Limiting stormwater management to already landscaped areas and setbacks could reduce other acquisition costs.

SARB_006485

3.3 Ensure Sidewalk Placement Meshes with Overall Development Design

Intent

Sidewalks should be placed in parts of the development where people are likely to use them. For instance, a sidewalk may be needed from a cluster of homes, through a common area, or to a bus stop located on another block. The overall goal is to optimize the amount of paths or sidewalks in the development to minimize the amount of impervious surface while still making the development easy to use for pedestrians. For instance, urban, high-density developments often have sidewalks on both sides of the street, but due to the amount and frequency of pedestrian traffic in some suburban developments, some streets used infrequently by pedestrians may warrant a sidewalk on only one side of the street or pathways can be placed through common areas to link local streets.

Considerations And Examples

- Mixed-use, high-density developments can effectively use sidewalks to link the development to adjacent communities, recreation, and shopping areas.
- In the development planning and design phase, identify locations in and adjacent to the development that would benefit from a sidewalk linking it to a large group of homes.
- Each street should permit pedestrian movement without introducing conflicts with automobile traffic.
- Consider both the short-term and long-term context of the development. The developer should take into account the development's long-term "walkability" during the design and construction phases. For instance, if adjacent land is zoned "commercial," it will most likely have amenities to which residents of the development would like to walk. Installing a sidewalk or dedicating an easement for a path that connects the development to outside areas will help facilitate pedestrian movement in the long-term.
- Consider using permeable materials and/or narrower sidewalks.

Cost Implications

- Reduced material costs due to fewer linear feet of sidewalk constructed.
- Lower long-term maintenance costs.

SARB_006486

3.4 Reduce Parking Areas and Requirements

Intent

The main goal is to reduce stormwater and stormwater pollutant runoff. Pollutants can be attributed to a vehicle's tire wear, emissions, and fluid leaks. Pollutants deposited onto parking lots, which usually consist of totally impervious surfaces, will be washed away with stormwater runoff. Often overlooked is the provision of stormwater management control and minimization of runoff. When designing on-street and off-street parking, optimize the number of spaces needed through shared parking and minimize driveway length to help reduce the amount of impervious surface.

Considerations And Examples

- Time sharing of spaces, overlapping use of paved parking areas (parking and basketball court).
- Parking located at the rear of buildings helps maintain a relationship between building scale and sidewalks.
- To address the issue of parking or reduced parking, consider local trends in vehicle ownership.
- Consider rear access to garage or house via an alleyway.
- Provide for on-street guest parking rather than open-lot parking. Determine if code permits on-street parking to count toward required parking.
- Provide shared parking. Provide a central lot for residents' recreational vehicles, boats, and other vehicles used infrequently. For businesses within a mixed-use community, shared lots and employee parking located behind buildings avoid the need for a large parking area in front of a business.
- Structured parking reduces the total footprint of a parking area.
- Reduce minimum parking requirements, allowing for construction of smaller parking lots.
- Use pervious materials if spillover parking areas are needed. Ensure that accessibility and climatic conditions are taken into account when selecting paving material. Conventional paving material should be used in handicapped parking areas and on public pathways.

Cost Implications

- Lower long-term maintenance/repair costs.
- Reduced material costs when using fewer amounts of impervious material.

SARB_006487

3.5 Use Alternative Street, Driveway, Walkway, and Parking Surfaces

Intent

To reduce runoff in parking areas and on pathways, use paving materials that are permeable or have permeable characteristics.

Considerations And Examples

- Use porous pavements such as pervious asphalt, concrete, or open paver blocks that allow rainfall to infiltrate into substrate.
- Consider providing unpaved trails for recreational use.

Cost Implications

- Increased maintenance and upfront costs.
- Permeable paving materials may require additional maintenance. For instance, they may need to be replaced more often in areas where climate requires the use of snowplows. Snowplows have a tendency to tear apart permeable pavers.
- According to CWP, construction costs for pervious pavements are greater than for conventional pavement. However, with pervious surfaces comes a reduced need for other stormwater facilities, which may help offset the cost difference.

Permeable Pavement Costs (Source: CWP)

Product	Manufacturer	Cost (per square foot)*
Asphalt	Numerous	$ 0.50 – $1.00
Geoweb	Presto Products, Inc.	$1.00 – $2.00
Grasspave™, Gravelpave™	Invisible Structures, Inc.	$1.00 – $2.00
GRASSY™ PAVERS	RK Manufacturing	$1.00 – $2.00
Geoblock	Presto Products	$2.00 – $3.00
Turfstone	Westcon Pavers	$2.00 – $3.00
UNI Eco-Stone	Concrete Paving Stones	$2.00 – $3.00
Checkerblock	Hastings Pavement Co.	$3.00 – $4.00
Grasscrete	Bomanite Corp.	$3.00 – $4.00

* Includes material cost, typical shipping, and installation on a fully prepared base course. Does not include cost of gravel, labor, or soil and grass fill. These costs add approximately $0.10 to $0.25 per square foot.

SARB_006488

Paving Material Comparisons (Source: CWP)

Material	Initial Cost	Maintenance Cost	Water Quality Effectiveness*
Conventional Asphalt / Concrete	Medium	Low	Low
Cobbles	Low	Medium	Medium
Concrete Unit Pavers	Medium	Medium	Medium
Brick	High	Medium	Medium
Natural Stone	High	Medium	Medium
Gravel	Low	Medium	High
Wood Mulch	Low	Medium	High
Turf Block	Medium	High	High
Pervious Concrete	High	High	High
Porous Asphalt	High	High	High

* Relative effectiveness in meeting stormwater quality goals.

SARB_006489

3.6 Use Alternatives to Large-Diameter Cul-de-Sacs

Intent

A cul-de-sac is a street in the shape of a large "bulb"; it is open at one end but wide enough to allow emergency and service vehicles to turn around. With a typical radius of 50 to 60 feet, a cul-de-sac takes the form of a large circle of impervious surface that is rarely ever fully used. Limit the size or use of cul-de-sacs; if an "end-of-road" look is needed, alternatives to a conventional cul-de-sac should be considered.

Considerations And Examples

- Vehicles Minimize the use of conventional cul-de-sacs by using alternative turnaround street designs. A "T-"shaped turnaround (hammerhead) creates less impervious cover than a traditional cul-de-sac.
- Develop smaller-radii cul-de-sac turnarounds with a 35 to 38-foot turning radius with approval of fire department. Reducing the radius by a few feet can greatly decrease impervious cover.
- Consider short interconnected streets with direct routes and loops instead of cul-de-sacs (Wilmington-Middletown, Delaware).
- Typically travel on the outside of a cul-de-sac; therefore, consider a pervious island in the center of the turn. The island in the middle of the cul-de-sac can be landscaped and designed to store and treat stormwater, ice and snow, and pollutant runoff. Small shrubs and groundcover can be used on the island.
- Consider loop roads; create a road that joins another road at each end and has two points of entry and exit, allowing for multiple access for emergency vehicles.

Cost Implications

- Reduced materials result in reduced construction costs.

SARB_006490

Stormwater Management Principles

4.1 Use Swales and Grassy Channels in Place of Curbs and Gutters

Intent

Minimize stormwater's impact on the local stormwater management system and improve the filtering of pollutants from stormwater. Stormwater collects materials such as oil, grease, salt, sand, and tire and brake pad particles and carries them away as the water flows along the ground. Using features such as swales, ditches, or depressions to convey surface water helps reduce runoff velocities, reduces stream erosion, enhances clarification, and removes pollutants from the water.

STORMWATER MANAGEMENT

Stormwater management relates to the movement of stormwater runoff through the built environment. Green land development encourages the use of natural features and/or environmentally friendly concepts to reduce flooding and waste.

Considerations And Examples

- Swales are engineered grass channels that provide full treatment of stormwater and pollutants. Runoff proceeds to the swale from impervious surfaces like roads and driveways, with some of the sediment load deposited as the water flows through the turf. Movement of the water through the sandy loam further removes pollutants from the runoff.
- Swales increase the filtration of pollutants from stormwater runoff. They also help to separate sidewalks from automobile travel lanes and protect pedestrian movement, thus encourage walking.
- Integrate landscape areas to promote infiltration of stormwater runoff.
- Provide tree-lined planting strips. A planting strip along the curb provides pedestrians with additional buffering from street traffic.

Cost Implications

- Swales cost less than paved channels, pipes, or curb and gutter.
- Low maintenance costs.
- Stormwater management carried out at the source decreases the requirements for larger downstream stormwater management facilities. The primary expenses for stormwater management are land acquisition, construction, and maintenance. Limiting stormwater management to already landscaped areas and setbacks could reduce other acquisition costs.
- Stormwater management requirements are reduced, and less stringent quality controls can be used.
- Some stormwater management facilities can reduce the need for storm sewers, in turn reducing other stormwater infrastructure costs.

SARB_006491

4.2 Incorporate Bioretention, Infiltration, and Retention/Detention Ponds into Development Design

Intent

Provide a place in which stormwater can settle and slowly drain back into the earth's surface.

Considerations And Examples

- Bioretention calls for integrating stormwater management practices directly into the landscape areas by locating planting strips within parking areas. The strips are shallow landscaped areas or beds that provide temporary detention. The beds filter the runoff, which then infiltrates the subsurface or collects in underdrain pipes for discharge into a second facility or stream. Bioretention encourages stormwater treatment at the source before pollutants enter the stream. Other advantages include enhanced groundwater recharge, parking areas' enhanced aesthetics, and reduced runoff velocities into waterways.
- Bioretention facilities are an integral part of the Prince George's County, Maryland, strategy for development. The county promotes the use of the facilities in commercial, industrial, and residential development to encourage low-impact development that minimizes the expanse of impervious surface. To encourage developers to use bioretention, the county provides incentives such as reduced stormwater management requirements and mitigation credits for environmental impact.
- Use small permanent check dams and level spreaders. A check dam is a constructed across a drainage ditch, swale, or channel to lower the speed of runoff flows. A level spreader is a drainage outlet constructed by cutting a shallow trench at zero grade across a slope to disperse concentrated runoff. Level spreaders convert concentrated flow into sheet flow for discharge onto areas stabilized by vegetation. By reducing runoff velocity check dams and level spreaders help reduce erosion, enable sediment to settle out, and enhance infiltration.
- Use infiltration trenches, or stone-filled reservoirs, to remove pollutants from stormwater as runoff flows downward through the soils beneath the reservoirs. Compared with bioretention, infiltration trenches require greater care in design, maintenance, and operation.
- Bioretention translates into extra areas for snow storage and little engineering design relative to other systems.
- Parking lot stormwater management can be addressed with bioretention, dry swales, perimeter sand filters, and filter strips.

Cost Implications

- Minimal costs are associated with bioretention's low-engineered techniques.
- May require more landscaping but could be offset by lower stormwater management costs elsewhere.
- Low maintenance costs.

SARB_006492

4.3 Capture Sheetflow off Paved Areas

Intent

Sheetflow off a paved surface is preferred to a concentrated stream of water moving offsite. However, the carrying capacity of the earth adjacent to a paved area often cannot hold the volume of sheetflow running off the paved area. Thus, the stormwater is wasted instead of used as a natural resource that recharges the local aquifer.

Considerations And Examples

- Provide tree-lined planting strips along curbs to capture as much sheetflow runoff as possible.
- Perimeter sand filters are engineered at the source of pollution and runoff and located underground along the downstream side of parking lots, consuming little usable land. Runoff flows into a graded sedimentation chamber that traps coarse sediments. The runoff spreads over the filter bed, and pollutants are captured as runoff flows through the filter. Treated runoff collects at the bottom and is returned to the storm sewer or stream.
- Filter strips rely on vegetation to decrease the speed of runoff, filtering out sediments and other pollutants. They are most effective in sheetflow conditions and require a significant amount of land that is equivalent to 100 percent of the impervious drainage area. Thus, strips are recommended for small parking lots or sections of parking lots and are best suited to areas adjacent to stream buffers or open space.
- Install vegetative buffers on the downstream side of parking lots. Vegetative buffers should be at least four feet wide and planted with grass and other plants; (plants should reach a 30-inch maximum height).

Cost Implications

- Minimal costs are associated with these low-engineered techniques.

SARB_006493

4.4 Use Porous Pavements and Other Pervious Materials to Help Recharge the Water Table

See Section 3: Streets and Parking Principles for details.

SARB_006494

Landscaping and Grading Principles

5.1 Use Sensible Landscaping Techniques (e.g., Xeriscaping)

Intent

By using orientation techniques as well as landforms that create buffers and microclimates, the landscape itself can contribute to energy conservation and water savings.

SENSIBLE LANDSCAPING

Concepts relating to water-wise and native landscaping promote the planting and retention of landscaping that reduces overall water use and improves the vitality, livability, and integration of a community or development into the natural landscape or environment.

Considerations And Examples

- Xeriscape principles include:
  - Improve the soil (mix in organic material)
  - Select appropriate turf areas
  - Use native/drought-tolerant grasses
  - Use mulches
  - Install efficient irrigation
  - Group plants according to moisture and sunlight needs
  - Provide maintenance guidelines
- Use nonpotable water for common area irrigation.

Cost Implications

- Implementation of the above considerations can reduce water needs and lead to only minimal, if any, increases in developer costs. The primary cost increase is associated with the longer design time.

SARB_006495

5.2 Use and/or Create Wind Breaks to Reduce the Development's Overall Energy Needs

Intent

Trees and shrubs can greatly reduce a homeowner's heating or cooling requirements. The developer should identify healthy trees and shrubs and denote which ones should be left undisturbed to help shade and protect the homes planned for a site.

Considerations And Examples

- Implement landscaping techniques for energy conservation (e.g., evergreen trees for wind and snow breaks to reduce heating costs; deciduous trees for summer shading to reduce cooling needs/costs; vegetation and tree planting that encourages channeling of breezes for summer cooling; and the use of insulating shrubs and vines).

Cost Implications

- Evergreen wind and snow breaks reduce heating costs.
- Deciduous tree canopies provide shade that reduces cooling costs.
- May require higher initial landscaping costs.

SARB_006496

5.3 Use/Plant Street Trees in Urban Areas

Intent

A planting strip along the curb offers pedestrians additional buffering from street traffic. In addition, such trees also help capture stormwater runoff, allowing it to filter into the ground.

Considerations And Examples

- Provide tree-lined planting strips and allow for regular tree maintenance.
- Landscaping consists of groundcover, a mix of trees, and high and low shrubs and is required in building and street setbacks, typically five to ten feet in width (Portland, Oregon).

Cost Implications

- Evergreen wind and snow breaks can help reduce residents' heating costs.
- Increased initial landscaping costs and maintenance costs.

SARB_006497

5.4 Preserve Trees and Other Natural Resources

Intent

Developers can preserve native trees and other plantings without significantly increasing costs. Preserving existing trees and plants help preserve topsoil and shades/shields homes from the weather elements (i.e., wind and sun).

Considerations And Examples

- Preserving existing trees adds value to properties, making homes easier to sell at a premium price.
- Preserve portions of lowlands and areas with mature vegetated soils. Use geological survey information and ecologists to help identify areas with mature vegetated soils. Vegetated areas and lowlands help manage stormwater runoff by providing natural storage areas.
- Balance cut-and-fill work while maintaining a site's original topography.
- During the site design phase of the project, a developer should have a certified arborist or landscape architect assess the property for tree health and value, making decisions on which trees to retain or remove. Once a plan is made, all trees tagged to remain should be fenced, and those designated for removal should be cut down.
- When the homes are being built, the developer and builders should constantly communicate with subcontractors, reminding them not to store heavy materials and equipment near trees.

Cost Implications

- Creating nontraditional neighborhood layouts that utilize islands of natural areas, wetlands or stands of trees can reduce infrastructure costs for roads and sidewalks.

SARB_006498

5.5 Limit Turf Areas

Intent

Decrease the use of turf grass and substitute other forms of landscaping to promote the "right plant/right place" concept to reduce water consumption.

Considerations And Examples

- Mulch landscape beds with two-inch organic mulch.
- Limit use of turf grass within landscaped areas.
- Replace large turf areas with planted beds and pervious materials. Large turf areas require more irrigation and maintenance than beds of well-adapted plants.
- Preserve as much "natural" area as possible.

Cost Implications

- Reduced maintenance costs for the homebuyer.
- Reduced initial landscaping costs when land is left in its natural state.

SARB_006499

5.6 Use/Preserve Native Plant Species

Intent

Incorporate native plant materials into common areas to help restore pre-existing ecosystems and to help re-establish a healthy and diverse ecology that limits the need for artificial alternation, enhancement, and irrigation. Eliminate or reduce irrigation using potable drinking water.

Considerations And Examples

- Landscape with plants appropriate for a site's topography, climate, and soil type; adopt the "right plant/right place" approach.
- Replant removed vegetation for reuse.
- Use grass types requiring less irrigation and maintenance.
- Minimize common area irrigation systems and use drip irrigation systems.
- Reduce lawn size.

Cost Implications

- Reduced maintenance costs for the homebuyer.

5.7 Use Soils with Increased Organic Materials and Reuse Topsoil

Intent

Use soils with higher levels of organic materials to allow for greater infiltration and moisture content. The goal is to integrate organic materials into the soil that is excavated during site development in order to create a mixture that will allow for greater filtration. In addition, reuse nutrient-rich topsoil to reduce erosion and save landfill costs.

Considerations And Examples

- Protect topsoil with mulch or plastic.
- Improve the soil and save and reuse topsoil.
- Remove/replace topsoil in all disturbed areas (house pad and street excluded).
- Encourage use of compost soil with turf and other vegetation, reducing the need for irrigation, fertilizer, and other chemicals.
- Limit soil compaction by creating movement zones for areas of heavy movement or heavy machinery to limit soil compaction. It is more difficult for water to infiltrate compacted soil.
- Grind land-cleared wood and stumps for reuse on the construction site. Used wisely, mulch can renew the soil by improving water and nutrient retention.

Cost Implications

- Reduced waste results in decreased landfill tipping fees.

SARB_006501

5.8 Grade the Site So That Slopes Follow Natural Contours as Much as Possible

Intent

Conserve natural and existing hydrologic patterns and develop for most efficient use of resources.

Considerations And Examples

- Create architecture and build with foundations that "step" with existing slopes by incorporating walk-out basements, tuck-under garages, and garden-level units.
- Employ sensitive site grading practices such as the following:
  - Creating forms that step with the existing slope
  - Designing roads to follow natural topography
  - Using retaining walls to protect sensitive areas
  - Developing parcel grading solutions to create smaller terraces
- Balance cut-and-fill work while maintaining a site's original topography.
- Follow natural topography in the development of lots and sites, avoiding cut and fill as much as possible.
- Use retaining walls to protect important site features and sensitive areas.
- Develop grading solutions for parcels and lots to create smaller terraces instead of large, oversized "flat-pad" grading solutions.
- Clear only those areas needed for homes, roads, driveways, and so forth.
- Clearly mark on plans areas to be graded, and use field stakes or on-site flags.
- Review with excavation crews site areas to be graded. Monitor grading operations often to ensure adherence to the grading plan.

Cost Implications

- Reduced labor costs by decreasing the amount of land to be cleared. Possible increased planning costs associated with assessing the site's slope and optimizing the grading accordingly.

SARB_006502

Wastewater Principles

6.1 Treatment of Wastewater Onsite for Small Communities

Intent

Onsite wastewater treatment systems for small communities may offer a less expensive, more environmentally benign alternative when compared to connecting a small number of homes to a municipal treatment system.

Considerations And Examples

- The viability of onsite wastewater treatment systems depends upon the site topography, depth of the water table, and soil characteristics.
- Onsite treatment takes advantage of the earth's natural capacity to process waste.
- Most onsite treatment systems require periodic maintenance.
- An example of an onsite treatment system is a septic tank and mound system, which is viable for a site with high groundwater levels or clay soils. Effluent waste from the septic tank is pumped to the top of a sand mound that has been constructed onsite. The effluent is treated as it filters down through the sand mound before infiltrating into the ground.

Cost Implications

- The cost-effectiveness of onsite treatment will weigh heavily upon the cost required to connect to a municipal system.
- Maintenance costs for onsite systems should be considered when compared to alternative approaches.

6.2 Collection of Wastewater Effluent for Offsite Treatment with Onsite Solids Collection

Intent

The use of a treatment system with both onsite and offsite components can help the developer realize savings and reduce environmental impacts by centralizing some treatment processes while conducting others at individual sites.

Considerations And Examples

- The decision to group homes together to utilize central treatment components (e.g., a central septic tank, a central pump for effluent) will depend upon the development's topography, excavation costs, and the number of houses and their proximity to each other.
- Treatment systems of this type may allow for higher density housing compared to a traditional onsite septic system because the need for absorption fields can be eliminated.
- Systems of this type will require central management and regular maintenance.
- One example of this category of system is a small rural development that slopes downhill. Each individual house is outfitted with its own septic tank to collect solids, while liquid effluent is gravity-fed through low-pressure, small diameter pipes to a centralized pump station located downhill. Houses below the sewer line elevation use auxiliary effluent pumps to rout their effluent to the low-pressure sewer line. At the centralized pump station the community effluent is pumped to a main sewer line which feeds into a treatment system.

Cost Implications

- The cost-effectiveness of this approach depends on several factors, including the cost to rout all waste to a municipal system, the added revenue that could result from higher density housing in the development, and the maintenance and management costs.

Site Selection Principles

7.1 Place a New Development in Existing Service and Infrastructure Areas

Intent

Building and construction on infill lots takes advantage of existing infrastructure and reduces the development of virgin sites (i.e., greenfields). Such development is often located near transportation systems and commercial amenities. Trips are shorter and lend themselves to walking, cycling, or using public transportation. People, especially children and the elderly, enjoy enhanced mobility, resulting in fewer vehicle miles traveled for necessities.

SITE SELECTION

Infill development helps preserve open space, reduce vehicle miles traveled, and limit the need to extend existing lines of infrastructure. In-fill developments help reduce "leap-frogging" development patterns and encourage the systematic extension of essential infrastructure. Such developments also encourage the use of vacant or dilapidated land in a development or city.

Considerations And Examples

- Locate new developments within planned service and infrastructure areas (e.g., water, wastewater, electricity, streets, public transportation, and schools).
- Locate new developments adjacent to existing population and business centers already served by community services and facilities. In addition, locate near existing open space or parks.
- Develop an infill subdivision. "Smart growth" development encourages people to live where expensive public services already exist rather than creating new demand at the edges of an urban area.

Cost Implications

- Locating within an area with access to urban services leads to greater efficiency, i.e., more people share the same sewer and water lines, roads, emergency services, and schools, resulting in lower per capita infrastructure costs.

7.2 Conduct a Site-Suitability Analysis

Intent

It may be worthwhile to consider the environmental impacts of development on various parcels of land if the developer has not already chosen a site on which to build. To balance market demands against site capacity, consider existing topography, soil, hydrology, microclimates, vegetation, wetlands, habitat, wildlife, and agricultural value.

Considerations And Examples

- Determine the community character and quality of life in adjacent neighborhoods.
- Consider the land's potential in terms of solar orientation, natural drainage, vegetation, winds, and other elements.
- Consider the ability to preserve wildlife corridors in conjunction with the development of pedestrian linkages.

Cost Implications

- Locating a neighborhood that is rich and diverse in natural resources (e.g., lakes, streams, trees) often results in higher property values when compared with similarly sized developments lacking such natural amenities.
- Locating a neighborhood near existing commercial and business centers leads to higher property values. People do not have to travel far for employment and basic needs.

SARB_006506

7.3 Remediate Abandoned or Brownfield Properties Instead of Developing Open Space

Intent

This can be considered a subset of "infill development." Reclaim and repair blighted and abandoned areas within existing neighborhoods by using an infill strategy that conserves the previous economic investment and social fabric. That is, attempt to take advantage of changes in land use/economics, often with government subsidies. Preserve the quality and character of existing and historic buildings. Use brownfield remediation policies and techniques to reduce the need for development on greenfields.

Considerations And Examples

- Use infill and redevelopment strategies to reduce new impervious coverage.
- Use local, state, and even federal incentives for cleaning up potential contaminants.
- Take advantage of adaptive use strategies to preserve historic value and a sense of place.
- Expect a lengthy development approval process because of the need to coordinate the actions of a greater number of city and metropolitan agencies when compared to development in the suburbs. For instance, Historical Preservation officials may be involved in the development process in older cities that have maintained their historic districts.

Cost Implications

- If a site requires no remediation, a brownfield property can prove lucrative for a developer because it takes advantage of existing infrastructure and nearby business centers.
- Longer time frames that sometimes accompany brownfield development can tie up cash for longer periods than for other types of development.

SARB_006507

Other Green Land Development Principles

8.1 Educate Homeowners on Transportation Options Such As Transit and Ridesharing

Intent

Some organizations believe that traffic levels can be reduced with higher vehicle occupancy levels. Car- and van-pooling programs can increase the number of persons per vehicle and reduce the number of cars on the road.

Considerations And Examples

- Educate residents on ways to organize their travel more efficiently by, for example, combining trips or carpooling.
- Provide information to residents explaining how mixed-use developments can reduce time in traffic.
- Highlight elements in the development's design, such as commuter parking areas, that facilitate the use of public transit.
- Educate homebuyers on the benefits of purchasing homes that are located near public transit/bus stops.

HOMEOWNER EDUCATION

Once the developer has created a resource-efficient community, the products, space, and amenities provided to the homeowners must be used optimally. To that end, homeowner education packets should be created to help residents establish a resource-efficient community for the long-term.

Cost Implications

- Cost of printing educational materials or providing education sessions.

8.2 Involve Public in Site Development Process

Intent

Integrate environmental issues into the public involvement process. Involve the public at all levels, including residents, adjacent neighbors, politicians, developers, community facility managers, and other institutions, in the planning process. Reduce differences between groups and neighbors to spur efficient and effective revitalization and development.

Considerations And Examples

- Conduct a workshop to gather ideas, concepts, and insights into longstanding problems and issues for an area.
- Conduct a workshop that tests alternative designs through models and drawings.
- Valley Green/Sky Tower Redevelopment Project, 314 new units of mixed-income housing for both rental and ownership. Work replaces traditional public housing. (Washington, D.C.).
- It has been suggested that disjointed projects contribute to community mistrust; thus, a cohesive and community-driven vision leads to long-term revitalization. In addition, by including stakeholders in the early stages of the development process, developers are apt to streamline the process. Empowering the stakeholders makes it less likely that they will delay the project later in the process.

Cost Implications

- Possibility of longer project approval time line.

SARB_006509

8.3 Educate Municipalities and Homeowners on Green Land Development

Intent

To continue the resource efficiency of the development once the developer leaves the site.

Considerations And Examples

- Establish community involvement through education of residents about the development's achievements, what is expected of residents to ensure that the development retains its green focus, and how to create social initiatives to support the project and its principles.
- An explicit plan of resource-conserving goals accompanied by an implementation plan for how the community will meet its goals and create a self-sustaining program.
- Homeowner guidebook to efficient operation of home, with list of additional resources.
- Seminar or seminar series for each new family to explain efficient operation of home and the lot, and other programs to reduce resource use.
- Ongoing series of open-space habitat restoration programs.
- Community events/festivals/performances that help educate children and adults about the community's environmental mission.
- Environmental award program.
- Neighborhood information kiosk and signage to promote green initiatives (e.g., opportunities to exchange used appliances, cars; flea market/community garage sale; baby-sitter cooperative, and so forth).
- Produce a community newsletter.
- Establish and sponsor community meetings.
- Establish and maintain an Internet community communication/ education link.
- Establish ongoing education and awareness with community signage.
- Provide signage highlighting the development's environmental features.

Cost Implications

- Cost of printing educational materials or providing education sessions.

SARB_006510

8.4 Educate Public on Wise Water Use and Resource-Efficient Lawn Care

Intent

Provide information on alternatives to chemicals, pesticides, and fertilizers for lawn and garden care in order to decrease pollution use and runoff and nutrient runoff.

Considerations And Examples

- Provide list of native and pest- and disease-resistant plants for consideration. Native plants often do not need additional fertilizer.
- Provide information about operation and maintenance of irrigation equipment to optimize their use.
- Provide information on the most resource-efficient methods to care for lawns and landscaping. Information would include items like when to water, mulching lawn mowers, and alternatives to chemical agents.
- Clearly label all storm sewer inlets. A visual reminder that storm sewer inlets lead to area waterways can help educate the community. For example, a simple stencil can read, "Caution–leads to stream!" In addition, develop an accompanying educational brochure to help residents understand the problems with dumping items like waste oil and antifreeze down the drains.
- Provide residents with a green building occupant's manual to help them understand the green benefits of their home.
- Provide homebuyers with a list of drought-resistant plants for arid or drought-prone areas.

Cost Implications

- Cost of printing educational materials or providing education sessions.

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8.5 Promote green homes to lot buyers

Intent

The NAHB Research Center's *Guide to Developing Green Builder Programs* provides a wealth of information on the various aspects of green building. In addition, there are numerous local green building programs that have been developed by HBAs. This principle's goal is to not only make the land development aspects of the community "green," but to also make the homes that are on the land green as well.

Each house should direct roof-top runoff to pervious areas such as yards, open channels, or vegetated areas to minimize erosion, the amount of topsoil nutrients carried away, and the flow of runoff onto roadways and into stormwater systems. The availability and use of recycled-content building materials in turn conserves the use of natural resources. Reduced setbacks minimize yard and grass area as well as total road length and reduce a lot's impervious area. Incorporate plumbing in the house design that takes advantage of available greywater and roof-top runoff for irrigation use.

SITE GRADING AND SITE DESIGN

This section encourages waste minimization on the job site and preservation of on-site natural resources. Reducing setback requirements allows for minimizing driveway length and limiting overall development imperviousness. Reducing lot sizes and lot lines decreases lawn area and creates open space, allowing for increased groundwater infiltration and slower stormwater runoff stormwater.

Considerations And Examples

- Requiring that each home be built to "green" standards may limit the number of builders willing to build in that development.
- Each home in a Denver Built Green™ Community will be a registered Built Green™ Colorado home (Denver HBA prerequisite).
- Relax front setbacks, allow narrower frontages, and minimize driveway length to reduce total road length and site and lot impervious areas.
- Materials should be durable and require minimal maintenance. Appliances and fixtures should be energy and water efficient.
- Efficient framing techniques can be used to help reduce the amount of raw materials used and increase energy efficiency by using more insulation.
- Avoid routing roof-top runoff to roadways and stormwater conveyance systems to reduce ponding of water and ice formation on driveways and walkways and to promote localized ground water recharge.
- Driveways can be reduced in length by placing them behind units along an alley. Reduction of driveway length is a function of reducing setback requirements.
- Decrease lot size from a 40,000-square-foot minimum to a 10,000-square-foot minimum.
- Plumb housing and other development for greywater irrigation.
- Install rainwater collection system, or cistern, for reuse of water for irrigation.

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Cost Implications

- Designating a development as "green" and establishing minimum building criteria may result in higher building costs. A perception of higher value will be gained as well, however.
- Typical requirements for fire protection allow detached housing to be as close as five feet from another house without fire-protection measures. If houses are fewer than five feet apart, protection is more than likely required. Such a requirement can increase construction costs; however, reduced road and driveway areas decrease material cost.
- Other "green" measures like greywater systems for water or efficient framing techniques may involve added initial costs or some savings. The long-term performance of a home implementing green features will be more efficient than a typical home.

8.6 Provide Access to and Incentives for Public Transit

Intent

Offering alternative transportation options can reduce vehicle miles, enhance air quality, and decrease infrastructure maintenance costs. It is estimated that private cars use 30 times more road space than trains or buses to move each person. Thus, the intent is to make both the existing road space and the existing public transportation network more efficient.

PUBLIC TRANSIT, AMENITIES, AND PARKING

Principles related to public transit, public amenities, and parking encourage the use of public transit by ensuring that public amenities locate along transit lines. Furthermore, the principles encourage the placement of facilities within walking distance of users or near transit lines. Parking at transit lines or centers should become a priority and should be convenient so as to encourage transit use.

Considerations And Examples

- Minimize walking distance from homes to public transit.
- Encourage new public transportation systems where existing systems are inadequate by:
    - Ensuring advanced coordination with local transport officials
    - Adding an internal bus system
    - Reserving land for future transit use
    - Creating nonmotorized, continuous, and connected open-space linkages between neighborhoods and basic services.
- Provide convenient access to transit stops.
- Provide incentives to increase public transit use and to reduce automobile dependency by:
    - Providing bicycle racks or lockers.
    - Routing bicycle/pedestrian paths to transit stations/stops.
    - Encouraging public transit groups to accommodate cyclists who want to bring their bike on the transit system.
    - Installing permanent signage for transit information and access
    - Covering transit stations/stops
- Provide a commuter lot located near major arterials or collector streets.
- Provide convenient access to transit stops.
- Provide a commuter lot near arterials or collector streets. Encouraging transit use and car pooling will help reduce vehicle miles traveled.

Cost Implications

- Time and effort to research the local public transportation options and schedules.
- Cost of creating on-site bus stops.
- Additional materials cost

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APPENDIX A

Home Builder Association Green Land Development Checklists

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This Appendix contains applicable elements of local HBA green building and green land development checklists. We have included only those checklist elements that pertain to green land development, and we have omitted the checklist sections that focus on making the house itself more environmentally friendly. You may contact the local HBA at the telephone numbers below if you would like a copy of their complete checklist.

- Build A Better Clark (360) 694-0933
- Evergreen Builders Guide (425) 391-4700
- Built Green (425) 451-7920

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BUILD A BETTER CLARK DEVELOPER SELF-CERTIFICATION

Check items you will be including in this project to qualify your development for a *Build A Better Clark* certificate.

Requirements to Qualify (Minimum 30 Points):

- Attend a *Build A Better Clark* Program Orientation (one time only)
- Earn 15 points from Section One
- Earn 15 points from Section Two

(Note: The number of points given for each action item is noted in parentheses before its description)

Section One: Build Pedestrian/ Transit-Oriented Neighborhoods	
❑	(1) Provide proper street lighting.
❑	(1) Use fencing other than plain cyclone around detention ponds.
❑	(I) Connect to surrounding street network at 660-800 ft. intervals.
❑	(2) Provide tree-lined planting strips.
❑	(2) Provide shared parking
❑	(2) Provide narrower, slower, local streets.
❑	(2) Use traffic-calming devices, such as curb bulbs.
❑	(2) Provide for guest parking on street instead of on lot.
❑	(2) Provide convenient access to transit stops.
❑	(2) Provide a commuter lot near arterials or collector streets.
❑	(2) Preserve open space beyond required.
❑	(3) Orient over *50%* of lots for passive solar.
❑	(3) Provide crosswalks and bike lanes, paths, or routes.
❑	(3) Provide apartments and other multi-family housing.
❑	(3) Create a mixed-use (residential/commercial) development.
❑	(3) Provide attached parks or pocket parks.
❑	(3) Develop an infill subdivision.
❑	(3) Cluster homes on smaller lots in exchange for more public space.
❑	(3) Create a comprehensive “smart” development.

_____ Subtotal for Section One

Section Two: Protect Ecosystems, Conserve Natural Resources	
❑	(1-3) Preserve x% of lowlands and areas with mature vegetated soils (see text).
❑	(1) Use drought-tolerant groundcover in *50%* of all common areas.
❑	(1) Clearly label all storm sewer inlets.
❑	(1) Use infiltration basins and/or detention ponds.
❑	(1) Use small permanent check dams and level spreaders.
❑	(1) Use vegetated swales and small holding areas.
❑	(2) Grind land clearing wood and stumps for reuse on site.
❑	(2) Replant or donate removed vegetation.
❑	(2) Design for no curbs or gutters (where allowed).
❑	(2) Use planted “closes” instead of cul-de-sacs.
❑	(2) Implement storm water management beyond code.
❑	(2) Install vegetative buffers on downstream side of parking lots.
❑	(2) Provide signage highlighting development’s environmental features.
❑	(3) Phase construction so that no more than 40% of site is disturbed at a time.
❑	(3) Preserve 30% of existing native vegetation.
❑	(3) Provide wildlife corridors.
❑	(3) Construct multiple small pools and wetlands.

_____ Subtotal for Section Two

_____ **Total Points for Your Project**

Evergreen Builders Guide

Community Enhancement Checklist

One Star	★	**50 points**
Two Star	★★	**100 points**
Three Star	★★★	**150 points**
Four Star	★★★★	**200 points**

A strong sense of community and good proximity to transportation and shopping can increase the market appeal of residential real estate. Neighborhoods that include well-planned open space and amenities can result in significantly higher property values.

Neighborhood design can also impact infrastructure cost and availability, as well as affect the health and safety and level of interaction of residents with elements such as pedestrian friendly design. Communities that also include a mix of housing types, including affordable housing, will add to the diversity and vibrancy of the community. The overall goal of building a sustainable neighborhood includes providing for a thriving community that cares for and preserves the natural environment, for ourselves and future generations.

Two strategies for Community Enhancement have been identified. First, *Create Livable Neighborhoods* is a strategy that identifies the importance of social functions in new development. Measures that increase density, while at the same time maintaining public safety and preserving open space have been identified.

Many of these measures are related to the impact and use of the car. Studies have shown annual costs for owning and operating an automobile in a pedestrian friendly setting can be as much as $13,000 lower than in a car dependent suburb. Reduction of automobile trips in a community can lower demand for parking in commercial buildings ($20,000/space), and multi-family ($600/year). Including commercial space in the development allows residents to work and live in one community, also reducing travel miles and costs.

Secondly, by consciously following a strategy of *Connecting with Nature*, development can occur while preserving the natural beauty that residents in the Evergreen State value highly. Creating livable neighborhoods within a natural setting, as opposed to replacing nature with a uniform suburban plan, strengthens a resident's connection to nature and has been demonstrated to improve property values.

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Builder

Points

❑ 5 **Green building occupant's manual**

Provide residents with a green building occupant's manual to help them understand the green benefits of their home. The manual will guide the homeowner through the functions, benefits, and life cycle considerations of the green features that have been built into the home. The projected benefits of the home can be used as a selling point.

❑ 25 **North lot area built first**

Build on the north area of the lot first when doing lot site planning. Place the home on the lot to leave as much as possible of the east, west, and south areas for outdoor use. The cooler, darker, north area of the lot is the least useful for outdoor activity areas such as gardens and patios.

Developer

❑ 25 **Existing service area location**

Locate the development in an existing infrastructure service area for water, wastewater, electricity, streets, public transportation, and schools. Utilizing existing infrastructure helps to keep development costs lower, and minimizes urban sprawl. Minimizing the need for new infrastructure can help to control municipal costs which are passed on to the consumer.

❑ 25 **Pedestrian & bicycle provisions**

Provide easy, safe bicycle and pedestrian circulation paths protected by neighborhood design and covenant. Link these to parks, schools, open space, and landmarks. Providing sidewalks, bicycle lanes, and separated bicycle or pedestrian corridors will enhance the value of the neighborhood and create a stronger sense of community. Refer to the Grand Ridge Guiding Principles Document under Circulation guidelines.

❑ 25 **Traffic-calming devices**

Install traffic calming devices such as traffic roundabouts and crosswalks to limit vehicle speed. Such devices increase pedestrian and vehicle safety in a neighborhood. Refer to the Grand Ridge Guiding Principles Document under Circulation guidelines.

❑ 25 **Diverse neighborhood**

Locate the housing development in a neighborhood with diverse housing types and economic value, or in a mixed use neighborhood with mixed use zoning. Mixed use neighborhoods provide employment and shopping opportunities located nearby. Diverse housing types can create the opportunity for granny flats, single and multi-family housing in one neighborhood, and a more diverse range of ages and backgrounds of residents. Refer to the Grand Ridge Guiding Principles Document under Housing Examples.

❑ 100 **Wildlife corridor**

Provide wildlife corridors by setting aside unfenced, contiguous land that is undisturbed or restored and linked to regional corridors. Wildlife habitat areas should contain native plants and understory for shelter possible. Wildlife can move about more easily by using corridors, which also provide valuable habitat area.

❑ 100 **Garden areas**

Provide garden areas on the site or within easy walking distance. Garden areas can be used to produce food, herbs, and flowers. Gardening is a good learning activity for children, and shared gardens help to bring neighbors together.

❑ 100 **Open space preservation**

Set aside and preserve as much contiguous open space as possible when planning a community. Preserving open space can help increase property values up to 15% for units facing the green area, and helps to preserve natural features such as trees and waterways. Open space becomes an amenity for the neighborhood, providing opportunities for recreation, gardening, and wildlife viewing. Clustering housing units is one technique for preserving open space. Open space to be set aside should not be disturbed or cleared.

❑ 100 **Easy access location**

Locate the neighborhood within an easy, safe ten-minute walk to amenities such as public transit, shopping, schools, recreation, and daycare. Easy pedestrian access to such features decreases the need for short automobile trips which clog traffic and create air pollution.

❑ 100 **Density 20 d.u./acre or higher**

For multi-family housing, create housing densities of 20 units per acre, or higher. Higher densities can be created by clustering or stacking units, building garden homes, or with sensible lot planning. Using higher housing density can save the developer on land and infrastructure costs, and create opportunities to set aside more green space or common areas. Smaller lots can save homeowners on maintenance costs.

Job Foreman

❑ 100 **Trees & natural features protected**

During construction, provide protection for large trees and other natural features. Use temporary fencing to protect trees in groups, setting aside as large an area as possible. Prohibit material storage, vehicle parking, and dumping solvents or paints under trees. Protecting trees in this way will help them through the shock of construction disturbance and help ensure their long term health and survival. Other natural features to protect include wetlands, landmarks, and significant outcrops.

730 Total Available Points for Community Enhancement

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HOME BUILDER Self-Certification Checklist

Section One: Build to Green Codes/Regulations

(★) 1-1. Meet Washington State Wtr Use Effcy Stds
(★) 1-2. Meet Stormwater/Site Development Stds
(★) 1-3. Meet Washington State Energy Code
(★) 1-4. Meet Washington State Ventilation/IAQ Code

Section Two: Site and Water

SITE PROTECTION

Overall

(3) 2-1. Build on an infill lot to take advantage of existing infrastructure and reduce development of virgin sites
(10) 2-2. Build in a BUILT GREEN™ development

Protect Site's Natural Features

(3) 2-3. Limit heavy equipment use zone to limit soil compaction
(3) 2-4. Preserve existing native vegetation as landscaping
(3) 2-5. Take extra precautions to protect trees during construction
(3) 2-6. Preserve and protect wetlands, shorelines, bluffs, and other critical areas during construction
(5-10) 2-7. Set aside percentage of site to be left undisturbed

Protect Natural Processes On-Site

(1) 2-8. Install temporary erosion control devices and optimally maintain them
(1) 2-9. Use compost to stabilize disturbed slopes
(1) 2-10. Protect topsoil with mulch or plastic
(3) 2-11. Balance cut and fill, while maintaining original topography
(3) 2-12. Limit grading to 20 ft outside building footprint
(4) 2-13. Amend disturbed soil to a depth of 8 to 10 inches to restore soil environmental functions
(5) 2-14. Replant or donate removed vegetation for immediate reuse
(5) 2-15. Grind landclearing wood and stumps for reuse
(5) 2-16. Use a water management system that allows groundwater to recharge
(5) 2-17. Design to achieve effective impervious surface equivalent to 0% for 5 acres and above; <10% for less than 5 acres
(5) 2-18. Use pervious materials for at least one-third of total area for driveways, walkways, patios
(10) 2-19. Bonus Points: Install vegetated roof system (e.g. eco-roof) to reduce impervious surface
(10) 2-20. Bonus Points: Construct no impervious surfaces outside house footprint

Eliminate Water Pollutants

(1) 2-21. Take extra care to establish and maintain a single stabilized construction entrance (quarry spall or crushed rock)
(1) 2-22. Take extra precautions to install and maintain sediment traps

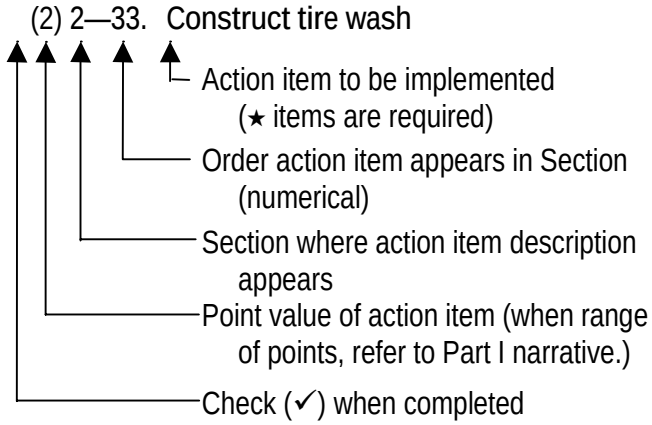
(1) 2-23. Establish and post clean up protocol for tire wash
(1) 2-24. Take extra precautions to not dispose of topsoil in lowlands or wetlands
(1) 2-25. Wash out concrete trucks in slab or pavement subbase areas
(1) 2-26. Prohibit burying construction waste
(1) 2-27. When construction is complete, leave no part of the disturbed site uncovered or unstabilized
(1) 2-28. Recycle antifreeze, oil, and oil filters at appropriate outlets
(1) 2-29. Dispose of non-recyclable hazardous waste at legally permitted facilities
(1) 2-30. Establish and post clean up procedures for spills to prevent illegal discharges
(2) 2-31. Reduce hazardous waste through good jobsite housekeeping
(2) 2-32. Provide an infiltration system for rooftop runoff
(2) 2-33. Construct tire wash
(2) 2-34. Use slow-release organic fertilizers to establish vegetation
(2) 2-35. Use less toxic form releasers
(3) 2-36. Use non-toxic or low-toxic outdoor lumber for landscaping (e.g. plastic, least-toxic treated wood)
(4) 2-37. Phase construction so that no more than 60% of site is disturbed at a time and to prevent adverse impacts on adjoining properties or critical areas
(5) 2-38. No clearing or grading during winter months
(5) 2-39. No zinc galvanized ridge caps, copper flashing or copper wires for moss prevention

Section Three: Energy Efficiency

EFFICIENT DESIGN

(3) 3-35. Use building and landscaping plans that reduce heating/cooling loads naturally

HOW TO USE THE CHECKLIST



Section Six: Promote Environmentally Friendly Homeowner O&M

HOMEOWNER'S KIT

(★) 6-1. Provide owner with operations & maintenance kit

WATER PROTECTION

Outdoor Conservation

(1) 6-2. Mulch landscape beds with 2 in. organic mulch
(1) 6-3. Use grass type requiring less irrigation and minimal maintenance
(3) 6-4. Use compost soil amendments to establish turf and other vegetation with less irrigation
(3) 6-5. Limit use of turf grass to 25% of landscaped area
(3) 6-6. Landscape with plants appropriate for site topography and soil types, emphasizing use of plants with low watering requirements
(4) 6-7. Plumb for greywater irrigation
(5) 6-8. Install rainwater collection system (cistern) for reuse
(10) 6-9. Bonus Points: Install irrigation system using recycled water
(10) 6-10. Bonus points: No turf grass

APPENDIX B

Home Builders Association of Metropolitan Denver Green Land Development Checklist

DRAFT

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Denver's Built Green™ Communities Program

The Home Builders Association of Metropolitan Denver volunteered to use the draft list of green land development principles developed by the NAHB Research Center and apply them to local conditions. Metro Denver HBA members met several times and modified the list to meet local green development needs. Appendix B presents Denver's draft program checklist as of the time this guidebook went to press.

Planned for introduction in the first part of 2001, Denver's Built Green™ Communities program has been under development for the past 12 to 14 months as described below.

The 2000 president of the HBA, Bob Koran, appointed a task force to develop guidelines and operating procedures for a voluntary program to be offered to developers in metropolitan Denver. As a companion to Built Green Colorado, the program was envisioned as the next logical step to move the home building and development industry toward more resource-efficient practices.

The task force members represented several disciplines: land planning, development, water conservation, landscape architecture, architecture, energy efficiency, government, banking, engineering, and others interested in furthering the environmental responsibility of the building industry.

Initially, the group spent several meetings discussing the feasibility and challenges of, and the intent behind, a green building program. Members researched examples of sustainable development and shared their knowledge and experience with the group. They also discussed who else needed to be brought into the group as stakeholders. As a result, the group extended additional invitations for participation.

A subgroup of task force members assumed the task of drafting a mission statement to provide the larger group with overall guidance, to set forth the goals of the program to be formed, and to craft an introductory statement around which conversation could begin with others outside the task force in its efforts to align support for its mission and, ultimately, its product. The mission statement approved and adopted by the task force follows:

> "The Built Green™ Communities Program, through a partnership of planners, developers, builders, lenders and government agencies, will promote voluntary land use and community design guidelines that will minimize environmental impact, promoting the understanding and acceptance of responsible community design to benefit all citizens."

Specific objectives of the program call for preserving natural resources; balancing open space and density; reducing infrastructure costs through efficient design; encouraging cost-effective, innovative ideas and technologies; and creating diverse housing options.

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Concurrently, the NAHB Research Center had launched its work with the U.S. Environmental Protection Agency to develop a list of green land development principles for use by all local home builders associations in implementing similar green development programs.

The NAHB Research Center provided the Denver task force with a checklist of possible features subdivided into green development categories (e.g., street design, curbs and gutters). The task force then broke into groups assigned to various development categories and began the task of critically evaluating the lengthy list of possible features.

Two clear developments emerged: a natural reduction in the number of task force participants because of time availability and recognition that the task force would become hopelessly mired in process and never arrive at resolution if it attempted too large a task.

The task force held a half-day focus group to identify which features on the initial checklist had both high value and high potential for acceptance/implementation by city planners and developers. The result was a greatly reduced, much more focused checklist that would become the starting point for development of the program's guidelines.

The task force next clarified the checklist's language and separated consolidated green land development concepts into single features. During this phase of its work, the task force returned repeatedly to two connected issues: the potential for developers to select inconsistent features from within the checklist and the group's desire to build into the checklist the concept of "systems thinking." The best solution, albeit not a complete one, was to use a system of point-weighting that encouraged the selection of some features over others.

The group stalled as it grappled with how to allocate points and create a structure so that the checklist would achieve its aims. It was of enormous benefit to the process when Robin Snyder of EPA provided the group with a copy of the "Smart Scorecard for Development Projects" authored by Will Fleissig and Vickie Jacobsen in collaboration with the Congress for New Urbanism.

With the language of the individual checklist features established, the format for the checklist finalized, and each feature assigned points, the task force presented its work to the board of directors of the home builders association to obtain its approval for moving forward with the development and introduction of the program. The board unanimously approved the program.

The checklist is currently undergoing a "road test" to score a variety of existing or on-the-board housing developments and to solicit feedback from the developers participating in the test. Further assessment and evaluation need to be completed before the checklist can be considered ready for introduction.

While the task force nears completion of its work, it must still refine further its allocation of points as well as define the minimum threshold for qualification.

Other tasks to be tackled primarily address the operational needs of the program and include but are not limited to the following:

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- An analysis of the projected costs and levels of participation needed to arrive at appropriate participation fees;
- Establishing some form of compliance verification;
- Establishing a system to track and verify compliance with the requirement that all homes in a Built Green™ Community are registered in the Built Green™ Colorado program (the green home building program); and
- Developing program materials, including a "guide" to the checklist that clearly defines the qualifications for each point.

The task force is a committed group of individuals eager to deliver a viable, valuable program to serve the industry, the community, and all citizens in better managing growth and protecting the environment. Task force members look forward to success.

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Built Green™ Communities Checklist (working draft)

January 23 weighting decisions; new scores reflect the valuations below

1. Buildings…….**10%**
2. Site selection…… **7%**
3. Transportation…….**18%**
4. Planning and design……**30%**
5. Preservation and conservation……**20%**
6. Community…….**15%**

100%

1. Buildings

Feature	Assessment	Possible Points	Your Score
All homes registered under Built Green Colorado (REQUIRED)	NA	NA	NA
All homes meet 83 points on the E-Star home energy rating point scale, 100% verified by E-Star Colorado		35	
All homes meet 83 points on the E-Star home energy rating point scale, 25% verified by E-Star Colorado		25	
All homes meet 85 points on the E-Star home energy rating point scale, 100% verified by E-Star Colorado		45	
All homes meet 85 points on the E-Star home energy rating point scale, 25% verified by E-Star Colorado		35	
All homes meet 90 points on the E-Star home energy rating point scale, 100% verified by E-Star Colorado		60	
All homes meet 90 points on the E-Star home energy rating point scale, 25% verified by E-Star Colorado		50	
	Subtotal Buildings		
	Maximum Possible	**60**	
	Minimum for Qualification	N/A	

*Remember that the Built Green Checklist energy requirement is under review. The point threshold for the minimum E-Star rating is not yet set.

2. Site Selection

Feature	Assessment	Possible Points	Your Score
Locate new developments adjacent* to existing population and business centers with existing community services and facilities, and with utility infrastructure within ¼ mile of property line. *Adjacent means the new development has a shared boundary with existing development. Boundary may be interrupted by a road or alley way.		7	
Promote infill development by locating new developments surrounded by existing population and business centers with existing community services and facilities.		14	
Promote brownfield development by remediating and building on a site classified as a brownfield.		14	
Participate in EPA's Brownfields Economic Redevelopment Initiative.		5	
Development is located within walking distance of existing open space or park (available to the public; assumes walking speed of 265 ft per minute)			
0 – 5 minutes		5	
6 – 10 minutes		3	
11 – 15 minutes		1	
	Subtotal Site Selection		
	Maximum Possible	**45**	
	Minimum for Qualification		

3. Transportation

Feature	Assessment	Possible Points	Your Score
Create a mixed use development with a variety of land uses and neighborhood gathering place (see Guide) and/or village centers within close proximity to minimize automobile trips, encourage walking and increase social and economic vitality			
Potential uses for the community: Single-family (for sale) residential; Multi-family (rental) residential; Retail; Business; Recreational; Educational; Cultural* (* Examples of cultural uses include theater, band shell, historical trail, museum, preserved historic site, etc.)			
Community include as mix of:	5 uses	17	
Community include as mix of:	4 uses	13	
Community include as mix of:	3 uses	11	
Community include as mix of:	2 uses	6	
Walking distance (assumes walking speed of 265 ft per minute) from 75% of the homes to activity center*, on or off-site, is:			
0-5 minutes		15	
6-10 minutes		11	
11-15 minutes		7	
* "Activity center" is defined as including 2 or more of the following: Retail; Business; Recreational; Educational; Cultural			
Provide incentives to increase public transit use and to reduce auto dependency			
Provide bike racks or lockers		1	
Bike/pedestrian paths to transit stations/stops		2	
Permanent signage for transit information and access		1	
Covered transit stations/stops		3	
Develop under or over pass elements for bike or pedestrian paths		8	
Public transit accessibility			
Walking distance (assumes walking speed of 265 ft per minute) from 75% of the homes to public transit) is:			
0-5 minutes		12	
6-10 minutes		8	
11-15 minutes		5	
Encourage new public transportation systems where existing systems are not adequate			
Advanced coordination with RTD		5	
Internal bus system		13	
Reserve land for future mass transit use		13	
Create non-motorized, continuous and connected open space linkages between neighborhoods and basic services			
Internal and External		12	
External only		5	
Internal only		5	
Develop under or over pass elements for open space linkages interior or exterior		8	
"Internal" is within the boundaries of the community; "external" refers to links with features and/or services outside the community boundary.			
Note: Points for individual options adjusted to maintain % relationship to total	Subtotal Transportation		
	Maximum Poss	**110**	

4. Planning and Design

Feature	Assessment	Possible Points	Your Score
Create efficient land use through developing land in higher gross residential density. (du/ac = dwelling units per acre of total acreage of development to be scored.)			
Average gross density (du/ac) is: 14 or more		31	
10 to 13.9		24	
7 to 9.9		16	
4 to 6.9		8	
The following percentages of gross development area are set aside as common-area open space.			
Percentage of common area open space to total area is: 40% or more		31	
35 to 39.9%		24	
30 to 34.9%		16	
20 to 29.9%		8	
10 to 19.9%		4	
Promote energy conservation by maximizing solar exposure through access and building orientation.			
85% of the homes have their front or rear facade facing within 15 degrees of solar south, and have 75% wintertime solar access (structural, see notes)		19	
75 to 84.9%		14	
65 to 74.9%		10	
55 to 64.9%		5	
Reduce areas of imperviousness by use of relaxed front setbacks, narrower frontages, and minimized driveway lengths.			
Push homes forward so that 50% of homes sit less than 18 ft from front property line		6	
Neck down driveway to maximum of 10 ft width @ street connection		6	
Use shared driveways to reduce impervious areas		6	
Efficient Street Design			
Construct residential streets to 24 foot back of curb to back of curb		10	
Construct residential streets to 28 foot back of curb to back of curb		6	
Construct residential streets to 32 foot back of curb to back of curb		3	
Provide detached walks on local streets		5	
Water conservation through appropriate landscaping			
Utilize the Principles of Xeriscape in landscape design and construction.			
Common areas:			
Improve the soil (Mix in organic material at 3 cubic yards/1000 s.f.)		4	
Select appropriate turf areas. Limit cool season turf to no more than 50% of landscaped area; use native/drought tolerant grasses in turf areas exceeding 50%.		4	
Use appropriate mulches in bedding areas to a depth of 3”		3	
Install efficient irrigation* as defined in the Guide		3	
Group plants according to moisture and sunlight needs		3	
Provide landscaping maintenance guidelines		2	
Individual residences, covenant required:			
Improve the soil (Mix in organic material at 3 cubic yards/1000 sf.)		3	
Select appropriate turf areas (Limit cool season turf to no more than 50% of landscaped area; use native/drought tolerant grasses in turf		3	

areas exceeding 50%.)			
Use appropriate mulches in bedding areas to a depth of 3”		3	
Install efficient irrigation as defined in the Guide*		3	
Group plants according to moisture and sunlight needs		3	
Provide landscaping maintenance guidelines		2	
NO FURTHER REVISIONS TO BE CONSIDERED ABOVE THIS LINE AT THIS TIME WITH THE EXCEPTION OF OPEN SPACE.	**********	********	*******
Common areas irrigated with non-potable** water		15	
Common areas irrigated with recycled water (greywater)			
In common non-turf areas only use native or bio-diverse plants to eliminate need for irrigation and to support native wildlife habitat		3	
50% of common area is restored or undisturbed native plant community, including a minimum of 6” topsoil, forbs, grasses, sedges, and woody plants			
In common non-turf areas only use climate-tolerant plantings (for example, drought tolerant)			
All private lots irrigated with non-potable** or recycled water (greywater)			
In private lot non-turf areas only use native or bio-diverse to support native wildlife habitat		10	
In private non-turf areas only use climate-tolerant plantings (for example, drought tolerant)			
Plant one 2-inch^ caliper, habitat-appropriate tree per house		4	
Plant two 2-inch^ caliper, habitat-appropriate trees per house		8	
	Subtotal Planning and Design		
	Maximum Possible	**185**	
	Minimum for Qualification		

*Definition of efficient irrigation: System is professionally designed for even application of water and includes separate zones for turf and non-turf planting areas, low-flow irrigation for non-turf areas (i.e. drip or micro spray), and rain or moisture sensors. Provide written maintenance guidelines for appropriate irrigation system management practices, such as regular adjustments based on changing seasonal needs of the landscape.

**Non-potable means any non-drinkable water and includes both untreated and recycled, but can also be treated to some extent but still non-potable

5. Preservation, Conservation, and Restoration

Feature	Assessment	Possible Points	Your Score
Perform natural resources inventory to identify important natural features, i.e. plant and animal habitat, agricultural uses, sensitive natural areas, etc. Set aside land for agricultural use or natural areas to encourage plant and animal (i.e. biological) diversity.			
Internal and External set asides		13	
External set aside only		6	
Internal set aside only		6	
Definition: An "internal " set aside is within the boundaries of the community; an "external" set aside refers to links with features and/or services outside the community boundary.			
Preserve sensitive natural areas and preserve open space for common space, recreation, buffers and habitats.			
Protect existing watercourses, riparian areas and wetlands		4	
Protect native growth in all open areas		4	
Save and reuse topsoil that has nutrient value based upon soils analysis. Remove, store, then replace topsoil in all disturbed areas (house pad and street excluded from replacement requirement)		4	
Include a tree expert on the development team; conduct a tree survey prior to planning and design, and create a tree conservation plan.			
Participate in the tree conservation program as defined in the *Building with Trees Program* created in 1998 by The National Arbor Day Foundation in cooperation with the Nation Association of Homebuilders (Kristin's recommendation – need points)		10	
Protect 66-100% of trees greater than 4-inch diameter		6	
Protect 25-65% of trees greater than 4-inch diameter		4	
Replace destroyed trees per caliper (i.e. 12-inch=6-2" new) @ 4 to 1 ratio		8	
Replace destroyed trees per caliper (i.e. 12-inch=6-2" new) @ 2 to 1 ratio		4	
Require builder compliance with tree preservation guidelines during construction and maintenance stages of the project.			
Implement landscaping techniques for energy conservation (e.g. evergreen trees for wind and snow breaks to reduce heating costs; deciduous trees for summer shading to reduce cooling needs/costs; vegetation and tree planting that encourages channeling of breezes for summer cooling; and the use of insulating shrubs and vines)			
Streets have deciduous trees planted for canopy cooling (see Guide to reference types of trees and proximity to street), 2-inch caliper diameter planted every 50 feet or as required by local jurisdiction, required by developer.		12	
Integrate wetlands and landscape areas to promote infiltration of storm water runoff.			
Create onsite mitigation for disturbed/destroyed wetland @ 1 to 1 ratio		3	
Create onsite mitigation for disturbed/destroyed wetland @ 2 to 1 ratio		6	
Create onsite mitigation for disturbed/destroyed wetland @ 3 to 1 ratio or greater		9	

Definition: Mitigation of wetland impacts can include: Avoiding the impact altogether by not taking certain action or parts of an action; minimizing impacts by limiting the degree or magnitude of an action and it's implementation; rectifying the impact by repairing, rehabilitating, or restoring the affected environment; reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; compensating for the impact by replacing or providing substitute resources or environments. See Guide.			
Enhance/create non-required wetlands		12	
Create natural alternative to conventional stormwater detention (see Guide)		7	
Create sediment traps in detention ponds to filter water		3	
Create natural conveyance drainage system (e.g. eliminate curb & gutter and underground storm piping)		7	
Create retention pond to retain 50% of increased flow beyond historical rates		3	
Create retention pond for full retention of increased flow beyond historical rates		7	
Employ sensitive site grading practices.			
Create forms that step with the existing slope		5	
For sloping sites, follow natural topography (for example, develop parcel grading solutions to create smaller terraces)		5	
Protect sensitive areas (e.g., use retaining walls or other engineering solutions)		2	
Create on-site environmentally appropriate wastewater treatment facility.			
Constructed wetland, Living Machine, or other biological wastewater treatment facility (would need specific info for Guide)		6	
	Subtotal Preservation, Conservation and Restoration		
	Maximum Possible	**124***	
	Minimum for Qualification		

* Points in preservation, conservation, and restoration section have been adjusted to maintain the section's ratio to the overall point structure

6. Community

Feature	Assessment	Possible Points	Your Score
Establish community involvement through education of residents about what the development has done, what is expected of the resident to ensure that the development retains its green focus, and creating social initiatives to support the project and its principles.			
An explicit plan of resource conserving goals with implementation plan for how the community will meet the goals and create a self-sustaining program.		6	
Full time paid staff position dedicated to helping the community meet environmental goals		9	
Part-time paid staff or volunteer position dedicated to helping the community meet environmental goals		6	
Homeowner guidebook to efficient operation of home with list of additional resources		3	
Seminar or seminar series for each new family explaining efficient operation of home and other programs to reduce resource use (minimum 4 hours)		3	
Ongoing series of open space habitat restoration programs		1	
Community events/festivals/performances that help educate children and adults about the community's environmental mission		1	
On-going environmental award program		1	
Neighborhood information kiosk and signage to promote green initiatives (e.g.: sharing exchange for appliances, cars; flea market/community garage sale; baby-sitter exchange, etc)		1	
Produce and distribute a regularly scheduled community newsletter		1	
Establish and sponsor community meetings.		1	
Establish and maintain an Internet community communication/ education link		1	
Establish on-going education and awareness with community signage		1	
Create civic infrastructure by providing places for programs that bring people together, providing parks and land uses for the benefit of the overall community, and providing community facilities that are the heart of neighborhoods			
Parking is separated and residents access homes through a common green		1	
50% or more of residences look out to a common green/pedestrian area		1	
Provide developed parks within the community			
10-15% of total site		4	
16-20% of total site		8	
21% or more of total site		12	
Walking distance to developed parks within community from 75% or more of the homes (assumes walking speed of 265 ft per minute)			

0-5 minutes		8	
6-10 minutes		4	
Provide a community meeting center, club house or common house or other community owned space within the development with any of the following features:			
A place for community meetings within the development		3	
A place for residents to share common meals		3	
Guest rooms for community use		1	
An indoor children's playroom		1	
A common laundry room		1	
An office for community use		1	
A community library or media room		1	
A community teen room		1	
Provide land and an organized program for community gardens within the development		2	
Provide community recreation facilities within the development with any of the following features:			
A community swimming pool		3	
A community exercise room or fitness course		1	
Community tennis courts		1	
Provide neighborhood educational facilities within the development including any of the following:			
A public library		3	
A school		4	
A daycare facility		3	
Provide commercial facilities and uses that promote community interaction within the development including any of the following:			
A neighborhood coffee house or small restaurant		3	
Small office spaces for rent to resident businesses		3	
	Subtotal Community		
	Maximum Possible	92	
	Minimum for Qualification		

Final Score	
Maximum Possible	**613***

* The group has yet to determine where to set the threshold for certification.

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APPENDIX C

Green Land Development Resources

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SARB_006545

The resources considered and used for in the creation of this green development guide and for the completion of this project include:

- *A Guide to Developing Green Builder Programs*, by the NAHB Research Center, Inc., for the United States Environmental Protection Agency, 1999.
- *Affordable Housing: Development Guidelines for State and Local Government*, by the NAHB Research Center, Inc., for the Office of Policy Development and Research of the United States Department of Housing and Urban Development, 1991.
- *Affordable Residential Land Development: A Guide for Local Government and Developers*, by the NAHB Research Center, Inc., for the Office of Policy Development and Research of the United States Department of Housing and Urban Development, 1987.
- *Better Site Design: A Handbook for Changing Development Rules in Your Community*, by the Center for Watershed Protection, 1998.
- *Build a Better Clark*, A Program of the Clark County Home Builders Association, 1998.
- *Consensus Agreement On Model Development Principles to Protect Our Streams, Lakes, and Wetlands*, by the Center for Watershed Protection, 1998.
- *Built-Green Program of King and Snohomish Counties, Washington*, 2000.
- *Evergreen Builder's Guide for the Issaquah Highlands, Issaquah, Washington*, 1998.
- *Granting Air Quality Credit for Land Use Measures: Policy Options*, by Jack Faucett Associates and Sierra Research, Inc., United States Environmental Protection Agency, 1999.
- *Green Building Options Study: The City's Role in Promoting Resource Efficient and Healthy Building Practices*, by the City of Portland (Oregon) Energy Office, 1999.
- *Green Development: Integrating Ecology and Real Estate*, by various authors for the Rocky Mountain Institute, 1998.
- *Growing Greener: Putting Conservation into Local Plans and Ordinances*, by Randall Aren't for the National Lands Trust, American Planning Association, and the American Society of Landscape Architects, 1999.
- *Land Development, Eighth Edition*, by D. Linda Kone for the Home Builder Press of the National Association of Home Builders, 1994.
- *Land-Use Regulations Handbook*, by the National Institute of Building Sciences, 1990.
- *Moving Toward Environmentally Responsible Development: Principles and Guidelines for the Real Estate Industry*, by the Urban Land Institute, 1995.
- *Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation*, by the NAHB Research Center, Inc., for the Office of Policy Development and Research of the United States Department of Housing and Urban Development, 1993.
- *Site Planning and Community Design for Great Neighborhoods*, by Frederick Jarvis of LDR International, Inc., for Home Builder Press of the National Association of Home Builders, 1993.
- *Smart Growth Network*, http://www.smartgrowth.org
- *SMBIA Building Green Program*, Suburban Maryland Building Industry Association, Silver Spring, Maryland.
- *Stormwater Runoff and Nonpoint Source Pollution Control: A Guide for Builders and Developers*, by the NAHB Research Center, Inc.
- *Traffic Calming: The Solution to Urban Traffic and a New Vision for Neighborhood Livability*, by Citizens Advocating Responsible Transportation (CART) and Sensible Transportation Options for People (STOP), 1993.
- Various articles from NAHB and ULI publications, as well as Environmental Building News.

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Low Impact Development Offers Some Solutions for Groundwater Issues

In recent years, the availability and quality of water in areas throughout the country have become more driving factors in how business gets done, particularly the business of building. From droughts to flooding, from quantity of water to quality of water—awareness and scrutiny of water management practices is at an all-time high, and will continue. Since water quality plays a key role in all elements of the ecology, organizations from community groups, to regional watershed authorities, to state and federal agencies have become involved in this issue. Low Impact Development, a practice pioneered by the Department of Environmental Resources for Prince George's County, Md., is one form of stormwater management that may satisfy many of these stakeholders, while at the same time resulting in potential cost savings for builders, developers, and consumers.

In terms of the bottom line, water quality protection through regulation can impact consumer interests by affecting new home affordability. According to some estimates, stormwater, erosion control, and sedimentation regulations together can account for up to six percent of land development costs, and can add significantly to the total cost of building a home. As new requirements have attempted to address water quality, erosion, flow volume, and other problems created by common conveyance methods, the cost and complexity of these engineered systems have increased.

Cost benefits to builders and developers utilizing Low Impact Development (LID) strategies can be significant. According to the Center for Watershed Protection, traditional curbs, gutters, storm drain inlets, piping, and detention basins can cost two to three times more than engineered grass swales and other LID techniques to handle roadway runoff. Other strategies, as described below, can have similar cost-saving impact. LID techniques can offer builders and developers a more cost effective way to address stormwater management through management practices and site design modifications.

Problem Solving By Design

Pollution from stormwater runoff can be a major concern, especially in urban areas. Rainwater washing across streets and sidewalks can pick up spilled oil, detergents, solvents, de-icing salt, pesticides, fertilizer, and bacteria from pet waste. Traditional stormwater drains do not typically channel water to treatment facilities, but carry runoff directly into streams, rivers, and lakes. Most surface pollutants are collected during the first one-half inch of rainfall in any storm event. If carried untreated into streams and waterways, these materials become non-point source pollutants, which can increase algae content, reduce aquatic life, and require additional treatment to make the water potable for downstream water systems.

LID strategies allow natural infiltration to occur as close as possible to the original area of rainfall, as opposed to traditional conveyance systems. By engineering terrain, vegetation, and soil features to perform this function, costly conveyance systems can be avoided, and the landscape can retain more of its natural hydrological function. Strategies fall under the two broad categories of Practices and Site Design.

Basic LID Practices for handling runoff are implemented to reduce the volume of runoff and decentralize water

flows. This is usually best accomplished by creating a series of smaller retention or detention areas that allow localized filtration rather than carrying runoff to a remote collection area. Some common structural and non-structural methods include:

- **Bio-Retention Cells**, also called "rain gardens," consist of grass buffers, sand beds, a ponding area for excess runoff storage, organic layers, planting soil, and vegetation. They provide a storage area away from buildings and roadways, where stormwater collects and filters into the soil. They are usually landscaped with native plants and grasses, selected according to their moisture requirements and ability to tolerate pollutants.

- **Grass Swales** provide an alternative to curb and gutter systems by using grasses or other vegetation to reduce runoff velocity and allow filtration, while high volume flows are channeled away safely. In areas where salts are commonly used for winter de-icing, careful attention must be paid to selecting plant species which are salt tolerant.

- **Filter Strips** can be incorporated within parking lots or other areas to collect flow from large impervious surfaces. They may direct water into vegetated detention areas or sand filters that capture pollutants and gradually discharge water over a period of time.

- **Disconnected Impervious Areas** direct water flows from structures, driveways, or street sections, into separate localized detention cells rather than combining them in drainpipes with other runoff. Disconnecting the flow limits the velocity and overall amount of conveyed water that must be handled by end-of-pipe facilities.

In terms of Site Design, decreasing impervious surfaces can be a simple strategy to avoid problems from stormwater runoff and water table depletion, by reducing surfaces that prevent natural filtration. Some methods include:

- **Reducing Roadway Surfaces** can retain more permeable land area. Pavement needs can be reduced significantly by using longer, undulating roads that create more available lot frontage. Shared driveways, "flag" lots with reduced street frontage, landscaped detention islands within cul-de-sacs, or alternate designs for turn-around areas are other options.

- **Permeable Pavement Surfaces**, which allow water to flow through and replenish soil areas below, can be constructed from materials, including traditional asphalt and concrete, gravel, or pavers. In many cases, they can reduce or eliminate the need for traditional stormwater structures.

- **Planning Site Layout and Grading to Natural Land Contours** can minimize grading costs and retain a greater percentage of the land's natural hydrology. Contours which function as filtration basins can be retained or enhanced and incorporated into the landscaping design.

- **Natural Resource Preservation and Xeriscaping** can be used to minimize the need for irrigation systems and enhance property values. Preserving existing wooded areas, mature trees, and natural terrain can give new developments a premium "mature landscape" and provide residents with additional recreational amenities. Both of these features can improve marketability. Xeriscaping refers to landscaping with plants native to area climate and soil conditions. These plants thrive naturally, requiring less maintenance and irrigation than most hybrid or imported varieties.

Not all sites can effectively utilize LID techniques. Soil permeability, slope, and water table characteristics may limit the potential for local infiltration. In urban areas, and areas with existing high contaminant levels, use of LID filtration techniques may be precluded.

Codes may also pose a barrier. Many existing local codes and regulations for zoning, parking, and streets were developed prior to the emergence of water management concerns, and may be at odds with LID practices. Established practices can be difficult to modify, although cost factors may help drive change.

If Low Impact Development is a possibility for your site, keep in mind that it requires more precise engineering for soil characteristics, filtration rates, water tables, native vegetation, and other site features, so participation of environmental consultants and planners is critical from the beginning for residential development. For more information, visit the Land Use category on the ToolBase Services website.

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storm water management

objectives, principles & design considerations

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About the Publishers

ASCE—the American Society of Civil Engineers
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The American Society of Civil Engineers was the first national engineering society to be established in the United States. Founded in 1852, ASCE's objective is the "advancement of the science and profession of engineering."

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The National Association of Home Builders of the United States is a professional trade organization representing the bulk of the housing industry. It has more than 75,000 members in some 580 affiliated local and state associations in the United States and Puerto Rico and 43 international affiliates.

As the "Voice of America's Housing Industry" NAHB presents the industry's views to the Administration, to Congress, and to government housing agencies. It offers its members advice and guidance on every phase of building operations, from land use to cost data, from marketing to construction techniques.

Headquarters for the NAHB is the National Housing Center in Washington, D.C.

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ULI—the Urban Land Institute is an independent, nonprofit organization incorporated December 14, 1936 to improve the quality and standards of land use and development.

The Institute is committed to conducting practical research in the various fields of real estate knowledge; identifying and interpreting land use trends in relation to the changing economic, social and civic needs of the people; and disseminating pertinent information leading to development of land.

ULI receives its financial support from membership dues and sale of publications and contributions for research and panel services.

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An undertaking such as this required the cooperative participation by a significant number of representatives from each of the organizations. The need for a report on residential storm water management originated in the NAHB Land Use and Engineering Committee in 1971. An initial survey and interim report completed in 1973 by the NAHB Research Foundation and its staff was the basis for initiation of the joint effort among NAHB, ASCE and ULI. This initial effort was reviewed by each organization. As a result of that review, a revision was prepared by Carl F. Izzard under a grant from the Urban Land Research Foundation. This revision was then reviewed by the committees of NAHB, ASCE & ULI; a further draft, including a discussion of legal implications by Ruth M. Wright of Boulder, Colorado, was prepared with the participation of staff members from NAHB, ULI and the NAHB Research Foundation. The draft was further reviewed and modified with additions from members of the ASCE review committee. Special acknowledgement needs to be given to the Urban Water Resources Research Council of ASCE, especially Messrs. Izzard, Jens and Jones, for providing leadership and counsel as well as a testing ground for the concepts set forth in this report. Without the willing and diligent participation of all those involved, this joint effort could not have been brought to fruition.

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Foreword

Publication of this report under the joint auspices of the American Society of Civil Engineers, the National Association of Home Builders and ULI—the Urban Land Institute is a continuation of the unique cooperative effort which resulted in a previous jointly sponsored publication, *Residential Streets: Objectives, Principles, and Design Considerations.* This report is a second jointly sponsored and reviewed report which represents the attitudes and concerns of the three organizations on a subject of common interest and importance—the setting of objectives, principles and design considerations to be applied to the development of storm water management systems to serve residential communities.

The content of this report evolved, as did its predecessor, from an assessment of current practices to a guide toward a more creative and thoughtful approach to storm water runoff management. While not rejecting past practice, it clearly identifies and articulates a new underlying philosophy and approach which diverges significantly from the past.

It is hoped that this report will stimulate communities of all sizes, in all locales, to rethink current storm water management practices and to adopt those which are responsive to local conditions and supportive of the basic objectives and principles presented herein.

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SARB_006556

INTRODUCTION

The Need for Change

The basic philosophy of storm water management in residential, and for that matter, all kinds of development, is open to challenge and revision. Nationwide experience with the effects of narrow and inadequate philosophies on past practices indicates that storm water has rarely been well managed, and has in fact often been mismanaged. To some extent, at least in residential developments, past approaches, development patterns and public policies inadvertently encouraged the very approaches this report seeks to modify. Simply stated, past philosophy sought maximum convenience at an individual site by the most rapid possible elimination of excess surface water after a rainfall and the containment and disposal of that water as quickly as possible through a closed system. The cumulative effects of such approaches have been a major cause of increased frequency of downstream flooding, often accompanied by diminishing groundwater supplies, as direct results of urbanization; or have necessitated development of massive downstream engineering works to prevent flood damage. The downstream urban flooding problem has become acute during the past thirty years as communities have grown and as curbed roadways (paved channels) have been installed in both new suburban areas and throughout older areas that formerly provided runoff-retarding storage in roadside swales or ditches. Amelioration of the unfortunate results of past urbanization requires very large investments to construct additional flood control works. Where flood control is infeasible, the flooding hazard reduces property values and may lead to abandonment, which is unacceptable to community leaders.

The entire process of storm water runoff management is currently undergoing a significant redirection, if not a revolution. This is evidenced by a new emphasis on the desirability of detaining or storing rainfall where it falls, on-site, which sometimes requires tradeoffs with short-term localized inconvenience. These kinds of solutions applied to individual sites or developments often have beneficial cumulative effects by attenuating both peak runoff and total short-term runoff. If fully applied throughout a drainage basin, they would reduce major facilities investments required to protect against flood hazards in the lower portion of the drainage basin.

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The Problem

In an undeveloped area, the storm water management system is provided by nature. The cycle begins with rainfall—the storm. Some of the water stands where it falls on leaf or plant, and evaporates; some is absorbed into the ground near the surface and feeds trees and plants, ultimately to be returned to the atmosphere by transpiration; some percolates deeply into the ground and replenishes the groundwater supply. The remainder gradually or quickly collects into rivulets, accumulating both in quantity and speed as it hurries down the watershed through drainageways and streams to its ultimate destination—the river and then the sea, to begin the cycle again (Figure 1).

All of us have been exposed to this simple explanation but its seeming simplicity belies its complexity. Nature's inability to accommodate severe storms without significant damage, even where urbanization has not occurred, is quite apparent. The natural drainage systems in an undeveloped area are not static in design, but are constantly changing. Streams change course, banks erode, vegetation and soil permeability change with seasons, lakes fill in with sediment and disappear. The stripping of ground and tree cover by fire may change an entire system, forcing new natural accommodations throughout the system. Urbanization has required new drainage systems because man was both unwilling to suffer inconvenience where it could be avoided and because he would not tolerate the loss of life or property. In an urbanizing area, those concerns often have been translated into storm water management system requirements for convenience and safety, without recognition of other significant considerations. This has meant that no matter how large the rainfall or its duration, the drainage system was expected to remove runoff as quickly as possible, to restore maximum convenience in the shortest possible period of time. At the same time, fears of loss of life and of damage to possessions have encouraged a search for 100 percent protection against the worst storm that nature might generate.

It is the premise of this report that these two objectives are not mutually achievable without extremely high "cost". Where we have sought maximum convenience as our first choice in the upper and middle reaches of a watershed, we have created imbalanced systems, and increased hazard and risk of damage along the lower reaches. The need is obvious — to strike a realistic balance between elimination of inconvenience and protection against hazard. Past practice has not always achieved such a balance. In fact, it more often than not has encouraged acceleration of imbalance as areas urbanized.

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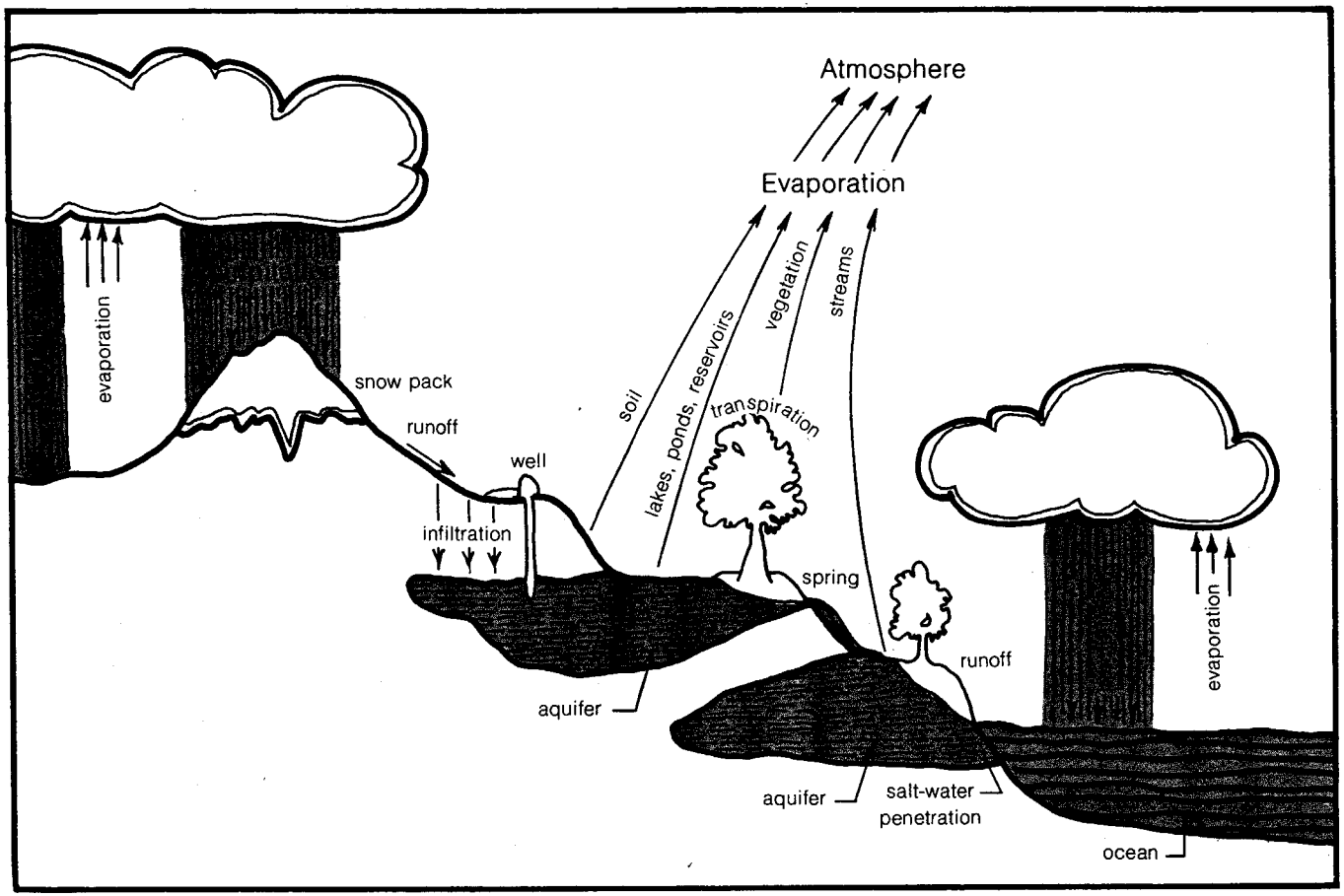

Figure 1 Hydrologic Cycle

New Development Patterns Provide New Opportunities

Every parcel of land is part of a larger watershed. Ideally, a storm water runoff management solution for each development project should be based on, and supportive of, a plan for its entire drainage basin. This is not a revolutionary idea, but only recently have data collection and data handling technology made this economically possible in a meaningful way. Even in the absence of such basin-wide plans, new approaches to residential land planning, which have been evolving since about 1955, have made it possible to apply more creative approaches to storm water management within a project.[43, 49] With their application, the net effects of incremental urbanization can avoid most negative impacts and may produce benefits, enhancing opportunities for future implementation of an overall basin-wide drainage plan.

Before 1945, most residential development involved small parcels of land and often proceeded on a lot-by-lot basis. Development was easily accommodated using the then-prevalent philosophy of maximum convenience and rapid downstream disposal of surface water. The pace of urbanization was slow and the cumulative impact of drainage decisions was difficult to assess, if it was even considered.

The major residential boom in the post 1945 era, relying on total subdivision of land into individual lots, often with complete stripping of natural site features and replacement by an "efficient" design, was the logical extension of that approach. Beginning in the late 1950's, however, some proposed residential developments clustered dwellings and created common open space, seeking to preserve and enhance natural site attributes. These various innovative concepts of land planning, which have now become grouped under the common title Planned Unit Development, present opportunities for storm water management consistent with the emerging new philosophy advocated by this report. Traditional subdivision design practices will also benefit from the new storm water management approaches, but not always to the same degree.

Note: Reference numbers shown at various points in the text refer to references provided on page 63 of this report.

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The Basic Concepts

It is almost impossible to summarize the development of this report into a concise series of statements of objectives, principles, and design considerations. The ideas are far reaching and deal with many levels of concern. Following, however, are at least some of the basic concepts upon which these principles and objectives are built.

- The water falling on a given site should, in an ideal design solution, be absorbed or retained on-site to the extent that after development the quantity and rate of water leaving the site would not be significantly different than if the site had remained undeveloped. This objective may conflict with present statutory and case law in some locales, which does not reduce its validity.
- Optimum design of storm water collection, storage and treatment facilities should strike a balance among capital costs, operation and maintenance costs, public convenience, risk of significant water-related damage, environmental protection and enhancement, and other community objectives. The optimum balance among these factors is dynamic, changing over time with changing physical conditions and value perceptions.
- Just as the importance of water quality is being increasingly recognized, a major new emphasis needs to be placed on the identification and application of "natural" engineering techniques to preserve and enhance the natural features of a site. and to maximize economic-environmental benefit. "Natural" engineering techniques are those which capitalize on and are consistent with natural resources and processes. Engineering design can be used to improve the effectiveness of natural systems, rather than negate, replace or ignore them.
- Among the new trends in basic philosophy that should be pursued, are concurrent recognition of the convenience drainage and overflow or flood conveyance elements of drainage systems, the use of on-site detention storage and "blue-green" [18] development, the increased use of storage to balance out handling or treatment of peak flows, the use of land treatment systems for handling and disposal of storm water, and perhaps most important a recognition that temporary ponding at various points in the system, including on the individual lot, is a potential design solution rather than a problem in many situations.
- A continuing recognition that there is a balance of responsibilities and obligations for collection, storage and treatment of storm water to be shared by individual property owners and the community as a whole.
- A new recognition that storm water is a component of the total water resources of an area which should not be casually discarded but rather should be used to replenish that resource. Storm water problems signal either misuse of a resource or unwise land occupancy.
- A growing emphasis on the recognition that every site or situation presents a unique array of physical resources, occupancy requirements, land use conditions, and environmental values. Variations of such factors within a community generally will require variations in design standards for optimal achievement of runoff management objectives.

The above key concerns, while not all-inclusive, embody a basic philosophy that should receive wide dissemination and due consideration. Although this

report focuses primarily on residential design practices, these concepts should be considered and applied to entire drainage basins in which any development may proceed. Therefore, underlying the points made above is another basic idea that is already well perceived and that is being implemented:

- Reevaluation of the approach to basin-wide runoff management is a universal need. It is the responsibility of, and should be an objective of, the public sector.

Responsible solutions for individual developments in the absence of basin-wide plans will be more difficult to achieve particularly where current practices are based on traditional drainage concepts. For example, if current practices allow upstream development to use traditional drainage approaches that increase runoff, a development relying on new concepts might be unable to accommodate the amount of excess runoff thereby generated without additional significant costs. The approaches suggested herein should allow development to proceed on individual projects in the absence of a basin-wide plan since the strategy for retention and attenuation of peak runoff and total runoff to values not significantly different from predevelopment levels would normally be compatible with any future plan that might evolve for a watershed. Unfortunately, this can probably only be achieved at an initially higher cost for the project. Therefore, development of basin-wide plans should be pursued.

A Note for Readers

An area of concern as complex as that of storm water management defies translation into simple terms that would be easily and completely understandable by all the audiences to whom this is addressed. It would be misleading not to have included a significant amount of technical material, which will be of more specific value to engineers attempting to apply the concepts embodied herein, but which may confuse and cloud the understanding of the less initiated reader. To the greatest extent possible, Objectives and Principles and to a lesser extent Design Considerations are described in a manner that will achieve general comprehension without ignoring the complexities and technical concerns. At the same time, there are significant amounts of technical information and references which can be useful to the engineer seeking to apply this report in actual practice.

Like all documents seeking to serve a wide audience but dealing with technical terms that have of necessity acquired very precise meanings for use in design formulae, the participants in the preparation of this report are very concerned about the choice of words and the definition of terms. The obvious temptation when trying to espouse new thinking is to establish new and never before used nomenclature. Even the use of the word *storm* can be questioned because it does not clearly define the true nature and complexities of natural events, each of which is unique. The term "storm" is often applied to synthetic events that for convenience are used in derived equations that sometimes approximate real events.

This report prefers to avoid such precise definitions during general discussion and to accept them, of necessity, when they are part of a technical discussion. This dichotomy will be more apparent to the technically trained reader than to the non-technical audience.

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A Definition of "Storm Water Runoff System"

The term "storm water runoff system" is used frequently and will be used herein, as described below.

First of all, a storm water runoff system is composed of both natural and man-made elements. In the past, designers have often failed to capitalize upon natural elements and have at times ignored them when a constructed element was installed.

Secondly, these components include not only those which contain and convey storm water, but also those which absorb, store and otherwise use storm water rather than dispose of it.

Thirdly, the storm water runoff system is a single system having two purposes: (1) the control of storm water runoff to prevent or minimize damage to property and physical injury and loss of life which may occur during or after a very infrequent or unusual storm; and (2) the control of storm water to eliminate or minimize inconvenience or disruption of activity as a result of runoff from more frequently occurring, less significant storms. Some individual components of the drainage system may operate only in fulfillment of the first purpose. This dual purpose is characterized in much of the technical literature as "major" and "minor" functions.[18, 29] Many American and foreign cities have revised their drainage design approaches to embrace the dual function approach.

Fourthly, within a single system, there are components that are designed primarily to obtain convenience at the smallest scale of the system at the individual site or intersection, during minor or frequent storms. During an infrequent or major storm, the capacities of many of the convenience-oriented components will be exceeded and flow capacity must be provided by other components designed to provide safety and minimize damage throughout the system, from the individual site to the discharge point of the drainage basin or watershed. It must be recognized and emphasized that a total storm water runoff system, subjected to an infrequent major storm, cannot be expected to prevent inconvenience and minor property damage. A design that would eliminate all such stress would be fundamentally unreasonable and almost certainly infeasible. Expected damages from such a major runoff event would include minor erosion and scour, damage to lawns and vegetation, and damage to unwisely located structures, but flooding or undermining of buildings or essential facilities should not occur.

Most of our Nation's past urban drainage construction expenditures have been for small pipes and inlets that cannot intercept and transport the total runoff volume from infrequent storms. The designer's attention should focus upon controlling and safely routing all foreseeable runoff, especially that which cannot find its way into storm sewer pipes. Such a focus often will lead to wiser land occupancy practices, and minimize expensive drainage works construction, while mitigating potential damages from runoff.

Using This Report

In the next 25 years, more money may be spent for storm water management than has been spent for drainage during the entire history of the Nation. This will amount to billions of dollars, not including funds that will be expended to maintain water quality, which also is an increasing national concern. Much, if not most, of this investment will be private funds expended during the development of land for urban uses. Ultimately, however, all costs (capital, debt and maintenance) are borne by all citizens. Public investments should be made wisely in furtherance of the quality of life so highly valued. It is the opinion of ASCE, NAHB, and ULI that the application of the Objectives, Principles, and Design Considerations contained in this report, with due regard for unique and particular circumstances and conditions found in various areas of the country, will be a significant step in the right direction.

For the concepts in the report to achieve wide application there will be a need to induce institutional changes even beyond the design professions and the regulatory institutions of governments. Changes also are necessary in the financial institutions which fund development based on their approval of a project's design, in the insuring institutions and their perceptions of the insurability of this approach, and in the legal professions in relationship to the pre-existing body of land use law regarding rights, responsibilities and liabilities. The implication of the above statement, that change may be precluded by institutional constraints, is real. The importance of encouraging application of worthwhile new approaches should provide the impetus to achieve necessary changes.

It is hoped that this report will motivate creative rethinking and updating of drainage design practices. Anyone disagreeing with any part of this report is encouraged to advise the publishers of that disagreement, including their detailed reasons and alternative recommendations. Such information will help guide future revisions and enhance the document's value to our Nation.

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OBJECTIVES

- To provide a clear understanding of residential storm water runoff systems, including their intended functions and the impacts of alternative philosophies or policies on the design and effectiveness of storm water runoff systems.

Residential storm water runoff systems must fulfill two objectives: (1) they must prevent significant loss of life and property due to runoff from any foreseeable rainfall event; (2) they must provide an acceptable degree of convenient access to property during and following frequent rainfall events. Both of these objectives must be accommodated in the design process with the understanding that some protection components of the storm water runoff system may have to operate only infrequently. It must also be understood that providing protection against a given event, e.g. against the worst storm water runoff of record, does not guarantee that a greater runoff event will not occur during the useful life of the property. Similarly the enlargement of storm water runoff system components providing access convenience is generally an infeasible approach to fulfillment of property protection objectives.

- To promote a philosophy for the design of residential storm water runoff systems which anticipates the impact of alternative design solutions within both the land subdivision and the overall drainage basin.

Residential storm water runoff systems are not restricted in their design or impact to the immediate tract of land which they serve. Each is a part of a basin-wide drainage system and must, at a minimum, accommodate storm water flowing into the tract from upstream sources and mitigate the impacts of the outflow on downstream properties.

- To provide a methodology for determining the type and degree of analyses necessary to derive the optimum design solution.

To a large degree it is only in recent years that the cumulative impact of subdivision drainage in a basin has been assessed with a concern for basin-wide runoff management.

- To provide guidance toward identification and selection of alternative solutions to drainage problems which utilize and preserve, to the extent possible, desirable existing natural systems.

This has led some local ordinances to require that storm water runoff rates after development not exceed predevelopment runoff peaks, both to aid in erosion control and to decrease the probability of downstream flooding. This goal rarely is fully attainable.

- To encourage the design of systems which will minimize potential erosion and sedimentation problems.

- To encourage the design of systems which respond to the need to maintain or enhance ground water resources, including ground water quality, except where land stability might be impaired.

Practices suggested herein should not increase localized capital costs for development of quality storm water systems. They should reduce cumulative downstream drainage construction costs by comparison with the effects of past practices that forced rapid runoff from land developments. The suggested practices are not new but their optimum implementation often requires reevaluation of the basic philosophy of storm water runoff system design. Changes in philosophy may produce additional alternatives for design solutions which this document may not cover. It is hoped that additional alternatives will achieve the primary goals of safety, economy and the enhancement of residential environments.

- To encourage the design of systems which will reduce capital and environmental costs to the community.

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- To encourage the design of systems which will minimize potential pollution from residential surface drainage.

- To encourage system designs which conserve materials.

- To encourage continuing development of additional methods and practices designed to enhance storm water management contributions to life and environmental quality.

- To encourage continuous improvement of regulatory practices and policies, at all levels of government.

- To summarize recent advances in practice for the benefit of professionals not routinely involved in drainage design.

The design of residential storm water systems can utilize various methodologies to arrive at solutions or alternatives for the drainage plans. Differences in runoff management philosophies and in environmental conditions should be carefully evaluated in selecting methodologies to be used. The scale of development and the size and physical characteristics of the drainage area affect selection of methods, as do climatic characteristics. While certain methods may be desirable for assessing small sites with simple drainage patterns, they may be inappropriate for larger sites with more complex patterns. Conversely, the methods available for assessing large scale or basin-wide storm water systems may be too complex, costly and/or inefficient to be useful for smaller sites, and often fail to consider important micro-scale details and alternatives. No one method or solution is possible for all areas. This document will suggest some logical methods of analysis for selection of optimum localized approaches to storm water management. Inherent in the philosophy regarding those choices is the basic need for practical conservation of natural systems while providing for safety and convenience in land development.

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PRINCIPLES

General

Future problems can be minimized or avoided if all political jurisdictions within a drainage basin collaborate to define and implement optimum analytical methodologies, standards and regulations pertaining to drainage systems and land development.[51]

- Local government should study and develop master plans for each drainage basin within its jurisdiction which may be impacted by development. Optimally, contiguous communities will collaborate to master-plan drainage basins that extend across jurisdictional boundaries.

- All individual land development proposals should include storm water runoff system plans that will be compatible with any basin-wide master drainage plans, and that anticipate and provide for potential effects of upstream development on the proposal area and on downstream areas.

The design of a storm water system must consider convenience and safety both at the subdivision level and at the drainage basin level. Cumulative basin-wide effects of proposed land development practices should provide the basis for decision-making, rather than the generally minimal incremental effects of individual land developments.

- Storm water runoff systems should be designed to assure provision of both major and minor components which will serve specific access convenience and property protection objectives.

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Storage

- The design of permanent and temporary ponding and/or storage should be an integral part of the overall development planning process, and should consider opportunities within the open space and landscaped areas for the creation of such facilities.

When provision of storage is being considered, the designer should verify that attenuation of the runoff peak will not aggravate any potential downstream peaking conditions.

- Storm water runoff systems should be designed to facilitate aquifer recharge when it may be advantageous to compensate for ground water withdrawals. Conversely, designs should avoid recharge where groundwater effects might be harmful.

- Design of permanent storage facilities should consider safety, appearance, recreational use and effective, economical maintenance operations, in addition to the primary storage function.

Storage should not be created by happenstance or strictly in response to aesthetics. Storage must be rationally planned to accomplish its intended functions. Improperly located storage may create its own flooding problems or aggravate others.

Open Channels

- Natural overland flows, and open channel and swale routings should be the preferred alignments for major components of a residential drainage system.

Open channels and swales should harmonize with the natural features of the site. They should relate closely to individual lots so that occupants will not be tempted to use them for disposal of lawn clippings or other debris or wastes. Provisions must be made for maintenance on a routine basis to assure that open channels can function at or near design capacity. The utilization of open channels must be carefully evaluated. They may become depositories for debris if installed in neighborhoods not having a strong pride of ownership. The *blue-green* approach can help make a channel into an aesthetic focal point and discourage its abuse.

- Open channels and swales should be routed and designed to avoid or minimize safety hazards.

- Alignment of open components of a drainage system must be coordinated with the design of lot and street patterns and grades.

Generally, street and lot patterns and grades should be designed around natural drainage routings, if excessive land development expenses are to be avoided and environmental values preserved and enhanced.

Streets and Curbs

- Storm water management systems, street layout, lotting patterns, and the horizontal and vertical locations of curbs, inlets and site drainage and overflow swales should be concurrently designed.

Residential streets may be broken down into five classifications which may be utilized in the determination of safety and convenience associated with storm drainage considerations.[34] Each of the five classes — place, lane, subcollector, collector and arterial — has its own limitations on the depth of flow in gutters and spread of water across the pavement. Arterial streets should remain as free of water as is practical. The incidence of high traffic volumes and speeds and probable pedestrian traffic preclude any appreciable spread of water from the standpoint of both safety and convenience.

- The depth of flows in gutters and the allowable spread of water across the pavement should be consistent with the classification of the street based upon its anticipated use and traffic load.

Depth and velocity of runoff flows in the gutters (if any) on places and lanes must be given careful consideration due to the likely presence of children shortly after the end of the rainfall. Prudence suggests that safe velocities for pedestrians, especially small children, will be substantially less than ten feet per second.

- Appreciable amounts of runoff usually should not be permitted to flow across an intersection under normal rainfall conditions.

- The maximum velocity of flow, in the deepest part of the gutter under "convenience" design conditions, should not exceed ten feet per second.

Storm Water Inlets

- The number and spacing of inlets should be carefully regulated.

Consideration should be given to:
1. Inlet hydraulic capacities as limited by gutter gradients and cross sections.
2. Peak flow and time of concentration.
3. Erosion, debris and potential inlet blockage.

- Inlet design should consider pedestrian and bicycle safety as well as hydraulic efficiency.

Grated inlets will generally prove more hazardous and more subject to debris blockage than properly designed side-opening inlets.

- Sediment traps should not be designed into the inlet box. Inlet boxes should be self-scouring, even under low-flow conditions.

The use of enclosed components should be minimized to the extent consistent with (1) the ability of the existing natural systems to accommodate storm runoff, and (2) the degree to which the local public will accept and act responsibly toward open channels.

Enclosed Systems

- Enclosed components of a storm water runoff system should help manage storm water, not just dispose of it.

- Energy dissipators and other outfall protection should be designed and installed where enclosed drains discharge onto erodible soils.

- Conduit sizes of enclosed components of a drainage system should be selected by use of computed hydrologic and hydraulic data.

Other

- Erosion from storm water runoff should be minimized by appropriate design within the system, but erosion control or prevention generally should be achieved at the source if downstream sedimentation problems are to be avoided.

Siltation (sedimentation) ponds should be installed at the start of construction, but only where the soil's particle sizes and specific gravity are sufficiently large to assure entrapment of a significant proportion of eroded materials. Where sedimentation ponds foreseeably will have only limited effectiveness, erosion control at the sediment source should be emphasized. Direct flows from parking lots, streets, and roofs to natural water courses should be minimized. Where practical the outflow from small parking lots and roofs should be sheeted across turf. Detention storage should be incorporated in their design, whenever feasible.

- Construction, amortization, maintenance and operating costs are integrally related over time and their initial *present value* should be minimized.

DESIGN CONSIDERATIONS STORM WATER RUNOFF ANALYSIS CONSIDERATIONS

Storm water runoff is the water flowing over ground surfaces during and immediately following a rainfall. In specialized cases storm water runoff may be augmented by ground water flow and melting ice and snow. The runoff passing a particular point is the total rainfall at that point less the amounts of infiltration, transpiration, surface storage and other losses.

The primary goal of storm water runoff management is to assure the provision of facilities to control storm water runoff in ways which will minimize hazards to life. In addition, such systems should reduce inconvenience and minimize hazards to property. Achievement of such a system requires careful estimation of hydrologic factors at controlling design points in the system and includes the siting of property improvements in relation to all potential hazards. The primary factors are discharge rates, runoff volume, flow velocities, stage-discharge characteristics, maintenance of downstream flow conditions and water quality.

Initial planning for a residential subdivision should begin with a study of the total drainage area. The major components of the system (which should be readily identifiable; e.g. streams, large depressions, existing lakes and ponds) should be located and their potentials for storm water management assessed. Utilization of storage facilities should be given particular attention, as they can often significantly reduce the in-place cost of the system. Storage facilities are not inherently beneficial unless they are properly located and designed. Improperly designed or located ponds or recreational lakes may be undesirable.

In this initial planning phase, existing plans for storm water management—or the lack of such plans—should be assessed both as to the effect of the subdivision drainage on basin-wide drainage and vice-versa. Preliminary decisions should identify acceptable levels of temporary inconvenience to residents, such as ponding at inlets or limited storage in swales or depressions.

It may be desirable or necessary to estimate amounts of runoff at various design points within the system prior to planning street layouts and system details. Runoff estimates can range from a single point estimate—e.g. peak flow rate at the discharge point(s) from the proposed subdivision—to normal or integrated hydrographs, which account for varying flows, over time, at various points in the drainage system.

The selection of controlling design points depends upon the methodology employed to evaluate rainfall and runoff rates, on the component of the system under consideration, and on the specific local terrain and its existing or planned development characteristics. The major components of the system are outfalls, storage ponds, reservoirs, large channels (open or closed), emergency overflow routes, natural streams and others. The minor components include inlets, drainage swales, storm sewers and feeder pipes, and minor drainage-way crossings.

The degree of sophistication used in the runoff analyses depends on the size and complexity of the drainage area under consideration, the available flexibility in site improvements to avoid flooding losses, the nature of potential losses, and the types

of drainage facilities to be incorporated in the design. It should be emphasized that sensitive planning in the development of a storm water runoff system which maximizes the use of natural elements can dramatically reduce initial capital costs and future maintenance costs of the system. The storm water runoff system design should also be correlated with the earliest design and layout of the street system. The street system is an integral component of the storm water runoff system and its coordination with drainage design is essential to conserve costs, avoid problems, and enhance the neighborhood.

There are a wide range of analysis techniques available for guiding the design of storm water runoff systems. The choice of technique must be suited to the size and complexity of the area, the degree of safety and convenience sought, and the cost factors involved. Regardless of the techniques selected to guide the design the following factors must be considered:*

1. Rainfall
   a. historic
   b. predictable future
   c. bases for design
2. Drainage Area Characteristics
   a. at the site
   b. downstream
   c. upstream
   d. basin-wide
3. Land Use Characteristics
   a. present
   b. future—short term
   c. full development
4. Design Options
   a. on site detention/storage
   b. overland flow
   c. channel capacity; volume/storage
   d. storage, detention, routing
5. Risk Analysis
   a. to life
   b. to property
      (i) on the site
      (ii) downstream
      (iii) upstream
6. Costs
   a. initial
   b. amortization
   c. operation
   d. maintenance
   e. replacement
   f. *inconvenience*
   g. flood damage

* Local government should develop basin-wide drainage studies to which individual sites can relate their specific designs.

Review of Analysis Techniques

The quantification of expected rainfall generally is a prerequisite to storm water runoff analyses. Rainfall estimation permits approximation of runoff discharge rate, volume and stage.

A rainfall event is a random occurrence—no two events are alike. All analysis techniques must therefore begin with a description of historical rainfall events which will be used in the analysis. Ideally, an analysis would be able to accurately describe the management of a wide variety of natural rainfall events with all their differences and complexities. The degree of refinement of analysis techniques and data precludes this ideal.

Rainfall quantification is achieved through an analysis of historical records and translation into a synthesized description which approximates a natural event. This description has three parameters: intensity—how much water; duration—in how much time; and frequency—how often this situation occurs. More sophisticated analysis techniques will use many sets of parameters. The National Weather Service publishes reports on rainfall frequency, intensity and duration for many cities. Their local offices can provide up-to-date information and references.

The following section is a brief summary of the prime analysis and design techniques currently used in the design of urban storm water runoff systems. Past designs of storm water runoff systems have most commonly been based on the Rational Method for rainfall runoff analysis, and steady rate flow equations for sewer flow analyses.[16, 52] The limitation of these approaches in the design of relatively complex urban systems under dynamic flow conditions is well recognized.[25] A number of mathematical models have been developed recently to aid the design engineer in his task. The decision as to what level of sophistication is desirable and, indeed, achievable must be made for each project. There are no hard and fast rules as to what the "optimum" technique might be in a general sense. The decision must be made in the light of the size of the drainage basin, type of development under consideration, terrain variables, natural stream systems, aesthetic goals, drainage codes, data availability and so on. The primary techniques of practical importance are reviewed below with their merits and problems briefly noted.

Quantitative estimates of runoff in a given drainage system or from a watershed or drainage area can be made by using one of four basic techniques, or combinations thereof.

Hydrologic Simulation Models

For decision-makers, designers and operators, a comprehensive mathematical computer simulation program that models quantity (flows) and quality (concentrations) during the total urban rainfall runoff process can be an invaluable tool. Such a model can give a good representation of the physical system. It can also serve to evaluate the physical and cost effects of alternate schemes of storm water management or pollution abatement procedures.

An urban runoff model in its elementary form is simply a group of mathematical expressions that simulate the processes of the conversion of rainfall to runoff. Additionally, it may realistically reflect dry weather flow, infiltration, treatment and storage, and water quality parameters. Models can range from the crude approximations of the Rational Method to the solution of many simultaneous differential equations. Nearly all applications of detailed models require a high speed digital computer.

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The physical characteristics of the tributary area and the drainage system (size, slope, land use, imperviousness, sewer characteristics) must be embodied to some degree in the input to all models. The extent of data and processing required varies with the model employed. Much of the data reduction is relatively straightforward (e.g. tabulation of diameters, slopes, lengths of a sewer system).

Many models are designed such that if all input parameters are reasonably accurate, the physics of the processes are simulated well enough to secure satisfactory results without calibration. However, neither the input data nor the numerical methods are accurate enough for most specific areas. Additionally, there are computational procedures within some models that have been developed from limited data. This is particularly true of the quality components of models. Consequently, it is normally essential that some local verification-calibration data be available for a specific application site to lend reliability to the predictions of any urban runoff model. Calibration of most models against measured rainfall amounts and associated runoff flows can be accomplished through adjustment of the input parameters. Quality measurements, to be of calibration value, require time-related flow measurements.

There are three categories of models: planning, design/analysis, and operation. Such models have somewhat different characteristics and various models overlap on objectives to some degree.

Planning models give an overall assessment of the urban runoff problem and may also provide estimates of the effectiveness and costs of alternative storm runoff management procedures. Relatively large time steps (hours) and long-term simulation periods (months and years) generally characterize these broad-objective models. Minimum data requirements and low mathematical complexity are typical. Long-term planning models may also generate initial conditions for input to design models. The effects of urbanization are readily computed.

Design models generally involve the simulation of selected storm events with short-time steps such as minutes (the shortest interval for which Weather Service data is generally available is 5 minutes) and short simulation periods (hours). Several of these can be used for a complete description of flow, storage and pollution routing from the point of rainfall through the total drainage system and into the receiving waters. As with planning models, design models can be used to arrive at least-cost abatement procedures for both quantity and quality problems. Data requirements can be moderate to very extensive depending on the particular model involved.

Operational models help resolve actual control decisions during a storm event. From telemetered rain and flow gauge signals as inputs to the model, estimated system responses are projected a short time into the future. In-system storage, regulator settings, or diversions, or combinations of these, may then be employed as control options. Informational needs for operations models are much greater than for either planning or design models. A number of models have been developed and variations and improvements are almost continuously evolving, making it difficult to characterize them in any lasting way. However, several comparisons of model characteristics were reported in 1974 and 1975, and the reader is referred to them for details.[3, 4, 13, 26, 27, 50]

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Quality aspects will become increasingly important with the growing emphasis on minimizing the ecological impact of all developments on their surroundings. In those models accommodating water quality considerations, components considered range from erosion rates and sediment loads to biochemical oxygen demand, nitrogen and phosphates.

Hydrologic modeling is as much an art as a science and thus can never be, and need not be, perfect or complete. Discussions of the current (1974-75) use of storm water models are in Huber APWA, 1975; and McPherson and Schneider WRR, 1975; and each of these has a good coverage of related recent literature.[13, 27]

Unit Hydrograph Techniques

A unit hydrograph is the runoff hydrograph resulting from one inch of excess rainfall applied to a given drainage basin over some specified time interval.

Hydrographs for a given storm can be computed from the unit hydrographs through a simple scaling and lagging operation. The unit hydrograph itself is derived either from analysis of historic records or through a regression equation(s) based on watershed characteristics such as area, length and slope. Although unit hydrograph techniques have been widely used for rural watersheds, their use in urban areas is limited by data availability. Several regions in the country have performed the necessary studies, however, to enable acceptable synthetic unit hydrographs to be derived for given development patterns.[12, 22, 32, 40] Reliability of these hydrographs reportedly is good in the regions for which they were developed.

Unit hydrograph techniques yield the total runoff hydrograph at various locations within the drainage system and can be combined with suitable reservoir simulation techniques to evaluate the operation of storage as a control measure in the system.

Regression Models

Regression models, of which many exist, seek to relate a causal factor such as rainfall and/or watershed characteristics with an effect such as peak discharge, runoff volume or annual mean flows, through statistical correlation.[32] Their applicability to urban storm water systems is minimal, mainly because of the lack of adequate historic data for regression analysis and because of the constantly changing watershed characteristics where urbanization is in process. These models do not in general predict the total hydrograph and are of limited use whenever storage in the system is being considered.

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Empirical Formulas

A wide range of empirical formulas to relate runoff to rainfall have been developed over the years. The oldest of these is the Rational Method, which together with its derivatives, forms the basis for much of urban hydrology as currently practiced. The Rational Method is presented below in some detail, since it is the most popular method and may be useful in the detailed design of the minor components where a high degree of accuracy is not required.

In the Rational Method, the peak of runoff, Q, in cubic feet per second, is computed as:

$$Q = CiA$$

in which C = runoff coefficient representing the characteristics of the drainage area.

i = average intensity of rainfall in inches per hour for a duration equal to the time of concentration, t, for a selected rainfall frequency.

t = time in minutes after the beginning of rainfall for runoff to peak at the point under consideration.

A = size of drainage area in acres.

Guidance for selection of coefficient C is provided by Table 1 which shows commonly used values in accordance with the type of development and local soil characteristics. A composite C value should be weighed in proportion to the acreage in each part of the subdrainage area.

Common practice in determining the time of concentration, t, to a given design point has been to specify a fixed time for the flow to reach the first inlet and then to add the time of flow in the pipe system to that point. The time of concentration in overland flow can be estimated from Figure 2, which was extrapolated by Wright-McLaughlin Engineers.[51] In determining the time of concentration for downstream locations, paved gutter, swale or channel velocities may be estimated by making a preliminary estimate of their discharges and using open-channel flow charts published by the Bureau of Public Roads.[5] Travel time is then computed using these velocities.

Appropriate values of rainfall intensity, i, may be available from local studies or obtained from the intensity/frequency/duration data.[46, 47] Coefficients usually used in the Rational Method must be revised if the method is used to forecast peak runoffs from very infrequent rainfall events.

For more definitive information regarding the Rational Method and its appropriate application, several works are available.[7, 25, 32, 52]

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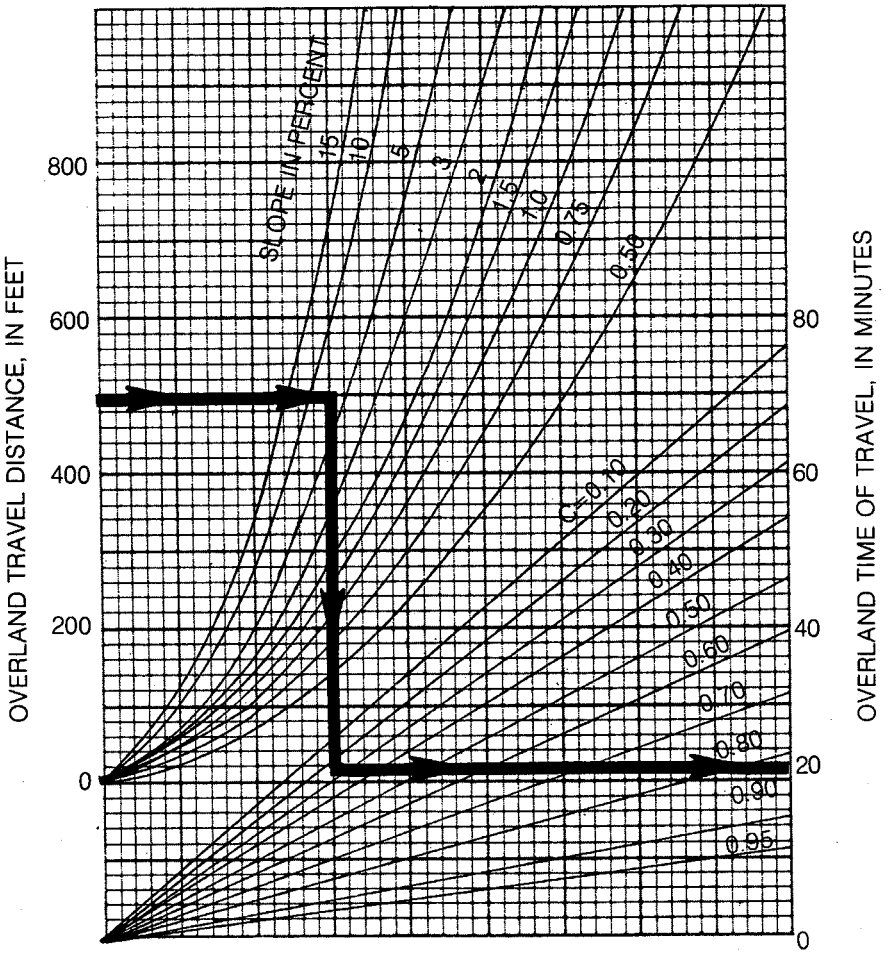

Figure 2
Relation of overland time of travel to overland travel distance, average overland slope, and coefficient C —for use in Rational Method.

Source:
Wright-McLaughlin Engineers/
"Airport Drainage,"
Federal Aviation Administration
Washington, DC 1965.

Table 1

RUNOFF COEFFICIENTS

Description of Area	Runoff Coefficients
Business	
Downtown	0.70 to 0.95
Neighborhood	0.50 to 0.70
Residential	
Single Family	0.30 to 0.50
Multi-units, detached	0.40 to 0.60
Multi-units, attached	0.60 to 0.75
Residential (suburban)	0.25 to 0.40
Apartment	0.50 to 0.70
Industrial	
Light	0.50 to 0.80
Heavy	0.60 to 0.90
Parks, cemeteries	0.10 to 0.25
Railroad yard	0.20 to 0.35
Unimproved	0.10 to 0.30

Character of Surface	Runoff Coefficients
Pavement	
Asphalt or Concrete	0.70 to 0.95
Brick	0.70 to 0.85
Roofs	0.70 to 0.95
Lawns, sandy soil	
Flat, 2 percent	0.05 to 0.10
Average, 2 to 7 percent	0.10 to 0.15
Steep, 7 percent or more	0.15 to 0.20
Lawns, heavy soil	
Flat, 2 percent	0.13 to 0.17
Average, 2 to 7 percent	0.18 to 0.22
Steep, 7 percent or more	0.25 to 0.35

The coefficients in these two tabulations are only applicable for storms of five to ten year return frequencies, and were originally developed when many streets were uncurbed and drainage was conveyed in roadside swales.

For recurrence intervals longer than ten years, the indicated runoff coefficients should be increased assuming that nearly all of the rainfall in excess of that expected from the ten year recurrence interval rainfall will become runoff and should be accommodated by an increased runoff coefficient.

The runoff coefficients indicated for different soil conditions reflect runoff behavior shortly after initial construction. With the passage of time, the runoff behavior of sandy soil areas will tend to approach that of heavy soil areas. If the designer's interest is long-term, the reduced response indicated for sandy soil areas should be disregarded.

Source: *Design and Construction of Sanitary and Storm Sewers*, ASCE Manual of Practice No. 37, 1970. Notes revised by D. Earl Jones, Jr.

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STORAGE CONSIDERATIONS AND CRITERIA

One of the primary factors to consider in storm water runoff management is storage. The availability or absence of facilities for temporary or permanent runoff storage is an important element in selecting the analysis methodology and establishing the underlying philosophy for design. As important as storage is, it should not be seen as the cure-all for storm drainage design. It is likely that in many instances the storage capacity required to assure both maximum safety and convenience will not be economically feasible; but, this amount may still be desirable.

Provision of storage can reduce peak runoff rates; aid in the replenishment of the water supply; provide an attenuation mechanism if storm water is to be treated; lessen the possibility of downstream flooding, stream erosion, and sedimentation; and can be used in the development of upstream areas to avoid increasing the runoff peaks which impact existing downstream facilities.

Storage occurs naturally on a small scale in most drainage areas. Natural storage is provided during overland flow in surface depressions and on wetted vegetation. Greater storage is possible where larger depressions and swales exist in the drainage area and where highly pervious recharge areas exist. Much natural storage is temporary, of small volume, and can be lost through development. This volume can be replaced by using swales, by revegetation and by utilizing special inlets that meter the outflow from planned ponding areas. Where detention storage is used, overflow routing must be provided with sufficient hydraulic capacity to assure freedom from significant downstream damages in the event of improbable runoff peaks. Large scale temporary retention storage can be used to replace storage loss due to the increase of impervious surfaces associated with development.

Rooftop and parking lot ponding are just two methods for temporarily storing and then slowly releasing this outflow of storm water. In addition, the design of percolation ground storage facilities and dry ponds may be utilized to accommodate large amounts of storm water.

Permanent storage (ponds, reservoirs and stream channels) provides maximum amounts of storage with the greatest amount of certainty. The "blue-green" approach to development, where practical, provides such storage in an economical manner consistent with environmental protection and enhancement.[18, 31]

Degrees of Storage

Different degrees of storage should be considered in residential design. The lowest degree is the natural storage provided by surface depressions and by foliage and ground cover interception of rainfall. To take advantage of this storage, natural ground cover should be maintained. Temporary, usually small volume storage can be provided for in the design of swales, pipes, and channels upstream from embankments. Outlets from temporary storage can be choked or otherwise controlled to attenuate peak outflow, but safety and protection of adjacent and downstream properties should be assured by conscious design of overflow capacity and siting of

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damage-susceptible improvements. Facilities may be designed specifically for storage. Roof-top and parking lot ponding, recharge basin storage and normally dry ponds, may be employed in a storm water runoff management system. Permanent storage, especially as provided by use of the "blue-green" approach may be particularly useful. The comparative amounts of storage that may be achieved using different combinations of facilities will vary. The designer of storage should determine that the cost of storage provisions will not exceed benefits accrued and that the designs will be economical to maintain. The residential storage system should be coordinated with watershed and regional storage plans for flood control, water supply and recreation.

Factors to Consider

Permanent ponds and lakes have multiple benefits including short-term and long-term enhancement of property values and the landscape; possibilities for boating, ice skating, fishing and swimming; and habitat for resident and migratory wildlife. Proper maintenance and protection from health and safety hazards and positive control of visual appearance must be integral parts of storage design and planning. Permanent storage sites must be evaluated to assure their capability to retain water and to determine if an adequate natural or artificial supply of water is available year round to replace evaporation and infiltration losses.[31] Eutrophication, or declining water quality, can be a very serious problem in shallow lakes.[35]

Excessive lowering of the water surface during dry spells can decrease the aesthetic and recreational value of storage. Siltation of permanent ponds may result in loss of storage capacity or undesirable weed growth. Control of erosion is a major consideration in the design, construction and maintenance of storage facilities. General information on residential lakes is available from the U.S. Geological Survey (USGS).[35]

Temporary storage in "dry ponds" can be used effectively in areas designed specifically for that purpose; water can accumulate in these areas during and for a short period after storms. Since these facilities are designed to completely drain after the storm, they can serve a dual purpose. Golf courses, recreation fields and parks are examples of compatible uses. Temporary storage can also be obtained in parking lots, on rooftops or in underground seepage pits. Reference[31], sponsored by the Office of Water Resources Research and published (1974) by the American Public Works Association on "Practices in Detention of Urban Storm Water Runoff" can be consulted as a current investigation of some of the concepts, techniques, applications, costs, problems and legal aspects of urban storm water storage.

Parking lot storage has been combined with percolation trenches filled with coarse gravel which intercept some runoff from the lot. Some experimental parking areas on non-cohesive sub-grades are being constructed with a porous pavement that allows direct recharge of ground water. These types of storage may prove advantageous in some built-up areas where large amounts of open spaces are not economically available.[31, 48]

Rooftop Ponding

The structural capability of the roof system must be considered when designing a temporary rooftop storage system. A three-inch water depth is equivalent to a load of 15.6 lbs./sq. ft. which is less than most current building code requirements for live loads. Overflow mechanisms should be provided so that there is no danger of overloading during major storms. Special considerations of roof watertightness may be necessary since storage may be effective only if the water is detained for a significant period of time. Many flat roofs already pond significant amounts of water, although not by design, which should be considered when evaluating drainage conditions in established commercial areas.

Parking Lot Ponding

Parking lot ponding should be arranged so that pedestrians can reach their destinations without walking through ponded water. The ponding should be relegated to those portions farthest from the use served or to overflow parking areas, and should be a reasonable portion of the total area so that sufficient parking remains available for use. The maximum design depth of ponding can vary depending upon the location. A seven-inch design depth is not unreasonable where access to parked vehicles will not be impaired. An overflow outlet should be provided so that runoff from major storms will be limited to a seven-inch depth. Debris may accumulate at outlet drains, which may reduce the capacity of the drain and become unsightly, so provisions must be made for periodic cleaning. Thought should be given to the use of semi-paved/semi-grassed areas for overflow parking which will permit infiltration of rainfall and reduce the total runoff associated with parking lot pavements.

Percolation Storage

Under favorable conditions of a deep, permeable subsoil, runoff may be discharged into trenches back-filled with sands and gravels chosen and placed in accordance with sound graded filter principles. So long as the system does not become clogged by sediment, it will accomplish the dual purpose of disposing of at least part of the storm water and of recharging ground water storage. Percolation tests must be run on the stratum at the bottom of the proposed trench. The rate of percolation will then control the outflow from the trench (exfiltration) provided the ground water table is below the trench. An excess of inflow rate over percolation rate will result in temporary storage of water in the voids in the filter materials. Design of percolation storage must consider the potential effects of clogging of voids over a period of time and reduced load carrying capacity of pavement subbase in a saturated condition. An overflow channel should be provided to carry off excess storm water when the percolation trench capacity is exceeded. Under appropriate conditions, piped storm drains can be open-jointed or perforated to permit exfiltration.

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Lakes and Ponds

The design criteria for storm water runoff storage in lakes and ponds are numerous. Hydrographs of runoff from both frequent and unusual storms must be evaluated. For major installations, stream flow measurements in advance of the planning stage may be desirable.

The retaining structure, usually an earth dam except where storage is created by further excavation of a low point in the site, must be designed and constructed according to the best accepted practices for such structures. The outlet works:

- must be designed to release the allowable flow in the downstream channel at the storage level established for the minor storm;
- must include an overflow spillway to handle potential peak runoff from major storms so as not to cause serious damage to adjoining and downstream properties; and
- must provide for draining of the lake or pond.

Adequate provision must be included for energy dissipation and erosion protection where outlet works discharge into the outfall channel. The outlet channel must be capable of handling the released flows without being damaged during a minor storm event and, where practical, within acceptable damage limits during a major storm. It is often completely impractical to avoid damages from a rare major storm.

The probable quantities of sediment coming off the watershed during the life of the facility should be estimated, taking into account the degree of erosion control likely to be achieved during and after construction. Temporary structures may be necessary to trap sediment before it enters the storage facilities during the construction phase. Planning of the facility must recognize loss of storage capacity from silting or anticipate occasional sediment removal. In the case of permanent lakes the maintenance of a minimum level should be ensured by the inflow from the watershed (or by other augmentation) during prolonged dry periods and by the capability of the pool bottom to retain water.

The design of storage facilities to meet these criteria requires the services of engineers experienced in hydrology, hydraulics and earth structures. Aesthetic considerations suggest the services of a landscape architect. The engineering economy aspects of the design are especially important since considerations of alternative design possibilities as they affect the costs of construction and maintenance, reduced to average annual costs, can substantially lower the ultimate cost to the public.

"Blue-Green" Storage

Where streets must cross drainageways, there is an opportunity to utilize the roadway embankment as an effective dam for only moderate additional cost. Such dams are the heart of the "blue-green" development approach.[18, 35] Embankment quality and stability must be assured as for any dam, but the entire roadway and embankment may serve as the overflow spillway. This necessitates continuous erosion protection from the upstream point on the embankment face, where approach velocities become significant, to below the downstream toe of the embankment. Such dams may be used to provide a chain of lakes as neighborhood focal points that enhance long term neighborhood values and stability. Potential overflow areas usually should be developed as green spaces. If left substanially open to public access and view, the blue-green spaces created can enhance entire neighborhoods rather than just immediately adjacent properties.

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Other Storage Considerations

In creating urban ponds or lakes, certain special considerations are worthy of mention.

- Access to and along shorelines may be effectively limited to desired locations by planting thorny decorative shrubs.
- Lake bottoms within ten feet of the shore should be so graded that water depth normally will not exceed eighteen inches, to simplify immediate rescue of small children.
- Extensive areas of shallow water, especially in upper reaches of the lake, should be avoided to prevent undesirable weed growth.
- Dense plantings of shrubs that will act as barriers to automobiles are appropriate where vehicles might otherwise run into the lake, especially at night.
- Paved walkways roughly paralleling the shoreline, low-level night lighting, fixed benches, floored rain shelters and sensitive landscaping can add considerably to the charm of a lake or pond setting, and to the desirability of the surrounding neighborhood. Massive plantings of seasonally colorful shrubs, such as azaleas, redbud, dogwood or Japanese maple, can help publicize an area and create particular pride of ownership throughout the neighborhood.

STREETS AND CURBS

The primary purpose of residential streets is to provide vehicular access to homes and community facilities. Vehicles using the streets will vary from routine automobile traffic to larger delivery and service trucks and emergency police and fire vehicles. Streets also have several secondary functions. One is to provide routes for pedestrian and bicycle traffic; another, more relevant, is to collect and convey storm water runoff.

Planning a drainage system should be done simultaneously with street layout and gradient planning, and careful consideration should be given to the following:

- The functions of streets as parts of the storm water management system.
- Street slopes in relation to storm water capacity and flow velocity in gutters and/or street swales.
- The location and sizing of street culverts. Culverts may be sized to create temporary upstream storage if there is proper consideration of earth bank stability and potential overflow effects during major flood conditions.
- Location of streets in relation to natural streams, storage ponds and open channel components of the system.
- Location and capacity of inlet points to pipes in relation to gutter slopes, the spread of water across streets and the flow of water across intersections.
- Coordination of street grades with lot drainage. Positive slope away from all sides of the house must be accomplished. Lot drainage becomes difficult when there is less than 1½ to 2 percent (usually from 14 to 24 inches) fall from the earth grade at the center rear of the house to the street curb at the lowest front corner of the lot.

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Table 2

DRAINAGE ADVANTAGES AND DISADVANTAGES OF STREET CROSS SECTIONS

Type of Cross Section	Advantages	Disadvantages
Normal crown with curb and gutter.	• Center lane clear during minor storms. • Traffic barrier on both sides. • Driveway ramps behind curb keep water confined.	• Curb and gutter increases cost. • Must have longitudinal grade to assure drainage. • Concentrates water and increases downstream flooding.
Cross slope	• Reduces number of inlets and manholes. • Decreases earthwork. • Fits better with natural topography. • Traffic barrier on both sides.	• Water from streets intersecting on high side must be picked up as it will overflow intersection rather than "run around corner." • Maximum width of sheet flow. • Hazardous if sheet flow from rain or snow melt freezes. • Flow capacity can be achieved in only one gutter.
Asymmetrical crown	• No cross flow until crown is overtopped. • Lessens hazard of icing. • Fits better with natural topography. • Traffic barrier on both sides.	• Limited flow capacity on upper side. • Allows less cross fall than section above. • Rides "funny"
Drainage Swales	• Lowest cost where usable. • Allows for infiltration of runoff in channels. • No water confined on pavement so freer movement of traffic during storms. • Can be merged into the natural topography. • Fewer underground storm drains. • Slows down the runoff because of much lower velocities in the grass-lined channel and because considerable storage must be filled before overflow.	• Not advisable where small lots require frequent driveway culverts. • More of a maintenance problem on shoulders and channel. • May require wider right-of-way to accommodate flat side slopes on drainage swales. • Less adaptable to sidewalks, but compatible with off-street walk systems.

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Street and Curb Cross Sections

There are typical street cross sections in common usage. The advantages and disadvantages of each from the drainage standpoint are summarized in Table 2.

The most commonly used cross section is a center crown sloping at a rate of one-quarter inch per foot toward a swale or curb and gutter, on each side of the street. Sidewalks, if present, can be placed against the curb or, as is more common, more desirable and necessary in wet or snowy areas, can be separated from the curb by a planting area.

On a sidehill section, the street section can be designed with a straight crown or with a crown at the one-third point with a slope toward each curb. This section should not be used on collector streets where speeds are higher because the ridge tends to make car control more difficult. The cross slope on roadway sections should not exceed five percent in any case.

A street cross section with drainage swales replacing curb and gutter, and often with no sidewalks, is currently being used for many residential streets. This approach is compatible with development concepts which utilize path and walkway systems and low traffic volume streets such as cul-de-sacs, loops and courts.[34] Such practice is a return to urban practice, common to the early part of this century, which provided about 40 acre-feet of streetside storage per square mile. Elimination of that storage and installation of curbs during the past 35 years has created significant urban flooding problems where none previously existed, by accelerating downstream runoff peaking.[53]

Since slip forming of curbs and of curbs and gutters often is generally used for construction economy, it is important that uniform curb and gutter sections be used as much as possible. The hydraulic capacities of the straight and battered curbs are about the same and they lend themselves to side-opening curb inlets. The rolled or mountable curb has a lower hydraulic capacity and requires a transition to a vertical face to accommodate a side-opening curb inlet; flexibility in accommodating field changes in driveway locations is a characteristic of rolled curbs that should be considered where their limited hydraulic capacity is not a significant issue.

Hydraulic Capacity

The hydraulic capacity of a street section to convey water can readily be calculated by the Manning Equation in the following form as developed by Izzard:

$$Q = 0.56 \frac{Z}{n} d^{8/3} S^{1/2}$$

In this equation the symbols are defined as follows:

- Q = discharge in cfs
- Z = $1/S_x$ where S_x is the cross slope of the pavement
- d = depth of water in feet at face of curb
- S = longitudinal grade of street
- n = Manning's roughness coefficient

Experiments have proved that this form of the equation is more accurate than would be obtainable by computing the hydraulic radius based on the wetted perimeter and the area of the cross section. The equation applies directly to a section having a straight cross slope.

The compound section, with the gutter having a Z-value of 12, is widely used for streets because the hydraulic capacity for a given spread of water on the pavement is substantially increased. (About 30 per-

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width.) This is because the velocity at any point on the cross section is directly proportional to the two-thirds power of the depth, which is increased by steepening the gutter cross slope.

Since more water is concentrated close to the curb the compound section also increases the capacity of inlets to intercept flow. To facilitate computation of inlet capacity, the compound section can be converted to an equivalent straight cross slope having the same capacity as the compound section for a given depth "d" measured from the gutter flow line.

The equivalent straight-slope section can be computed by the following equation:

$$Z_3 = Z_1\left[1 + (Z_2/Z_1 - 1)\left(\frac{T\text{-}W}{T + W(Z_2/Z_1 - 1)}\right)^{8/3}\right]$$

in which

Z_3 = reciprocal of cross slope of equivalent section

Z_1 = reciprocal of cross slope of gutter

Z_2 = reciprocal of cross slope of pavement

W = width of gutter in feet (this often will be identical to the width of the depression of a curb opening inlet since it is impractical to extend the inlet depression appreciably beyond the gutter width.)

T = top width of water surface

By using this value of Z_3 in the previous equation and the same value of "d" as for the compound section, the exact Z for the latter is found. The first equation given can be directly applied to a compound section by use of Nomographs.[8]

Estimating Runoff in Streets

The peak flow contributed to a gutter or swale is normally estimated by the Rational Method. Drainage areas are subdivided so that runoff contributed to each gutter or swale can be computed at the end of a block or at other points where an inlet or pick up point is required. Inlets are usually sized so that a portion of the flow is bypassed; the actual flow in the next reach of gutter includes this bypass flow. The flow reaching the second inlet is a portion of the flow contributed from its drainage subarea plus the flow bypassing the first inlet. The low point or sump inlet catches the remaining flow from both directions and must be sized accordingly.

Locations and required capacities of inlets and swales are established by computing estimated flow rates, depth and velocity of flow, and spread across street. The design of sump inlet capacity may provide a degree of outflow control from the sump storage, safely obtained, through localized temporary ponding.

Under conditions prevailing during a major storm, the storm drain system will be surcharged and the rest of the flow will be carried on the lawns, the streets, etc. Inlet capacity in this case is indeterminate but is probably somewhat less than the inlet would handle under sump conditions because of debris blockage and surcharge back pressures. It is probably safe to assume that the flow on the street would be the difference between the total runoff and the capacity of the storm drain surcharged to the level of the gutter. Since debris blockage of inlets is most likely during extreme runoff events, emergency overflow routing and analyses for runoff extremes should assume that no more than 50 percent of pipe capacity is available under these circumstances.

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Criteria for Spread of Water Across Street

The allowable spread of water across the street from the curb is limited by the criterion of maintaining two clear ten-foot moving lanes of traffic for collector streets during minor storms. One clear lane should be maintained on subcollectors, and lanes and places may have a spread equal to one-half of their width. These criteria are fully justifiable in humid areas, but may be difficult to meet in arid areas where:

- available slope is limited,
- runoff may contain considerable suspended solids,
- drainage essentially is by surface flow, and
- the public accepts the resulting inconvenience.

When a steep cross slope is used (five percent is suggested as a limit), a ten-foot spread would produce an excessive depth at the curb making it difficult to intercept the flow except with a very long curb opening inlet.

Consequently with pavement cross-sloped from three to five percent, the depth of flow at the curb should not exceed six inches.

Flow Across Intersections

The most critical situation exists where a street on a grade intersects with another street, especially a collector or subcollector. Even when the flow on the grade is severely limited, great care must be taken to provide inlets which will intercept virtually all the flow from a minor storm. Full interception may be impossible for a major storm.

A "T-intersection" requires special care because houses directly below a steep "T" stem are particularly subject to intersection overflow damage during major storms. Overflow of "T" intersections can be somewhat impeded by:

- elevating the through-curb;
- installing a higher-then-normal roadway crown on the through street; and
- using a straight-faced through-curb of 7½ inch or greater height. In severe situations, a decorative wall (low) placed behind the through-curb and landscaped will provide practical control, often more economically and assuredly than inlet construction.

Flow across collector streets should not be allowed during frequent storms. Controlled flow across subcollectors is acceptable and there are no design limitations placed on flow across lanes and places. During major storms, permissible flow across intersections will be a function of the street's traffic-carrying importance and the availability of convenient alternative access.

Ponding at Low Points in Grade

Some ponding of water at low points in the grade is inevitable, even during a minor storm, and in some cases may be desirable. However, because of the driving hazard and splashing of water on pedestrians, ponding should be minimized. This is done best by intercepting most of the flow before it gets to the bottom of the grade. In picking up most of the flow prior to the sump location, a large percentage of sediment will also be removed from the flow. This prevents sediment deposition in the gutter as velocity is checked on the decreasing grade. A curb-opening inlet at the low point in the grade is an efficient structure but must be of ample size because this is the point where debris is most likely to accumulate. Effective performance during a major storm should be assured by considering:

- damage from water overtopping curb and sidewalk
- methods of minimizing damage
- relative sizing of inlet and pipe
- overflow mechanisms

Maximum Velocity in Gutters

Water flowing down steep grades can be dangerous. For example, water flowing at ten feet per second can exert a force of 100 pounds against a flat, one-foot wide object placed across the flow. A 20-pound push at shoe level will sweep a grown man off his feet, so gutter flow can be very hazardous to a child. Aside from the safety hazard, such flows are difficult to intercept at inlets and can create difficulties, such as shooting across an intersecting street or overriding curbs and causing severe localized erosion and sometimes damage to downhill properties.

A recommended criterion is that the velocity in the deepest part of the gutter be limited to ten feet per second. This velocity is readily computed by the Manning equation using the depth at a point six inches from the face of the curb as the hydraulic radius.[41] The mean velocity for the entire cross section is not a good measure. If the calculated velocity exceeds ten feet per second, the allowable discharge in the gutter must be reduced until velocity is within the limit. The designer is then faced with the problem of where and how to reduce the runoff entering this gutter. Additional inlets could be installed upstream, but this is expensive. If possible, some way should be found to divert runoff to some path other than the steep street, preferably by a revised street layout. Future street resurfacing which will reduce capacity should be considered in the calculations.

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NATURAL DRAINAGE

Natural drainage flow techniques serve very useful functions in the control and management of storm water runoff. The primary function is to provide an opportunity for natural infiltration of storm water to the ground water supply system. Secondly, it helps to control the velocity of runoff flows, which is a necessary factor in the control of erosion and sedimentation. Thirdly, and perhaps most important, natural drainage techniques can extend the time of concentration of storm water runoff, thereby contributing to the ultimate goal of maintaining the rate of runoff at or near the levels existing prior to development. As noted earlier, street swales can provide up to about 40 acre-feet of runoff storage per square mile, thereby contributing significantly to runoff attenuation.

The achievement of the goals stated above is important. Urban and suburban areas have experienced a rise in the frequency of severe flooding and an increase in the amount of hazard and damage associated with floods at or near past levels. An important factor in this phenomenon is the rate at which storm water runoff reaches the receiving streams from developments in the drainage basin. Natural storm water runoff systems can help to control that rate and release the accumulated runoff over a longer period, thus contributing to a reduction in the rate and volume at given points in the lower reaches of the receiving streams. This is especially important where older areas downstream of new developments either have inadequate storm drainage systems or a combined sanitary and storm sewer system. Specific reduction in the amount of runoff contributed from each new development in the upper and middle reaches of a drainage basin will reduce the cumulative runoff impact of development thereby contributing to reduction of hazard and/or reduction in the need for costly supplemental systems in the downstream areas. Natural drainage systems must be properly maintained to assure their continued performance at the designed capacity. It must be noted that open channel flows in residential storm water management systems are not completely "natural" systems, although they rely heavily on existing natural features and qualities of the development site. Virtually all development will increase the amount of storm water that becomes runoff during and after an event because of the impervious surfaces used in development. Increases in runoff which change the dynamic equilibrium of natural areas used in the system mandate specific engineering solutions to conserve these natural systems and the predevelopment characteristics of the area. The creation of swales, alteration of small channel capacity or direction, changing of ground cover and the lining of existing channels with other materials, natural or man-produced are necessary in some parts of the system to achieve the desired objectives.

These alterations or improvements will have to be maintained if the total system is to function properly. The maintenance of swales and open channels in the interior areas of residential development is most critical during construction. Debris from this source, including plastic wrapping materials and other non-

biodegradable substances, can diminish the capacity of the system or effect changes in the flow characteristics of the runoff which tend to cause erosion and sedimentation. After construction, internal maintenance problems within residential areas will not be significantly higher if property owners understand that their normal maintenance responsibilities are integrally related to regular public maintenance efforts. The primary problem areas for roadside swales or open channels are along major arterials bordering residential areas or areas where non-residential uses contribute large quantities of man-made debris.

An awareness of potential problems is the first step towards their prevention, but should not be an overriding cause for rejection of a system which would produce benefits that exceed potential maintenance disadvantages.

The characteristics, function and maintenance of open channel elements should be evaluated prior to the final design of the total network which forms a residential storm water management system.

Overland Flow

In planning an open channel system, overland flow distances should be made as long as possible consistent with other constraints and requirements. Overland flow should be over and through turf or other flow retardants such as ground cover or forest litter. This is one reason why natural woods should be preserved whenever possible. Slopes of overland flow areas should be as flat as possible, but maintaining natural topography and ground cover should take precedence over regrading to achieve flat slopes.

Overland sheet flow is a significant factor affecting the peak rate of runoff reaching the first collecting channel. Gently sloping turf areas shorter than 100 feet will probably not detain runoff significantly during intense rainfalls. The runoff rate from meaningful overland flow areas will be substantially less than the rate at which rain is falling. Minor surface depressions due to irregularities in grading add further to the storage potential. In addition, the retarded passage of water provides additional time for infiltration into the soil (if permeable), thus reducing the quantity of runoff. On paved surfaces, such as on parking areas, the storage in overland sheet flow is only about one-fifth as much as on turf, but is still a significant factor. On steeper slopes, whether pavement or turf, the velocity increases and storage decreases, so that less time is required for runoff rates to become equal to the rate at which the rain is falling. Most presently available mathematical models for computing runoff include the length and other characteristics of overland flow as essential inputs.

Hydraulics for Swales and Open Channels

When runoff reaches swales and open channels, principles similar to those for overland flow should be applied. If feasible, they should be wide and shallow with a rough surface and on as flat a grade as topography will permit. In this way, storage will further retard runoff and reduce the peak flow. Flat slopes may present the problem of marshy low areas after a storm. A minimum slope should be established, based on soil permeability and the capacity of the swale or channel.

The Manning Equation is almost universally used in calculating open channel flow. Numerous aids to facilitate computations are available including computer programs. A very useful publication for those not having access to a computer is *Design Charts for Open Channel Flow.*[5] This publication includes consideration of flow in open channels and swales on mild and steep slopes. Velocity of flow in open channels and swales is dependent on rate of flow, slope, surface roughness, and cross section and can be calculated using the Manning Equation. Suface roughness and consequent velocity will depend on the quality of maintenance. Well-mown grass will have a different surface roughness coefficient than tall grass.

Control of Erosion

In designing channels for erosion control, the velocity must be estimated and compared to the allowable velocity for the material on which the water is flowing. Table 3 indicates the allowable velocities for grass channels. It should be noted that the quantity of water which can be carried in well-established, dense turf swales without erosion is surprisingly large, even for steep slopes. For urban residential drainageways, flow velocities for erosion potential evaluations should be based upon the ten-year frequency runoff event, which generally is a practical break-point between initial cost and excessive maintenance cost.

However, when the allowable velocity for a turf channel is exceeded, there are a number of alternatives to consider as shown in Table 4. They include: lining channel with an impervious material; drop structures or other velocity and erosion control measures; gravel or rip-rap bottoms; and gabions (rock enclosed in wire baskets).

The probable performance of the open channels and swales should be evaluated for major storm runoff with respect to the depth and spread of water and the erosion potential. Antecedent flow conditions resulting from previous storms are an important consideration. Open channels and swales may suffer damage during major storms, even if properly designed. The potential for incurring these infrequent maintenance costs should be balanced against the initial cost of attempting to make them "flood proof" during the design process.

It is important that open channels be constructed in accordance with plans. When intermittent channels are sodded to the depth of the expected flow, they can immediately provide protection for minor storms. It is not practical to establish turf in a drainage channel by seeding and mulching unless jute mats, or similar protective materials, are placed over the seed bed.

Flow and Erosion in Natural Streams

Maintenance of streams in their natural condition is a desirable goal. A natural stream normally adjusts its cross section and slope so that they are in approximate equilibrium and flowing bankful at the average annual peak flow rate. For greater flows, the banks are overtopped and flow also occurs on the flood plain. If the flood plain is then constricted due to development, more flow will be concentrated in the channel, probably disturbing its equilibrium and resulting in more than normal erosion. Similarly, additional erosion may result if the peak discharge is increased, even if the flood plain is not constricted. Limiting the minor storm discharge from a residential or other development to pre-developed flow rates is a means of controlling the peak discharge. The two concepts, of storage and the use of natural open channel flow, assist in this objective.

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Table 3 Permissible velocities for swales, open channels and ditches with uniform stands of various well maintained grass covers.

Cover	Slope Range Percent	Permissible Velocity on:[a]	
		Erosion-Resistant Soils (fps)[b]	Easily Eroded Soils (fps)[c]
Bermudagrass	0-5 5-10 Over 10	8 7 6	6 5 4
Buffalograss Kentucky bluegrass Smooth brome	0-5 5-1 Over 10	7 6 5	5 4 3
Grass mixture	0-5 5-10	5 4	4 3
Lespedeza Weeping lovegrass Yellow bluestem Kudzu Alfalfa Crabgrass	0-5	3.5	2.5
Common lespedeza[d] Sundangrass[d]	0-5	3.5	2.5

Original table from *Handbook of Channel Design for Soil and Water Conservation,* Soil Conservation Service, U.S. Department of Agriculture Publication No. SCS-TP-61 March 1947, revised June 1959.

[a]Velocities in excess of 5 fps to be used only where good cover and proper maintenance can be assured.
[b]Defined as CL, CH, OH, GM, GP, GC and GW (Unified Soil Classification System Designation).
[c]Defined as ML, SM, SC, MH and OL (Unified Soil Classification System Designation).
[d]Annuals, used on mild slopes or as temporary protection until permanent cover is established.

Source: *Slope Protection for Residential Developments,* National Academy of Sciences, Washington, D.C. 1969.

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Table 4 ALTERNATE METHODS OF CONTROLLING EROSION IN OPEN CHANNELS

Type of Control	Advantages	Disadvantages
1. P. C. or asphaltic concrete or soil cement paving.	Permanent if carefully constructed and maintained.	High cost. Speeds up runoff.
2. Drop structures across channel at intervals so that slope of channel between drops restricts allowable velocity for turf.[41]	Satisfactory if drops are well-designed and built. Does not speed up runoff.	Unsightly, if natural material is not used. May have maintenance problems.
3. Lining with crushed rock or gravel sized for requirements.[1]	Satisfactory if well-designed. Can harmonize with landscape. Can allow both infiltration into permeable soil and exfiltration of ground water.	Can be costly if rock or gravel are not available locally.
4. Rip-rap.[42]	Permanent if carefully placed and maintained.	Can be costly. Can be unattractive.
5. Rock enclosed in galvanized wire baskets (gabions). This generally requires wide shallow channels so that drops will not be over-ridden and channels destroyed during unusual extreme flow events.	Permanent if carefully placed. Can allow infiltration on permeable soil. Aesthetically pleasing—becomes invisible. No limit to range of flow.	Can be costly.

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UNDERGROUND PIPE SYSTEMS

Layout of the Storm Drain System

The layout of the storm drain system for residential areas should make maximum use of existing open channels and natural streams, before resorting to enclosure of runoff in underground pipes. Former practice tended toward enclosing small streams in conduits which was not only costly, but also concentrated the flow downstream and increased the peak rates of discharge. The preferred approach is to leave natural streams undisturbed and to limit peak runoff conditions. Erosion of the stream channel usually is not accelerated when this is accomplished. As recommended in this report, runoff will be collected in swales or open channels and curb and gutter sections and carried as far as practical before entering an underground pipe system. The underground pipe system consists of a series of inlets, pipes, and manholes. Output from computer simulation models of runoff or empirical techniques may be used in the detailed design of the system. Decisions made in the planning stages of the residential development, some of which are listed below, will have a great influence on the final form and cost of the underground pipe system.

- Planning of both minor and major components with appropriate design rainfall recurrence intervals.
- Limitation of peak runoff rates after development.
- Type and amount of storage.
- Use and incorporation of natural drainage such as overland flow, street swales, open channels and natural streams.
- Assurance that all contributory upstream areas will be similarly regulated or initially assessed and developed, so projected conditions may be relied upon.

Pipe Location and Alignment

The pipe system is usually in the street right-of-way, but portions may be in easements along lot lines when that route provides the best outlet path to a natural stream. One common location within the right-of-way is behind the curb. This method connects inlet boxes with the least amount of pipe and junctions.

There is no reasonable objection to the pipe being laid on horizontal and vertical curves conforming to the curvature of the street. The horizontal and vertical alignment of storm drain pipes must be coordinated with the location of all other uilities. In cases where joint trenching of electrical, telephone, CATV, gas and possibly water lines is allowed, it is much easier to coordinate the locations of utility lines during construction. Since storm drains are generally constructed early in a residential project, require gravity profiles, are located at shallow depths, and require trench backfill density control, the opportunity for joint trenching with other utilities rarely exists. As most localities now require electrical power and telephone lines to be underground, there no longer are possible conflicts with utility poles behind curbs.[33]

Culverts

With the emphasis on keeping surface runoff in street swales and open channels, culverts may be required for street crossings. Driveways crossing properly designed street swales should not automatically require culverts, as vehicles should be able to cross the swale. When required, culverts preferably should have flared end sections for good appearance and hydraulic characteristics.[9] Precast or pre-fabricated flared end sections for pipes are available.

Any culvert will cause an increase in water level in the upstream channel. This backwater can flood property and overflow into the streets. The frequency with which this is allowed to happen should depend on the amount of damage, including delays to traffic, caused by the backwater.

Where storage is required to control peak discharge, a road fill can provide a dam for temporary impounding of storm water.[18, 35] Legal and physical requirements for such temporary ponding are constraints to be considered.

Culverts may also require energy dissipators at the outlet if the stream bed is erodible. These can range from simple placement of rip-rap to elaborate concrete stilling basins. Similar structures may also be required on storm drain outlets.[6, 45]

Materials

Storm drain pipes are most commonly plain or reinforced precast concrete; however, other materials may be used.[16] There has also been good experience using carefully controlled installations of unreinforced cast-in-place concrete pipe, which may also provide initial construction cost savings. Corrugated metal pipe can be used for short runs, but its high resistance factor often requires a larger pipe size for equivalent flow capacity which weighs against its use for long lines, unless grades are very steep or unless the invert and sides are lined with asphalt to give a smooth interior. Where culvert hydraulics are governed by inlet control, concrete and corrugated metal pipes may be interchanged size for size.

Curb opening inlets are usually reinforced concrete, often with precast units for top slabs and other parts. Concrete block can also be used for walls if the inlet opening is short. On longer openings, the structural problem of carrying the top slab across the opening with no intermediate supports and very limited thickness of slab allowable, may require cantilevering the slab off the rear wall of the reinforced concrete inlet box.

Manholes can be brickmasonry or reinforced concrete and are frequently built as precast concrete units. Fiberglass units are seeing limited use.

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Hydraulics

The usual hydraulic practice is to select the pipe size for the accumulated runoff rate at each inlet or manhole assuming that the pipe is just barely flowing full. For the water to accelerate to the uniform flow velocity computed from the Manning Equation, water must back up into the inlet to a depth above the pipe equal to the outflow velocity head plus the inlet lateral entrance loss. Standard practice also requires that the hydraulic gradient, or pressure head line, be computed for the full length of the pipe system, usually starting at the downstream end. The pressure (head) losses at junctions must also be computed.[37] Guide vanes and other geometric improvements within the junction or manhole can be used to minimize pressure losses. The pressure losses become particularly significant for velocities in excess of eight feet per second. The pressure line should be kept close to the crown of the pipe for the design discharge of the minor rainfall. Surcharging the pipe with the pressure line above the crown of the pipe but still remaining about 0.5 feet below ground level is acceptable.

During a major rainfall, the underground system will be under pressure with the pressure line probably at the surface of the water in the gutter. Since the pipe slope is usually about the same as the street slope, the pipe will be carrying only the discharge for that slope, the remainder of the storm water being on the surface of the street. When testing a tentative design for performance under major storm runoff conditions, it may be necessary to increase the size of one or more reaches of pipe to avoid incurring excessive damage costs resulting from overflowing the street. Other alternatives for disposing of the excess flow may be more economical.

The minimum pipe size required should be based on hydraulic considerations rather than arbitrary standards; it should be noted that if a less than 15-inch pipe is satisfactory, then the storm sewer is probably unnecessary, since a curbed 26-foot wide roadway will handle more than three times the flow of a 15-inch pipe on the same grade. Consideration should be given to hydraulic capacity of a pipe given its size, slope and roughness characteristics, tendency to become clogged, self-scouring velocities and ability to clean the pipe and remove obstructions. The use of street swales to collect water, and criteria which allow more flow in gutters prior to initial pick-up, will mean that the initial minimum pipe size will generally be larger than under the old philosophy of "get it into pipes as quickly as possible."

The minimum allowable velocity to keep small particles of sediment moving in a pipe is about two feet per second. It is advisable to have a minimum pipe slope of about 0.1 percent in the approach to a junction box. While the thrust of the storm water management program includes keeping sediment out of the system as much as possible, some sediment load may be unavoidable. With a heavy sediment load, coarser particles may settle out where there is a reduction in transport capacity because of decreasing grade.[21]

The use of an inlet box as a sediment trap is ill-advised. Experiments have shown that the turbulence created by the falling jet moves sediment beyond the box. In addition, catch basins are costly to clean out, and the pipe system usually has the capacity to carry away the sediment anyway. If trapping of sediment becomes necessary, it should be done by designing a sediment trap located at a point where the pipe capacity to transport sediment is reducing. The trap should be accessible for cleaning with mechanical equipment. Storm water loaded with abrasive sediment particles can cause wear on a concrete pipe at high velocities, so the entrance of such sediments should be minimized. The duration of storm water flow is relatively short and infrequent so abrasion by particles that do get into the pipe may not be serious. There is little that can be done to slow down water on a steep grade, other than building a vertical drop structure to dissipate excess energy.

Difficulty with high velocity flow is more likely to occur when the energy gradient (the position of pressure head plus the velocity head) is allowed to rise well above the ground surface at a manhole where the pipe slope decreases abruptly. A hydraulic jump can occur which would check the velocity and result in conversion of velocity head to pressure head sufficient to blow off the manhole cover or the whole top of the manhole. This is a particular problem where pipe alignments cause flow through inlet boxes, which are often shallow, as the intended inlets may instead function as outlets.

Manholes

The principal purpose of manholes is to provide access for cleaning and inspection. They usually should not be more than 500 feet apart on small pipes; spacing may be greater for larger pipes and unlimited for 66-inches and larger. Maintenance and safety requirements will dictate spacing on the big pipes. Inlet boxes should also have manhole openings to provide access. If storm drain pipes run through inlet boxes, they can be used for inspection and maintenance and can be counted when determining minimum spacing. This practice is only recommended where there is no likelihood of soil movements or external live loads on the inlets. Where pipes are routed through inlet boxes both pipes and boxes usually must be at least one foot below conventional depths to offset hydraulically adverse head recoveries, turbulence and entrance losses, to assure functioning of the inlets.

STORM WATER INLETS

Storm water inlets are located at the transition between open surface flow and a closed conduit system. They are either constructed as part of the street's curb and gutter system, located in street swales or used to drain open areas. The inlets should remove runoff from surfaces when the flows exceed the criteria for velocity, spread of water across streets, or flow across intersections. Inlets in street swales also remove flow when it exceeds swale capacity. Drainage of open areas is often picked up by an inlet in a depressed area.

In utilizing natural systems effectively, the employment of inlets should be delayed as long as possible because as soon as the runoff enters the pipe system, it is carried rapidly downstream.

Grate Inlets

Grate inlets consist of metal bars or a grid encased in a frame. When grate inlets are placed in the street, the bars are usually aligned with gutter flow for maximum hydraulic efficiency. This allows the intercepted water to fall between the bars. The bars of the grate may be placed at right angles to the curb for the safety of cyclists. When this is done, water hitting the bars may be projected upward, causing some of the flow to be deflected away from the inlet. The efficiency of both applications is improved by depressing the grate below the plane of the gutter within the transition area. This creates a sump condition and the small amount of ponding helps reduce approach velocity abating the tendency of the water to be deflected beyond the inlet.

Grate inlets are often placed in street swales and other overland flow areas, when it is necessary to intercept the flow due to velocity or the lack of a satisfactory route for continued flow. Grate inlets are also used to drain parking lots. The design of these inlets must account for any expected reduction in inlet interception capacity due to clogging by grass cuttings, and water borne debris.

Periodic maintenance to assure the capacity of the inlet is necessary. Grate inlets in unpaved areas should be placed according to the most efficient design, as it is not likely that bicycle traffic will be a factor in this type of installation. Grate inlets on urban streets are not recommended.

Curb Opening Inlets

The capacity of an inlet to intercept water flowing down the street depends to a large degree on the distribution and velocity of water in the gutter cross-section. On a continuous grade, an inlet will intercept only that flow within its hydraulic reach. In the case of the curb opening inlet, the width, length and depth of the depressed section of the gutter in front of the opening is very important. Steepening of the cross slope of the gutter enables gravity to begin turning the flow into the opening, but because of the inertia of the flow considerable opening length is necessary.

The vertical height of the opening should be not greater than six inches in order to eliminate the possibility of a child being washed into the inlet basin. This places a restriction on hydraulic capacity for major storm conditions when most of the street may be flooded. The outlet pipe would probably be flowing full by that time and would limit the inflow anyway. The opening preferably should be clear for the entire length on continuous grades.

A sediment trap formed by lowering the floor of the inlet box below the elevation of the outlet pipe is unnecessary and undersirable since there is too much turbulence for effective trapping, and cleaning is costly.

Capacity of Curb Opening Inlets

The most authoritative data on capacity of curb opening inlets is contained in a circular published by the Federal Highway Administration (FHWA).[8] That report includes charts for estimating the interception ratio Q_i/Q for inlets five, ten and fifteen feet long, and curb widths of one, two and three feet when used on street sections with cross slopes ranging from 0.015 to 0.06 ft./ft. and roadway grades up to four percent. The charts, as published, are based on full scale tests by Colorado State University. Extension of the charts to steeper grades has been developed and is awaiting publication.

Curb Opening Inlets at Sump Locations

Curb opening inlets at a low point in the grade (sump) operate efficiently, since the water is trapped at the opening. Charts are available for estimating the capacity of inlets five, ten and fifteen feet long in terms of the depth of ponding over the inlet lip. [8] It also has a procedure for determining when a given inlet will restrict flow to the point where backwater will occur in the approach gutters, thus increasing the width of ponding. For major storms, the restriction caused by the outflow pipe may govern.

Curb Opening Inlets—Deflector Type

The state-of-the-art literature contains references to the use of deflector vanes on the surface of the depressed gutter in front of an inlet to force more water into the curb opening. The only experimental data available on deflector vanes were based on a steep crown slope $S_x = 0.055$ with a narrow range of water depth and with water spread only twice the width of the depression. These results are not applicable to flatter cross slopes, and are applicable least of all to large ratios of water spread to curb width. The Colorado experiments on which the charts in *FHWA's Drainage of Highway Pavements* were based demonstrated conclusively that the interception ratio is a function of water spread to curb width.[8]

The use of deflector vanes is not recommended, since they complicate construction and in the past have been rendered inoperative when buried by street resurfacing.

OTHER DESIGN CONSIDERATIONS

Soil Erosion

Control of erosion *during residential construction* requires an examination of the entire site to pinpoint potential problem areas, such as steep slopes, highly erodible soils, soil areas that will be unprotected for long periods or during peak rainy seasons and natural drainageways. Steps should be taken to assure erosion control in these critical areas. After a heavy storm the effectiveness of erosion control measures should be evaluated. Periodic maintenance and cleaning of the facilities is also important.

Control of erosion *after construction* consists primarily of minimizing bottom and side scouring of natural drainageways. This can be accomplished by proper initial design which limits velocities and specifies correct drainageway linings and structures, and by proper routine maintenance and repair of the system.

Some of the basic concepts for controlling erosion during and after construction are:[2, 7, 30, 54]

- Earth slopes: Erosion of cut or fill slopes is usually caused by water concentrations at the top of the slope flowing down an unprotected bank. Runoff should be diverted to safe outlets. Slopes should be protected from erosion by quick establishment of vegetative cover, benches, terraces ,slope protection structures, mulches, or a combination of these practices as appropriate.
- Waterways or Channels: Waterways should be designed to avoid serious erosion problems. Wide channels with flat side slopes lined with grass or other vegetation will usually be free from erosion. Where channel gradients are steep, linings or grade control structures may be required. Space limitations may make it necessary to use concrete or stone linings. Every effort should be made to preserve natural channels.
- Structures for Erosion Control: Erosion may be controlled by the use of grade control structures, energy dissipators, special culverts, and various types of pipe structures. Structures are expensive and should be used only after it has been determined that recommended vegetation, rock revetment or other measures will not provide adequate erosion control.
- Existing Vegetation: Good stands of existing vegetation adequate to control erosion should be preserved wherever possible.
- Soil Treatment, Seeding and Mulching: The ability of the soil to sustain vegetation intended for erosion control must be ascertained. The admixture of a fine textured topsoil may be warranted to assure success of more attractive, lower maintenance vegetation. Liming and fertilization should be done according to recommendations based upon soil test information. After the soil has been prepared, the correct seed mixture, sod, ground cover and mulch should be applied.
- Outfall Design: The outfall pipe should be designed and located so as to minimize erosion; especially if the outfall is to an overland flow area with a steep slope or is elevated above the base flow of the receiving streams. An energy dissipator may be necessary.

Siltation and Sediment Control

Proper control of soil erosion during and after construction is the most important element of siltation and sediment control. However, it is physically and economically impractical to entirely eliminate soil erosion. Secondly, erosion is a natural function and is required in certain portions of the drainage system in order to provide future stream capacity. Therefore, provisions should be made to trap eroded material at specified points. Some measures that can be implemented are:[11, 30, 54]

- Temporary ponds which store runoff and allow suspended solids to settle out can be used during construction and may be retained as part of the permanent storage system after construction.
- Protection of inlets to the underground pipe system can be accomplished during construction by placing hay bales around the structure.
- Egress points from construction sites should be controlled, so that sediment is not carried off-site by construction traffic.

Storm Water Runoff Pollution

As storm water runoff flows over surfaces, it picks up pollutants and carries them downstream. The magnitude of the pollution load has been the subject of recent investigations by the Environmental Protection Agency (EPA) and others.[2, 38] It is generally conceded that the magnitude is sufficient to warrant serious examination of alternate methods of controlling and treating storm water runoff pollution.

Documentation of pollution loads in streams before and after construction is a necessary first step prior to embarking on extensive runoff treatment programs. Measurements might include suspended solids, Biochemical Oxygen Demand (BOD), dissolved oxygen and the concentrations of toxic materials, bacteria and nutrients. Under ideal conditions the measurement of pollution should be coordinated with simultaneous collection of data on rainfall and runoff. Pollution loads are the result of:

- soil erosion and dissolving of minerals in the natural ground cover;
- overland flow which picks up fertilizer, animal droppings, and organic material, and
- flow on parking lots, roofs and streets which carries petroleum products, trash, dust fall and debris from cars and trucks into the drainage system.

Three basic methods of treatment can be used:

- The first controls pollution loads at their source. For example, proper erosion control and sediment control will reduce the suspended solids levels. Also, periodic street cleaning will reduce pollution loads.

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- Storm water runoff can be treated at the source. Temporary storage of runoff to allow suspended solids to settle out is one example. Diversion of runoff to land treatment areas for spraying or controlled overland flow is another. The fact that most runoff pollution results from the "first flush" of runoff should be considered when planning source treatment facilities.
- Treatment of storm water runoff at a centralized plant downstream is the third alternative. This is probably the most costly method because of the vast volume of water requiring treatment. Consideration may be given to storage facilities enabling storm water to be released to treatment plants at a gradual rate after the runoff peak has passed.
- Treatment of runoff to reduce pollution loads is probably unnecessary for most low-density residential development, but the availability of pertinent information is limited. It seems obvious that the cost of such treatment will be high, so it follows that treatment should not be considered unless there is documentation of the need and a demonstration that the benefits from treatment will be consistent with its costs.

Maintenance

Adequate provision for short- and long-term maintenance of the residential storm water system is an important design consideration. Maintenance and replacement needs and costs should be part of the economic analyses.

Maintenance requirements for the type of system suggested in this document may be different from those for a fully enclosed pipe system. Mowing, trash and sediment removal, replacement of sod and repair of eroded areas will become parts of the maintenance program. Conversely, less pipe inspections, repair and cleaning will be required.

When planning an on-site storage system, determination must be made about long-term ownership and/or maintenance and operation of the facility. The choices will generally be between public and private organizations and the final decision will be dependent on local conditions.

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Encroachment into Potential Flood Plain Areas

No consideration of residential storm drainage is complete without recognition of potential flood hazard exposure. These potential hazards are obvious along major rivers and streams but can also occur along tributaries and drainageways and in headwater areas as will be discussed later.

Management of major drainage basins and rivers is usually controlled by other than local governments; however, local government should be concerned with controls for development in all other areas subject to flooding.

The Federal Insurance Administration (FIA) is currently involved in a two-staged effort to delineate and map some floodplains and their potential flood elevations for many communities as part of an effort to provide insurance for structures located in areas of potential hazard. The first stage provides a gross delineation of the floodplain, to permit subsidized insurance for properties already located within a hazard zone and a basis for planning future land uses in such areas. The second phase provides more accurate and detailed mapping of the floodplain to guide future land use practices and determine insurance rates for structures permitted to locate in a designated hazard zone. It will take years to complete this mapping effort, and it is uncertain whether it will be possible to identify and map all potential flood hazard areas. Thus it is necessary for all involved in the process of land development to recognize and consider any potential flood hazards associated with the land being developed.

In a subsequent discussion of basic legal aspects of urban drainage and flood control, potential liabilities associated with land use and development are outlined. The direction of liability may be shifting, by placing increasing culpability on parties involved in the approval of land uses in a hazardous area or in the creation of hazards. The availability from FIA and others of hazard information and delineated potential hazards makes it easier to assess liability for improper location or land use.

As a result of FIA actions and Federal regulations relating to flood hazards, local governments have been stimulated to provide new regulations for their jurisdictions. These regulations cover areas delineated by FIA and may cover tributary and headwater areas not currently mapped. The new regulations do not prohibit all development in potential flood hazard areas but rather require that development be consistent with wise floodplain management to qualify for insurance or loans from federally regulated or insured institutions.

Within flood hazard areas, there are often locations where occupancy is fully justifiable under certain conditions. The Minimum Property Standards (MPS) of the Department of Housing and Urban Development recognize this and permit floodplain occupancy provided the finished first floor of a dwelling is no lower than the 100-year frequency flood elevation and the building site grades adjacent to the dwelling area are no lower than the 50-year frequency flood level.

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In practice, the use of the 50-year frequency flood elevation as a limit to acceptable encroachment upon a flood plain may justifiably be varied. Where the difference in elevation between the 50-year and 100-year frequency flood levels is less than eight inches, it often will be fully justifiable to occupy sites having elevations below the 50-year frequency flood elevation, sometimes as low as the 20-year frequency flood elevation, if dwellings will have their floors at or above the 100-year flood elevation and the dwellings will have no basements. This justification reflects the typical low-flow velocity of floodwaters in such locations and the minimal effect of buildings upon flooding depths upstream from such locations. Where the difference in elevation between the 50-year and 100-year frequency flood levels is more than eighteen inches, residential encroachment upon the flood plain to the 50-year frequency flood elevation generally is unwise since potential flooding depths and fast-flow velocities could cause severe damage to properties. Where properties may potentially be flooded for more than a few hours, more stringent encroachment limits than the 50-year frequency flood elevation may be appropriate because the social displacements and flooding damages will usually be greater than from short-term flooding of similar depth. Of course, technical justification of a variation will not necessarily be acceptable to regulatory authorities.

The economic benefits that may be derived from occupancy of portions of a designated special flood hazard area, or other areas subject to flooding, may be appreciably greater than probable future flooding losses. There is a statutory provision for Federal acceptance of alternative land use and control measures applicable to such locations, but the burden of developing alternative measures and demonstrating their assured fulfillment of Federal loss mitigation objectives is upon the local community. The community must demonstrate conclusively that the economic and social benefits derived from occupancy will be greater than, and of overriding importance relative to, the potential flooding losses. For locally-suggested alternative measures to be given credence, proponents of the alternative measures should clearly explore whether immediate costs and adverse effects upon property values, tax revenues and public facilities (including utilities), attributable to adoption of generally promulgated land use and control measures, are greater than the probable future flooding losses discounted to present value. Locally-suggested alternative measures should also demonstrate how their implementation would mitigate future flooding losses, and to what degree. Regardless of whether flooding is caused by inadequate drainage or by streamflow, the derivation and support of locally-suggested alternatives optimally requires interaction and close cooperation among all local interests.

Selection of appropriate types of dwelling units for construction in areas exposed to flooding may significantly reduce potential flooding losses, by comparison with potential losses using other dwelling types. Where the occupancy will be in a community that is generally exposed to flooding, or in a substantially developed area in which it is not feasible or reasonable to forego building upon vacant sites, selection of the merchantable building type having the lowest flooding loss expectancy is appropriate. In such situations, the probable market response to a change in building type should be carefully assessed during decision making. Based upon the Federal Insurance Administrations' Depth-Damage curves,[10] the relative flooding loss characteristics of common types of residential buildings are as follows:

Building Type	Ratio of Damage*
Two-story dwelling without basement	1.0
Split level dwelling	1.15
Two-story dwelling with basement	1.2
One-story dwelling without basement	1.5
One-story dwelling with basement	1.65
Mobile home	2.3

*Base level is two-story dwelling without basement

As shown, substitution of a building type with a lesser loss potential could reduce potential average annual flooding losses to levels comparable to loss expectancies outside of other designated special flood hazard areas. Where such an alternative relationship can be demonstrated, there would seem to be a persuasive argument for acceptance.

Additional loss mitigation can be effected by reducing land occupancy densities, thereby reducing the total value of exposed property per acre, and by floodproofing, to reduce the losses expected from any given level of potential flooding. Floodproofing[17, 19, 44] involves a series of construction modifications either to exclude water from entering buildings or to reduce the potential for water damage if water does enter buildings. In some situations, floodproofing can reduce potential flood losses by as much as 60 percent by minor initial increases in construction costs.

The potential for flood hazards and the issues of encroachment into flood plain areas discussed above tend to presume a continuation of past practices in runoff management in upstream tributary areas. A major objective of this publication is to encourage new approaches to storm water runoff management which would attenuate peak runoff thus reducing frequent flood hazard threats in the middle and lower reaches of a drainage basin. Thus, application of the objectives, principles, and design considerations set forth in this publication may in themselves provide further justification for cautious variations of limitations on land use in flood hazard areas.

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Potential Flood Hazards in Tributary and Headwater Areas

The prior discussion has been concerned with flooding associated with overflow of channels, streams and rivers into adjacent, generally identifiable, flood hazard areas. There is considerable potential for water damage associated with unwise siting and drainage practices which are often overlooked and are often a source of residential flooding in tributary and headwater areas. These hazards generally are foreseeable, are usually the result of poor application of good design practices, and can be avoided without significant increase in development or construction costs.

Streets, highways and railroad crossing drainageways or streams are commonly elevated, on embankments, with culverts or small bridges passing beneath them to accommodate runoff flows. When the runoff flow is too great to pass through the culvert or bridge, or when the culvert or bridge is blocked by debris, the embankment will act as a dam causing runoff to accumulate upstream and possibly overflow the embankment. The depths of potential flows over roadway embankments are variable and should be computed, but most commonly are from one to two feet. The potential for residential flooding upstream from drainageway-crossing embankments can be eliminated if dwelling floors and openings into dwellings are higher than potential runoff overflow elevations at embankments. Failure to recognize such conditions is a widespread source of residential flooding. A proper application of the *blue green* concept discussed elsewhere should eliminate this hazard.

One common but easily overlooked source of residential flooding occurs where runoff from small areas will naturally follow a lot line swale between dwellings. Even though a drainage area may be very small, the quantity of foreseeable funoff will be frequency-related. The worst foreseeable flows should be anticipated during design. Appropriate designs for such locations will consider both the size of the swales and the elevations at which buildings are sited. There is always a potential for water-related damage, from storm water runoff or ground water, to structures improperly sited or improperly graded. Thus, detention ponding on individual sites, as suggested elsewhere in this publication, may be impractical or unwise because of such local problems as impermeable soils, expansive soils or seasonally high ground water. Under such conditions, positive drainage of individual building sites may be essential.

Some relationships between basement construction and flood hazard exposure should be emphasized. Typical basement construction is incompatible with on-site detention ponding where site soils are more than slightly permeable and where detention ponding might contribute to the rise of ground water to building footing elevations. The most commonly observed cause of residential basement flooding is entry or penetration of storm water runoff due to the failure to drain runoff quickly and positively away from buildings. Where soils are essentially impermeable, protective slopes around a dwelling can be used to assure quick and positive drainage of runoff away from the dwellings either to off-site locations or to ponding storage areas on-site with controlled outfall.

Again, it should be emphasized that the flood or water damage hazards described here would be the result of improper site-specific application of recommended design approaches suggested earlier in this publication. Proper application of on-site detention, and proper use of swales and other engineering techniques should avoid creation of residential flood hazards.

SARB_006609

LEGAL IMPLICATIONS

Homebuilders and developers are familiar with zoning, subdivision regulations and building codes. Storm water law is another control which the public sector has placed on the use and development of land or which has arisen through liability imposed by courts when the acts of one land owner have adversely affected the property of another. Storm water law, like storm water engineering, can be divided into two areas—floods and drainage—even though they obviously belong to the same system of surface water runoff.

Regulating the Flood Plain

The flood plain is usually defined as that area bordering a watercourse which would be inundated by a flood of a certain magnitude. The magnitude used in establishing the federal flood hazard areas is the "one-hundred-year flood", that is, a flood which has a statistical one percent chance of occurring or being exceeded in any one year. Often this flood plain is further subdivided into a "floodway" and a peripheral area.

Billions of dollars have been spent on flood protection works. In spite of this, nationwide flood losses have continued to escalate. The response to this dilemma has been a change in philosophy in dealing with flooding. Instead of attempting to keep rivers away from people by damming and channelizing them, the trend is towards keeping people away from rivers by preventing further unwise encroachment onto the flood plains. This is not to say that no development should occur at all, but rather that development must be consistent with good flood plain management. The greatest impetus has come from the federal government through its National Flood Insurance Program, the Flood Disaster Protection Act of 1973 (PL 93-234, amending 24 U.S.C. Ch. 50).

Briefly, it works in the following manner. First, special flood hazard areas are identified and designated on maps by the federal government. If the community has become a "participating community" by adopting adequate land use measures and other controls for its flood plains, those buildings which already exist in the flood hazard areas are eligible for heavily-subsidized flood insurance. Flood insurance for new construction, however, will not be subsidized; instead, premiums will reflect the actual flooding risks to the property. The crux of the program is that flood insurance is *required* before the vast majority of lending institutions in the United States can make, increase, extend or renew any loan secured by improved real estate located or to be located in one of these special flood hazard areas. For the developer, this means he must investigate whether or not the property he proposes to develop is or is likely to be in a federally-designated special flood hazard area. If it is, and the community has failed to become a "participating community" by adopting acceptable land use controls, residential financing will probably be unavailable. If the land is within a "participating community," the developer must investigate what controls the community has placed on the land and what the flood insurance costs would be. A federal rate map identifies applicable insurance rates. Occupancy and insurance costs can be mitigated by taking certain precautions (such as raising the elevation of the building), but may still make construction in that location less feasible. Therefore not only how the building is constructed, but whether the building should be built at that site at all, is an initial consideration affected by the National Flood Insurance Program. Another site, outside of the hazard area, may be financially more advantageous for development.

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Additionally, even if the federal government has not designated an area, both state and local laws should be consulted. Some states and communities have adopted flood plain regulations and maps on their own initiative, or areas in addition to the federally-designated areas might be locally controlled, such as on smaller tributaries of the main stem. Local land use controls may be in the form of building codes, subdivision regulations, or specific flood plain regulations. Since the floodway is supposed to be adequate for the safe passage of the floodwaters through the community, building restrictions within it are severe. In the peripheral area, sometimes called the low-hazard zone or flood storage area, development is usually permitted within certain less restrictive design parameters and precautions. Since the federal requirements are minimum, local flood plain controls can be more restrictive. It behooves a developer to find out what they are. Some regulations declare that a building which is not in compliance with the flood plain regulations is a public nuisance which can be enjoined or even abated. In addition, where such development is the proximate cause of injury to the person or property of another, and the non-compliance could constitute negligence, the owner or developer might be liable for damages in a tort action.

Drainage Law

While flood plain regulation is of fairly recent vintage, drainage law dates back to ancient times. Here we are looking at the respective rights and duties of the "upper" landowner versus the rights and duties of an adjoining "lower" landowner. The "upper" land lies at a higher elevation, and water drains down onto the "lower" land. This relationship is based on the lands in their natural, unaltered state.

There are basically two doctrines which have been adopted by various state courts: the "common enemy rule" and the "civil law rule". Under the "common enemy rule" the lower landowner may take any measures necessary to keep water off his land, even to the point of turning the water back onto the upper land. The upper owner can similarly protect his property from the "enemy" by diverting water around his property causing greater quantities at higher velocities to flow onto his neighbor's land. In its pure form it would be a might-makes-right situation.

Therefore, courts have modified the rule to require that such acts be reasonable *vis-a-vis* each other. The "civil law rule" states that the upper land owner has an easement over the lower land for the natural drainage off of his land. The key word is "natural", meaning the same quantity and velocity as drained from the upper land in its undeveloped state. It was felt that, in its pure form, the law would substantially restrict development of the upper land, so again courts have modified it to accommodate reasonable use of the upper property. Finally, both of these doctrines, which are based on the property-law concepts of dominant versus servient lands, have been rejected by some courts. These courts focus on "reasonable use" alone, based on tort-oriented law. While these modifications tend towards the same results, the practical questions of predictability and proof requirements remain substantially different.

The developer will want to protect himself from possible exposure to a potential liability suit for damages, or from a time-consuming and costly injunction action. Under any of the doctrines mentioned above, his best protection is to develop in such a manner as to keep the runoff as close as possible to runoff conditions in the natural state—in quantity, velocity, and location. If he has obtained the hydrologic, soils, and other data recommended for good engineering design, and has developed his project accordingly, the same facts will protect him from liability because he can prove that he has not materially changed the natural drainage conditions and has acted in a reasonable, non-negligent manner.

Some communities have established special assessment districts or storm drainage fees for the purpose of constructing drainage improvements. The developer should also investigate how these might affect the property. The basis for the fee may be the difference between the amount of runoff which was generated from that property in its developed condition. Here again if the same amount of runoff has been maintained, by on-site ponding or other techniques, the fee may be negligible. If, on the other hand, the natural permeability has been reduced by extensive paving, he may be committing the property to be subjected to high drainage fees. Or the fee may reflect the cost of flood control works which are necessary to remove the property from a flood hazard zone. This may affect not only how he constructs, but whether he constructs there at all.

Conclusion

From a legal point of view, as from an engineering point of view, the developer must accept the fact that every piece of property involves storm water runoff in either a major or minor way and as both a contributor and recipient. It is imperative, before purchase or development, to get the physical facts and to investigate the local, state and federal laws which could affect the property. The storm water aspects of the property may be one of the controlling factors on how to develop or even whether to develop that site at all. However, after having done his homework, and developed the property in a responsible and reasonable manner, the developer can rest assured that he has good protection from liability.

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BUILDER news WESTERN REGION
THE LARGEST REGIONAL BUILDING TRADE MAGAZINE IN THE NATION

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By: Robia Chang and Carolyn Nelson R

DEPARTMENTS / / LAW / / LOW-IMPACT DEVELOPMENT

A Growing Trend in Stormwater Management

Increasingly, Western communities—particularly urban areas—are using an approach known as "low-impact development" (LID) to control stormwater pollution. Instead of making large investments in complex and costly engineering strategies for municipality-wide stormwater management, LID accomplishes this by various lot-level design strategies that are designed to mimic natural hydrology and processes, customized to each individual development and implemented by developers. LID addresses runoff close to the source by employing various features, including, for example, disconnecting roofs and paved areas from traditional drainage infrastructure and directing runoff to natural areas such as vegetated open spaces, which look like landscaped areas but are actually engineered systems that use plants and soil to trap and treat various contaminants. Other common LID practices include rooftop gardens, tree planter boxes, and the use of permeable pavement in low-traffic areas, parking areas and walking paths.

For the most part, LID has been a voluntary approach, promoted but not required, in the Western states. Localities and developers have chosen to adopt such measures because of their benefits, not because they were mandatory. However, recent developments in Southern California signal significant changes that may indicate an increasing trend toward mandatory LID techniques throughout the state. In San Diego County, the California State Regional Water Quality Control Board, the regional branch of the state agency responsible for administering the state stormwater management program, recently approved a stormwater runoff permit that will require the county of San Diego, the Port District and the county's 18 cities to increase the testing and monitoring of runoff, street sweeping and sewer-line cleaning. Significantly, the renewal permit will also require the use of two types of LID at specified categories of development projects, as designated in local Standard Urban Storm Water Mitigation Plans. Both the routing of runoff from impervious to pervious areas, and the use of permeable surfaces for portions of low-traffic areas, are now required LID techniques, and within three years, all sites that are greater than one acre will be subject to the requirements.

Additional provisions require the inclusion of hydromodification measures that typically involve the use of large holding basins that detain the increased stormwater runoff resulting from development projects and release the runoff to the receiving storm drain in a pattern similar to the pre-project condition. Where the county and cities previously had discretion to require LID based on applicability and feasibility, under the new permit, this determination will not be made at the sole discretion of a co-permittee; rather, the regional board will have discretion to provide its input.

Similarly, the draft Municipal Separate Storm Sewer System (MS4) Permit issued to Ventura County by the Los Angeles Regional Board on Dec. 27, 2006, requires that all new development and redevelopment projects integrate LID principles into project design. The permittees, including the County Watershed Protection District, the County of Ventura and 10 cities within the county, are to develop a LID Technical Guidance Document for use by planners and developers within 18 months of the issuance of the permit. These regional precedents likely will result in the remaining seven regional boards following suit when their

MS4 permits are renewed.

While these Southern California localities appear to be leading the way by making the use of LID mandatory, many Western states have been promoting LID for some time. For example, in the state of Washington, generally recognized as having some of the nation's most stringent stormwater management regulations, the use of LID techniques is strongly encouraged. The State Department of Ecology administers the state stormwater management program and this month issued separate permits for the eastern and western portions of the state. In response to comments relating to LID requirements, the department recognized that there are circumstances where LID approaches, such as infiltration-based strategies, may not be appropriate due to soils and site constraints. A Low-Impact Technical Guidance Manual for Puget Sound, targeted at engineers, planners, developers, builders and architects, provides LID goals and objectives and site assessment and design methods. Decisions on the use of LID techniques will be made on a site-specific basis, or may be locally mandated to meet zoning requirements. For example, in the city of Olympia, mandatory LID techniques have been adopted in a specific basin area known to contain aquatic habitat, and in Snohomish County, LID is already required for so-called Fully Contained Communities (i.e., communities located in rural areas at least one mile outside of current urban-growth areas, on at least 2,000 acres).

The use of LID techniques is also encouraged, but not required, by the Oregon State Department of Environmental Quality. The Willamette Basin Total Maximum Daily Load defines the amount of a pollutant that can be present in a water body without causing water quality criteria to be exceeded. One of the strategies suggested in the September 2006 Water Quality Management Plan (WQMP) to attain and maintain the water quality standards is LID. To prevent pollution in urban and rural areas, the WQMP suggests environmentally sound development, including LID standards. It also suggests the use of various management strategies characteristic of LID, such as minimizing the amount and disconnecting impervious areas and reducing the amount of new impervious surfaces associated with new development projects. Similarly, the March 2006 Tenmile Watershed Draft WQMP recommends LID as one of the Coastal Nonpoint Pollution Control Program strategies, and suggests that the "innovative" LID approaches can be used to meet a wide range of Wet Weather Flow control and community development goals while reducing the cost of stormwater treatment and management facilities construction and operation.

At the local level, municipalities in the state of Nevada have been encouraging the use of LID. The Truckee Meadows Regional Stormwater Quality Management Program—which is a collaborative effort between the city of Reno, city of Sparks and Washoe County—issued a Draft Low-Impact Development Handbook, providing guidance on LID practices for new development and redevelopment. The handbook, which is supposed to be the first guidance document referenced during the development planning process, was developed to assist planners, developers, architects, landscape professionals, city and county community development, and public works staff with the selection and design of features and practices that mimic natural hydrological functions. It suggests a variety of LID techniques, such as porous paving systems, roof rainwater collection systems, design considerations, and disconnection and reduction of impervious surfaces.

LID techniques are not required in the state of Idaho, where the EPA Region 10 issues general permits for MS4s. The Idaho Department of Environmental Quality issues a guidance manual that gives possible solutions to stormwater runoff. Counties generally have policies to require the construction of retention basins for new development or redevelopment to contain runoff and in some areas, post-construction stormwater runoff is allowed to drain to ditches or flood channels. The EPA recently issued renewal permits, proposing minimum components of the post-construction runoff control program, subject to the permittees' review. The permittees are also encouraged to consider requiring or promoting other LID practices. The state has developed a catalog of BMPs, including LID, to provide technical guidance for the selection and site design of stormwater BMPs.

Some Western states, such as New Mexico, have not yet made a strong (or at least statewide) push for the adoption of LID techniques, but it seems clear that the voluntary use of LID strategies has increased in the West as of late, likely because of the fact that they effectively control stormwater pollution, are affordable and may increase property values. But while everyone may agree that communities should strive for cleaner water, the question is whether developers should bear the costs. Now that San Diego and Los Angeles have answered that question by mandating more stringent LID requirements, other Western communities may well follow. Only time will tell. Regardless of whether other Western states and communities decide to mandate the use of LID, it is particularly likely that LID techniques are here to stay and will be adopted with increasing frequency in the near future.

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Storm Water Regulations

	Author/Agency/Organization	Title	Date	URL
1	California (City of Carlsbad)	Standard Urban Storm Water Mitigation Plan Storm Water Standards	04/03	http://www.ci.carlsbad.ca.us/stormwater/susmppdf/susmp.pdf
2	California (City of Santa Monica)	Santa Monica Municipal Code, Chapter 7.10: Urban Runoff Pollution	11/28/00	http://www.qcode.us/codes/santamonica/index.php
3	California (RWQCB, Los Angeles Region)	Order No. 01-182 (Dec. 13, 2001) (NPDES Permit No. CAS004001)	12/13/01	http://63.199.216.5/webdata/data/docs/6948_01-182_WDR.pdf
4	California (RWQCB, San Francisco Bay Region)	Contra Costa Countrywide NPDES Municipal Stormwater Permit Amendment	02/19/03	http://www.swrcb.ca.gov/rwqcb2/Agenda/02-19-03/02-19-03-13finalorder.doc
5	Florida (St. Johns River Waste Management District)	Environmental Resource Permits: Regulations of Stormwater Management Systems	10/03/95	
6	Illinois	General NPDES Permit For Discharges from Small Municipal Separate Storm Sewer Systems	12/20/02	http://www.epa.state.il.us/water/permits/storm-water/general-ms4-permit.pdf
7	Maryland	Maryland's Stormwater Management Program	11/88	
8	Maryland	Explanation of Maryland's Stormwater Management Program	05/31/00	
9	Maryland	Maryland Model Stormwater Management Ordinance	07/00	http://www.mde.state.md.us/assets/document/sediment stormwater/model_ordinance.pdf
10	Maryland	Stormwater Management Code, Title 26, Subtitle 17 Water Management, Chapter 02 Stormwater Management	10/00	http://www.dsd.state.md.us/comar/26/26.17.02.05.htm
11	Maryland (City of Chestertown)	Stormwater Management Ordinance	06/25/84	http://www.chestertown.com/gov/codehtml/0767-142.htm
12	Michigan (Grand Traverse County)	Soil Erosion, Sedimentation, and Stormwater Runoff Control Ordinance	2003	http://www.co.grand-traverse.mi.us/Assets/Departments/Drain+Commissioner/Departments-Drain+Commissioner-Soil+Erosion+Ordinance+9-9-03.pdf
13	Missouri	Missouri State Operating Permit	03/10/03	http://www.dnr.mo.gov/env/wpp/permits/issued/R004000.pdf
14	New Jersey	Stormwater Rules (N.J.A.C. Chapter 7:8)	2004	
15	New Jersey	Annual Groundwater Recharge Analysis	09/01/03	http://www.state.nj.us/dep/stormwater/tier_A/pdf/april2004public_excel2002njgrs_v2_0.xls
16	New Jersey	Tier A Municipal Stormwater NPDES Master General Permit	09/01/05	http://www.nj.gov/dep/dwq/pdf/final_tier_a_permit.pdf
17	New Jersey	NSPS Computations	01/31/06	http://www.state.nj.us/dep/stormwater/pdf/nsps_publicversion20060131.xls
18	New Jersey	NSPS User's Guide	01/06	http://www.njstormwater.org/pdf/nsps_userguide2006013.pdf
19	New Jersey	New Jersey Stormwater Best Management Practices Manual	02/04	http://www.state.nj.us/dep/stormwater/bmp_manual2.htm
20	New Jersey	Guidance for Development of Municipal Mitigation Plans	02/06	http://www.njstormwater.org/docs/munimitipplan030706.pdf
21	New Jersey (Zomorodi, K.)	Curve Number and Groundwater Recharge Credits for LID Facilities in NJ	2004	http://www.dewberry.com/uploadedFiles/Curve_Number_And_Groundwater_Recharge_Credits.PDF
22	New York	New York State Stormwater Management Design Manual	10/01	
23	Oregon (City of Portland)	Stormwater Management Manual	2004	http://www.portlandonline.com/bes/index.cfm?c=35122
24	Oregon (City of Portland)	Portland Title 33: Planning and Zoning Code, for Landscaping and Screening, and Parking and Loading	04/22/06	http://www.portlandonline.com/shared/cfm/image.cfm?id=53315
25	Stafford County, Virginia Board of Supervisors	Municipal Code, Chapter 21.5 Stormwater Management	12/13/05	http://www.municode.com/resources/gateway.asp?sid=46&pid=11500
26	Washington	Stormwater Management in Washington State, Volume I, Minimum Technical Requirements	08/99	
27	Washington	Phase I Municipal Stormwater NPDES General Permit (Draft)	02/15/06	http://www.ecy.wa.gov/programs/wq/stormwater/municipal/phase_I_permit/draft_docs/Phase_I_final_draft_2_15_06.pdf
28	Washington (City of Olympia)	Low-Impact Development Strategy for Green Cove Basin: A Case Study in Regulatory Protection of Aquatic Habitat in Urbanizing Watersheds	10/02	http://www.psat.wa.gov/Programs/LID/Green_Cove.pdf
29	Washington (City of Seattle)	City of Seattle Stormwater, Grading, and Drainage Control Code	07/05/00	http://www.seattle.gov/dclu/codes/sgdccode.pdf
30	West Virginia	General National Pollutant Discharge Elimination System Water Pollution Control Permit	03/07/03	http://www.dep.state.wv.us/Docs/4582_SW_MS4_FinalDraft_issuance.pdf

City of Carlsbad
Public Works Department

Standard Urban Storm Water Mitigation Plan

Storm Water Standards

A Manual for Construction & Permanent Storm Water Best Management Practices Requirements

April 2003

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I. INTRODUCTION

1. Storm Water Standards Manual Organization

This manual is intended to provide information to applicants for private projects processed through the Development Services Division of the Engineering Department (DSD), on how to comply with the permanent and construction storm water requirements for new private and public development projects in the City of Carlsbad. This manual further guides the project applicant through the selection, design, and incorporation of storm water BMPs into the project's design plan.

Section 1, "Introduction," describes storm water pollution background information and legal or regulatory requirements associated with storm water pollution control.

Section II, "Project Review & Permitting Process," outlines the project plan review and approval process for both discretionary actions and construction permits for private development projects. Applicants should use Section II as the roadmap to navigate through this manual and ensure storm water requirements are accurately and efficiently incorporated into their projects during project review. The remaining sections provide technical information necessary to incorporate the storm water requirements in the review process outlined in Section II.

Section III, "Permanent Storm Water BMP Selection Procedure," lists the permanent storm water BMP requirements, which are organized into a progression intended to dovetail with a typical project planning and design process and maximize storm water protections while minimizing project costs. Section IV, "Construction Storm Water BMP Performance Standards," describes the City's construction storm water BMP standards. Section V, "Implementation & Maintenance of Requirements," describes how implementation and maintenance of construction and permanent BMPs must be assured for both construction permits and discretionary actions. For permanent BMPs, this section provides a process and requirements for executing a maintenance agreement with the City. Section VI contains appendices to the Storm Water Standards manual that are either necessary or designed to provide guidance in completing the storm water requirements in this manual.

2. Background

Urban runoff discharged from municipal storm water conveyance systems has been identified by local, regional, and national research programs as one of the principal causes of water quality problems in most urban areas. The City of Carlsbad's storm water conveyance system, which collects runoff and rainwater from our streets, rooftops, driveways, parking lots, and other impervious areas, flows directly to our beaches and lagoons without receiving treatment (our storm water conveyance system is separate from our sanitary sewer system). Urban runoff potentially contains a host of

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pollutants like trash and debris, bacteria and viruses, oil and grease, sediments, nutrients, metals, and toxic chemicals. These contaminants can adversely affect receiving and coastal waters, associated wildlife, and public health. Urban runoff pollution is not only a problem during rainy seasons, but also year-round due to many types of urban water use that discharge runoff to the storm water conveyance system.

Storm water pollution can negatively affect human health and aquatic plant and animal life. Potentially harmful viruses and bacteria are now found in our coastal waters along with soil particles, solids/debris, litter, oil, grease, and chemical compounds. Oil and grease from parking lots, pesticides, cleaning solvents, and other toxic chemicals can contaminate storm water and these contaminants can be transported into receiving waters—the beaches, lagoons and creeks we all enjoy. Fertilizer constituents from lawns and golf courses or leaking septic tanks can cause algal blooms and encourage microbial growth to create an increasing spiral of biological activity known as eutrophication. Disturbances of the soil from construction can allow silt to wash into storm channels and receiving waters making them muddy, turbid, and inhospitable to natural aquatic organisms. Many artificial surfaces of the urban environment such as galvanized metal, paint, or preserved wood containing metals, contribute to pollution by storm water run-on or leaching by storm water as the surfaces corrode, flake, dissolve, or decay. Heavy metals, such as, copper from automobile brakes, and lead and chromium from paints and primer coatings, are toxic to aquatic organisms and may bio-accumulate.

Land development and construction activities significantly alter drainage patterns and contribute pollutants to urban runoff primarily through erosion and removal or change of existing natural vegetation during construction, and the creation of new impervious surfaces, such as parking lots, which often permanently contribute pollutants throughout the “use” of the project site. When homes, work places, recreational areas, roads, parking lots, and structures are built, new impervious areas are built- creating the potential for a “double-negative” impact to water quality. First, the natural landscape’s ability to infiltrate and cleanse storm water and urban runoff is “capped” by the impervious surfaces. As impervious surfaces increase, water that normally would have percolated into the soil where it could be naturally filtered now flows over the land surface directly to downstream wetlands, creeks, and eventually the Pacific Ocean. Accordingly, increases in impervious cover can increase the frequency and intensity of storm water flows. Second, new impervious surfaces often become a source of pollutants associated with development such as, automotive fluids, cleaning solvents, toxic or hazardous chemicals, detergents, sediment, metals, pesticides, oil and grease, and food wastes. These pollutants, which are often temporarily captured on impervious surfaces, are transported to the storm water conveyance system by storm water and urban runoff. The pollutants flow untreated through the storm water conveyance system and ultimately into our creeks, rivers, beaches, and lagoons. With the growing concerns of urban runoff and storm water pollution, local, state, and federal agencies devised regulations requiring development planning and construction controls to treat storm water-related pollution from new development projects before it reaches any receiving waters.

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The Municipal Storm Water National Pollutant Discharge Elimination System (NPDES) Permit (Municipal Permit), issued on February 21, 2001 to the City of San Diego, the County of San Diego, the Port of San Diego, and 17 other cities in the region by the San Diego Regional Water Quality Control Board (Regional Board), requires the development and implementation of storm water regulations addressing storm water pollution issues in development planning and construction associated with private and public development projects. Specifically, private and public development projects are required to include storm water best management practices (BMPs) both during construction, and in the projects permanent design, to reduce pollutants discharged from the project site, to the maximum extent practicable (see Appendix C for a detailed description of the various types and categories of BMPs discussed in this manual). The primary objectives of the Storm Water Standards manual requirements are to: (1) Effectively prohibit non-storm water discharges; and (2) Reduce the discharge of pollutants from storm water conveyance systems to the Maximum Extent Practicable (MEP statutory standard) both during construction and throughout the use of a developed site. To address pollutants that may be generated from new development once the site is in use, the Municipal Permit further requires that the City implement a series of permanent BMPs described in a document called the Model Standard Urban Storm Water Mitigation Plan, or SUSMP (pronounced “sue-sump”), which was approved by the Regional Board on June 12, 2002.

The City’s Storm Water Standards manual is intended to provide information on how to comply with all of the City’s permanent and construction storm water BMP requirements, for new private and public development projects in the City of Carlsbad. The effective date of the Storm Water Standards manual is December 2, 2002, and applies to all projects requiring any permit approvals on or after December 2, 2002, even if the project is currently under review or if previous approvals have been obtained. These Standards will be modified from time to time and are effective on the date issued.

3. Legal Framework

The requirement to implement storm water BMP requirements for development projects is based on Section 402 (p) of the Clean Water Act. The Federal Clean Water Act amendments of 1987 established a framework for regulating storm water discharges from municipal, industrial, and construction activities under the NPDES program. Under the Federal Clean Water Act, municipalities throughout the nation are issued a Municipal NPDES Permit. The primary goal of the Municipal Permit is to reduce polluted discharges from entering the storm water conveyance system and local receiving and coastal waters and to ensure the beneficial uses of protected receiving waters.

In California, the State Water Resources Control Board (SWRCB), through the nine Regional Boards, administers the NPDES storm water municipal permitting program. Based on the San Diego Municipal Permit issued by the San Diego Regional Board, the City is required to develop and implement construction and permanent storm water BMPs addressing pollution from new private and public development projects.

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II. PROJECT REVIEW & PERMITTING PROCESS

Per the National Pollution Discharge Elimination System (NPDES) permit (Order No. 2001-01 NPDES No. CAS0108758) the City of Carlsbad requires development and significant redevelopment, that fall under the category of "priority projects", include Best Management Practices (BMP's) be incorporated to ensure that those projects reduce potential urban pollutant runoff to the maximum extent practicable (MEP). These storm water pollution prevention requirements, which are described in detail in Sections III, "Permanent Storm Water Best Management Practices Selection Procedure," and Section IV, "Construction Storm Water Best Management Practices Performance Standards," are site specific and vary based on the project's potential impact on receiving water quality.

The steps below describe the elements of the development application plan review and permitting processes for storm water best management practice (BMP) requirements. The flow chart in Figure 1, "Review Process For Discretionary Actions" demonstrates how storm water requirements are incorporated into projects requiring subdivision approvals, development permits, discretionary actions or ministerial permits. The flow chart in Figure 2, "Construction Permit Review & Approval Process" describes how storm water requirements are incorporated into projects during the construction permit review process.

Public projects are also subject to the requirements of this Storm Water Standards manual, and although this manual is designed to address the development review process for private projects, City project managers should use this document to identify storm water requirements that must be incorporated into capital improvement projects.

Step 1: Determine Applicable Storm Water BMP Requirements

Prior to submittal, applicants must complete the "Storm Water Requirements Applicability Checklist" in Appendix A, to determine if their project is subject to permanent and construction storm water best management practice (BMP) requirements. (Note: this form must be completed for all permit applications, even if previous approvals exist. Projects with previous approvals will be required to comply with the storm water requirements in this document). This checklist must be completed, signed by the responsible party for the project, and submitted with the permit application. For private projects, the project design must include all required permanent BMPs prior to deeming the application package complete. For public projects, the City project manager shall review and approve the required BMP information prior to bidding for construction contracts.

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Figure 1. Review Process for Discretionary Actions

The following figure provides an overview of the project review process for projects that require a discretionary action by the City of Carlsbad. Discretionary actions include land use plan amendments, rezonings, subdivisions, planned development permits, planned industrial permits, redevelopment permits, coastal development permits, conditional use permits, site development plans.

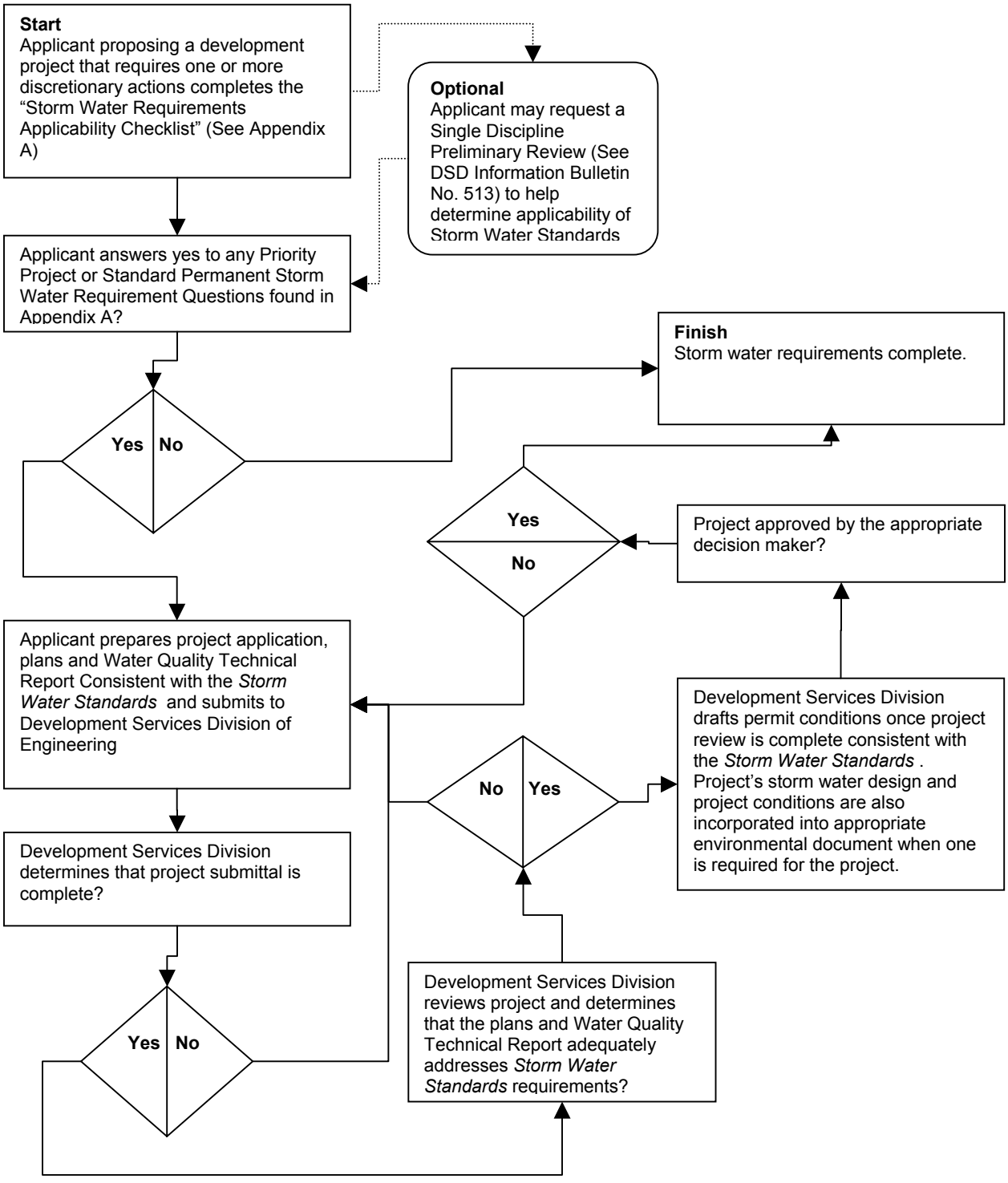
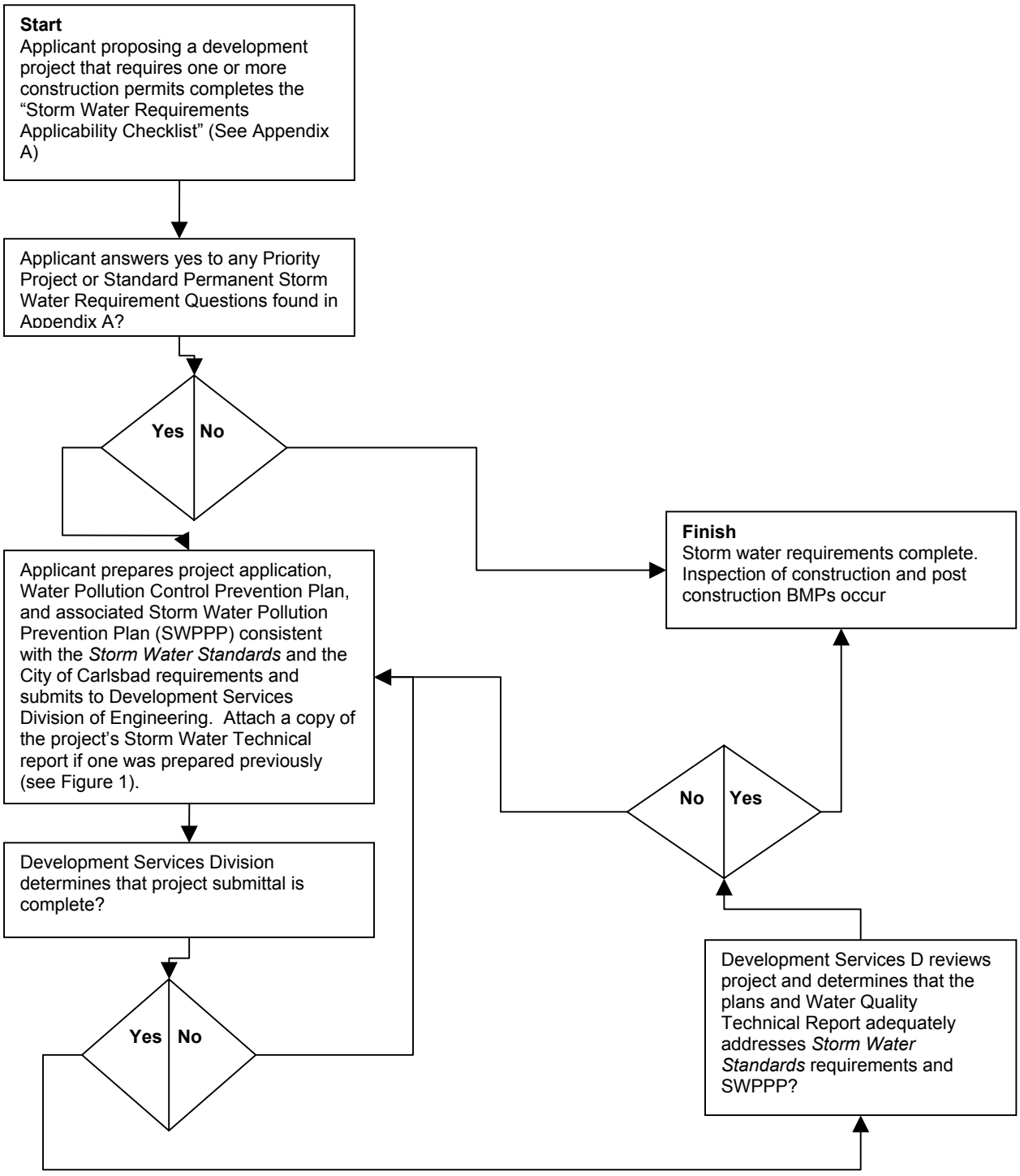


Figure 2. Construction Permit Review & Approval Process

The following figure provides an overview of the project review process for projects that require a construction permit from the City of Carlsbad. Construction permits include building permits, grading permits, demolition permits, ministerial permits and public right-of-way permits.



A. Permanent Storm Water BMP Requirements

i. Standard Requirements. Projects subject to standard permanent storm water requirements as appropriate will incorporate the site design and source control requirements identified in Sections III.2.A and B (requirements 1 through 15), into the project (see Table 1). Refer to Step 2: "Prepare & Submit Appropriate Plans," for guidance in the BMP design process.

ii. Priority Project Requirements. Projects subject to priority project permanent storm water requirements as appropriate will incorporate all applicable requirements in Section III.2, "Establish Permanent Storm Water Best Management Practices," (requirements 1 through 35) into the project design. This includes the site design and source control BMPs, BMPs applicable to individual priority project categories, and treatment control BMP requirements. If a priority project meets more than one priority project category definition, as shown in Table 1, the project is subject to all BMPs applicable to individual priority project categories that apply. For example, if a project is proposing to build 50 attached residential units and a 6,000 square foot restaurant with a 70-space surface parking lot, the project would be subject to the individual priority project category BMP requirements for "Attached Residential Development," "Restaurants," and "Parking Lots," as shown in Table 1 below. Refer to Step 2: "Prepare & Submit Appropriate Plans," for guidance in the permanent BMP design process.

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Table 1. Standard Development Project & Priority Project Storm Water BMP Requirements Matrix.

	Site Design BMPs(1)	***Source Control BMPs(2)***	***BMPs Applicable to Individual Priority Project Categories(3)***										***Treatment Control BMPs(4)***
			a. Private Roads	b. Residential Driveways & Guest Parking	c. Dock Areas	d. Maintenance Bays	e. Vehicle Wash Areas	f. Equipment Wash Areas	g. Outdoor Processing Areas	h. Surface Parking Areas	i. Fueling Areas	j. Hillside Landscaping	
Standard Projects	R	R	O	O	O	O	O	O	O	O	O	O	O
Priority Projects:													
Detached Residential Development	R	R	R	R								R	S
Attached Residential Development	R	R	R										S
Commercial Development >100,000 ft^2	R	R			R	R	R		R				S
Automotive Repair Shop	R	R			R	R	R	R			R		S
Restaurants	R	R			R			R					S
Hillside Development >5,000 ft^2	R	R	R									R	S
Parking Lots	R	R								R(5)			S
Streets, Highways & Freeways	R	R											S

R = Required; select one or more applicable and appropriate BMPs from the applicable steps in Section III.2.A-D, or equivalent as identified in Appendix C.

O = Optional/ or may be required by City staff. As appropriate, applicants are encouraged to incorporate treatment control BMPs and BMPs applicable to individual priority project categories into the project design. City staff may require one or more of these BMPs, where appropriate.

S = Select one or more applicable and appropriate treatment control BMPs from Appendix C.

(1) Refer to Section III.2.A.

(2) Refer to Section III.2.B.

(3) Priority project categories must apply specific storm water BMP requirements, where applicable. Priority projects are subject to the requirements of all priority project categories that apply.

(4) Refer to Section III.2.D.

(5) Applies if the paved area totals >5,000 square feet or with >15 parking spaces and is potentially exposed to urban runoff.

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B. Construction Storm Water BMP Requirements

Projects subject to the construction storm water best management practices requirements must comply with the standards included in Section IV, "Construction Storm Water BMP Performance Standards," as appropriate depending on the site conditions, season, and project design, and construction methods. Each project must be given a priority ranking (high, medium or low) for the construction phase (see Appendix A). The prioritization will determine the inspection frequency by City staff but will not change the construction BMP requirements. Refer to Step 2: "Prepare & Submit Appropriate Plans," for guidance in navigating through this manual to ensure construction BMP performance standards are met.

Step 2 – Prepare & Submit Appropriate Plans.

After determining the general categories of storm water requirements that apply to the project in Step 1 (e.g., construction BMPs, standard permanent BMPs, and/or priority project permanent BMPs), refer to the instructions in this step (see below) to determine what analysis and/or specific BMP requirements in Sections III and IV of the Storm Water Standards manual must be provided and/or incorporated into the project[1].

A. Permanent Storm Water BMPs

Section III, "Permanent Best Management Practices Selection Procedure," contains a process for reviewing the project site's location and preliminary project design before progressively identifying and incorporating site design BMPs, source control BMPs, requirements for individual priority project types, and treatment control BMPs into the project design. The procedure is organized so that the level of analysis required is commensurate with the potential pollutant type and quantity, the location of the project relative to sensitive receiving waters, and with the type of storm water requirements that apply to a particular project.

i. Standard Requirements. Projects (requiring either discretionary actions or construction permits), subject to only standard permanent BMP requirements need only to complete the "Identify Pollutants from the Project Area" procedure (Section III.1.A), and then incorporate the requirements in Section III.2.A, "Site Design BMPs" and Section III.2.B, "Source Control BMPs" (requirements 1-15). Applicants must incorporate all necessary permanent BMPs into the project plans prior to submittal, regardless of project type. Analysis of the project's anticipated pollutants of concern must also be included with the project submittal.

[1] Projects are only required to provide applicable BMPs. For example, an attached residential development project subject to the priority project requirements would not have to meet the "private road" requirements in this manual if no private roads were proposed. In addition, the City Engineer may approve proposed alternatives to the BMP requirements in this manual if they are determined to be applicable and equally effective.

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ii. Priority Project Requirements. Projects (requiring either discretionary actions or construction permits), subject to the priority project permanent BMP requirements must complete all of the analyses required in Section III.1, "Identify Pollutants and Conditions of Concern," and incorporate all of the applicable BMP requirements in Section III.2, "Establish Storm Water BMP Requirements" (requirements 1-33). Applicants must incorporate all necessary permanent BMPs into the project plans prior to submittal, regardless of project type. In addition, projects subject to priority project requirements must prepare and submit a Water Quality Technical Report in accordance with Appendix D. Analysis of the project's anticipated pollutants of concern, anticipated pollutants of concern in downstream receiving waters, and conditions of concern, must also be included in the Water Quality Technical Report as part of the project submittal.

B. Construction Storm Water BMPs

Section IV, "Construction Storm Water BMP Performance Standards," describes the construction site management requirements that contractors must comply with. In addition, Section IV lists the performance standards that construction sites must meet, and provides a list of erosion control, sediment control, and materials management BMPs for reference. Additionally, each project must be given a priority of high, medium or low (see Appendix A). (Note: Prioritization of construction projects will determine the inspection frequency by City staff and may be changed during the construction process based on the potential for pollutants to be discharged from the site.)

i. Those projects that have been determined to require construction BMPs in Step 1 must identify the construction BMPs to be implemented in accordance with the performance standards in Section IV, "Construction Storm Water BMP Performance Standards." The applicant must provide a Storm Water Pollution Prevention Plan (SWPPP), which identifies all construction BMP requirements required by Section IV, in accordance with Order No. 99-08-DWQ of the State General Permit for Storm Water Discharges Associated with Construction Activity (State General Construction Permit). For projects that disturb 1-acre or more, and are determined to have a potential to impact water quality during construction, the applicant must provide a Water Pollution Control Plan (WPCP), which identifies all construction BMP requirements required by Section IV, with the project submittal. The WPCP shall depict the BMP's to be implemented during construction to reduce/eliminate discharges of pollutants to the storm drain conveyance system. The WPCP shall include but not be limited to erosion and sediment control BMP's, good housekeeping measures and site and materials management.

Consistent with the State General Construction Permit, the City will require that both erosion and sediment control BMPs be installed and maintained for all applicable projects in addition to good housekeeping and site and materials management. Appendix E provides general guidelines for preparation of a SWPPP as well as a more detailed checklist to meet the requirements.

After preparing plans and supporting documents according to the requirements in this manual, submit plans to the Development Services Division of the Engineering Department for review (See Step 3).

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Step 3 – Determine Adequacy of Proposed Plans.

The City Engineer will review submitted plans for compliance with the applicable storm water requirements contained in this manual. The City Engineer may approve proposed alternatives to the BMP requirements in this manual if they are determined to be applicable and equally effective. Additional analysis or information may be required to enable staff to determine the adequacy of proposed BMPs, and will be requested through a project issues report following the conclusion of a staff review cycle. After all storm water requirements have been approved by the City Engineer, proceed to Step 4 to assure implementation and maintenance of the approved BMPs through permit conditions, plan notes, and if necessary, maintenance agreements.

Step 4 -- Assure Implementation & Maintenance of Requirements.

Applicants must provide assurances that required permanent storm water BMPs will be constructed and permanently maintained throughout the use of a developed site, and that construction BMPs will be implemented and maintained until construction is complete. The summaries below describe how construction and permanent BMP requirements must be assured during both discretionary actions and construction permit review processes. After the City Engineer has approved all construction and/or permanent BMPs, refer to Section V, “Implementation & Maintenance of Requirements” to determine how construction and permanent BMP implementation and maintenance will be assured.

A. Discretionary Action

For any discretionary action, required permanent storm water requirements shall be incorporated into the project design and be shown on the plans. If the project will be required to provide construction BMPs, the permit/approval shall include the “Standard Construction BMP Implementation And Maintenance Condition” listed in Section V, “Implementation & Maintenance of Requirements”.

B. Construction Permits

For projects requiring construction permits, construction and required permanent BMP requirements shall be incorporated into the project design and shown on the plans prior to the issuance of any permits. Construction and permanent BMP requirements shall also be noted on the plans. Any construction BMP requirements that cannot be shown graphically must be noted on the plans.

C. Public Projects

For public projects, required permanent, as well as construction, BMP requirements must be incorporated into the project design and shown on the plans prior to bidding for construction contracts, or equivalent. Public project contracts must also add the requirement for the project to implement and maintain construction BMP requirements in accordance with this manual.

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III. PERMANENT BEST MANAGEMENT PRACTICES SELECTION PROCEDURE

When referred to this Section, by Step 2 of Section II, complete the analysis required for your project in the subsections of Section III.1 below.

1. IDENTIFY POLLUTANTS & CONDITIONS OF CONCERN

A. Identify Pollutants from the Project Area

Using Table 1, identify the project's anticipated pollutants. Pollutants associated with any hazardous material sites that have been remediated or are not threatened by the proposed project are not considered a pollutant of concern. Projects meeting the definition of more than one project category shall identify all general pollutant categories that apply.

Table 2. Anticipated and Potential Pollutants Generated by Land Use Type.

	General Pollutant Categories								
Project Categories	Sediments	Nutrients	Heavy Metals	Organic Compounds	Trash & Debris	Oxygen Demanding Substances	Oil & Grease	Bacteria & Viruses	Pesticides
Detached Residential Development	X	X			X	X	X	X	X
Attached Residential Development	X	X			X	P(1)	P(2)	P(1)	X
Commercial Development >100,000 ft^2	P(1)	P(1)		P(2)	X	P(5)	X	P(3)	P(5)
Automotive Repair			X	X(4)(5)	X		X		
Restaurants					X	X	X	X	
Hillside Development >5,000 ft^2	X	X			X	X	X		X
Parking Lots	P(1)	P(1)	X		X	P(1)	X		P(1)
Streets, Highways & Freeways	X	P(1) X	X	X(4)	X	P(5)	X		

X = anticipated
P = potential
(1) A potential pollutant if landscaping exists on-site.
(2) A potential pollutant if the project includes uncovered parking areas.
(3) A potential pollutant if land use involves food or animal waste products.
(4) Including petroleum hydrocarbons.
(5) Including solvents.

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B. Identify Pollutants of Concern in Receiving Waters

For priority projects, the following analysis shall be conducted and reported in the project's Water Quality Technical Report:

1. For each of the proposed projects discharge points, identify the receiving water(s) that each discharge point proposes to discharge to, including hydrologic unit basin number(s), as identified in the most recent version of the *Water Quality Control Plan for the San Diego Basin*[2], prepared by the San Diego Regional Water Quality Control Board.
2. Identify any receiving waters, into which the developed area would discharge to, listed on the most recent list of Clean Water Act Section 303(d) impaired water bodies[3]. List any and all pollutants for which the receiving waters are impaired.

Sites tributary to Clean Water Act section 303(d) water bodies impaired for sediment and sites discharging directly into environmentally sensitive areas (ESA) require additional BMP implementation. These sites are by definition classified as posing a high threat to water quality. In the 1998 303(d) listing, the Agua Hedionda Lagoon is impaired for sediment and siltation. Buena Vista Lagoon also has impaired beneficial uses (aquatic life) due to high sedimentation/siltation. Portions of Carlsbad where construction sites have the potential to discharge into a tributary of a 303(d) or directly into a 303(d) water body or sites located within 200 feet of an ESA require additional BMP implementation. These water bodies include the Pacific Ocean, Buena Vista Lagoon, Encinas Creek, Agua Hedionda Lagoon, and Batiquitos Lagoon.

C. Identify Conditions of Concern

For priority projects, the following analysis shall be conducted and reported in the project's Water Quality Technical Report:

1. Evaluate the project's conditions of concern in a drainage study report prepared by a registered civil engineer in the State of California, with experience in the science of stream and river generated surface features (i.e., fluvial geomorphology) and water resources management. The report shall consider the project area's location (from the larger watershed perspective), topography, soil and vegetation conditions, percent impervious area, natural and infrastructure drainage features, and any other relevant hydrologic and environmental factors to be protected specific to the project area's watershed.
2. As part of the drainage study, the applicant's civil engineer shall conduct a field reconnaissance to observe and report on downstream conditions, including undercutting erosion, slope stability, vegetative stress (due to flooding, erosion, water quality degradation, or loss of water supplies) and the area's susceptibility to erosion or habitat alteration as a result of any future upstream development.

2. Go to: http://www.swrcb.ca.gov/~rwqcb9/Programs/Basin_PLanning/Basin_PLan/basin_plan.html
3. Go to: http://www.swrcb.ca.gov/tmdl/303d_lists.html. San Diego is in Region 9 (a link is provided).

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3. The drainage study shall utilize the most recent edition of the San Diego County Hydrology Manual, compute rainfall runoff characteristics from the project area including, at a minimum, runoff volume, time of concentration, and retention volume. These characteristics shall be developed for the two-year and 10-year frequency, Type I storm, of six-hour or 24-hour duration (whichever is the closer approximation of the site's time of concentration), during critical hydrologic conditions for soil and vegetative cover[4]. The drainage study shall also report the project's conditions of concern based on the hydrologic and downstream conditions discussed above. Where downstream conditions of concern have been identified, the drainage study shall establish that pre-project hydrologic conditions that minimize impacts on those downstream conditions of concern would be either improved or maintained by the proposed project, satisfactory to the City Engineer, by incorporating the permanent BMP requirements identified in Section III.2, below.

2. ESTABLISH PERMANENT STORM WATER BEST MANAGEMENT PRACTICES

After identifying the project's pollutants of concern, and conditions of concern (for priority projects), in Section III.1, projects subject to standard or priority project requirements shall implement all applicable site design, source control BMPs listed below. Projects subject to priority project requirements must also implement the BMPs applicable to individual priority project categories and structural treatment control BMPs. Applicants may employ alternative comparable and equally effective site design and source control BMPs (including requirements applicable to individual priority project categories), satisfactory to the City Engineer.

Projects are encouraged to address these objectives through the creation of a hydrologically functional project design that attempts to mimic the natural hydrologic regime. Mimicking a site's natural hydrologic regime may be pursued by:

- Reducing imperviousness, conserving natural resources and areas, maintaining and using natural drainage courses in the storm water conveyance system, and minimizing clearing and grading that is necessary for the project.
- Providing runoff storage measures dispersed uniformly throughout a site's landscape with the appropriate use of a variety of detention, retention, and runoff practices.
- Implementing on-lot hydrologically functional landscape design and management practices.

4. Design storms can be found at http://www.wrcc.dri.edu/pcpnfreq.html.

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These design principles offer an innovative approach to urban storm water management, one that does not rely on the conventional end-of-pipe or in-the-pipe structural methods but instead uniformly or strategically integrates storm water controls throughout the urban landscape. Useful resources for applying these principles are referenced in Appendix G. Effective source controls offer another strategy to reduce a project's need for treatment. Therefore, projects shall incorporate, where applicable, storm water BMPs into the project design, in the following progression:

- Site Design BMPs
- Source Control BMPs
- BMPs for Individual Priority Project Categories (these are site design and source control BMPs)
- Treatment Control BMPs

The series of best management practices listed in Section III.2 have been organized sequentially to allow the applicant and design professional to incorporate the site design, source control BMPs, and where necessary, requirements applicable to individual priority project categories and treatment control BMPs in this progression.

A. Site Design BMPs

Maintain Pre-Development Rainfall Runoff Characteristics

Control post-development peak storm water runoff discharge rates and velocities to maintain or reduce pre-development development downstream erosion by applying the following or similar concepts:

1. Minimize impervious footprint to the maximum extent practicable consistent with the General Plan, Municipal Code, and other City standards by utilization of measures of the following types: (1) Increase building density (number of stories above or below ground); (2) construct walkways, trails, patios, overflow parking lots and alleys and other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials; (3) construct streets, sidewalks and parking lot aisles to the minimum widths required, provided that public safety and a walkable environment for pedestrians are not compromised; and (4) minimize the use of impervious surfaces, such as decorative concrete, in the landscape design.
2. Conserve natural areas. (1) Concentrate or clustering development on the least environmentally sensitive portions of a site while leaving the remaining land in a natural, undisturbed condition; and (2) Use natural drainage systems to the maximum extent practicable.
3. Minimize Directly Connected Impervious Areas. (1) Where landscaping is proposed, drain rooftops into adjacent landscaping prior to discharging to the storm water conveyance system; and (2) where landscaping is proposed, drain impervious parking lots, sidewalks, walkways, trails, and patios into adjacent landscaping.
4. Maximize canopy interception and water conservation consistent with the Carlsbad Landscape Manual. (1) Preserve existing native trees and shrubs; and (2) plant additional native or drought tolerant trees and large shrubs in place of non-drought tolerant exotics.

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Protect Slopes and Channels

5. Convey runoff safely from the tops of slopes.
6. Vegetate slopes with native or drought tolerant vegetation where practicable consistent with the Carlsbad Landscape Manual.
7. Stabilize permanent channel crossings.
8. Install energy dissipaters, at the outlets of new storm drains, culverts, conduits, or channels that enter unlined channels in accordance with applicable standards and specifications to minimize erosion. Energy dissipaters shall be installed in such a way as to minimize impacts to receiving waters.

B. Source Control BMPs

Design Outdoor Material Storage Areas to Reduce Pollution Introduction

9. Hazardous materials with the potential to contaminate urban runoff shall be: (1) placed in an enclosure such as, but not limited to, a cabinet, shed, or similar structure that prevents contact with rain, runoff or spillage to the storm water conveyance system; and (2) protected by secondary containment structures such as berms, dikes, or curbs. The storage area shall be paved and sufficiently impervious to contain leaks and spills, and have a roof or awning to minimize direct precipitation within the secondary containment area.

Design Trash Storage Areas to Reduce Pollution Introduction

10. Trash storage areas shall be: (1) paved with an impervious surface, designed not to allow run-on from adjoining areas, screened or walled to prevent off-site transport of trash; and) contain attached lids on all trash containers that exclude rain; or contain a roof or awning to minimize direct precipitation.

Limited exclusion: detached residential homes.

Use Efficient Irrigation Systems & Landscape Design

11. Employ rain shutoff devices to prevent irrigation during precipitation consistent with the Carlsbad Landscape Manual.
12. Design irrigation systems to each landscape area's specific water requirements consistent with the Carlsbad Landscape Manual.

Limited exclusion: detached residential homes.

Provide Storm Water conveyance System Stenciling and Signage

13. Provide concrete stamping, porcelain tile, inset permanent marking or equivalent as approved by the City of Carlsbad, of all storm water conveyance system inlets and catch basins within the project area with prohibitive language (e.g., “No Dumping – I Live Downstream”), satisfactory to the City Engineer.
14. Post signs and prohibitive language and/or graphical icons, which prohibit illegal dumping at public access points along channels and creeks within the project area, trailheads and parks.

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C. BMPs Applicable to Individual Priority Project Categories

Where identified in Table 1, the following requirements shall be incorporated into applicable priority projects. Projects shall adhere to each of the individual priority project category requirements that apply to the project (e.g., a restaurant with more than 15 parking spaces would be required to incorporate the requirements for "h. Parking Areas" into the project design).

a. Private Roads

15. The design of private roadway drainage where appropriate, shall incorporate, to the extent practicable, (1) rural swale system- street sheet flows to vegetated swale or gravel shoulder, curbs at street corners, culverts under driveways and street crossings; (2) urban curb/swale system- street slopes to curb, periodic swale inlets drain to vegetated swale/biofilter; or (3) dual drainage system- first flush captured in street catch basins and discharged to adjacent vegetated swale or gravel shoulder, (4) other treatment control BMP methods approved by the City Engineer to reduce storm water runoff pollution.

b. Residential Driveways & Guest Parking

16. Driveways shall have, to the extent practicable, one of the following: (1) shared access; (2) flared entrance (single lane at street); (3) wheelstrips (paving only under tires); or (4) designed to drain into landscaping prior to discharging to the storm water conveyance system.

17. Uncovered temporary or guest parking on private residential lots shall be, to the extent practicable,: (1) paved with a permeable surface; or (2) designed to drain into landscaping prior to discharging to the storm water conveyance system.

c. Dock Areas

18. Loading/unloading dock areas shall include the following: (1) cover loading dock areas, or design drainage to preclude urban run-on and runoff; and (2) Direct connections to storm drains from depressed loading docks (truck wells) are prohibited.

d. Maintenance Bays

19. Maintenance bays shall include at least one of the following: (1) repair/ maintenance bays shall be indoors; or, (2) designed to preclude urban run-on and runoff.

20. Maintenance bays shall include a repair/maintenance bay drainage system to capture all wash water, leaks and spills. Connect drains to a sump for collection and disposal. Direct connection of the repair/maintenance bays to the storm water conveyance system is prohibited. Where areas are allowed to connect to the sanitary sewer system, an Industrial Waste Permit from the Encina Water Pollution Control Facility may be required.

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e. & f. Vehicle & Equipment Wash Areas

21. Areas for washing/steam cleaning of vehicles and areas for outdoor equipment/accessory washing and steam cleaning shall be: (1) self-contained to preclude run-on and run-off, covered with a roof or overhang, and equipped with a clarifier or other pretreatment facility; and (2) properly connected to a sanitary sewer if appropriate. Where areas are connected to a sanitary sewer, an Industrial Waste Permit may be required from the Encina Water Pollution Control Facility.

g. Outdoor Processing Areas

22. Outdoor processing areas shall: (1) cover or enclose areas that would be the most significant source of pollutants; or, (2) slope the area toward a dead-end sump or, (3) discharge to the sanitary sewer system
23. Grade or berm processing area to prevent run-on from surrounding areas.
24. Installation of storm drains in areas of equipment repair is prohibited.

h. Surface Parking Areas

25. Where landscaping is proposed in surface parking areas (both covered and uncovered), incorporate landscape areas into the drainage design.
26. Overflow parking (parking in excess of the project's minimum parking requirements) may be constructed with permeable paving subject to the City Engineer’s approval.

i. Non-Retail Fueling Areas

Non-Retail fueling areas shall be designed with the following:

27. Fuel dispensing area that is: (1) paved with Portland cement concrete or equivalent smooth impervious surface (asphalt concrete is prohibited); (2) designed to extend 6.5 feet from the corner of each fuel dispenser, or the length at which the hose and nozzle assembly may be operated plus 1 foot, whichever is greater; (3) sloped to prevent ponding; (4) separated from the rest of the site by a grade break that prevents run-on of urban runoff; and (5) designed to drain to the project's treatment control BMP(s) prior to discharging to the storm water conveyance system.
28. Overhanging roof structure or canopy that is: (1) equal to or greater than the area within the fuel dispensing area's grade break; and (2) designed not to drain onto or across the fuel dispensing area.

j. Hillside Landscaping

29. Hillside areas disturbed by project development shall be landscaped with deep-rooted, drought tolerant plant species selected for erosion control, in accordance with the with the Carlsbad Landscape Manual.

D. Treatment Control BMPs

30. Where identified in Table 1, and after site design and source control BMPs have been incorporated into the project, applicants of priority projects shall design a single or combination of treatment control BMPs designed to infiltrate, filter, and/or treat runoff from the project footprint to one of the "Numeric Sizing Treatment Standards" listed in Table 3, below. Applicants must use the Structural Treatment BMP Selection Procedure outlined in Section III.2.D.i, below to select appropriate treatment control BMPs. Applicants are encouraged to design projects so that runoff is treated by site design BMPs, such as rooftop runoff treated in landscaping, so that it may be applied towards the numeric sizing treatment standards, satisfactory to the City Engineer. In addition, applicants are encouraged to apply a "drainage basin approach" in meeting the treatment requirements. Treating entire hydrologic sub-drainages, which often extend off-site, is an equitable, environmentally sound regional solution that applies treatment requirements to hydrologically defined areas, rather than legally defined parcels. When integrated with other projects, this approach can provide a more efficient and cost effective method of treatment by locating fewer, more effective BMPs to treat entire sub-drainages once. In all instances, structural treatment BMP(s) may be located on- or off-site, used singly or in combination, or shared by multiple new developments, pursuant to the following criteria:

    (a) All structural treatment control BMPs shall infiltrate, filter, and/or treat the required runoff volume or flow prior to discharging to any receiving water body supporting beneficial uses;

    (b) Multiple post-construction structural treatment control BMPs for a single priority project shall collectively be designed to comply with the numeric sizing treatment standards;

    (c) Shared BMPs shall be operational prior to the use of any dependent development or phase of development. The shared BMPs shall only be required to treat the dependent developments or phases of development that are in use;

    (d) Interim storm water BMPs that provide equivalent or greater treatment than is required may be implemented by a dependent development until each shared BMP is operational. If interim BMPs are selected, the BMPs shall remain in use until permanent BMPs are operational.

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Table 3. Numeric Sizing Treatment Standards.

Volume

1. Volume-based BMPs shall be designed to mitigate (infiltrate, filter, or treat) the volume of runoff produced from a 24-hour 85th percentile storm event, as determined from isopluvial maps contained in the County of San Diego Hydrology Manual.

OR

Flow

2. Flow-based BMPs shall be designed to mitigate (infiltrate, filter, or treat) the maximum flow rate of runoff produced from a rainfall intensity of 0.2 inch of rainfall per hour for each hour of a storm event.

i. Structural Treatment BMP Selection Procedure

Priority projects shall select a single or combination of treatment BMPs from the categories in Table 4 that maximize pollutant removal for the particular pollutant(s) of concern. Any pollutants the project is expected to generate that are also causing a Clean Water Act section 303(d) impairment of the downstream receiving waters of the project should be given top priority in selecting treatment BMPs.

To select a structural treatment BMP using the Structural Treatment Control BMP Selection Matrix (Table 4), each priority project shall compare the list of pollutants for which the downstream receiving waters are impaired (if any). According to the 1998 303(d) listing, the Agua Hedionda Lagoon is impaired for sediment and siltation. Buena Vista Lagoon also has impaired beneficial uses (aquatic life) due to high sedimentation/siltation. Portions of Carlsbad where construction sites have the potential to discharge into a tributary of a 303(d) or directly into a 303(d) water body or sites located within 200 feet of an ESA require additional BMP implementation. These water bodies include the Pacific Ocean, Buena Vista Lagoon, Encinas Creek, Agua Hedionda Lagoon, and Batiquitos Lagoon.

Priority projects that are not anticipated to generate a pollutant for which the receiving water is Clean Water Act Section 303(d) impaired shall select a single or combination of structural treatment BMPs from Table 4 that are effective for pollutant removal of the identified pollutants of concern determined to be most significant for the project. Selected BMPs must be effective for the widest range of pollutants of concern anticipated to be generated by a priority project (as identified in Table 1).

Alternative storm water BMPs not identified in Table 4 may be approved at the discretion of the City Engineer, provided the alternative BMP is as effective in removal of pollutants of concern as other feasible BMPs listed in Table 4.

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Table 4. Structural Treatment Control BMP Selection Matrix.

Pollutant of Concern	*Treatment Control BMP Categories*						
	Biofilters	Detention Basins	Infiltration Basins(1)	Wet Ponds or Wetlands	Drainage Inserts	Filtration	Hydrodynamic Separator Systems(2)
Sediment	M	H	H	H	L	H	M
Nutrients	L	M	M	M	L	M	L
Heavy Metals	M	M	M	H	L	H	L
Organic Compounds	U	U	U	U	L	M	L
Trash & Debris	L	H	U	U	M	H	M
Oxygen Demanding Substances	L	M	M	M	L	M	L
Bacteria	U	U	H	U	L	M	L
Oil & Grease	M	M	U	U	L	H	L
Pesticides	U	U	U	U	L	U	L

(1) Including trenches and porous pavement.
(2) Also known as hydrodynamic devices and baffle boxes.

L: Low removal efficiency
M: Medium removal efficiency
H: High removal efficiency
U: Unknown removal efficiency

Sources: *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (1993), *National Stormwater Best Management Practices Database* (2001), and *Guide for BMP Selection in Urban Developed Areas* (2001).

ii. Restrictions on the Use of Infiltration Treatment BMPs

31. Treatment control BMPs that are designed to primarily function as infiltration devices shall meet the following conditions (these conditions do not apply to treatment BMPs which allow incidental infiltration and are not designed to primarily function as infiltration devices, such as grassy swales, detention basins, vegetated buffer strips, constructed wetlands, etc.): (1) urban runoff from commercial developments shall undergo pretreatment to remove both physical and chemical contaminants, such as sedimentation or filtration, prior to infiltration; (2) all dry weather flows shall be diverted from infiltration devices except for those non-storm water discharges authorized pursuant to 40 CFR 122.26(d)(2)(iv)(B)(1): diverted stream flows, rising ground waters, uncontaminated ground water infiltration [as defined at 40 CFR 35.2005(20)] to storm water conveyance systems, uncontaminated pumped ground water, foundation drains, springs, water from crawl space pumps, footing drains, air conditioning condensation, flow from riparian habitats and wetlands, water line flushing, landscape irrigation, discharges from potable water sources other than water main breaks, irrigation water, individual residential car washing, and dechlorinated swimming pool discharges; (3) pollution prevention and source control BMPs shall be implemented at a level appropriate to protect groundwater quality at sites where infiltration structural treatment BMPs are to be used; (4) the vertical distance from the base of any infiltration structural treatment BMP to the seasonal high groundwater mark shall be at least 10 feet. Where groundwater does not support beneficial uses, this vertical distance criterion may be reduced, provided groundwater quality is maintained; (5) the soil through which infiltration is to occur shall have physical and

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chemical characteristics that are adequate for proper infiltration durations and treatment of urban runoff for the protection of groundwater beneficial uses; (6) the horizontal distance between the base of any infiltration structural BMP and any water supply wells shall be 100 feet or as determined appropriate by the City Engineer.

32. Notification to neighboring jurisdictions may be required where staff determines the infiltration BMP(s) may impact the groundwater in a neighboring jurisdiction.

Structural Treatment Limited Exclusions

(a.) Proposed restaurants, where the land area for development or redevelopment is less than 5,000 square feet, are excluded from the numerical sizing criteria requirements listed in Table 3.

(b.) Where significant redevelopment results in an increase of less than 50 percent of the impervious surfaces of a previously existing development, and the existing development was not subject to priority project requirements, the numeric sizing criteria apply only to the addition, and not to the entire development.

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IV. CONSTRUCTION STORM WATER BMP PERFORMANCE STANDARDS

Those projects that have been determined to require construction BMPs in Steps 1 and 2 of Section II, must identify the construction BMPs to be implemented in accordance with the performance standards in this section. The construction BMPs must be identified in a Storm Water Pollution Prevention Plan or Water Pollution Control Plan for projects disturbing more than 1-acre. These plans must be prepared in accordance with the guidelines in Appendix E.

It is the responsibility of the property owner and/or contractor to select, install and maintain appropriate BMPs. A list of construction BMPs is provided for reference in Appendix F. BMPs must be installed in accordance with an industry recommended standard or in accordance with the requirements of the State General Construction Permit. More information about BMPs is provided in the Model Construction Program for San Diego Copermittees, the City of Los Angeles "Reference Guide for Stormwater Best Management Practices," State Storm Water BMP Manuals, and Caltrans Standard BMP handbook.

BMP requirements differ between the rainy season(Oct. 1 – Apr. 30) and the dry season (May 1 – Sept. 30), the type of the project and topography of the site, as described below.

1. Site Management Requirements

Construction is a dynamic operation where changes are expected. Storm water BMPs for construction sites are usually temporary measures that require frequent maintenance to maintain their effectiveness and may require relocation, revision and re-installation, particularly as project grading progresses. Therefore, owner/contractor self-inspections are required. They shall be performed by the owner's/contractor's Qualified Contact Person specifically trained in storm water pollution prevention site management and storm water BMPs, including the installation and maintenance of sediment and erosion control measures. Additional qualified persons may assist with the inspection activities under the direction of the Qualified Contact Person. A Qualified Contact Person is required for all sites during both wet and dry weather conditions.

There are four primary purposes of the self-inspections conducted by owners and contractors:

- To ensure that the owners/contractors take full responsibility for managing storm water pollution caused by their activities.
- To ensure that storm water BMPs are properly documented and implemented and are functioning effectively.
- To identify maintenance (e.g., sediment removal) and repair needs.
- To ensure that the project proponents implement their storm water management plans.

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A self-inspection checklist, noting date, time, conditions and inspection date, must be kept on-site and made available for inspection, if requested. Self-inspections must be performed by a Qualified Contact Person according to the following schedule:

- Daily weather forecasting at all times
- At 24-hour intervals during extended rainfall events
- Daily evaluations as earth moving/grading is being conducted during the wet season
- Weekly (every 7 days) in the dry season as earth moving/grading is progressing
- Self inspection checklists shall be submitted to the project inspector on a weekly basis during the rainy season.

Storm water pollution prevention site management requirements include:

A. A qualified person who is trained and competent in the use of BMPs shall be on site daily, although not necessarily full time, to evaluate the conditions of the site with respect to storm water pollution prevention. This qualified contact person shall represent the contractor/ owner on storm water issues.
B. The qualified person shall implement the conditions of the Storm Water Pollution Prevention Plan, contract documents and/or local ordinances with respect to erosion and sediment control and other waste management regulations.
C. The qualified person is responsible for monitoring the weather and implementation of any emergency plans as needed. The weather shall be monitored on a 5-day forecast plan and a full BMP protection plan shall be activated when there is a 40% chance of rain.
D. The qualified person is responsible for overseeing any site grading and operations and evaluating the effectiveness of the BMPs. This person shall modify the BMPs as necessary to keep the dynamics of the site in compliance. This person or other qualified persons are responsible for checking the BMPs routinely for maintenance and documenting the BMPs being implemented.

2. Performance Standards

The City of Carlsbad will evaluate the adequacy of the owner's/contractor's site management for storm water pollution prevention, inclusive of BMP implementation, on construction sites based on performance standards for storm water BMPs. Poor BMP practices shall be challenged. Performance standards shall include:

A. Prevent increase in pollution to the maximum extent practicable.
B. Minimize slope erosion.
C. Control discharge velocities moving offsite to limit down stream erosion potential to the pre-construction levels. .

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A site will be considered inactive if construction activities have ceased for a period of 7 or more consecutive calendar days. At any time of year, an inactive site must be fully protected from erosion and discharges of sediment. It is also the owner's/contractor's responsibility at both active and inactive sites to implement a plan to address all potential non-storm water discharges.

Regardless of any inspections conducted by the City, property owners or contractors are required to prevent any construction-related materials, trash, wastes, spills or residues from entering a storm water conveyance system.

3. Seasonal Requirements

A. Dry Season Requirements (May 1 through September 30):

1. Perimeter protection BMPs must be installed and maintained to comply with performance standards (above).
2. Sediment control BMPs must be installed and maintained to comply with performance standards (above).
3. BMPs to control sediment tracking must be installed and maintained at entrances/exits to comply with performance standards (above).
4. Material needed to install standby BMP's necessary to completely protect the exposed portions of the site from erosion, and to prevent sediment discharges, must be stored on site Areas that have already been protected from erosion using physical stabilization or established vegetation stabilization BMP's as described below are not considered to be "exposed" for purposes of this requirement.
5. The owner/contractor must have an approved "weather triggered" action plan and have the ability to deploy standby BMPs as needed to completely protect the exposed portions of the site within 24 hours of prediction of a storm event (a predicted storm event is defined as a forecasted, 40% chance of rain). On request, the owner/contractor must provide proof of this capability that is acceptable to the City of Carlsbad.
6. Deployment of physical or vegetation erosion control BMP's must commence as soon as grading and/or excavation is completed for any portion of the site. The project proponent may not continue to rely on the ability to deploy standby BMP materials to prevent erosion of graded areas that have been completed.
7. The area that can be cleared or graded and left exposed at one time is limited to the amount of acreage that the owner/contractor can adequately protect prior to a predicted rainstorm.

Requirement "7" will require grading to be phased at larger sites. For example, it may be necessary to deploy erosion and sediment control BMPs in areas that are not completed but are not actively being worked before additional grading is done.

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B. Rainy Season Requirements (October 1 through April 30):

1. Perimeter protection BMPs must be installed and maintained to comply with performance standards (above).
2. Sediment control BMPs must be installed and maintained to comply with performance standards (above).
3. BMPs to control sediment tracking must be installed and maintained at site entrances/exits to comply with performance standards (above).
4. Material needed to install standby BMPs necessary to completely protect the exposed portions of the site from erosion, and to prevent sediment discharges, must be stored on site. Areas that have already been protected from erosion using physical stabilization or established vegetation stabilization BMPs as described below are not considered to be "exposed" for purposes of this requirement.
5. The owner/contractor must have an approved "weather triggered" action plan and have the ability to deploy standby BMPs as needed to completely protect the exposed portions of the site within 24 hours of prediction of a storm event (a predicted storm event is defined as a forecasted, 40% chance of rain). On request, the owner/contractor must provide proof of this capability that is acceptable to the City of Carlsbad.
6. Deployment of physical or vegetation erosion control BMPs must commence as soon as grading and/or excavation is completed for any portion of the site. The owner/contractor may not continue to rely on the ability to deploy standby BMP materials to prevent erosion of graded areas that have been completed.
7. The area that can be cleared or graded and left exposed at one time is limited to the amount of acreage that the owner/contractor can adequately protect prior to a predicted rainstorm.
8. Erosion control BMPs must be upgraded if necessary to provide sufficient protection for storms likely to occur during the rainy season.
9. Perimeter protection and sediment control BMPs must be upgraded if necessary to provide sufficient protection for storms likely to occur during the rainy season.
10. Adequate physical or vegetation erosion control BMPs must be installed and established for all graded areas prior to the start of the rainy season. These BMPs must be maintained throughout the rainy season. If a selected BMP fails, it must be repaired and improved, or replaced with an acceptable alternate as soon as it is safe to do so. The failure of a BMP shows that the BMP, as installed, was not adequate for the circumstances in which it was used and shall be corrected or modified as necessary. Repairs or replacements must therefore put a more effective BMP in place.
11. All vegetation erosion control must be established prior to the rainy season to be considered as a BMP.

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V. IMPLEMENTATION & MAINTENANCE OF REQUIREMENTS

After all project BMPs have been approved by the City Engineer, applicants and City project managers must ensure implementation and maintenance of the BMPs according to the processes outlined in the applicable sections for projects requesting discretionary actions, construction permits, or for public projects. In addition, any project that will require a "General NPDES Permit for Storm Water Discharges Associated with Industrial Activities," shall include the following note on the plans and condition in the permit/approval:

Industrial NPDES Permit Requirement

"The Permittee or designee (or contractor for public projects) shall provide evidence of coverage under the General Industrial National Pollutant Discharge Elimination System Permit, in the form of a Notice of Intent (NOI) filed with the State Water Resources Control Board, prior to the issuance of any construction permits."

1. Discretionary Actions

A. *Permanent BMP Requirements.* Applicants proposing projects that include permanent BMPs shall enter into a maintenance agreement, satisfactory to the City, following the program outlined in the "Permanent Storm Water BMP Maintenance Agreement Requirements" below, prior to the issuance of any permits or approvals. The permanent BMPs shall be graphically shown on the plans, where possible, and made a condition of the project's permit/approval. The permanent BMP's operation and maintenance requirements (O & M plan discussed below) shall also be noted on the plans and made a condition of the project's permit/approval.

B. *Construction BMP Requirements.* Projects seeking discretionary approvals are not required to graphically demonstrate any construction BMP requirements on the project plans. Instead, the discretionary action shall be conditioned to provide BMP's in accordance with the City's Storm Water Standards.

2. Construction Permits

A. *Construction Permits for Projects Under 1 Acre*. Projects proposing to disturb less than 1 acre during construction shall include construction requirements, where possible, on the plans. Any remaining construction BMPs that cannot be shown graphically on the plans shall be either noted on, or stapled to, the plans (Water Pollution Control Plan) and made a condition of the permit. The project's construction priority ranking (see Appendix E) must also be noted on the construction plans. Applicants proposing projects that include permanent BMPs must prepare (if not already prepared as part of a previous permit or approval), and execute a maintenance agreement, prepared satisfactory to the City, following the program outlined below prior to the issuance of any construction permits. The permanent BMPs shall be graphically shown on the plans, where

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possible, and made a condition of the project's permit/approval. The permanent BMP's operation and maintenance requirements (O & M plan discussed below) shall also be noted on the plans and made a condition of the project's permit/approval.

B. *Construction Permits for Projects Over 1 Acre*. Projects proposing to disturb more than 1 acre during construction shall include all construction BMPs in a Storm Water Pollution Prevention Plan, prepared in accordance with Appendix E, "Storm Water Pollution Prevention Plan Guidelines." The construction BMPs shall also be shown on the plans, where possible. Any remaining construction BMPs that cannot be shown graphically on the plans shall be either noted or stapled to the plans and made a condition of the permit. The project's construction priority ranking (see Appendix A) must also be noted on the construction plans. Applicants proposing projects that include permanent BMPs must prepare (if not already prepared as part of a previous permit or approval), and execute a maintenance agreement, prepared satisfactory to the City, following the program outlined below prior to the issuance of any construction permits. The permanent BMPs shall be graphically shown on the plans, where possible, and made a condition of the project's permit/approval. The permanent BMP's operation and maintenance requirements (O & M plan discussed below) shall also be noted on the plans and made a condition of the project's permit/approval.

3. Public Projects

Construction and Permanent storm water requirements must be incorporated into the project design and described in the contract documents (plans and specifications) prior to bidding for construction contracts, or equivalent. In addition, the permanent BMP's maintenance requirements shall also be noted on the plans and/or specifications and made a condition of the project's permit/approval. Project Managers should utilize the standard boiler specification and expound upon any project specific requirements.

For projects disturbing over 1 acre, City project managers must include the requirement for the preparation of a Storm Water Pollution Prevention Plan in the contract documents to be sent out to bid. The contract documents must also include the requirement for the contractor to periodically update the Storm Water Pollution Prevention Plan throughout the construction phase of the project.

For projects disturbing less than 1 acre, City projects shall have a specific Water Pollution Control Plan developed to identify construction BMP requirements prior to sending the public project contracts out to bid. The contract documents shall include a requirement for the contractor to update the Water Pollution Control Plan throughout the construction phase of the project.

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4. Permanent BMP Maintenance Agreement Requirements

Applicants shall propose a maintenance agreement assuring all permanent BMPs will be maintained throughout the "use" of a project site, satisfactory to the City Engineer (see Appendix H for a list of potential mechanisms). The City-approved method of permanent BMP maintenance shall be incorporated into the project's construction permit, and shall be consistent with permits issued by resource agencies, before City approval of the permit.

City project managers carrying out public projects that are not required to obtain permits shall be responsible for ensuring that a client department-approved method of storm water BMP maintenance, repair and replacement is executed prior to the commencement of construction.

For all properties, the verification mechanism will include the project proponent's signed statement, as part of the project application, accepting responsibility for all permanent BMP maintenance, repair and replacement.

The maintenance agreement shall include the following:

1. Operation & Maintenance (O&M) Plan: The applicant shall include an Operation & Maintenance (O&M) plan, prepared satisfactory to the City, with the approved maintenance agreement, which describes the designated responsible party to manage the storm water BMP(s), employee's training program and duties, operating schedule, maintenance frequency, routine service schedule, specific maintenance activities (including maintenance of storm water conveyance system stamps), copies of resource agency permits, and any other necessary activities. At a minimum, maintenance agreements shall require the applicant to provide inspection and servicing of all permanent treatment BMPs on an annual basis. The project proponent or City-approved maintenance entity shall complete and maintain O&M forms to document all maintenance requirements. Parties responsible for the O&M plan shall retain records for at least 5 years. These documents shall be made available to the City for inspection upon request at any time.

2. Access Easement/Agreement: If a permanent BMP requires access for maintenance, as part of the O&M plan , the applicant shall execute and record an access easement or agreement that shall be binding on the under lying land throughout the life of the project in favor of the party responsible for maintenance, until such time that the permanent treatment BMP requiring access for maintenance is removed or replaced. The City shall approve any changes to permanent BMP's, O&M Plans or access agreements. The agreement shall include a provision that gives the City the right, but not the obligation to perform the maintenance. The party responsible for BMP maintenance will pay the City for any and all costs incurred by the City for maintaining any BMP's. The agreement will provide a cost recovery provision in favor of the City satisfactory to the City Attorney.

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VI. RESOURCES & REFERENCES

APPENDIX A

STORM WATER REQUIREMENTS APPLICABILITY CHECKLIST

Complete Sections 1 and 2 of the following checklist to determine your project's permanent and construction storm water best management practices requirements. This form must be completed and submitted with your permit application.

Section 1. Permanent Storm Water BMP Requirements:
If any answers to Part A are answered "Yes," your project is subject to the "Priority Project Permanent Storm Water BMP Requirements," and "Standard Permanent Storm Water BMP Requirements" in Section III, "Permanent Storm Water BMP Selection Procedure" in the *Storm Water Standards* manual.

If all answers to Part A are "No," and any answers to Part B are "Yes," your project is only subject to the "Standard Permanent Storm Water BMP Requirements". If every question in Part A and B is answered "No," your project is exempt from permanent storm water requirements.

Part A: Determine Priority Project Permanent Storm Water BMP Requirements.

Does the project meet the definition of one or more of the priority project categories?*	**Yes**	**No**
1. Detached residential development of 10 or more units		
2. Attached residential development of 10 or more units		
3. Commercial development greater than 100,000 square feet		
4. Automotive repair shop		
5. Restaurant		
6. Steep hillside development greater than 5,000 square feet		
7. Project discharging to receiving waters within Environmentally Sensitive Areas		
8. Parking lots greater than or equal to 5,000 ft^2 or with at least 15 parking spaces, and potentially exposed to urban runoff		
9. Streets, roads, highways, and freeways which would create a new paved surface that is 5,000 square feet or greater		
* Refer to the definitions section in the *Storm Water Standards* for expanded definitions of the priority project categories.		
Limited Exclusion: Trenching and resurfacing work associated with utility projects are not considered priority projects. Parking lots, buildings and other structures associated with utility projects are priority projects if one or more of the criteria in Part A is met. If all answers to Part A are "No", continue to Part B.		

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Part B: Determine Standard Permanent Storm Water Requirements.

Does the project propose:	Yes	No
1. New impervious areas, such as rooftops, roads, parking lots, driveways, paths and sidewalks?		
2. New pervious landscape areas and irrigation systems?		
3. Permanent structures within 100 feet of any natural water body?		
4. Trash storage areas?		
5. Liquid or solid material loading and unloading areas?		
6. Vehicle or equipment fueling, washing, or maintenance areas?		
7. Require a General NPDES Permit for Storm Water Discharges Associated with Industrial Activities (Except construction)?*		
8. Commercial or industrial waste handling or storage, excluding typical office or household waste?		
9. Any grading or ground disturbance during construction?		
10. Any new storm drains, or alteration to existing storm drains?		
*To find out if your project is required to obtain an individual General NPDES Permit for Storm Water Discharges Associated with Industrial Activities, visit the State Water Resources Control Board web site at, www.swrcb.ca.gov/stormwtr/industrial.html		

Section 2. Construction Storm Water BMP Requirements:

If the answer to question 1 of Part C is answered "Yes," your project is subject to Section IV, "Construction Storm Water BMP Performance Standards," and must prepare a Storm Water Pollution Prevention Plan (SWPPP). If the answer to question 1 is "No," but the answer to any of the remaining questions is "Yes," your project is subject to Section IV, "Construction Storm Water BMP Performance Standards," and must prepare a Water Pollution Control Plan (WPCP). If every question in Part C is answered "No," your project is exempt from any construction storm water BMP requirements. If any of the answers to the questions in Part C are "Yes," complete the construction site prioritization in Part D, below.

Part C: Determine Construction Phase Storm Water Requirements.

Would the project meet any of these criteria during construction?	Yes	No
1. Is the project subject to California's statewide General NPDES Permit for Storm Water Discharges Associated With Construction Activities?		
2. Does the project propose grading or soil disturbance?		
3. Would storm water or urban runoff have the potential to contact any portion of the construction area, including washing and staging areas?		
4. Would the project use any construction materials that could negatively affect water quality if discharged from the site (such as, paints, solvents, concrete, and stucco)?		

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Part D: Determine Construction Site Priority

In accordance with the Municipal Permit, each construction site with construction storm water BMP requirements must be designated with a priority: high, medium or low. This prioritization must be completed with this form, noted on the plans, and included in the SWPPP or WPCP. Indicate the project's priority in one of the check boxes using the criteria below, and existing and surrounding conditions of the project, the type of activities necessary to complete the construction and any other extenuating circumstances that may pose a threat to water quality. The City reserves the right to adjust the priority of the projects both before and during construction. [Note: The construction priority does NOT change construction BMP requirements that apply to projects; all construction BMP requirements must be identified on a case-by-case basis. The construction priority does affect the frequency of inspections that will be conducted by City staff. See Section IV.1 for more details on construction BMP requirements.]

❑ *A) High Priority*

1) Projects where the site is 50 acres or more and grading will occur during the rainy season
2) Projects 5 acres or more. 3) Projects 5 acres or more within or directly adjacent to or discharging directly to a coastal lagoon or other receiving water within an environmentally sensitive area

   Projects, active or inactive, adjacent or tributary to sensitive water bodies

❑ *B) Medium Priority*

1) Capital Improvement Projects where grading occurs, however a Storm Water Pollution Prevention Plan (SWPPP) is not required under the State General Construction Permit (i.e., water and sewer replacement projects, intersection and street re-alignments, widening, comfort stations, etc.)
2) Permit projects in the public right-of-way where grading occurs, such as installation of sidewalk, substantial retaining walls, curb and gutter for an entire street frontage, etc. , however SWPPPs are not required.
3) Permit projects on private property where grading permits are required, however, Notice Of Intents (NOIs) and SWPPPs are not required.

❑ *C) Low Priority*

1) Capital Projects where minimal to no grading occurs, such as signal light and loop installations, street light installations, etc.
2) Permit projects in the public right-of-way where minimal to no grading occurs, such as pedestrian ramps, driveway additions, small retaining walls, etc.
3) Permit projects on private property where grading permits are not required, such as small retaining walls, single-family homes, small tenant improvements, etc.

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APPENDIX B

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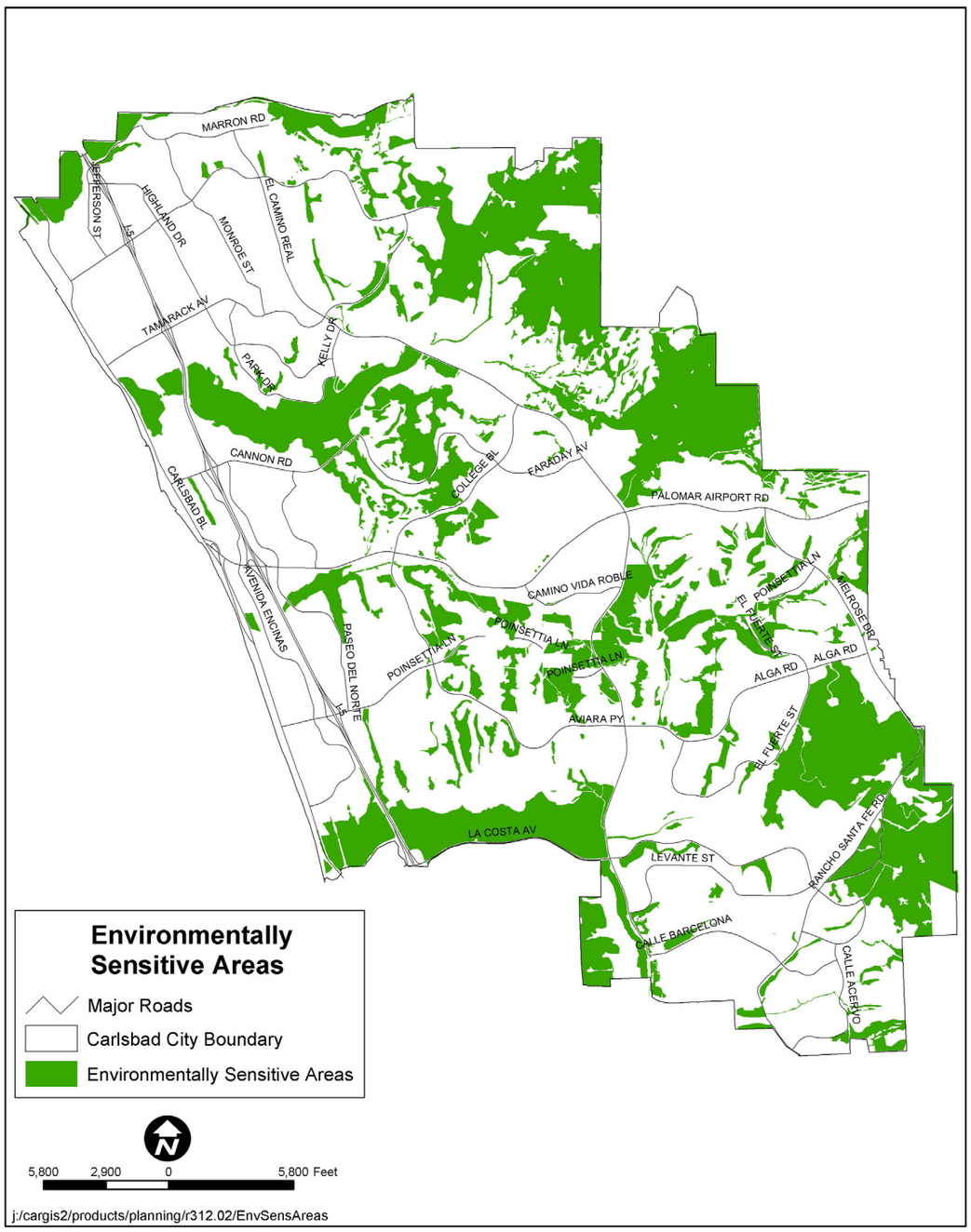
ENVIRONMENTALLY SENSITIVE AREAS WITHIN THE CITY OF CARLSBAD



APPENDIX C

EXAMPLE PERMANENT STORM WATER BEST MANAGEMENT PRACTICES

The following are a list of BMPs that may be used to minimize the introduction of pollutants of concern that may result in significant impacts to receiving waters. Other BMPs approved by the Development Services Division as being equal or more effective in pollutant reduction than comparable BMPs identified below are acceptable. All BMPs must comply with local zoning and building codes and other applicable regulations.

Site Design BMPs

Minimizing Impervious Areas Consistent With City Standards, Ordinances and Policies

- Incorporate landscaped buffer areas between sidewalks and streets.
- Design residential streets for the required pavement widths
- Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their impervious cover.
- Use open space development that incorporates smaller lot sizes
- Increase building density while decreasing the building footprint
- Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together
- Reduce overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, and using pervious materials in spillover parking areas

Increase Rainfall Infiltration

- Use permeable materials for private sidewalks, driveways, parking lots, and interior roadway surfaces (examples: hybrid lots, parking groves, permeable overflow parking, etc.) to the extent practicable consistent with City standards.
- Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas, and avoid routing rooftop runoff to the roadway or the urban runoff conveyance system to the extent practicable consistent with City standards.

Maximize Rainfall Interception

- Maximizing canopy interception and water conservation by preserving existing native trees and shrubs, and planting additional native or drought tolerant trees and large shrubs. to the extent practicable consistent with City Landscape Manual.

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Minimize Directly Connected Impervious Areas (DCIAs)

- Draining rooftops into adjacent landscaping prior to discharging to the storm water conveyance system to the extent practicable consistent with City standards
- Draining parking lots into landscape areas co-designed as biofiltration areas to the extent practicable consistent with City standards
- Draining roads, sidewalks, and impervious trails into adjacent landscaping to the extent practicable consistent with City standards

Use of natural drainage systems to the maximum extent practicable

- Stabilized permanent channel crossings
- Planting native or drought tolerant vegetation on slopes to the extent practicable consistent with City Landscape Manual.

Maximize Rainfall Interception

- Cisterns
- Foundation planting

Increase Rainfall Infiltration

- Dry wells

Source Control BMPs

- Storm water conveyance system stenciling and signage
- Outdoor material and trash storage area designed to reduce or control rainfall runoff
- Efficient irrigation system

Treatment Control BMPs

Biofilters

- Grass swale
- Grass strip
- Wetland vegetation swale
- Bioretention

Detention Basins

- Extended/dry detention basin with vegetated lining
- Extended/dry detention basin with impervious lining

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Infiltration

- Infiltration basin
- Infiltration trench

Pervious Paving

- Porous asphalt
- Porous concrete
- Porous modular concrete block

Wet Ponds and Wetlands

- Wet pond (permanent pool)
- Constructed wetland

Drainage Inserts

- Catch basin/storm drain inserts
- Catch basin screens

Filtration Systems

- Media filtration
- Sand filtration

Hydrodynamic Separation Systems

- Swirl concentrator
- Cyclone separator
- Baffle boxes

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APPENDIX D

WATER QUALITY TECHNICAL REPORT GUIDELINES

Purpose

To describe the permanent storm water Best Management Practices (BMPs) that will be incorporated in the project to mitigate the impacts of urban runoff due to the development.

Minimum Requirements

- Prepared by Registered Civil Engineer

Organization & Content

Table of Contents
Vicinity Map
Project Description
- Narrative of project activities

Site Map
- Entire property included on one map (use key map if multi-sheets)
- Drainage areas and direction of flow
- Private storm drain system(s)
- Nearby water bodies and municipal storm drain inlets
- Location of storm water conveyance systems (ditches, inlets, storm drains, etc.)
- Location of existing and proposed storm water controls
- Location of “impervious” areas- paved areas, buildings, covered areas
- Locations where materials would be directly exposed to storm water
- Location of building and activity areas (e.g. fueling islands, garages, waste container area, wash racks, hazardous material storage areas, etc.)
- Areas of potential soil erosion (including areas downstream of project)

Pollutants and Conditions of Concern
- Name and number of Carlsbad Watershed Hydrological UnitImpaired water bodies downstream of the project and impairment
- Impacts to hydrologic regime
- Pollutants based upon land use

Types of BMPs:

Site Design BMPs
- Reduce impervious surfaces
- Conserve natural areas
- Minimize directly connected impervious areas
- Protect slopes and channels

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Source Control BMPs

- Inlet stenciling and signage
- Materials Storage
- Trash storage
- Efficient irrigation
- Other controls (as applicable)

Structural Treatment BMPs

- Basis for selection (include targeted pollutants, justification, and alternative analysis)
- Design criteria (include calculations)
- Pollutant removal information (other than vendor specifications)
- Literature References

Maintenance (i.e. identify the responsible parties who will implement the Best Management Practices)

- Maintenance schedule
- Maintenance Costs
- Qualifications of maintenance personnel

Drainage Study

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APPENDIX E

STORM WATER POLLUTION PREVENTION PLAN/WATER POLLUTION CONTROL PLAN GUIDELINES

At a minimum, the Storm Water Pollution Prevention Plan (SWPPP) or Water Pollution Control Plan (WPCP), whichever is required, must cover the areas listed below. The SWPPP must be kept on site and made available upon request of a representative of the City of Carlsbad. Projects that are also required to obtain a general construction National Pollutant Discharge Elimination System (NPDES) Permit are encouraged to visit the State Water Resource Control Board's website for permit application instructions, NOI and NOT forms and guidance in preparing a Storm Water Pollution Prevention Plan (go to: www.swrcb.ca.gov/stormwtr/docs/constpermit).

Planning and Organization

- Identify the pollution prevention team members who will maintain and implement the SWPPP.
- If applicable, incorporate or reference the appropriate elements of other regulatory requirements.

Site Map

Features displayed on the map must include:

- An outline of the entire property
- Drainage areas on the property and direction of flow
- Areas of soil erosion
- Nearby water bodies and municipal storm drain inlets
- Location of storm water conveyance systems (ditches, inlets, storm drains, etc.)
- Location of existing storm water controls (oil/ water separators, sumps, etc.)
- Location of "impervious" areas- paved areas, buildings, covered areas
- Locations where materials are directly exposed to storm water
- Locations where toxic or hazardous materials have spilled in the past
- Location of building and activity areas (e.g. fueling islands, garages, waste container area, wash racks, hazardous material storage areas, etc.)

List of Significant Materials

List materials stored and handled at the site. Include the location and typical quantities.

Description of Potential Pollutant Sources

- Provide a narrative description of the site's activities and list the potential pollutant sources and the potential pollutants that could be discharged in storm water discharges from each activity.
- List non-storm water discharges including the source, quantity, frequency, and characteristics of the discharges and drainage area.

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Assessment of Potential Sources

Describe which activities are likely to be sources of pollution in storm water and which pollutants are likely to be present in storm water discharges.

Best Management Practices

Describe the BMPs that will be implemented at the site for each potential pollutant and its source.

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APPENDIX F

EXAMPLE CONSTRUCTION BEST MANAGEMENT PRACTICES

A. Erosion Control

Physical stabilization BMPs, vegetation stabilization BMPs, or both, will be required to prevent erosion and sediment runoff from exposed graded areas. BMPs for physical and vegetation stabilization include:

1) Physical Stabilization
    a) Geotextiles
    b) Mats
    c) Fiber rolls
    d) Sprayed on binders
    e) Mulch on flat areas
    f) Other material approved by the City for use in specific circumstances

If physical stabilization is selected, materials must be appropriate to the circumstances in which they are deployed, and sufficient material must be deployed.

2) Vegetation Stabilization
    a) Preservation of existing vegetation
    b) Established interim vegetation (via Hydroseed, seeded mats, etc.)
    c) Established permanent landscaping

If vegetation stabilization is selected, the stabilizing vegetation must be installed, irrigated and established (uniform vegetative coverage with 70% coverage established) prior to October 1. In the event stabilizing vegetation has not been established by October 1, other forms of physical stabilization must be employed to prevent erosion until the stabilizing vegetation is established.

B. Sediment Control

2) Perimeter protection. Protect the perimeter of the site or exposed area from sediment ingress/discharge in sheet flows using:
    a) Silt fencing
    b) Gravel bag barriers
    c) Fiber rolls

3) Resource protection. Protect environmentally sensitive areas, and watercourses from sediment in sheet flows by using:
    a) Silt fencing
    b) Gravel bag barriers
    c) Fiber rolls

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4) Sediment Capture. Capture sediments in channeled storm water by using:
    a) Storm-drain inlet protection measures
    b) De-silting basins (Designed in accordance with an industry standard such as Caltrans, California Storm water BMP manual etc. If the project is 5 acres or greater the desilting basin(s) must be designed in accordance with the State General Construction Permit, Order DWQ 99-08.)

5) Velocity Reduction. Reduce the velocity of storm water by using:
    a) Outlet protection (energy dissipater)
    b) Equalization basins
    c) Check dams

6) Off-site Sediment Tracking. Prevent sediment from being tracked off-site by using:
    a) Stabilized construction entrances/exits
    b) Construction road stabilization
    c) Tracking control (i.e., corrugated steel panels, wheel washes)
    d) Dust control

C. Materials Management

7) Prevent the contamination of storm water by wastes through proper management of the following types of wastes:
    a) Solid
    b) Sanitary
    c) Concrete
    d) Hazardous
    e) Equipment – related wastes
    f) Stock piles (protection from wind and rain)

8) Prevent the contamination of storm water by construction materials by:
    a) Covering and/or providing secondary containment of storage areas
    b) Taking adequate precautions when handling materials.

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APPENDIX G

SUGGESTED RESOURCES	HOW TO GET A COPY
Better Site Design: A Handbook for Changing Development Rules in Your Community (1998) Presents guidance for different model development alternatives.	Center for Watershed Protection 8391 Main Street Ellicott City, MD 21043 410-461-8323 www.cwp.org
California Urban runoff Best Management Practices Handbooks (1993) for Construction Activity, Municipal, and Industrial/Commercial Presents a description of a large variety of Structural BMPs, Treatment Control, BMPs and Source Control BMPs	Los Angeles County Department of Public Works Cashiers Office 900 S. Fremont Avenue Alhambra, CA 91803 626-458-6959
Caltrans Urban runoff Quality Handbook: Planning and Design Staff Guide (Best Management Practices Handbooks (1998) Presents guidance for design of urban runoff BMPs	California Department of Transportation P.O. Box 942874 Sacramento, CA 94274-0001 916-653-2975
Design Manual for Use of Bioretention in Stormwater Management (1993) Presents guidance for designing bioretention facilities.	Prince George's County Watershed Protection Branch 9400 Peppercorn Place, Suite 600 Landover, MD 20785
Design of Stormwater Filtering Systems (1996) by Richard A. Claytor and Thomas R. Schuler Presents detailed engineering guidance on ten different urban runoff-filtering systems.	Center for Watershed Protection 8391 Main Street Ellicott City, MD 21043 410-461-8323
Development Planning for Stormwater Management, A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), (May 2000)	Los Angeles County Department of Public Works http://dpw.co.la.ca.us/epd/ or http://www.888cleanLA.com
Florida Development Manual: A Guide to Sound Land and Water Management (1988) Presents detailed guidance for designing BMPs	Florida Department of the Environment 2600 Blairstone Road, Mail Station 3570 Tallahassee, FL 32399 850-921-9472
Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters (1993) Report No. EPA–840-B-92-002. Provides an overview of, planning and design considerations, programmatic and regulatory aspects, maintenance considerations, and costs.	National Technical Information Service U.S. Department of Commerce Springfield, VA 22161 800-553-6847
Guide for BMP Selection in Urban Developed Areas (2001)	ASCE Envir. and Water Res. Inst. 1801 Alexander Bell Dr. Reston, VA 20191-4400 (800) 548-2723

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SUGGESTED RESOURCES	HOW TO GET A COPY
Low-Impact Development Design Strategies - An Integrated Design Approach (June 1999)	Prince George's County, Maryland Department of Environmental Resource Programs and Planning Division 9400 Peppercorn Place Largo, Maryland 20774 *http://www.co.pg.md.us/Government/DER/PPD/pgcounty/lidmain.htm*
Maryland Stormwater Design Manual (1999) Presents guidance for designing urban runoff BMPs	Maryland Department of the Environment 2500 Broening Highway Baltimore, MD 21224 410-631-3000
National Stormwater Best Management Practices (BMP) Database, Version 1.0 Provides data on performance and evaluation of urban runoff BMPs	American Society of Civil Engineers 1801 Alexander Bell Drive Reston, VA 20191 703-296-6000
National Stormwater Best Management Practices Database (2001)	Urban Water Resources Research Council of ASCE Wright Water Engineers, Inc. (303) 480-1700
Operation, Maintenance and Management of Stormwater Management (1997) Provides a thorough look at storm water practices including, planning and design considerations, programmatic and regulatory aspects, maintenance considerations, and costs.	Watershed Management Institute, Inc. 410 White Oak Drive Crawfordville, FL 32327 850-926-5310
Potential Groundwater Contamination from Intentional and Non-Intentional Stormwater Infiltration	Report No. EPA/600/R-94/051, USEPA (1994).
Preliminary Data Summary of Urban runoff Best Management Practices (August 1999) EPA-821-R-99-012	*http://www.epa.gov/ost/stormwater/*
Reference Guide for Stormwater Best Management Practices (July 2000)	City of Los Angeles Urban runoff Management Division 650 South Spring Street, 7th Floor Los Angeles, California 90014 *http://www.lacity.org/san/swmd/*
Second Nature: Adapting LA's Landscape for Sustainable Living (1999) by Tree People Detailed discussion of BMP designs presented to conserve water, improve water quality, and achieve flood protection.	Tree People 12601 Mullholland Drive Beverly Hills, CA 90210 (818) 623-4848 Fax (818) 753-4625
Start at the Source (1999) Detailed discussion of permeable pavements and alternative driveway designs presented.	Bay Area Stormwater Management Agencies Association 2101 Webster Street Suite 500 Oakland, CA 510-286-1255

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SUGGESTED RESOURCES	HOW TO GET A COPY
Stormwater Management in Washington State (1999) Vols. 1-5 Presents detailed guidance on BMP design for new development and construction.	Department of Printing State of Washington Department of Ecology P.O. Box 798 Olympia, WA 98507-0798 360-407-7529
Stormwater, Grading and Drainage Control Code, Seattle Municipal Code Section 22.800-22.808, and Director's Rules, Volumes 1-4. (Ordinance 119965, effective July 5, 2000)	City of Seattle Department of Design, Construction & Land Use 700 5th Avenue, Suite 1900 Seattle, WA 98104-5070 (206) 684-8880 *http://www.ci.seattle.wa.us/dclu/Codes/sgdccode.htm*
Texas Nonpoint Source Book – Online Module (1998)www.txnpsbook.org Presents BMP design and guidance information on-line	Texas Statewide Urban runoff Quality Task Force North Central Texas Council of Governments 616 Six Flags Drive Arlington, TX 76005 817-695-9150
The Practice of Watershed Protection by Thomas R. Shchuler and Heather K. Holland	Center for Watershed Protection 8391 Main Street Ellicott City, MD 21043 410-461-8323 www.cwp.org
Urban Storm Drainage, Criteria Manual – Volume 3, Best Management Practices (1999) Presents guidance for designing BMPs	Urban Drainage and Flood Control District 2480 West 26th Avenue, Suite 156-B Denver, CO 80211 303-455-6277

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APPENDIX H

POTENTIAL PERMANENT TREATMENT BMP MAINTENANCE MECHANISMS

1. Project proponent agreement to maintain storm water BMPs: The City may enter into a contract with the project proponent obliging the project proponent to maintain, repair and replace the storm water BMP as necessary into perpetuity. Security may be required.
2. Assessment districts: The City may approve an Assessment District or other funding mechanism created by the project proponent to provide funds for storm water BMP maintenance, repair and replacement on an ongoing basis. Any agreement with such a District shall be subject to the Public Entity Maintenance Provisions above.
3. Lease provisions: In those cases where the City holds title to the land in question, and the land is being leased to another party for private or public use, the City may assure storm water BMP maintenance, repair and replacement through conditions in the lease.
4. Public entity maintenance: The City may approve a public or acceptable quasi-public entity (e.g., the County Flood Control District, or annex to an existing assessment district, an existing utility district, a state or federal resource agency, or a conservation conservancy) to assume responsibility for maintenance, repair and replacement of the permanent treatment BMP. Unless acceptable to the City, public entity maintenance agreements shall ensure estimated costs are front-funded or reliably guaranteed, (e.g., through a trust fund, assessment district fees, bond, letter of credit or similar means). In addition, the City may seek protection from liability by appropriate releases and indemnities. The City shall have the authority to approve storm water BMPs proposed for transfer to any other public entity within its jurisdiction before installation. The City shall be involved in the negotiation of maintenance requirements with any other public entities accepting maintenance responsibilities within their respective jurisdictions; and in negotiations with the resource agencies responsible for issuing permits for the construction and/or maintenance of the facilities. The City must be identified as a third party beneficiary empowered to enforce any such maintenance agreement within their respective jurisdictions.

The City may accept alternative maintenance mechanisms if such mechanisms are as protective as those listed above.

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APPENDIX I

DEFINITIONS

"Attached Residential Development" means any development that provides 10 or more residential units that share an interior/exterior wall. This category includes, but is not limited to: dormitories, condominiums and apartments.

"Automotive Repair Shop" means a facility that is categorized in any one of the following Standard Industrial Classification (SIC) codes: 5013, 5014, 5541, 7532-7534, or 7536-7539.

“Best Management Practices” see: “storm water best management practices”.

"Commercial Development" means any development on private land that is not exclusively heavy industrial or residential uses. The category includes, but is not limited to: automotive dealerships, commercial airfields, mini-malls and other business complexes, shopping malls, hotels, office buildings, public warehouses, hospitals, laboratories and other medical facilities, educational institutions, recreational facilities, plant nurseries, car wash facilities, and other light industrial complexes.

"Commercial Development greater than 100,000 square feet" means any commercial development that with a project footprint of at least 100,000 square feet.

“Construction Permits” means any ministerial, building, demolition/removal, grading and public right-of-way permits

"Detached Residential Development" means any development that provides 10 or more freestanding residential units. This category includes, but is not limited to: detached homes, such as single-family homes and detached condominiums.

"Directly Connected Impervious Area (DCIA)" means the area covered by a building, impermeable pavement, and/ or other impervious surfaces, which drains directly into the storm water conveyance system without first flowing across permeable vegetated land area (e.g., lawns).

“Discretionary Actions” means any adoption or amendment of a land use plan, zoning or rezoning action, development agreement, subdivision of land in accordance with the Subdivision Map Act, or development permits

"Environmentally Sensitive Areas" (ESA) means areas that include, but are not limited to, all Clean Water Act 303(d) impaired water bodies ("303[d] water bodies"); areas designated as an "Area of Special Biological Significance" (ASBS) by the State Water Resources Control Board (Water Quality Control Plan for the San Diego Basin (1994) and amendments); water bodies designated as having a RARE beneficial use by the State Water Resources Control Board (Water Quality Control Plan for the San Diego

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Basin (1994) and amendments), or areas designated as preserves or their equivalent under the Multiple Species Conservation Program (MSCP) within the Cities and County of San Diego. The limits of Areas of Special Biological Significance are those defined in the Water Quality Control Plan for the San Diego Basin (1994 and amendments).

Environmentally sensitive area is defined for the purposes of implementing SUSMP requirements, and does not replace or supplement other environmental resource-based terms, such as "Environmentally Sensitive Lands," employed by the City in their land development review processes.

"Hillside" means lands that have a natural gradient of 25 percent (4 feet of horizontal distance for every 1 foot of vertical distance) or greater and a minimum elevation differential of 50 feet, or a natural gradient of 200 percent (1 foot of horizontal distance for every 2 feet of vertical distance) or greater and a minimum elevation differential of 10 feet.

"Hillside development greater than 5,000 square feet" means any development that would create more than 5,000 square feet of impervious surfaces in hillsides with known erosive soil conditions.

"Infiltration" means the downward entry of water into the surface of the soil.

"Maximum Extent Practicable (MEP)" means the technology-based standard established by Congress in the Clean Water Act 402(p)(3)(B)(iii) that municipal dischargers of urban runoff must meet. MEP generally emphasizes pollution prevention and source control BMPs primarily (as the first line of defense) in combination with treatment methods serving as a backup (additional lines of defense).

"New Development" means land disturbing activities; structural development, including construction or installation of a building or structure, the creation of impervious surfaces; and land subdivision.

"Parking Lot" means land area or facility for the temporary parking or storage of motor vehicles used personally, or for business or commerce.

"Projects Discharging to Receiving Waters within Environmentally Sensitive Areas" means all development and significant redevelopment that would create 2,500 square feet of impervious surfaces or increase the area of imperviousness of a project site to 10% or more of its naturally occurring condition, and either discharge urban runoff to a receiving water within an environmentally sensitive area (where any portion of the project footprint is located within 200 feet of the environmentally sensitive area), or discharge to a receiving water within an environmentally sensitive area without mixing with flows from adjacent lands (where the project footprint is located more than 200 feet from the environmentally sensitive area).

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"Project Footprint" means the limits of all grading and ground disturbance, including landscaping, associated with a project.

"Receiving Waters" means surface bodies of water, which directly or indirectly receive discharges from urban runoff conveyance systems, including naturally occurring wetlands, streams (perennial, intermittent, and ephemeral (exhibiting bed, bank, and ordinary high water mark)), creeks, rivers, reservoirs, lakes, lagoons, estuaries, harbors, bays and the Pacific Ocean. The City shall determine the definition for wetlands and the limits thereof for the purposes of this definition, provided the City definition is as protective as the Federal definition utilized by the United States Army Corps of Engineers and the United States Environmental Protection Agency. Constructed wetlands are not considered wetlands under this definition, unless the wetlands were constructed as mitigation for habitat loss. Other constructed BMP's are not considered receiving waters under this definition, unless the BMP was originally constructed in receiving waters.

"Residential Development" means any development on private land that provides living accommodations for one or more persons. This category includes, but is not limited to: single-family homes, multi-family homes, condominiums, and apartments.

"Restaurant" means a stand-alone facility that sells prepared foods and drinks for consumption, including stationary lunch counters and refreshment stands selling prepared foods and drinks for immediate consumption (SIC code 5812).

"Significant Redevelopment" means development that would create or add at least 5,000 square feet of impervious surfaces on an already developed site. Significant redevelopment includes, but is not limited to: the expansion of a building footprint; addition to or replacement of a structure; replacement of an impervious surface that is not part of a routine maintenance activity; and land disturbing activities related with structural or impervious surfaces. Replacement of impervious surfaces includes any activity that is not part of a routine maintenance activity where impervious material(s) are removed, exposing underlying soil during construction. Significant redevelopment does not include trenching and resurfacing associated with utility work; resurfacing and reconfiguring surface parking lots; new sidewalk construction, pedestrian ramps, or bikelane on existing roads; and replacement of damaged pavement.

"Site Design BMP" means any project design feature that reduces the creation or severity of potential pollutant sources or reduces the alteration of the project site's natural flow regime. Redevelopment projects that are undertaken to remove pollutant sources (such as existing surface parking lots and other impervious surfaces) or to reduce the need for new roads and other impervious surfaces (as compared to conventional or low-density new development) by incorporating higher densities and/or mixed land uses into the project design, are also considered site design BMPs.

"Source Control BMP (both structural and non-structural)" means land use or site planning practices, or structures that aim to prevent urban runoff pollution by reducing the potential for contamination at the source of pollution. Source control BMPs minimize the contact between pollutants and urban runoff. Examples include roof structures over trash or material storage areas, and berms around fuel dispensing areas.

"Storm Water Best Management Practice (BMP)" means any schedules of activities, prohibitions of practices, general good house keeping practices, pollution prevention and educational practices, maintenance procedures, structural treatment BMPs, and other management practices to prevent or reduce to the maximum extent practicable the discharge of pollutants directly or indirectly to receiving waters. Storm Water BMPs also include treatment requirements, operating procedures and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. This manual groups development-related storm water BMPs into two categories: (1) *construction BMPs*, which are practices, procedures, devices or materials used to prevent the transport and introduction of pollutants both on and from a project site during construction; and (2) *permanent BMPs*, which are the site design features, source control features, and treatment control BMPs that become a permanent part of a project's design and remain functioning throughout the "use" phase of a project site. (See the definitions for site design, source control and treatment control BMPs in this appendix).

"Storm Water Conveyance System" means private and public drainage facilities by which storm water may be conveyed to Receiving Waters, such as: ditches, natural drainages, roads, streets, constructed channels, aqueducts, storm drains, pipes, street gutters, or catch basins.

"Streets, Roads, Highways, and Freeways" means any project that is not part of a routine maintenance activity, and would create a new paved surface that is 5,000 square feet or greater used for the transportation of automobiles, trucks, motorcycles and other vehicles. For the purposes of SUSMP requirements, Streets, Roads, Highways and Freeways do not include trenching and resurfacing associated with utility work; applying asphalt overlay to existing pavement; new sidewalk, pedestrian ramps, or bikelane construction on existing roads; and replacement of damaged pavement.

"Treatment Control (Structural) BMP" means any engineered system designed and constructed to remove pollutants from urban runoff. Pollutant removal is achieved by simple gravity settling of particulate pollutants, filtration, biological uptake, media adsorption or any other physical, biological, or chemical process.

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Chapter 7.10 URBAN RUNOFF POLLUTION

7.10.010 Findings.

The City Council finds and declares:

(a) The City's storm and surface water drainage system is planned, designed and operated to handle storm water runoff flows from public and private properties. In order to function effectively, this system requires all private connections to it to be properly constructed, maintained and operated.

(b) Urban runoff flows from individual properties onto the streets, then through storm drains to the beaches. It is therefore in the public interest to ensure that both public and private drainage systems are properly maintained, in order to facilitate the proper functioning of the City's storm and surface water drainage system, and to prevent pollutants from entering the Santa Monica Bay.

(c) The number of beach closures in the state due to ocean pollution have continued to increase, especially in Southern California, while beach closures have declined in other parts of the nation. Urban runoff is the single largest source of this ocean pollution, and consequently, is the number one threat in the State to public health and water quality.

(d) The City is a co-permittee under the Los Angeles County National Pollutant Discharge Elimination System (NPDES) Municipal Permit and as such is obligated to implement a Standard Urban Storm Water Mitigation Plan ("SUSMP") and Best Management Practice ("BMP") procedures to prevent and control the entry of pollutants into the City storm drain system and reduce the overall amount of urban runoff.

(e) In order to better control the quantity and quality of urban runoff pollution, a program requiring existing properties to adopt "good housekeeping" practices is essential.

(f) In order to reduce runoff contamination and runoff volume from private and publicly owned properties that will be newly developed, substantially rehabilitated or redeveloped in the future, a program ensuring that new developments incorporate design elements which facilitate such control is required.

(g) It is in the best interest of the City to establish guidelines and procedures for control of the quality and quantity of urban runoff from construction sites within the City. (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

7.10.020 Purpose.

The purpose of this Chapter is to permanently modify the structural causes of urban runoff pollution. The objectives of this Chapter include the reduction of both runoff volume and runoff contamination from existing residential and nonresidential properties and from future developments. This Chapter has two main goals. First, it aims to ensure that project sites maximize on-site percolation of runoff. Second, this Chapter aims to ensure that rain water is directed or contained so as not to become polluted by passage through contaminating material. (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

7.10.030 Definitions.

The following words and phrases shall have the following meanings when used in this Chapter:

(a) **Area Susceptible to Runoff.** Any non-permeable surface directly exposed to precipitation or in the path

of runoff which leads directly to neighboring properties or to the public right-of-way.

(b) **Best Management Practices ("BMP").** Practices principally applicable to construction sites and new developments that reduce the toxicity contained in, and the volume of, water which runs into storm drains, treatment facilities and the Santa Monica Bay. The Los Angeles Regional Water Quality Board ("Regional Board") has an approved list of BMPs and a list of technical resources and reference materials. Any BMP not specifically approved by the Regional Board may be used if they have been recommended in one of the listed technical resources and reference materials. The City Urban Runoff Management Coordinator and Engineering Department shall maintain updated copies of these lists and shall provide them upon request.

(c) **Good Housekeeping Requirements ("GHR").** Urban runoff pollution control practices applicable to existing properties, which have been demonstrated to significantly reduce and control urban runoff pollution that runs into storm drains, treatment facilities and the Santa Monica Bay.

(d) **New Development.** For purposes of this Chapter, new development shall constitute any of the following:

(1) Any construction project on a vacant site or on a site where fifty percent or more of the square footage of the structures is removed prior to construction.

(2) Any construction project where an existing building or structure has been damaged, or is in need of repairs, or the owner desires to make repairs, alterations, or rehabilitation in an amount exceeding fifty percent of the replacement cost of the building or structure. For purposes of this subsection, the City's Building Officer shall determine the replacement cost of the building or structure and may use the most current building valuation table published by the International Conference of Building Officials. The Building Officer shall also determine the fair market value of any necessary repairs and may calculate the fair market value of repairs based on three responsible bids from properly licensed contractors.

(3) Any construction project that (a) results in improvements to fifty percent or greater of the square footage of a building, (b) creates or adds at least five thousand square feet of impervious surfaces, or (c) creates or adds fifty percent or more of impervious surfaces.

(4) Any construction project undertaken by the City where the runoff controls required by this Chapter are feasible and economical, as determined by the Director of the Department of Environmental and Public Works Management, but which would not otherwise constitute new development as defined by subdivisions (1), (2) or (3) of this subsection (d).

(e) **Source Control BMP.** Non-structural activities, practices, and procedures that are designed to prevent urban runoff pollution.

(f) **Storm Event.** 0.75 inches of rainfall within a consecutive twenty-four-hour period that is separated from the previous storm event by at least seventy-two hours of dry weather.

(g) **Structural BMP.** Any structural facility designed and constructed to mitigate the adverse impacts of storm water and urban runoff pollution (e.g. canopy, structural enclosure). The category may include both Source Control and Treatment Control BMPs.

(h) **Treatment Control BMP.** Any engineered system designed to remove pollutants by simple gravity settling of particulate pollutants, filtration, biological uptake, media adsorption or any other physical, biological or chemical process.

(i) **Urban Runoff or Urban Runoff Pollution.** Water and suspended or dissolved materials deposited on surfaces and washed by storms or other sources of flowing water, through the flood control system to the ocean. Research studies have shown that urban runoff contributes many pollutants to receiving waters. Contamination includes bacteria and viruses, solid waste, and toxics such as heavy metals and petroleum-based compounds.

(j) **Urban Runoff Mitigation Plan.** A plan that shall be submitted and approved in connection with any new development. (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

7.10.040 Good housekeeping requirements for reduction of urban runoff applicable to all properties.

The following good housekeeping requirements shall be adhered to by all persons within the City.

(a) **Collection, Storage and Minimization of Runoff.**

(1) Water used for irrigation purposes shall not be allowed to run off of a site.

(2) Washing down paved areas shall be prohibited unless necessary for health or safety purposes and not in violation of any other provision of this Code. If washing down paved areas is authorized pursuant to this subdivision (2), BMP measures shall be implemented to remove solids, such as litter and debris, sediments and hydrocarbons and other organic chemicals.

(3) The uncovered outdoor storage of unsealed containers of building materials and lawn and automotive care products containing substances that may contribute pollutants to the storm water conveyance system is prohibited.

(4) Commercial tenants, multi-family building managers and industrial owners shall inspect trash receptacles and refuse storage areas on a weekly basis for loose garbage and liquid waste residue and shall not allow such garbage and residue to enter the storm drain system. Trash receptacles shall have solid covers and shall be closed to prevent the entry of rain and the exit of wind-blown litter. Trash receptacles shall be maintained without broken covers and leaks.

(5) Swimming pools, hot tubs and spas shall be drained to permeable surfaces and/or to the sewer and the water shall not be allowed to flow off the site.

(b) **Maintenance of Equipment.**

(1) Objects such as vehicle motor parts containing grease, oil or other hazardous substances, and unsealed receptacles containing hazardous materials, shall not be stored in areas susceptible to runoff.

(2) Any machine which is to be repaired or maintained in an uncovered outdoor area shall be placed on a pad of absorbent material to contain leaks, spills or small discharges.

(3) Machinery and equipment, including motor vehicles, which are leaking significant amounts of oil or fluid must be repaired.

(c) **Removal of Debris and Residue.**

(1) All motor vehicle parking lots susceptible to runoff shall be swept, at minimum, on a monthly basis to remove debris. Lots with more than ten parking spaces and all public parking facilities shall be vacuum swept, at minimum, on a quarterly basis. However, lots are not required to be vacuum swept for one month following a day when precipitation of one-half inch or more occurs.

(2) Fuel and chemical residue or other types of potentially harmful material, such as animal waste, garbage or batteries, which is located in an area susceptible to runoff, shall be removed immediately and disposed of properly. Household hazardous waste may be disposed of at the City's household hazardous waste collection facility or at any other appropriate disposal site and shall not be placed in a trash container.

(3) Intentional disposal of any trash, litter, debris or hazardous material of any type into a storm drain is prohibited. Section 5.20.040 of this Code prohibits discharge of other types of pollutants into the storm drain.

(d) **Prohibition on Use of Pesticides and Fungicides Banned from Manufacture.**

Use of any pesticide, herbicide or fungicide, the manufacture of which has been either voluntarily discontinued or prohibited by the Environmental Protection Agency, is prohibited. A list of these prohibited substances shall be maintained and made available to the public by the Environmental Programs Division (EPD). (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

7.10.050 Urban runoff reduction requirements for new development.

The following urban runoff reduction requirements shall apply to all persons submitting applications for new development within the City.

(a) At the time of submittal of an application for a new development project, an applicant shall be required to submit an Urban Runoff Mitigation Plan to the Department of Environmental and Public Works Management.

(b) In developing an Urban Runoff Mitigation Plan, an applicant shall infiltrate or treat projected runoff for the new development by an amount equal to or greater than the volume of runoff produced from a storm event through incorporation of design elements that address one or more of the goals set forth below in subdivisions (1), (2), and (3) of this subsection. The design elements utilized by an applicant may, but are not required to, include those provided on the list below so long as the required projected runoff infiltration or treatment is achieved:

(1) Maximize permeable areas to allow more percolation of runoff into the ground through such means as:

(i) Biofilters;

(ii) Green strips;

(iii) Swales.

The use of permeable materials in lieu of or to replace hardscapes will increase the amount of runoff seepage into the ground.

(2) Maximize the amount of runoff directed to permeable areas and/or maximize stormwater storage for reuse or infiltration by such means as:

(i) Orienting roof runoff towards permeable surfaces, drywells, French drains, or other structural BMPs rather than directly to driveways or non-permeable surfaces so that runoff will penetrate into the ground instead of flowing off-site.

(ii) Grading the site to divert flow to permeable areas.

(iii) Using cisterns, retention structures or green rooftops to store precipitation or runoff for reuse.

(iv) Removing or designing curbs, berms or the like so as to avoid isolation of permeable or landscaped areas.

(3) Remove pollutants through installation of treatment control BMPs.

(4) For purposes of compliance with this Section, pools, hot tubs, and spas shall be considered impermeable surfaces.

(5) The Urban Runoff Mitigation Plan must also include the applicant’s plan for the maintenance of all BMP’s requiring ongoing maintenance.

(6) All Urban Runoff Mitigation Plans must include the applicant’s signed statement accepting responsibility for all structural and treatment control BMP maintenance. The transfer of property subject to an Urban Runoff Mitigation Plan must include as a written condition to the transfer that the transferee assumes full responsibility for maintenance of any structural, and/or source or treatment control BMPs.

(c) The design elements established in this subsection (c) shall be required for all new development except single- family residences:

(1) Urban runoff shall not be allowed to come into contact with the following areas:

(i) Loading and unloading dock areas;

(ii) Repair and maintenance bays;

(iii) Vehicle and equipment wash areas;

(iv) Fueling areas.

(2) Where new development will include outdoor areas for the storage of material that may contribute pollutants to the storm water conveyance system, these materials must be:

(i) Placed in an enclosure such as, but not limited to, a cabinet, shed, or similar structure that prevents contact with runoff or spillage to the storm water conveyance system; or

(ii) Protected by secondary containment structures such as berms, dikes, or curbs.

(3) The outdoor storage area for materials subject to subdivision (2) of this Section must be:

(i) Paved and sufficiently impervious to contain leaks and spills;

(ii) Covered with a roof or awning to minimize collection of storm water within the secondary containment area.

(4) The area where a trash receptacle or receptacles are located for use as a repository for solid wastes must meet the following Structural or Treatment Control BMP requirements:

(i) Drainage from adjoining roofs and pavement must be diverted away from the trash storage areas.

(ii) The area must be covered with roof or awning (to prevent rain from entering the area and sewer or storm drain conveyance system), screened or walled to prevent off-site transport of trash, and connected to the sanitary sewer.

(iii) Trash bins must have solid covers and be covered at all times except while being emptied.

(d) Any construction project adding down spouts, gutters and subsurface pipes directing stormwater to the curb face shall have a French drain system of perforated pipe and gravel unless site-specific circumstances endanger public safety so as to prohibit its use as determined by the Director of the Department of Environmental and Public Works Management. The requirements of this subsection (d) shall apply even if the project does not constitute new development as defined by this Chapter.

(e) The City's evaluation of each Urban Runoff Mitigation Plan will ascertain if the proposed plan meets the standards set forth in subsection (b) of this Section. Each plan will be evaluated on its own merits according to the particular characteristics of the project and the site to be developed.

(f) The Director of the Department of Environmental and Public Works Management or his or her designee shall approve or disapprove the plan. If the plan is disapproved, the reasons for disapproval shall be given in writing to the developer. Any plan disapproved by the Director of Environmental and Public Works Management or his or her designee must be revised by the developer and resubmitted for approval. No building permit shall be issued until an Urban Runoff Mitigation Plan has been approved by the Department of Environmental and Public Works Management.

(g) A waiver from subsection (b) of this Section may be issued by the Director of the Department of Environmental and Public Works Management or his or her designee if the petitioner shows impracticability of implementing these requirements. Recognized circumstances demonstrating impracticability include: (i) extreme limitations of space for treatment; (ii) unfavorable or unstable soil conditions at a site to attempt infiltration; and (iii) risk of groundwater contamination because a known unconfined aquifer lies beneath the land surface or an existing or potential underground source of drinking water is less than ten feet from the soil surface. Any other justification for impracticability must be separately petitioned by the City and submitted to the Regional Board for consideration.

(h) If a waiver is granted for impracticability, the petitioner will be required to transfer the savings in cost, as determined by the Director of the Department of Environmental and Public Works Management, to a City stormwater mitigation fund to be used to promote regional or alternative solutions for urban runoff pollution in

the storm watershed, which may be operated by a public agency or a non-profit entity.

(i) Compliance with an approved Urban Runoff Mitigation Plan shall be a condition of any required planning approval. (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

7.10.060 Urban runoff requirements for construction sites.

The following Best Management Practices, which address the problem of urban runoff, shall apply to all construction sites in the City. These requirements shall apply at the commencement of demolition of an existing structure and/or commencement of construction and until receipt of a certificate of occupancy.

(a) A copy of any Storm Water Pollution Prevention Plan (SWPPP) required to be submitted to the Regional Board shall be submitted to the City at the same time.

(b) Polluted runoff (runoff containing sediments and/or construction wastes) from construction sites shall not leave the site.

(c) Any sediments or other materials that are tracked off the site by vehicles and equipment shall be removed the same day as they are tracked off the site. Where determined to be necessary by the Director of the Department of Environmental and Public Works Management or his or her designated representative, a temporary sediment barrier shall be installed.

(d) For any painting removal, paint preparation, or sandblasting activities that will result in particles entering the air or landing on the ground, BMP steps shall be implemented to prevent or minimize to the maximum extent practicable such particle releases into the environment.

(e) Plastic covering shall be utilized to prevent erosion of an otherwise unprotected area, along with runoff devices to intercept and safely convey the runoff.

(f) No washing of construction or other vehicles shall be allowed adjacent to a construction site. No polluted runoff from washing vehicles on a construction site shall be allowed to leave the site.

(g) Drainage controls shall be utilized depending on the extent of proposed grading and topography of the site, including but not limited to the following:

(1) Detention ponds, sediment ponds, or infiltration pits;

(2) Dikes, filter berms or ditches;

(3) Down drains, chutes or flumes. (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

7.10.070 Enforcement and penalties.

(a) The Director of the Department of Environmental and Public Works Management, or his or her designee, is authorized to enforce Sections 7.10.040, 7.10.050 and 7.10.060 as follows:

(1) For the first failure to comply with any provision of Sections 7.10.040, 7.10.050 and 7.10.060, the Department of Environmental and Public Works Management shall issue to the affected person a written notice that includes the following information:

(i) A statement specifying the violation committed;

(ii) A specified time period within which the affected person must correct the failure or file a written notice disputing the notice of failure to comply;

(iii) A statement of the penalty for continued noncompliance.

(2) For each subsequent failure to comply with any provision of Sections 7.10.040, 7.10.050 and 7.10.060 following written notice pursuant to this Section, the Director of the Department of Environmental and Public

Works Management may levy a penalty not to exceed five hundred dollars. Any statement informing a violator of a citation shall include a notice setting forth the hearing rights provided in subsection (a)(3) below.

(3) Any person assessed a penalty pursuant to subsection (a)(2) may dispute the penalty by requesting a hearing on a form provided by the City within the time and manner set forth in Section 6.16.030, provided that no hearing request shall be deemed timely filed and no hearing shall be held unless, within the time period to request a hearing, the person deposits with the City Treasurer money in the amount of any unpaid penalty due under this Section. If as a result of the hearing it is determined that the penalty was wrongly assessed, the City shall refund any money deposited to the person. The decision of the Hearing Examiner shall be final except for judicial review and shall not be appealable to the City Council.

(4) It shall not be a defense to the assessment of any penalty or to any other civil enforcement action provided for under this Section for a person to assert that any violation of Sections 7.10.040, 7.10.050 and 7.10.060 was caused by the actions of a person other than the person assessed except if the violation was caused by the criminal or negligent action of a person who was not an agent, servant, employee or family member of the person.

(5) Any penalty collected hereunder shall be deposited in the City's Stormwater Fund to be used as reimbursement for the Department of Environmental and Public Works Management's costs and expenses of administration and enforcement of this Chapter.

(b) Any violation of this Chapter shall constitute an infraction punishable by a fine of five hundred dollars. Each day that a violation occurs shall constitute a separate offense.

(c) A violation of any provision of this Chapter is declared to be a public nuisance and may be abated pursuant to Santa Monica Municipal Code Chapter 8.96 or by means of a civil action.

(d) The City may enforce the provisions of this Chapter by means of a civil action. The burden of proof in such cases shall be preponderance of the evidence.

(e) Any person who commits an act, proposes to commit an act, or engages in any pattern and practice which violates this Chapter may be enjoined therefrom by any court of competent jurisdiction.

(f) The penalties and remedies established by this Chapter are not exclusive, and nothing in this Chapter shall preclude any person from seeking any other remedies, penalties or procedures provided by law. (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

7.10.080 Citywide urban runoff pollution prevention education program.

The Department of Environmental and Public Works Management, along with other City departments, shall conduct an informational program to educate the public about the dangers of urban runoff pollution and the means of preventing such pollution. The program shall educate residents and business persons who operate within the City about the contents of this Chapter. (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

7.10.090 Additional best management practices requirements.

If a determination is made by the Director of the Department of Environmental and Public Works Management that the public health and safety may be compromised through the release of contaminants or pollutants from a construction site or an existing parcel or as a result of new development, the Director or his or her designee shall have the authority to require additional BMPs besides those already required by this Chapter and/or by an Urban Runoff Mitigation Plan. (Added by Ord. No. 1992CCS § 1 (part), adopted 11/28/00)

STATE OF CALIFORNIA

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
LOS ANGELES REGION

ORDER NO. 01-182
NPDES PERMIT NO. CAS004001
WASTE DISCHARGE REQUIREMENTS
FOR
MUNICIPAL STORM WATER AND URBAN RUNOFF DISCHARGES WITHIN THE COUNTY OF LOS ANGELES, AND THE INCORPORATED CITIES THEREIN, EXCEPT THE CITY OF LONG BEACH

December 13, 2001

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STATE OF CALIFORNIA

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
LOS ANGELES REGION

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WASTE DISCHARGE REQUIREMENTS
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MUNICIPAL STORM WATER AND URBAN RUNOFF DISCHARGES WITHIN THE COUNTY OF LOS ANGELES, AND THE INCORPORATED CITIES THEREIN, EXCEPT THE CITY OF LONG BEACH

The California Regional Water Quality Control Board, Los Angeles Region (hereinafter referred to as the Regional Board) finds:

A. Existing Permit

The Los Angeles County Flood Control District, the County of Los Angeles, and 84 incorporated cities within the Los Angeles County Flood Control District (see Attachment A, List of Permittees), hereinafter referred to separately as Permittees and jointly as the Discharger, discharge or contribute to discharges of storm water and urban runoff from municipal separate storm sewer systems (MS4s), also called storm drain systems. The discharges flow to water courses within the Los Angeles County Flood Control District and into receiving waters of the Los Angeles Region. These discharges are covered under countywide waste discharge requirements contained in Order No. 96-054 adopted by this Regional Board on July 15, 1996, which replaced Order No. 90-079 adopted by this Regional Board on June 18, 1990. Order No. 96-054 also serves as a National Pollutant Discharge Elimination System (NPDES) permit for the discharge of municipal storm water.

B. Nature of Discharges and Sources of Pollutant

1. Storm water discharges consist of surface runoff generated from various land uses in all the hydrologic drainage basins that discharge into water bodies of the State. The quality of these discharges varies considerably and is affected by the hydrology, geology, land use, season, and sequence and duration of hydrologic events. The primary constituents of concern currently identified by the Los Angeles County Flood Control District Integrated Receiving Water Impacts Report (1994-2000) are cyanide, indicator bacteria, total dissolved solids, turbidity, total suspended solids, nutrients, total aluminum, dissolved cadmium, copper, lead, total mercury, nickel, zinc, bis(2-ethylhexyl)phthalate, polycyclic aromatic hydrocarbons (PAHs), diazinon, and chlorpyrifos.

2. Certain pollutants present in storm water and/or urban runoff may be derived from extraneous sources that Permittees have no or limited jurisdiction over. Examples of such pollutants and their respective sources are: PAHs which are products of internal combustion engine

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operation, nitrates, bis (2-ethylhexyl) phthalate and mercury from atmospheric deposition, lead from fuels, copper from brake pad wear, zinc from tire wear, dioxins as products of combustion, and natural-occurring minerals from local geology. However, the implementation of the measures set forth in this Order is intended to reduce the entry of these pollutants into storm water and their discharge to receiving waters.

3. Water quality assessments conducted by the Regional Board identified impairment, or threatened impairment, of beneficial uses of water bodies in the Los Angeles Region. The causes of impairments include pollutants of concern identified in municipal storm water discharges by the County of Los Angeles in the Integrated Receiving Water Impacts Report (1994-2000). Pollutants in storm water can have damaging effects on both human health and aquatic ecosystems.

4. The Los Angeles County Grand Jury, September 2000, completed an investigation into the health risks of swimming near beaches in Los Angeles County and made several recommendations to reduce public health risks (Final Report, Grand Jury, Los Angeles County, 1999-2000). The Grand Jury recommended that the Regional Board consider among other actions, (i) a focus on setting contaminant limits rather than programmatic evaluations, (ii) audit of MS4 Permittee programs; and (iii) clarifying enforcement responsibilities between the State and local governments.

5. Studies and research conducted by other Regional agencies, academic institutions, and universities have also identified storm water and urban runoff as significant sources of pollutants to surface waters in Southern California. See, e.g., [*Surface Runoff to the Southern California Bight*, Southern California Coastal Water Research Project, (1992); *Impacts of Urban Runoff on Santa Monica Bay and Surrounding Ocean Waters* (Gersberg, R.M., 1995); *State of the Bay 1998*, Santa Monica Bay Restoration Project; *Storm Water Impact*, In, Southern California Environmental Report Card 1999, Institute of the Environment, University of California, Los Angeles (Stenstrom, M.S., 1999); *Distribution of Anthropogenic and Natural Debris on the Mainland Shelf of Southern California Bight,* Shelly L. Moore and M. James Allen (1999); *The Health Effects of Swimming in Ocean Water Contaminated by Storm Drain Runoff*, Haile, R.W. et al. (1999); *Huntington Beach Closure Investigation: Technical Review* (University of Southern California, 2000); *A Regional Survey of the Microbiological Water Quality Along the Shoreline of the Southern California Bight,* Rachel T. Noble *et al.* (2001*); Integrated Receiving Water Impacts Report (1994-2000)*, County of Los Angeles (2001)].

6. Development and urbanization increase pollutant load, volume, and discharge velocity. First, natural vegetated pervious ground cover is converted to impervious surfaces such as paved highways, streets, rooftops and parking lots. Natural vegetated soil can both absorb rainwater and remove pollutants providing an effective natural purification process. In contrast, pavement and concrete can neither absorb water nor remove pollutants, and thus the natural purification characteristics are

lost. Second, urban development creates new pollution sources as the increased density of human population brings proportionately higher levels of vehicle emissions, vehicle maintenance wastes, municipal sewage waste, pesticides, household hazardous wastes, pet wastes, trash, and other anthropogenic pollutants. Development and urbanization especially threaten environmentally sensitive areas. Such areas have a much lower capacity to withstand pollutant shocks than might be acceptable in the general circumstance. In essence, development that is ordinarily insignificant in its impact on the environment may in a particular sensitive environment become significant. These environmentally sensitive areas designated by the State and/or the County of Los Angeles include Areas of Special Biological Significance (ASBS), water bodies designated as supporting a RARE beneficial use, Significant Natural Areas (SNAs), and Significant Ecological Areas (SEAs).

7. The increased volume, increased velocity, and discharge duration of storm water runoff from developed areas has the potential to greatly accelerate downstream erosion and impair stream habitat in natural drainages. Studies have demonstrated a direct correlation between the degree of imperviousness of an area and the degradation of its receiving waters. Significant declines in the biological integrity and physical habitat of streams and other receiving waters have been found to occur with as little as 10 percent conversion from natural to impervious surfaces. Percentage impervious cover is a reliable indicator and predictor of potential water quality degradation expected from new development. (*Impervious Cover as An Urban Stream Indicator and a Watershed Management Tool*, Schueler, T. and R. Claytor, In, Effects of Water Development and Management on Aquatic Ecosystems (1995), ASCE, New York; Leopold, L. B., (1973), *River Channel Change with Time: An Example*, Geological Society of America Bulletin, v. 84, p. 1845-1860; Hammer, T. R., (1972), *Stream Channel Enlargement Due to Urbanization: Water Resources Research*, v. 8, p. 1530-1540; Booth, D. B., (1991), *Urbanization and the Natural Drainage System--Impacts, Solutions and Prognoses*: The Northwest Environmental Journal, v. 7, p. 93-118; Klein, R. D., (1979), *Urbanization and Stream Quality Impairment*: Water Resources Bulletin, v. 15, p. 948-963; May, C. W., Horner, R. R., Karr, J. R., Mar, B. W., and Welch, E. B., (1997), *Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion*: Watershed Protection Techniques, v. 2, p. 483-494; Morisawa, M. and LaFlure, E. *Hydraulic Geometry, Stream Equilibrium and Urbanization* In Rhodes, D. P. and Williams, G. P. *Adjustments to the Fluvial System* p.333-350. (1979); Dubuque, Iowa, Kendall/Hunt. Tenth Annual Geomorphology Symposia Series; and *The Importance of Imperviousness*: Watershed Protection Techniques, 1(3), Schueler, T. (1994).)

8. The County of Los Angeles has identified as the seven highest priority industrial and commercial critical source types, (i) wholesale trade (scrap recycling, auto dismantling); (ii) automotive repair/parking; (iii) fabricated metal products; (iv) motor freight; (v) chemical and allied products; (vi) automotive dealers/gas stations; (vii) primary metal products (*Critical*

Source Selection and Monitoring Report, Los Angeles County Department of Public Works -Sept 1996). Monitoring conducted by Los Angeles County and the Regional Board demonstrates that the priority industrial sectors and auto repair facilities (one of the commercial sectors) on the list, contribute significant concentrations of heavy metals to storm water (*Los Angeles County 1999-2000 Storm Water Monitoring Report*, Los Angeles County Department of Public Works -July 2000; *Compliance Assessment of the Auto Dismantling Industry; Evaluation of the California General Industrial Storm Water Permit*, H. Chang, (2001), 70 pp., California Regional Water Quality Control Board, Los Angeles Region).

9. The discharge of washwaters and contaminated storm water from industries and businesses specified in this Order for inspection by Permittees is an environmental threat and can also adversely impact public health and safety. For example, a review of industrial waste/ pretreatment records performed in 1995 in the County of Los Angeles on illicit discharges indicates that automotive service facilities and food service facilities sometimes discharge polluted washwaters to the MS4. The pollutants of concern in such washwaters include food waste, oil and grease, and toxic chemicals. Other storm water/industrial waste programs in California have reported similar observations. Illicit discharges from automotive service facilities and food service facilities have been identified elsewhere as a major cause of widespread contamination and water quality problems (Washtenaw County Statutory Drainage Board - 1987 Huron River Pollution Abatement Program).

10. Studies indicate that facilities with paved surfaces subject to frequent motor vehicular traffic (such as parking lots and fast food restaurants), or facilities that perform vehicle repair, maintenance, or fueling (automotive service facilities) are potential sources of pollutants of concern in storm water. [References: Pitt *et a*l., *Urban Storm Water Toxic Pollutants: Assessment, Sources, and Treatability*, Water Environment Res., 67, 260 (1995)*; Results of Retail Gas Outlet and Commercial Parking Lot Storm Water Runoff Study*, Western States Petroleum Association and American Petroleum Institute, (1994); *Action Plan Demonstration Project, Demonstration of Gasoline Fueling Station Best Management Practices*, Final Report, County of Sacramento (1993); *Source Characterization*, R. Pitt, In Innovative Urban Wet-Weather Flow Management Systems (2000) Technomic Press, Field, R *et al*. editors; *Characteristics of Parking Lot Runoff Produced by Simulated Rainfall*, , L.L. Tiefenthaler *et al*. Technical Report 343, Southern California Coastal Water Research Project (2001).]

11. Retail Gasoline Outlets (RGOs) are points of convergence for vehicular traffic and are similar to parking lots and urban roads. Studies indicate that storm water discharges from RGOs have high concentrations of hydrocarbons and heavy metals. [*The Quality of Trapped Sediments and Poor Water within Oil Grit Separators in Suburban MD,* Schueler T. and Shepp D. (1992), and *Concentrations of Selected Constituents in Runoff from Impervious Surfaces in Four Urban Catchments of Different*

Landuse, Ranabal, F.I., and T.J. Gizzard (1995), In Proceedings of the Fourth Biennial Stormwater Research Conference, Florida, pp-42-52]. Pilot studies indicate that treatment control best management practices installed at retail gasoline stations are effective in removing pollutants, reasonable in capital cost, easy to operate, and do not present safety risks [*Rouge River National Wet Weather Demonstration Project, Task Product Memorandum – Evaluation of On-line Media Filters RPO-NPS-TPM59.00*, Wayne County, MI, March 1999]. The Regional Board and the San Diego Regional Board have jointly prepared a Technical Report on the applicability of new development BMP design criteria for retail gasoline outlets, (*Retail Gasoline Outlets: New Development Design Standards for Mitigation of Storm Water Impacts*, (June 2001)). Retail Gasoline Outlets in Western U.S. States (such as Washington and Oregon) are already subject to numerical BMP design criteria, as well in other U.S. States.

C. Permit Background

1. The essential components of the Storm Water Management Program, as established by federal regulations [40 CFR 122.26(d)] are: (i) Adequate Legal Authority, (ii) Fiscal Resources, (iii) Storm Water Quality Management Program (SQMP) - (Public Information and Participation Program, Industrial/Commercial Facilities Program, Development Planning Program, Development Construction Program, Public Agency Activities Program, Illicit Connection and Illicit Discharges Elimination Program), and (iv) Monitoring and Reporting Program.

2. The Permittees have filed a Report of Waste Discharge (ROWD), dated February 1, 2001, and applied for renewal of their waste discharge requirements that serves as an NPDES permit to discharge wastes to surface waters. The ROWD includes a proposed SQMP and a Monitoring Program. The proposed SQMP contains programs previously approved under Board Order No. 96-054 in the following areas:

   Public Information and Participation
   Development Planning
   Development Construction
   Public Agency Activities
   Illicit Connection/Illicit Discharge Elimination Program

   These programs are revised pursuant to the provisions of this Order after adoption.

3. The County of Los Angeles has previously conducted source identification and pollutant characterization consistent with 40 CFR 122.26(d)(1)(ii) and (iii) under its storm water Monitoring Program. The Monitoring Program submitted with the ROWD proposes to advance the assessment of receiving water impacts, identification of sources of pollution, evaluation of Best Management Practices (BMPs), and measurement of long term trends in mass emissions.

4. The Regional Board has reviewed the ROWD and has determined it to be complete under the reapplication policy of MS4s issued by the U.S. Environmental Protection Agency (USEPA) (61 *Fed. Reg*. 41697). The Regional Board finds that the Permittees' proposed SQMP, incorporating the additional and/or revised provisions contained in this Order would meet the minimum requirements of federal regulations.

5. The City of Los Angeles has conducted shoreline and nearshore water quality monitoring off the Santa Monica Bay since the 1950s under the monitoring program for the Hyperion Waste Water Treatment Plant (NPDES No. CA0109991). The monitoring results indicate that effluent from Hyperion's 5-Mile Outfall does not impinge the shoreline, and that elevated bacterial counts are associated with runoff from storm drains and discharges from piers. In 1994, the Regional Board approved the relocation of Hyperion's shoreline stations to implement a bay-wide, regional shoreline-monitoring program associated with storm drain outfalls in the Santa Monica Bay. The City of Los Angeles requested that the shoreline-monitoring requirement be incorporated in this Order. The shoreline pathogen monitoring requirements are outlined in the Monitoring Program for this Order.

D. Permit Coverage

1. The requirements in this Order cover all areas within the boundaries of the Permittee municipalities (see Attachment A) over which they have regulatory jurisdiction as well as unincorporated areas in Los Angeles County within the jurisdiction of the Regional Board. The Permittees serve a population of about 9.5 million [Reference: *2000 Census of Population and Housing,* Bureau of the Census, U.S. Department of Commerce (2001)] in an area of approximately 3,100 square miles.

2. Federal, state, regional or local entities within the Permittees' boundaries or in jurisdictions outside the Los Angeles County Flood Control District, and not currently named in this Order, may operate storm drain facilities and/or discharge storm water to storm drains and watercourses covered by this Order. The Permittees may lack legal jurisdiction over these entities under state and federal constitutions. The Regional Board will coordinate with these entities to implement programs that are consistent with the requirements of this Order. The Regional Board will consider such facilities for coverage in 2003 under its NPDES permitting scheme pursuant to USEPA Phase II storm water regulations.

3. Sources of discharges into receiving waters in the County of Los Angeles but in jurisdictions outside its boundary include the following:

   About 34 square miles of unincorporated area in Ventura County, which drain into Malibu Creek and then to Santa Monica Bay,

   About 9 square miles of the City of Thousand Oaks, which also drain into Malibu Creek and then to Santa Monica Bay, and

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About 86 square miles of area in Orange County, which drain into Coyote Creek and then into the San Gabriel River.

The Regional Board will ensure that storm water management programs for the areas in Ventura County and the City of Thousand Oaks that drain into Santa Monica Bay are consistent with the requirements of this Order. The Regional Board will coordinate with the Santa Ana Regional Board so that storm water management programs for the areas in Orange County that drain into Coyote Creek are consistent with the requirements of this Order.

4. This permit is intended to develop, achieve, and implement a timely, comprehensive, cost-effective storm water pollution control program to reduce the discharge of pollutants in storm water to the Maximum Extent Practicable (MEP) from the permitted areas in the County of Los Angeles to the waters of the U.S. subject to the Permittees' jurisdiction.

5. Permittees have expressed their intention to work cooperatively to control the contribution of pollutants from one portion of the MS4 to another portion of the system. Permittees may control the contribution of pollutants to the MS4 from non-permittee dischargers such as Caltrans, the U.S. Department of Defense, and other state and federal facilities, through interagency agreements.

E. Federal, State, and Regional Regulations

1. The Water Quality Act of 1987 added Section 402(p) to the federal Clean Water Act (CWA) (33 U.S.C. § 1251-1387). This section requires the USEPA to establish regulations setting forth NPDES requirements for storm water discharges in two phases.

   - The USEPA Phase I storm water regulations were directed at MS4s serving a population of 100,000 or more, including interconnected systems and storm water discharges associated with industrial activities, including construction activities. The Phase I Final Rule was published on November 16, 1990 (55 *Fed. Reg*. 47990).

   - The USEPA Phase II storm water regulations are directed at storm water discharges not covered in Phase I, including small MS4s (serving a population of less than 100,000), small construction projects (one to five acres), municipal facilities with delayed coverage under the Intermodal Surface Transportation Efficiency Act of 1991, and other discharges for which the USEPA Administrator or the State determines that the storm water discharge contributes to a violation of a water quality standard, or is a significant contributor of pollutants to waters of the United States. The Phase II Final Rule was published on December 8, 1999 (64 *Fed. Reg*. 68722).

2. The USEPA published an 'Interim Permitting Approach for Water Quality-Based Effluent Limitations in Storm Water Permits' on August 26, 1996 (61 *Fed. Reg.* 43761). This policy discusses the appropriate kinds of

water quality-based effluent limitations to be included in NPDES storm water permits to provide for the attainment of water quality standards.

3. The USEPA published an 'Interpretative Policy Memorandum on Reapplication Requirements' for MS4 permits on August 9, 1996 (61 *Fed. Reg*. 41697). This policy requires that MS4 reapplication for reissuance for a subsequent five-year permit term contain certain basic information and information for proposed changes and improvements to the storm water management program and monitoring program.

4. The USEPA has entered into a Memorandum of Agreement (MOA) with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service for enhancing coordination regarding the protection of endangered and threatened species under Section 7 of the Endangered Species Act and the CWA's Water Quality Standards and NPDES programs. Among other actions, the MOA establishes a framework for coordination of actions by the USEPA, the Services, and CWA delegated States on CWA permit issuance under Section 402 of the CWA [66 *Fed. Reg*. 11202 – 11217].

5. USEPA regulations at 40 CFR 122.26(d)(2)(iv)(A) and 40 CFR 122.26(d)(2)(iv)(C) require that MS4 permittees implement a program to monitor and control pollutants in discharges to the municipal system from industrial and commercial facilities that contribute a substantial pollutant load to the MS4. The regulations require that permittees establish priorities and procedures for inspection of industrial facilities and priority commercial establishments. This permit, consistent with the USEPA policy, incorporates a cooperative partnership, including the specifications of minimum expectations, between the Regional Board and the Permittees for the inspection of industrial facilities and priority commercial establishments to control pollutants in storm water discharges (58 *Fed. Reg.* 61157).

6. Section 402 (p) of the CWA (33 U.S.C. § 1342(p) provides that MS4 permits must "require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design engineering method and such other provisions as the [EPA] Administrator or the State determines appropriate for the control of such pollutants." The State Water Resources Control Board's (State Board) Office of Chief Counsel (OCC) has issued a memorandum interpreting the meaning of MEP to include technical feasibility, cost, and benefit derived with the burden being on the municipality to demonstrate compliance with MEP by showing that a BMP is not technically feasible in the locality or that BMPs costs would exceed any benefit to be derived (dated February 11, 1993).

7. The CWA authorizes the USEPA to permit a state to serve as the NPDES permitting authority in lieu of the USEPA. The State of California has in-lieu authority for an NPDES program. The Porter-Cologne Water Quality Control Act authorizes the State Board, through the Regional Boards, to regulate and control the discharge of pollutants into waters of the State. The State Board entered into a MOA with the USEPA, on

September 22, 1989, to administer the NPDES Program governing discharges to waters of the U.S.

8. Section 303(d) of the CWA requires that the State identify a list of impaired water-bodies and develop and implement Total Maximum Daily Loads (TMDLs) for these waterbodies (33 U.S.C. §1313(d)(1)). A TMDL specifies the maximum amount of a pollutant that a water-body can receive, still meet applicable water quality standards and protect beneficial uses. The USEPA entered into a consent decree with the Natural Resources Defense Council (NRDC), Heal the Bay, and the Santa Monica BayKeeper on March 22, 1999, under which the Regional Board must adopt all TMDLs for the Los Angeles Region within 13 years from that date. This permit incorporates a provision to implement and enforce approved load allocations for municipal storm water discharges and requires amending the SQMP after pollutants loads have been allocated and approved.

9. Section 6217(g) of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) requires coastal states with approved coastal zone management programs to address non-point pollution impacting or threatening coastal water quality. CZARA (16 U.S.C. § 1451-1465) amends the Coastal Zone Management Act of 1972, to address five sources of non-point pollution: agriculture, silviculture, urban, marinas, and hydromodification. This NPDES permit addresses the management measures required for the urban category, with the exception of septic systems. The Regional Board addresses septic systems through the administration of other programs.

10. On May 18, 2000, the USEPA established numeric criteria for priority toxic pollutants for the State of California (California Toxics Rule (CTR)) 65 *Fed. Reg*. 31682 (40 CFR 131.38), for the protection of human health and aquatic life. These apply as ambient water quality criteria for inland surface waters, enclosed bays, and estuaries. The State Board adopted the *Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California (SIP) – 2000,* on March 2, 2000, for implementation of the CTR (State Board Resolution No. 2000-15 as amended by Board Resolution No. 2000-030). This policy requires that discharges comply with TMDL-derived load allocations as soon as possible but no later than 20 years from the effective date of the policy.

11. The State Board adopted a revised Water Quality Control Plan for Ocean Waters of California (Ocean Plan) on July 23, 1997. The Ocean Plan contains water quality objectives which apply to all discharges to the coastal waters of California.

12. The State Board in *In Re*: California Department of Transportation (State Board Order WQ 2001-08), determined that the discharge of storm water to ASBS is subject to the prohibition in the Ocean Plan against the discharge of wastes to an ASBS.

13. The Regional Board adopted an updated Water Quality Control Plan (Basin Plan) for the Los Angeles Region on June 13, 1994, *'Water Quality Control Plan, Los Angeles Region: Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties*, (1994).' The Basin Plan designates beneficial uses of receiving waters and specifies both narrative and numerical water quality objectives for the receiving waters in Los Angeles County.

14. The Regional Board on September 19, 2001, adopted amendments to the Basin Plan, to incorporate TMDLs for trash in the Los Angeles River (Resolution No. 01-013) and Ballona Creek (Resolution No. 01-014). After approval by the State Board, the Office of Administrative Law, and the USEPA, the TMDLs for trash will be effective and enforceable.

15. The Regional Board on April 13, 1998, approved BMPs for sidewalk rinsing to minimize the discharge of wash waters to the storm drain system (Resolution No. 98-08). By the same resolution, the Regional Board prohibited the discharge of municipal street wash waters to the storm drain system.

16. The Regional Board on April 13, 1998, approved recommended BMPs for industrial/commercial facilities (Resolution No. 98-08).

17. The Regional Board on April 22, 1999, approved a list of BMPs for use in development planning and development construction (Resolution No. 99-03)

18. The Regional Board adopted and approved requirements for new development and significant redevelopment projects in Los Angeles County to control the discharge of storm water pollutants in post-construction storm water, on January 26, 2000, in Board Resolution No. R-00-02. The Regional Board Executive Officer issued the approved Standard Urban Storm Water Mitigation Plans (SUSMPs) on March 8, 2000. The State Board in large part affirmed the Regional Board action and SUSMPs in State Board Order No. WQ 2000-11 issued on October 5, 2000.

    - The State Board's Chief Counsel has issued a statewide policy memorandum (dated December 26, 2000), which interprets the Order to provide broad discretion to Regional Boards and identifies potential future areas for inclusion in SUSMPs and the types of evidence and findings necessary. Such areas include ministerial projects, projects in environmentally sensitive areas, and water quality design criteria for RGOs.

    - The State Board's Chief Counsel interprets the Order to encourage regional solutions and endorses a mitigation fund or "bank" that may be funded by developers who obtain waivers from the numerical design standards for new development and significant redevelopment.

19. 40 CFR 131.10(a) prohibits states from designating waste transport or waste assimilation as a use for any water of the U.S. Authorizing the

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construction of a storm water/ urban runoff treatment facility in a jurisdictional water body would be tantamount to accepting waste assimilation as an appropriate use for that water body. Furthermore, the construction and operation of a pollution control facility in a water body can impact the physical, chemical, and biological integrity as well as the beneficial uses of the water body. Therefore, storm water treatment and/or mitigation in accordance with SUSMPs and any other requirements of this Order must occur prior to the discharge of storm water into a water of the U.S.

20. The Regional Board supports a Watershed Management Approach to address water quality protection in the region. The objective of the Watershed Management Approach should be to provide a comprehensive and integrated strategy towards water resource protection, enhancement, and restoration while balancing economic and environmental impacts within a hydrologically defined drainage basin or watershed. It emphasizes cooperative relationships between regulatory agencies, the regulated community, environmental groups, and other stakeholders in the watershed to achieve the greatest environmental improvements with available resources.

21. To promote a watershed management approach, the County of Los Angeles is divided into six Watershed Management Areas (WMAs) as follows:

    Malibu Creek and Rural Santa Monica Bay WMA
    Ballona Creek and Urban Santa Monica Bay WMA
    Los Angeles River WMA
    San Gabriel River WMA
    Dominguez Channel/Los Angeles Harbor WMA, and
    Santa Clara River WMA

    Attachment A shows the list of Permittees under each WMA and some Permittees have expressed an intent to form sub-watershed groups within the WMA to promote regional solutions for the mitigation of storm water discharge pollution.

22. To facilitate compliance with federal regulations, the State Board has issued two statewide general NPDES permits for storm water discharges: one for storm water from industrial sites [NPDES No. CAS000001, General Industrial Activity Storm Water Permit (GIASP)] and the other for storm water from construction sites [NPDES No. CAS000002, General Construction Activity Storm Water Permit (GCASP)]. The GCASP was reissued on August 19, 1999. The GIASP was reissued on April 17, 1997. Facilities discharging storm water associated with industrial activities and construction projects with a disturbed area of five acres or more are required to obtain individual NPDES permits for storm water discharges, or to be covered by a statewide general permit by completing and filing a Notice of Intent (NOI) with the State Board. The USEPA guidance anticipates coordination of the state-administered programs for

industrial and construction activities with the local agency program to reduce pollutants in storm water discharges to the MS4.

The Regional Board is the enforcement authority in the Los Angeles Region for the two statewide general permits regulating discharges from industrial facilities and construction sites, and all NPDES storm water and non-storm water permits issued by the Regional Board. These industrial and construction sites and discharges are also regulated under local laws and regulations.

23. The State Board, on October 28, 1968, adopted Resolution No. 68-16, which established an anti-degradation policy for the State and Regional Boards. This policy restricts the degradation of surface waters and protects waterbodies where existing water quality is higher than is necessary for the protection of beneficial uses.

24. The State Board, on June 17, 1999, adopted Order No. WQ 99-05, which, in a precedential decision, identifies acceptable receiving water limitations language to be included in municipal storm water permits issued by the State and Regional Boards. The receiving water limitations included herein are consistent with the State Board Order, USEPA Policy, and the U.S. Appellate court decision in, *Defenders of Wildlife v. Browner* (9th. Cir, 1999). The State Board OCC has determined that the federal court decision did not conflict with State Board Order No. WQ 99-05 (memorandum dated October 14, 1999)

25. California Water Code (CWC) § 13263(a) requires that waste discharge requirements issued by the Regional Board shall implement any relevant water quality control plans that have been adopted; shall take into consideration the beneficial uses to be protected and the water quality objectives reasonably required for that purpose; other waste discharges; the need to prevent nuisance; and provisions of CWC § 13241. The Regional Board has considered the requirements of § 13263 and § 13241, and applicable plans, policies, rules, and regulations in developing these waste discharge requirements.

26. CWC § 13370 *et seq.* requires that waste discharge requirements issued by the Regional Boards be consistent with provisions of the federal CWA and its amendments.

27. On March 12, 2001, the U.S. Court of Appeals ruled that it is necessary to obtain a NPDES permit for application of aquatic pesticides to waterways. (*Headwaters, Inc. vs. Talent Irrigation District,* 243 F.3d. 526 (9th Cir., 2001)) This decision is controlling in California for nonagricultural applications of pesticides to waterways. The State Board adopted a general NPDES permit (Order No. 2001-12-DWQ) on July 19, 2001, for public entities that discharge pollutants to waters of the U.S. associated with the application of aquatic pesticides for resource or pest management. Public entities that conduct such activities must seek coverage under the general permit.

F. Implementation

1. The California Environmental Quality Act (CEQA) (Cal. Pub. Resources Code § 21000 *et seq*.) requires that public agencies consider the environmental impacts of the projects they approve for development. CEQA applies to projects that are considered discretionary and does not apply to ministerial projects, which involve the use of established standards or objective measurements. A ministerial project may be made discretionary by adopting local ordinance provisions or imposing conditions to create decision-making discretion in approving the project. In the alternative, Permittees may establish standards and objective criteria administratively for storm water mitigation for ministerial projects. For water quality purposes, the Regional Board considers that all new development and significant redevelopment activity in specified categories, that receive approval or permits from a municipality, are subject to storm water mitigation requirements.

2. The objective of this Order is to protect the beneficial uses of receiving waters in Los Angeles County. To meet this objective, this Order requires that the SQMP specify BMPs that will be implemented to reduce the discharge of pollutants in storm water to the maximum extent practicable. Further, Permittees are to assure that storm water discharges from the MS4 shall neither cause nor contribute to the exceedance of water quality standards and objectives nor create conditions of nuisance in the receiving waters, and that the discharge of non-storm water to the MS4 has been effectively prohibited.

3. The SQMP required in this Order builds upon the programs established in Order Nos. 90-079, and 96-054, consists of the components recommended in the USEPA guidance manual, and was developed with the cooperation of representatives from the regulated community and environmental groups. The SQMP includes provisions that promote customized initiatives, both on a countywide and watershed basis, in developing and implementing cost-effective measures to minimize discharge of pollutants to the receiving water. The various components of the SQMP, taken as a whole rather than individually, are expected to reduce pollutants in storm water and urban runoff to the maximum extent practicable. Provisions of the SQMP are fully enforceable under provisions of this Order.

4. The emphasis of the SQMP is pollution prevention through education, public outreach, planning, and implementation as source control BMPs first and then Structural and Treatment Control BMPs next. Successful implementation of the provisions of the SQMP will require cooperation and coordination of all public agencies in each Permittee's organization, among Permittees, and with the regulated community.

5. The implementation of a Public Information and Participation Program is a critical component of a storm water management program. An informed and knowledgeable community is critical to the success of a storm water management program since it helps insure the following: (i) greater support for the program as the public gains a greater understanding of

the reasons why it is necessary and important, and (ii) greater compliance with the program as the public becomes aware of the personal responsibilities expected of them and others in the community, including the individual actions they can take to protect or improve the quality of area waters.

6. This Order includes a Monitoring Program that incorporates Minimum Levels (MLs) established under the SIP. The SIP's MLs represent the lowest quantifiable concentration for priority toxic pollutants that is measurable with the use of proper method-based analytical procedures and factoring out matrix interference. The SIP's MLs therefore represent the best available science for determining MLs and are appropriate for a storm water monitoring program. The use of MLs allows the detection of toxic priority pollutants at concentrations of concern using recent advances in chemical analytical methods.

7. This Order provides flexibility for Permittees to petition the Regional Board Executive Officer to substitute a BMP under the SQMP with an alternative BMP, if they can provide information and documentation on the effectiveness of the alternative, equal to or greater than the prescribed BMP in meeting the objectives of this Order.

8. This Order contemplates that the Permittees are responsible for considering potential storm water impacts when making planning decisions in order to fulfill the Permittees' CWA requirement to reduce the discharge of pollutants in municipal storm water to the MEP from new development and redevelopment activities. However, the Permittees retain authority to make the final land-use decisions and retain full statutory authority for deciding what land uses are appropriate at specific locations within each Permittee's jurisdiction. This Order and its requirements are not intended to restrict or control local land use decision-making authority.

9. This Order is not intended to prohibit the inspection for or abatement of vectors by the State Department of Health Services or local vector agencies in accordance with Cal. Health and Safety Code § 2270 *et seq*. and §116110 *et seq*. Certain Treatment Control BMPs if not properly designed, operated or maintained may create habitats for vectors (e.g. mosquito and rodents). This Order contemplates that the Permittees will closely cooperate and collaborate with local vector control agencies and the State Department of Health Services for the implementation, operation, and maintenance of Treatment Control BMPs in order to minimize the risk to public health from vector borne diseases.

G. Public Process

1. The Regional Board has notified the Permittees and interested agencies and persons of its intent to issue waste discharge requirements for this discharge, and has provided them with an opportunity to submit their written view and recommendations.

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2. The Regional Board, in a public hearing, heard and considered all comments pertaining to the discharge and to the tentative requirements.

3. The Regional Board has conducted public workshops to discuss drafts of the permit. On April 24, 2001, Regional Board staff conducted a workshop outlining the reasoning behind the changes proposed for the new permit and received input from the Permittees and the public regarding those proposed changes. On July 26, 2001, a second public workshop was held at a special Regional Board meeting. The Permittees and the public had another opportunity to express their opinions regarding the proposed changes to the permit in front of the Regional Board members. A significant number of working meetings with the Permittees and other interested parties have occurred throughout the period from the submittal of the ROWD and completion of the tentative draft, in an attempt to incorporate and address all the comments presented.

4. The Los Angeles County Flood Control District, the County of Los Angeles and the other municipalities are co-permittees as defined in 40 CFR 122.26 (b)(1). Los Angeles County Flood Control District will coordinate with the other municipalities and facilitate program implementation. Each Permittee is responsible only for a discharge for which it is the operator.

5. This Order shall serve as a NPDES Permit, pursuant to CWA § 402, or amendments thereto, and shall take effect 50 days from Order adoption provided the Regional Administrator of the USEPA has no objections.

6. The action to adopt an NPDES permit is exempt from the provisions of Chapter 3 of CEQA (Cal. Pub. Resources Code § 21100 *et seq*.), in accordance with CWC § 13389.

7. Pursuant to CWC §13320, any aggrieved party may seek review of this Order by filing a petition with the State Board. A petition must be sent to: State Water Resources Control Board, P.O. Box 100, Sacramento, California, 95812, within 30 days of adoption of the Order by the Regional Board.

8. This Order may be modified or alternatively revoked or reissued prior to its expiration date, in accordance with the procedural requirements of the NPDES program, and the CWC for the issuance of waste discharge requirements.

IT IS HEREBY ORDERED that the Los Angeles County Flood Control District, Los Angeles County, and the Cities of Agoura Hills, Alhambra, Arcadia, Artesia, Azusa, Baldwin Park, Bell, Bellflower, Bell Gardens, Beverly Hills, Bradbury, Burbank, Calabasas, Carson, Cerritos, Claremont, Commerce, Compton, Covina, Cudahy, Culver City, Diamond Bar, Downey, Duarte, El Monte, El Segundo, Gardena, Glendale, Glendora, Hawaiian Gardens, Hawthorne, Hermosa Beach, Hidden Hills, Huntington Park, Industry, Inglewood, Irwindale, La Cañada Flintridge, La Habra Heights, Lakewood, La Mirada, La Puente, La Verne, Lawndale, Lomita, Los Angeles, Lynwood, Malibu, Manhattan Beach, Maywood, Monrovia, Montebello, Monterey Park, Norwalk, Palos Verdes Estates, Paramount, Pasadena, Pico Rivera, Pomona, Rancho Palos Verdes,

Redondo Beach, Rolling Hills, Rolling Hills Estates, Rosemead, San Dimas, San Fernando, San Gabriel, San Marino, Santa Clarita, Santa Fe Springs, Santa Monica, Sierra Madre, Signal Hill, South El Monte, South Gate, South Pasadena, Temple City, Torrance, Vernon, Walnut, West Covina, West Hollywood, Westlake Village, and Whittier, in order to meet the provisions contained in Division 7 of the CWC and regulations adopted thereunder, and the provisions of the CWA, as amended, and regulations and guidelines adopted thereunder, shall comply with the following:

Part 1. DISCHARGE PROHIBITIONS

The Permittees shall effectively prohibit non-storm water discharges into the MS4 and watercourses, except where such discharges:

1. Are covered by a separate individual or general NPDES permit for non-storm water discharges; or

2. Fall within one of the categories below, and meet all conditions when specified by the Regional Board Executive Officer:

   a) Category A - Natural flow:

      (1) Natural springs and rising ground water;

      (2) Flows from riparian habitats or wetlands;

      (3) Stream diversions, permitted by the State Board; and

      (4) Uncontaminated ground water infiltration [as defined by 40 CFR 35.2005(20)].

   b) Category B - Flows from emergency fire fighting activity.

   c) Category C - Flows incidental to urban activities:

      (1) Reclaimed and potable landscape irrigation runoff;

      (2) Potable drinking water supply and distribution system releases (consistent with American Water Works Association guidelines for dechlorination and suspended solids reduction practices);

      (3) Drains for foundations, footings, and crawl spaces;

      (4) Air conditioning condensate;

      (5) Dechlorinated/debrominated swimming pool discharges;

      (6) Dewatering of lakes and decorative fountains;

      (7) Non-commercial car washing by residents or by non-profit organizations; and

      (8) Sidewalk rinsing.

   The Regional Board Executive Officer may add or remove categories of non-storm water discharges above. Furthermore, in the event that any of

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the above categories of non-storm water discharges are determined to be a source of pollutants by the Regional Board Executive Officer, the discharge will no longer be exempt from this prohibition unless the Permittee implements conditions approved by the Regional Board Executive Officer to ensure that the discharge is not a source of pollutants. Notwithstanding the above, the Regional Board Executive Officer may impose additional prohibitions of non-storm water discharges in consideration of anti-degradation policies and TMDLs.

Part 2. RECEIVING WATER LIMITATIONS

1. Discharges from the MS4 that cause or contribute to the violation of Water Quality Standards or water quality objectives are prohibited.

2. Discharges from the MS4 of storm water, or non-storm water, for which a Permittee is responsible for, shall not cause or contribute to a condition of nuisance.

3. The Permittees shall comply with Part 2.1. and 2.2. through timely implementation of control measures and other actions to reduce pollutants in the discharges in accordance with the SQMP and its components and other requirements of this Order including any modifications. The SQMP and its components shall be designed to achieve compliance with receiving water limitations. If exceedances of Water Quality Objectives or Water Quality Standards (collectively, Water Quality Standards) persist, notwithstanding implementation of the SQMP and its components and other requirements of this permit, the Permittee shall assure compliance with discharge prohibitions and receiving water limitations by complying with the following procedure:

   a) Upon a determination by either the Permittee or the Regional Board that discharges are causing or contributing to an exceedance of an applicable Water Quality Standard, the Permittee shall promptly notify and thereafter submit a Receiving Water Limitations (RWL) Compliance Report (as described in the Program Reporting Requirements, Section I of the Monitoring and Reporting Program) to the Regional Board that describes BMPs that are currently being implemented and additional BMPs that will be implemented to prevent or reduce any pollutants that are causing or contributing to the exceedances of Water Quality Standards. This RWL Compliance Report may be incorporated in the annual Storm Water Report and Assessment unless the Regional Board directs an earlier submittal. The RWL Compliance Report shall include an implementation schedule. The Regional Board may require modifications to the RWL Compliance Report.

   b) Submit any modifications to the RWL Compliance Report required by the Regional Board within 30 days of notification.

   c) Within 30 days following the approval of the RWL Compliance Report, the Permittee shall revise the SQMP and its components and monitoring program to incorporate the approved modified

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BMPs that have been and will be implemented, an implementation schedule, and any additional monitoring required.

d) Implement the revised SQMP and its components and monitoring program according to the approved schedule.

4. So long as the Permittee has complied with the procedures set forth above and is implementing the revised SQMP and its components, the Permittee does not have to repeat the same procedure for continuing or recurring exceedances of the same receiving water limitations unless directed by the Regional Board to develop additional BMPs.

Part 3. STORM WATER QUALITY MANAGEMENT PROGRAM (SQMP) IMPLEMENTATION

A. General Requirements

1. Each Permittee shall, at a minimum, implement the SQMP. The SQMP is an enforceable element of this Order. The SQMP shall be implemented no later than February 1, 2002, unless a later date has been specified for a particular provision in this Order.

2. The SQMP shall, at a minimum, comply with the applicable storm water program requirements of 40 CFR 122.26(d)(2). The SQMP and its components shall be implemented so as to reduce the discharges of pollutants in storm water to the MEP.

3. Each Permittee shall implement additional controls, where necessary, to reduce the discharges of pollutants in storm water to the MEP.

4. Permittees that modify the countywide SQMP (i.e., implement additional controls, implement different controls than described in the countywide SQMP, or determine that certain BMPs in the countywide SQMP are not applicable in the area under its jurisdiction), shall develop a local SQMP, no later than August 1, 2002. The local SQMP shall be customized to reflect the conditions in the area under the Permittee's jurisdiction and shall specify activities being implemented under the appropriate elements described in the countywide SQMP.

B. Best Management Practice Implementation

The Permittees shall implement or require the implementation of the most effective combination of BMPs for storm water/urban runoff pollution control. When implemented, BMPs are intended to result in the reduction of pollutants in storm water to the MEP.

C. Revision of the Storm Water Quality Management Program

The Permittees shall revise the SQMP, at the direction of the Regional Board Executive Officer, to incorporate program implementation amendments so as to comply with regional, watershed specific requirements, and/or waste load

allocations developed and approved pursuant to the process for the designation and implementation of Total Maximum Daily Loads (TMDLs) for impaired water bodies.

D. Designation and Responsibilities of the Principal Permittee

The Los Angeles County Flood Control District is hereby designated as the Principal Permittee. As such, the Principal Permittee shall:

1. Coordinate and facilitate activities necessary to comply with the requirements of this Order, but is not responsible for ensuring compliance of any individual Permittee;

2. Coordinate permit activities among Permittees and act as liaison between Permittees and the Regional Board on permitting issues;

3. Provide personnel and fiscal resources for the necessary updates of the SQMP and its components;

4. Provide technical and administrative support for committees that will be organized to implement the SQMP and its components;

5. Convene the Watershed Management Committees (WMCs) constituted pursuant to Part F, below, upon designation of representatives;

6. Implement the Countywide Monitoring Program required under this Order and evaluate, assess and synthesize the results of the monitoring program;

7. Provide personnel and fiscal resources for the collection, processing and submittal to the Regional Board of annual reports and summaries of other reports required under the SQMP; and

8. Comply with the "Responsibilities of the Permittees" in Part 3.E., below.

E. Responsibilities of the Permittees

Each Permittee is required to comply with the requirements of this Order applicable to discharges within its boundaries (see Findings D.1, D.2. and D.3.) and not for the implementation of the provisions applicable to the Principal Permittee or other Permittees. Each Permittee shall, within its geographic jurisdiction:

1. Comply with the requirements of the SQMP and any modifications thereto;

2. Coordinate among its internal departments and agencies, as appropriate, to facilitate the implementation of the requirements of the SQMP applicable to such Permittee in an efficient and cost-effective manner;

3. Designate a technically knowledgeable representative to the appropriate WMC;

4. Participate in intra-agency coordination (e.g. Fire Department, Building and Safety, Code Enforcement, Public Health, etc.) necessary to successfully implement the provisions of this Order and the SQMP.

5. Prepare an annual Budget Summary of expenditures applied to the storm water management program. This summary shall identify the storm water budget for the following year, using estimated percentages and written explanations where necessary, for the specific categories noted below:

   a) Program management
      - Administrative costs

   b) Program Implementation

      Where information is available, provide an estimated percent breakdown of expenditures for the categories below:
      - Illicit connection/illicit discharge
      - Development planning
      - Development construction
      - Construction inspection activities
      - Industrial/Commercial inspection activities
      - Public Agency Activities
        - Maintenance of Structural BMPs and Treatment Control BMPs
        - Municipal Street Sweeping
        - Catch basin clean-up
        - Trash collection
        - Capital costs

   c) Public Information and Participation

   d) Monitoring Program

   e) Miscellaneous Expenditures

6. Each Permittee, in addition to the Budget Summary, shall report any supplemental dedicated budgets for the same categories.

F. Watershed Management Committees (WMCs)

1. Each WMC shall be comprised of a voting representative from each Permittee in the WMA.

2. The WMC's chair and secretary shall be chosen by the WMC upon Order adoption and on an annual basis, thereafter. In the absence of volunteer Permittee(s) for the positions, the Principal Permittee shall assume those roles until the WMC chooses members of the committee for the positions.

3. Each WMC shall:

   a) Facilitate cooperation and exchange of information among Permittees;

b) Establish additional goals and objectives and associated deadlines for the WMA, as the program implementation progresses;

c) Prioritize pollution control efforts based on beneficial use impairment(s), watershed characteristics and analysis of results from studies and the monitoring program;

d) Develop and/or update and monitor the adequate implementation, on an annual basis, of the tasks identified for the WMA;

e) Assess the effectiveness of, prepare revisions for, and recommend appropriate changes to the SQMP and its components;

f) Continue to prioritize the Industrial/Commercial critical sources for investigation, outreach and follow-up; and

g) Meet four times per year and, as necessary.

G. Legal Authority

1. Permittees shall possess the necessary legal authority to prohibit non-storm water discharges to the storm drain system, including, but not limited to:

a) Illicit discharges and illicit connections and require removal of illicit connections;

b) The discharge of wash waters to the MS4 from the cleaning of gas stations, auto repair garages, or other types of automotive service facilities;

c) The discharge of runoff to the MS4 from mobile auto washing, steam cleaning, mobile carpet cleaning, and other such mobile commercial and industrial operations;

d) The discharge of runoff to the MS4 from areas where repair of machinery and equipment which are visibly leaking oil, fluid or antifreeze, is undertaken;

e) The discharge of runoff to the MS4 from storage areas of materials containing grease, oil, or other hazardous substances, and uncovered receptacles containing hazardous materials;

f) The discharge of chlorinated/ brominated swimming pool water and filter backwash to the MS4;

g) The discharge of runoff from the washing of toxic materials from paved or unpaved areas to the MS4;

h) Washing impervious surfaces in industrial/commercial areas that results in a discharge of runoff to the MS4;

i) The discharge of concrete or cement laden wash water from concrete trucks, pumps, tools, and equipment to the MS4; and

j) Dumping or disposal of materials into the MS4 other than storm water, such as:

(1) Litter, landscape debris and construction debris;

(2) Any state or federally banned or unregistered pesticides;

(3) Food and food processing wastes; and

(4) Fuel and chemical wastes, animal wastes, garbage, batteries, and other materials that have potential adverse impacts on water quality.

2. The Permittees shall possess adequate legal authority to:

a) Require persons within their jurisdiction to comply with conditions in Permittees' ordinances, permits, contracts, model programs, or orders (i.e. hold dischargers to its MS4 accountable for their contributions of pollutants and flows);

b) Utilize enforcement mechanisms to require compliance with Permittees ordinances, permits, contracts, or orders;

c) Control pollutants, including potential contribution, in discharges of storm water runoff associated with industrial activities (including construction activities) to its MS4 and control the quality of storm water runoff from industrial sites (including construction sites). This requirement applies to Source Control, and Treatment Control BMPs;

d) Carry out all inspection, surveillance and monitoring procedures necessary to determine compliance and non-compliance with permit conditions, including the prohibition of illicit discharges to the MS4. Permittees must possess authority to enter, sample, inspect, review and copy records, and require regular reports from industrial facilities (including construction sites) discharging polluted or with the potential to discharge polluted storm water runoff into its MS4;

e) Require the use of BMPs to prevent or reduce the discharge of pollutants to MS4s to MEP; and

f) Require that Treatment Control BMPs be properly operated and maintained to prevent the breeding of vectors.

3. Each Permittee shall, no later than November 1, 2002, amend and adopt (if necessary), a Permittee-specific storm water and urban runoff ordinance to enforce all requirements of this permit.

4. Each Permittee shall submit no later than December 2, 2002, a new or updated statement by its legal counsel that the Permittee has obtained all

necessary legal authority to comply with this Order through adoption of ordinances and/or municipal code modifications.

Part 4. SPECIAL PROVISIONS

Maximum Extent Practicable Standard

This permit, and the provisions herein, are intended to develop, achieve, and implement a timely, comprehensive, cost-effective storm water pollution control program to reduce the discharge of pollutants in storm water to the MEP from the permitted areas in the County of Los Angeles to the waters of the State.

A. General Requirements

1. Best Management Practice Substitution

   The Regional Board Executive Officer may approve any site-specific BMP substitution upon petition by a Permittee(s), if the Permittee can document that:

   a) The proposed alternative BMP or program will meet or exceed the objective of the original BMP or program in the reduction of storm water pollutants; or

   b) The fiscal burden of the original BMP or program is substantially greater than the proposed alternative and does not achieve a substantially greater improvement in storm water quality; and,

   c) The proposed alternative BMP or program will be implemented within a similar period of time.

B. Public Information and Participation Program (PIPP)

The Principal Permittee shall implement a Public Information and Participation Program (PIPP) that includes, but is not limited to, the requirements listed in this section. The Principal Permittee shall be responsible for developing and implementing the Public Education Program, as described in the SQMP, and shall coordinate with Permittees to implement specific requirements.

The objectives of the PIPP are as follows:

- To measurably increase the knowledge of the target audiences regarding the MS4, the impacts of storm water pollution on receiving waters, and potential solutions to mitigate the problems caused;
- To measurably change the waste disposal and runoff pollution generation behavior of target audiences by encouraging implementation of appropriate solutions; and
- To involve and engage socio-economic groups and ethnic communities in Los Angeles County to participate in mitigating the impacts of storm water pollution.

The Principal Permittee shall convene an advisory committee to provide input and assistance in meeting the goals and objectives of the public education campaign. The advisory committee shall be consulted during the process of developing the PIPP campaign, and shall provide comments and advice during the process of preparing a Request For Proposals for a storm water public education contractor. The committee may participate as a part of a working group that evaluates contractor proposals and other tasks as appropriate. The committee shall be comprised of representatives of the environmental community, Permittee cities, Regional Board staff, and experts in the fields of public education and marketing. The Principal Permittee shall ensure that the committee meets at least once a year.

1. Residential Program

a) "No Dumping" Message

Each Permittee shall mark all storm drain inlets that they own with a legible “no dumping” message. In addition, signs with prohibitive language discouraging illegal dumping must be posted at designated public access points to creeks, other relevant water bodies, and channels no later than February 2, 2004. Signage and storm drain messages shall be legible and maintained as necessary during the term of the permit.

b) Countywide Hotline

The 888-CLEAN-LA hotline will serve as the general public reporting contact for reporting clogged catch basin inlets and illicit discharges/dumping, faded or lack of catch basin stencils, and general storm water management information. Each Permittee may establish its own hotline if preferred. Permittees shall include this information, updated when necessary, in public information, and the government pages of the telephone book, as they are developed or published. The Principal Permittee shall compile a list of the general public reporting contacts from all Permittees and make this information available on the web site (888CleanLA.com) and upon request. Permittees shall provide the Principal Permittee with their reporting contacts no later than March 1, 2002. Permittees are responsible for providing current, updated information to the Principal Permittee.

c) Outreach and Education

(1) The Principal Permittee shall continue to implement the following activities that were components of the first five-year PIPP:

(i) Advertising;

(ii) Media relations;

(iii) Public service announcements;

(iv) "How To" instructional material distributed in a targeted and activity-related manner;

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(v) Corporate, community association, environmental organization and entertainment industry tie-ins; and

(vi) Events targeted to specific activities and population subgroups.

(2) The Principal Permittee shall develop a strategy to educate ethnic communities and businesses through culturally effective methods. Details of this strategy should be incorporated into the Public Education Program, and implemented, no later than February 3, 2003.

(3) The Principal Permittee shall enhance the existing outreach efforts to residents and businesses related to the proper disposal of cigarette butts.

(4) Each Permittee shall conduct educational activities within its jurisdiction and participate in countywide events.

(5) The Principal Permittee shall organize Public Outreach Strategy meetings for Permittees on a quarterly basis, beginning no later than May 1, 2002. The Principal Permittee shall provide guidance for Permittees to augment the countywide outreach and education program. Permittees shall coordinate regional and local outreach and education to reduce duplication of efforts. Permittees are encouraged to include other interested parties in the outreach strategy to strengthen and coordinate educational efforts.

(6) The Principal Permittee shall ensure that a minimum of 35 million impressions per year are made on the general public about storm water quality via print, local TV access, local radio, or other appropriate media.

(7) The Principal Permittee, in cooperation with the Permittees, shall provide schools within each School District in the County with materials, including, but not limited to, videos, live presentations, and other information necessary to educate a minimum of 50 percent of all school children (K-12) every 2 years on storm water pollution.

(8) Permittees shall provide the contact information for their appropriate staff responsible for storm water public education activities to the Principal Permittee no later than April 1, 2002, and changes to contact information no later than 30 days after a change occurs.

(9) The Principal Permittee shall develop a strategy to measure the effectiveness of in-school educational programs. The protocol shall include assessment of students' knowledge of storm water pollution problems and

solutions before and after educational efforts are conducted. The protocol shall be developed and submitted to the Regional Board Executive Officer for approval no later than May 1, 2002. It shall be implemented upon approval.

(10) In order to ensure that the PIPP is demonstrably effective in changing the behavior of the public, the Principal Permittee shall develop a behavioral change assessment strategy no later than May 1, 2002. The strategy shall be developed based on sociological data and studies (such as the County Segmentation Study). The Principal Permittee shall submit the assessment strategy to the Regional Board Executive Office for approval. It shall be implemented on approval.

d) Pollutant-Specific Outreach

The Principal Permittee, in cooperation with Permittees, shall coordinate to develop outreach programs that focus on the watershed-specific pollutants listed in Table 1 no later than February 3, 2003. Metals may be appropriately addressed through the Industrial/Commercial Facilities Program (e.g. distribute education materials on appropriate BMPs for metal waste management to facilities that have been identified as a potential source, such as metal fabricating facilities). Region-wide pollutants may be included in the Principal Permittee's mass media outreach efforts.

Table 1.	
Watershed	***Target Pollutants for Outreach***
Ballona Creek	Trash, Indicator Bacteria, Metals, PAHs
Malibu Creek	Trash, Nutrients (Nitrogen), Indicator Bacteria, Sediments
Los Angeles River	Trash, Nutrients (Nitrogen), Indicator Bacteria, Metals, Pesticides, PAHs
San Gabriel River	Trash, Nutrients (Nitrogen), Indicator Bacteria, Metals
Santa Clara River	Nutrients (Nitrogen), Coliform
Dominguez Channel	Trash, Indicator Bacteria, PAHs

Each Permittee shall make outreach materials available to the general public and target audiences, such as schools, community groups, contractors and developers, and at appropriate public counters and events. Outreach material shall include information on pollutants, sources of concern, and source abatement measures.

2. Businesses Program

a) Corporate Outreach

The Principal Permittee shall develop and implement a Corporate Outreach program to educate and inform corporate managers about storm water regulations. The program shall target RGOs and restaurant chains. At a minimum, this program shall include:

(1) Conferring with corporate management to explain storm water regulations;

(2) Distribution and discussion of educational material regarding storm water pollution and BMPs, and provide managers with suggestions to facilitate employee compliance with storm water regulations.

Corporate Outreach for all RGOs and restaurant chain corporations shall be conducted not less than twice during the permit term, with the first outreach contact to begin no later than February 3, 2003.

b) Business Assistance Program

The Principal Permittee and Permittees may implement a Business Assistance Program to provide technical resource assistance to small businesses to advise them on BMPs implementation to reduce the discharge of pollutants in storm water runoff. Programs may include:

(1) On-site technical assistance or consultation via telephone to identify and implement storm water pollution prevention methods and best management practices; and

(2) Making available, distributing, and discussing of applicable BMP and educational materials.

C. Industrial/Commercial Facilities Control Program

Each Permittee shall require implementation of pollutant reduction and control measures at industrial and commercial facilities, with the objective of reducing pollutants in storm water runoff. Except as specified in other sections of this Order, pollutant reduction and control measures can be used alone or in combination, and can include Structural and Source Control BMPs, and operation and maintenance procedures, which can be applied before, during, and/or after pollution generating activities. At a minimum, the Industrial/Commercial Facilities Control Program shall include requirements to: (1) track, (2) inspect, and (3) ensure compliance at industrial and commercial facilities that are critical sources of pollutants in storm water.

1. Track Critical Sources

a) Each Permittee shall maintain a watershed-based inventory or database of all facilities within its jurisdiction that are critical sources of storm water pollution. Critical sources to be tracked are summarized below, and also specified in Attachment B:

(1) Commercial Facilities

- restaurants;
- automotive service facilities; and
- RGOs and automotive dealerships.

(2) USEPA Phase I Facilities (Tier 1 and 2)

(3) Other Federally-mandated Facilities [as specified in 40 CFR 122.26(d)(2)(iv)(C)]

- municipal landfills;
- hazardous waste treatment, disposal, and recovery facilities; and
- facilities subject to SARA Title III (also known as EPCRA).

b) Each Permittee shall include the following minimum fields of information for each industrial and commercial facility:

- name of facility and name of owner/operator;
- address;
- coverage under the GIASP or other individual or general NPDES permits; and
- a narrative description including SIC codes that best reflects the industrial activities at and principal products of each facility.

The Regional Board encourages Permittees to add other fields of information, such as material usage and/or industrial output, and discrepancies between SIC Code designations (as reported by facility operators) and the actual type of industrial activity has the potential to pollute storm water. In addition, the Regional Board recommends use of an automated database system, such as a Geographical Information System (GIS) or Internet-based system; however, this is not required.

c) Each Permittee shall update its inventory of critical sources at least annually. The update may be accomplished through collection of new information obtained through field activities or through other readily available intra-agency informational databases (e.g. business licenses, pretreatment permits, sanitary sewer hook-up permits).

2. Inspect Critical Sources

Each Permittee shall inspect all facilities in the categories and at a level and frequency as specified in the following subsections.

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a) Commercial Facilities

(1) Restaurants

Frequency of Inspections: Twice during the 5-year term of the Order, provided that the first inspection occurs no later than August 1, 2004, and that there is a minimum interval of one year in between the first compliance inspection and the second compliance inspection.

Level of inspections: Each Permittee, in cooperation with its appropriate department (such as health or public works), shall inspect all restaurants within its jurisdiction to confirm that storm water BMPs are being effectively implemented in compliance with State law, County and municipal ordinances, Regional Board Resolution 98-08, and the SQMP. At each restaurant, inspectors shall verify that the restaurant operator:

- has received educational materials on storm water pollution prevention practices;
- does not pour oil and grease or oil and grease residue onto a parking lot, street or adjacent catch basin;
- keeps the trash bin area clean and trash bin lids closed, and does not fill trash bins with washout water or any other liquid;
- does not allow illicit discharges, such as discharge of washwater from floormats, floors, porches, parking lots, alleys, sidewalks and street areas (in the immediate vicinity of the establishment), filters or garbage/trash containers;
- removes food waste, rubbish or other materials from parking lot areas in a sanitary manner that does not create a nuisance or discharge to the storm drain.

(2) Automotive Service Facilities

Frequency of Inspections: Twice during the 5-year term of the Order, provided that the first inspection occurs no later than August 1, 2004, and that there is a minimum interval of one year in between the first compliance inspection and the second compliance inspection.

Level of inspections: Each Permittee shall inspect all automotive service facilities within its jurisdiction to confirm that storm water BMPs are effectively implemented in compliance with County and municipal ordinances, Regional Board Resolution 98-08, and the SQMP. At each

automotive service facility, inspectors shall verify that each operator:

- maintains the facility area so that it is clean and dry and without evidence of excessive staining;
- implements housekeeping BMPs to prevent spills and leaks;
- properly discharges wastewaters to a sanitary sewer and/or contains wastewaters for transfer to a legal point of disposal;
- is aware of the prohibition on discharge of non-storm water to the storm drain;
- properly manages raw and waste materials including proper disposal of hazardous waste;
- protects outdoor work and storage areas to prevent contact of pollutants with rainfall and runoff;
- labels, inspects, and routinely cleans storm drain inlets that are located on the facility's property; and
- trains employees to implement storm water pollution prevention practices.

(3) Retail Gasoline Outlets and Automotive Dealerships

Frequency of Inspection: Twice during the 5-year term of the Order, provided that the first inspection occurs no later than August 1, 2004, and that there is a minimum interval of one year in between the first compliance inspection and the second compliance inspection.

Level of Inspection: Each Permittee shall confirm that BMPs are being effectively implemented at each RGO and automotive dealership within its jurisdiction, in compliance with the SQMP, Regional Board Resolution 98-08, and the Stormwater Quality Task Force Best Management Practice Guide for RGOs. At each RGO and automotive dealership, inspectors shall verify that each operator:

- routinely sweeps fuel-dispensing areas for removal of litter and debris, and keeps rags and absorbents ready for use in case of leaks and spills;
- is aware that washdown of facility area to the storm drain is prohibited;
- is aware of design flaws (such as grading that doesn't prevent run-on, or inadequate roof covers and berms), and that equivalent BMPs are implemented;
- inspects and cleans storm drain inlets and catch basins within each facility's boundaries no later than October 1st of each year;

- posts signs close to fuel dispensers, which warn vehicle owners/operators against "topping off" of vehicle fuel tanks and installation of automatic shutoff fuel dispensing nozzles;
- routinely checks outdoor waste receptacle and air/water supply areas, cleans leaks and drips, and ensures that only watertight waste receptacles are used and that lids are closed; and
- trains employees to properly manage hazardous materials and wastes as well as to implement other storm water pollution prevention practices.

b) Phase I Facilities

Permittees need not inspect facilities that have been inspected by the Regional Board within the past 24 months. For the remaining Phase I facilities that the Regional Board has not inspected, each Permittee shall conduct compliance inspections as specified below.

Frequency of Inspection

Facilities in Tier 1 Categories: Twice during the 5-year term of the Order, provided that the first inspection occurs no later than August 1, 2004, and that there is a minimum interval of one year in between the first compliance inspection and the second compliance inspection.

Facilities in Tier 2 Categories: Twice during the 5-year term of the permit, provided that the first inspection occurs no later than August 1, 2004. Permittees need not perform additional inspections at those facilities determined to have no risk of exposure of industrial activity to storm water. For those facilities that do have exposure of industrial activities to storm water, a Permittee may reduce the frequency of additional compliance inspections to once every 5 years, provided that the Permittee inspects at least 20% of the facilities in Tier 2 each year.

Level of Inspection: Each Permittee shall confirm that each operator:

- has a current Waste Discharge Identification (WDID) number for facilities discharging storm water associated with industrial activity, and that a Storm Water Pollution Prevention Plan is available on-site, and
- is effectively implementing BMPs in compliance with County and municipal ordinances, Regional Board Resolution 98-08, and the SQMP.

c) Other Federally-mandated Facilities

Frequency of Inspection: Twice during the 5-year term of the Order, provided that the first inspection occurs no later than August 1, 2004, and that there is a minimum interval of one year in between the first compliance inspection and the second compliance inspection.

Level of Inspection: Each Permittee shall confirm that each operator:

- has a current Waste Discharge Identification (WDID) number for facilities discharging storm water associated with industrial activity, and that a Storm Water Pollution Prevention Plan is available on-site, and
- is effectively implementing BMPs in compliance with County and municipal ordinances, Regional Board Resolution 98-08, and the SQMP.

3. Ensure Compliance of Critical Sources

a) **BMP Implementation:** In the event that a Permittee determines that a BMP specified by the SQMP or Regional Board Resolution 98-08 is infeasible at any site, that Permittee shall require implementation of other BMPs that will achieve the equivalent reduction of pollutants in the storm water discharges. Likewise, for those BMPs that are not adequate to achieve water quality objectives, Permittees may require additional site-specific controls, such as Treatment Control BMPs.

b) **Environmentally Sensitive Areas and Impaired Waters:** For critical sources that are in ESAs or that are tributary to CWA § 303(d) impaired water bodies, Permittees shall consider requiring operators to implement additional controls to reduce pollutants in storm water runoff that are causing or contributing to the exceedences of Water Quality Objectives.

c) **Progressive Enforcement:** Each Permittee shall implement a progressive enforcement policy to ensure that facilities are brought into compliance with all storm water requirements within a reasonable time period as specified below.

(1) In the event that a Permittee determines, based on an inspection conducted above, that an operator has failed to adequately implement all necessary BMPs, that Permittee shall take progressive enforcement action which, at a minimum, shall include a follow-up inspection within 4 weeks from the date of the initial inspection.

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(2) In the event that a Permittee determines that an operator has failed to adequately implement BMPs after a follow-up inspection, that Permittee shall take further enforcement action as established through authority in its municipal code and ordinances or through the judicial system.

(3) Each Permittee shall maintain records, including inspection reports, warning letters, notices of violations, and other enforcement records, demonstrating a good faith effort to bring facilities into compliance.

d) Interagency Coordination

(1) **Referral of Violations of the SQMP, Regional Board Resolution 98-08, and Municipal Storm Water Ordinances:** A Permittee may refer a violation(s) to the Regional Board provided that that Permittee has made a good faith effort of progressive enforcement. At a minimum, a Permittee's good faith effort must include documentation of:

- Two follow-up inspections, and
- Two warning letters or notices of violation.

(2) **Referral of Violations of the GIASP, including Requirements to File a Notice of Intent:** For those facilities in violation of the GIASP, Permittees may escalate referral of such violations to the Regional Board after one inspection and one written notice to the operator regarding the violation. In making such referrals, Permittees shall include, at a minimum, the following documentation:

- Name of the facility;
- Operator of the facility;
- Owner of the facility;
- Industrial activity being conducted at the facility that is subject to the GIASP; and
- Records of communication with the facility operator regarding the violation, which shall include at least an inspection report and one written notice of the violation.

Permittees shall, at a minimum, make such referrals on a quarterly basis.

(3) **Investigation of Complaints Regarding Facilities – Transmitted by the Regional Board Staff:** Each Permittee shall initiate, within one business day, investigation of complaints (other than non-storm water discharges) regarding facilities within its jurisdiction. The initial investigation shall include, at a minimum, a limited

inspection of the facility to confirm the complaint to determine if the facility is effectively complying with the SQMP and municipal storm water/urban runoff ordinances, and to oversee corrective action.

(4) **Support of Regional Board Enforcement Actions:** As directed by the Regional Board Executive Officer, Permittees shall support Regional Board enforcement actions by: assisting in identification of current owners, operators, and lessees of facilities; providing staff, when available, for joint inspections with Regional Board inspectors; appearing as witnesses in Regional Board enforcement hearings; and providing copies of inspection reports and other progressive enforcement documentation.

(5) **Participation in a Task Force:** The Permittees, Regional Board, and other stakeholders may form a Storm Water Task Force, the purpose of which is to communicate concerns regarding special cases of storm water violations by industrial and commercial facilities and to develop a coordinated approach to enforcement action.

D. Development Planning Program

The Permittees shall implement a development-planning program that will require all Planning Priority development and Redevelopment projects to:

- Minimize impacts from storm water and urban runoff on the biological integrity of Natural Drainage Systems and water bodies in accordance with requirements under CEQA (Cal. Pub. Resources Code § 21100), CWC § 13369, CWA § 319, CWA § 402(p), CWA § 404, CZARA § 6217(g), ESA § 7, and local government ordinances ;
- Maximize the percentage of pervious surfaces to allow percolation of storm water into the ground;
- Minimize the quantity of storm water directed to impervious surfaces and the MS4;
- Minimize pollution emanating from parking lots through the use of appropriate Treatment Control BMPs and good housekeeping practices;
- Properly design and maintain Treatment Control BMPs in a manner that does not promote the breeding of vectors; and
- Provide for appropriate permanent measures to reduce storm water pollutant loads in storm water from the development site.

1. Peak Flow Control

The Permittees shall control post-development peak storm water runoff discharge rates, velocities, and duration (peak flow control) in Natural

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Drainage Systems (i.e., mimic pre-development hydrology) to prevent accelerated stream erosion and to protect stream habitat. Natural Drainage Systems are located in the following areas:

a) Malibu Creek;

b) Topanga Canyon Creek;

c) Upper Los Angeles River;

d) Upper San Gabriel River;

e) Santa Clara River; and

f) Los Angeles County Coastal streams (see Basin Plan Table 2-1).

The Principal Permittee in consultation with Permittees shall develop numerical criteria for peak flow control, based on the results of the Peak Discharge Impact Study (see Monitoring Program Section II.I).

Each Permittee shall, no later than February 1, 2005, implement numerical criteria for peak flow control.

A Permittee or group of Permittees may substitute for the countywide peak flow control criteria with a Hydromodification Control Plan (HCP), on approval by the Regional Board, in the following circumstances:

(1) Stream or watershed-specific conditions indicate the need for a different peak flow control criteria, and the alternative numerical criteria is developed through the application of hydrologic modeling and supporting field observations; or

(2) A watershed-wide plan has been developed for implementation of control measures to reduce erosion and stabilize drainage systems on a watershed basis.

2. Standard Urban Storm Water Mitigation Plans (SUSMPs)

a) Each Permittee shall amend codes and ordinances not later than August 1, 2002 to give legal effect to SUSMP changes contained in this Order. Changes to SUSMP requirements shall take effect not later than September 2, 2002.

b) Each Permittee shall require that a single-family hillside home:

(1) Conserve natural areas;

(2) Protect slopes and channels;

(3) Provide storm drain system stenciling and signage;

(4) Divert roof runoff to vegetated areas before discharge unless the diversion would result in slope instability; and

(5) Direct surface flow to vegetated areas before discharge unless the diversion would result in slope instability.

c) Each Permittee shall require that a SUSMP as approved by the Regional Board in Board Resolution No. R 00-02 be implemented for the following categories of developments:

(1) Ten or more unit homes (includes single family homes, multifamily homes, condominiums, and apartments);

(2) A 100,000 or more square feet of impervious surface area industrial/ commercial development;

(3) Automotive service facilities (SIC 5013, 5014, 5541, 7532-7534, and 7536-7539);

(4) Retail gasoline outlets;

(5) Restaurants (SIC 5812);

(6) Parking lots 5,000 square feet or more of surface area or with 25 or more parking spaces; and

(7) Redevelopment projects in subject categories that meet Redevelopment thresholds.

d) Each Permittee shall submit an ESA Delineation Map for its jurisdictional boundary, based on the Regional Board's ESA Definition, no later than June 3, 2002, for approval by the Regional Board Executive Officer in consultation with the California Department of Fish and Game, and the California Coastal Commission.

e) Each Permittee shall require the implementation of SUSMP provisions no later than September 2, 2002, for all projects located in or directly adjacent to or discharging directly to an ESA, where the development will:

(1) Discharge storm water and urban runoff that is likely to impact a sensitive biological species or habitat; and

(2) Create 2,500 square feet or more of impervious surface area.

3. Numerical Design Criteria

The Permittees shall require that post-construction Treatment Control BMPs incorporate, at a minimum, either a volumetric or flow based treatment control design standard, or both, as identified below to mitigate (infiltrate, filter or treat) storm water runoff:

a) Volumetric Treatment Control BMP

(1) The 85th percentile 24-hour runoff event determined as the maximized capture storm water volume for the area, from

the formula recommended in *Urban Runoff Quality Management, WEF Manual of Practice No. 23/ ASCE Manual of Practice No. 87, (1998*); or

(2) The volume of annual runoff based on unit basin storage water quality volume, to achieve 80 percent or more volume treatment by the method recommended in *California Stormwater Best Management Practices Handbook – Industrial/ Commercial,* (1993); or

(3) The volume of runoff produced from a 0.75 inch storm event, prior to its discharge to a storm water conveyance system; or

(4) The volume of runoff produced from a historical-record based reference 24-hour rainfall criterion for "treatment" (0.75 inch average for the Los Angeles County area) that achieves approximately the same reduction in pollutant loads achieved by the 85th percentile 24-hour runoff event.

b) Flow Based Treatment Control BMP

(1) The flow of runoff produced from a rain event equal to at least 0.2 inches per hour intensity; or

(2) The flow of runoff produced from a rain event equal to at least two times the 85th percentile hourly rainfall intensity for Los Angeles County; or

(3) The flow of runoff produced from a rain event that will result in treatment of the same portion of runoff as treated using volumetric standards above.

4. Applicability of Numerical Design Criteria

The Permittees shall require the following categories of Planning Priority Projects to design and implement post-construction treatment controls to mitigate storm water pollution:

a) Single-family hillside residential developments of one acre or more of surface area;

b) Housing developments (includes single family homes, multifamily homes, condominiums, and apartments) of ten units or more;

c) A 100,000 square feet or more impervious surface area industrial/ commercial development;

d) Automotive service facilities (SIC 5013, 5014, 5541, 7532-7534 and 7536-7539) [5,000 square feet or more of surface area];

e) Retail gasoline outlets [5,000 square feet or more of impervious surface area and with projected Average Daily Traffic (ADT) of 100 or more vehicles]. Subsurface Treatment Control BMPs

which may endanger public safety (i.e., create an explosive environment) are considered not appropriate;

f) Restaurants (SIC 5812) [5,000 square feet or more of surface area];

g) Parking lots 5,000 square feet or more of surface area or with 25 or more parking spaces;

h) Projects located in, adjacent to or discharging directly to an ESA that meet threshold conditions identified above in 2.e; and

i) Redevelopment projects in subject categories that meet Redevelopment thresholds.

5. Not later than March 10, 2003, each Permittee shall require the implementation of SUSMP and post-construction control requirements for the industrial/commercial development category to projects that disturb one acre or more of surface area.

6. Site Specific Mitigation

Each Permittee shall, no later than September 2, 2002, require the implementation of a site-specific plan to mitigate post-development storm water for new development and redevelopment not requiring a SUSMP but which may potentially have adverse impacts on post-development storm water quality, where one or more of the following project characteristics exist:

a) Vehicle or equipment fueling areas;

b) Vehicle or equipment maintenance areas, including washing and repair;

c) Commercial or industrial waste handling or storage;

d) Outdoor handling or storage of hazardous materials;

e) Outdoor manufacturing areas;

f) Outdoor food handling or processing;

g) Outdoor animal care, confinement, or slaughter; or

h) Outdoor horticulture activities.

7. Redevelopment Projects

The Permittees shall apply the SUSMP, or site specific requirements including post-construction storm water mitigation to all Planning Priority Projects that undergo significant Redevelopment in their respective categories.

a) Significant Redevelopment means land-disturbing activity that results in the creation or addition or replacement of 5,000 square

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feet or more of impervious surface area on an already developed site.

Where Redevelopment results in an alteration to more than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to post development storm water quality control requirements, the entire project must be mitigated. Where Redevelopment results in an alteration to less than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to post development storm water quality control requirements, only the alteration must be mitigated, and not the entire development.

b) Redevelopment does not include routine maintenance activities that are conducted to maintain original line and grade, hydraulic capacity, original purpose of facility or emergency redevelopment activity required to protect public health and safety.

c) Existing single family structures are exempt from the Redevelopment requirements.

8. Maintenance Agreement and Transfer

Each Permittee shall require that all developments subject to SUSMP and site specific plan requirements provide verification of maintenance provisions for Structural and Treatment Control BMPs, including but not limited to legal agreements, covenants, CEQA mitigation requirements, and or conditional use permits. Verification at a minimum shall include:

a) The developer's signed statement accepting responsibility for maintenance until the responsibility is legally transferred; and either

b) A signed statement from the public entity assuming responsibility for Structural or Treatment Control BMP maintenance and that it meets all local agency design standards; or

c) Written conditions in the sales or lease agreement, which requires the recipient to assume responsibility for maintenance and conduct a maintenance inspection at least once a year; or

d) Written text in project conditions, covenants and restrictions (CCRs) for residential properties assigning maintenance responsibilities to the Home Owners Association for maintenance of the Structural and Treatment Control BMPs; or

e) Any other legally enforceable agreement that assigns responsibility for the maintenance of post-construction Structural or Treatment Control BMPs.

9. Regional Storm Water Mitigation Program

A Permittee or Permittee group may apply to the Regional Board for approval of a regional or sub-regional storm water mitigation program to substitute in part or wholly SUSMP requirements. Upon review and a determination by the Regional Board Executive Officer that the proposal is technically valid and appropriate, the Regional Board may consider for approval such a program if its implementation will:

a) Result in equivalent or improved storm water quality;

b) Protect stream habitat;

c) Promote cooperative problem solving by diverse interests;

d) Be fiscally sustainable and has secure funding; and

e) Be completed in five years including the construction and start-up of treatment facilities.

Nothing in this provision shall be construed as to delay the implementation of SUSMP requirements, as approved in this Order.

10. Mitigation Funding

The Permittees may propose a management framework, for endorsement by the Regional Board Executive Officer, to support regional or sub-regional solutions to storm water pollution, where any of the following situations occur:

a) A waiver for impracticability is granted;

b) Legislative funds become available;

c) Off-site mitigation is required because of loss of environmental habitat; or

d) An approved watershed management plan or a regional storm water mitigation plan exists that incorporates an equivalent or improved strategy for storm water mitigation.

11. California Environmental Quality Act (CEQA) Document Update

Each Permittee shall incorporate into its CEQA process, with immediate effect, procedures for considering potential storm water quality impacts and providing for appropriate mitigation when preparing and reviewing CEQA documents. The procedures shall require consideration of the following:

a) Potential impact of project construction on storm water runoff;

b) Potential impact of project post-construction activity on storm water runoff;

c) Potential for discharge of storm water from areas from material storage, vehicle or equipment fueling, vehicle or equipment maintenance (including washing), waste handling, hazardous

materials handling or storage, delivery areas or loading docks, or other outdoor work areas;

d) Potential for discharge of storm water to impair the beneficial uses of the receiving waters or areas that provide water quality benefit;

e) Potential for the discharge of storm water to cause significant harm on the biological integrity of the waterways and water bodies;

f) Potential for significant changes in the flow velocity or volume of storm water runoff that can cause environmental harm; and

g) Potential for significant increases in erosion of the project site or surrounding areas.

12. General Plan Update

a) Each Permittee shall amend, revise or update its General Plan to include watershed and storm water quality and quantity management considerations and policies when any of the following General Plan elements are updated or amended: (i) Land Use, (ii) Housing, (iii) Conservation, and (iv) Open Space.

b) Each Permittee shall provide the Regional Board with the draft amendment or revision when a listed General Plan element or the General Plan is noticed for comment in accordance with Cal. Govt. Code § 65350 *et seq*.

13. Targeted Employee Training

Each Permittee shall train its employees in targeted positions (whose jobs or activities are engaged in development planning) regarding the development planning requirements on an annual basis beginning no later than August 1, 2002, and more frequently if necessary. For Permittees with a population of 250,000 or more (2000 U.S. Census), training shall be completed no later than February 3, 2003.

14. Developer Technical Guidance and Information

a) Each Permittee shall develop and make available to the developer community SUSMP (development planning) guidelines immediately.

b) The Principal Permittee in partnership with Permittees shall issue no later than February 2, 2004, a technical manual for the siting and design of BMPs for the development community in Los Angeles County. The technical manual may be adapted from the revised California Storm Water Quality Task Force Best Management Practices Handbooks scheduled for publication in September 2002. The technical manual shall at a minimum include:

(1) Treatment Control BMPs based on flow-based and volumetric water quality design criteria for the purposes of countywide consistency;

(2) Peak Flow Control criteria to control peak discharge rates, velocities and duration;

(3) Expected pollutant removal performance ranges obtained from national databases, technical reports and the scientific literature;

(4) Maintenance considerations; and

(5) Cost considerations.

E. Development Construction Program

1. Each Permittee shall implement a program to control runoff from construction activity at all construction sites within its jurisdiction. The program shall ensure the following minimum requirements are effectively implemented at all construction sites:

   a) Sediments generated on the project site shall be retained using adequate Treatment Control or Structural BMPs;

   b) Construction-related materials, wastes, spills, or residues shall be retained at the project site to avoid discharge to streets, drainage facilities, receiving waters, or adjacent properties by wind or runoff;

   c) Non-storm water runoff from equipment and vehicle washing and any other activity shall be contained at the project site; and

   d) Erosion from slopes and channels shall be controlled by implementing an effective combination of BMPs (as approved in Regional Board Resolution No. 99-03), such as the limiting of grading scheduled during the wet season; inspecting graded areas during rain events; planting and maintenance of vegetation on slopes; and covering erosion susceptible slopes.

2. For construction sites one acre and greater, each Permittee shall comply with all conditions in section E.1. above and shall:

   a) Require the preparation and submittal of a Local Storm Water Pollution Prevention Plan (Local SWPPP), for approval prior to issuance of a grading permit for construction projects.

   The Local SWPPP shall include appropriate construction site BMPs and maintenance schedules. (A Local SWPPP may substitute for the State SWPPP if the Local SWPPP is at least as inclusive in controls and BMPs as the State SWPPP). The Local SWPPP must include the rationale used for selecting or rejecting BMPs. The project architect, or engineer of record, or authorized

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qualified designee, must sign a statement on the Local SWPPP to the effect:

"As the architect/engineer of record, I have selected appropriate BMPs to effectively minimize the negative impacts of this project's construction activities on storm water quality. The project owner and contractor are aware that the selected BMPs must be installed, monitored, and maintained to ensure their effectiveness. The BMPs not selected for implementation are redundant or deemed not applicable to the proposed construction activity."

The landowner or the landowner's agent shall sign a statement to the effect:

"I certify that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, to the best of my knowledge and belief, the information submitted is true, accurate, and complete. I am aware that submitting false and/or inaccurate information, failing to update the Local SWPPP to reflect current conditions, or failing to properly and/or adequately implement the Local SWPPP may result in revocation of grading and/or other permits or other sanctions provided by law."

The Local SWPPP certification shall be signed by the landowner as follows, for a corporation: by a responsible corporate officer which means (a) a president, secretary, treasurer, or vice president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision-making functions for the corporation, or (b) the manager of the construction activity if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures; for a partnership or sole proprietorship: by a general partner or the proprietor; or for a municipality or other public agency: by an elected official, a ranking management official (e.g., County Administrative Officer, City Manager, Director of Public Works, City Engineer, District Manager), or the manager of the construction activity if authority to sign Local SWPPPs has been assigned or delegated to the manager in accordance with established agency policy.

b) Inspect all construction sites for storm water quality requirements during routine inspections a minimum of once during the wet season. The Local SWPPP shall be reviewed for compliance with local codes, ordinances, and permits. For inspected sites that have not adequately implemented their Local SWPPP, a follow-up inspection to ensure compliance will take place within 2 weeks. If compliance has not been attained, the Permittee will take additional actions to achieve compliance (as specified in municipal

codes). If compliance has not been achieved, and the site is also covered under a statewide general construction storm water permit, each Permittee shall enforce their local ordinance requirements, and if non-compliance continues the Regional Board shall be notified for further joint enforcement actions.

c) Require, no later than March 10, 2003, prior to issuing a grading permit for all projects less than five acres requiring coverage under a statewide general construction storm water permit, proof of a Waste Discharger Identification (WDID) Number for filing a Notice of Intent (NOI) for permit coverage and a certification that a SWPPP has been prepared by the project developer. A Local SWPPP may substitute for the State SWPPP if the Local SWPPP is at least as inclusive in controls and BMPs as the State SWPPP.

3. For sites five acres and greater, each Permittee shall comply with all conditions in Sections E.1. and E.2. and shall:

a) Require, prior to issuing a grading permit for all projects requiring coverage under the state general permit, proof of a Waste Discharger Identification (WDID) Number for filing a Notice of Intent (NOI) for coverage under the GCASP and a certification that a SWPPP has been prepared by the project developer. A Local SWPPP may substitute for the State SWPPP if the Local SWPPP is at least as inclusive in controls and BMPs as the State SWPPP.

b) Require proof of an NOI and a copy of the SWPPP at any time a transfer of ownership takes place for the entire development or portions of the common plan of development where construction activities are still on-going.

c) Use an effective system to track grading permits issued by each Permittee. To satisfy this requirement, the use of a database or GIS system is encouraged, but not required.

4. GCASP Violation Referrals

a) Referral of Violations of the SQMP, Regional Board Resolution 98-08, and municipal storm water ordinances:

A Permittee may refer a violation(s) to the Regional Board provided that the Permittee has made a good faith effort of progressive enforcement. At a minimum, a Permittee's good faith effort must include documentation of:

- Two follow-up inspections within 3 months, and
- Two warning letters or notices of violation.

b) Referral of Violations of GCASP Filing Requirements:

For those projects subject to the GCASP, Permittees shall refer non-filers (i.e., those projects which cannot demonstrate that they have a WDID number) to the Regional Board, within 15 days of

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making a determination. In making such referrals, Permittees shall include, at a minimum, the following documentation:

- Project location;
- Developer;
- Estimated project size; and
- Records of communication with the developer regarding filing requirements.

5. Each Permittee shall train employees in targeted positions (whose jobs or activities are engaged in construction activities including construction inspection staff) regarding the requirements of the storm water management program no later than August 1, 2002, and annually thereafter. For Permittees with a population of 250,000 or more (2000 U.S. Census), initial training shall be completed no later than February 3, 2003. Each Permittee shall maintain a list of trained employees.

F. Public Agency Activities Program

Each Permittee shall implement a Public Agency program to minimize storm water pollution impacts from public agency activities. Public Agency requirements consist of:

- Sewage Systems Maintenance, Overflow, and Spill Prevention
- Public Construction Activities Management
- Vehicle Maintenance/Material Storage Facilities/Corporation Yards Management
- Landscape and Recreational Facilities Management
- Storm Drain Operation and Management
- Streets and Roads Maintenance
- Parking Facilities Management
- Public Industrial Activities Management
- Emergency Procedures
- Treatment Feasibility Study

1. Sewage System Maintenance, Overflow, and Spill Prevention

   a) Each Permittee shall implement a response plan for overflows of the sanitary sewer system within their respective jurisdiction, which shall consist at a minimum of the following:

      (1) Investigation of any complaints received;

      (2) Upon notification, immediate response to overflows for containment; and

      (3) Notification to appropriate sewer and public health agencies when a sewer overflows to the MS4.

   b) In addition to 1.a.1, 1.a.2, and 1.a.3 above, for those Permittees, which own and/or operate a sanitary sewer system, the Permittee shall also implement the following requirements:

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(1) Procedures to prevent sewage spills or leaks from sewage facilities from entering the MS4; and

(2) Identify, repair, and remediate sanitary sewer blockages, exfiltration, overflow, and wet weather overflows from sanitary sewers to the MS4.

2. Public Construction Activities Management

a) Each Permittee shall implement the Development Planning Program requirements (Permit Part 4.D) at public construction projects.

b) Each Permittee shall implement the Development Construction Program requirements (Permit Part 4.E) at Permittee owned construction sites.

c) Each Permittee shall obtain coverage under the GCASP for public construction sites 5 acres or greater (or part of a larger area of development) except that a municipality under 100,000 in population (1990 U.S. Census) need not obtain coverage under a separate permit until March 10, 2003.

d) Each Permittee, no later than March 10, 2003, shall obtain coverage under a statewide general construction storm water permit for public construction sites for projects between one and five acres.

3. Vehicle Maintenance/Material Storage Facilities/Corporation Yards Management

a) Each Permittee, consistent with the SQMP, shall implement SWPPPs for public vehicle maintenance facilities, material storage facilities, and corporation yards which have the potential to discharge pollutants into storm water.

b) Each Permittee shall implement BMPs to minimize pollutant discharges in storm water including but not be limited to:

(1) Good housekeeping practices;

(2) Material storage control;

(3) Vehicle leaks and spill control; and

(4) Illicit discharge control.

c) Each Permittee shall implement the following measures to prevent the discharge of pollutants to the MS4:

(1) For existing facilities, that are not already plumbed to the sanitary sewer, all vehicle and equipment wash areas (except for fire stations) shall either be:

(i) Self-contained;

(ii) Equipped with a clarifier;

(iii) Equipped with an alternative pre-treatment device; or

(iv) Plumbed to the sanitary sewer.

(2) For new facilities, or during redevelopment of existing facilities (including fire stations), all vehicle and equipment wash areas shall be plumbed to the sanitary sewer and be equipped with a pre-treatment device in accordance with requirements of the sewer agency.

4. Landscape and Recreational Facilities Management

Each Permittee shall implement the following requirements:

a) A standardized protocol for the routine and non-routine application of pesticides, herbicides (including pre-emergents), and fertilizers;

b) Consistency with State Board's guidelines and monitoring requirements for application of aquatic pesticides to surface waters (WQ Order No. 2001-12 DWQ);

c) Ensure no application of pesticides or fertilizers immediately before, during, or immediately after a rain event or when water is flowing off the area to be applied;

d) Ensure that no banned or unregistered pesticides are stored or applied;

e) Ensure that staff applying pesticides are certified by the California Department of Food and Agriculture, or are under the direct supervision of a certified pesticide applicator;

f) Implement procedures to encourage retention and planting of native vegetation and to reduce water, fertilizer, and pesticide needs;

g) Store fertilizers and pesticides indoors or under cover on paved surfaces or use secondary containment;

h) Reduce the use, storage, and handling of hazardous materials to reduce the potential for spills; and

i) Regularly inspect storage areas.

5. Storm Drain Operation and Management

a) Each Permittee shall designate catch basin inlets within its jurisdiction as one of the following:

Priority A: Catch basins that are designated as consistently generating the highest volumes of trash and/or debris.

Priority B: Catch basins that are designated as consistently generating moderate volumes of trash and/or debris.

Priority C: Catch basins that are designated as generating low volumes of trash and/or debris.

b) Permittees subject to a trash TMDL (Los Angeles River and Ballona Creek WMAs) shall continue to implement the requirements listed below until trash TMDL implementation measures are adopted. Thereafter, the subject Permittees shall implement programs in conformance with the TMDL implementation schedule, which shall include an effective combination of measures such as street sweeping, catch basin cleaning, installation of treatment devices and trash receptacles, or other BMPs. Default requirements include:

(1) Inspection and cleaning of catch basins between May 1 and September 30 of each year;

(2) Additional cleaning of any catch basin that is at least 40% full of trash and/or debris;

(3) Record keeping of catch basins cleaned; and

(4) Recording of the overall quantity of catch basin waste collected.

If the implementation phase for the Los Angeles River and Ballona Creek Trash TMDLs has not begun by October 2003, subject Permittees shall implement the requirements described below in subsection 5(c), until such time programs in conformance with the subject Trash TMDLs are being implemented.

c) Permittees not subject to a trash TMDL shall:

(1) Clean catch basins according to the following schedule:

Priority A: A minimum of three times during the wet season and once during the dry season every year.

Priority B: A minimum of once during the wet season and once during the dry season every year.

Priority C: A minimum of once per year.

In addition to the schedule above, between February 1, 2002 and July 1, 2003, Permittees shall ensure that any catch basin that is at least 40% full of trash and/or debris shall be cleaned out. After July 1, 2003, Permittees shall ensure that any catch basin that is at least 25% full of trash and debris shall be cleaned out.

(2) For any special event that can be reasonably expected to generate substantial quantities of trash and litter, include provisions that require for the proper management of trash and litter generated, as a condition of the special use permit issued for that event. At a minimum, the municipality who issues the permit for the special event shall arrange for either temporary screens to be placed on catch basins or for catch basins in that area to be cleaned out subsequent to the event and prior to any rain event.

(3) Place trash receptacles at all transit stops within its jurisdiction that have shelters no later than August 1, 2002, and at all other transit stops within its jurisdiction no later than February 3, 2003. All trash receptacles shall be maintained as necessary.

d) Each Permittee shall inspect the legibility of the catch basin stencil or label nearest the inlet. Catch basins with illegible stencils shall be recorded and re-stenciled or re-labeled within 180 days of inspection.

e) Each Permittee shall implement BMPs for Storm Drain Maintenance that include:

(1) A program to visually monitor Permittee-owned open channels and other drainage structures for debris at least annually and identify and prioritize problem areas of illicit discharge for regular inspection;

(2) A review of current maintenance activities to assure that appropriate storm water BMPs are being utilized to protect water quality;

(3) Removal of trash and debris from open channel storm drains shall occur a minimum of once per year before the storm season;

(4) Minimize the discharge of contaminants during MS4 maintenance and clean outs; and

(5) Proper disposal of material removed.

6. Streets and Roads Maintenance

a) Each Permittee shall designate streets and/or street segments within its jurisdiction as one of the following:

Priority A: Streets and/or street segments that are designated as consistently generating the highest volumes of trash and/or debris.

Priority B: Streets and/or street segments that are designated as consistently generating moderate volumes of trash and/or debris.

Priority C: Streets and/or street segments that are designated as generating low volumes of trash and/or debris.

b) Each Permittee shall perform street sweeping of curbed streets according to the following schedule:

Priority A: These streets and/or street segments shall be swept at least two times per month.

Priority B: Each Permittee shall ensure that each street and/or street segments is swept at least once per month.

Priority C: These streets and/or street segments shall be swept as necessary but in no case less than once per year.

c) Each Permittee shall require that:

(1) Sawcutting wastes be recovered and disposed of properly and that in no case shall waste be left on a roadway or allowed to enter the storm drain;

(2) Concrete and other street and road maintenance materials and wastes shall be managed to prevent discharge to the MS4; and

(3) The washout of concrete trucks and chutes shall only occur in designated areas and never discharged to storm drains, open ditches, streets, or catch basins.

d) Each Permittee shall, no later than August 1, 2002, train their employees in targeted positions (whose interactions, jobs, and activities affect storm water quality) regarding the requirements of the storm water management program to:

(1) Promote a clear understanding of the potential for maintenance activities to pollute storm water; and

(2) Identify and select appropriate BMPs.

For Permittees with a population of 250,000 or more (2000 U.S. Census) training shall be completed no later than February 1, 2003.

7. Parking Facilities Management

Permittee-owned parking lots exposed to storm water shall be kept clear of debris and excessive oil buildup and cleaned no less than 2 times per month and/or inspected no less than 2 times per month to determine if cleaning is necessary. In no case shall a Permittee-owned parking lot be cleaned less than once a month.

8. Public Industrial Activities Management

Each Permittee shall, for any municipal activity considered a discharge of storm water associated with industrial activity, obtain separate coverage under the GIASP except that a municipality under 100,000 in population (1990 U.S. Census) need not file the Notice Of Intent to be covered by said permit until March 10, 2003 (with the exception of power plants, airports, and uncontrolled sanitary landfills).

9. Emergency Procedures

Each Permittee shall repair essential public services and infrastructure in a manner to minimize environmental damage in emergency situations such as: earthquakes; fires; floods; landslides; or windstorms. BMPs shall be implemented to the extent that measures do not compromise public health and safety. After initial emergency response or emergency repair activities have been completed, each Permittee shall implement BMPs and programs as required under this Order.

10. Treatment Feasibility Study

The Permittees in cooperation with the County Sanitation Districts of Los Angeles County shall conduct a study to investigate the possible diversion of dry weather discharges or the use of alternative Treatment Control BMPs to treat flows from their jurisdiction which may impact public health and safety and/or the environment. The Permittees shall collectively review their individual prioritized lists and create a watershed based priority list of drains for potential diversion or treatment and submit the priority listing to the Regional Board Executive Officer, no later than July 1, 2003.

G. Illicit Connections and Illicit Discharges Elimination Program

Permittees shall eliminate all illicit connections and illicit discharges to the storm drain system, and shall document, track, and report all such cases in accordance

with the elements and performance measures specified in the following subsections.

1. General

   a) Implementation: Each Permittee must develop an Implementation Program which specifies how each Permittee is implementing revisions to the IC/ID Program of the SQMP. This Implementation Program must be documented, and available for review and approval by the Regional Board Executive Officer, upon request.

   b) Tracking: All Permittees shall, no later than February 3, 2003, develop and maintain a listing of all permitted connections to their storm drain system. All Permittees shall map at a scale and in a format specified by the Principal Permittee all illicit connections and discharges on their baseline maps, and shall transmit this information to the Principal Permittee. No later than February 3, 2003, the Principal Permittee shall use this information as well as results of baseline and priority screening for illicit connections (as set forth in subsection 2 below) to start an annual evaluation of patterns and trends of illicit connections and illicit discharges, with the objectives of identifying priority areas for elimination of illicit connections and illicit discharges.

   c) Training: All Permittees shall train all targeted employees who are responsible for identification, investigation, termination, cleanup, and reporting of illicit connections and discharges. For Permittees with a population of less than 250,000 (2000 U.S. Census), training shall be completed no later than August 1, 2002. For Permittees with a population of 250,000 or more (2000 U.S. Census), training shall be completed no later than February 3, 2003. Furthermore, all Permittees shall conduct refresher training on an annual basis thereafter.

2. Illicit Connections

   a) Screening for Illicit Connections

      (1) Field Screening: All Permittees shall field Screen the storm drain system for illicit connections in accordance with the following schedule:

         (i) Open channels: No later than February 3, 2003;

         (ii) Underground pipes in priority areas: No later than February 1, 2005; and

         (iii) Underground pipes with a diameter of 36 inches or greater: No later than December 12, 2006.

      Permittees shall report, to the Principal Permittee, on the location and length of open channels or underground pipes that have been Screened *vis a vis* the entire storm drain

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network, and on the status of suspected, confirmed, and terminated illicit connections. Permittees shall maintain a list containing all permitted connections and the status of connections under investigation for possible illicit connection.

(2) Permit Screening: No later than December 12, 2006, Permittees shall complete a review of all permitted connections to the storm drain system, to confirm compliance with Part 1 (Discharge Prohibition).

b) Response to Illicit Connections

(1) Investigation: Upon discovery or upon receiving a report of a suspected illicit connection, Permittees shall initiate an investigation within 21 days, to determine the source of the connection, the nature and volume of discharge through the connection, and the responsible party for the connection.

(2) Termination: Upon confirmation of the illicit nature of a storm drain connection, Permittees shall ensure termination of the connection within 180 days, using enforcement authority as needed.

3. Illicit Discharges

a) Abatement and Cleanup: Permittees shall respond, within one business day of discovery or a report of a suspected illicit discharge, with activities to abate, contain, and clean up all illicit discharges, including hazardous substances.

b) Investigation: Permittees shall investigate illicit discharges as soon as practicable (during or immediately following containment and cleanup activities), and shall take enforcement action as appropriate.

Part 5. DEFINITIONS

The following are definitions for terms applicable to this Order:

"Adverse Impact" means a detrimental effect upon water quality or beneficial uses caused by a discharge or loading of a pollutant or pollutants.

"Anti-degradation policies" means the *Statement of Policy with Respect to Maintaining High Quality Water in California* (State Board Resolution No. 68-16) which protects surface and ground waters from degradation. In particular, this policy protects waterbodies where existing quality is higher than that necessary for the protection of beneficial uses including the protection of fish and wildlife propagation and recreation on and in the water.

"Applicable Standards and Limitations" means all State, interstate, and federal standards and limitations to which a “discharge” or a related activity is subject under the CWA, including

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“effluent limitations, "water quality standards, standards of performance, toxic effluent standards or prohibitions, “best management practices,” and pretreatment standards under sections 301, 302, 303, 304, 306, 307, 308, 403 and 404 of CWA.

“**Areas of Special Biological Significance (ASBS)**” means all those areas of this state as ASBS, listed specifically within the California Ocean Plan or so designated by the State Board which, among other areas, includes the area from Mugu Lagoon to Latigo Point: Oceanwater within a line originating from Laguna Point at 34° 5’ 40” north, 119° 6’30” west, thence southeasterly following the mean high tideline to a point at Latigo Point defined by the intersection of the meanhigh tide line and a line extending due south of Benchmark 24; thence due south to a distance of 1000 feet offshore or to the 100 foot isobath, whichever distance is greater; thence northwesterly following the 100 foot isobath or maintaining a 1,000-foot distance from shore, whichever maintains the greater distance from shore, to a point lying due south of Laguna Point, thence due north to Laguna Point.

"Authorized Discharge" means any discharge that is authorized pursuant to an NPDES permit or meets the conditions set forth in this Order.

“Automotive Service Facilities” means a facility that is categorized in any one of the following Standard Industrial Classification (SIC) codes: 5013, 5014, 5541, 5511, 7532-7534, or 7536-7539. For inspection purposes, Permittees need not inspect facilities with SIC codes 5013, 5014, 5541, 5511, provided that these facilities have no outside activities or materials that may be exposed to storm water.

"Basin Plan" means the Water Quality Control Plan, Los Angeles Region, Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties, adopted by the Regional Board on June 13, 1994 and subsequent amendments.

"Beneficial Uses" means the existing or potential uses of receiving waters in the permit area as designated by the Regional Board in the Basin Plan.

"Best Management Practices (BMPs)" means methods, measures, or practices designed and selected to reduce or eliminate the discharge of pollutants to surface waters from point and nonpoint source discharges including storm water. BMPs include structural and nonstructural controls, and operation and maintenance procedures, which can be applied before, during, and/or after pollution producing activities.

"Commercial Development" means any development on private land that is not heavy industrial or residential. The category includes, but is not limited to: hospitals, laboratories and other medical facilities, educational institutions, recreational facilities, plant nurseries, car wash facilities, mini-malls and other business complexes, shopping malls, hotels, office buildings, public warehouses and other light industrial complexes.

"Construction" means constructing, clearing, grading, or excavation that results in soil disturbance. Construction includes structure teardown. It does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of facility; emergency construction activities required to immediately protect public health and safety; interior remodeling with no outside exposure of construction material or construction waste to storm water; mechanical permit work; or sign permit work.

"Control" means to minimize, reduce, eliminate, or prohibit by technological, legal, contractual or other means, the discharge of pollutants from an activity or activities.

"Dechlorinated/Debrominated Swimming Pool Discharge" means swimming pool discharges which have no measurable chlorine or bromine and do not contain any detergents, wastes, or additional chemicals not typically found in swimming pool water. The term does not include swimming pool filter backwash.

"Development" means any construction, rehabilitation, redevelopment or reconstruction of any public or private residential project (whether single-family, multi-unit or planned unit development); industrial, commercial, retail and other non-residential projects, including public agency projects; or mass grading for future construction. It does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of facility, nor does it include emergency construction activities required to immediately protect public health and safety.

"Directly Adjacent" means situated within 200 feet of the contiguous zone required for the continued maintenance, function, and structural stability of the environmentally sensitive area.

"Director" means the Director of a municipality and Person(s) designated by and under the Director's instruction and supervision.

"Discharge" means when used without qualification the "discharge of a pollutant."

"**Discharging Directly**" means outflow from a drainage conveyance system that is composed entirely or predominantly of flows from the subject, property, development, subdivision, or industrial facility, and not commingled with the flows from adjacent lands.

"Discharge of a Pollutant" means: any addition of any "pollutant" or combination of pollutants to "waters of the United States" from any "point source" or, any addition of any pollutant or combination of pollutants to the waters of the "contiguous zone" or the ocean from any point source other than a vessel or other floating craft which is being used as a means of transportation. The term discharge includes additions of pollutants into waters of the United States from: surface runoff which is collected or channeled by man; discharges through pipes, sewers, or other conveyances owned by a State, municipality, or other person which do not lead to a treatment works; and discharges through pipes, sewers, or other conveyances, leading into privately owned treatment works.

"Disturbed Area" means an area that is altered as a result of clearing, grading, and/or excavation.

"Environmentally Sensitive Areas (ESAs)" means an area in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which would be easily disturbed or degraded by human activities and developments (California Public Resources Code § 30107.5). Areas subject to storm water mitigation requirements are: areas designated as Significant Ecological Areas by the County of Los Angeles (*Los Angeles County Significant Areas Study, Los Angeles County Department of Regional Planning (1976)* and amendments); an area designated as a Significant Natural Area by the California Department of Fish and Game's Significant Natural Areas Program, provided that area has been field verified by the Department of Fish and Game; an area listed in the

Basin Plan as supporting the "Rare, Threatened, or Endangered Species (RARE)" beneficial use; and an area identified by a Permittee as environmentally sensitive.

"General Construction Activities Storm Water Permit (GCASP)" means the general NPDES permit adopted by the State Board which authorizes the discharge of storm water from construction activities under certain conditions.

"General Industrial Activities Storm Water Permit (GIASP)" means the general NPDES permit adopted by the State Board which authorizes the discharge of storm water from certain industrial activities under certain conditions.

"Hillside" means property located in an area with known erosive soil conditions, where the development contemplates grading on any natural slope that is 25% or greater and where grading contemplates cut or fill slopes.

"Illicit Connection" means any man-made conveyance that is connected to the storm drain system without a permit, excluding roof drains and other similar type connections. Examples include channels, pipelines, conduits, inlets, or outlets that are connected directly to the storm drain system.

"Illicit Discharge" means any discharge to the storm drain system that is prohibited under local, state, or federal statutes, ordinances, codes, or regulations. The term illicit discharge includes all non storm-water discharges except discharges pursuant to an NPDES permit, discharges that are identified in Part 1, "Discharge Prohibitions" of this order, and discharges authorized by the Regional Board Executive Officer.

"Illicit Disposal" means any disposal, either intentionally or unintentionally, of material(s) or waste(s) that can pollute storm water.

"Industrial/Commercial Facility" means any facility involved and/or used in the production, manufacture, storage, transportation, distribution, exchange or sale of goods and/or commodities, and any facility involved and/or used in providing professional and non-professional services. This category of facilities includes, but is not limited to, any facility defined by the Standard Industrial Classifications (SIC). Facility ownership (federal, state, municipal, private) and profit motive of the facility are not factors in this definition.

"Infiltration" means the downward entry of water into the surface of the soil.

"Inspection" means entry and the conduct of an on-site review of a facility and its operations, at reasonable times, to determine compliance with specific municipal or other legal requirements. The steps involved in performing an inspection, include, but are not limited to:

1. Pre-inspection documentation research.;
2. Request for entry;
3. Interview of facility personnel;
4. Facility walk-through.
5. Visual observation of the condition of facility premises;
6. Examination and copying of records as required;
7. Sample collection (if necessary or required);

8. Exit conference (to discuss preliminary evaluation); and,
9. Report preparation, and if appropriate, recommendations for coming into compliance.

In the case of restaurants, a Permittee may conduct an inspection from the curbside, provided that such "curbside" inspection provides the Permittee with adequate information to determine an operator's compliance with BMPs that must be implemented per requirements of this Order, Regional Board Resolution 98-08, County and municipal ordinances, and the SQMP.

"Large Municipal Separate Storm Sewer System (MS4)" means all MS4s that serve a population greater than 250,000 (1990 Census) as defined in 40 CFR 122.26 (b)(4). The Regional Board designated Los Angeles County as a large MS4 in 1990, based on: (i) the U.S. Census Bureau 1990 population count of 8.9 million, and (ii) the interconnectivity of the MS4s in the incorporated and unincorporated areas within the County.

"Local SWPPP" means the Storm Water Pollution Prevention Plan required by the local agency for a project that disturbs one or more acres of land.

"Maximum Extent Practicable (MEP)" means the standard for implementation of storm water management programs to reduce pollutants in storm water. CWA § 402(p)(3)(B)(iii) requires that municipal permits "shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants. See also State Board Order WQ 2000-11 at page 20.

"Method Detection Limit (MDL)" means the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero, as defined in 40 CFR 136, Appendix B.

"Minimum Level (ML)" means the concentration at which the entire analytical system must give a recognizable signal and acceptable calibration point. The ML is the concentration in a sample that is equivalent to the concentration of the lowest calibration standard analyzed by a specific analytical procedure, assuming that all the method specified sample weights, volumes, and processing steps have been followed.

“Municipal Separate Storm Sewer System (MS4)” means a conveyance or system of conveyances (including roads with drainage systems, municipal streets, alleys, catch basins, curbs, gutters, ditches, manmade channels, or storm drains) owned by a State, city, county, town or other public body, that is designed or used for collecting or conveying storm water, which is not a combined sewer, and which is not part of a publicly owned treatment works, and which discharges to Waters of the United States.

“National Pollutant Discharge Elimination System (NPDES)” means the national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under CWA §307, 402, 318, and 405. The term includes an “approved program.”

"Natural Drainage Systems" means unlined or unimproved (not engineered) creeks, streams, rivers or similar waterways.

“New Development” means land disturbing activities; structural development, including construction or installation of a building or structure, creation of impervious surfaces; and land subdivision.

“Non-Storm Water Discharge” means any discharge to a storm drain that is not composed entirely of storm water.

"Nuisance" means anything that meets all of the following requirements: (1) is injurious to health, or is indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property; (2) affects at the same time an entire community or neighborhood, or any considerable number of persons, although the extent of the annoyance or damage inflicted upon individuals may be unequal.; (3) occurs during, or as a result of, the treatment or disposal of wastes.

“Parking Lot” means land area or facility for the parking or storage of motor vehicles used for businesses, commerce, industry, or personal use, with a lot size of 5,000 square feet or more of surface area, or with 25 or more parking spaces.

"Permittee(s)" means Co-Permittees and any agency named in this Order as being responsible for permit conditions within its jurisdiction. Permittees to this Order include the Los Angeles County Flood Control District, Los Angeles County, and the cities of Agoura Hills, Alhambra, Arcadia, Artesia, Azusa, Baldwin Park, Bellflower, Bell Gardens, Beverly Hills, Bradbury, Burbank, Calabasas, Carson, Cerritos, Claremont, Commerce, Compton, Covina, Cudahy, Culver City, Diamond Bar, Downey, Duarte, El Monte, El Segundo, Gardena, Glendale, Glendora, Hawaiian Gardens, Hawthorne, Hermosa Beach, Hidden Hills, Huntington Park, Industry, Inglewood, Irwindale, La Canada Flintridge, La Habra Heights, Lakewood, La Mirada, La Puente, La Verne, Lawndale, Lomita, Los Angeles, Lynwood, Malibu, Manhattan Beach, Maywood, Monrovia, Montebello, Monterey Park, Norwalk, Palos Verdes Estates, Paramount, Pasadena, Pico Rivera, Pomona, Rancho Palos Verdes, Redondo Beach, Rolling Hills, Rolling Hills Estates, Rosemead, San Dimas, San Fernando, San Gabriel, San Marino, Santa Clarita, Santa Fe Springs, Santa Monica, Sierra Madre, Signal Hill, South El Monte, South Gate, South Pasadena, Temple City, Torrance, Vernon, Walnut, West Covina, West Hollywood, Westlake Village, and Whittier.

“Planning Priority Projects” means those projects that are required to incorporate appropriate storm water mitigation measures into the design plan for their respective project. These types of projects include:

1. Ten or more unit homes (includes single family homes, multifamily homes, condominiums, and apartments)
2. A 100,000 or more square feet of impervious surface area industrial/ commercial development (1 ac starting March 2003)
3. Automotive service facilities (SIC 5013, 5014, 5541, 7532-7534, and 7536-7539)
4. Retail gasoline outlets
5. Restaurants (SIC 5812)
6. Parking lots 5,000 square feet or more of surface area or with 25 or more parking spaces

7. Redevelopment projects in subject categories that meet Redevelopment thresholds
8. Projects located in or directly adjacent to or discharging directly to an ESA, which meet thresholds; and
9. Those projects that require the implementation of a site-specific plan to mitigate post-development storm water for new development not requiring a SUSMP but which may potentially have adverse impacts on post-development storm water quality, where the following project characteristics exist:

    a) Vehicle or equipment fueling areas;
    b) Vehicle or equipment maintenance areas, including washing and repair;
    c) Commercial or industrial waste handling or storage;
    d) Outdoor handling or storage of hazardous materials;
    e) Outdoor manufacturing areas;
    f) Outdoor food handling or processing;
    g) Outdoor animal care, confinement, or slaughter; or
    h) Outdoor horticulture activities.

"Pollutants" means those "pollutants" defined in CWA §502(6) (33.U.S.C.§1362(6)), and incorporated by reference into California Water Code §13373.

"Potable Water Distribution Systems Releases" means sources of flows from drinking water storage, supply and distribution systems including flows from system failures, pressure releases, system maintenance, distribution line testing, fire hydrant flow testing; and flushing and dewatering of pipes, reservoirs, vaults, and minor non-invasive well maintenance activities not involving chemical addition(s). It does not include wastewater discharges from activities that occur at wellheads, such as well construction, well development (i.e., aquifer pumping tests, well purging, etc.), or major well maintenance.

"Project" means all development, redevelopment, and land disturbing activities. The term is not limited to "Project" as defined under CEQA (Pub. Resources Code §21065).

“Rain Event” means any rain event greater than 0.1 inch in 24 hours except where specifically stated otherwise.

"Rare, Threatened, or Endangered Species (RARE)" means a beneficial use for waterbodies in the Los Angeles Region, as designated in the Basin Plan (Table 2-1), that supports habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened, or endangered.

"Receiving Waters" means all surface water bodies in the Los Angeles Region that are identified in the Basin Plan.

“Redevelopment” means land-disturbing activity that results in the creation, addition, or replacement of 5,000 square feet or more of impervious surface area on an already developed site. Redevelopment includes, but is not limited to: the expansion of a building footprint;

addition or replacement of a structure; replacement of impervious surface area that is not part of a routine maintenance activity; and land disturbing activities related to structural or impervious surfaces. It does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of facility, nor does it include emergency construction activities required to immediately protect public health and safety.

"Regional Administrator" means the Regional Administrator of the Regional Office of the USEPA or the authorized representative of the Regional Administrator.

"Restaurant" means a facility that sells prepared foods and drinks for consumption, including stationary lunch counters and refreshment stands selling prepared foods and drinks for immediate consumption (SIC Code 5812).

"Retail Gasoline Outlet" means any facility engaged in selling gasoline and lubricating oils.

"Runoff" means any runoff including storm water and dry weather flows from a drainage area that reaches a receiving water body or subsurface. During dry weather it is typically comprised of base flow either contaminated with pollutants or uncontaminated, and nuisance flows.

"Screening" means using proactive methods to identify illicit connections through a continuously narrowing process. The methods may include: performing baseline monitoring of open channels, conducting special investigations using a prioritization approach, analyzing maintenance records for catch basin and storm drain cleaning and operation, and verifying all permitted connections into the storm drains. Special investigation techniques may include: dye testing, visual inspection, smoke testing, flow monitoring, infrared, aerial and thermal photography, and remote control camera operation.

"Sidewalk Rinsing" means pressure washing of paved pedestrian walkways with average water usage of 0.006 gallons per square foot, with no cleaning agents, and properly disposing of all debris collected, as authorized under Regional Board Resolution No. 98-08.

"Significant Ecological Area (SEA)" means an area that is determined to possess an example of biotic resources that cumulatively represent biological diversity, for the purposes of protecting biotic diversity, as part of the Los Angeles County General Plan.[1]
Areas are designated as SEAs, if they possess one or more of the following criteria:

1. The habitat of rare, endangered, and threatened plant and animal species.
2. Biotic communities, vegetative associations, and habitat of plant and animal species that are either one of a kind, or are restricted in distribution on a regional basis.
3. Biotic communities, vegetative associations, and habitat of plant and animal species that are either one of a kind or are restricted in distribution in Los Angeles County.

[1] The 61 existing SEAs represent the findings of a study that was completed in 1976 by England and Nelson, Environmental Consultants, as amended through the adoption of a revised Los Angeles County General Plan in 1980. The results of an update study to evaluate existing SEAs within unincorporated Los Angeles County is currently being proposed to the Los Angeles County Planning Commission (*Los Angeles County Significant Ecological Area Update Study 2000, Background Report*, PCR Services Corporation). The *Update Study 2000*, which contains existing and proposed SEA boundaries, can be downloaded from the Los Angeles County Department of Planning website at http://planning.co.la.ca.us/drp_revw.html#SEA

4. Habitat that at some point in the life cycle of a species or group of species, serves as a concentrated breeding, feeding, resting, migrating grounds and is limited in availability either regionally or within Los Angeles County.
5. Biotic resources that are of scientific interest because they are either an extreme in physical/geographical limitations, or represent an unusual variation in a population or community.
6. Areas important as game species habitat or as fisheries.
7. Areas that would provide for the preservation of relatively undisturbed examples of natural biotic communities in Los Angeles County.
8. Special areas.[2]

"Significant Natural Area (SNA)" means an area defined by the California Department of Fish and Game (DFG), Significant Natural Areas Program, as an area that contains an important example of California's biological diversity. The most current SNA maps, reports, and descriptions can be downloaded from the DFG website at ftp://maphost.dfg.ca.gov/outgoing/whdab/sna/. These areas are identified using the following biological criteria only, irrespective of any administrative or jurisdictional considerations:

1. Areas supporting extremely rare species or habitats.
2. Areas supporting associations or concentrations of rare species or habitats.
3. Areas exhibiting the best examples of rare species and habitats in the state.

"Site" means the land or water area where any "facility or activity" is physically located or conducted, including adjacent land used in connection with the facility or activity.

"Source Control BMP" means any schedules of activities, prohibitions of practices, maintenance procedures, managerial practices or operational practices that aim to prevent storm water pollution by reducing the potential for contamination at the source of pollution.

"SQMP" means the Los Angeles Countywide Stormwater Quality Management Program.

"State Storm Water Pollution Prevention Plan (State SWPPP)" means a plan, as required by a State General Permit, identifying potential pollutant sources and describing the design, placement and implementation of BMPs, to effectively prevent non-stormwater Discharges and reduce Pollutants in Stormwater Discharges during activities covered by the General Permit.

"Storm Water" means storm water runoff, snow melt runoff, and surface runoff and drainage.

"Storm Water Discharge Associated with Industrial Activity" means industrial discharge as defined in 40 CFR 122.26(b)(14)

"Stormwater Quality Management Program" means the Los Angeles Countywide Stormwater Quality Management Program, which includes descriptions of programs, collectively developed by the Permittees in accordance with provisions of the NPDES Permit, to comply with applicable federal and state law, as the same is amended from time to time.

[2] These criteria from the 1976 study have been modified in the *Update Study 2000*.

"Structural BMP" means any structural facility designed and constructed to mitigate the adverse impacts of storm water and urban runoff pollution (e.g. canopy, structural enclosure). The category may include both Treatment Control BMPs and Source Control BMPs.

"SUSMP" means the Los Angeles Countywide Standard Urban Stormwater Mitigation Plan. The SUSMP shall address conditions and requirements of new development.

"Total Maximum Daily Load (TMDL)" means the sum of the individual waste load allocations for point sources and load allocations for nonpoint sources and natural background.

"Toxicity Identification Evaluation (TIE)" means a set of procedures to identify the specific chemical(s) responsible for toxicity. These procedures are performed in three phases (characterization, identification, and confirmation) using aquatic organism toxicity tests.

"Toxicity Reduction Evaluation (TRE)" means a study conducted in a step-wise process to identify the causative agents of effluent or ambient toxicity, isolate the sources of toxicity, evaluate the effectiveness of toxicity control options, and then confirm the reduction in toxicity.

"Treatment" means the application of engineered systems that use physical, chemical, or biological processes to remove pollutants. Such processes include, but are not limited to, filtration, gravity settling, media absorption, biodegradation, biological uptake, chemical oxidation and UV radiation.

"Treatment Control BMP" means any engineered system designed to remove pollutants by simple gravity settling of particulate pollutants, filtration, biological uptake, media absorption or any other physical, biological, or chemical process.

"USEPA Phase I Facilities" means facilities in specified industrial categories that are required to obtain an NPDES permit for storm water discharges, as required by 40 CFR 122.26(c). These categories include:

i. facilities subject to storm water effluent limitation guidelines, new source performance standards, or toxic pollutant effluent standards (40 CFR N)
ii. manufacturing facilities
iii. oil and gas/mining facilities
iv. hazardous waste treatment, storage, or disposal facilities
v. landfills, land application sites, and open dumps
vi. recycling facilities
vii. steam electric power generating facilities
viii. transportation facilities
ix. sewage of wastewater treatment works
x. light manufacturing facilities

"Vehicle Maintenance/Material Storage Facilities/Corporation Yards" means any Permittee owned or operated facility or portion thereof that:

i. Conducts industrial activity, operates equipment, handles materials, and provides services similar to Federal Phase I facilities;
ii. Performs fleet vehicle service/maintenance on ten or more vehicles per day including repair, maintenance, washing, and fueling;

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iii. Performs maintenance and/or repair of heavy industrial machinery/equipment ; and
iv. Stores chemicals, raw materials, or waste materials in quantities that require a hazardous materials business plan or a Spill Prevention, Control , and Counter-measures (SPCC) plan.

"Water Quality Standards and Water Quality Objectives" means water quality criteria contained in the Basin Plan, the California Ocean Plan, the National Toxics Rule, the California Toxics Rule, and other state or federally approved surface water quality plans. Such plans are used by the Regional Board to regulate all discharges, including storm water discharges.

"Waters of the State" means any surface water or groundwater, including saline waters, within boundaries of the state.

"Waters of the United States" or "Waters of the U.S." means:

a. All waters that are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;
b. All interstate waters, including interstate "wetlands";
c. All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, "wetlands," sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters:

    1. Which are or could be used by interstate or foreign travelers for recreational or other purposes;
    2. From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
    3. Which are used or could be used for industrial purposes by industries in interstate commerce;

d. All impoundments of waters otherwise defined as waters of the United States under this definition;
e. Tributaries of waters identified in paragraphs (a) through (d) of this definition;
f. The territorial sea; and
g. "Wetlands" adjacent to waters (other than waters that are themselves wetlands) identified in paragraph (a) through (f) of this definition.

Waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.22(m), which also meet the criteria of this definition) are not waters of the United States. This exclusion applies only to man-made bodies of water, which neither were originally created in waters of the United States (such as disposal area in wetlands) nor resulted from the impoundment of waters of the United States. Waters of the United States do not include prior converted cropland. Notwithstanding the determination of an area's status as prior converted cropland by any other federal agency, for the purposes of the CWA, the final authority regarding CWA jurisdiction remains with USEPA.

"Wet Season" means the calendar period beginning October 1 through April 15.

Part 6. STANDARD PROVISIONS

A. Standard Requirements

1. Each Permittee shall comply with all provisions and requirements of this permit.

2. Should a Permittee discover a failure to submit any relevant facts or that it submitted incorrect information in a report, it shall promptly submit the missing or correct information.

3. Each Permittee shall report all instances of non-compliance not otherwise reported at the time monitoring reports are submitted.

4. This Order includes the attached Monitoring and Reporting Program, and SUSMP(Regional Board Resolution No. R00-02), which are a part of the permit and must be complied with in the same manner as with the rest of the requirements in the permit.

B. Regional Board Review

Any formal determination or approval made by the Regional Board Executive Officer pursuant to the provisions of this Order may be reviewed by the Regional Board. A Permittee(s) or a member of the public may request such review upon petition within 30 days of the effective date of the notification of such decision to the Permittee(s) and interested parties on file at the Regional Board.

C. Public Review

1. All documents submitted to the Regional Board in compliance with the terms and conditions of this Order shall be made available to members of the public pursuant to the Freedom of Information Act (5 U.S.C. § 552 (as amended) and the Public Records Act (Cal. Government Code § 6250 *et seq.*).

2. All documents submitted to the Regional Board Executive Officer for approval shall be made available to the public for a 30-day period to allow for public comment.

D. Duty to Comply

1. Each Permittee must comply with all of the terms, requirements, and conditions of this Order. Any violation of this order constitutes a violation of the Clean Water Act, its regulations and the California Water Code, and is grounds for enforcement action, Order termination, Order revocation and reissuance, denial of an application for reissuance; or a combination thereof [40 CFR 122.41(a), CWC § 13261, 13263, 13265, 13268, 13300, 13301, 13304, 13340, 13350].

2. A copy of these waste discharge specifications shall be maintained by each Permittee so as to be available during normal business hours to Permittee employees and members of the public.

3. Any discharge of wastes at any point(s) other than specifically described in this Order is prohibited, and constitutes a violation of the Order.

E. Duty to Mitigate [40 CFR 122.41 (d)]

Each Permittee shall take all reasonable steps to minimize or prevent any discharge that has a reasonable likelihood of adversely affecting human health or the environment.

F. Inspection and Entry [40 CFR 122.41(i), CWC § 13267]

The Regional Board, USEPA, and other authorized representatives shall be allowed:

1. Entry upon premises where a regulated facility is located or conducted, or where records are kept under conditions of this Order;

2. Access to copy any records, at reasonable times, that are kept under the conditions of this Order;

3. To inspect at reasonable times any facility, equipment (including monitoring and control equipment), practices, or operations regulated or required under this Order; and,

4. To photograph, sample, and monitor at reasonable times for the purpose of assuring compliance with this Order, or as otherwise authorized by the CWA and the CWC.

G. Proper Operation and Maintenance [40 CFR 122.41 (e), CWC § 13263(f)]

The Permittees shall at all times properly operate and maintain all facilities and systems of treatment (and related appurtenances) that are installed or used by the Permittees to achieve compliance with this Order. Proper operation and maintenance includes adequate laboratory controls and appropriate quality assurance procedures. This provision requires the operation of backup or auxiliary facilities or similar system that are installed by a Permittee only when necessary to achieve compliance with the conditions of this Order.

H. Signatory Requirements [40 CFR 122.41(k) & 122.22]

Except as otherwise provided in this Order, all applications, reports, or information submitted to the Regional Board shall be signed by the Director of Public Works, City Engineer, or authorized designee and certified as set forth in 40 CFR 122.22.

I. Reopener and Modification [40 CFR 122.41(f) & 122.62]

1. This Order may only be modified, revoked, or reissued, prior to the expiration date, by the Regional Board, in accordance with the procedural requirements of the CWC and CCR Title 23 for the issuance of waste

discharge requirements, 40 CFR 122.62, and upon prior notice and hearing, to:

a) Address changed conditions identified in the required reports or other sources deemed significant by the Regional Board;

b) Incorporate applicable requirements or statewide water quality control plans adopted by the State Board or amendments to the Basin Plan;

c) Comply with any applicable requirements, guidelines, and/or regulations issued or approved pursuant to CWA Section 402(p); and/or,

d) Consider any other federal, or state laws or regulations that became effective after adoption of this Order.

2. After notice and opportunity for a hearing, this Order may be terminated or modified for cause, including, but not limited to:

a) Violation of any term or condition contained in this Order;

b) Obtaining this Order by misrepresentation, or failure to disclose all relevant facts; or,

c) A change in any condition that requires either a temporary or permanent reduction or elimination of the authorized discharge.

3. The filing of a request by the Principal Permittee or Permittees for a modification, revocation and re-issuance, or termination, or a notification of planned changes or anticipated noncompliance does not stay any condition of this Order.

4. This Order may be modified to make corrections or allowances for changes in the permitted activity listed in this section, following the procedures at 40 CFR 122.63, if processed as a minor modification. Minor modifications may only:

a) Correct typographical errors, or

b) Require more frequent monitoring or reporting by the Permittee.

J. Severability

The provisions of this permit are severable; and if any provision of this permit or the application of any provision of this permit to any circumstance is held invalid, the application of such provision to other circumstances and the remainder of this permit shall not be affected.

K. Duty to Provide Information [40 CFR 122.41(h)]

The Permittees shall furnish, within a reasonable time, any information the Regional Board or USEPA may request to determine whether cause exists for

modifying, revoking and reissuing, or terminating this Order. The Permittees shall also furnish to the Regional Board, upon request, copies of records required to be kept by this Order.

L. Twenty-four Hour Reporting [40 CFR 122.41(l)(6)][3]

1. The Permittees shall report to the Regional Board any noncompliance that may endanger health or the environment. Any information shall be provided orally within 24 hours from the time any Permittee becomes aware of the circumstances. A written submission shall also be provided within five days of the time the Permittee becomes aware of the circumstances. The written submission shall contain a description of the noncompliance and its cause; the period of noncompliance, including exact dates and times and, if the noncompliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the noncompliance.

2. The Regional Board may waive the required written report on a case-by-case basis.

M. Bypass [40 CFR 122.41(m)][4]

Bypass (the intentional diversion of waste streams from any portion of a treatment facility) is prohibited. The Regional Board may take enforcement action against Permittees for bypass unless:

1. Bypass was unavoidable to prevent loss of life, personal injury or severe property damage. (Severe property damage means substantial physical damage to property, damage to the treatment facilities that causes them to become inoperable, or substantial and permanent loss of natural resources that can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.);

2. There were no feasible alternatives to bypass, such as the use of auxiliary treatment facilities, retention of untreated waste, or maintenance during normal periods of equipment down time. This condition is not satisfied if adequate back-up equipment should have been installed in the exercise of reasonable engineering judgment to prevent a bypass that could occur during normal periods of equipment downtime or preventive maintenance;

3. The Permittee submitted a notice at least ten days in advance of the need for a bypass to the Regional Board; or,

4. Permittees may allow a bypass to occur that does not cause effluent limitations to be exceeded, but only if it is for essential maintenance to

[3] This provision applies to incidents where effluent limitations (numerical or narrative) as provided in this Order or in the Los Angeles County SQMP are exceeded, and which endanger public health or the environment.

[4] This provision applies to the operation and maintenance of storm water controls and BMPs as provided in this Order or in the SQMP.

assure efficient operation. In such a case, the above bypass conditions are not applicable. The Permittee shall submit notice of an unanticipated bypass as required.

N. Upset [40 CFR 122.41(n)][5]

Upset means an exceptional incident in which there is unintentional and temporary noncompliance with technology based permit effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

1. A Permittee that wishes to establish the affirmative defense of an upset in an action brought for non compliance shall demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

   a) An upset occurred and that the Permittee can identify the cause(s) of the upset;

   b) The permitted facility was being properly operated by the time of the upset;

   c) The Permittee submitted notice of the upset as required; and,

   d) The Permittee complied with any remedial measures required.

2. No determination made before an action for noncompliance, such as during administrative review of claims that non-compliance was caused by an upset, is final administrative action subject to judicial review.

3. In any enforcement proceeding, the Permittee seeking to establish the occurrence of an upset has the burden of proof.

O. Property Rights [40 CFR 122.41(g)]

This Order does not convey any property rights of any sort, or any exclusive privilege.

P. Enforcement

1. Violation of any of the provisions of the NPDES permit or any of the provisions of this Order may subject the violator to any of the penalties described herein, or any combination thereof, at the discretion of the prosecuting authority; except that only one kind of penalties may be applied for each kind of violation. The CWA provides the following:

   a) Criminal Penalties for:

[5] *Supra*. See footnote number 3.

(1) Negligent Violations:

The CWA provides that any person who negligently violates permit conditions implementing § 301, 302, 306, 307, 308, 318, or 405 is subject to a fine of not less than $2,500 nor more than $25,000 per day for each violation, or by imprisonment for not more than 1 year, or both.

(2) Knowing Violations:

The CWA provides that any person who knowingly violates permit conditions implementing § 301, 302, 306, 307, 308, 318, or 405 is subject to a fine of not less than $5,000 nor more than $50,000 per day of violation, or by imprisonment for not more than 3 years, or both.

(3) Knowing Endangerment:

The CWA provides that any person who knowingly violates permit conditions implementing § 301, 302, 307, 308, 318, or 405 and who knows at that time that he is placing another person in imminent danger of death or serious bodily injury is subject to a fine of not more than $250,000, or by imprisonment for not more than 15 years, or both.

(4) False Statement:

The CWA provides that any person who knowingly makes any false material statement, representation, or certification in any application, record, report, plan, or other document filed or required to be maintained under the Act or who knowingly falsifies, tampers with, or renders inaccurate, any monitoring device or method required to be maintained under the Act, shall upon conviction, be punished by a fine of not more than $10,000 or by imprisonment for not more than two years, or by both. If a conviction is for a violation committed after a first conviction of such person under this paragraph, punishment shall be by a fine of not more than $20,000 per day of violation, or by imprisonment of not more than four years, or by both. (See CWA § 309(c)(4))

b) Civil Penalties

The CWA provides that any person who violates a permit condition implementing § 301, 302, 306, 307, 308, 318, or 405 is subject to a civil penalty not to exceed $27,500 per day for each violation.

2. The CWC provides that any person who violates a waste discharge requirement provision of the CWC is subject to civil penalties of up to $5,000 per day, $10,000 per day, or $25,000 per day of violation; or when the violation involves the discharge of pollutants, is subject to civil penalties of up to $10 per gallon per day or $25 per gallon per day of violation; or some combination thereof, depending on the violation or combination of violations.

Q. Need to Halt or Reduce Activity not a Defense [40 CFR 122.41(c)]

It shall not be a defense for a Permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this Order.

R. Rescission

Regional Board Order No. 96-054 is hereby rescinded.

S. Expiration

This Order expires on December 12, 2006. The Permittees must submit a Report of Waste Discharges and a proposed Storm Water Quality Management Program in accordance with CCR Title 23 as application for reissuance of waste discharge requirements no later than June 12, 2006.

I, Dennis A. Dickerson, Regional Board Executive Officer, do hereby certify that the foregoing is a full, true, and correct copy of an order adopted by the California Regional Water Quality Control Board, Los Angeles Region, on December 13, 2001.

_____

Dennis A. Dickerson
Executive Officer

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SAN FRANCISCO BAY REGION

CONTRA COSTA COUNTYWIDE NPDES MUNICIPAL STORMWATER PERMIT AMENDMENT

ORDER NO. R2-2003-0022
AMENDING ORDER NO. 99-058
NPDES PERMIT NO. CAS0029912

FOR CONTRA COSTA COUNTY, CONTRA COSTA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT, CITY OF CLAYTON, CITY OF CONCORD, TOWN OF DANVILLE, CITY OF EL CERRITO, CITY OF HERCULES, CITY OF LAFAYETTE, CITY OF MARTINEZ, TOWN OF MORAGA, CITY OF ORINDA, CITY OF PINOLE, CITY OF PITTSBURG, CITY OF PLEASANT HILL, CITY OF RICHMOND, CITY OF SAN PABLO, CITY OF SAN RAMON, CITY OF WALNUT CREEK, which have joined together to form the CONTRA COSTA CLEAN WATER PROGRAM.

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CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD SAN FRANCISCO BAY REGION

ORDER NO. R2-2003-0022
NPDES PERMIT NO. CAS0029912

AMENDMENT REVISING ORDER NO. 99-058 FOR:

CONTRA COSTA COUNTY, CONTRA COSTA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT, CITY OF CLAYTON, CITY OF CONCORD, TOWN OF DANVILLE, CITY OF EL CERRITO, CITY OF HERCULES, CITY OF LAFAYETTE, CITY OF MARTINEZ, TOWN OF MORAGA, CITY OF ORINDA, CITY OF PINOLE, CITY OF PITTSBURG, CITY OF PLEASANT HILL, CITY OF RICHMOND, CITY OF SAN PABLO, CITY OF SAN RAMON, CITY OF WALNUT CREEK, which have joined together to form the CONTRA COSTA CLEAN WATER PROGRAM.

The California Regional Water Quality Control Board, San Francisco Bay Region (hereinafter referred to as the Regional Board) finds that:

Findings

Finding 1: Incorporation of Fact Sheet

1. The Fact Sheet for the Contra Costa Clean Water Program NPDES Permit Amendment includes cited references and additional explanatory information in support of the requirements of this Amendment. This information, including any supplements thereto, and any future response to comments on the Revised Tentative Order, is hereby incorporated by reference.

Finding 2-3: Existing Permit

2. The Regional Board adopted Order No. 99-058 on July 21, 1999, reissuing waste discharge requirements under the National Pollutant Discharge Elimination System (NPDES) permit for the Contra Costa Clean Water Program (the Program) for the discharge of stormwater into San Francisco Bay (Bay) and its tributaries, and the San Joaquin Delta (Delta) and its tributaries. The Program's NPDES permit is jointly issued to the sixteen cities named above, and Contra Costa County and the Contra Costa County Flood Control and Water Conservation District, all of which are permittees. These permittees are referred to collectively as the Dischargers and individually as the Discharger.

3. Order No. 99-058 recognizes the Contra Costa Clean Water Program's Stormwater Management Plan (Management Plan) as the Dischargers' comprehensive control program and requires implementation of the Management Plan, which describes a framework for management of stormwater discharges. The 1999 Management Plan describes the Program's goals and objectives and contains Performance Standards, which represent the baseline level of effort required of each of the Dischargers. The Management Plan contains Performance Standards for five different stormwater management components, including new development and significant redevelopment activities.

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Finding 4: Basis for Reopening the Permit for Amendment

4. This Order amends existing Order No. 99-058 for Waste Discharge Requirements, NPDES Permit No. CA0029912 (the "Existing Permit"), to require additional treatment controls to limit stormwater pollutant discharges associated with certain new development and significant redevelopment projects. Pursuant to applicable state and federal law, including without limitation Water Code § 13263 and 40 CFR § 123.25(a), the Board may modify the Existing Permit to require additional and more stringent controls during the term of the Existing Permit. Provision C.11 of Order No. 99-058 anticipated that amendments, revisions and modifications to the Management Plan and Existing Permit would be necessary from time to time, and provided direction that changes requiring major revision of the Management Plan shall be brought before the Regional Board as permit amendments. This Order is consistent with Provision C.11 of Order No. 99-058.

The additional treatment controls are appropriate to impose now to better reflect, and be consistent with, the current level of protection being instituted elsewhere in the Region, State and country to satisfy the Clean Water Act's requirement to control discharges of pollutants to the maximum extent practicable. For instance, other states and regions require that stormwater treatment measures are sized to treat an optimal volume or flow rate of stormwater runoff based on local precipitation, that the treatment measures be adequately maintained, and that the damaging effects of increased runoff peak flows and durations also be addressed, in addition to runoff pollutant impacts.

Finding 5: Applicable Federal, State and Regional Regulations

5. This action to modify an NPDES permit is exempt from the provisions of the California Environmental Quality Act (Division 13 of the Public Resources Code, Chapter 3, Section 21100, et. seq.) in accordance with Section 13389 of the California Water Code.

Findings 6-18: Nature of Discharges and Sources of Pollutants

6. Urban Development Increases Pollutant Load, Volume, and Velocity of Runoff: During urban development two important changes occur. First, natural vegetated pervious ground cover is converted to impervious surfaces such as paved highways, streets, rooftops, and parking lots. Natural vegetated soil can both absorb rainwater and remove pollutants providing a very effective natural purification process. Because pavement and concrete can neither absorb water nor remove pollutants, the natural purification characteristics of the land are lost. Secondly, urban development creates new pollution sources as human population density increases and brings with it proportionately higher levels of car emissions, car maintenance wastes, municipal sewage, pesticides, household hazardous wastes, pet wastes, trash, etc., which can be washed into the municipal separate storm sewer system. As a result of these two changes, the runoff leaving the developed urban area is significantly greater in volume, velocity and pollutant load than the pre-development runoff from the same area.

7. Certain pollutants present in stormwater and/or urban runoff may be derived from extraneous sources that the Dischargers have limited or no direct jurisdiction over. Examples of such pollutants and their respective sources are: PAHs which are products of internal combustion engine operation and other sources; heavy metals, such as copper from brake pad wear and zinc from tire wear; dioxins as products of combustion; mercury resulting from atmospheric

deposition; and natural-occurring minerals from local geology. All of these pollutants, and others, may be deposited on paved surfaces and roof-tops as fine airborne particles, thus yielding stormwater runoff pollution that is unrelated to the particular activity or use associated with a given new or redevelopment project. However, Dischargers can implement treatment control measures, or require developers to implement treatment control measures, to reduce entry of these pollutants into stormwater and their discharge to receiving waters.

8. Retail gasoline outlets (RGOs), commonly referred to as "gas stations," are hot spots for pollutants of concern in stormwater and have been widely documented as such. The most common pollutants of concern in stormwater runoff from RGOs are heavy metals, petroleum hydrocarbons (such as Polycyclic Aromatic Hydrocarbons (PAHs)), and oil and grease.[1] RGOs fall within the new development and significant redevelopment projects subject to Provision C.3 of this Order, when they meet the impervious surface thresholds within that Provision. Pursuant to Provision C.3, as with any other project meeting the thresholds of that Provision, RGOs are required to incorporate appropriate source controls and design measures, and to appropriately treat stormwater runoff prior to discharge to the storm drain or local water. As with any commercial and/or industrial activity within the Dischargers' jurisdictions that has the potential to discharge pollutants in stormwater runoff, RGOs may also be subject to regulation under other sections of the Existing Permit and incorporated Management Plan, including the Illicit Discharge Control and Industrial and Commercial Discharge Control sections.

9. The pollutants found in urban runoff can have damaging effects on both human health and aquatic ecosystems. In addition, the increased flows and volumes of stormwater discharged from new impervious surfaces resulting from new development and redevelopment can significantly impact beneficial uses of aquatic ecosystems due to physical modifications of watercourses, such as bank erosion and widening of channels.

10. Water Quality Degradation Increases with Percent Imperviousness: The increased volume and velocity of runoff from developed urban areas can greatly accelerate the erosion of downstream natural channels. A number of studies have demonstrated a direct correlation between the degree of imperviousness of an area and the degradation of beneficial uses of downstream receiving waters. Significant declines in the biological integrity and physical habitat of streams and other receiving waters have been found to occur with as little as a 10% conversion from natural to impervious surfaces. Typical medium-density single-family home projects range between 25 to 60% impervious. Even at very low densities, such as 1-2 housing units per acre, standard subdivision designs can exceed the 10% imperviousness threshold that, as noted above, is theorized to be the threshold for degradation of streams and other waters with increasing imperviousness.[2] Studies on the impacts of imperviousness on beneficial uses of waters include "Urbanization of aquatic systems: Degradation thresholds,

[1] *Retail Gasoline Outlets: New Development Design Standards for Mitigation of Stormwater Impacts* – California Water Quality Control Board, Los Angeles Region, and California Water Quality Control Board, San Diego Region, Technical Report, prepared by Radulescu, Swamikannu, and Hammer, 2001.

[2] A discussion of imperviousness based on type of development and time of construction is provided in Heaney, J.B., Pitt, R, and Field, R. **Innovative Urban Wet-Weather Flow Management Systems**, 1999. USEPA Doc. No. EPA/600/R-99/029 (Chapter 2).

stormwater detection, and the limits of mitigation," Derek B. Booth and C. Rhett Jackson, Journal of the American Water Resources Association 33(5), Oct. 1997, pp. 1077-1089; "Urbanization and Stream Quality Impairment," Richard D. Klein, Water Resources Bulletin 15(4), Aug. 1979, pp. 948-963; "Stream channel enlargement due to urbanization," Thomas R. Hammer, Water Resources Research 8(6), Dec. 1972, pp. 1530- 1540; and, summaries of work on the impacts of imperviousness, including "The Importance of Imperviousness," in Watershed Protection Techniques 1(3), Fall 1994, pp. 100-111, and "Impervious surface coverage: The emergence of a key environmental indicator," Chester L. Arnold et al., Journal of the American Planning Association 62(2), Spring 1996, pp. 243-259.

11. The Dischargers have encouraged developers to minimize increases in impervious surfaces through a number of techniques such as those described in the Bay Area Stormwater Management Agencies Association's (BASMAA's) "Start at the Source Design Guidance Manual for Stormwater Quality Protection," 1999 edition (Start at the Source). One of the techniques recommended by Start at the Source is to use permeable pavements to infiltrate stormwater while still providing a stable load-bearing surface. For purposes of this Order, the Program may submit guidelines for use of these techniques for minimizing increases in impervious surfaces described in Start at the Source, implementation of which will provide that such areas will not count toward the creation or replacement of impervious surfaces, or may be modeled differently for the purposes of sizing post-construction stormwater treatment controls, for approval by the Executive Officer.

12. Because land use planning is where urban development begins, it is the phase in which the greatest and most cost-effective opportunities to protect water quality in new and redevelopment exist. When a Discharger incorporates policies and principles designed to safeguard water resources into the General Plan and development project approval processes, it has taken a far-reaching step towards the preservation of local water resources for future generations.

13. The revised Provision C.3 is written with the assumption that the Dischargers are responsible for considering potential stormwater impacts when making planning and land use decisions. The goal of these requirements is to address pollutant discharges and changes in runoff flows from new development and significant redevelopment projects, through implementation of post-construction and treatment measures, source control, and site design measures, to the maximum extent practicable. Neither Provision C.3 nor any of its requirements are intended to restrict or control local land use decision-making authority.

14. For the purposes of this Order, the term "Redevelopment" is defined as a project on a previously developed site that results in the addition or replacement of impervious surface, and the term "brownfield site" means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.

15. Opportunities to address stormwater pollution and hydrograph modification can be limited by current local design standards and guidance. For example, such standards and guidance may reduce or prohibit opportunities to minimize impervious surfaces, minimize directly

connected impervious area, provide for small-scale detention, and implement other management measures. Revision of current standards and guidance can result in a significantly increased ability for project designers to minimize project impacts and can also enhance local property values, neighborhood character, and overall quality of life. Further, revision of standards and guidance can allow implementation of site design measures in projects to meet or help meet the numeric sizing criteria in Provision C.3.d and/or the hydrograph modification limitation in Provision C.3.f.

16. Certain control measures implemented or required by the Dischargers for urban runoff management may create a habitat for vectors (e.g., mosquitoes and rodents) if not properly designed or maintained. Close collaboration and cooperative effort between Dischargers, local vector control agencies, Regional Board staff, and the State Department of Health Services is necessary to minimize potential nuisances and public health impacts resulting from vector breeding.

17. Provision C.3.f requires the Dischargers to prepare a Hydrograph Modification Management Plan (HMP), for approval by the Regional Board, to manage impacts from changes to the volume and velocity of stormwater runoff from new development and significant redevelopment projects, where these changes can cause excessive erosion damage to downstream watercourses. Transit village type developments within ¼ to within ½ mile of transit stations and/or intermodal facilities, and projects within "Redevelopment Project Areas" (as defined by Health and Safety Code Section 33000, et. seq.) that redevelop an existing brownfield site or create housing units affordable to persons of low or moderate income as defined by Health and Safety Code Section 50093, are excepted from the requirements of C.3.f. and the HMP. Significant change in impervious surface or significant change in stormwater runoff volume or timing is unlikely in these redevelopment circumstances, because these developments would be within a largely already paved catchment, and on a site that is largely already paved or otherwise impervious.

Similarly, as specified in Provision C.3.g.v, an exemption without the requirement for alternate, equivalent offsite treatment is allowed for the following redevelopment projects after impracticability of including onsite treatment measures is established, where such projects are built as redevelopment projects as defined in Finding 14, and it is clearly demonstrated that cost of participation in alternate, equivalent offsite treatment through a regional treatment or other equivalent water quality benefit project fund will unduly burden the project: creation of housing units affordable to persons of low or moderate income as defined by Health and Safety Code Section 50093, brownfield sites, and/or transit village type developments within 1/4 mile of transit stations and/or intermodal facilities. Not only is significant change in impervious surface or significant change in stormwater runoff volume or timing unlikely in these redevelopment circumstances, but these redevelopment projects are also likely to provide reduced water quality impacts and/or other environmental benefits in their own right.

18. The Regional Board recognized, in its "Policy on the Use of Constructed Wetlands for Urban Runoff Pollution Control" (Resolution No. 94-102), that urban runoff treatment wetlands that are constructed and operated pursuant to that Resolution and are constructed outside of a

creek or other receiving water, are stormwater treatment systems and, as such, are not waters of the United States subject to regulation pursuant to Sections 401 or 404 of the federal Clean Water Act. Regional Board staff is working with the California Department of Fish and Game (CDFG) and the U.S. Fish and Wildlife Service (USFWS) to identify how maintenance for stormwater treatment controls required under permits such as this Permit can be appropriately streamlined, given CDFG and USFWS requirements, and particularly those that address special status species. The Dischargers are expected to work diligently and in good faith with the appropriate agencies to obtain any approvals necessary to complete maintenance activities for stormwater treatment and runoff controls. If the Dischargers have done so, and maintenance approvals are not granted, where necessary, the Dischargers shall be deemed by the Regional Board to be in compliance with Provision C.3.e of this Order.

Findings 19 - 20: Notification to Dischargers and Interested Public Parties

19. The Dischargers and interested agencies and persons have been notified of the Regional Board's intent to modify waste discharge requirements for the existing discharge and have been provided opportunities for public meetings and the opportunity to submit their written views and recommendations. The following is a brief summary of public meetings and comment periods on versions of the Tentative Order:

Public Meetings and Outreach Events:

- On March 8, 2001, ABAG hosted a seminar for elected officials, municipal planning directors and public works directors, and other public on upcoming regulatory approaches to controlling stormwater pollution from new and redevelopment projects. At this seminar, an attorney working with a Contra Costa municipality partnered with US EPA staff in presenting an overview of stormwater regulation, and other representatives of BASMAA described how municipalities can address upcoming new and redevelopment control measure requirements.
- On January 10, 2002, ABAG, the Board, BASMAA, BCDC, and the City of Oakland hosted a seminar for local and regional government officials, city managers, county administrators, municipal planning directors and public works directors, and other public on stormwater pollution control measures and successful redevelopment strategies to ensure clean runoff from development projects. At this seminar, public works staff from both Contra Costa County and municipalities in the County made presentations on how they were addressing the inclusion of stormwater control measures in redevelopment and flood management projects in Contra Costa County.
- On March 14, 2002, the Executive Officer and Watershed Management Division Chief briefed the Contra Costa City Managers Association on the proposed contents of this Order.
- On March 21, 2002, the Executive Officer spoke to ABAG's Executive Board, which included elected officials from Contra Costa County, about the status of updated regulations for stormwater control measures for new and redevelopment projects.
- On April 24, 2002, Regional Board staff spoke at a seminar, organized by the Program, to introduce the Contra Costa city and county planning and engineering departments to the proposed contents of this Order.
- On June 5, 2002, the Regional Board's South Bay Watershed Management Division Chief spoke to ABAG's Regional Planning Committee, which included elected officials from

Contra Costa County, about the status of updated regulations for stormwater control measures for new and redevelopment projects, and addressed questions raised by officials at the March 21 presentation to ABAG's Executive Board.

- On July 10, 2002, the Regional Board's North Bay Watershed Management Division Chief spoke before the Contra Costa Council regarding the proposed contents of this Order.
- On August 2, 2002, Regional Board staff gave a presentation to the Contra Costa Council Environmental Task Force on the technical aspects of the proposed contents of this Order.
- On October 8, 2002, Regional Board staff gave a presentation on the proposed contents of this Order to members of creek and watershed groups from west Contra Costa County.
- On November 12, 2002, Regional Board staff presented an overview of the proposed contents of this Order to members of creek and watershed groups from central Contra Costa County.
- On dates including April 23, May 22, and October 30, 2002, Regional Board staff met with representatives of the Coastal Region Vector Control Agencies, which includes Contra Costa County, to discuss the updated new development and redevelopment requirements.
- On December 18, 2002, and January 22, 2003, the Regional Board heard testimony from the Dischargers and interested public on the Revised Tentative Order.
- On January 17 and 31, and February 7 and 14, 2003, Regional Board staff conducted public meetings on the Revised Tentative Order.

Review and Comment Periods:

- June 13, 2002 – July 26, 2002: Administrative Draft circulated to the Dischargers for comments.
- August 22, 2002 – October 9, 2002: Tentative Order circulated to the Dischargers, the general public and interested parties for comments.
- December 20, 2002 – January 10, 2003: Comment Period reopened by the Regional Board to allow additional submittals relative to projected cost of the amendment of Order No. 99-058 to both the Dischargers and the development community.

20. The Regional Board, through public testimony in public meetings and in written form, has received and considered all comments pertaining to the amendment of Order No. 99-058.

Finding 21: Renumbering of Existing Provisions within Order No. 99-058

21. Provision C.3 of Order No. 99-058 stipulates Stormwater Management Plan requirements. Upon adoption of this Order, Provision C.3 will address New Development and Redevelopment Performance Standards, and existing provisions C.3 – C.15 will be renumbered C.4 – C.16 in the Existing Permit.

IT IS HEREBY ORDERED that the Dischargers, in order to meet the provisions contained in Division 7 of the California Water Code and regulations adopted hereunder and the provisions of the Clean Water Act as amended and regulations and guidelines adopted hereunder, shall comply with the following:

Provision C.3: New Development and Redevelopment Performance Standards

The Dischargers will continue to implement the new development and redevelopment Performance Standards contained in the Management Plan and improve them to achieve the control of stormwater pollutants to the maximum extent practicable in accordance with the following sections:

a. New Development and Redevelopment Performance Standard Implementation:
The Dischargers shall continue to implement and improve, as necessary and appropriate, the Performance Standards for new development and redevelopment controls (NDCC-1 through NDCC-26) detailed in Table 3-1 of the Program's 1999-2004 Stormwater Management Plan. In addition, the Dischargers shall implement the following Performance Standards:

i. Each Discharger shall ensure access to treatment measures to Contra Costa Mosquito and Vector Control District staff; and

ii. Each Discharger shall provide educational materials to municipal staff, developers, contractors, construction site operators, and owner/builders, early in the planning process and as appropriate.

b. Development Project Approval Process:
The Dischargers shall modify their project review processes as needed to incorporate the requirements of Provision C.3. Each Discharger shall include conditions of approval in permits for applicable projects, as defined in Provision C.3.c, to ensure that stormwater pollutant discharges are reduced by incorporation of treatment measures and other appropriate source control and site design measures, and increases in runoff flows are managed in accordance with Provision C.3.f, to the maximum extent practicable. Such conditions shall, at a minimum, address the following goals:

i. Require a project proponent to implement site design/landscape characteristics where feasible which maximize infiltration (where appropriate), provide retention or detention, slow runoff, and minimize impervious land coverage, so that post-development pollutant loads from a site have been reduced to the maximum extent practicable; and

ii. For new and redevelopment projects that discharge directly (not mixed with runoff from other developed sites) to water bodies listed as impaired by a pollutant(s) pursuant to Clean Water Act Section 303(d), ensure that post-project runoff does not exceed pre-project levels for such pollutant(s), through implementation of the control measures addressed in this provision, to the maximum extent practicable, in conformance with Provision C.1.

Modification of project review processes shall be completed by **February 15, 2005**.

c. Applicable Projects – New and Redevelopment Project Categories:
New development and significant redevelopment projects that are subject to Provision C.3 are grouped into two categories based on project size. While all projects regardless of size should consider incorporating appropriate source control and site design measures that minimize stormwater pollutant discharges to the maximum extent practicable, new and redevelopment projects that do not fall into Group 1 or Group 2 are not subject to the requirements of Provision C.3. Provision C.3 shall also not apply to projects for which a privately-sponsored development

application has been deemed complete by a Discharger or, with respect to public projects, for which funding has been committed and for which construction is scheduled by **February 15, 2005.**

i. Group 1 Projects:

Dischargers shall require Group 1 Projects to implement appropriate source control and site design measures and to design and implement stormwater treatment measures, to reduce the discharge of stormwater pollutants to the maximum extent practicable. Implementation of this requirement shall begin **February 15, 2005.** Group 1 Projects consist of all public and private projects in the following categories:

1. *Commercial, industrial, or residential developments that create one acre (43,560 square feet) or more of impervious surface, including roof area, streets and sidewalks.* This category includes any development of any type on public or private land, which falls under the planning and building authority of the Dischargers, where one acre or more of new impervious surface, collectively over the entire project site, will be created. Construction of one single-family home, which is not part of a larger common plan of development, with the incorporation of appropriate pollutant source control and design measures, and using landscaping to appropriately treat runoff from roof and house-associated impervious surfaces (e.g., runoff from roofs, patios, driveways, sidewalks, and similar surfaces), would be in substantial compliance with Provision C.3.

2. *Streets, roads, highways, and freeways that are under the Dischargers' jurisdiction and that create one acre (43,560 square feet) or more of new impervious surface.* This category includes any newly constructed paved surface used primarily for the transportation of automobiles, trucks, motorcycles, and other motorized vehicles. Excluded from this category are sidewalks, bicycle lanes, trails, bridge accessories, guardrails, and landscape features.

3. *Significant Redevelopment projects*. This category is defined as a project on a previously developed site that results in addition or replacement, which combined total 43,560 ft^2 or more of impervious surface on such an already developed site ("Significant Redevelopment"). Where a Significant Redevelopment project results in an increase of, or replacement of, more than fifty percent of the impervious surface of a previously existing development, and the existing development was not subject to stormwater treatment measures, the entire project must be included in the treatment measure design. Conversely, where a Significant Redevelopment project results in an increase of, or replacement of, less than fifty percent of the impervious surface of a previously existing development, and the existing development was not subject to stormwater treatment measures, only that affected portion must be included in treatment measure design. Excluded from this category are interior remodels and routine maintenance or repair. Excluded routine maintenance and repair includes roof or exterior surface replacement, pavement resurfacing, repaving and road pavement structural section rehabilitation within the existing footprint, and any other reconstruction work within a public street or road right-of-way where both sides of that right-of-way are developed.

ii. Group 2 Projects:

The Group 2 Project definition is in all ways the same as the Group 1 Project definition above, except that the size threshold of impervious area for new and Significant Redevelopment projects is reduced from one acre (43,560 ft^2) of impervious surface to 10,000 square feet. Dischargers shall require Group 2 Projects to implement appropriate source control and site design measures

and to design and implement appropriate stormwater treatment measures, to reduce stormwater pollution to the maximum extent practicable. Projects consisting of one single family home not part of a larger common plan of development are excluded from the Group 2 Project definition, and therefore excluded from the requirement to implement appropriate stormwater treatment measures. Implementation of this requirement shall begin by **August 15, 2006**, at which time the definition of Group 1 Projects is changed to include all Group 2 Projects.

iii. Proposal for Alternative Group 2 Project Definition: The Program and/or any Discharger may propose, for approval by the Regional Board, an Alternative Group 2 Project definition, with the goal that any such alternative definition aim to ensure that the maximum created impervious surface area is treated for the minimum number of projects subject to Discharger review. Any such proposal shall contain supporting information about the Dischargers' development patterns, and sizes and numbers of proposed projects for several years, that demonstrates that the proposed definition would be substantially as effective as the Group 2 Project definition in Provision C.3.c.ii. Proposals may include differentiating projects subject to the Alternative Group 2 Project definition by land use, by focusing solely on the techniques recommended by Start at the Source for documented low pollutant loading land uses, and/or by optimum use of landscape areas required by Dischargers under existing codes as treatment measures. Proposals may be submitted anytime, with the understanding that the Group 2 Project definition, as described in Provision C.3.c.ii will be upheld as the default in the absence of an approved Alternative Group 2 Project definition.

d. Numeric Sizing Criteria For Pollutant Removal Treatment Systems:
All Dischargers shall require that treatment measures be constructed for applicable projects, as defined in Provision C.3.c, that incorporate, at a minimum, the following hydraulic sizing design criteria to treat stormwater runoff. As appropriate for each criterion, the Dischargers shall use or appropriately analyze local rainfall data to be used for that criterion.

i. Volume Hydraulic Design Basis: Treatment measures whose primary mode of action depends on volume capacity, such as detention/retention units or infiltration structures, shall be designed to treat stormwater runoff equal to:

1. The maximized stormwater capture volume for the area, based on historical rainfall records, determined using the formula and volume capture coefficients set forth in *Urban Runoff Quality Management, WEF Manual of Practice No. 23/ ASCE Manual of Practice No. 87, (1998)*, pages 175-178 (e.g., approximately the 85th percentile 24-hour storm runoff event); or

2. The volume of annual runoff required to achieve 80 percent or more capture, determined in accordance with the methodology set forth in Appendix D of the *California Stormwater Best Management Practices Handbook, (1993)*, using local rainfall data.

ii. Flow Hydraulic Design Basis: Treatment measures whose primary mode of action depends on flow capacity, such as swales, sand filters, or wetlands, shall be sized to treat:

1. 10% of the 50-year peak flow rate; or
2. The flow of runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the applicable area, based on historical records of hourly rainfall depths; or
3. The flow of runoff resulting from a rain event equal to at least 0.2 inches per hour intensity.

e. Operation and Maintenance of Treatment Measures:

All treatment measures must be adequately operated and maintained by complying with the process described below. Beginning July 1, 2004, each Discharger shall implement a treatment measures operation and maintenance (O&M) verification program (O&M Program), which shall include the following:

i. Compiling a list of properties (public and private) and responsible operators for, at a minimum, all treatment measures implemented from the date of adoption of this Order. Information on the location of all stormwater treatment measures shall be sent to the local vector control district. In addition, the Dischargers shall inspect a subset of prioritized treatment measures for appropriate O&M, on an annual basis, with appropriate follow-up and correction.

ii. Verification and access assurance shall at a minimum include: Where a private entity is responsible for O&M, the entity's signed statement accepting responsibility for maintenance until the responsibility is legally transferred to another entity; and access permission for representatives of the Discharger, local vector control district, and Regional Board staff strictly for the purpose of O&M verification for the specific stormwater treatment system to the extent allowable by law; and, for all entities, either:

1. A signed statement from the public entity assuming post-construction responsibility for treatment measure maintenance and that the treatment measure meets all local agency design standards; or
2. Written conditions in the sales or lease agreement requiring the buyer or lessee to assume responsibility for O&M consistent with this provision, which conditions, in the case of purchase and sale agreements, shall be written to survive beyond the close of escrow; or
3. Written text in project conditions, covenants and restrictions (CCRs) for residential properties assigning O&M responsibilities to the home owners association for O&M of the treatment measures; or
4. Any other legally enforceable agreement or mechanism that assigns responsibility for the maintenance of treatment measures.

iii. O&M Reporting: The Dischargers shall report on their O&M Program in each Annual Report, starting with the Annual Report to be submitted September 2005. The Annual Report shall contain: a description of the organizational structure of the Discharger's O&M Program; an evaluation of that O&M Program's effectiveness; summary of any planned improvements to the O&M Program; and a list or summary of treatment measures that have been inspected that year with inspection results.

iv. The program shall submit by **June 1, 2004**, a vector control plan, acceptable to the Executive Officer, after consultation with the Contra Costa Mosquito and Vector Control District. The plan shall include design guidance for treatment measures to prevent the production of vectors, particularly mosquitoes, and provide guidance on including vector abatement concerns in O&M and verification inspection activities.

v. The Dischargers are expected to work diligently and in good faith with the appropriate state and federal agencies to obtain any approvals necessary to complete maintenance activities for stormwater treatment measures. If the Dischargers have done so, and maintenance approvals are not granted, where necessary, the Dischargers shall be deemed by the Regional Board to be in compliance with this Provision.

f. Limitation on Increase of Peak Stormwater Runoff Discharge Rates:

i. The Dischargers shall manage increases in peak runoff flow and increased runoff volume, for all Group 1 Projects, where such increased flow and/or volume is likely to cause increased erosion of creek beds and banks, silt pollutant generation, or other waterbody impacts to beneficial uses due to increased erosive force. Such management shall be through implementation of a Hydrograph Modification Management Plan (HMP). The HMP, once approved by the Regional Board, will be implemented so that post-project runoff shall not exceed estimated pre-project rates and/or durations, where the increased stormwater discharge rates and/or durations will result in increased potential for erosion or other significant adverse impacts to beneficial uses, attributable to changes in the amount and timing of runoff. The term duration in this Provision is defined as the period that flows are above a threshold that causes significant sediment transport and may cause excessive erosion damage to creeks and streams.

ii. Provision C.3.f.i does not apply to new development and significant redevelopment projects where the project discharges stormwater runoff into creeks or storm drains where the potential for erosion or other impacts to beneficial uses, is minimal. Such situations may include discharges into creeks that are concrete-lined or significantly hardened (e.g., with rip-rap, sackrete, etc.) downstream to their outfall in San Francisco Bay, underground storm drains discharging to the Bay, and construction of infill projects in highly developed watersheds, where the potential for single-project and/or cumulative impacts is minimal. Guidelines for identification of such situations shall be included as a part of the HMP. However, plans to restore a creek reach may re-introduce the applicability of HMP controls, and would need to be addressed in the HMP.

iii. The HMP may identify conditions under which some increases in runoff may not have a potential for increased erosion or other impacts to beneficial uses. Reduced controls or no controls on peak stormwater runoff discharge rates and/or durations may be appropriate in those cases, subject to the conditions in the HMP. In the absence of information demonstrating that changes in post-development runoff discharge rates and durations will not result in increased potential for erosion or other adverse impacts to beneficial uses, the HMP requirements shall apply.

iv. The HMP proposal shall include:

1. A review of pertinent literature;
2. A protocol to evaluate potential hydrograph change impacts to downstream watercourses from proposed projects;
3. An identification of the rainfall event below which these standards and management requirements apply, or range of rainfall events to which these requirements apply;
4. A description of how the Dischargers will incorporate these requirements into their local approval processes, or the equivalent; and
5. Guidance on management practices and measures to address identified impacts.

The Dischargers may prioritize which individual watersheds the HMP would initially apply to, if it were demonstrated in the HMP that such prioritization is appropriate.

The Dischargers may work appropriately with the Santa Clara Valley Urban Runoff Pollution Prevention Program and/or other Bay Area stormwater programs as part of completing these requirements. For example, the Dischargers may wish to expand on the literature review being

completed by the Santa Clara Valley Urban Runoff Program under its permit, rather than authoring their own literature review from scratch. While such cooperation is encouraged, it shall not be grounds for delaying compliance beyond the schedule set forth herein.

v. The identified maximum rainfall event or rainfall event range may be different for specific watersheds, streams, or stream reaches. Individual Dischargers may utilize the protocol to determine a site- or area-specific rainfall event standard.

vi. The HMP's evaluation protocols, management measures, and other information may include the following:

1. Evaluation of the cumulative impacts of urbanization of a watershed on stormwater discharge and stream morphology in the watershed;
2. Evaluation of stream form and condition, including slope, discharge, vegetation, underlying geology, and other information, as appropriate;
3. Implementation of measures to minimize impervious surfaces and directly connected impervious area in new development and redevelopment projects;
4. Implementation of measures including stormwater detention, retention, and infiltration;
5. Implementation of land use planning measures (e.g., stream buffers and stream restoration activities, including restoration-in-advance of floodplains, revegetation, use of less-impacting facilities at the point(s) of discharge, etc.) to allow expected changes in stream channel cross sections, stream vegetation, and discharge rates, velocities, and/or durations without adverse impacts to stream beneficial uses;
6. A mechanism for pre- vs. post-project assessment to determine the effectiveness of the HMP and to allow amendment of the HMP, as appropriate; and,
7. Other measures, as appropriate.

vii. Equivalent limitation of peak flow impacts: The Dischargers may develop an equivalent limitation protocol, as part of the HMP, to address impacts from changes in the volumes, velocities, and/or durations of peak flows through measures other than control of those volumes and/or durations. The protocol may allow increases in peak flow and/or durations, subject to the implementation of specified design, source control, and/or treatment control measures and land planning practices that take into account expected stream change (e.g., increases in the cross-sectional area of stream channel) resulting from changes in discharge rates and/or durations, while maintaining or improving beneficial uses of waters.

viii. The Dischargers as a group shall complete the HMP according to the schedule below. All required documents shall be submitted acceptable to the Executive Officer, based on the criteria set forth in this Order, except the HMP, which shall be submitted for approval by the Regional Board. Development and implementation status shall be reported in the Dischargers' Annual Reports, which shall also provide a summary of projects incorporating measures to address this Provision and the measures used.

1. **February 15, 2004:** Submit a detailed workplan and schedule for completion of the literature review, development of a protocol to identify an appropriate limiting storm, development of guidance materials, and other required information;
2. **February 15, 2004**: Submit literature review;
3. **November 15, 2004**: Submit a draft HMP, including the analysis that identifies the appropriate limiting storm and the identified limiting storm event(s) or event range(s);

4. **May 15, 2005**: Submit the HMP for Regional Board approval; and,

5. Upon adoption by the Regional Board, implement the HMP, which shall include the requirements of this Provision. Prior to approval of the HMP by the Regional Board, the early implementation of measures likely to be included in the HMP shall be encouraged by the Dischargers.

g. Alternative Compliance Based on Impracticability and Requiring Compensatory Mitigation:

i. The Dischargers may establish a program under which a project proponent may request alternative compliance with the requirement in Provision C.3.c to install treatment measures onsite for a given project, upon an appropriate showing of impracticability, and with provision to treat offsite an equivalent surface area, pollutant loading or quantity of stormwater runoff, or provide other equivalent water quality benefit, such as stream restoration or other activities that limit or mitigate impacts from excessive erosion or sedimentation. The offsite location of this equivalent stormwater treatment, or water quality benefit, shall be where no other requirement in Provision C.3.c. for treatment exists, and within the same stormwater runoff drainage basin and treating runoff discharging to the same receiving water, where feasible. Under this Provision, enhancements of existing mitigation projects are acceptable. The Dischargers should specifically define the basis for impracticability or infeasibility, which may include situations where onsite treatment is technically feasible, but excessively costly, as determined by set criteria.

ii. Regional Solutions: The alternative complianceprogram may allow a project proponent to participate in a regional or watershed-based stormwater treatment facility, without a showing of impracticability at the individual project site, if the regional or watershed-based stormwater treatment facility discharges into the same receiving water, where feasible.

iii. The Program is encouraged to propose a model alternative compliance program on behalf of the Dischargers, for approval by the Regional Board, and for potential adoption and implementation by the Dischargers.

iv. The alternative compliance program proposal should state the criteria for granting alternatives to the requirement to install treatment measures onsite; criteria for determining impracticability or infeasibility; and criteria for use of regional or watershed-based stormwater treatment facilities. The proposal should also describe how the project sponsor will provide equivalent water quality benefit or credit to an alternative project or to a regional or watershed-based treatment facility, and tracking mechanisms to support the reporting requirements set forth in Provision C.3.g.vi below.

v. An exemption without the requirement for alternate, equivalent offsite treatment is allowed for the following redevelopment projects after impracticability of including onsite treatment measures is established, where such projects are built as redevelopment projects as defined in Finding 14, and it is clearly demonstrated that cost of participation in alternate, equivalent offsite treatment through a regional treatment or other equivalent water quality benefit project fund will unduly burden the project: creation of housing units affordable to persons of low or moderate income as defined by Health and Safety Code Section 50093, brownfield sites, and/or transit village type developments within 1/4 mile of transit stations and/or intermodal facilities.

vi. Reporting: Each year, as part of its Annual Report, each Discharger shall provide a list of the alternative projects and exemptions it granted. For each project and exemption, the following information shall be provided:

1. Name and location of the project for which the alternative project or exemption was granted;
2. Project type (e.g., restaurant, residence, shopping center) and size;
3. Area or percent of impervious surface in the project's final design;
4. Reason for granting the alternative project exemption, including, for those projects granted an exemption without the requirement for alternate, equivalent offsite treatment, a demonstration that cost of such equivalent offsite treatment unduly burdened the project;
5. Terms of the alternative project or exemption; and,
6. The offsite stormwater treatment project receiving the benefit, and the date of completion of the project.

vii. Interim Alternative Compliance Program: In the event that an exemption program has not been proposed by the Program and/or a Discharger, approved by the Regional Board, or implemented by a particular Discharger by the date of implementation of Group 1 Projects, provision for an interim alternative to the requirement to install treatment measures onsite may be granted by a Discharger. An interim alternative compliance project may be granted if the project proponent (1) demonstrates onsite impracticability due to extreme limitations of space for treatment and lack of below grade surface treatment options, and (2) presents sufficient assurance of providing equivalent offsite stormwater pollutant and/or volume treatment at another location within the drainage basin, for which construction of stormwater treatment measures is not otherwise required, discharging into the same receiving water, where feasible. The Discharger shall be responsible for assuring that equivalent offsite treatment has occurred for any use of this interim alternative compliance program, within six months of project construction, and shall report the basis of onsite impracticability and the nature of equivalent offsite treatment for each project in its Annual Report. Any equivalent offsite treatment that does not include construction of stormwater treatment measures must be approved by the Executive Officer based on the criteria set forth in this Order. This interim alternative compliance clause will be void when the Regional Board approves the exemption program described in Provision C.3.g.i-vi, above.

h. Alternative Certification of Adherence to Design Criteria for Stormwater Treatment Measures:

In lieu of conducting detailed review to verify the adequacy of measures required pursuant to Provisions C.3.d, a Discharger may elect to accept a signed certification from a Civil Engineer or a Licensed Architect or Landscape Architect registered in the State of California, or another Discharger that has overlapping jurisdictional project permitting authority, that the plan meets the criteria established herein. The Discharger should verify that each certifying person has been trained on treatment measure design for water quality not more than three years prior to the signature date, and that each certifying person understands the groundwater protection principles applicable to the project site (see Provision C.3.i, Limitations on Use of Infiltration Treatment Measures). Training conducted by an organization with stormwater treatment measure design expertise (e.g., a university, American Society of Civil Engineers, American Society of Landscape Architects, American Public Works Association, or the California Water Environment Association) may be considered qualifying.

i. Limitations on Use of Infiltration Treatment Measures - Infiltration and Groundwater Protection:

In order to protect groundwater from pollutants that may be present in urban runoff, treatment measures that function primarily as infiltration devices (such as infiltration basins and infiltration trenches not deeper than their maximum width) shall meet, at a minimum, the following conditions:

i. Pollution prevention and source control measures shall be implemented at a level appropriate to protect groundwater quality at sites where infiltration devices are to be used;

ii. Use of infiltration devices shall not cause or contribute to degradation of groundwater water quality objectives;

iii. Infiltration devices shall be adequately maintained to maximize pollutant removal capabilities;

iv. The vertical distance from the base of any infiltration device to the seasonal high groundwater mark shall be at least 10 feet. Note that some locations within the Dischargers' jurisdiction are characterized by highly porous soils and/or a high groundwater table; in these areas, treatment measure approvals should be subject to a higher level of analysis (e.g., considering the potential for pollutants such as on-site chemical use, the level of pretreatment to be achieved, and similar factors);

v. Unless stormwater is first treated by a means other than infiltration, infiltration devices shall not be recommended as treatment measures for areas of industrial or light industrial activity; areas subject to high vehicular traffic (25,000 or greater average daily traffic on main roadway or 15,000 or more average daily traffic on any intersecting roadway); automotive repair shops; car washes; fleet storage areas (bus, truck, etc.); nurseries; and other high threat to water quality land uses and activities as designated by each Discharger; and,

vi. Infiltration devices shall be located a minimum of 100 feet horizontally from any known water supply wells.

j. Site Design Measures Guidance and Standards Development:

i. The Dischargers shall review their local design standards and guidance for opportunities to make revisions that would result in reduced impacts to water quality and beneficial uses of waters. In this event, the Dischargers shall make any such revisions and implement the updated standards and guidance, as necessary.

Areas of site design that may be appropriate to address include the following, which are offered as examples:

1. Minimize land disturbance;

2. Minimize impervious surfaces (e.g., roadway width, driveway area, and parking lot area), especially directly connected impervious areas;

3. Minimum-impact street design standards for new development and redevelopment, including typical specifications (e.g., neo-traditional street design standards and/or street standards recently revised in other cities, including Portland, Oregon, and Vancouver, British Columbia);

4. Minimum-impact parking lot design standards, including parking space maximization within a given area, use of landscaping as a stormwater drainage feature, use of pervious pavements, and parking maxima;

5. Clustering of structures and pavement;
6. Typical specifications or "acceptable design" guidelines for lot-level design measures, including:
   - Disconnected roof downspouts to splash blocks or "bubble-ups;"
   - Alternate driveway standards (e.g., wheelways, unit pavers, or other pervious pavements); and,
   - Microdetention, including landscape detention and use of cisterns (may also be considered treatment measures);
7. Preservation of high-quality open space;
8. Maintenance and/or restoration of riparian areas and wetlands as project amenities, including establishing vegetated buffer zones to reduce runoff into waterways, allow for stream channel change as a stream's contributing watershed urbanizes, and otherwise mitigate the effects of urban runoff on waters and beneficial uses of waters (may also be considered treatment measures); and,
9. Incorporation of supplemental controls to minimize changes in the volume, flow rate, timing, and duration of runoff, for a given precipitation event or events. These changes include cumulative hydromodification caused by site development. Measures may include landscape-based measures or other features to reduce the velocity of, detain, and/or infiltrate stormwater runoff (may also be considered treatment measures).

ii. The standards and guidance review shall be completed according to the schedule below. A summary of review, revision, and implementation status shall be submitted for acceptance by the Executive Officer and reported in the Dischargers' Annual Reports, beginning with the Annual Report due September 15, 2005.

1. No later than **August 15, 2003**: The Dischargers shall submit a detailed workplan and schedule for completion of the review of standards and guidelines, any proposed revisions thereto and any implementation of revised standards and guidance;
2. No later than **November 15, 2004**: The Dischargers shall submit a draft review and analysis of local standards and guidance, opportunities for revision, and any proposed revised standards and guidance; and,
3. No later than **November 15, 2005**: The Dischargers shall incorporate any revised standards and guidance into their local approval processes and shall fully implement the revised standards and guidance.

k. Source Control Measures Guidance Development:

The Dischargers shall, as part of their continuous improvement process, submit enhanced new development and significant redevelopment Performance Standards that summarize source control requirements for such projects to limit pollutant generation, discharge, and runoff, to the maximum extent practicable.

Examples of source control measures may include the following, which are offered as examples:

i. Indoor mat/equipment wash racks for restaurants, or covered outdoor wash racks plumbed to the sanitary sewer;

ii. Covered trash and food compactor enclosures with a sanitary sewer connection for dumpster drips and designed such that run-on to trash enclosure areas is avoided;

iii. Sanitary sewer drains for swimming pools;

iv. Sanitary drained outdoor covered wash areas for vehicles, equipment, and accessories;

v. Sanitary sewer drain connections to take fire sprinkler test water;

vi. Storm drain system stenciling;

vii. Landscaping that minimizes irrigation and runoff, promotes surface infiltration where appropriate, minimizes the use of pesticides and fertilizers, and where feasible removes pollutants from stormwater runoff; and,

viii. Appropriate covers, drains, and storage precautions for outdoor material storage areas, loading docks, repair/maintenance bays, and fueling areas.

A model enhanced new development and significant redevelopment source control Performance Standard and proposed workplan for its implementation shall be submitted by **August 15, 2004**. Implementation shall begin no later than **February 15, 2005,** and the status shall thereafter be reported in the Dischargers' Annual Reports, beginning with the Annual Report due September 15, 2005, which shall also provide appropriate detail on projects reflecting the application of the enhanced Performance Standards consistent with Provision C.3.b above.

l. Update General Plans:

If necessary (and only to the extent which is necessary) in order to be able to require implementation of the measures required by Provision C.3 for applicable development projects, at the next scheduled update/revision of its General Plan, each Discharger shall confirm that it has incorporated water quality and watershed protection principles and policies into its General Plan or equivalent plan. These principles and policies shall be designed to protect natural water bodies, reduce impervious land coverage, slow runoff, and where feasible, maximize opportunities for infiltration of rainwater into soil. Such water quality and watershed protection principles and policies may include the following, which are offered as examples:

i. Minimize the amount of impervious surfaces and directly connected impervious surfaces in areas of new development and redevelopment and where feasible maximize on-site infiltration of runoff;

ii. Implement pollution prevention methods supplemented by pollutant source controls and treatment. Use small collection strategies located at, or as close as possible to, the source (i.e., the point where water initially meets the ground) to minimize the transport of urban runoff and pollutants offsite and into a municipal separate storm sewer system;

iii. Preserve, and where possible, create or restore areas that provide important water quality benefits, such as riparian corridors, wetlands, and buffer zones. Encourage land acquisition and/or conservation easement acquisition of such areas;

iv. Limit disturbances of natural water bodies and natural drainage systems caused by development including roads, highways, and bridges;

v. Prior to making land use decisions, utilize methods available to estimate increases in pollutant loads and flows resulting from projected future development. Require incorporation of structural

and non-structural treatment measures to mitigate the projected increases in pollutant loads and flows;

vi. Avoid development of areas that are particularly susceptible to erosion and sediment loss; or establish development guidance that identifies these areas and protects them from erosion and sediment loss; and,

vii. Reduce pollutants associated with vehicles and increased traffic resulting from development.

If amendments of General Plans are determined to be legally necessary to allow for implementation of any aspect of Provision C.3, such amendments shall occur by the implementation date of the corresponding component of the Provision. If legally necessary General Plan amendments cannot occur by the implementation date because of CEQA requirements or other constraints imposed by the laws applicable to amending General Plans, the Discharger shall report this to the Executive Officer as soon as possible, and no later than in the Annual Report due more than six months in advance of the implementation date. Should changes to implementation dates to enable a Discharger to comply with CEQA and General Plan legal requirements be necessary, the Discharger shall recommend a new implementation date for approval by the Regional Board.

m. Water Quality Review Processes:

When Dischargers conduct environmental review of projects in their jurisdictions, the Dischargers shall evaluate water quality effects and identify appropriate mitigation measures. This requirement shall be implemented by **May 15, 2004.** Questions that evaluate increased pollutants and flows from the proposed project include the following, which are offered as examples:

i. Would the proposed project result in an increase in pollutant discharges to receiving waters? Consider water quality parameters such as temperature, dissolved oxygen, turbidity and other typical stormwater pollutants (e.g., heavy metals, pathogens, petroleum derivatives, synthetic organics, sediment, nutrients, oxygen-demanding substances, and trash).

ii. Would the proposed project result in significant alteration of receiving water quality during or following construction?

iii. Would the proposed project result in increased impervious surfaces and associated increased runoff?

iv. Would the proposed project create a significant adverse environmental impact to drainage patterns due to changes in runoff flow rates or volumes?

v. Would the proposed project result in increased erosion in its watershed?

vi. Is the project tributary to an already impaired water body, as listed on the Clean Water Act Section 303(d) list? If so, will it result in an increase in any pollutant for which the water body is already impaired?

vii. Would the proposed project have a potentially significant environmental impact on surface water quality, to marine, fresh, or wetland waters?

viii. Would the proposed project have a potentially significant adverse impact on ground water quality?

ix. Will the proposed project cause or contribute to an exceedance of applicable surface or groundwater receiving water quality objectives or degradation of beneficial uses?

x. Will the project impact aquatic, wetland, or riparian habitat?

n. Reporting:
The Dischargers shall demonstrate compliance with the requirements of Provision C.3 by providing in their Annual Reports the information described in Table 1, beginning with the dates shown in Table 1 and continuing thereafter. In addition, the following information shall be collected for Annual Report submittal, beginning upon the date of adoption of this Order, unless otherwise specified below.

i. For all new development and Significant Redevelopment projects which meet the Group 1 or Group 2 definitions in Provision C.3.c, collect and report the name or other identifier, type of project (using the categories in Provision C.3.c), site acreage or square footage, and square footage of new impervious surface.

ii. For projects that must implement treatment measures, report which treatment measures were used and numeric-sizing criteria employed, the O&M responsibility mechanism including responsible party, site design measures used, and source control measures required. This reporting shall begin in the Annual Report following the implementation date specified in Provision C.3.c. This information shall also be reported to the appropriate local vector control district, with additional information of access provisions for vector control district staff.

The Dischargers may utilize their Annual Reports to highlight their budget constraints and suggest reprioritization of any Program activities in order to achieve the most cost effective overall Program.

o. Implementation Schedule:
The Dischargers shall implement the requirements of Provisions C.3.b through C.3.n according to the schedule in Table 2.

I, Loretta K. Barsamian, Executive Officer, do hereby certify that the foregoing is a full, true, and correct copy of an Order adopted by the California Regional Water Quality Control Board, San Francisco Bay Region, on February 19, 2003.

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Loretta K. Barsamian
Executive Officer

ATTACHMENTS - Table 1: Summary of Annual and One-Time Reporting Requirements
Table 2: Implementation Schedule

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

CHAPTER 40C-42, F.A.C.

ENVIRONMENTAL RESOURCE PERMITS: REGULATION OF STORMWATER MANAGEMENT SYSTEMS

RECEIVED
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CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
LOS ANGELES REGION

Revised
October 3, 1995



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CHAPTER 40C-42

ENVIRONMENTAL RESOURCE PERMITS: REGULATION OF STORMWATER MANAGEMENT SYSTEMS

40C-42.011	Scope.
40C-42.021	Definitions.
40C-42.022	Permits Required.
40C-42.0225	Exemptions From Permitting for Stormwater Management Systems.
40C-42.023	Requirements for Issuance.
40C-42.024	Standard General and Individual Permits.
40C-42.025	Design and Performance Criteria for Stormwater Management Systems.
40C-42.026	Specific Design and Performance Criteria.
40C-42.0265	Design and Performance Criteria for Wetlands Stormwater Management Systems.
40C-42.027	Legal Operation and Maintenance Entity Requirements.
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40C-42.031	Exemptions for Stormwater Management Systems.(Repealed)
40C-42.032	Limiting Conditions.
40C-42.033	Implementation.
40C-42.035	Stormwater General Permits. (Repealed)
40C-42.041	Individual Permit Requirements for New Stormwater Discharge Facilities. (Repealed)
40C-42.061	Relationship to Other Permitting Requirements.
40C-42.071	Permit Processing Fee.
40C-42.081	General Provisions.
40C-42.091	Publications Incorporated by Reference.
40C-42.900	Forms and Instructions.

40C-42.011 Scope.

(1) This chapter governs stormwater management systems which are designed and constructed or implemented to control discharges necessitated by rainfall events. These systems may incorporate methods to collect, convey, store, absorb, inhibit, treat, use or reuse water to prevent or reduce flooding, overdrainage, environmental degradation and pollution, or otherwise affect the quality and quantity of discharges. Standard general and individual environmental resource stormwater permits are required under this chapter for construction, operation, maintenance, alteration, removal, or abandonment of systems that are not permitted under provisions of chapters 40C-4, 40C-40, or 40C-400, F.A.C. Permits issued under this chapter must be consistent with the objectives of the District and not cause harm to the water resource.

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(2) A permit under this chapter will be required only for certain stormwater management systems as defined herein. This provision shall not affect the District's authority to require appropriate corrective action whenever any system causes or contributes to violations of state water quality standards.

(3) Stormwater discharges to groundwaters shall be regulated under the provisions of section 62-28.700, F.A.C., and other applicable rules of the Department of Environmental Protection .

Specific Authority 373.044, 373.113, 373.171, 373.418 FS. Law Implemented 373.416, 403.812, 403.814 FS. History--New 4-1-86. Amended 9-25-91, 10-3-95.

40C-42.021 Definitions.

(1) "Appropriate Registered Professional" or "Registered Professional" means, for purposes of this rule, a professional registered in Florida with the necessary expertise in the fields of hydrology, drainage, flood control, erosion and sediment control, and stormwater pollution control to design and certify stormwater management systems. Examples of registered professionals may include professional engineers licensed under chapter 471, F.S., professional landscape architects licensed under chapter 481, F.S., and professional geologists licensed under chapter 492, F.S., who have the referenced skills.

(2) "As-Built Drawings" means plans certified by an appropriate registered professional or registered surveyor which accurately represents the constructed condition of a system.

(3) "Completion of Construction" means the time at which the stormwater management system is first placed into operation, when the project passes final building inspection or when the project receives a certificate of occupancy, whichever occurs first.

(4) "Construction" means any activity including land clearing, earth moving, or the erection of structures which will result in the creation of a stormwater management system.

(5) "Control Device" or "Bleed-down Device" means that element of a discharge structure which allows the gradual release of water under controlled conditions.

(6) "Control Elevation" means the lowest elevation at which water can be released through the control device.

(7) "Detention with Filtration" or "Filtration" means the selective removal of pollutants from stormwater by the collection and temporary storage of stormwater and the subsequent gradual release of the stormwater into surface waters in the state through at least 2 feet of suitable fine textured granular media such as porous soil, uniformly graded sand, or other natural or artificial fine aggregate, which may be used in conjunction with filter fabric and/or perforated pipe.

(8) "Detention" or "To Detain" means the collection and temporary storage of stormwater with subsequent gradual release of the stormwater.

(9) "Direct Discharge" means, for purposes of this chapter, a point or nonpoint discharge which enters Class I, Class II, or Outstanding Florida Waters, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting without an adequate opportunity for mixing and dilution to prevent significant degradation. Examples of direct discharge include the following:

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(a) discharge without entering any other water body or conveyance prior to release to the Class I, Class II, Outstanding Florida Waters, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting;

(b) discharge into an intermittent watercourse which is a tributary of a Class I, Class II, Outstanding Florida Water, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting; and

(c) discharge into a perennial watercourse which is a tributary of a Class I, Class II, Outstanding Florida Water, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting when there is not an adequate opportunity for mixing and dilution to prevent significant degradation.

(10) "Dry detention" means a system designed to collect and temporarily store stormwater in a normally dry basin with subsequent gradual release of the stormwater.

(11) "Effective Grain Size" means the diameter of filter sand or other aggregate that corresponds to the 10 percentile finer by dry weight on the grain size distribution curve.

(12) "Intermittent Watercourse" means a stream or waterway that flows only at certain times of the year, flows in direct response to rainfall, and is normally an influent stream except when the ground water table rises above the normal wet season level.

(13) "Littoral zone" means, in reference to stormwater management systems, that portion of a wet detention pond which is designed to contain rooted aquatic plants.

(14) "Off-line" means the storage of a specified portion of the stormwater in such a manner so that subsequent runoff in excess of the specified volume of stormwater does not flow into the area storing the initial stormwater.

(15) "Operational Maintenance" means any activity or repair required to keep a stormwater management system functioning as permitted and designed.

(16) "Operate" or "Operation" means to cause or to allow a stormwater management system to function.

(17) "Perennial Watercourse" means a stream or waterway which is not an intermittent watercourse.

(18) "Permanent Pool" means that portion of a wet detention pond, which normally holds water (e.g., between the normal water level and the pond bottom) excluding any water volume claimed as wet detention treatment volume pursuant to paragraph 40C-42.026(4)(a), F.A.C.

(19) "Pollution" means the presence in waters of the state of any substances, contaminants, or manmade or man-induced impairment of waters or alteration of the chemical, physical, biological, or radiological integrity of water in quantities or at levels which are or may be potentially harmful or injurious to human health or welfare, animal or plant life, or property or which unreasonably interfere with the enjoyment of life or property, including outdoor recreation unless authorized by applicable law.

(20) "Registered Surveyor" means a registered professional land surveyor licensed in the state of Florida under chapter 472, F.S.

(21) "Reconstruction" means rebuilding or construction in an area upon which construction has previously occurred.

(22) "Retention" means a system designed to prevent the discharge of a given volume of stormwater runoff into surface waters in the state by complete on-site storage. Examples may

include excavated or natural depression storage areas, pervious pavement with subgrade, or above ground storage areas.

(23) "Seasonal high ground water table elevation" means the highest level of the saturated zone in the soil in a year with normal rainfall.

(24) "Semi-impervious" means land surfaces which partially restrict the penetration of water; included as examples are porous concrete and asphalt pavements, limerock, and certain compacted soils.

(25) "Sensitive Karst Areas" means those areas of the District delineated in chapters 40C-4 and 40C-41, F.A.C., in which the Floridan aquifer is near the land surface.

(26) "Stormwater" means the flow of water which results from, and which occurs immediately following, a rainfall event.

(27) "Stormwater Discharge Facility" means a stormwater management system which discharges stormwater into surface waters of the State.

(28) "Stormwater Management System" means a system which is designed and constructed or implemented to control discharges which are necessitated by rainfall events, incorporating methods to collect, convey, store, absorb, inhibit, treat, use or reuse water to prevent or reduce flooding, overdrainage, environmental degradation, and water pollution or otherwise affect the quality and quantity of the discharges.

(29) "Swale" means a manmade trench which:

(a) Has a top width to depth ratio of the cross-section equal to or greater than 6:1, or side slopes equal to or greater than 3 feet horizontal to 1 foot vertical; and,

(b) Contains contiguous areas of standing or flowing water only following a rainfall event; and,

(c) Is planted with or has stabilized vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake; and,

(d) Is designed to take into account the soil erodibility, soil percolation, slope, slope length, and drainage area so as to prevent erosion and reduce pollutant concentration of any discharge.

(30) "Underdrain" means a drainage system installed beneath a stormwater holding area to improve the infiltration and percolation characteristics of the natural soil when permeability is restricted due to periodic high water table conditions or the presence of layers of fine textured soil below the bottom of the holding area. These systems usually consist of a system of interconnected below-ground conduits such as perforated pipe, which simultaneously limit the water table elevation and intercept, collect, and convey stormwater which has percolated through the soil.

(31) "Underground Exfiltration Trench" or "Exfiltration Trench" means a below-ground system consisting of a conduit such as perforated pipe surrounded by natural or artificial aggregate which is utilized to percolate stormwater into the ground.

(32) "Uniformity Coefficient" means the number representing the degree of homogeneity in the distribution of particle sizes of filter sand or other granular material. The coefficient is calculated by determining the D^{60}/D^{10} ratio where D^{10} and D^{60} refer to the particle diameter corresponding to the 10 and 60 percentile of the material which is finer by dry weight.

(33) "Waters" are as defined in subsection 373.019(8), F.S.

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(34) "Wet Detention" means the collection and temporary storage of stormwater in a permanently wet impoundment in such a manner as to provide for treatment through physical, chemical, and biological processes with subsequent gradual release of the stormwater.

(35) "Wetlands Stormwater Management System" means a stormwater management system which incorporates those wetland described in subsection 40C-42.0265(2), F.A.C., into the stormwater management system to provide stormwater treatment.

Specific Authority 373.044, 373.113, 373.171, 373.418 FS. Law Implemented 373.413, 373.416 FS. History--New 4-1-86. Amended 9-25-91, 3-21-93, 4-11-94, 10-3-95

40C-42.022 Permits Required.

(1) A permit is required under this chapter for construction (including operation and maintenance) of a stormwater management system which serves a project that exceeds any of the following thresholds:

(a) Construction of 4,000 square feet or more of impervious or semi-impervious surface area subject to vehicular traffic. This area includes roads, parking lots, driveways, and loading zones;

(b) Construction of 5000 square feet or more of building area or other impervious area not subject to vehicular traffic; or

(c) Construction of 5 acres or more of recreational area. Recreation areas include but are not limited to golf courses, tennis courts, putting greens, driving ranges, or ball fields.

(2) A permit is required under this chapter for alteration, removal, reconstruction, or abandonment of existing stormwater management systems which serve a project which may be expected to result in any of the following:

(a) Increase pollutant loadings (including sediment) in stormwater runoff from the project,

(b) Increase in peak discharge rate,

(c) Decrease in onsite or instream detention storage,

(d) Replacement of roadside swales with curb and gutter,

(e) Construction of 4,000 square feet or more of impervious or semi-impervious surface area subject to vehicular traffic. This area includes roads, parking lots, driveways, and loading zones;

(f) Construction of 5,000 square feet or more of building area or other impervious area not subject to vehicular traffic; or

(g) Construction of 5 acres or more of recreational area. Recreation areas include but not limited to golf courses, tennis courts, putting greens, driving ranges, or ball fields.

(3) These thresholds include all cumulative activity which occurs on or after September 25, 1991.

(4) For purposes of this section, the calculation of the amount of impervious surface shall not include water bodies.

(5) Applications received by the District for which a permit has not been issued prior to the rule revisions effective April 11, 1994, and which do not require a permit pursuant to sections (1) or (2), above, may be withdrawn by the applicant.

(6) Permits issued by the District for systems which no longer require a permit pursuant to sections (1) or (2), above, may either be abandoned or relinquished by the permittee subject to the following:

(a) Local governments may have concurrent jurisdiction with the District over a stormwater system. The permittee is not relieved by this rule of the responsibility to comply with any other applicable rules or ordinances which may govern such system.

(b) The permittee provides reasonable assurance that there will not be a violation of state water quality standards as set forth in chapter 62-302 and 62-550, F.A.C.;

(c) The permittee provides reasonable assurance that adjacent or nearby properties not owned or controlled by the applicant will not be adversely affected by drainage or flooding; and

(d) The permittee must apply to the District for and receive written authorization from the District prior to abandonment of the system.

Specific Authority 373.044, 373.113, 373.171, FS. Law Implemented 373.413, 373.416 FS. History--New 9-15-91. Amended 4-11-94, 11-22-94.

40C-42.0225 Exemptions From Permitting for Stormwater Management Systems. The following types of stormwater management systems are exempt from the notice and permit requirements of this chapter:

(1) Systems designed to accommodate only one single family dwelling unit, duplex, triplex, or quadruplex, provided the single unit, duplex, triplex or quadruplex is not part of a larger common plan of development or sale.

(2) Systems which are designed to serve single family residential projects, including duplexes, triplexes and quadruplexes, of less than 10 acres total land area and which have less than 2 acres impervious surface and if the systems:

(a) Comply with all regulations or ordinances applicable to stormwater management adopted by a city or county;

(b) Are not part of a larger common plan of development or sale; and

(c) Discharge into a stormwater management system exempted or permitted by the District under this chapter which has sufficient capacity and treatment capability as specified in this chapter and is owned, maintained, or operated by a city, county, special district with drainage responsibility, or water management district; however, this exemption does not authorize discharge to a system without the system owner's prior written consent.

(3) Systems that qualify for a noticed general permit pursuant to chapter 40C-400, F.A.C. and which comply with the requirements of such noticed general permit.

Specific Authority 373.044, 373.113, 373.171, 373.413 FS. Law Implemented 373.413, 373.416, 403.812 FS. History--New 9-25-91. Amended 3-21-93, 10-3-95.

40C-42.023 Requirements for Issuance.

(1) To receive a general or individual permit under this chapter the applicant must provide reasonable assurance based on plans, test results and other information, that the stormwater management system:

(a) will not result in discharges from the system to surface and ground water of the state that cause or contribute to violations of state water quality standards as set forth in chapters 62-3,

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62-4, 62-302 and 62-550, F.A.C., including any antidegradation provisions of sections 62-4.242(1)(a) and (b), 62-4.242(2) and (3), and 62-302.300, F.A.C., and any special standards for Outstanding Florida Waters and Outstanding National Resource Waters set forth in sections 62-4.242(2) and (3), F.A.C.;

(b) will not adversely affect drainage and flood protection on adjacent or nearby properties not owned or controlled by the applicant;

(c) will be capable of being effectively operated and maintained pursuant to the requirements of this chapter; and

(d) meets any applicable basin criteria contained in chapter 40C-41, F.A.C.

(2)(a) A showing by the applicant that the stormwater management system complies with the applicable criteria in sections 40C-42.024, 40C-42.025, 40C-42.026, and 40C-42.0265, F.A.C., shall create a presumption that the applicant has provided reasonable assurance that the proposed activity meets the requirements in paragraphs (a), above.

(b) A showing by the applicant that the stormwater management system complies with the criteria of subsections 40C-42.025(8) and (9), F.A.C., shall create a presumption that the applicant has provided reasonable assurance that the proposed activity meets the requirements in paragraph (b), above.

(c) A showing by the applicant that the stormwater management system complies with the applicable criteria of sections 40C-42.027, 40C-42.028, and 40C-42.029, F.A.C., shall create a presumption that the applicant has provided reasonable assurance that the proposed activity meets the requirements in paragraph (c), above.

Specific Authority 373.044, 373.113, 373.171, 373.418 FS. Law Implemented 373.413, 373.416 FS. History--New 9-25-91. Amended 3-21-93, 10-3-95.

40C-42.024 Standard General and Individual Permits.

(1) Any person proposing to construct, alter, operate, maintain, remove, or abandon a stormwater management system, which requires a permit pursuant to sections 40C-42.022, F.A.C., except those exempted pursuant to section 40C-42.0225, F.A.C., or noted in section 40C-42.061, F.A.C, shall apply to the District for a standard general or individual environmental resource stormwater permit, prior to the commencement of construction, alteration, removal, operation, maintenance, or abandonment of the stormwater management system. No construction, alteration, removal, operation, maintenance, or abandonment of a stormwater management system shall be undertaken without a valid standard general or individual environmental resource stormwater permit as required pursuant to this section.

(2) The following types of stormwater management systems qualify for a standard general environmental resource stormwater permit and shall be processed according to the administrative procedures set forth in chapter 40C-40, F.A.C.:

(a) Systems which discharge into a stormwater management system which is permitted pursuant to paragraph 40C-42.024(2)(b), (c), or (d), F.A.C., or subsection 40C-42.024(3), F.A.C., or which was previously approved pursuant to a noticed exemption under section 17-25.030 where the appropriate treatment criteria specified in this chapter and applied to the permitted or exempt system are not exceeded by the discharge; however, this does not authorize discharge to the permitted or exempt system without the system owner's prior written consent.

(b) Systems which meet the applicable design and performance standards of section 40C-42.025, F.A.C., and which comply with any one or more of the following:

1. Retention systems which meet the criteria of subsection 40C-42.026(1), F.A.C.;
2. Underdrain systems which meet the criteria of subsection 40C-42.026(2), F.A.C.;
3. Underground exfiltration trench systems which meet the criteria of subsection 40C-42.026(3), F.A.C.;
4. Wet detention systems which meet the criteria of subsection 40C-42.026(4), F.A.C.; or
5. Swale systems which meet the criteria in subsections 40C- 42.021(30) and 40C-42.026(5), F.A.C.
6. Dry detention systems within project areas less than 5 acres in size, and which serve draiage area less than 5 acres in size, and which meet the criteria of subsection 40C-42.026(6), F.A.C.

(c) Modification or reconstruction by a city, county, state agency, federal agency, or special district with drainage responsibility, of an existing stormwater management system which is not intended to increase the original design capacity, and which will not increase pollution loading, or change points of discharge in a manner that would adversely affect the designated uses of waters in the state.

(d) Paving of existing public dirt roads by a public entity if all of the following conditions are met:

1. The road will not serve new development.
2. Additional traffic lanes are not added to the road;
3. The traffic load is not expected to significantly increase;
4. The drainage system serving the road is not significantly altered;
5. Erosion and sediment controls are utilized to prevent turbidity during construction;
6. The project does not involve dredging or filling in wetlands or other surface waters, other than in ditches that were excavated through uplands ;
7. Permanent vegetative cover is established on both sides of the pavement within the road right of way; and
8. Swale blocks, or other means, are utilized to retain runoff and promote infiltration in areas with soil having good infiltration (i.e., SCS hydrologic soil groups "A" and "B").

(3) The following types of stormwater management systems will be processed as an individual permit according to the administrative procedures set forth in chapter 40C-4, F.A.C.:

(a) Wetlands stormwater management systems which are designed pursuant to the criteria in sections 40C-42.025 and 40C-42.0265, F.A.C.;

(b) Systems which propose to satisfy the standards of subsection 40C-42.023(1), F.A.C., by employing an alternative treatment methodology or device other than those described in subsection (2) or paragraph (3)(a), above. An affirmative showing by the applicant that the system design will provide treatment equivalent to retention systems described in paragraph (2)(b)1., above, will create a presumption in favor of satisfying the standards in paragraphs 40C-42.023(1)(a), F.A.C. In addition, systems which have a direct discharge to Class I, Class II, Outstanding Florida Waters, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting shall provide an additional level of

treatment (i.e., additional treatment volume and off-line treatment) pursuant to section 40C-42.026, F.A.C., or an alternative demonstrated by the applicant to be equivalent.

(c) Systems which do not meet the applicable criteria of sections 40C-42.025, 40C-42.026, or 40C-42.0265, F.A.C. An affirmative showing by the applicant based on plans, test results, calculations, or other information that an alternative design is appropriate for the specific site conditions will create a presumption in favor of satisfying the applicable standards in subsection 40C-42.023(1), F.A.C.

(4) In otherwise determining whether reasonable assurance has been provided for paragraphs (3)(b) and (c), above, the District shall, where appropriate, consider:

(a) Whether best management practices are proposed, such as those described in "Stormwater Management Manual (October, 1981)," "The Florida Development Manual: A Guide to Sound Land and Water Management (June, 1988)," or best management practices described in manuals adopted by the Environmental Regulation Commission pursuant to section 62-25.050, F.A.C., or other appropriate best management practices (the manuals listed above by name are adopted and made a part of this rule by reference. Copies of these documents may be inspected at all District offices);

(b) The public interest served by the system;

(c) The probable efficacy and costs of alternative controls; and

(d) Whether reasonable provisions have been made for the operation and maintenance of the proposed system.

(5) The standard general or individual environmental resource stormwater permit which is granted will include a specified period for which the permit will be valid. Such period, unless the permit is modified or revoked, is generally:

(a) five years for permits to construct, alter, or remove a system; and

(b) permanent for permits to operate, maintain, or abandon a system.

(6) Procedures governing transfers, permit revocation, permit modifications, and extensions are found in chapters 40C-1 and 40C-4, F.A.C., and apply to permits obtained pursuant to this chapter. Procedures governing converting construction to operation permits and transferring the system to the operation and maintenance entity are found in section 40C-42.027, F.A.C., below. *Specific Authority 373.044, 373.113, 373.118, 373.171, 373.418 FS. Law Implemented 373.413, 373.416, 403.813 FS. History--New 9-25-91. Amended 3-21-93, 4-11-94, 10-3-95.*

40C-42.025 Design and Performance Criteria for Stormwater Management Systems. The following criteria shall apply to stormwater management systems unless otherwise noted:

(1) Erosion and sediment control best management practices shall be used as necessary during construction to retain sediment on-site. These management practices shall be designed and certified by an appropriate registered professional experienced in the fields of soil conservation or sediment control according to specific site conditions and shall be shown or noted on the plans of the stormwater management system. The registered professional shall furnish the contractor with information pertaining to the construction, operation and maintenance of the erosion and sediment control practice. Sediment accumulations in the system from construction activities shall be removed to prevent loss of storage volume.

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(2) Stormwater management systems which either receive stormwater from areas with greater than 50 percent impervious surface or are a potential source of oil and grease contamination in concentrations that exceed applicable water quality standards shall include a baffle, skimmer, grease trap or other mechanism suitable for preventing oil and grease from leaving the stormwater management system in concentrations that would cause or contribute to violations of applicable water quality standards in the receiving waters. For purposes of this subsection, the calculation of the amount of impervious surface shall not include water bodies.

(3) Unless applicable local regulations are more restrictive, for purposes of public safety the following requirements apply:

(a) Normally dry basins designed to impound more than two feet of water or permanently wet basins shall be fenced or otherwise restricted from public access, or shall contain side slopes that are no steeper than 4:1 (horizontal:vertical) out to depth of two feet below the control elevation; and,

(b) Control devices that are designed to contain more than a two foot depth of water within the structure under the design storm and have openings greater than one foot minimum dimension shall be restricted from public access.

(4) All stormwater basin side slopes shall be stabilized by either vegetation or other materials to minimize erosion and sedimentation of the basins.

(5) Stormwater management systems must be designed to accommodate maintenance equipment access and to facilitate regular operational maintenance (such as underdrain replacement, unclogging filters, sediment removal, mowing and vegetation control). Operational maintenance and operation easements shall be provided when necessary to facilitate equipment access.

(6) The applicant must obtain sufficient legal authorization as appropriate prior to permit issuance for stormwater management systems which propose to utilize offsite areas to satisfy the requirements in subsection 40C-42.023(1), F.A.C.

(7) Stormwater management systems (except retention and exfiltration trench systems) shall provide gravity or pumped discharge that effectively operates under one of the following tailwater conditions:

(a) Maximum stage in the receiving water resulting from the mean annual 24-hour storm. This storm depth is described in "Rainfall Analysis for Northeast Florida;" St. Johns River Water Management District Technical Publication No. SJ 88-3 (May, 1988). Lower stages may be utilized if the applicant demonstrates that flow from the project will reach the receiving water prior to the time of maximum stage in the receiving water;

(b) Mean annual high tide for tidal areas;

(c) Mean annual seasonal high water elevation. This elevation may be determined by water lines on vegetation or structures, historical data, adventitious roots or other hydrological or biological indicators, design of man-made systems, or estimated by a registered professional using standard hydrological methods based on the site and receiving water characteristics; or

(d) As an alternative, the applicant may propose any applicable criterion established by a local government, state agency, or stormwater utility with jurisdiction over the project.

(8) Stormwater management systems which require a permit pursuant to subsection 40C-42.022(1), F.A.C., and which serve new construction area with greater than 50 percent

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impervious surface (excluding water bodies) must demonstrate that the post-development peak rate of discharge does not exceed the pre-development peak rate of discharge for one of the following:

(a) The mean annual 24-hour storm event. This storm depth is described in "Rainfall Analysis for Northeast Florida;" St. Johns River Water Management District Technical Publication No. SJ 88-3 (May, 1988). The criteria contained in sections 10.3.5 - 10.3.8 of the Management and Storage of Surface Waters Applicant's Handbook, (A.H.), are herein incorporated by reference;

(b) The mean annual 24-hour storm event utilizing the modified rational hydrograph method. This storm depth is described in the publication referenced in paragraph (a), above. This methodology should only be used for systems meeting the following criteria:

1. The drainage area is less than 40 acres;

2. The pre-development time of concentration for the system is less than 60 minutes; and,

3. The post-development time of concentration for the system is less than 30 minutes; or

(c) As an alternative to paragraphs (a) or (b), above, the applicant may propose a storm event, duration, and criteria specified by a local government, state agency, or stormwater utility with jurisdiction over the project.

(9) Stormwater management systems which alter existing conveyance systems must not adversely affect existing surface water conveyance capabilities. It is presumed that a system meets this criteria if one of the following are met:

(a) The existing hydraulic conveyance is maintained;

(b) The applicant demonstrates that changes in flood elevations or velocities will not adversely impact upstream or downstream off-site property;

(c) The applicant demonstrates that the criteria in 10.5.2(b), Applicant's Handbook, are met; or

(d) As an alternative, the applicant may propose to comply with applicable criteria established by a local government, state agency, or stormwater utility with jurisdiction over the project.

(10) The construction plans and supporting calculations must be signed, sealed, and dated by an appropriate registered professional as required by the relevant statutory provisions when the design of the stormwater management system requires the services of an appropriate registered professional.

(11) Stormwater management systems located within Sensitive Karst Areas must meet the requirements of subsection 40C-41.063(6), F.A.C.

Specific Authority 373.044, 373.113, 373.171, 373.418 FS. Law Implemented 373.117, 373.413, 373.416, 403.0877 FS. History--New 4-1-86. Amended 9-25-91, 3-21-93.

40C-42.026 Specific Design and Performance Criteria.

(1) Retention systems shall:

(a) Provide for one of the following:

1. Off-line retention of the first one half inch of runoff or 1.25 inches of runoff from the impervious area, whichever is greater;

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2. On-line retention of an additional one half inch of runoff from the drainage area over that volume specified in subparagraph 1., above;

3. On-line retention that provides for percolation of the runoff from the three year, one-hour storm; or

4. On-line retention of the runoff from one inch of rainfall or 1.25 inches of runoff from the impervious area, whichever is greater, for systems which serve an area with less than 40 percent impervious surface and that contain only U.S. Department of Agriculture Soil Conservation Service (SCS) hydrologic group "A" soils.

(b) Provide retention in accordance with one of the following for those systems which have direct discharge to Class I, Class II, Outstanding Florida Waters, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting:

1. At least an additional fifty percent of the applicable treatment volume specified in subparagraph 1., above. Off-line retention must be provided for at least the first one half inch of runoff or 1.25 inches of runoff from the impervious area, whichever is greater, of the total amount of runoff required to be treated;

2. On-line retention of an additional fifty percent of the treatment volume specified in subparagraph 2., above;

3. On-line retention that provides percolation of the runoff from the three-year, one-hour storm; or

4. On-line retention that provides at least an additional 50 percent of the runoff volume specified in subparagraph 40C-42.026(1)(a)4., above, for systems which serve an area with less that 40 percent impervious surface and that contain only U.S. Department of Agriculture Soil Conservation Service (SCS) hydrologic group "A" soils.

(c) Provide the capacity for the appropriate treatment volume of stormwater specified in paragraphs (a) or (b) above, within 72 hours following the storm event assuming average antecedent moisture conditions. The storage volume must be provided by a decrease of stored water caused only by percolation through soil, evaporation or evapotranspiration.

(d) Be stabilized with pervious material or permanent vegetative cover. Permanent vegetative cover must be utilized, except for pervious pavement systems, when U.S. Department of Agriculture Soil Conservation Service (SCS) hydrologic group "A" soils underlie the retention basin.

(2) Underdrain stormwater management systems shall:

(a) Provide for either of the following:

1. Off-line storage of the first one half inch of runoff or 1.25 inches of runoff from the impervious area, whichever is greater; or

2. On-line storage of an additional one half inch of runoff from the drainage area over that volume specified in subparagraph 1., above.

(b) Provide either of the following for those underdrain systems which have direct discharge to Class I, Class II, Outstanding Florida Waters, or Class III waters which are approved, restricted, or conditionally restricted for shellfish harvesting:

1. At least an additional fifty percent of the applicable treatment volume specified in subparagraph 1., above. Off-line storage must be provided for at least the first one half inch of

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runoff or 1.25 inches of runoff from the impervious area, whichever is greater, of the total amount of runoff required to be treated; or

2. On-line storage of the runoff from a three-year, one-hour storm or an additional fifty percent of the treatment volume specified in subparagraph 2., above, whichever is greater.

(c) Provide the capacity for the appropriate treatment volume of stormwater specified in paragraphs (a) or (b), above, within 72 hours following a storm event. The storage volume must be provided by a decrease of stored water caused only by percolation through soil with subsequent transport through the underdrain pipes, evaporation or evapotranspiration.

(d) Provide at least two feet of indigenous soil between the bottom of the stormwater holding area and the underdrain pipe(s).

(e) Be designed with a safety factor of at least two unless the applicant affirmatively demonstrates based on plans, test results, calculations or other information that a lower safety factor is appropriate for the specific site conditions. Examples of how to apply this factor include but are not limited to reducing the design percolation rate by half or designing for the required drawdown within 36 hours instead of 72 hours.

(f) Contain areas of standing water only following a rainfall event.

(g) Be stabilized with permanent vegetative cover.

(h) Include, at a minimum, a capped and sealed inspection and cleanout ports which extend to the surface of the ground at the following locations of each drainage pipe:

1. The terminus; and

2. Every 400 feet or every bend of 45 or more degrees, whichever is less.

(i) Utilize filter fabric or other means used to prevent the soil from moving and being washed out through the underdrain pipe.

(3) Underground exfiltration trench systems shall:

(a) Provide for either of the following:

1. Off-line storage of the first one half inch of runoff or 1.25 inches of runoff from the impervious area, whichever is greater; or

2. On-line storage of an additional one half inch of runoff from the drainage area over that volume specified in subparagraph 1., above.

(b) Provide either of the following for those exfiltration trench systems which have direct discharge to Class I, Class II, Outstanding Florida Waters, or Class III waters which are approved, conditionally approved, restricted, conditionally restricted for shellfish harvesting:

1. At least an additional fifty percent of the applicable treatment volume specified in subparagraph 1., above. Off-line storage must be provided for at least the first one half inch of runoff or 1.25 inches of runoff from the impervious area, whichever is greater, of the total amount of runoff required to be treated; or

2. On-line storage of the runoff from the three-year, one-hour storm or an additional fifty percent of the treatment volume specified in subparagraph 2., above, whichever is greater.

(c) Provide the capacity for the appropriate treatment volume of stormwater specified in paragraphs (a) or (b), above, within 72 hours following a storm event assuming average antecedent moisture conditions. The storage volume must be provided by a decrease of stored water caused only by percolation into the soil.

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(d) Be designed with a safety factor of at least two unless the applicant affirmatively demonstrates based on plans, test results, calculations or other information that a lower safety factor is appropriate for the specific site conditions. Examples of how to apply this factor include but are not limited to reducing the design percolation rate by half or designing for the required drawdown within 36 hours instead of 72 hours.

(e) Be designed with a twelve (12) inch minimum pipe diameter.

(f) Be designed with a three (3) foot minimum trench width.

(g) Be designed so that aggregate in the trench is enclosed in filter fabric.

(h) Provide cleanout and inspection structures which extend to the surface of the ground at the inlet and terminus of each pipe. Inlet structures should include sediment sumps.

(i) Be designed so that the invert elevation of the trench must be at least two feet above the seasonal high ground water table elevation unless the applicant demonstrates based on plans, test results, calculations or other information that a alternative design is appropriate for the specific site conditions.

(j) Be designed so that the system must have the capacity to retain the required treatment volume without considering discharges to ground or surface waters.

(4) Wet detention stormwater management systems shall:

(a) Provide a treatment volume of the greater of the following:

1. First one inch of runoff; or

2. 2.5 inches of runoff from the impervious area.

(b) Be designed so that the outfall structures shall bleed down one-half the volume of stormwater specified in paragraph (a), above, within 48 to 60 hours following a storm event, but no more than one-half of this volume will be discharged within the first 48 hours.

(c) Contain a permanent pool of water sized to provide an average residence time of at least 14 days during the wet season (June - October).

(d)1. Provide a littoral zone to be designed as follows:

a. The littoral zone shall be gently sloped (6:1 or flatter). At least 30 percent of the wet detention system surface area shall consist of a littoral zone. The percentage of littoral zone is based on the ratio of vegetated littoral zone to surface area of the pond at the control elevation.

b. The treatment volume should not cause the pond level to rise more than 18 inches above the control elevation unless the applicant affirmatively demonstrates that the littoral zone vegetation can survive at greater depths.

c. Eighty percent coverage of the littoral zone by suitable aquatic plants is required within the first twenty-four months of completion of the system or as specified by permit conditions.

d. To meet the 80% coverage requirement, planting of the littoral zone is recommended. As an alternative, portions of the littoral zone may be established by placement of wetland top soils (at least a four inch depth) containing a seed source of desirable native plants. When utilizing this alternative, the littoral zone must be stabilized by mulching or other means and at least the portion of the littoral zone within 25 feet of the inlet and outlet structures must be planted.

2. In lieu of the requirements of subparagraph 1., above, the applicant may provide either of the following:

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a. At least fifty percent additional permanent pool volume over that specified in paragraph (c), above; or

b. Treatment of the stormwater pursuant to subparagraphs 40C- 42.024(2)(b)2., 3., 4., or 6., F.A.C., prior to the stormwater entering the wet detention pond.

(e) Be designed so that the mean depth of the permanent pool is between 2 and 8 feet and the maximum depth does not exceed 12 feet below the invert of the bleed down device, unless the applicant affirmatively demonstrates that alternative depths will not inhibit the physical, chemical, and biological treatment processes or cause the resuspension of pollutants into the water column due to anaerobic conditions in the water column.

(f) Be designed so the flow path through the pond has an average length to width ratio of at least 2:1. The alignment and location of inlets and outlets should be designed to maximize flow paths in the pond. If short flow paths are unavoidable, the effective flow path should be increased by adding diversion barriers such as islands, peninsulas, or baffles to the pond. Inlet structures shall be designed to dissipate the energy of water entering the pond.

(g) Be designed so that bleed down devices incorporating dimensions smaller than three inches minimum width or less than 20 degrees for "v" notches shall include a device to eliminate clogging. Examples include baffles, grates, and pipe elbows.

(h) Be designed so that bleed down structure invert elevations are at or above the estimated post-development normal ground water table elevation. If the structure is proposed to be set below this elevation, ground water inflow must be considered in the drawdown calculations, calculation of average residence time, estimated normal water level in the pond, and pollution removal efficiency of the system.

(i) Provide for permanent maintenance easements or other acceptable legal instruments to allow for access to and maintenance of the system, including the pond, littoral zone, inlets, and outlets. The easement or other acceptable instrument must cover the entire littoral zone.

(j) Be designed so that the average pond side slope measured between the control elevation and two feet below the control elevation is no steeper than 3:1 (horizontal:vertical).

(k) Wet detention systems which have direct discharge to Class I, Class II Outstanding Florida Waters, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting shall provide either of the following in addition to the requirements in paragraphs (b), (d), and (e) - (j), above:

1. An additional fifty percent of the applicable treatment volume specified in paragraph (a), above, and an additional fifty percent of the applicable permanent pool volumes specified in paragraphs (c) or subparagraph (d)2., above; or

2. Treatment pursuant to subsections (1), (2), (3) above, or (5) below, prior to discharging into a wet detention pond designed pursuant to paragraphs (a) - (j), above.

(5) Swale systems shall:

(a) Percolate 80% of the runoff from the three year, one-hour storm.

(b) Percolate the runoff from the three-year, one-hour storm for those swale systems which have direct discharge to Class I, Class II, Outstanding Florida Waters, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting.

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(c) -- Provide the capacity for the given volume of stormwater pursuant to paragraphs (a) or (b), above, and contain no contiguous areas of standing or flowing water within 72 hours following the storm event referenced in paragraphs (a) and (b), above, assuming average antecedent moisture conditions. The storage volume must be provided by a decrease of stored water caused only by percolation through soil, evaporation or evapotranspiration.

(d) Meet the criteria in subsection 40C-42.021(29), F.A.C.

(6) Dry detention systems shall:

(a) Provide off-line detention of the first one inch of runoff or 2.5 inches of runoff from the impervious area, whichever is greater.

(b) Provide at least an additional fifty percent of the applicable treatment volume specified in subparagraph 1., above, for those systems which have direct discharge to Class I, Class II, Outstanding Florida Waters, or Class III waters which are approved, conditionally approved, restricted, or conditionally restricted for shellfish harvesting.

(c) Be designed so that the outfall structures shall discharge one-half the appropriate treatment volume of stormwater specified in paragraphs (a) or (b), above, between 24 to 30 hours following a storm event.

(d) Be designed so that discharge structures shall include a device to prevent the discharge of accumulated sediment, minimize exit velocities, and prevent clogging. Examples include perforated riser enclosed in a gravel jacket and perforated pipes enclosed in sand or gravel.

(e) Contain areas of standing water for no longer than 3 days following a rainfall event.

(f) Be stabilized with permanent vegetative cover.

(g) Be designed so the average flow path through the basin has a length to width ratio of at least 2:1. The alignment and location of inlets and outlets should be designed to maximize flow paths in the basin. If short flow paths are unavoidable, the effective flow path should be increased by adding diversion barriers such as baffles to the basin.

(h) Be designed so inlet structures dissipate the energy of water entering the basin.

(i) Be designed to include a maintenance schedule for removal of sediment and debris on at least a bi-monthly basis from the basin and mowing and removal of grass clippings.

(j) Be designed so the basin floor is level or uniformly sloped toward the outfall structure.

(k) Be designed so that the basin floor and control elevation is at least one foot above the seasonal high ground water table elevation. Sumps may be placed up to one foot below the control elevation.

Specific Authority 373.044, 373.113, 373.118, 373.177, 373.418 FS. Law Implemented 373.413, 373.416, 403.813 FS. History--New 9-25-91. Amended 3-21-93, 6-15-93, 4-11-94, 7-20-95.

40C-42.0265 Design and Performance Criteria for Wetlands Stormwater Management Systems.

(1) The wetlands stormwater management system design and performance criteria and other provisions relating to such systems are an initial but necessary step by the District in a field in which there exists limited knowledge. In an effort to further refine the District's wetlands stormwater management system policies, monitoring data and other pertinent information relating to the performance criteria will be collected and analyzed and periodic reports of the results of this

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monitoring shall be made available to the public. The District must attempt to ensure that the wetlands stormwater management system is compatible with the ecological characteristics of the wetlands utilized for stormwater treatment and to ensure that water quality standards will not be violated by discharges from wetlands stormwater management system. To achieve these goals, specific performance criteria are set forth in this section for systems which incorporate wetlands for stormwater treatment.

(2) The only wetlands to be used for stormwater treatment are those:

(a) Which are isolated wetlands; and

(b) Which would be isolated wetlands, but for a hydrologic connection to other wetlands or surface waters via another watercourse that was excavated through uplands.

(3) Applications for wetland stormwater management systems shall be processed by the District as an individual permit application according to the administrative procedures set forth in chapter 40C-4, F.A.C.

(4) In the review of wetlands stormwater management system permit applications, the District shall consider the following:

(a) Compliance of the wetlands stormwater management system permit with the performance criteria specified in subsection 40C-42.0265(5).

(b) If the applicant is unable to show compliance with the performance criteria in subsection 40C-42.0265(5), the applicant shall qualify for a wetlands stormwater management system permit using alternative design and performance criteria if the applicant affirmatively demonstrates that the use of the wetlands is compatible with the ecological characteristics of the wetland and the applicant complies with the standards in section 40C-42.023, F.A.C.

(c) If the applicant proposes to dredge or fill in the wetlands used for stormwater treatment, the District in its review of the permit application shall evaluate the adverse effects of the dredging or filling on the treatment capability of the wetland.

(5) A showing by the applicant that the wetlands stormwater management system design complies with the performance criteria listed below shall create a presumption in favor of the issuance of the permit:

(a) The system complies with the requirements of section 40C-42.025 and subsection 40C-42.0265(2), F.A.C.

(b) The system is part of a comprehensive stormwater management system that utilizes wetlands in combination with other best management practices to provide treatment of the runoff from the greater of the following:

1. First one inch of runoff; or

2. 2.5 inches times the impervious area.

(c) Those systems which direct discharge to Class I, Class II, or Outstanding Florida Waters shall provide an additional fifty percent of the applicable treatment volume specified in paragraph (b), above.

(d) The wetlands stormwater management system must provide treatment for the runoff as specified in paragraph 40C-42.0265(5)(b) or (c), F.A.C., within the wetlands. The design features of the system shall maximize residence time of the stormwater within the wetland. The outfall structure shall be designed to bleed down one-half the volume specified in paragraph 40C-42.0265(5)(b) or (c) within the first 60 to 72 hours.

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(e) Stormwater shall be discharged into the wetlands utilized so as to minimize the channelized flow of stormwater by employing methods including, but not limited to, sprinklers, overland flow or spreader swales.

(f) The use of wetlands for stormwater must meet the criteria in section 12.0, Environmental Considerations, of the Applicant's Handbook: Management and Storage of Surface Waters, adopted by reference in section 40C-4.091, F.A.C.

(6) In order to establish a reliable, scientifically valid data base upon which to evaluate the performance criteria and the performance of the wetlands stormwater management system, a monitoring program may be required. Monitoring programs shall provide the District with comparable data for different types of wetlands and drainage designs. Data to be collected shall include (unless irrelevant to the permitted system): sedimentation rate, sediment trace metal concentrations, sediment nitrogen and phosphorus concentrations, changes in the frequency, abundance and distribution of vegetation, and inflow and outflow water quality for nutrients, metals, turbidity, oils and greases, bacteria and other parameters related to the specific site conditions. Inflow and outflow water quality parameters will be monitored on such storm event occurrences as established by the District based on a site specific basis. The District shall eliminate the requirement to continue the monitoring program upon its determination that no further data is necessary to evaluate the performance criteria or ensure compliance with the performance criteria and applicable water quality standards.

Specific Authority 373.044, 373.113, 373.177, 373.418 FS. Law Implemented 373.413, 373.416 FS. History--New 9-25-91, 3-21-93, 10-3-95.

40C-42.027 Legal Operation and Maintenance Entity Requirements.

(1) The District considers the following entities to be acceptable for meeting the requirements necessary to ensure that a stormwater management system will be operated and maintained in compliance with the requirements of this Chapter and other District regulations in chapters 40C-4 or 40C-40, F.A.C.:

(a) Local governmental units including counties or municipalities, or Municipal Service Taxing Units established pursuant to section 125.01, F.S.;

(b) Active water control districts created pursuant to chapter 298, F.S., or drainage districts created by special act, or Community Development Districts created pursuant to chapter 190, F.S., or Special Assessment Districts created pursuant to chapter 170, F.S.;

(c) State or federal agencies; or

(d) Duly constituted stormwater, communication, water, sewer, electrical or other public utilities.

(2) The property owner or developer is normally not acceptable as a responsible entity when the property is intended to be subdivided. The property owner or developer shall be acceptable in any of the following circumstances:

(a) Written proof is furnished either by letter or resolution, that a governmental entity or such other acceptable entity as set forth in paragraphs (a)-(d) above, will accept the operation and maintenance of the stormwater management system at a time certain in the future;

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(b) Proof of bonding or assurance of a similar nature is furnished in an amount sufficient to cover the cost of the operation and maintenance of the stormwater management system;

(c) The property is wholly owned by the permittee and ownership is intended to be retained. This would apply to a farm, corporate office or single industrial facility, for example; or

(d) The ownership of the property is retained by the permittee and is either leased or rented to third parties such as in shopping centers or mobile home parks.

(3) Profit or non-profit corporations including homeowners associations, property owners associations, condominium owners associations or master associations shall be acceptable only under certain conditions that ensure that the corporation has the financial, legal and administrative capability to provide for the long term operation and maintenance of the stormwater management system.

(4) Entity Requirements.

(a) If a multimember association such as a Homeowner, Property Owner, Condominium or Master Association is proposed, the owner or developer must submit Articles of Incorporation for the Association, and Declaration of Covenants and Restrictions, or such other organizational and operational documents which affirmatively assign authority and responsibility for the operation or maintenance of the stormwater management system.

(b) The Association shall have sufficient powers reflected in its organizational or operational documents to:

1. Operate and maintain the stormwater management system as permitted or exempted by the District;

2. Establish rules and regulations;

3. Assess members a fee for the cost of operation and maintenance of the system, and enforce collection of such assessments;

4. Contract for services (if the Association contemplates employing a maintenance company) to provide the services for operation and maintenance;

5. Exist in perpetuity. The Articles of Incorporation must provide that if the association is dissolved the stormwater management system shall be transferred to and maintained by an entity acceptable to the District as defined in this section. Transfer of maintenance responsibility shall be effectuated prior to dissolution of the association;

6. Enforce the restrictions relating to the operation and maintenance of the stormwater management system;

7. Provide that the portions of the Declarations which relate to the operation and maintenance may be enforced by the District in a proceeding at law or in equity; and

8. Require that amendments to the documents which alter the stormwater management system beyond maintenance in its original condition must receive District approval prior to taking effect.

(5) Phased Projects.

(a) If an Operation and Maintenance entity is proposed for a project which will be constructed in phases, and subsequent phases will utilize the same stormwater management systems as the initial phase or phases, the entity shall have the ability to accept responsibility for the operation and maintenance of stormwater management system for future phases of the project.

(b) If the development scheme contemplates independent operation and maintenance entities for different phases, and the stormwater management system is integrated throughout the project, the entities either separately or collectively shall have the authority and responsibility to operate and maintain the stormwater management system for the entire project. That authority shall include cross easements for stormwater management and the ability to enter and maintain the various systems, should any sub-entity fail to maintain a portion of the stormwater management system within the project.

(6) The applicant shall be an acceptable entity from the time construction begins until the stormwater management system is dedicated to and accepted by a legal entity established pursuant to this section. The applicant shall provide proof of the existence of an entity pursuant to this section or of the future acceptance of the system by an entity described in this section prior to initiating construction.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 403.812, 403.814 FS. History--New 4-1-86. Amended 9-25-91, 3-21-93.

40C-42.028 Operation Phase Permits.

(1) The operation phase of a stormwater management system permit which was designed by an appropriate registered professional does not become effective until all of the following criteria in this subsection and subsection (3) have occurred:

(a) Within 30 days after completion of construction of the stormwater management system, permittee shall submit a signed and sealed certification by an appropriate registered professional indicating that the system has been constructed and that the system is ready for inspection by the District.

(b) The certification prepared by a registered professional (not necessarily the project design registered professional but one who has been retained by the permittee to provide professional services during the construction phase of project completion) shall be made on form number 40C-1.181(13), As Built Certification by a Registered Professional.

(c) The registered professional shall certify that:

1. The system has been constructed substantially in accordance with approved plans and specifications, or;

2. Any deviations from the approved plans and specifications will not prevent the system from functioning in compliance with the requirements of this chapter. The registered professional shall note and explain substantial deviations from the approved plans and specifications and provide two copies of as-built drawings to the District.

(d) The certification shall be based upon on-site observation of construction (scheduled and conducted by the professional or by a project representative under his or her direct supervision) or review of as-built drawings for the purpose of determining if the work was completed in compliance with approved plans and specifications.

(e) As-built drawings shall be the permitted drawings revised to reflect any changes made during construction. Both the original and revised specifications must be clearly shown. The plans must be clearly labeled as "as-built" or "record" drawings. All surveyed dimensions and elevations required shall be certified by a registered surveyor. The following information, at a minimum, shall be verified on the as-built drawings:

1. Dimensions and elevations of all discharge structures including all weirs, slots, gates pumps, pipes, and oil and grease skimmers;

2. Locations, dimensions, and elevations of all filter, exfiltration, or underdrain systems including cleanouts, pipes, connections to control structures, and points of discharge to the receiving waters;

3. Dimensions, elevations, contours, or cross-sections of all treatment storage areas sufficient to determine stage-storage relationships of the storage area and the permanent pool depth and volume below the control elevation for normally wet systems, when appropriate;

4. Dimensions, elevations, contours, final grades, or cross-sections of the system to determine flow directions and conveyance of runoff to the treatment system;

5. Dimensions, elevations, contours, final grades, or cross-sections of all conveyance systems utilized to convey off-site runoff around the system;

6. Existing water elevation(s) and the date determined; and

7. Elevation and location of benchmark(s) for the survey.

(2) The operation phase of a stormwater management system permit which was not designed by an appropriate registered professional does not become effective until all of the criteria in this subsection, and subsection (3) below, have occurred. Within 30 days after completion of construction of the stormwater management system, permittee shall submit a certification, on form number 40C-1.181(14), As Built Certification, that the system has been constructed in accordance with the design approved by the District and shall notify the District that the system is ready for inspection.

(3) The permittee shall submit documentation to the District showing that adequate provisions have been made for the operation and maintenance of the system and for meeting any special permit conditions. Entities which qualify to operate and maintain systems for purposes of this rule are listed at section 40C-42.027, supra. Documentation must include an affirmative indication that the entity intends to or agrees to take over maintenance responsibility for the system, unless the transfer is associated with the conversion of the construction permit to its operation phase and the maintenenac entity exists as approved under the permit.

(4) The permit will be converted from a construction permit to an operation permit once the project is determined to be in compliance with the permitted plans and an appropriate entity exists for maintenance of the system. The District will transfer the permit to the maintenance entity upon request, pursuant to section 40C-4.351, F.A.C., once all conditions for converting the construction permit to an operation permit have been met.

Specific Authority 373.044, 373.113, 373.171, 373.418 FS. Law Implemented 373.413, 373.416 FS. History--New 9-25-91, 3-21-93. Amended 7-20-95.

40C-42.029 Monitoring and Operational Maintenance Requirements.

(1) The operation and maintenance entity is required to provide for periodic inspections of the stormwater management system to insure that the system is functioning as designed and permitted. The entity shall submit inspection reports to the District, certifying that the stormwater management system is operating as designed. In addition, the entity will state in the report what operational maintenance has been performed on the system. The reports shall only be required for those systems which are subject to operation phase permits pursuant to subsection 40C-42.028(1),

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F.A.C., after the effective date of this rule adoption, unless indicated otherwise in a permit. The reports shall be submitted to the District as follows unless otherwise required by a permit condition:

(a) Inspection reports for retention, underdrain, wet detention, swales, and wetland stormwater management systems shall be submitted two years after the completion of construction and every two years thereafter on form number 40C-1.181(15), Registered Professional's Inspection Report, for systems designed by a registered professional. For systems not designed by a registered professional, the inspection reports shall be submitted on form number 40C-1.181(16), Statement of Inspection Report. However, reports for those systems in sensitive karst areas must be submitted pursuant to paragraph (c) below.

(b) Inspection reports for dry detention, exfiltration, and pumped systems shall be submitted one year after the completion of construction and every two years thereafter on form number 40C-1.181(15), Registered Professional's Inspection Report. A registered professional must sign and seal the report certifying the dry detention, filtration, exfiltration, or pumped system is operating as designed. However, reports for those systems in sensitive karst areas must be submitted pursuant to paragraph (c) below.

(c) Systems in sensitive karst areas must be inspected monthly for the occurrence of sinkholes and solution pipes. The inspection reports for these systems must be submitted to the District annually on form number 40C-1.181(15), Registered Professional's Inspection Report, for systems designed by a registered professional. For systems not designed by a registered professional, the inspection reports shall be submitted on form number 40C-1.181(16), Statement of Inspection Report.

(2) Permittees which operate stormwater management systems that are designed and constructed to accept stormwater from multiple parcels within the drainage area served by the system shall notify the District annually of the stormwater discharge volumes of all new parcels which have been allowed to discharge into the system in the previous year and shall certify that the maximum allowable treatment volume of stormwater has not been exceeded.

(3) The following operational maintenance activities shall be performed on all permitted systems on a regular basis or as needed:

(a) Removal of trash and debris,

(b) Inspection of inlets and outlets,

(c) Removal of sediments when the storage volume or conveyance capacity of the stormwater management system is below design levels, and

(d) Stabilization and restoration of eroded areas.

(4) Specific operational maintenance activities are required, depending on the type of permitted system, in addition to the practices listed in subsection (3), above.

(a) Retention, swale and underdrain systems shall include provisions for:

1. Mowing and removal of grass clippings, and

2. Aeration, tilling, or replacement of topsoil as needed to restore the percolation capability of the system. If tilling or replacement of the topsoil is utilized, vegetation must be established on the disturbed surfaces.

(b) Exfiltration systems shall include provisions for removal of sediment and debris from sediment sumps.

(c) Wet detention systems shall include provisions for operational maintenance of the littoral zone. Replanting shall be required if the percentage of vegetative cover falls below the permitted level. It is recommended that native vegetation be maintained in the littoral zone as part of the system's operation and maintenance plan. Undesirable species such as cattail and exotic plants should be controlled if they become a nuisance.

(d) Dry detention systems shall include provisions for mowing and removal of grass clippings

(e) Systems in sensitive karst areas shall include provisions for the repair of any sinkhole or solution pipe that develops in the system.

(5) If the system is not functioning as designed and permitted, operational maintenance must be performed immediately to restore the system. If operational maintenance measures are insufficient to enable the system to meet the design and performance standards of this chapter, the permittee must either replace the system or construct an alternative design. A permit modification must be obtained from the District prior to constructing such alternative design pursuant to section 40C-4.331, F.A.C.

Specific Authority 373.044, 373.113, 373.171, 373.418 FS. Law Implemented 373.413, 373.416 FS. History--New 9-25-91. Amended 3-21-93, 4-11-94.

40C-42.031 Exemptions for Stormwater Management Systems.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 403.812, 403.814 FS. History--New 4-1-86. Amended 8-11-91. Repealed 9-25-91.

40C-42.032 Limiting Conditions.

(1) The Governing Board shall impose upon any permit granted pursuant to this Chapter such reasonable conditions as are necessary to assure that construction and operation of the permitted system will not be inconsistent with the District's permitting standards set forth in section 40C-42.023, F.A.C., and will not be harmful to the water resources of the District.

(2)(a) In addition to project-specific special conditions, the following standard limiting conditions shall be attached to all permits issued pursuant to this Chapter unless waived by the Board upon a determination that the conditions are inapplicable for the work authorized by a given permit:

1. This permit for construction will expire five years from the date of issuance unless otherwise specified by a special condition of the permit.

2. Permittee must obtain a permit from the District prior to beginning construction of subsequent phases or any other work associated with this project not specifically authorized by this permit.

3. Before any offsite discharge from the stormwater management system occurs, the retention and detention storage must be excavated to rough grade prior to building construction or placement of impervious surface within the area served by those systems. Adequate measures must be taken to prevent siltation of these treatment systems and control structures during construction or siltation must be removed prior to final grading and stabilization.

4. The permittee must maintain a copy of this permit complete with all conditions, attachments, exhibits, and permit modifications, in good condition at the construction site. The

complete permit must be available for review upon request by District representatives. The permittee shall require the contractor to review the complete permit prior to commencement of the activity authorized by this permit.

5. All activities shall be implemented as set forth in the plans, specifications and performance criteria as approved by this permit. Any deviation from the permitted activity and the conditions for undertaking that activity shall be considered a violation of this permit.

6. District authorized staff, upon proper identification, must be granted permission to enter, inspect and observe the system to insure conformity with the plans and specifications approved by the permit.

7. Prior to and during construction, the permittee shall implement and maintain all erosion and sediment control measures (best management practices) required to retain sediment on-site and to prevent violations of state water quality standards. All practices must be in accordance with the guidelines and specifications in chapter 6 of the Florida Land Development Manual: A Guide to Sound Land and Water Management (Florida Department of Environmental Regulation 1988), which are hereby incroporated by reference, unless a project specific erosion and sediment control plan is approved as part of the permit, in which case the practices must be in accordance with the plan. If site specific conditions require additional measures during any phase of construction or operation to prevent erosion or control sediment, beyond those specified in the erosion and sediment control plan, the permittee shall implement additional best management practices as necessary, in accordance with the specifications in chapter 6 of the Florida Land Development Manual: A Guide to Sound Land and Water Management (Florida Department of Environmental Regulation 1988). The permittee shall correct any erosion or shoaling that causes adverse impacts to the water resources.

8. If the permitted system was designed by a registered professional, within 30 days after completion of the stormwater system, the permittee must submit to the District the following: District Form No. 40C-1.181(13) (As Built Certification By a Registered Professional), signed and sealed by an appropriate professional registered in the State of Florida, and two (2) sets of "As Built" drawings when a) required by a special condition of this permit, b) the professional uses "As Built" drawings to support the As Built Certification, or c) when the completed system substantially differs from permitted plans. This submittal will serve to notify the District staff that the system is ready for inspection and approval.

9. If the permitted system was not designed by a registered professional, within 30 days after completion of the stormwater system, the permittee must submit to the District the following: District Form No. 40C-1.181(14) (As Built Certification), signed by the permittee and two (2) sets of "As Built" drawings when required by a special condition of this permit, or when the completed system substantially differs from permitted plans. This submittal will serve to notify the District staff that the system is ready for inspection and approval.

10. Stabilization measures shall be initiated for erosion and sediment control on disturbed areas as soon as practicable in portions of the site where construction activities have temporarily or permanently ceased, but in no case more than seven (7) days after the construction activity in that portion of the site has temporarily or permanently ceased.

11. Should any other regulatory agency require changes to the permitted system, the permittee shall provide written notification to the District of the changes prior to implementation so that a determination can be made whether a permit modification is required.

12. Within thirty (30) days after sale or conveyance of the permitted stormwater management system or the real property on which the system is located, the owner in whose name the permit was granted shall notify the District of such change of ownership. Transfer of this permit shall be in accordance with the provisions of section 40C-1.612, Florida Administrative Code. All terms and conditions of this permit shall be binding upon the transferee. The permittee transferring the permit shall remain liable for any corrective actions that may be required as a result of any permit violations prior to such sale, conveyance or other transfer.

13. The stormwater management system must be completed in accordance with the permitted plans and permit conditions prior to the initiation of the permitted use of site infrastructure. The system must be completed in accordance with the permitted plans and permit conditions prior to transfer of responsibility for operation and maintenance of the stormwater management system to a local government or other responsible entity.

14. The operation phase of the permit shall not become effective until the requirements of condition No. 8 or 9 have been met, the District determines that the system complies with the permitted plans, and the entity approved by the District in accordance with section 40C-42.027, F.A.C., accepts responsibility for operation and maintenance of the system. The permit cannot be transferred to such an approved responsible operation and maintenance entity until the requirements of section 40C-42.028, F.A.C., are met, and the operation phase of the permit becomes effective. Following inspection and approval of the permitted system by the District in accordance with section 40C-42.028, F.A.C., the permittee shall request transfer of the permit to the responsible approved operation and maintenance entity, if different from the permittee. Until the permit is transferred pursuant to subsection 40C-42.028(4), F.A.C., the permittee shall be liable for compliance with the terms of the permit.

15. Prior to lot or unit sales, or upon completion of construction of the system, whichever occurs first, the District must receive the final operation and maintenance document(s) approved by the District and recorded, if the latter is appropriate. For those systems which are proposed to be maintained by county or municipal entities, final operation and maintenance documents must be received by the District when maintenance and operation of the system is accepted by the local government entity. Failure to submit the appropriate final document will result in the permittee remaining personally liable for carrying out maintenance and operation of the permitted system.

16. This permit does not eliminate the necessity to obtain any required federal, state, local and special district authorizations prior to the start of any activity approved by this permit. This permit does not convey to the permittee or create in the permittee any property right, or any interest in real property, nor does it authorize any entrance upon or activities on property which is not owned or controlled by the permittee, or convey any rights or privileges other than those specified in the permit and Chapter 40C-42, F.A.C.

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17. The permittee shall hold and save the District harmless from any and all damages, claims, or liabilities which may arise by reason of the activities authorized by the permit or any use of the permitted system.

18. The permittee shall immediately notify the District in writing of any previously submitted information that is later discovered to be inaccurate.

19. Activities approved by this permit shall be conducted in a manner which do not cause violations of state water quality standards.

(b) This section shall not be construed as a limitation on the authority of the Board to impose such other limiting conditions as may be necessary in order to assure that the permitted system is consistent with the requirements for issuance listed in section 40C-42.023, F.A.C.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.409, 373.413, 373.416, 373.419, 373.423, 373.426 FS. History--New 3-21-93, 10-3-95.

40C-42.033 Implementation.

(1) This chapter shall become effective on September 25, 1991.

(2)(a) Each construction permit issued under chapter 40C-42, F.A.C., prior to the effective date of this rule shall remain valid according to its terms.

(b) Each construction permit application which is filed with the District prior to the effective date of this rule will be processed and evaluated under the rules implemented on April 1, 1986.

(c) Each construction permit application which is not filed with the District prior to September 25, 1991, will be processed and evaluated according to the rule provisions implemented on September 25, 1991.

(3) If the validity of any provisions of chapter 40C-42, F.A.C., or the application thereof to any person or circumstance is challenged pursuant to Chapter 120 or 373, F.S., or pursuant to any other basis in law, it is the intent of the Governing Board of the St. Johns River Water Management District that neither a challenge to the validity of a provision or application thereof nor the invalidation of a provision or application thereof shall affect the validity or application of other provisions of the rule which can be given effect without the challenged or invalidated provision or application and to this end the provisions of chapter 40C-42, F.A.C., are declared severable.

Specific Authority 373.044, 373.113, 373.171, 373.429 FS. Law Implemented 373.416 FS. History--New 9-25-91.

40C-42.035 Stormwater General Permits.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 403.812, 403.814 FS. History--New 4-1-86. Repealed 9-25-91.

40C-42.041 Individual Permit Requirements for New Stormwater Discharge Facilities.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 403.812, 403.814 FS. History--New 4-1-86. Repealed 9-25-91.

40C-42.061 Relationship to Other Permitting Requirements.

(1) Whenever the construction, alteration, removal, operation, maintenance, or abandonment of a stormwater management system requires that an environmental resource permit be secured pursuant to Chapters 40C-4 or 40C-40 , F.A.C., the requirements in this chapter shall be reviewed as part of those permit applications. A separate permit application under this chapter shall not be required. However, the applicant must provide the required technical information as part of those applications to demonstrate compliance with this chapter. If the applicant requests a separate environmental resource stormwater permit, the applicant must notify the District of any other District permits, exemptions, or certifications which have or will be requested for the project.

(2) When a permit is required pursuant to this chapter and an individual environmental resource permit is required pursuant to chapter 40C-4 for the same system, the time frames of chapter 40C-4 shall apply to issuance of a permit under section 40C-42.024(2), F.A.C.

(3) This rule does not apply to any stormwater discharge facility listed in (a) and (b) below, unless such facility is modified pursuant to section 40C-42.024, F.A.C.:

(a) Which was in existence on February 1, 1982; or

(b) Which was permitted, modified, or found to be exempt, under Chapter 62-25, F.A.C., by the Department of Environmental Regulation (DER) after February 1, 1982, but prior to April 1, 1986, provided the facility was constructed in accordance with the DER permit or exemption, and is functioning in accordance with the requirements of chapter 62-25, F.A.C.

(4) The operation phase permit requirements set forth in subsection 40C-42.028(1), F.A.C., shall not apply to systems permitted and found to be in compliance with all rule requirements prior to the effective date of this rule.

(5) Applications for conceptual agency review of stormwater management systems, as required by section 380.06, F.S., will be reviewed in accordance with the procedure used by the District to review conceptual approval permit applications pursuant to subsection 40C-4.041(2), F.A.C.

(6) Systems for agricultural lands will be regulated under chapter 40C-44, F.A.C.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.413, 373.416, 380.06(9) FS. History--New 4-1-86. Amended 9-25-91, 3-21-93, 4-11-94, 7-20-95, 8-3-95.

40C-42.071 Permit Processing Fee. There shall be a non-refundable permit processing fee as specified by section 40C-1.603, F.A.C., payable to the District at the time that an application for a permit is submitted.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.109, 373.113 FS. History--New 4-1-86. Amended 9-25-91.

40C-42.081 General Provisions. Nothing under this chapter shall preclude:

(1) Stormwater effects from being considered in the evaluation of other types of permits where such consideration is relevant to a determination of compliance with applicable District requirements.

(2) The legal joinder in a permitting proceeding under this chapter of any person who owns or controls an unpermitted stormwater management system or systems which comprise a significant portion of the stormwater management system.

(3) The District from taking appropriate legal action including but not limited to the requiring of a permit to prevent the impairment of a use for which a water of the state has been designated under chapter 62-3, F.A.C.

(4) The District from entering interagency or interlocal agreements to accomplish the provisions of this chapter.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 403.812, 403.814 FS. History--New 4-1-86. Amended 9-25-91.

40C-42.091 Publications Incorporated by Reference.

(1) The Governing Board adopts by reference Part I "Policy and Procedures", Part II, "Criteria for Evaluation", and Part III "Operation and Maintenance", of the document entitled "Applicant's Handbook: Regulation of Stormwater Management Systems, Chapter 40C-42, F.A.C.", effective 10-3-95.

(2) This document provides information regarding the stormwater management system permitting program

(3) A copy of this document may be obtained by contacting:
Director, Division of Permitting Data Services,
St. Johns River Water Management District,
P.O. Box 1429,
Palatka, Florida 32178-1429

St. Johns River Water Management District,
7775 Baymeadows Way, Suite 102
Jacksonville, Florida 32256

St. Johns River Water Management District,
618 East South Street, Suite 200,
Orlando, Florida 32801

St. Johns River Water Management District,
305 East Drive,
Melbourne, Florida 32904

Specific Authority 120.54(8), 373.044, 373.113, 373.171, 373.418 F.S. Law Implemented 373.413, 373.416, 373.426. History--New 4-11-94. Amended 7-20-95, 10-3-95.

40C-42.900 Forms and Instructions. The following forms and instructions incorporated by reference have been approved the Governing Board and are available upon request from:

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Department of Resource Management
St. Johns River Water Management District
P.O.Box 1429
Palatka, Florida 32178-1429.

(1) Joint Application For Environmental Resource Permit/Authorization to Use State Lands/Federal Dredge and Fill Permit , form number 40C-4.900(1) adopted 10-3-95 .

(2) As Built Certification by a Registered Professional, form number 40C-1.181(13), adopted March 21, 1993.

(3) As Built Certification, form number 40C-1.181(14), adopted 3-21-93.

(4) Registered Professional's Inspection Report, form number 40C-1.181(15), adopted 3-21-93.

(5) Statement of Inspection Report, form number 40C-1.181(16), adopted 3-21-93.

Specific Authority 120.53(1), 373.044, 373.113, 373.118 FS. Law Implemented 120.52(16), 120.53(1), 373.085, 373.116, 373.118, 373.103, 373.106, 373.229, 373.413 FS. History--New 5-30-90. Amended 9-25-91, 3-21-93, 2-27-94, 10-3-95.

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General NPDES Permit No. ILR40

Illinois Environmental Protection Agency
Division of Water Pollution Control
1021 North Grand East
P.O. Box 19276
Springfield, Illinois 62794-9276

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

General NPDES Permit
For
Discharges from Small Municipal Separate Storm Sewer Systems

Expiration Date:	February 29, 2008	**Issue Date:**	December 20, 2002
		Effective Date:	March 1, 2003

Discharges authorized by this General Permit: In compliance with the provisions of the Illinois Environmental Protection Act, the Illinois Pollution Control Board Rules and Regulations (35 Ill. Adm. Code, Subtitle C, Chapter 1) and the Clean Water Act, the following discharges may be authorized by this permit in accordance with the conditions herein:

Discharges of storm water from small municipal separate storm sewer systems, as defined and limited herein. Storm water means storm water runoff, snow melt runoff, and surface runoff and drainage.

This general permit regulates only storm water discharges. Other discharges such as process wastewater or cooling water shall be regulated by other NPDES permits.

Receiving waters: Discharges may be authorized to any surface water of the State.

To receive authorization to discharge under this general permit, a facility operator must submit an application as described in the permit conditions to the Illinois Environmental Protection Agency. Authorization, if granted, will be by letter and include a copy of this permit.

Thomas G. McSwiggin, P.E.
Manager, Permit Section
Division of Water Pollution Control

ILR40.wpd

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PART I. COVERAGE UNDER THIS PERMIT

A. Permit Area

This permit covers all areas of the State of Illinois.

B. Eligibility

1. This permit authorizes discharges of storm water from small municipal separate storm sewer systems (MS4s) as defined in 40 CFR 122.26(b)(16) as designated for permit authorization pursuant to 40 CFR 122.32.

2. This permit authorizes the following non-storm water discharges provided they have been determined not to be substantial contributors of pollutants to a particular small MS4 applying for coverage under this permit:

   - water line and fire hydrant flushing,
   - landscape irrigation water,
   - rising ground waters,
   - ground water infiltration,
   - pumped ground water,
   - discharges from potable water sources,
   - foundation drains,
   - air conditioning condensate,
   - irrigation water, (except for wastewater irrigation),
   - springs,
   - water from crawl space pumps,
   - footing drains,
   - storm sewer cleaning water,
   - water from individual residential car washing,
   - routine external building washdown which does not use detergents,
   - flows from riparian habitats and wetlands,
   - dechlorinated pH neutral swimming pool discharges,
   - residual street wash water,
   - discharges or flows from fire fighting activities
   - dechlorinated water reservoir discharges, and
   - pavement washwaters where spills or leaks of toxic or hazardous materials have not occurred (unless all spilled material has been removed).

3. Any municipality covered by this general permit is also granted automatic coverage under Permit No. ILR10 for the discharge of storm water associated with construction site activities for municipal construction projects disturbing one acre or more. The permittee shall comply with all the requirements of Permit ILR10 for all such construction projects.

C. Limitations on Coverage

The following discharges are not authorized by this permit:

1. Storm water discharges that are mixed with non-storm water or storm water associated with industrial activity unless such discharges are:

   a. in compliance with a separate NPDES permit, or

   b. identified by and in compliance with Part I.B.2 of this permit.

2. Storm water discharges that the Agency determines are not appropriately covered by this general permit.

D. Obtaining Authorization

In order for storm water discharges from small municipal separate storm sewer systems to be authorized to discharge under this general permit, a discharger must:

1. Submit a Notice of Intent (NOI) in accordance with the requirements of Part II using an NOI form provided by the Agency (or a photocopy thereof) or the appropriate U.S. EPA NOI form.

2. Where the operator changes, or where a new operator is added after the submittal of an NOI under Part II, a new NOI must be submitted in accordance with Part II within 30 days of the change.

3. Unless notified by the Agency to the contrary, dischargers who submit an NOI in accordance with the requirements of this permit are authorized to discharge storm water from small municipal separate storm sewer systems under the terms and conditions of this permit 30 days after the date that the NOI is received. The Agency may deny coverage under this permit and require submittal of an application for an individual NPDES permit based on a review of the NOI or other information.

PART II. NOTICE OF INTENT REQUIREMENTS

A. Deadlines for Notification

1. If you are an operator of a regulated small municipal separate storm sewer system designated under § 122.32(a)(1), you must apply for coverage under an NPDES permit, or apply for a modification of an existing NPDES permit by March 10, 2003.

2. If you are an operator of a regulated small municipal separate storm sewer system designated under § 122.32(a)(2), you must apply for coverage under an NPDES permit, or apply for a modification of an existing NPDES permit within 180 days of notice, from the Agency or by a later date as specified by the Agency.

3. Submitting a late NOI. You are not prohibited from submitting an NOI after the dates provided in Part II.A.1 and II.A.2. If a late NOI is submitted, your authorization is only for discharges that occur after permit coverage is granted. The Agency reserves the right to take appropriate enforcement actions for any unpermitted discharges.

B. Contents of Notice of Intent

Dischargers seeking coverage under this permit shall submit either the Illinois MS4 NOI form or the U.S. EPA MS4 NOI form. The Notice(s) of Intent shall be signed in accordance with Standard Condition 11 of this permit and shall include the following information:

1. The street address, county, and the latitude and longitude of the municipal office for which the notification is submitted;

2. The name, address, and telephone number of the operator(s) filing the NOI for permit coverage;

3. The name of the receiving water(s); and

4. The following shall be provided as an attachment to the NOI:

   a. the best management practices (BMPs) to be implemented and the measurable goals for each of the storm water minimum control measures in paragraph IV. B. of this permit designed to reduce the discharge of pollutants to the maximum extent practicable;

   b. the month and year in which you will start and fully implement each of the minimum control measures or indicate the frequency of the action;

   c. the person or persons responsible for implementing or coordinating your storm water management program; and

   d. identification of a local qualifying program if any.

C. The required information shall be submitted to the following address:

Illinois Environmental Protection Agency
Division of Water Pollution Control
Permit Section
Post Office Box 19276
Springfield, Illinois 62794-9276

D. Shared Responsibilities

You may partner with other MS4s to develop and implement your storm water management program. You may also jointly submit an NOI with one or more MS4s. Each MS4 must fill out the NOI form. The description of your storm water management program must clearly describe which permittees are responsible for implementing each of the control measures.

PART III. SPECIAL CONDITIONS

A. Your discharges, alone or in combination with other sources, shall not cause or contribute to a violation of any applicable water quality standard outlined in 35 Ill. Adm. Code 302.

B. If there is evidence indicating that the storm water discharges authorized by this permit cause, or have the reasonable potential to cause or contribute to a violation of water quality standard, you may be required to obtain an individual permit or an alternative general permit or the permit may be modified to include different limitations and/or requirements.

C. If a total maximum daily load (TMDL) allocation or watershed management plan is approved for any waterbody into which you discharge, you must review your storm water management program to determine whether the TMDL or watershed management plan includes requirements for control of storm water discharges. If you are not meeting the TMDL allocations, you must modify your storm water management program to implement the TMDL or watershed management plan within eighteen months of notification by the Agency of the TMDL's approval. Where a TMDL or watershed management plan is approved, you must:

1. Determine whether the approved TMDL is for a pollutant likely to be found in storm water discharges from your MS4.

2. Determine whether the TMDL includes a pollutant wasteload allocation (WLA) or other performance requirements specifically for storm water discharge from your MS4.

3. Determine whether the TMDL addresses a flow regime likely to occur during periods of storm water discharge.

4. After the determinations above have been made and if it is found that your MS4 must implement specific WLA provisions of the TMDL, assess whether the WLAs are being met through implementation of existing storm water control measures or if additional control measures are necessary.

5. Document all control measures currently being implemented or planned to be implemented. Also include a schedule of implementation for all planned controls. Document the calculations or other evidence that shows that the WLA will be met.

6. Describe and implement a monitoring program to determine whether the storm water controls are adequate to meet the WLA.

7. If the evaluation shows that additional or modified controls are necessary, describe the type and schedule for the control additions/revisions. Continue Paragraphs 4 above through 7 until two continuous monitoring cycles show that the WLAs are being met or that WQ standards are being met.

D. If this permit is not reissued or replaced prior to the expiration date, it will be administratively continued in accordance with the Administrative Procedures Act and remain in force and effect. Any permittee who was granted permit coverage prior to the expiration date will automatically remain covered by the continued permit until the earlier of:

1. Reissuance or replacement of this permit, at which time you must comply with the Notice of Intent conditions of the new permit to maintain authorization to discharge; or

2. Your submittal of a Notice of Termination; or

3. Issuance of an individual permit for your discharges; or

4. A formal permit decision by the Agency not to reissue this general permit at which time you must seek coverage under an alternative general permit or an individual permit.

E. The Agency may require any person authorized to discharge by this permit to apply for and obtain either an individual NPDES permit or an alternative NPDES general permit. Any interested person may petition the Agency to take action under this paragraph. The Agency may require any owner or operator authorized to discharge under this permit to apply for an individual NPDES permit only if the owner or operator has been notified in writing that a permit application is required. This notice shall include a brief statement of the reasons for this decision, an application form, a statement setting a deadline for the owner or operator to file the application, and a statement that on the effective date of the individual NPDES permit or the alternative general permit as it applies to the individual permittee, coverage under this general permit shall automatically terminate. The Agency may grant additional time to submit the application upon request of the applicant. If an owner or operator fails to submit in a timely manner an individual NPDES permit application required by the Agency under this paragraph, then the applicability of this permit to the individual NPDES permittee is automatically terminated at the end of the day specified for application submittal.

F. Any owner or operator authorized by this permit may request to be excluded from the coverage of this permit by applying for an individual permit. The owner or operator shall submit an individual application with reasons supporting the request, in accordance with the requirements of 40 CFR 122.28, to the Agency. The request will be granted by issuing an individual permit or an alternative general permit if the reasons cited by the owner or operator are adequate to support the request.

G. When an individual NPDES permit is issued to an owner or operator otherwise subject to this permit, or the owner or operator is approved for coverage under an alternative NPDES general permit, the applicability of this permit to the individual NPDES permittee is automatically terminated on the issue date of the individual permit or the date of approval for coverage under the alternative general permit, whichever the case may be.

H. When an individual NPDES permit is denied to an owner or operator otherwise subject to this permit, or the owner or operator is denied coverage under an alternative NPDES general permit the applicability of this permit to the individual NPDES permitted is automatically terminated on the date of such denial, unless otherwise specified by the Agency.

PART IV. STORM WATER MANAGEMENT PROGRAMS

A. Requirements

You must develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from your small municipal separate storm sewer system to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Illinois Pollution Control Board Rules and Regulations (35 Ill. Adm. Code, Subtitle C, Chapter 1) and the Clean Water Act. Your storm water management program must include the minimum control measures described in section B of this Part. You must develop and implement your program by five years from your coverage date under this permit.

B. Minimum Control Measures

The 6 minimum control measures to be included in your storm water management program are:

1. Public education and outreach on storm water impacts

You must:

a. implement a public education program to distribute educational materials to the community or conduct equivalent outreach activities about the impacts of storm water discharges on water bodies and the steps that the public can take to reduce pollutants in storm water runoff; and

b. define appropriate BMPs for this minimum control measure and measurable goals for each BMP. These measurable goals must ensure the reduction of all of the pollutants of concern in your storm water discharges to the maximum extent practicable.

2. Public Involvement/Participation

You must:

a. at a minimum, comply with State and local public notice requirements when implementing a public involvement/ participation program; and

b. define appropriate BMPs for this minimum control measure and measurable goals for each BMP, which must ensure the reduction of all of the pollutants of concern in your storm water discharges to the maximum extent practicable.

3. Illicit discharge detection and elimination

You must:

a. develop, implement and enforce a program to detect and eliminate illicit discharges into your small MS4;

b. develop, if not already completed, a storm sewer system map, showing the location of all outfalls and the names and location of all waters that receive discharges from those outfalls;

c. to the extent allowable under state or local law, effectively prohibit, through ordinance, or other regulatory mechanism, non-storm water discharges into your storm sewer system and implement appropriate enforcement procedures and actions;

d. develop, implement, and adequately fund a plan to detect and address non-storm water discharges, including illegal dumping, to your system;

e. inform public employees, businesses, and the general public of hazards associated with illegal discharges and improper disposal of waste;

f. address the categories of non-storm water discharges listed in Section I.B.2 only if you identify them as significant contributor of pollutants to your small MS4 (discharges or flows from the fire fighting activities are excluded from the effective prohibition against non-storm water and need only be addressed where they are identified as significant sources of pollutants to waters of the United States); and

g. define appropriate BMPs for this minimum control measure and measurable goals for each BMP. These measurable goals must ensure the reduction of all of the pollutants of concern in your storm water discharges to the maximum extent practicable.

4. Construction site storm water runoff control

You must:

a. develop, implement, and enforce a program to reduce pollutants in any storm water runoff to your small MS4 from construction activities that result in a land disturbance of greater than or equal to one acre. Reduction of storm water discharges from construction activity disturbing less than one acre must be included in your program if that construction activity is part of a larger common plan of development or sale that would disturb one acre or more or has been designated by the permitting authority.

Your program must include the development and implementation of, at a minimum:

i. an ordinance or other regulatory mechanism to require erosion and sediment controls, as well as sanctions to ensure compliance, to the extent allowable under state or local law;

ii. requirements for construction site operators to implement appropriate erosion and sediment control best management practices;

iii. requirements for construction site operators to control waste such as discarded building materials, concrete truck washout, chemicals, litter, and sanitary waste at the construction site that may cause adverse impacts to water quality;

iv. require all regulated construction sites to have a storm water pollution prevention plan that meets the requirements of Part IV of NPDES permit No. ILR10 including management practices, controls, and other provisions at least as protective as the requirements contained in the Illinois Urban Manual, 2002;

v. procedures for site plan review which incorporate consideration of potential water quality impacts and review of individual pre-construction site plans to ensure consistency with local sediment and erosion control requirements;

vi. procedures for receipt and consideration of information submitted by the public; and

vii. procedures for site inspections and enforcement of control measures.

b. define appropriate BMPs for this minimum control measure and measurable goals for each BMP. These measurable goals must ensure the reduction of all of the pollutants of concern in your storm water discharges to the maximum extent practicable.

5. Post-construction storm water management in new development and redevelopment

You must:

a. develop, implement, and enforce a program to address storm water runoff from new development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale or that have been designated to protect water quality, that discharge into your small MS4. Your program must ensure that controls are in place that would protect water quality and reduce the discharge of pollutants to the maximum extent practicable;

b. develop and implement strategies which include a combination of structural and/or non-structural BMPs appropriate for your community that will reduce the discharge of pollutants to the maximum extent practicable;

c. use an ordinance or other regulatory mechanism to address post-construction runoff from new development and redevelopment projects to the extent allowable under state or local law;

d. require all regulated construction sites to have post-construction management that meets or exceeds the requirements of Section IV (D)(2)(b) of NPDES permit No. ILR10 including management practices, controls, and other provisions at least as protective as the requirements contained in the Illinois Urban Manual, 2002;

e. ensure adequate long-term operation and maintenance of BMPs; and

f. define appropriate BMPs for this minimum control measure and measurable goals for each BMP. These measurable goals must ensure the reduction of all of the pollutants of concern in your storm water discharges to the maximum extent practicable.

6. Pollution prevention/good housekeeping for municipal operations

You must:

a. develop and implement an operation and maintenance program that includes a training component and is designed to prevent and reduce the discharge of pollutants to the maximum extent practicable;

b. using training materials that are available from EPA, the state of Illinois, or other organizations, your program must include employee training to prevent and reduce storm water pollution from activities such as park and open space maintenance, fleet and building maintenance, operation of storage yards, snow disposal, new construction and land disturbances, and storm water system maintenance procedures for proper disposal of street cleaning debris and catch basin material, address ways that flood management projects impact water quality, nonpoint source pollution control, and aquatic habitat; and

c. define appropriate BMPs for this minimum control measure and measurable goals for each BMP. These measurable goals must ensure the reduction of all of the pollutants of concern in your storm water discharges to the maximum extent practicable.

C. Qualifying State, County, or Local Program

If an existing qualifying local program requires you to implement one or more of the minimum control measures of B. above, you may follow that qualifying program's requirements rather than the requirements of B. above. A qualifying local program is a local, county or state municipal storm water management program that imposes, at a minimum, the relevant requirements of Section B. Any qualifying local programs that you intend to follow shall be specified in your storm water management plan.

D. Sharing Responsibility

1. Implementation of one or more of the minimum measures may be shared with another entity, or the entity may fully take over the measure. You may rely on another entity only if:

a. The other entity, in fact, implements the control measure;

b. The particular control measure, or component of that measure is at least as stringent as the corresponding permit requirement.

c. The other entity agrees to implement the control measure on your behalf. Written acceptance of this obligation is expected. This obligation must be maintained as part of the description of your storm water management program. If the other entity agrees to report on the minimum measure, you must supply the other entity with the reporting requirements contained in Section V (C) of this permit. If the other entity fails to implement the control measure on your behalf, then you remain liable for any discharges due to that failure to implement.

E. Reviewing and Updating Storm Water Management Programs

1. Storm Water Management Program Review: You must do an annual review of your Storm Water Management Program in conjunction with preparation of the annual report required under Part V.(C).

2. Storm Water Management Program Update: You may change your Storm Water Management Program during the life of the permit in accordance with the following procedures:

a. Changes adding (but not subtracting or replacing) components, controls, or requirements to the Storm Water Management Program may be made at any time upon written notification to the Agency; and

b. Changes replacing an ineffective or unfeasible BMP specifically identified in the Storm Water Management Program with an alternate BMP may be requested at any time. Unless denied by the Agency, changes proposed in accordance with the criteria below shall be deemed approved and may be implemented 60 days from submittal of the request. If request is denied, the Agency will send you a written response giving a reason for the decision. Your modification requests must include the following:

1. An analysis of why the BMP is ineffective or infeasible (including cost prohibitive);

2. Expectations on the effectiveness of the replacement BMP; and

3. An analysis of why the replacement BMP is expected to achieve the goals of the BMP to be replaced.

c. Change requests or notifications must be made in writing and signed in accordance with Standard Condition II of Attachment H.

3. Storm Water Management Program Updates Required by the Agency. The Agency may require changes to the Storm Water Management Program as needed to:

   a. Address impacts on receiving water quality caused, or contributed to, by discharges from the municipal separate storm sewer system;

   b. Include more stringent requirements necessary to comply with new federal statutory or regulatory requirements; or

   c. Include such other conditions deemed necessary by the Agency to comply with the goals and requirements of the Clean Water Act.

   d. Changes requested by the Agency must be made in writing, set forth the time schedule for you to develop the changes, and offer you the opportunity to propose alternative program changes to meet the objective of the requested modification. All changes required by the Permitting Authority will be made in accordance with 40 CFR 124.5, 40 CFR 122.62, or as appropriate 40 CFR 122.63.

PART V. MONITORING, RECORDKEEPING AND REPORTING

A. Monitoring

You must evaluate program compliance, the appropriateness of your identified best management practices, and progress towards achieving your identified measurable goals, which must include reducing the discharge of pollutants to the maximum extent practicable (MEP).

B. Recordkeeping

You must keep records required by this permit for at least 3 years. All records shall be kept onsite or locally available and shall be made accessible to the Agency for review at the time of an on-site inspection. You must submit your records to the Agency only when specifically asked to do so. You must make your records, including your notice of intent (NOI) and your storm water management plan, available to the public at reasonable times during regular business hours within 10 working days of its approval by the permitting authority. (You may assess a reasonable charge for copying. You may require a member of the public to provide advance notice, not to exceed seven working days.) Storm sewer maps may be withheld for security reasons.

C. Reporting

You must submit annual reports to the Agency by the first day of June for each year that this permit is in effect. The first report is due June 1, 2004. Each report shall cover the period from March of the previous year through March of the current year. Your report must include:

1. The status of compliance with permit conditions, an assessment of the appropriateness of your identified best management practices and progress towards achieving the statutory goal of reducing the discharge of pollutants to the MEP, and your identified measurable goals for each of the minimum control measures;

2. Results of information collected and analyzed, including monitoring data, if any, during the reporting period;

3. A summary of the storm water activities you plan to undertake during the next reporting cycle (including an implementation schedule);

4. A change in any identified best management practices or measurable goals that apply to the program elements; and

5. Notice that you are relying on another government entity to satisfy some of your permit obligations (if applicable).

6. Municipal storm water inspection reports shall be submitted to the following address:

   Illinois Environmental Protection Agency
   Division of Water Pollution Control
   Compliance Assurance Section
   Municipal Annual Inspection Report
   1021 North Grand Avenue East
   P.O. Box 19276
   Springfield, Illinois 62794-9276

General NPDES Permit No. ILR40

PART VI. DEFINITIONS AND ACRONYMS (SEE ALSO SPECIAL CONDITIONS)

All definitions contained in Section 502 of the Clean Water Act, 40 CFR 122, and 35 Ill. Adm. Code 309 shall apply to this permit and are incorporated herein by reference. For convenience, simplified explanations of some regulatory/statutory definitions have been provided, but in the event of a conflict, the definition found in the statute or regulation takes precedence.

Best Management Practices (BMPs) means schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the state. BMPs also include treatment requirements, operating procedures, and practices to control runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

BMP is an acronym for “Best Management Practices.”

CFR is an acronym for “Code of Federal Regulations.”

Control Measure as used in this permit, refers to any Best Management Practice or other method used to prevent or reduce the discharge of pollutants to waters of the United States.

CWA or The Act means the Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972) Pub. L. 92-500, as amended Pub. L. 95-217, Pub. L. 95-576, Pub. L. 96-483 and Pub. L. 97-117, 33 U.S.C. 1251 et. seq.

Discharge, when used without a qualifier, refers to discharge of a pollutant as defined at 40 CFR 122.2.

Illicit Connection means any man-made conveyance connecting an illicit discharge directly to a municipal separate storm sewer.

Illicit Discharge is defined at 40 CFR 122.26(b)(2) and refers to any discharge to a municipal separate storm sewer that is not composed entirely of storm water, except discharges authorized under an NPDES permit (other than the NPDES permit for discharges from the MS4) and discharges resulting from fire fighting activities.

MEP is an acronym for "Maximum Extent Practicable," the technology-based discharge standard for Municipal Separate Storm Sewer Systems to reduce pollutants in storm water discharges that was established by CWA Section 402(p). A discussion of MEP as it applies to small MS4s is found at 40 CFR 122.34.

MS4 is an acronym for "Municipal Separate Storm Sewer System" and is used to refer to either a Large, Medium, or Small Municipal Separate Storm Sewer System (e.g. "the Dallas MS4"). The term is used to refer to either the system operated by a single entity or a group of systems within an area that are operated by multiple entities (e.g., the Houston MS4 includes MS4s operated by the city of Houston, the Texas Department of Transportation, the Harris County Flood Control District, Harris County, and others).

Municipal Separate Storm Sewer is defined at 40 CFR 122.26(b)(8) and means a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains): (i) Owned or operated by a State, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State law) having jurisdiction over disposal of sewage, industrial wastes, storm water, or other wastes, including special districts under State law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under Section 208 of the CWA that discharges to waters of the United States; (ii) Designed or used for collecting or conveying storm water; (iii) Which is not a combined sewer; and (iv) Which is not part of a Publicly Owned Treatment Works (POTW) as defined at 40 CFR 122.2.

NOI is an acronym for “Notice of Intent” to be covered by this permit and is the mechanism used to “register” for coverage under a general permit.

NPDES is an acronym for “National Pollutant Discharge Elimination System.”

Outfall is defined at 40 CFR 122.26(b)(9) and means a point source as defined by 40 CFR 122.2 at the point where a municipal separate storm sewer discharges to waters of the United States and does not include open conveyances connecting two municipal storm sewers, or pipes, tunnels or other conveyances which connect segments of the same stream or other waters of the United States and are used to convey waters of the United States.

Owner or Operator is defined at 40 CFR 122.2 and means the owner or operator of any “facility or activity” subject to regulation under the NPDES program.

Permitting Authority means the Illinois EPA.

Point Source is defined at 40 CFR 122.2 and means any discernable, confined and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural storm water runoff.

Qualifying Local Program is defined at 40 CFR 122.34(c) and means a local, state, or Tribal municipal storm water management program that imposes, at a minimum, the relevant requirements of paragraph (b) of Section 122.34.

Small Municipal Separate Storm Sewer System is defined at 40 CFR 122.26(b)(16) and refers to all separate storm sewers that are owned or operated by the United States, a State [sic], city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State [sic] law) having jurisdiction over disposal of sewage, industrial wastes, storm water, or other wastes, including special districts under State law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under Section 208 of the CWA that discharges to waters of the United States, but is not defined as "large" or "medium" municipal separate storm sewer system. This term includes systems similar to separate storm sewer systems in municipalities, such as systems at military bases, large hospital or prison complexes, and highways and other thoroughfares. The term does not include separate storm sewers in very discrete areas, such as individual buildings.

Storm Water is defined at 40 CFR 122.26(b)(13) and means storm water runoff, snowmelt runoff, and surface runoff and drainage.

Storm Water Management Program (SWMP) refers to a comprehensive program to manage the quality of storm water discharged from the municipal separate storm sewer system.

SWMP is an acronym for "Storm Water Management Program."

TMDL is an acronym for "Total Maximum Daily Load."

Waters (also referred to as waters of the state or receiving water) is defined at Section 301.440 of Title 35: Subtitle C: Chapter I of the Illinois Pollution Control Board Regulations and means all accumulations of water, surface and underground, natural, and artificial, public and private, or parts thereof, which are wholly or partially within, flow through, or border upon the State of Illinois, except that sewers and treatment works are not included except as specially mentioned; provided, that nothing herein contained shall authorize the use of natural or otherwise protected waters as sewers or treatment works except that in-stream aeration under Agency permit is allowable.

"You" and "Your" as used in this permit is intended to refer to the permittee, the operator, or the discharger as the context indicates and that party's responsibilities (e.g., the city, the country, the flood control district, the U.S. Air Force, etc.).

MS4 PERMIT ILR40.DOC

General NPDES Permit No. ILR40

Attachment H
Standard Conditions
Definitions

Act means the Illinois Environmental Protection Act, 415 ILCS 5 as Amended.

Agency means the Illinois Environmental Protection Agency.

Board means the Illinois Pollution Control Board.

Clean Water Act (formerly referred to as the Federal Water Pollution Control Act) means Pub. L 92-500, as amended. 33 U.S.C. 1251 et seq.

NPDES (National Pollutant Discharge Elimination System) means the national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 402, 318 and 405 of the Clean Water Act.

USEPA means the United States Environmental Protection Agency.

Daily Discharge means the discharge of a pollutant measured during a calendar day or any 24-hour period that reasonably represents the calendar day for purposes of sampling. For pollutants with limitations expressed in units of mass, the Adaily discharge@ is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurements, the Adaily discharge@ is calculated as the average measurement of the pollutant over the day.

Maximum Daily Discharge Limitation (daily maximum) means the highest allowable daily discharge.

Average Monthly Discharge Limitation (30 day average) means the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.

Average Weekly Discharge Limitation (7 day average) means the highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges measured during that week.

Best Management Practices (BMPs) means schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the State. BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Aliquot means a sample of specified volume used to make up a total composite sample.

Grab Sample means an individual sample of at least 100 milliliters collected at a randomly-selected time over a period not exceeding 15 minutes.

24 Hour Composite Sample means a combination of at least 8 sample aliquots of at least 100 milliliters, collected at periodic intervals during the operating hours of a facility over a 24-hour period.

8 Hour Composite Sample means a combination of at least 3 sample aliquots of at least 100 milliliters, collected at periodic intervals during the operating hours of a facility over an 8-hour period.

Flow Proportional Composite Sample means a combination of sample aliquots of at least 100 milliliters collected at periodic intervals such that either the time interval between each aliquot or the volume of each aliquot is proportional to either the stream flow at the time of sampling or the total stream flow since the collection of the previous aliquot.

(1) Duty to comply. The permittee must comply with all conditions of this permit. Any permit noncompliance constitutes a violation of the Act and is grounds for enforcement action, permit termination, revocation and reissuance, modification, or for denial of a permit renewal application. The permittee shall comply with effluent standards or prohibitions established under Section 307(a) of the Clean Water Act for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.

(2) Duty to reapply. If the permittee wishes to continue an activity regulated by this permit after the expiration date of this permit, the permittee must apply for and obtain a new permit. If the permittee submits a proper application as required by the Agency no later than 180 days prior to the expiration date, this permit shall continue in full force and effect until the final Agency decision on the application has been made.

(3) Need to halt or reduce activity not a defense. It shall not be a defense for a permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this permit.

(4) Duty to mitigate. The permittee shall take all reasonable steps to minimize or prevent any discharge in violation of this permit which has a reasonable likelihood of adversely affecting human health or the environment.

(5) Proper operation and maintenance. The permittee shall at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the permittee to achieve compliance with conditions of this permit. Proper operation and maintenance includes effective performance, adequate funding, adequate operator staffing and training, and adequate laboratory and process controls, including appropriate quality assurance procedures. This provision requires the operation of back-up, or auxiliary facilities, or similar systems only when necessary to achieve compliance with the conditions of the permit

(6) Permit actions. This permit may be modified, revoked and reissued, or terminated for cause by the Agency pursuant to 40 CFR 122.62. The filing of a request by the permittee for a permit modification, revocation and reissuance, or termination, or a notification of planned changes or anticipated noncompliance, does not stay any permit condition.

(7) Property rights. This permit does not convey any property rights of any sort, or any exclusive privilege.

(8) Duty to provide information. The permittee shall furnish to the Agency within a reasonable time, any information which the Agency may request to determine whether cause exists for modifying, revoking and reissuing, or terminating this permit, or to determine compliance with the permit. The permittee shall also furnish to the Agency, upon request, copies of records required to be kept by this permit.

(9) Inspection and entry. The permittee shall allow an authorized representative of the Agency, upon the presentation of credentials and other documents as may be required by law, to:

(a) Enter upon the permittee=s premises where a regulated facility or activity is located or conducted, or where records must be kept under the conditions of this permit;

(b) Have access to and copy, at reasonable times, any records that must be kept under the conditions of this permit;

(c) Inspect at reasonable times any facilities, equipment (including monitoring and control equipment), practices, or operations regulated or required under this permit; and

(d) Sample or monitor at reasonable times, for the purpose of assuring permit compliance, or as otherwise authorized by the Act, any substances or parameters at any location.

(10) Monitoring and records.

(a) Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity.

(b) The permittee shall retain records of all monitoring information, including all calibration and maintenance records, and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for this permit, for a period of at least 3 years from the date of this permit, measurement, report or application. This period may be extended by request of the Agency at any time.

(c) Records of monitoring information shall include:

(1) The date, exact place, and time of sampling or measurements;

(2) The individual(s) who performed the sampling or measurements;

(3) The date(s) analyses were performed;

(4) The individual(s) who performed the analyses;

(5) The analytical techniques or methods used; and

(6) The results of such analyses.

(d) Monitoring must be conducted according to test procedures approved under 40 CFR Part 136, unless other test procedures have been specified in this permit. Where no test procedure under 40 CFR Part 136 has been approved, the permittee must submit to the Agency a test method for approval. The permittee shall calibrate and perform maintenance procedures on all monitoring and analytical instrumentation at intervals to ensure accuracy of measurements.

(11) Signatory requirement. All applications, reports or information submitted to the Agency shall be signed and certified.

(a) Application. All permit applications shall be signed as follows:

(1) For a corporation: by a principal executive officer of at least the level of vice president or a person or position having overall responsibility for environmental matters for the corporation;

(2) For a partnership or sole proprietorship: by a general partner or the proprietor, respectively; or

(3) For a municipality, State, Federal, or other public agency: by either a principal executive officer or ranking elected official.

(b) Reports. All reports required by permits, or other information requested by the Agency shall be signed by a person described in paragraph (a) or by a duly authorized representative of that person. A person is a duly authorized representative only if:

(1) The authorization is made in writing by a person described in paragraph (a); and

(2) The authorization specifies either an individual or a position responsible for the overall operation of the facility, from which the discharge originates, such as a plant manager, superintendent or person of equivalent responsibility; and

(3) The written authorization is submitted to the Agency.

(c) Changes of Authorization. If an authorization under (b) is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of (b) must be submitted to the Agency prior to or together with any reports, information, or applications to be signed by an authorized representative.

(12) Reporting requirements.

(a) Planned changes. The permittee shall give notice to the Agency as soon as possible of any planned physical alterations or additions to the permitted facility.

(b) Anticipated noncompliance. The permittee shall give advance notice to the Agency of any planned changes in the permitted facility or activity which may result in noncompliance with permit requirements.

(c) Compliance schedules. Reports of compliance or noncompliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of this permit shall be submitted no later than 14 days following each schedule date.

(d) Monitoring reports. Monitoring results shall be reported at the intervals specified elsewhere in this permit.

(1) Monitoring results must be reported on a Discharge Monitoring Report (DMR).

(2) If the permittee monitors any pollutant more frequently than required by the permit, using test procedures approved under 40 CFR 136 or as specified in the permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the DMR.

(3) Calculations for all limitations which require averaging of measurements shall utilize an arithmetic mean unless otherwise specified by the Agency in the permit.

(e) Twenty-four hour reporting. The permittee shall report any noncompliance which may endanger health or the environment. Any information shall be provided orally within 24 hours from the time the permittee becomes aware of the circumstances. A written submission shall also be provided within 5 days of the time the permittee becomes aware of the circumstances. The written submission shall contain a description of the noncompliance and its cause; the period of noncompliance, including exact dates and time; and if the noncompliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the noncompliance. The following shall be included as information which must be reported within 24 hours:

(1) Any unanticipated bypass which exceeds any effluent limitation in the permit;

(2) Violation of a maximum daily discharge limitation for any of the pollutants listed by the Agency in the permit to be reported within 24 hours.

The Agency may waive the written report on a case-by-case basis if the oral report has been received within 24 hours.

(f) Other noncompliance. The permittee shall report all instances of noncompliance not reported under paragraphs (12)(c), (d), or (e), at the time monitoring reports are submitted. The reports shall contain the information listed in paragraph (12)(e).

(g) Other information. Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application, or in any report to the Agency, it shall promptly submit such facts or information.

(13) Transfer of permits. A permit may be automatically transferred to a new permittee if:

(a) The current permittee notifies the Agency at least 30 days in advance of the proposed transfer date:

(b) The notice includes a written agreement between the existing and new permittees containing a specific date for transfer of permit responsibility, coverage and liability between the current and new permittees; and

(c) The Agency does not notify the existing permittee and the proposed new permittee of its intent to modify or revoke and reissue the permit. If this notice is not received, the transfer is effective on the date specified in the agreement.

(14) All manufacturing, commercial, mining, and silvicultural dischargers must notify the Agency as soon as they know or have reason to believe:

(a) That any activity has occurred or will occur which would result in the discharge of any toxic pollutant identified under Section 307 of the Clean Water Act which is not limited in the permit, if that discharge will exceed the highest of the following notification levels:

(1) One hundred micrograms per liter (100 ug/l);
(2) Two hundred micrograms per liter (200 ug/l) for acrolein and acrylonitrile; five hundred micrograms per liter (500 ug/l) for 2,4-dinitrophenol and for 2-methyl-4,6 dinitrophenol; and one milligram per liter (1 mg/l) for antimony.

(3) Five (5) times the maximum concentration value reported for that pollutant in the NPDES permit application; or

(4) The level established by the Agency in this permit.

(b) That they have begun or expect to begin to use or manufacture as an intermediate or final product or byproduct any toxic pollutant which was not reported in the NPDES permit application.

(15) All Publicly Owned Treatment Works (POTWs) must provide adequate notice to the Agency of the following:

(a) Any new introduction of pollutants into that POTW from an indirect discharge which would be subject to Sections 301 or 306 of the Clean Water Act if it were directly discharging those pollutants; and

(b) Any substantial change in the volume or character of pollutants being introduced into that POTW by a source introducing pollutants into the POTW at the time of issuance of the permit.

(c) For purposes of this paragraph, adequate notice shall include information on (i) the quality and quantity of effluent introduced into the POTW, and (ii) any anticipated impact of the change on the quantity or quality of effluent to be discharged from the POTW.

(16) If the permit is issued to a publicly owned or publicly regulated treatment works, the permittees shall require any industrial user of such treatment works to comply with federal requirements concerning:

(a) User charges pursuant to Section 204(b) of the Clean Water Act, and applicable regulations appearing in 40 CFR 35;

(b) Toxic pollutant effluent standards and pretreatment standards pursuant to Section 307 of the Clean Water Act; and

(c) Inspection, monitoring and entry pursuant to Section 308 of the Clean Water Act.

(17) If an applicable standard or limitation is promulgated under Section 301(b)(2)(C) and (D), 304(b)(2), or 307(a)(2) and that effluent standard or limitation is more stringent than any effluent limitation in the permit, or controls a pollutant not limited in the permit, the permit shall be promptly modified or revoked, and reissued to conform to that effluent standard or limitation.

(18) Any authorization to construct issued to the permittee pursuant to 35 Ill. Adm. Code 309.154 is hereby incorporated by reference as a condition of this permit.

(19) The permittee shall not make any false statement, representation or certification in any application, record, report, plan or other document submitted to the Agency or the USEPA, or required to be maintained under this permit.

(20) The Clean Water Act provides that any person who violates a permit condition implementing Sections 301, 302, 306, 307, 308, 318, or 405 of the Clean Water Act is subject to a civil penalty not to exceed $10,000 per day of such violation. Any person who willfully or negligently violates permit conditions implementing Sections 301, 302, 306, 307, or 308 of the Clean Water Act is subject to a fine of not less than $2,500 nor more than $25,000 per day of violation, or by imprisonment for not more than one year, or both.

(21) The Clean Water Act provides that any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under permit shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.

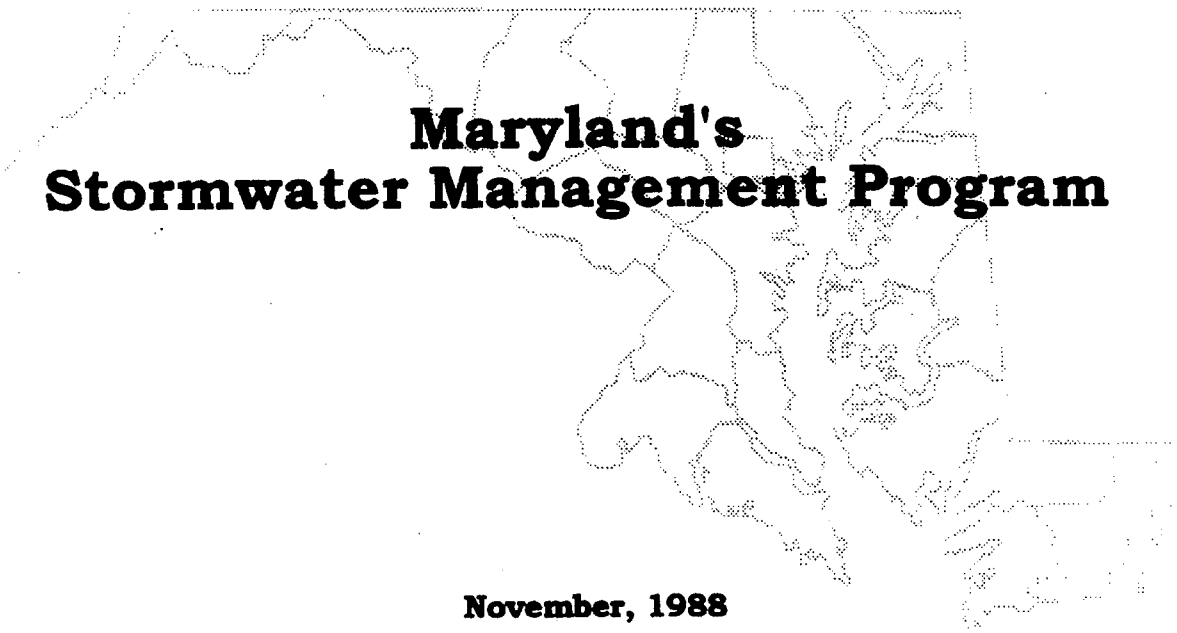
(22) The Clean Water Act provides that any person who knowingly makes any false statement, representation, or certification in any record or other document submitted or required to be maintained under this permit shall, including monitoring reports or reports of compliance or non-compliance shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.

(23) Collected screening, slurries, sludges, and other solids shall be disposed of in such a manner as to prevent entry of those wastes (or runoff from the wastes) into waters of the State. The proper authorization for such disposal shall be obtained from the Agency and is incorporated as part hereof by reference.

(24) In case of conflict between these standard conditions and any other condition(s) included in this permit, the other condition(s) shall govern.

(25) The permittee shall comply with, in addition to the requirements of the permit, all applicable provisions of 35 Ill. Adm. Code, Subtitle C, Subtitle D, Subtitle E, and all applicable orders of the Board.

(26) The provisions of this permit are severable, and if any provision of this permit, or the application of any provision of this permit is held invalid, the remaining provisions of this permit shall continue in full force and effect.



Maryland's Stormwater Management Program

November, 1988

Prepared By:
Robert L. Kort

Maryland Department of the Environment

Water Management Administration

2500 Broening Highway
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The Sediment and Stormwater Administration (SSA) was incorporated into the Water Management Administration (WMA) in October, 1992. For additional information concerning this publication, please contact WMA (410) 631-3543.

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MARYLAND'S STORMWATER MANAGEMENT PROGRAM

Robert L. Kort[1]

ABSTRACT

The adverse impacts of urbanization have contributed to a decline in the water quality of some of Maryland's streams and rivers, and the Chesapeake Bay. One of the state of Maryland's initiatives in response to this was the creation of a statewide stormwater management (SWM) program in 1982. This multipurpose program addresses a full range of hydrologic consequences and not just traditional runoff peak control. The Maryland Department of the Environment administers the program and is responsible for program implementation, plan review and approval, grants administration, education and training, and inspection and enforcement. Local jurisdictions administer their own programs that must meet minimum State standards. Water quality measures to enhance pollutant removal are emphasized. Practices used for the treatment of stormwater include infiltration structures, shallow marsh creation, extended detention basins, and water quality inlets. Retrofitting of existing SWM structures is done to enhance pollutant removal. Maryland's erosion and sediment control program is a key part of management efforts. Research and monitoring are conducted, and the use of innovative practices is encouraged.

INTRODUCTION

Urbanization generates detrimental changes to the hydrologic equilibrium of the land surface and the receiving fluvial estuarine environments. These changes include: increases in peak flow and total volume of stormwater runoff; accelerated stream channel erosion; decreases in low flow volumes in receiving streams; and decreases in water quality and the stream environment.

Efforts to control these conditions in the state of Maryland have resulted in statewide programs for erosion and sediment control, stormwater management (SWM), and flood plain management. Impetus for the control of runoff from new developments came from pressure by environmental groups because of the declining water quality of some of the state's streams and rivers, and the Chesapeake Bay; and the U.S. Environmental Protection Agency report on the Bay. The report documented the declining water quality of the Bay and identified urban stormwater as one of the causes. Nutrients, sediments, toxics, and other pollutants from surface runoff entering the Bay are not readily flushed out into the ocean but accumulate within the Bay.

Prior to a statewide program, stormwater management efforts in Maryland had focused on the control of increased peak flows and were not universally implemented. Water quality as well as quantity control implemented on a statewide basis had to be addressed if the program was to protect and improve the quality of surface waters in Maryland. The State's multipurpose program was designed to address the full range of hydrologic consequences resulting from urban development, and reduce the adverse effects of stormwater runoff. Erosion and sediment control is a key part of management efforts - runoff during construction is often greater than after site stabilization.

LAWS AND REGULATIONS

Legislation creating a statewide stormwater management (SWM) program in Maryland was enacted in 1982. It required each county and municipality to adopt a stormwater management program by July, 1984 subject to minimum criteria established in Regulations promulgated in July, 1983. For the first time in Maryland, water quality protection became a major component of all stormwater programs. Highlights of the act include:

1. Providing for an approved SWM plan for residential, commercial, industrial, or institutional land development. Agricultural land is exempt from these requirements;

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2. Permitting each county and municipality to adopt a fee system to cover the cost of SWM plan review and program implementation;

3. Requiring the State to review the local SWM programs at least once every 3 years;

4. Providing for civil and criminal penalties for violations of the SWM Law;

5. Requiring the State to provide technical assistance, training, research, and coordination in SWM technology to the local governments;

6. Requiring that Rules and Regulations be adopted, and outlining the items to be addressed by these;

Rules and Regulations established criteria and procedures for SWM in Maryland to ensure effective implementation of the local programs as well as the State program. The Regulations contained:

1. Responsibilities of the State for implementation and supervision of the SWM program.

2. The minimum content of the local county and municipal SWM ordinances;

3. Exemptions from the provisions of the regulations;

4. Allowance for waiver provisions in local ordinances for individual developments;

5. Minimum control requirements based on the hydrologic characteristics and SWM needs of different parts of the state;

6. A preferential list of SWM measures plus design criteria that must be used in developing a SWM plan;

7. Requirements for proper construction inspection of SWM facilities;

8. Provisions for periodic inspection and maintenance of stormwater facilities.

The Regulations were not universally accepted throughout Maryland, especially in the nine counties with existing programs (Maryland has 23 counties) and some municipalities for which SWM programs also existed. There was some resentment by local governments to the State redirecting the local programs. Change was not always easily accepted. One newspaper article from a county with no SWM program told how "the County Commissioner's room shook under the specter of a monster... Armageddon? No. Stormwater Management Regulations." It then related how the requirements "...could put an end to life as we know it." Nine public hearings were held throughout the state and there was considerable consultation with the local jurisdictions.

An amendment to the SWM law was enacted in the spring of 1988 that provides for the use of stormwater management practices to enhance water quality when land is redeveloped, even when the amount of impervious area does not increase. The SWM Rules and Regulations will be updated to reflect this change.

IMPLEMENTATION

The Sediment and Stormwater Administration of the Maryland Department of the Environment is responsible for administering the state's stormwater management and sediment control programs. The Administration is currently composed of three Programs: the Policy and Evaluation Program, the Construction Management Program, and the Compliance Program.

The Policy and Evaluation Program is responsible for promulgation of Rules and Regulations which establish criteria and procedures for State, county, and municipal programs. Publications are produced to provide technical guidance for local jurisdictions in the implementation of their programs. Research is conducted to refine current practices and evaluate innovative approaches initiated by the Program.

This Program administers the State's nonpoint source management program. The primary goal of the program is to implement Maryland's Chesapeake Bay Nutrient Reduction plan which calls for a 40% reduction in nutrient loadings to the Bay.

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The Program oversees local stormwater management programs which are reviewed and evaluated every three years. The county or municipal stormwater management ordinance, the administrative procedures that guide implementation of the program, the plan review and approval process, the use of State funding for program implementation, and the effectiveness of inspection and enforcement procedures to correct violations are considered during the review.

Education and training opportunities are available for government agencies, consultants, developers and home builders, and environmental groups. Events include: a sediment and stormwater conference, inspectors workshops, technical assistance, presentations to groups upon request, and displays at various events.

The Construction Management Program reviews and approves sediment control and SWM plans for State and Federal construction projects to ensure compliance with SWM Regulations. Coordination occurs with inspectors from the Enforcement Division to evaluate field implementation and approve field modifications as required. In FY89 there were 400 new State and Federal projects for which over 1000 submittals were received and reviewed.

Funding is provided by the State for stormwater management retrofit projects and local SWM programs. Retrofit funds are used for the implementation of state-of-the-art best management practices and the modification of existing SWM structures in urban areas to enhance water quality benefits. Since 1984 five million dollars has been awarded under this program. Funds come from the sale of State bonds. The grant program funds plan review, inspection, and other personnel to implement the local programs. Grant funds of approximately $1.6 million per year have been authorized for the 23 counties and 9 municipalities with approved SWM programs. Funding is from the financial commitment included in Maryland's "Chesapeake Bay Initiatives" and comes from state general funds.

The Compliance Program is responsible for inspection and enforcement of sediment control and SWM for all State and Federal construction projects. It is also responsible for sediment control inspection and enforcement for some of Maryland's counties and municipalities. The Program is organized into four field regions. Periodic and unscheduled inspections of approved projects are made to ensure compliance with approved plans.

A majority of the inspector's time is spent on erosion and sediment control as opposed to SWM. Good erosion and sediment control is crucial for innovative SWM practices such as infiltration and shallow marshes - sediment can clog infiltration structures or smother young marsh plants. Stormwater responsibilities include inspection of structures during construction, coordinating field modifications to the approved plans, and responding to citizen's complaints about drainage problems due to a particular project. Twelve to fourteen thousand site inspections of approved projects are made annually.

Enforcement actions, either administrative or legal, are based on the nature, extent, and impact of the violations. Primary emphasis is given to "in the field" corrective action and follow-up. Administrative civil penalties of $1,000 per day for sediment control violations are possible. Fifteen to twenty criminal or judicial civil actions are initiated yearly. The Program is responsible for emergency response and immediate enforcement actions for violations of the Laws and Regulations.

PRACTICES

The primary goal of the Maryland SWM Program is to maintain after development, as nearly as possible, the predevelopment runoff characteristics. Achieving this goal requires that the full range of hydrologic consequences resulting from urban development be addressed. In addition to the traditional control of peak flow, consideration of flow volume reduction, stream low flow augmentation, water quality control, and ecological protection is necessary.

A preferential list of SWM Practices to be considered on each proposed development is used. Justification needs to be provided by the person developing land for rejecting each practice based on site conditions. Ranking is determined by the water quality benefits associated with each practice. A combination of successive practices may be used to achieve the applicable water quantity control requirements. Minimum control requirements are established based on the hydrologic characteristics and SWM needs of different parts of the state. Most of the state has a 2 and 10-year control requirement because stream channel erosion and flood increases are of equal concern. Only 2-year control is required for the extremely flat terrain of Maryland's Eastern Shore.

State Regulations require consideration of infiltration practices first because of the many benefits they provide to negate the adverse environmental impacts resulting from land development. Infiltration of stormwater

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from a site can recharge groundwater, augment low stream flows, reduce the total runoff volume, and enhance water quality. If their use for peak discharge control is not feasible due to limiting constraints, the practice can be designed to capture the first flush of runoff. The first flush is recommended to be 0.5 inches of runoff per impervious area (MDE, 1986). Capturing this volume will result in the removal of many waterborne pollutants.

"Standards and Specifications for Infiltration Practices" (MDE, 1984) were developed to provide design guidance to consultants and regulatory agencies. The document establishes minimum criteria for the design, review, approval, construction, and maintenance of infiltration practices. Practices detailed include the infiltration basin, infiltration trench, dry well, porous asphalt pavement, and vegetated swales with check dams. Feasibility tests to determine if infiltration is suitable for a specific site, and the extent to which it may be applied are included.

The use of infiltration throughout the state has proceeded in a somewhat cautious manner due to concerns and unanswered questions. Research is currently in progress to investigate the potential for ground water pollution through the entry of runoff into the soil subgrade. Premature failure of infiltration practices due to a lack of adequate runoff filtering in the design, poor construction techniques, or a lack of proper sediment control during construction has been a problem. Maintenance of these structures may be difficult to accomplish or neglected. A utility approach that would include the financing of SWM maintenance is being pursued to address this. This involves the creation of a local government enterprise that provides services of stormwater management (quantity and quality control), drainage, and flood control. It is funded by user charges based on runoff volumes or impervious area, not property taxes.

The second item on the preferential list is open vegetated swales which have a high resistance to flow, and natural depressions. These practices retard the runoff and provide some water quality benefit. Vegetative methods, when kept within erosion control design limitations, are generally preferred over structural methods. The State's intention with this preference is to encourage local jurisdictions to be more flexible in the utilization of curb and gutter.

The third item on the preferential list is stormwater retention structures or wet ponds. The benefits of retention ponds regarding water quality enhancement are well documented in the U.S. EPA Nationwide Urban Runoff Program (NURP) studies (Wash. COG, 1983). In addition to water quality benefits, retention ponds provide aesthetic and possible wildlife benefits when properly designed. They provide an excellent opportunity for creation of shallow marsh habitat. Design criteria for the creation of artificial wetlands have been prepared (MDE, 1988). The guidelines contain physical and biological requirements for constructing wetlands. Research is currently proceeding at three artificial wetlands in Maryland to monitor water quantity and quality benefits.

The last item on the preferential list is detention structures (dry ponds) which generally only provide shaving of peak discharge rates to a specified level. Detention ponds have little or no water quality benefits, which accounts for their lowly position on the State preferential list. The use of extended detention is encouraged since it allows additional time for the settling of particulate pollutants and decreases downstream erosion of the receiving stream. The State has used a criteria that requires the runoff volume generated from the one year frequency storm be released over a minimum of 24 hours. Recent research has indicated that even slower runoff release rates than currently required are preferable to adequately protect stream channels (McCuen et al, 1988). Forthcoming changes to SWM Regulations will require the use of extended detention instead of detention.

CONCLUSION

Maryland's statewide SWM program is six years old. The decline of some of the state's streams and rivers, and the Chesapeake Bay was years in the making, and it will be years before SWM and other initiatives to restore surface water quality will fully achieve that goal. What has been learned in the short term can provide guidance for those considering the implementation of a SWM program:

1. The SWM program should have a clearly defined direction and the enabling legislation and regulations should reflect this;

2. Innovation, research, and monitoring are needed for successful evolution of a program;

3. A commitment to program implementation requires adequate monetary and manpower support;

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4. Erosion and sediment control should be included as an integral part of the program;

5. Inspection of SWM practices is critical to avoid failure due to improper construction;

6. Maintenance of SWM structures is critical. A funding mechanism, such as a stormwater utility, is required;

7. An education and training program is essential. A lack of understanding SWM concepts can lead to poor design, plan review, and construction;

8. Enforcement penalties for non-compliance with stormwater requirements that are extreme enough to act as a determent are necessary;

9. Implementation of "natural engineering" techniques and practices which preserve and enhance existing features of a site should be addressed;

Stormwater management is not an exact science and will continue to evolve as our knowledge and experience increases. Implementation of Maryland's program has not been a simple process... the stormwater problem is multifaceted and has to be approached that way.

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MARYLAND DEPARTMENT OF THE ENVIRONMENT
2500 Broening Highway • Baltimore, Maryland 21224
(410) 631-3000

Parris N. Glendening
Governor

Jane T. Nishida
Secretary

May 31, 2000

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD LOS ANGELES REGION
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Ms. Elizabeth M. Jennings, Esq.
Office of Chief Counsel
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-0100

And,

Mr. Xavier Swamikannu
Storm Water Program
California Regional Water Quality Control Board – LA Region
320 W. 4th Street, Suite 200
Los Angeles, CA 90013

Dear Ms. Jennings and Mr. Swamikannu:

Enclosed are several items that may help you understand the goals attributed to Maryland's stormwater management program. The Maryland Department of the Environment is nearing 20 years worth of experience in administering an urban runoff program. Some basic tenets of the program and the successes and failures are described in the three reports provided.

Additionally, a brief background summary is provided in order to explain the transition we are making from current requirements to those proposed in the "2000 Maryland Stormwater Design Manual." This summary also helped to better answer the design and performance standards questions that you posed regarding stormwater management in our State. We hope this material will be of some use to you.

If you have any questions or need any more information, please call me at 410-631-3543.

Sincerely,

Brian S. Clevenger
Water Management Administration

w\Enclosures

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MARYLAND'S STORMWATER MANAGEMENT PROGRAM
SUMMARY

Introduction

The State of Maryland has recently completed the development of the "*2000 Maryland Stormwater Design Manual*" (Manual). This document took nearly 5 years to compose and is intended to improve the State's stormwater management program that has been in existence since 1982. The Maryland Department of the Environment, Water Management Administration (MDE/WMA) provides here a synopsis of Maryland's program's evolution over the last 18 years. This summary will provide the perspective needed to answer questions regarding programmatic goals, performance standards, and strengths and weaknesses. Apologies for the lack of brevity.

Background

Maryland's stormwater management program was a logical progression from its erosion and sediment control efforts. The Attorney General of the State declared "sediment" a pollutant in 1969. The next year a statute was passed that required sediment control practices to be implemented for any earth disturbing activities over 5,000 square feet. Maryland's erosion and sediment control program was implemented statewide by local government beginning in 1970.

The next step from controlling runoff from grading and construction would obviously be controlling runoff after development has been completed. This progression then, is stormwater management. Recognizing that urban runoff was a contributing factor to water quality degradation, the Maryland legislature passed the Stormwater Management Act in 1982. This law, and commensurate regulations adopted the following year, sought to ensure that pre-development runoff characteristics were maintained after development.

During the mid 1980s when Maryland's program was first conceived and implemented, the prevailing attitude was that if peak discharge increases caused by urbanization were controlled, the receiving waters would be protected from excess volume, increased velocities, channel erosion, sedimentation, flooding, etc. Therefore, Maryland's program was, and is currently, based on this flood control perspective. Current State regulations require that all new development project designs include provisions for reducing peak discharge increases for the 2 and 10 year frequency storm events back to pre-development conditions. Clearly, this requires a best management practice (BMP) approach and typically, the BMP of choice is a pond.

Because of the prevailing attitudes regarding how best to control stormwater (e.g., flood management), very little specific design criteria were included in Maryland's stormwater management program. The approach taken, and the one we work under currently, was a "preferred practices" list. State regulations require that infiltration be considered first and, if not feasible, the designer would then progress through a list of BMPs each with lesser water quality efficiency than the one previous. In latter years, rules-of-thumb for water quality design were implemented sporadically throughout the State (e.g., one half inch times total site

imperviousness). However, Maryland still operates under its original design criteria (e.g., 2 and 10 year management and the preferred practices list).

Chesapeake Bay Protection and Environmental Awareness

Given the above historical explanation, several points need to be made that will provide other factors affecting program implementation and help explain why a major change of philosophy has been contemplated with the Manual. First, it cannot be overemphasized how much Chesapeake Bay restoration efforts play on bringing to the forefront environmental concerns, especially those related to water quality. Chesapeake Bay garners much attention in the State, region, and, arguably, the world for protection and restoration. This was the case in 1983 when the Six Bay states and Washington, D.C signed the original "Chesapeake Bay Agreement." Therefore, the protection of this valuable resource was very much a factor for implementing an urban runoff program.

Another factor contributing to Maryland's stormwater management program development was the groundswell of environmental awareness caused primarily by nutrient enrichment of the Chesapeake Bay. Nutrient reduction goals, wetland protection, and sediment control all served as catalysts for grass roots organizations to bring to light the importance of environmental issues. This public and sometimes political support cannot be overlooked.

Technical Program Improvements Needed

Finally, because of over 12 years of program oversight and experience, changes with our program were clearly needed in the mid 1990s. Some issues have been mentioned above (e.g., no specific water quality design standards; too much flood control emphasis). However, explaining a couple of technical issues related to our program will address questions regarding stormwater management program goals and specific issues such as redevelopment.

As originally conceived, the State program makes no mention of where new development takes place. Nor does it specify what land use types are affected. If 5,000 square feet of earth is disturbed with new development, you must address stormwater runoff. This would presumably include redevelopment or in-fill situations. However, as with most regulatory programs, Maryland's stormwater regulations contain exemptions and allow for waivers provided certain conditions are met. Since 1982, certain projects have been waived depending on hydrological circumstances. Three major waiver categories have been allowed and these demonstrate the flood management program emphasis on which the program was founded. These categories are:

1) Less than a ten percent increase in the pre-development 2 year storm event,
2) Direct discharges to tidewater, and
3) Projects completely surrounded by an existing storm drain system of sufficient capacity to convey the increase in discharge caused by the new development.

The emphasis on peak management and flood control is quite obvious. It was MDE's want to change this emphasis when regulatory changes were proposed and the Manual was conceived in

1995. Beginning with the Manual's composition, the issue of stormwater control for redevelopment projects was debated vigorously.

The above waiver provisions that local jurisdictions applied to certain "new development" caused most redevelopment and in-fill work to avoid BMP implementation. A fast food restaurant built in the corner of a shopping mall parking lot would surely not change hydrologic characteristics, especially peak discharge. Additionally, this and similar urban "redevelopment" would most likely be surrounded by an existing storm drain system of adequate capacity. Therefore, most redevelopment is waived under Maryland's original and current stormwater regulations. This was an additional reason why MDE felt improvements were warranted.

Summary

Under increased environmental awareness caused by Chesapeake Bay protection concerns, Maryland instituted a stormwater management program that emphasized peak flood management for new development projects disturbing 5,000 square feet of earth. Relatively little specific water quality control design criteria were included in original regulations as a "preferred practices" list was used. With an obvious flood control emphasis, most redevelopment projects were waived because pre-development hydrologic conditions remained after construction completion.

With over 12 years of program implementation experience, a recognition that improved water quality management was needed, and a need to eliminate many waivers of stormwater management requirements for such things as redevelopment, MDE developed the "*2000 Maryland Stormwater Design Manual.*" This document, along with major regulatory modifications, is intended to address many of Maryland's stormwater management program weaknesses. When adopted later this year, major improvement to controlling urban runoff is expected.

POLICY STATEMENT ON CONTROLS AND REQUIREMENTS FOR NEW DEVELOPMENT AND REDEVELOPMENT IN THE STATE OF MARYLAND

i) Why did your state elect to have requirements on new development and redevelopment?

In 1982, restoration and protection of Chesapeake Bay was one of the most important factors contributing to the development of Maryland's stormwater management program. Heightened environmental awareness and a recognition that urban runoff contributed to water quality degradation combined to produce a program that emphasized peak flood control. Because of this emphasis on peak management, typical redevelopment projects were often waived from stormwater controls.

To address various program shortcomings, MDE development the "*2000 Maryland Stormwater Design Manual*" (Manual). This document is intended to provide better water quality control, an area not specifically addressed currently. Relative to redevelopment, the choice to impose requirements was based primarily on "everyone contributes runoff, everyone ought contribute

management." However, a balance between management contributions for environmental purposes, and, practical requirements that make economic sense must be struck. Everyone should contribute management. However, conventional BMPs (e.g., ponds) are not feasible in major metropolitan areas where land values prevent typical management strategies. Flexibility is key.

ii) Does your state have design standards and performance standards for treatment control BMPs for new development/redevelopment?

Currently, there are no performance standards for BMPs only design standards. Maryland requires that BMPs be designed to maintain pre-development peak discharges for the 2 and 10 year storm events in most of the State.

Maryland's proposed Manual contains both design standards and performance standards.. A suite of design volumes has been developed to address recharge (Re_v), water quality (WQ_v), channel protection (Cp_v), and overbank flood protection (Q_p). All of these volumes need to be included in new development designs. Additionally, BMP performance standards are implicit in Maryland's proposed Manual. Based on pollutant removal efficiency studies, all BMPs in the Manual have been equated in terms of efficiency. If a BMP is designed according to the criteria specified in the Manual, an 80% total suspended solids (TSS) and a 40% total phosphorus (P) reduction will both be realized. In fact, this 80:40 criteria is used to judge whether new technology is allowed to be used to address the required suite of volumes above. If the proverbial "new mousetrap" can meet 80% TSS and 40% P removal, it can be used as a stand alone BMP.

iii) Do you have thresholds for new development and or redevelopment (impervious area; size; etc.) for requirements to apply?

If a project disturbs 5,000 square feet of earth in Maryland, the site design must address stormwater management.

iv) What development categories do the requirements apply to [i.e. commercial; parking lots; residential, etc.]?

There are no specific development categories. If you disturb 5,000 square feet with any new development, you automatically are included. State regulations, however, do "exempt" agricultural land management activities.

v) How long have such requirements been in place? Are they statewide or region specific?

Stormwater management has been on the books since 1982. This is a statewide program that does have design variations based on hydrologic areas of the State (e.g., no 10 year management requirements in the Coastal Plain on our "Eastern Shore."

vi) Have the design standards and performance standards unduly burdened cities and builders with unsupportable costs? Has compliance been difficult? Has change been for the better or have you seen none? Any noticeable improvements in water quality?

All of these questions have been, are, and will not doubt continue to be debated. Volumes could be written to explain perspectives for burdens, costs, compliance, or noticeable improvements. To avoid this, some very random thoughts about these issues.

Generally, the answer to all of these questions could be "it depends on whom you ask" or "it depends on where you ask it." Maryland has three distinct geographic areas. These are a "Western" section; a central, "Urban" area; and our "Eastern Shore." The Urban area houses most of the State's population; can be defined in terms of the corridor between Washington, D.C., Baltimore, and toward Philadelphia, PA; and, not coincidentally, contains the most sophisticated stormwater programs in our State. It is not uncommon for a central Maryland county to have 8 or 10 plan reviewers and as many field staff dedicated solely to stormwater functions. The burden on these places currently is minimal.

As you travel west or east from this Urban region, the stormwater programs locally tend to become more burdensome. There is less sophistication technically, less resources, and obviously less compliance. In Western Maryland and on our Eastern Shore, localities may only have a single staff person to perform both review and inspection. The burden associated with changing to the proposed Manual in these regions will increase dramatically. However, again, it depends on whom you ask.

Environmental groups have told us we are not doing enough and have actually demanded "zero discharge" from new development. Developers and builders believe we are making them do too much now and are severely questioning our proposed changes and the Manual requirements. Frankly, and with tongue only partially in cheek, we believe we are close to where we need to be with the Manual because we have aggravated an equal number of people on both sides of this regulatory fence.

Some really random thoughts:

- In the beginning of the program (circa 1982), the design standards were very burdensome. Localities had to hire staff and purchase vehicles and equipment. Developers endured the added cost of BMP construction.
- Currently, stormwater management on both sides is a routine part of the development process.
- Compliance varies with the level of resources and the distance from Urban Maryland as described above. One difficulty we do have is the interpretation of the same requirement differently from locality to locality.
- We have seen only modest water quality improvement. This is expected to change dramatically with our Manual.

vii) Typically, what is your estimate of the range in additional cost (in percent of project cost) that the requirements have imposed on builders?

Obviously, this depends on that real estate saying "location, location, location." However, currently, stormwater management for 2 and 10 year control ranges from 0% to 20%. We have proposed to make optional the control of the 10 year storm. Because "lots are money" and "more stormwater means less lots," costs are anticipated to decrease about 20% of current costs without 10 year management. Costs will increase commensurately with 10 year management under the Manual.

viii) How have municipalities ensured that the post construction BMPs O & M has been provided and/or BMPs are properly maintained?

Operation and Maintenance Agreements are required as a condition of plan approval and permit issuance. Localities are required by State regulation to inspect and cause to be maintained BMPs every three years. Some jurisdictions assume ownership of BMPs. This is best for ensuring future maintenance. Other localities require private ownership, which makes it difficult for requiring maintenance due to the limited resources of entities such as homeowners' associations.

ix) What are the policy goals that the standards are intended to achieve (reverse impairment; hold the line; etc.)?

Basically, the best way to describe our proposed program's goal is to minimize damage caused by urban runoff. For us, this boils down to basic hydrology. When you change natural conditions to developed conditions, bad things happen to water quality. We also know that all soils have some recharge value, sustained bankfull discharges create severe channel erosion, and minimizing impervious surfaces is the best way to mimic pre-development hydrology. Therefore, we are hoping to change how development occurs. Hopefully, we can incorporate water management early in the site design process rather than having a BMP placed at the bottom discharge point of a site as an afterthought.

Individual volume goals and design criteria:

1) Recharge (Re_v) – mimic existing annual groundwater recharge rates.
2) Water quality volume (WQ_v) – 80% TSS removal (a Coastal Zone Management Act requirement), 40% P removal (a Chesapeake Bay Program goal), and treatment of 90% of the average annual rainfall.
3) Channel protection volume (Cp_v) – the 2 year storm control policy has actually created more channel erosion in some cases. This method sustains bankfull discharges over a longer period of time. Therefore, more frequent storm event control is essential. We are choosing the 1 year storm using extended detention. This is delaying the 1 year storm's inflow hydrograph by 24 hours.
4) Overbank flood protection (Q_p) – 10 year storm control is optional provided no additional downstream flooding occurs.

5) Redevelopment – the goal is to reduce by 20% the total site imperviousness. If not feasible, BMPs elsewhere in the watershed, stream restoration, fees paid are all acceptable but subject to local approval.



MARYLAND MODEL STORMWATER MANAGEMENT ORDINANCE

JULY 2000

&

SUPPLEMENT

JANUARY 2007

MARYLAND
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MODEL STORMWATER MANAGEMENT ORDINANCE

This model stormwater management ordinance provides the minimum content for implementing and enforcing Maryland's stormwater management program consistent with the Code of Maryland Regulations (COMAR) 26.17.02. The Maryland Department of the Environment, Water Management Administration (MDE/WMA) provides this model ordinance for guidance to establish minimum criteria for county and municipal code development. While all local development review and approval processes are unique, WMA will use this document as a template to ensure that all stormwater management ordinances contain the minimum requirements for effective program implementation.

The complexity of local stormwater management implementation varies depending upon the extent and nature of local development. While Maryland's urbanizing jurisdictions may find this model ordinance helpful in supplementing existing codes, the model also provides assistance to jurisdictions that are developing new stormwater management ordinances. This model stormwater management ordinance provides minimum content only. Each local jurisdiction should review the enclosed components and tailor their ordinances in accordance with local conditions and development activities. All local stormwater management ordinances within Maryland are subject to the MDE/WMA approval. Inclusion of all model ordinance components is necessary to obtain MDE/WMA approval.

If there are any questions or comments regarding this model stormwater management ordinance please contact the MDE/WMA at (410) 537-3543.

July 2005

MARYLAND DEPARTMENT OF THE ENVIRONMENT
MODEL STORMWATER MANAGEMENT ORDINANCE
JULY 2005

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MODEL STORMWATER MANAGEMENT ORDINANCE

1.0 PURPOSE AND AUTHORITY

The purpose of this Ordinance is to protect, maintain and enhance the public health, safety, and general welfare by establishing minimum requirements and procedures to control the adverse impacts associated with increased stormwater runoff. Proper management of stormwater runoff will minimize damage to public and private property, reduce the effects of development on land, control stream channel erosion, reduce local flooding, and maintain after development, as nearly as possible, the pre-development runoff characteristics.

The provisions of this Ordinance, pursuant to the Environment Article, Title 4, Subtitle 2, Annotated Code of Maryland, 1996 replacement volume, are adopted under the authority of the (local unit) Code and shall apply to all development occurring within the unincorporated/incorporated area of (local unit). The application of this Ordinance and provisions expressed herein shall be the minimum stormwater management requirements and shall not be deemed a limitation or repeal of any other powers granted by State statute. The (governing authority/agency) shall be responsible for the coordination and enforcement of the provisions of this Ordinance.

1.1 Incorporation By Reference

For the purpose of this Ordinance, the following documents are incorporated by reference:

A. The 2000 Maryland Stormwater Design Manual, Volumes I & II (Maryland Department of the Environment, April 2000) is incorporated by reference by (governing authority/agency) and shall serve as the official guide for stormwater principles, methods, and practices.

B. USDA Natural Resources Conservation Service Maryland Conservation Practice Standard Pond Code 378 (January 2000).

2.0 DEFINITIONS

A. For the purpose of this Ordinance, the following definitions describe the meaning of the terms used in this Ordinance:

(1) “Administration” means the Maryland Department of the Environment (MDE) Water Management Administration (WMA).

(2) "Adverse impact" means any deleterious effect on waters or wetlands, including their quality, quantity, surface area, species composition, aesthetics or usefulness for human or natural uses which are or may potentially be harmful or injurious to human health, welfare, safety or property, to biological productivity, diversity, or stability or which unreasonably interfere with the enjoyment of life or property, including outdoor recreation.

(3) "Agricultural land management practices" means those methods and procedures used in the cultivation of land in order to further crop and livestock production and conservation of related soil and water resources.

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(4) "Applicant" means any person, firm, or governmental agency who executes the necessary forms to procure official approval of a project or a permit to carry out construction of a project.

(5) "Aquifer" means a porous water bearing geologic formation generally restricted to materials capable of yielding an appreciable supply of water.

(6) "Best Management Practice (BMP)" means a structural device or nonstructural practice designed to temporarily store or treat stormwater runoff in order to mitigate flooding, reduce pollution, and provide other amenties.

(7) "Channel Protection Storage Volume (Cp_v)" means the volume used to design structural management practices to control stream channel erosion. Methods for calculating the channel protection storage volume are specified in the 2000 Maryland Stormwater Design Manual, Volumes I & II.

(8) "Clearing" means the removal of trees and brush from the land but shall not include the ordinary mowing of grass.

(9) "Design Manual" means the 2000 Maryland Stormwater Design Manual Volumes I & II that serves as the official guide for stormwater management principles, methods, and practices.

(10) "Detention structure" means a permanent structure for the temporary storage of runoff, which is designed so as not to create a permanent pool of water.

(11) "Develop land" means to change the runoff characteristics of a parcel of land in conjunction with residential, commercial, industrial, or institutional construction or alteration.

(12) "Direct discharge" means the concentrated release of stormwater to tidal waters or vegetated tidal wetlands from new development or redevelopment projects in the Critical Area.

(13) "Drainage area" means that area contributing runoff to a single point measured in a horizontal plane, which is enclosed by a ridge line.

(14) "Easement" means a grant or reservation by the owner of land for the use of such land by others for a specific purpose or purposes, and which must be included in the conveyance of land affected by such easement.

(15) "Exemption" means those land development activities that are not subject to the stormwater management requirements contained in this Ordinance.

(16) "Extended detention" means a stormwater design feature that provides gradual release of a volume of water in order to increase settling of pollutants and protect downstream channels from frequent storm events. Methods for designing extended detention BMPs are specified in the Design Manual.

(17) “Extreme flood volume (Q_f)” means the storage volume required to control those infrequent but large storm events in which overbank flows reach or exceed the boundaries of the 100- year floodplain.

(18) "Flow attenuation" means prolonging the flow time of runoff to reduce the peak discharge.

(19) "Grading” means any act by which soil is cleared, stripped, stockpiled, excavated, scarified, filled or any combination thereof.

(20) "Infiltration" means the passage or movement of water into the soil surface.

(21) "Off-site stormwater management" means the design and construction of a facility necessary to control stormwater from more than one development.

(22) "On-site stormwater management" means the design and construction of systems necessary to control stormwater within an immediate development.

(23) “Overbank flood protection volume (Q_p)” means the volume controlled by structural practices to prevent an increase in the frequency of out of bank flooding generated by development. Methods for calculating the overbank flood protection volume are specified in the Design Manual.

(24) “Recharge volume (Re_v)” means that portion of the water quality volume used to maintain groundwater recharge rates at development sites. Methods for calculating the recharge volume are specified in the Design Manual.

(25) “Redevelopment” means any construction, alteration, or improvement exceeding 5000 square feet of land disturbance performed on sites where existing land use is commercial, industrial, institutional or multifamily residential.

(26) "Retention structure" means a permanent structure that provides for the storage of runoff by means of a permanent pool of water.

(27) “Retrofitting” means the construction of a structural BMP in a previously developed area, the modification of an existing structural BMP, or the implementation of a nonstructural practice to improve water quality over current conditions.

(28) "Sediment" means soils or other surficial materials transported or deposited by the action of wind, water, ice, or gravity as a product of erosion.

(29) "Site" means:

(a) for “new development” any tract, lot or parcel of land or combination of tracts, lots, or parcels of land, which are in one ownership, or are contiguous and in diverse ownership where development is to be performed as part of a unit, subdivision, or project.

(b) for “redevelopment” the area of new construction as shown on an approved site plan; or the original parcel. Final determination of the applicable are shall be made by (local agency).

(30) "Stabilization" means the prevention of soil movement by any of various vegetative and/or structural means.

(31) "Stormwater management" means:

(a) For quantitative control, a system of vegetative and structural measures that control the increased volume and rate of surface runoff caused by man-made changes to the land; and

(b) For qualitative control, a system of vegetative, structural, and other measures that reduce or eliminate pollutants that might otherwise be carried by surface runoff.

(32) "Stormwater Management Plan" means a set of drawings or other documents submitted by a person as a prerequisite to obtaining a stormwater management approval, which contain all of the information and specifications pertaining to stormwater management.

(33) "Stripping" means any activity which removes the vegetative surface cover including tree removal, clearing, grubbing and storage or removal of topsoil.

(34) "Variance" means the modification of the minimum stormwater management requirements for specific circumstances such that strict adherence to the requirements would result in necessary hardship and not fulfill the intent of the Ordinance.

(35) "Waiver" means the relinquishment from stormwater management requirements by the (local agency) for a specific development on a case-by-case review basis.

(a) “Qualitative stormwater management waiver” includes water quality volume and recharge volume design parameters.

(b) “Quantitative stormwater management waiver” includes channel protection storage volume, overbank flood protection volume, and extreme flood volume design parameter.

(36) "Watercourse" means any natural or artificial stream, river, creek, ditch, channel, canal, conduit, culvert, drain, waterway, gully, ravine or wash, in and including any adjacent area that is subject to inundation from overflow or flood water.

(37) "Watershed" means the total drainage area contributing runoff to a single point.

(38) ”Water quality volume (WQ_v)” means the volume needed to capture and treat the runoff from 90 percent of the average annual rainfall at a development site. Methods for calculating the water quality volume are specified in the Design Manual.

3.0 APPLICABILITY

3.1 Scope

No person shall develop any land for residential, commercial, industrial, or institutional uses without having provided stormwater management measures that control or manage runoff from such developments, except as provided within this section. The stormwater management measures must be designed consistent with the Design Manual and constructed according to an approved plan for new development or the policies stated in section 3.4 for redevelopment.

3.2 Exemptions

The following development activities are exempt from the provisions of this Ordinance and the requirements of providing stormwater management:

A. Agricultural land management activities;

B. Additions or modifications to existing single family detached residential structures if they comply with C of this section;

C. Developments that do not disturb over 5,000 square feet of land area;

D. Land development activities that the Administration determines will be regulated under specific State laws, which provide for managing stormwater runoff.

3.3 Waivers / Watershed Management Plans

[**NOTE:** Developing a waiver policy that is consistent and applicable throughout the entire State is quite difficult. Local development patterns, economic conditions, hydrology, and many other relevant factors make a single pattern for issuing stormwater management waivers virtually impossible. However, because the design policies in the 2000 Maryland Stormwater Design Manual, Volumes I and II change drastically the way BMPs are now implemented, a commensurate change in how waivers are granted is appropriate. Given the inclusion of nonstructural practices and innovative site planning techniques, the Design Manual provides greater opportunity to manage runoff than in the past. While WMA will evaluate all proposed local waiver policies on their own merits, the following section outlines those tenets that shall be included to ensure adequate stormwater management implementation.]

A. Stormwater management quantitative control waivers shall be granted only to those projects within areas where watershed management plans have been developed consistent with F. of this section.

B. If watershed management plans consistent with F. of this section have not been developed, then stormwater management quantitative control waivers may be granted to projects:

(1) That have direct discharges to tidally influenced receiving waters;

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(2) That do not increase the post-development peak discharge for the 2-year storm event by more than 10 percent in those areas of the State where the 2-year storm serves as the overbank flood protection volume according to the Design Manual (NOTE: This waiver category applies to jurisdictions located on the eastern shore of the Chesapeake Bay only); or

(3) When the approving agency determines that circumstances exist that prevent the reasonable implementation of quantity control practices.

C. Stormwater management qualitative control waivers apply only to:

(1) In-fill development projects where stormwater management implementation is not feasible;

(2) Redevelopment projects if the requirements of section 3.4 of this ordinance are satisfied; or

(3) Sites where the approving agency determines that circumstances exist that prevent the reasonable implementation of quality control practices.

D. Waivers granted must:

(1) Be on a case-by-case basis;

(2) Consider the cumulative effects of the (local agency) waiver policy; and

(3) Reasonably ensure the development will not adversely impact stream quality.

E. If (local agency) has established an overall watershed management plan for a specific watershed, then (local agency) may develop quantitative waiver and redevelopment provisions that differ from sections 3.3B and 3.4.

F. A watershed management plan developed for the purpose of implementing different stormwater management policies for waivers and redevelopment shall:

(1) Include detailed hydrologic and hydraulic analyses to determine hydrograph timing;

(2) Evaluate both quantity and quality management;

(3) Include cumulative impact assessment of watershed development;

(4) Identify existing flooding and receiving stream channel conditions;

(5) Be conducted at a reasonable scale;

(6) Specify where on-site or off-site quantitative and qualitative stormwater management practices are to be implemented;

(7) Be consistent with the General Performance Standards for Stormwater Management in Maryland found in Section 1.2 of the Design Manual; and

(8) Be approved by the Administration.

G. The (local agency) may grant a waiver of quantitative stormwater management requirements for individual developments in areas where watershed management plans have been developed provided that a written request is submitted by the applicant containing descriptions, drawings, and any other information that is necessary to evaluate the proposed development. A separate written waiver request shall be required in accordance with the provisions of this section if there are subsequent additions, extensions, or modifications to a development receiving a waiver.

3.4 Redevelopment

A. Stormwater management plans for redevelopment shall be consistent with the Design Manual except that the recharge, channel protection storage volume, and overbank flood protection volume requirements specified in the Design Manual do not apply unless required by (local agency).

B. All redevelopment projects shall reduce existing site impervious areas by at least 20 percent. Where site conditions prevent the reduction of impervious area, then stormwater management practices shall be implemented to provide qualitative control for at least 20 percent of the site's impervious area. When a combination of impervious area reduction and stormwater practice implementation is used, the combined area shall equal or exceed 20 percent of the site.

C. Where conditions prevent impervious area reduction or on-site stormwater management, practical alternatives may be considered, including but not limited to:

(1) Fees;

(2) Off-site BMP implementation for a drainage area comparable in size and percent imperviousness to that of the project;

(3) Watershed or stream restoration;

(4) Retrofitting; or

(5) Other practices approved by (local agency).

3.5 Variance

The (local agency) may grant a written variance from any requirement of Section 4.0 (Stormwater Management Criteria), of this Ordinance if there are exceptional circumstances applicable to the site such that strict adherence will result in unnecessary hardship and not fulfill the intent of the Ordinance. A written request for variance shall be provided to the (local agency) and shall state the specific variances sought and reasons for their granting. The (local agency) shall not grant a variance unless and until sufficient justification is provided by the person developing land.

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4.0 STORMWATER MANAGEMENT CRITERIA

4.1 Minimum Control Requirements

A. The minimum control requirements established in this section and the Design Manual are as follows:

(1) Caroline, Dorchester, Kent, Queen Anne's, Somerset, Talbot, Wicomico, and Worcester counties and their incorporated municipalities shall require that the recharge volume, water quality volume, and overbank flood protection volume for the 2-year frequency storm event be used to design BMP's according to the Design Manual; and

(2) The City of Baltimore, Allegany, Anne Arundel, Baltimore, Calvert, Carroll, Cecil, Charles, Frederick, Garrett, Harford, Howard, Montgomery, Prince George's, St. Mary's, and Washington counties and their incorporated municipalities shall require that the recharge volume, water quality volume, and channel protection storage volume sizing criteria be used to design BMP's according to the Design Manual. Control of the 10-year frequency storm event is required according to the Design Manual if the (local agency) determines that historical flooding problems exist and downstream floodplain development and conveyance system design cannot be controlled.

(3) (Local agency) may require more than the minimum control requirements specified in this Ordinance if hydrologic or topographic conditions warrant or if flooding, stream channel erosion, or water quality problems exist downstream from a proposed project.

B. Stormwater management and development plans where applicable, shall be consistent with adopted and approved watershed management plans or flood management plans as approved by the Maryland Department of the Environment in accordance with the Flood Hazard Management Act of 1976.

4.2 Stormwater Management Measures

The structural and nonstructural stormwater management measures established in this Ordinance shall be used, either alone or in a combination, in developing a stormwater management plan.

A. Structural Stormwater Management Measures.

(1) The following structural stormwater management practices shall be designed according to the Design Manual to satisfy the applicable minimum control requirements established in Section 4.1 of this Ordinance.

(a) Stormwater management ponds;

(b) Stormwater management wetlands;

(c) Stormwater management infiltration;

(d) Stormwater management filtering systems; and

(e) Stormwater management open channel systems.

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(2) The performance criteria specified in the Design Manual with regard to general feasibility, conveyance, pretreatment, treatment and geometry, environment and landscaping, and maintenance shall be considered when selecting structural stormwater management practices.

(3) Structural stormwater management practices shall be selected to accommodate the unique hydrologic or geologic regions of the state.

B. Nonstructural Stormwater Management Measures.

(1) The following nonstructural stormwater management practices shall be applied according to the Design Manual to minimize increases in new development runoff:

(a) Natural area conservation;

(b) Disconnection of rooftop runoff;

(c) Disconnection of non-rooftop runoff;

(d) Sheet flow to buffers;

(e) Grass channels; and

(f) Environmentally sensitive development.

(2) The use of nonstructural stormwater management practices shall be encouraged to minimize the reliance on structural BMP's.

(3) The minimum control requirements listed in Section 4.1 of this Ordinance may be reduced when nonstructural stormwater management practices are incorporated into site designs according to the Design Manual.

(4) The use of nonstructural stormwater management practices may not conflict with existing State or local laws, ordinances, regulations, or policies.

(5) Nonstructural stormwater management practices used to reduce the minimum control requirements must be recorded in the land records of (appropriate county) and remain unaltered by subsequent property owners. Prior approval from (local agency) shall be obtained before nonstructural stormwater practices are altered.

C. Alternative structural and nonstructural stormwater management practices may be used for new development water quality control if they meet the performance criteria established in the Design Manual and are approved by the Administration. Practices used for redevelopment projects shall be approved by (local agency).

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D. For the purposes of modifying the minimum control requirements or design criteria, the owner/developer shall submit to (local agency) an analysis of the impacts of stormwater flows downstream in the watershed. The analysis shall include hydrologic and hydraulic calculations necessary to determine the impact of hydrograph timing modifications of the proposed development upon a dam, highway, structure, or natural point of restricted streamflow. The point of investigation is to be established with the concurrence of (local agency), downstream of the first downstream tributary whose drainage area equals or exceeds the contributing area to the project or stormwater management facility.

4.3 Specific Design Criteria

The basic design criteria, methodologies, and construction specifications, subject to the approval of the (local agency) and the WMA, shall be those of the Design Manual.

5.0 STORMWATER MANAGEMENT PLANS

5.1 Review and Approval of Stormwater Management Plans

A. For any proposed development, the developer shall submit a stormwater management plan or waiver application to the (local agency) for review and approval, unless otherwise exempted. The stormwater management plan shall contain supporting computations, drawings, and sufficient information describing the manner, location, and type of measures in which stormwater runoff will be managed from the entire development. The (local agency) shall review the plan to determine compliance with the requirements of this Ordinance prior to approval. The plan shall serve as the basis for all subsequent construction.

B. Notification of approval or reasons for disapproval or modification shall be given to the applicant within [30 days](time frame) after submission of the completed stormwater plan. If a decision is not made within [30 days](time frame) the applicant shall be informed of the status of the review process and the anticipated completion date. The stormwater management plan shall not be considered approved without the inclusion of the signature and date of signature of the (approving agency) on the plan.

5.2 Contents of the Stormwater Management Plan

A. The developer is responsible for submitting a stormwater management plan that meets the design requirements of this Ordinance. The plan shall be accompanied by a report that includes sufficient information to evaluate the environmental characteristics of affected areas, the potential impacts of the proposed development on water resources, and the effectiveness and acceptability of measures proposed for managing stormwater runoff. The developer or builder shall certify on the drawings that all clearing, grading, drainage, construction, and development shall be conducted in strict accordance with the plan. If a stormwater management plan involves direction of some or all runoff off of the site, it is the responsibility of the developer to obtain from adjacent property owners any easements or necessary property interests concerning flowage of water. Approval of a stormwater management plan does not create or affect any right to direct runoff onto adjacent property without that property owner's permission. The minimum information submitted for support of a stormwater management plan or application for a waiver shall be as follows:

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B. Reports submitted for stormwater management plan approval shall include:

(1) A brief narrative description of the project;

(2) Geotechnicial investigations including soil maps, borings, site specific recommendations, and any additional information necessary for the proposed stormwater management design;

(3) Descriptions of all water courses, impoundments, and wetlands on or adjacent to the site or into which stormwater directly flows;

(4) Hydrologic computations, including drainage area maps depicting pre development and post development runoff flow path segmentation and land use;

(5) Hydraulic computations;

(6) Structural computations;

(7) Unified sizing criteria volume computations according to the Design Manual; and

(8) Any other information required by (local agency).

C. Construction drawings submitted for stormwater management plan approval shall include the following:

(1) A vicinity map;

(2) Topography survey showing existing and proposed contours, including the area necessary to determine downstream analysis for proposed stormwater management facilities;

(3) Any proposed improvements including location of buildings or other structures, impervious surfaces, storm drainage facilities, and all grading;

(4) The location of existing and proposed structures and utilities;

(5) Any easements and rights-of-way;

(6) The delineation, if applicable, of the 100-year floodplain and any on-site wetlands;

(7) Structural and construction details for all components of the proposed drainage system or systems, and stormwater management facilities.

(8) All necessary construction specifications;

(9) A sequence of construction;

(10) Data for total site area, disturbed area, new impervious area, and total impervious area;

(11) A table showing the unified sizing criteria volumes required in the Design Manual;

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(12) A table of materials to be used for stormwater management facility planting;

(13) All soil boring logs and locations;

(14) A maintenance schedule;

(15) Certification by the owner/developer that all stormwater management construction will be done according to this plan;

(16) An as-built certification signature block to be executed after project completion; and

(17) Any other information required by (local agency).

5.3 Preparation of the Stormwater Management Plan

A. The design of stormwater management plans shall be prepared by any individual whose qualifications are acceptable to (local agency). (Local agency) may require that the design be prepared by either a professional engineer, professional land surveyor, or landscape architect licensed in the State, as necessary to protect the public or the environment.

B. If a stormwater BMP requires either a dam safety permit from MDE or small pond approval from the (local) Soil Conservation District (SCD), (local agency) shall require that the design be prepared by a professional engineer licensed in the State.

6.0 PERMITS

6.1 Permit Requirement

A grading or building permit may not be issued for any parcel or lot unless a stormwater management plan has been approved or waived by the (local agency) as meeting all the requirements of this Ordinance. Where appropriate, a building permit may not be issued without:

A. Recorded easements for the stormwater management facility and easements to provide adequate access for inspection and maintenance from a public right-of-way;

B. A recorded stormwater management maintenance agreement;

C. A performance bond; and

D. Permission from adjacent property owners as necessary.

6.2 Permit Fee

A non-refundable permit fee will be collected at the time the stormwater management plan or application for waiver is submitted. The permit fee will provide for the cost of plan review, administration, and management of the permitting process, and inspection of all projects subject to this Ordinance. A permit fee schedule shall be established by the (local agency) based upon the relative complexity of the project and may be amended from time to time.

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6.3 Permit Suspension and Revocation

Any grading or building permit issued by the (local agency) may be suspended or revoked after written notice is given to the permittee for any of the following reasons:

A. Any violation(s) of the conditions of the stormwater management plan approval.

B. Changes in site runoff characteristics upon which an approval or waiver was granted.

C. Construction is not in accordance with the approved plan.

D. Noncompliance with correction notice(s) or stop work order(s) issued for the construction of the stormwater management facility.

E. An immediate danger exists in a downstream area in the opinion of the (local agency).

6.4 Permit Conditions

In granting the plan approval, the (local agency) may impose such conditions that may be deemed necessary to ensure compliance with the provisions of this Ordinance and the preservation of the public health and safety.

7.0 PERFORMANCE BOND

The (local authority) shall require from the developer a surety or cash bond, irrevocable letter of credit, or other means of security acceptable to the (local authority) prior to the issuance of any building and/or grading permit for the construction of a development requiring a stormwater management facility. The amount of the security shall not be less than the total estimated construction cost of the stormwater management facility. The bond required in this section shall include provisions relative to forfeiture for failure to complete work specified in the approved stormwater management plan, compliance with all of the provisions of this Ordinance, and other applicable laws and regulations, and any time limitations. The bond shall not be fully released without a final inspection of the completed work by the (local agency), submission of "As-built" plans, and certification of completion by the (local agency) that the stormwater management facilities comply with the approved plan and the provisions of this Ordinance. A procedure may be used to release parts of the bond held by (local agency) after various stages of construction have been completed and accepted by (local agency). The procedures used for partially releasing performance bonds must be specified by (local agency) in writing prior to stormwater management plan approval.

8.0 INSPECTION

8.1 Inspection Schedule and Reports

A. The developer shall notify the (local agency) at least 48 hours before commencing any work in conjunction with the stormwater management plan and upon completion of the project when a final inspection will be conducted.

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B. Inspections shall be conducted by (local agency) , its authorized representative, or certified by a professional engineer licensed in the State. Written inspection reports shall be made of the periodic inspections necessary during construction of stormwater management systems to ensure compliance with the approved plans.

C. Written inspection reports shall include:

(1) The date and location of the inspection;

(2) Whether construction was in compliance with the approved stormwater management plan;

(3) Any variations from the approved construction specifications; and

(4) Any violations that exist.

D. The owner/developer and on-site personnel shall be notified in writing when violations are observed. Written notification shall describe the nature of the violation and the required corrective action.

E. No work shall proceed until the (local agency) inspects and approves the work previously completed and furnishes the developer with the results of the inspection reports as soon as possible after completion of each required inspection.

8.2 Inspection Requirements During Construction

A. At a minimum regular inspections shall be made and documented at the following specified stages of construction:

(1) For Ponds:

(a) Upon completion of excavation to sub-foundation and when required, installation of structural supports or reinforcement for structures, including but not limited to:

(i) Core trenches for structural embankments
(ii) Inlet and outlet structures, anti-seep collars or diaphragms, and watertight connectors on pipes; and
(iii) Trenches for enclosed storm drainage facilities;

(b) During placement of structural fill, concrete, and installation of piping and catch basins;
(c) During backfill of foundations and trenches;
(d) During embankment construction; and
(e) Upon completion of final grading and establishment of permanent stabilization.

(2) Wetlands – at the stages specified for pond construction in 8.2 A (1) of this section, during and after wetland reservoir area planting, and during the second growing season to verify a vegetation survival rate of at least 50 percent.

(3) For infiltration trenches:

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(a) During excavation to subgrade;
(b) During placement and backfill of underdrain systems and observation wells;
(c) During placement of geotextiles and all filter media;
(d) During construction of appurtenant conveyance systems such as diversion structures, pre-filters and filters, inlets, outlets, and flow distribution structures; and
(e) Upon completion of final grading and establishment of permanent stabilization;

(4) For infiltration basins – at the stages specified for pond construction in 8.2 A (1) of this section and during placement and backfill of underdrain systems.

(5) For filtering systems:

(a) During excavation to subgrade;
(b) During placement and backfill of underdrain systems;
(c) During placement of geotextiles and all filter media;
(d) During construction of appurtenant conveyance systems such as flow diversion structures, pre-filters and filters, inlets, outlets, orifices, and flow distribution structures; and
(e) Upon completion of final grading and establishment of permanent stabilization.

(6) For open channel systems:

(a) During excavation to subgrade;
(b) During placement and backfill of underdrain systems for dry swales;
(c) During installation of diaphragms, check dams, or weirs; and
(d) Upon completion of final grading and establishment of permanent stabilization.

(7) For nonstructural practices – upon completion of final grading, the establishment of permanent stabilization, and before issuance of use and occupancy approval.

B. The (local agency) may, for enforcement purposes, use any one or a combination of the following actions:

(1) A notice of violation shall be issued specifying the need for a violation to be corrected if stormwater management plan noncompliance is identified;

(2) A stop work order shall be issued for the site by (local agency) if a violation persists;

(3) Bonds or securities may be withheld or the case may be referred for legal action if reasonable efforts to correct the violation have not been undertaken; or

(4) In addition to any other sanctions, a civil action or criminal prosecution may be brought against any person in violation of the Stormwater Management subtitle or this Ordinance.

C. Any step in the enforcement process may be taken at any time, depending on the severity of the violation.

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D. Once construction is complete, as-built plan certification shall be submitted by either a professional engineer or professional land surveyor licensed in the State to ensure that constructed stormwater management practices and conveyance systems comply with the specifications contained in the approved plans. At a minimum, as-built certification shall include a set of drawings comparing the approved stormwater management plan with what was constructed. (Local agency) may require additional information.

E. (Local agency) shall submit notice of construction to the Administration on a form supplied by the Administration for each stormwater management practice within 45 days of construction completion. If BMPs requiring SCD approval are constructed, notice of construction completion shall also be submitted to the appropriate SCD.

9.0 MAINTENANCE

9.1 Maintenance Inspection

The (local agency) shall ensure that preventative maintenance is performed by inspecting all stormwater management systems. Inspection shall occur during the first year of operation and at least once every 3 years thereafter. In addition, a maintenance agreement between the owner and (local agency) shall be executed for privately owned stormwater management systems as described in 9.2 of this section.

A. Inspection reports shall be maintained by the (local agency) for all stormwater management systems.

B. Inspection reports for stormwater management systems shall include the following:

(1) The date of inspection;

(2) Name of inspector;

(3) The condition of:

(a) Vegetation or filter media;

(b) Fences or other safety devices;

(c) Spillways, valves, or other control structures;

(d) Embankments, slopes, and safety benches;

(e) Reservoir or treatment areas;

(f) Inlet and outlet channels or structures;

(g) Underground drainage;

(h) Sediment and debris accumulation in storage and forebay areas;

(i) Any nonstructural practices to the extent practicable; and

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(j) Any other item that could affect the proper function of the stormwater management system.

(4) Description of needed maintenance.

C. After notification is provided to the owner of any deficiencies discovered from an inspection of a stormwater management system, the owner shall have 30 days or other time frame mutually agreed to between (local agency) and the owner to correct the deficiencies. (Local agency) shall then conduct a subsequent inspection to ensure completion of the repairs.

D. If repairs are not undertaken or are not found to be done properly, then enforcement procedures following 9.2 C of this section shall be followed by (local agency)

E. If, after an inspection by the (local agency), the condition of a stormwater management facility presents an immediate danger to the public health or safety, because of an unsafe condition or improper maintenance, the (local agency) shall take such action as may be necessary to protect the public and make the facility safe. Any cost incurred by the County/Municipality shall be assessed against the owner(s), as provided in section 9.2 C.

9.2 Maintenance Agreement

A. Prior to the issuance of any building permit for which stormwater management is required, the (local agency) shall require the applicant or owner to execute an inspection and maintenance agreement binding on all subsequent owners of land served by a private stormwater management facility. Such agreement shall provide for access to the facility at reasonable times for regular inspections by the (local agency) or its authorized representative to ensure that the facility is maintained in proper working condition to meet design standards.

B. The agreement shall be recorded by the applicant and/or owner in the land records of the County/Municipality.

C. The agreement shall also provide that, if after notice by the (local agency) to correct a violation requiring maintenance work, satisfactory corrections are not made by the owner(s) within a reasonable period of time (30 days maximum), the (local agency) may perform all necessary work to place the facility in proper working condition. The owner(s) of the facility shall be assessed the cost of the work and any penalties. This may be accomplished by placing a lien on the property, which may be placed on the tax bill and collected as ordinary taxes by the County/Municipality.

9.3 Maintenance Responsibility

A. The owner of the property on which work has been done pursuant to this Ordinance for private stormwater management facilities, or any other person or agent in control of such property, shall maintain in good condition and promptly repair and restore all grade surfaces, walls, drains, dams and structures, vegetation, erosion and sediment control measures, and other protective devices. Such repairs or restoration and maintenance shall be in accordance with approved plans.

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B. A maintenance schedule shall be developed for the life of any stormwater management facility and shall state the maintenance to be completed, the time period for completion, and who shall perform the maintenance. This maintenance schedule shall be printed on the approved stormwater management plan.

10.0 APPEALS

Any person aggrieved by the action of any official charged with the enforcement of this Ordinance, as the result of the disapproval of a properly filed application for a permit, issuance of a written notice of violation, or an alleged failure to properly enforce the Ordinance in regard to a specific application, shall have the right to appeal the action to the (special hearing examiner). The appeal shall be filed in writing within (time frame) of the date of official transmittal of the final decision or determination to the applicant, shall state clearly the grounds on which the appeal is based, and shall be processed in the manner prescribed for hearing administrative appeals under (local or state code provision).

11.0 SEVERABILITY

If any portion of this Ordinance is held invalid or unconstitutional by a court of competent jurisdiction, such portion shall not affect the validity of the remaining portions of this Ordinance. It is the intent of the (governing authority) that this Ordinance shall stand, even if a section, subsection, sentence, clause, phrase, or portion may be found invalid.

12.0 PENALTIES

Any person convicted of violating the provisions of this Ordinance shall be guilty of a misdemeanor, and upon conviction thereof, shall be subject to a fine of not more than Five Thousand Dollars ($5,000.00) or imprisonment not exceeding 1 year or both for each violation with costs imposed in the discretion of the court. Each day that a violation continues shall be a separate offense. In addition, the (governing authority) may institute injunctive, mandamus or other appropriate action or proceedings of law to correct violations of this Ordinance. Any court of competent jurisdiction shall have the right to issue temporary or permanent restraining orders, injunctions or mandamus, or other appropriate forms of relief.

13.0 EFFECTIVE DATE

And be it further enacted, that this Ordinance shall take effect (time frame) from the date it becomes adopted.

SARB_006854

SUPPLEMENT TO THE MODEL STORMWATER MANAGEMENT ORDINANCE

This supplement to the Maryland Department of the Environment's (MDE) **Model Stormwater Management Ordinance** contains optional content for implementing an advanced stormwater management program in Maryland. MDE provides this guidance to assist county and municipal code development as part of local land use and planning to enhance protection of receiving waters, and meet the requirements of the Water Resources Element of local Comprehensive Plans. While all local development review and approval processes are unique, MDE will use this document as a template to ensure effective implementation of advanced stormwater management ordinances.

HOW TO USE THIS GUIDANCE

MDE developed the **2000 Maryland Stormwater Design Manual** (Manual) to address three goals:

(1) Protect the waters of the State from the adverse impacts urban stormwater;
(2) Provide design guidance on effective structural and nonstructural best management practices (BMPs) for new development sites; and
(3) Improve the quality of BMPs that are constructed in Maryland.

The Manual recognizes an evolving, more comprehensive approach to stormwater management. Included in this approach is better guidance and incentives for environmentally sustainable or "green" development techniques. The projected outcome of this new approach will be site designs that more closely mimic natural processes and reduce reliance on the use of structural management techniques. It is difficult to accommodate the full spectrum of water resource protection principles into each project. However, the importance of these principles should be recognized and their use encouraged during project planning. This supplement provides options that can be used in local stormwater management ordinances to shift focus from the structural management of runoff to mimicking natural processes as part of total site design.

The various options listed in this guidance are designed to replace **Section 4.2** (Stormwater Management Measures) of MDE's **Model Stormwater Management Ordinance**. Each option requires that nonstructural practices be used to some extent to minimize reliance on structural best management practices (BMPs) and more closely mimic natural processes. After all nonstructural options have been exhausted, the remaining runoff should then be treated using structural BMPs to mitigate water quality and channel stability impacts. Each local jurisdiction should review these options and tailor their ordinances in accordance with local conditions and development activities. All local stormwater management ordinances within Maryland are subject to the MDE approval. If there are any questions or comments regarding this supplemental guidance, please contact the MDE/WMA at (410) 537-3543.

4.2 Stormwater Management Measures.

The structural and nonstructural stormwater management measures established in this Ordinance shall be used, either alone or in a combination, in developing a stormwater management plan.

A. Nonstructural Stormwater Management Measures.

(1) [Option 1] Nonstructural stormwater management practices shall be used to the maximum extent practicable to minimize the reliance on structural BMPs. As a minimum, the recharge volume shall be addressed using nonstructural practices.

[Option 2] Nonstructural stormwater management practices shall be used to the maximum extent practicable to treat the recharge volume and a minimum of (X) percent of the water quality volume before implementing structural BMPs.

[Option 3] Nonstructural stormwater management practices shall be used to the maximum extent practicable to treat the recharge volume, water quality volume, and channel protection volume before implementing structural BMPs.

(2) With respect to the requirements of A.1, the "maximum extent practicable" means the stormwater management plan achieving maximum compliance and conforming to the following:

(a) the plan includes no stormwater management practices that are inconsistent with the provisions of this ordinance or with other stormwater policies adopted by (local agency);
(b) the plan considers natural conditions of the site for the purposes of stormwater management;
(c) the plan takes into consideration existing science and technology; and
(d) the plan satisfies other relevant factors as may be determined by the (local agency)

(3) The following nonstructural stormwater management practices shall be applied according to the Design Manual to minimize increases in new development runoff:

(a) Natural area conservation;
(b) Disconnection of rooftop runoff;
(c) Disconnection of non-rooftop runoff;
(d) Sheet flow to buffers;
(e) Grass channels; and
(f) Environmentally sensitive development.

(4) The minimum control requirements listed in Section 4.1 of this Ordinance may be reduced when nonstructural stormwater management practices are incorporated into site designs according to the Design Manual.

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(5) The use of nonstructural stormwater management practices may not conflict with existing State or local laws, ordinances, regulations, or policies.

(6) Nonstructural stormwater management practices used to reduce the minimum control requirements must be recorded and remain unaltered by subsequent property owners. Prior approval from (local agency) shall be obtained before nonstructural stormwater practices are altered.

B. Structural Stormwater Management Measures.

(1) [Options 1 & 2] Structural stormwater management practices may be used to supplement nonstructural techniques to satisfy the applicable minimum control requirements established in Section 4.1 of this Ordinance.

[Option 3] Structural stormwater management practices may only be used to treat the water quality volume and channel protection volume after all opportunities to implement nonstructural practices are exhausted.

(2) The following structural stormwater management practices shall be designed according to the Design Manual:

(a) Stormwater management ponds;
(b) Stormwater management wetlands;
(c) Stormwater management infiltration;
(d) Stormwater management filtering systems; and
(e) Stormwater management open channel systems.

(3) The performance criteria specified in the Design Manual with regard to general feasibility, conveyance, pretreatment, treatment and geometry, environment and landscaping, and maintenance shall be considered when selecting structural stormwater management practices.

(4) Structural stormwater management practices shall be selected to accommodate the unique hydrologic or geologic regions of the state.

C. Alternative structural and nonstructural stormwater management practices may be used for new development water quality control if they meet the performance criteria established in the Design Manual and are approved by the WMA. Practices used for redevelopment projects shall be approved by (local agency).

D. For the purposes of modifying the minimum control requirements or design criteria, the owner/developer shall submit to (local agency) an analysis of the impacts of stormwater flows downstream in the watershed. The analysis shall include hydrologic and hydraulic calculations necessary to determine the impact of hydrograph timing modifications of the proposed development upon a dam, highway, structure, or natural point of restricted streamflow. The point of investigation is to be established with the concurrence of (local

agency), downstream of the first downstream tributary whose drainage area equals or exceeds the contributing area to the project or stormwater management facility.

4.3 Specific Design Criteria.

The basic design criteria, methodologies, and construction specifications, subject to the approval of the (local agency) and the WMA, shall be those of the Design Manual.

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26.17.02.05

.05 When Stormwater Management is Required.

A. Unless the particular activity is exempted by this regulation, a person may not develop any land without an approved stormwater management plan from the approving agency. A grading or building permit may not be issued for a property unless a stormwater management plan has been approved that is consistent with:

(1) The Stormwater Management Subtitle;

(2) This chapter;

(3) The county or municipal ordinance.

(4) The Design Manual for new development; and

(5) Policies established by the local approving agency for redevelopment.

B. The following activities are exempt from the provisions of this chapter:

(1) Additions or modifications to existing single family detached residential structures if they comply with §B(2) of this regulation;

(2) Developments that do not disturb over 5,000 square feet of land area; and

(3) Land development activities which the Administration determines will be regulated under specific State laws which provide for managing stormwater runoff.

C. Waivers.

(1) County and municipal ordinances may contain waiver policies for individual developments if the ordinances are approved by the Administration. The Administration will approve county and municipal ordinances and waiver policies if:

(a) They reasonably ensure that a development will not adversely impact stream quality;

(b) Waiver decisions are made on a case-by-case basis; and

(c) The cumulative effects of the waiver policy are evaluated.

(2) Stormwater management quantitative control waivers shall be granted only to those projects within areas where watershed management plans have been developed consistent with §E of this regulation.

(3) If watershed management plans consistent with §E of this regulation have not been developed, stormwater management quantitative control waivers may be granted to projects:

(a) That have direct discharges to tidally influenced receiving waters;

(b) That do not increase the post-development peak discharge for the 2-year storm event by more than 10 percent in those areas of the State where the 2-year storm serves as the overbank flood protection volume according to the Design Manual; or

(c) When the approving agency determines that circumstances exist that prevent the reasonable implementation of quantity control practices.

(4) Stormwater management qualitative control waivers apply only to:

(a) In-fill development projects where stormwater management implementation is not feasible;

(b) Redevelopment projects if the requirements of §D of this regulation are satisfied; or

(c) Sites where the approving agency determines that circumstances exist that prevent the reasonable implementation of quality control practices.

D. Redevelopment.

(1) An approving agency shall require that stormwater management be addressed for redevelopment. Proposed redevelopment project designs shall include:

(a) A reduction in impervious area;

(b) The implementation of stormwater management practices; or

(c) A combination of both §D(1)(a) and (b) of this regulation to result in an improvement to water quality.

(2) Unless otherwise specified by watershed management plans developed according to §E of this regulation, all redevelopment projects shall reduce existing site impervious area by at least 20 percent.

(3) Where site conditions prevent the reduction of impervious area, stormwater management practices shall be implemented to provide water quality control for at least 20 percent of the site's impervious area.

(4) When a combination of impervious area reduction and stormwater management practice implementation is used for redevelopment projects, the combination of impervious area reduction and the area controlled by a stormwater management practice shall equal or exceed 20 percent.

(5) An approval authority may allow practical alternatives where conditions prevent impervious area reduction or on-site stormwater management. Practical alternatives include, but are not limited to:

(a) Fees paid in an amount specified by the approving agency;

(b) Off-site BMP implementation for a drainage area comparable in size and percent imperviousness to that of the project;

(c) Watershed or stream restoration;

(d) Retrofitting; or

(e) Other practices approved by the appropriate authority.

(6) The recharge, channel protection storage volume, and overbank flood protection volume requirements specified in the Design Manual do not apply to redevelopment projects unless specified by the approving agency.

(7) On-site or off-site channel protection storage volume requirements as specified in the Design Manual may be imposed if watershed management plans developed according to §E of this regulation indicate that downstream flooding or erosion need to be addressed.

(8) Variations of this redevelopment policy shall be approved by the Administration.

E. An approving agency may develop quantitative waiver and redevelopment provisions for stormwater management that differ from the requirements of this chapter. These provisions shall be developed only as part of an overall watershed

management plan. Watershed management plans developed for the purposes of implementing different stormwater management policies for waivers and redevelopment shall:

(1) Include detailed hydrologic and hydraulic analyses to determine hydrograph timing;

(2) Evaluate both quantity and quality management;

(3) Include cumulative impact assessment of watershed development;

(4) Identify existing flooding and receiving stream channel conditions;

(5) Be conducted at a scale determined by the approving agency; and

(6) Specify where on-site or off-site quantitative and qualitative stormwater management practices are to be implemented.

Chapter 142

STORMWATER MANAGEMENT

[HISTORY: Adopted by the Mayor and Council of the Town of Chestertown 6-25-1984 as Ord. No. 2-84. Amendments noted where applicable.]

GENERAL REFERENCES

Planning Commission -- See Ch. 25.

Building construction -- See Ch. 57.

Floodplain management -- See Ch. 81.

Grading and sediment control -- See Ch. 88.

Subdivision of land -- See Ch. 148.

Water and sewers -- See Ch. 164.

Zoning -- See Ch. 170.

~ 142-1. Legislative purpose; statutory authority and applicability.

A. Purpose. The purpose of this chapter is to protect, maintain and enhance public health and safety and general welfare by establishing minimum requirements and procedures to control the adverse impacts associated with increased stormwater runoff. Proper management of stormwater runoff will minimize damage to public and private property, reduce the effects of development on land and stream channel erosion, assist in the attainment and maintenance of water quality standards, reduce local flooding and maintain after development, as nearly as possible, the predevelopment runoff characteristics.

B. Authority; applicability of provisions; enforcement. The provisions of this chapter, pursuant to the Natural Resources Article, ~ 8-11A-02, of the Annotated Code of Maryland, 1983 Replacement Volume, are adopted under the authority of the Municipal Corporation Charter of Chestertown, Maryland, and shall apply to all development occurring within the incorporated area of the Town of Chestertown. The application of this chapter and the provisions expressed herein shall be the minimum stormwater management requirements and shall not be deemed a limitation or repeal of any other powers granted by state statute. The Mayor and Council of Chestertown shall be responsible for the coordination and enforcement of the provisions of this chapter.

~ 142-2. Definitions.

For the purposes of this chapter, the following definitions describe the meanings of the terms used in this chapter:

ADVERSE IMPACT -- Any deleterious effect on waters or wetlands, including their quality, quantity, surface area, species composition, aesthetics or usefulness for human or natural uses, which is or may potentially be harmful or injurious to human health, welfare, safety or property, to biological productivity, diversity or stability or which unreasonably interferes with the enjoyment of life or property, including outdoor recreation.

AGRICULTURAL LAND MANAGEMENT PRACTICES -- Those methods and procedures used in the cultivation of land in order to further crop and livestock production and conservation of related soil and water resources.

APPLICANT -- Any person, firm or governmental agency which executes the necessary forms to procure official approval of a project or a permit to carry out construction of a project.

AQUIFER -- A porous, water-bearing geologic formation, generally restricted to materials capable of yielding an appreciable supply of water.

CLEARING -- The removal of trees and brush from the land, but shall not include the ordinary mowing of grass.

DETENTION STRUCTURE -- A permanent structure for the temporary storage of runoff which is designed so as not to create a permanent pool of water.

DEVELOP LAND -- To change the runoff characteristics of a parcel of land in conjunction with residential, commercial, industrial or institutional construction or alteration.

DRAINAGE AREA -- That area contributing runoff to a single point, measured in a horizontal plane, which is enclosed by a ridge line.

EASEMENT -- A grant or reservation by the owner of land for the use of such land by others for a specific purpose or purposes and which must be included in the conveyance of land affected by such easement.

EXEMPTION -- Those land development activities that are not subject to the stormwater management requirements contained in this chapter.

FLOW ATTENUATION -- Prolonging the flow time of runoff to reduce the peak discharge.

GRADING -- Any act by which soil is cleared, stripped, stockpiled, excavated, scarified,

filled or any combination thereof.

INFILTRATION -- The passage or movement of water into the soil surface.

OFF-SITE STORMWATER MANAGEMENT -- The design and construction of a facility necessary to control stormwater from more than one (1) development.

ON-SITE STORMWATER MANAGEMENT -- The design and construction of systems necessary to control stormwater within an immediate development.

POROUS PAVING -- An open-graded asphaltic or reticular concrete or other material which allows water to pass through it.

RETENTION STRUCTURE -- A permanent structure that provides for the storage of runoff by means of a permanent pool of water.

SEDIMENT -- Soils or other surficial materials transported or deposited by the action of wind, water, ice or gravity as a product of erosion.

SITE -- Any tract, lot or parcel of land or combination of tracts, lots or parcels of land which are in one (1) ownership or are contiguous and in diverse ownership where development is to be performed as part of a unit, subdivision or project.

STABILIZATION -- The prevention of soil movement by any vegetative and/or structural means.

STORMWATER MANAGEMENT:

A. For quantitative control, a system of vegetative and structural measures that control the increased volume and rate of surface runoff caused by man-made changes to the land.

B. For qualitative control, a system of vegetative, structural and other measures that reduce or eliminate pollutants that might otherwise be carried by surface runoff.

STORMWATER MANAGEMENT PLAN -- A set of drawings or other documents submitted by a person as a prerequisite to obtaining a stormwater management approval, which contain all of the information and specifications pertaining to stormwater management.

STRIPPING -- Any activity which removes the vegetative surface cover, including tree removal, clearing, grubbing and storage or removal of topsoil.

VARIANCE -- The modification of the minimum stormwater management requirements for specific circumstances where strict adherence to the requirements would result in unnecessary hardship and not fulfill the intent of this chapter.

WAIVER -- The relinquishment from stormwater management requirements by the Town of Chestertown for a specific development on a case-by-case review basis.

WATERCOURSE -- Any natural or artificial stream, river, creek, ditch, channel, canal, conduit, culvert, drain, waterway, gully, ravine or wash, in and including any area adjacent thereto, which is subject to inundation by reason of overflow or floodwater.

WATERSHED -- The total drainage area contributing runoff to a single point.

WETLANDS -- An area that has saturated soils or periodic high groundwater levels and vegetation adapted to wet conditions and periodic flooding.

~ 142-3. Control measures.

A. Control measures required prior to development. No person shall develop any land for residential, commercial, industrial or institutional uses without having provided for appropriate storm water management measures that control or manage runoff from such developments, except as provided in this section.

B. Exemptions. The following development activities are exempt from the provisions of this chapter and the requirements of providing stormwater management:

(1) Normally accepted agricultural land management activities.

(2) Additions or modifications to existing single-family detached residential structures.

(3) Developments that do not disturb over five thousand (5,000) square feet of land area.

(4) Land development activities which the Water Resources Administration determines will be regulated under specific state laws which provide for managing stormwater runoff.

(5) Residential developments consisting of single-family houses, each on a lot of two (2) acres or greater.

C. Waiver; eligibility. The Town of Chestertown may grant a waiver of the stormwater management requirements for the individual developments, provided that a written request is submitted by the applicant which contains descriptions, drawings and any other information that is necessary to evaluate the proposed development. A separate written waiver request shall be required in accordance with the provisions of this section if there are subsequent additions, extensions or modifications to a development receiving a waiver. Eligibility for a waiver shall be determined if the applicant can conclusively demonstrate that:

(1) The proposed development will not generate an increase of more than ten percent

(10%) in the two-year predevelopment peak discharge rate and will not cause an adverse impact on the receiving wetland, watercourse or body of water;

(2) A site is completely surrounded by existing areas which are served by an existing network of public storm drainage systems of a capacity adequate to accommodate the runoff from the additional development;

(3) Provisions to control direct outfall to tidewater are provided when the first inch of rainfall is managed according to infiltration standards and specifications promulgated by the Water Resources Administration; or

(4) A high-water table exists on the site such that the potential health risks caused by retention of stormwater exceed the benefit of such retention for stormwater management purposes.

D. Variances. The Town of Chestertown may grant a written variance from any requirement of ~ 142-6 of this chapter if there are exceptional circumstances applicable to the site such that strict adherence to the provisions of this chapter will result in unnecessary hardship and not fulfill the intent of the chapter. A written request for variances shall be provided to the Town of Chestertown and shall state the specific variances sought and reasons for their granting. The Town of Chestertown shall not grant a variance unless and until sufficient specific reasons justifying the variance are provided by the person developing the land.

~ 142-4. Stormwater management plans.

A. Review and approval.

(1) A stormwater management plan or an application for a waiver shall be submitted to the Town of Chestertown by the developer for the review and approval of any proposed development, unless otherwise exempted. The stormwater management plan shall contain supporting computations, drawings and sufficient information describing the manner, location and type of measures with which stormwater runoff will be managed from the entire development. The Town of Chestertown shall review the plan to determine compliance with the requirements of this chapter prior to approval. The plan shall serve as the basis for all subsequent construction.

(2) Notification of approval or reasons for the disapproval or modification shall be given to the applicant within forty-five (45) days after submission of the completed stormwater plan. If a decision is not made within forty-five (45) days, the applicant shall be informed of the status of the review process and the anticipated completion date. The stormwater management plan shall be considered approved without the inclusion of the signature and date of signature of the Kent Soil Conservation District on the plan.

B. Contents. The developer is responsible for submitting a stormwater management plan which meets the design requirements provided by this chapter. The plan shall include sufficient information to evaluate the environmental characteristics of the affected areas, the potential impacts of the proposed development on water resources and the effectiveness and acceptability of measures proposed for managing stormwater runoff. The developer or builder shall certify on the drawings that all clearing, grading, drainage, construction and development shall be conducted in strict accordance with the plan. The minimum information submitted for support of a stormwater management plan or application for a waiver shall be as follows:

(1) Site characteristics.

(a) A topography survey showing existing and proposed contours, including the area necessary to determine a downstream analysis for the proposed stormwater management facility.

(b) A soils investigation, including borings for construction of small ponds and infiltration practices.

(c) A description of all watercourses, impoundments and wetlands on or adjacent to the site or into which stormwater flows.

(d) A delineation of one-hundred-year floodplains, if applicable.

(e) A structure classification (SCS Pond Standard 378).

(2) Computations.

(a) Hydrologic.

(b) Hydraulic.

(c) Structural.

(3) In addition to the information listed above, stormwater management design plans shall include the following:

(a) Stormwater management plans.

[1] A vicinity map.

[2] A drainage area map showing the watershed boundaries, drainage area and stormwater flow paths.

[3] Proposed improvements, including the location of buildings or other structures,

impervious surfaces and storm drainage facilities, if applicable.

[4] The location of utilities.

[5] Structural details for all components of the proposed drainage systems and stormwater management facilities.

[6] Timing schedules and the sequence of development clearing, including stripping, rough grading, construction, final grading and vegetative stabilization.

[7] A maintenance schedule.

[8] Notes on drawings specifying materials to be used.

[9] Construction specifications.

[10] The location of easements.

(b) An estimate of stormwater management construction costs.

(c) Other information as required.

~ 142-5. Permit requirements; fee; suspension and revocation.

A. Prerequisites for permit issuance. A grading or building permit may not be issued for any parcel or lot unless a stormwater management plan has been approved or waived by the Town of Chestertown as meeting all the requirements of this chapter. Where appropriate, a building permit may not be issued without the following:

(1) Recorded easements for the stormwater management facility and easements to provide adequate access for inspection and maintenance of a public right-of-way.

(2) A recorded stormwater management maintenance agreement.

(3) Performance bond.

B. Fees. A nonrefundable permit fee will be collected at the time the stormwater management plan or application for waiver is submitted. The permit fee will provide for the cost of plan review, administration and management of the permitting process, and inspection of all projects subject to this chapter. A permit fee schedule shall be established by the Town of Chestertown based upon the relative complexity of the project, and such may be amended from time to time.

C. Suspension and revocation. Any grading or building permit issued by the Town of Chestertown may be suspended or revoked after written notice is given to the permittee

for any of the following reasons:

(1) Any violation(s) of the conditions of the stormwater management plan approval.

(2) Changes in the site runoff characteristics upon which a waiver was granted.

(3) When construction is not in accordance with the approved plans.

(4) Noncompliance with a correction notice(s) or stop work order(s) issued for the construction of the stormwater management facility.

(5) When an immediate danger exists in a downstream area in the opinion of the Town of Chestertown.

D. Conditions of plan approval. In granting the plan approval, the Town of Chestertown may impose such conditions thereto as may be deemed necessary to ensure compliance with the provisions of this chapter and the preservation of the public health and safety.

~ 142-6. Criteria for control measures established; design standards.

A. Minimum control requirements.

(1) The minimum stormwater control requirements shall require that all developments provide management measures necessary to maintain the post-development peak discharges for a twenty-four-hour, two-year and ten-year frequency storm event at a level that is equal to or less than the respective twenty-four-hour, two-year and ten-year predevelopment peak discharge rates through stormwater management practices that control the volume, timing and rate of flows. Where runoff is discharged into an off-site stormwater management facility, the control requirements and procedures shall be in accordance with Subsection (3) of this section.

(2) Stormwater management and development plans, where applicable, shall be consistent with adopted and approved watershed management plans or flood management plans as approved by the Water Resources Administration in accordance with the Flood Control and Watershed Management Act of 1976 (Natural Resources Article, ~ 8-9A-01 et seq., of the Annotated Code of Maryland.

B. Stormwater management measures.

(1) Stormwater management measures shall be required to satisfy the minimum control requirements. The stormwater management practices to be utilized in developing a stormwater management plan shall be according to the following order of preference:

(a) Infiltration of runoff on site.

(b) Flow attenuation by use of open, vegetated swales and natural depressions.

(c) Stormwater retention structures.

(d) Stormwater detention structures.

(2) Infiltration practices shall be utilized to reduce volume increases to the extent possible as determined in accordance with infiltration standards and specifications established by the Water Resources Administration. A combination of successive practices may be used to achieve the applicable minimum control requirements. Justification shall be provided by the person developing land for rejecting each practice based on site conditions.

C. Specific design criteria.

(1) Infiltration systems shall be designed in accordance with standards and specifications that are developed or approved by the Water Resources Administration and shall meet the following requirements:

(a) Infiltration systems greater than three (3) feet deep shall be located at least ten (10) feet from a basement wall.

(b) Infiltration systems designed to handle runoff from commercial or industrial impervious parking areas shall be a minimum of one hundred (100) feet from any water supply well.

(c) Infiltration systems may not receive runoff until the entire contributory drainage area to the infiltration system has received final stabilization.

(d) The stormwater management facility design shall provide an overflow system with measures to prod vide a nonerosive velocity of flow along its length and at the outfall.

(2) Retention and detention ponds shall be designed and constructed in accordance with the criteria of the Soil Conservation Service and shall include the following items:

(a) Velocity-dissipation devices shall be placed at the outfall of all detention or retention structures and along the length of any outfall channel as necessary to provide a nonerosive velocity of flow from the structure to a watercourse.

(b) The developer shall submit to the Town of Chestertown an analysis of the impacts of stormwater flows downstream in the watershed. The analysis shall include hydrologic and hydraulic calculations necessary to determine the impact of hydrograph timing modifications of the proposed development upon a dam, highway, structure or natural point of restricted streamflow, established with the concurrence of the Town of Chestertown, downstream of a tributary of the following size:

[1] The first downstream tributary whose drainage area equals or exceeds the contributing area to the pond; or

[2] The first downstream tributary whose peak discharge exceeds the largest designed release rate of the pond.

(c) The designed release rate of the structure shall be modified if any increase in flooding or stream channel erosion would result at the downstream dam, highway, structure or natural point of restricted streamflow. The release rate of the structure shall:

[1] Be reduced to a level that will prevent any increase in flooding or stream channel erosion at the downstream control point.

[2] Be not less than a one-year predevelopment peak discharge rate.

[3] Meet the requirements established in Subsection A of this section.

(d) Small pond approval shall be obtained from the Soil Conservation District or the Water Resources Administration pursuant to the Natural Resources Article, ~ 8-803(b), of the Annotated Code of Maryland.

(3) Off-site structures to be considered:

(a) Shall have a contributory drainage area not in excess of four hundred (400) acres unless, on a case-by-case basis, a larger drainage area is approved by the Water Resources Administration.

(b) Shall provide for a permanent pool of water or provide for a twenty-four-hour detention period for the one-year-frequency storm peak discharge,

(c) Shall manage the increase in peak discharge(s) for the two-year- and ten-year-frequency storm event(s).

(d) May not be located so as to discharge to Class III natural trout waters identified in COMAR 10.50.01.02I, unless authorized by the Water Resources Administration in permits issued pursuant to the Natural Resources Article, ~ 8-803, of the Annotated Code of Maryland.

(4) The predevelopment peak discharge rate shall be computed assuming that all land uses in the site to be developed are in good hydrologic condition.

(5) The developer shall give consideration to incorporating the use of the natural topography and land cover, such as wetlands, ponds, natural swales and depressions, as they existed prior to development to the degree that they can accommodate the additional flow of water.

(6) The Town of Chestertown shall give preference to the use of swales in place of the traditional use of curbs and gutters, based on a case-by-case review of stormwater management plans.

(7) Where a stormwater management plan involves direction of some or all runoff of the site, it shall be the responsibility of the developer to obtain from adjacent property owners any easements or other necessary property interests concerning flowage of water. Approval of a stormwater management plan does not create or effect any such rights.

(8) The basic design criteria, methodologies and construction specifications, subject to the approval of the Town of Chestertown and the Water Resources Administration, shall be those of the Soil Conservation Service generally found in the most current edition of the following publications or subsequent revisions:

(a) Urban Hydrology for Small Watersheds, Technical Release No. 55, January 1975.

(b) Storm Water Management Pond Design Manual, Maryland Association of Soil Conservation Districts, June 1975.

(c) Soil Conservation Service Engineering Field Manual, latest edition, as applicable.

(d) Soil Conservation Service Standard and Specification for Ponds, Specification No. 378, July 1981.

~ 142-7. Performance bond.

The Town of Chestertown shall require from the developer a surety or cash bond, irrevocable letter of credit or some other means of security acceptable to the Town of Chestertown prior to the issuance of any building and/or grading permit for construction of a development requiring a stormwater management facility. The amount of the security shall not be less than the total estimated construction cost of the stormwater management facility. The bond so required in this section shall include provisions relative to forfeiture for the failure to complete work specified in the approved stormwater management plan, compliance with all the provisions of this chapter and other applicable laws and regulations and any time limitations. The bond shall not be fully released without a final inspection of completed work by the Town of Chestertown, the submission of as-built plans and a certification of completion by the Town of Chestertown of the stormwater management facility as being in compliance with the approved plan and the provisions of this chapter. A provision may be made for partial release of the amount of the bond prorated upon completion and acceptance of the various stages of development as specifically delineated, described and scheduled on the required plans and specifications. The developer shall notify the Town of Chestertown upon completion of each stage that is ready for inspection.

~ 142-8. Inspections.

A. Schedule and reports.

(1) Prior to approval of a stormwater management plan, the developer will submit to the Town of Chestertown a proposed inspection and construction control schedule. The Town of Chestertown or its authorized representative shall conduct inspections and file reports for periodic inspections necessary, during construction of stormwater management systems, to ensure compliance with the approved plans.

(2) No work shall proceed until the Town of Chestertown inspects and approves the work previously completed and furnishes the developer with the results of the inspection reports as soon as possible after completion of each required inspection.

(3) Any portion of the work which does not comply will be promptly corrected by the developer after written notice from the Town of Chestertown. The notice shall set forth the nature of corrections required and the time within which corrections will be made.

(4) The developer shall notify the Town of Chestertown before commencing any work in conjunction with the stormwater management plan and upon completion of the project when a final inspection will be conducted.

B. Inspections required at certain stages of construction. After commencing initial site operations, regular inspections shall be made at the following specified stages of construction:

(1) Infiltration systems. Infiltration systems shall be inspected at commencement, during and upon completion of construction.

(2) Porous paving infiltration systems. Porous paving infiltration systems shall be inspected at the following stages so as to ensure proper placement and allow for infiltration into the subgrade:

(a) Upon completion of stripping, stockpiling and the construction of temporary sediment control and drainage facilities.

(b) Upon completion of the subgrade section.

(c) Upon completion of the reservoir base course.

(d) Upon completion of the top crushed stone course.

(e) Throughout the placement of the porous asphaltic concrete surface course to ensure proper laying temperatures and compaction.

(3) Flow attenuation devices. Flow attenuation devices, such as open vegetated swales, shall be inspected upon completion of construction.

(4) Retention and detention structures. Retention and detention structures shall be inspected at the following stages:

(a) Upon completion of excavation to the subfoundation and, where required, installation of structural supports or reinforcement for structures, including, but not limited to, the following:

[1] Core trenches for structural embankments.

[2] Inlet-outlet structures, antiseep structures and watertight connectors on pipes.

[3] Trenches for enclosed storm drainage facilities.

(b) During placement of structural fill and concrete and installation of piping and catch basins.

(c) During backfilling of foundations and trenches.

(d) During embankment construction.

(e) Upon completion of final grading and establishment of permanent stabilization.

C. Final inspection reports. A final inspection shall be conducted by the Town of Chestertown upon the completion of the stormwater management facility to determine if the completed work is constructed in accordance with the approved plan and this chapter. As-built certification by a registered professional engineer licensed in Maryland is also required to certify that the facility has been constructed as shown on the as-built plans and meets approved plans and specifications. The developer will receive written notification of the results of the final inspection. The Town of Chestertown shall maintain a permanent file of inspection reports.

D. Preventive maintenance inspections.

(1) Preventive maintenance shall be ensured through inspection of all infiltration systems and retention or detention structures by the Town of Chestertown. The Inspection shall occur during the first year of operation and at least every three (3) years thereafter.

(2) Inspection reports shall be maintained by the Town of Chestertown on all retention and detention structures and shall include the following:

(a) The date of inspection.

(b) The name of the inspector.

(c) The condition of the following:

[1] Vegetation.

[2] Fences.

[3] Spillways.

[4] Embankments.

[5] Reservoir area.

[6] Outlet channels.

[7] Underground drainage.

[8] Sediment load.

[9] Any other item that could affect the proper functioning of the stormwater management system.

(d) Description of needed maintenance.

(3) If after an inspection by the Town of Chestertown the condition of a stormwater management facility presents an immediate danger to the public health or safety because of unsafe conditions or improper maintenance, the Town of Chestertown shall take such action as may be necessary to protect the public and make the facility safe. Any cost incurred by the county/municipality shall be assessed against the owner(s) as provided in ~ 142-9A(3) of this chapter.

~ 142-9. Maintenance of facilities.

A. Inspection and maintenance agreement.

(1) Prior to the issuance of any building permit for which stormwater management is required, the Town of Chestertown shall require the applicant or owner to execute an inspection and maintenance agreement which is binding on all subsequent owners of land served by the private stormwater management facility. Such agreement shall provide for access to the facility at reasonable times for regular inspections by the Town of Chestertown or its authorized representative and for regular or special assessments of property owners to ensure that the facility is maintained in proper working condition to enable it to meet design standards and any provisions established.

(2) The agreement shall be recorded by the applicant and/or owner in the land records of the county/municipality.

(3) The agreement shall also provide that if, after notice by the Town of Chestertown to correct a violation requiring maintenance work, satisfactory corrections are not made by the owner(s) within a reasonable period of time [thirty (30) days maximum], the Town of Chestertown may perform all necessary work to place the facility in proper working condition. The owner(s) of the facility shall be assessed the cost of the work and any penalties, and there shall be a lien on the property which may be placed on the tax bill and collected as ordinary taxes by the county/municipality.

B. Responsibility for maintenance; maintenance schedule.

(1) The owner or any other person or agent in control of the property on which work has been done pursuant to this chapter for private stormwater management facilities shall maintain in good condition and promptly repair and restore all grade surfaces, walls, drains, dams and structures, vegetation, erosion and sediment control measures and other protective devices. Such repairs or restorations and maintenance shall be in accordance with approved plans.

(2) A maintenance schedule shall be developed for the life of any stormwater management facility and shall state the maintenance to be completed, the time period for completion and who shall perform the maintenance. This maintenance schedule shall be printed on the stormwater management plan.

~ 142-10. Appeals.

Any person aggrieved by the action of any official charged with the enforcement of this chapter as the result of the disapproval of a properly filed application for a permit, issuance of a written notice of violation or an alleged failure to properly enforce this chapter in regard to a specific application shall have the right to appeal the action to the Chestertown Board of Appeals. The appeal shall be filed, in writing, within thirty (30) days of the date of official transmittal of the final decision or determination to the applicant, shall state clearly the grounds on which the appeal is based and shall be processed in the manner prescribed for hearing administrative appeals under the Chestertown Zoning Ordinance.

~ 142-11. Violations and penalties.

Any person convicted of violating the provisions of this chapter shall be guilty of a misdemeanor and, upon conviction thereof, shall be subject to a fine of not more than five thousand dollars ($5,000.) or to imprisonment not exceeding one (1) year, or both, for each and every violation, with costs imposed in the discretion of the court. Each day that the violation continues shall be a separate offense. In addition thereto, the Town of

Chestertown may institute injunctive, mandamus or other appropriate actions or proceedings for the enforcement of this chapter or to correct violations of this chapter, and any court of competent jurisdiction shall have the right to issue restraining orders, temporary or permanent, injunctions or mandamus or other appropriate forms of remedy or relief.

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Editor's Note: See Ch. 170, Zoning.

GRAND TRAVERSE COUNTY
SOIL EROSION, SEDIMENTATION AND STORM WATER RUNOFF CONTROL ORDINANCE

adopted by resolution of the Board of County Commissioners in accordance with provisions of Section 9105(3) of Part 91 (Soil Erosion and Sedimentation Control) of the Natural Resources and Environmental Protection Act (Act 451 of 1994 as amended), the Michigan Drain Code (Act 40 of 1956 as amended) and Article IV, Section 52 of the Constitution of the State of Michigan

I. PURPOSE

The Grand Traverse County Board of Commissioners hereby adopts this Ordinance which sets forth the procedures, standards and enforcement remedies which shall be used by the Grand Traverse County Drain Commissioner in (1) meeting the requirements of Part 91 of the Natural Resources and Environmental Protection Act (Act 451 0f 1994, as amended) and the Michigan Drain Code (Act 40 of 1956, as amended) and (2) promoting the safety, public health, and general welfare of the community through effectively sustaining the goal of stormwater management and clean water in Grand Traverse County, and the State of Michigan.

II. OBJECTIVES

Specific objectives of this Ordinance include:

1. To prevent accelerated soil erosion and sedimentation and to control storm water runoff resulting from earth changes proposed within Grand Traverse County, both during and after construction by requiring proper provisions for drainage and the protection of soil surfaces during and after construction.

2. To prevent the unnecessary stripping of vegetation and loss of soils, especially adjacent to lakes, streams, watercourses, and wetlands.

3. To control construction activity that may cause slumping or erosion of land surfaces.

4. To ensure that soil erosion and sedimentation control practices and storm water runoff control systems are incorporated into site development in the planning and design process.

5. To ensure that all soil erosion and sedimentation control facilities are properly designed, constructed and maintained so as to provide water quality protection and prevent the conveyance of sediment via wind and storm water runoff.

6. To ensure that landowners control the volume and rate of storm water runoff originating from their property and maintain available flood storage areas so that surface water and ground water quality is protected, soil erosion minimized, and flooding potential reduced.

7. To preserve and use the natural drainage system for receiving and conveying storm water runoff and to minimize the need to construct enclosed, below-grade storm drainage systems.

8. To preserve natural infiltration and the recharge of groundwater and to maintain subsurface flows which replenish lakes, streams and wetlands.

9. To reduce the detrimental impacts of storm water flows on downstream communities.

10. To encourage the design and construction of storm water control systems which enhance flood prevention, water quality protection, wildlife habitat preservation, education, recreation and wetland protection.

11. To reduce maintenance costs and eliminate the need for costly remediation projects as a result of accelerated soil erosion and sedimentation and uncontrolled storm water runoff.

12. To provide for enforcement of this Ordinance and establish penalties for violations.

13. To assure that all storm water control facilities will be properly designed, constructed, and maintained.

III. AUTHORITY

This Ordinance is adopted under the authority granted by Part 91 of the Natural Resources and Environmental Protection Act (Act 451 of 1994), being Sections 324.9101 through 324.9123a, as amended, of the Michigan Compiled Laws Annotated (hereafter "Part 91"); the Michigan Drain Code (Act 40 of 1956), being Sections 280.1 through 280.630, as amended, of the Michigan Compiled Laws Annotated (hereafter the "Drain Code"); and the County's authority to provide for the public health, safety and welfare.

IV. RULES

Part 91 of the Natural Resources and Environmental Protection Act as amended, and the rules adopted there under, which do not conflict with this Ordinance, are hereby adopted and incorporated by reference.

V. DEFINITIONS

The following terms and phrases shall have the meaning given in this Ordinance and the Guidelines promulgated hereunder, unless the context otherwise requires:

A. **Accelerated Soil Erosion**: The increased loss of the land surface that occurs as a result of human activities.

B. **Appeals Board:** The Grand Traverse County Appeals Board for Building Code, Soil Erosion, Health and BOCA Fire.

C. **Authorized Public Agency:** A state agency or an agency of a local unit of government authorized under Section 9110 of Part 91 to implement soil erosion and sedimentation control procedures with regard to earth changes undertaken by it.

D. **Best Management Practice (BMP)**: Structural, vegetative or managerial measures, activities, facilities or devices which help to achieve soil erosion, sediment and storm water management runoff control objectives.

E. **Board of Commissioners:** Grand Traverse County Board of Commissioners.

F. **Cease and Desist Order:** An order issued under this Ordinance by the Drain Commissioner to the permittee or permittee's agents, representatives, employees or contractors requiring the cessation of activities.

G. **Channel:** The portion of a natural stream which conveys normal flows of water, or a ditch or channel excavated for the flow of water.

H. **Commercial Use:** All land uses except for one-family detached dwellings and appurtenant structures connected with the residential use. Property utilized or proposed to be utilized in connection with or for the purchase, sale, display, manufacturing, storage, warehousing or distribution of goods, merchandise or personal services, rental dwellings or operation of businesses or recreational, amusement or telecommunications enterprises whether for profit or not for profit.

I. **Consultant:** An individual who has a current certificate of training under Section 9123 of Part 91 or an individual who employs 1 or more individuals who have certificates of training under section 9123 of Part 91.

J. **Conveyance Facility:** A surface or subsurface structure or channel which transports storm water runoff.

K. **County Drain:** Drains established pursuant to the Michigan Drain Code (Act 40 of 1956, as amended).

L. **County Enforcing Agency:** A county agency or a conservation district designated by a county board of commissioners under Section 9105 of Part 91.

M. **Depression Storage:** The portion of precipitation trapped in depressions in the ground surface.

N. **Design Standard:** A specification that prescribes the type of design, location, mode of construction, mode of operation, or other engineering detail for soil erosion and sedimentation or storm water control facilities.

O. **Designated Agent:** A person who has written authorization from the landowner to sign the application and secure a permit in the landowner's name.

P. **Designated Use:** The use of a stream segment assigned by the Michigan Department of Environmental Quality as part of the regulatory process of establishing water quality control standards. Uses may be public drinking water supply, irrigation, recreational use, fishing, regulated discharges or other categories, as established by the Michigan Department of Environmental Quality.

Q. **Detention Basin:** A structure or facility, natural or artificial, which stores storm water on a temporary basis and may release it at a controlled rate. A detention basin may drain completely after a storm event, or it may be a body of water with a fixed minimum and maximum water elevation between runoff events.

R. **Disturbed Area/Area of Disturbance:** An area of land subjected to erosion due to the removal of vegetative cover and/or earthmoving activities, including filling.

S. **Drain Commissioner:** The Grand Traverse County Drain Commissioner or the authorized representative of the Drain Commissioner.

T. **Drainage Well:** A bed of stone or hole in the ground constructed for the purpose of trapping storm water for infiltration into the ground.

U. **Drainage System:** All facilities, channels, and areas which serve to convey, filter, store and/or receive storm water, either on temporary or permanent basis.

V. **Earth Change:** A human-made change in the natural cover or topography of land, including cut and fill activities, which may result in or contribute to soil erosion or sedimentation of the waters of the State. Earth change does not include the practice of plowing and tilling soil for the purpose of crop production or the harvesting of crops.

W. **Environmentally Sensitive Site:** Any site with a proposed earth change with one or more of the following characteristics:

1. Sites that have been planned where the area of disturbance is on a slope of 10 percent or greater (10 feet horizontal to 1 foot vertical or greater) or where the disturbed area will create a slope greater than 10 percent.

2. Sites with heavy clay soils (commonly termed hardpan clay), and soils classified in hydrologic Group D in the Grand Traverse County Soil Survey, published by the Natural Resources Conservation Service, U.S. Department of Agriculture.

3. Sites where earth changes may cause excessive erosion or sedimentation or which may increase flow onto adjacent lands.

4. Sites located within 100 feet of wetlands regulated pursuant to Part 303, Wetland Protection of Natural Resources and Environmental Protection Act.

5. Sites that are adjacent to or traversed by a drainage easement.

6. Other sites identified by local units of government as having a high potential for environmental degradation and flooding as a result of soil erosion or storm water runoff on-site or off-site.

X. **Extended Detention Basin:** A detention basin designed to provide substantial removal of suspended solids and particulates, typically achieved by holding storm water for 24 hours or more.

Y. **Fill:** Non-polluting material placed on-site which raises an existing elevation.

Z. **Grading:** Any stripping, clearing, stumping, excavating, filling, or stockpiling of the land, or any combination thereof, including the land in its excavated or filled condition.

AA. **Guidelines:** The Soil Erosion and Stormwater Design Guidelines promulgated pursuant to this Ordinance.

BB. **Lake:** The Great Lakes and all natural and artificial inland lakes or impoundments that have definite banks, a bed, visible evidence of a continued occurrence of water, and a surface area of water that is equal to, or greater than, 1 acre. "Lake" does not include sediment basins and basins constructed for the sole use of storm water retention or detention, cooling water, or treating polluted water.

CC. **Landowner:** The person who owns or holds a recorded easement on the property or who is engaged in construction in a public right-of-way in accordance with Sections 13, 14, 15, and 16 of Act No. 368 of the Public Acts of 1925, as amended.

DD. **Maintenance Agreement:** A binding agreement between the landowner and Grand Traverse County which sets forth the location and design of best management practices, as well as the terms and requirements for storm water, erosion and sedimentation control facility maintenance recorded with the Register of Deeds.

EE. **Nonerosive Velocity:** A speed of water movement that is not conducive to the development of accelerated soil erosion.

FF. **Ordinary High-Water Mark:** The line between upland and bottomland that persists through successive changes in water levels, below which the presence and action of water is so common or recurrent that the character of the land is marked distinctly from the upland and is apparent in the soil itself, the configuration of the surface of the soil, and the vegetation. On an inland lake that has a level established by law, it means the high established level. Where water returns to its natural level as the result of the permanent removal or abandonment of a dam, it means the natural ordinary high-water mark. For the Great Lakes, it is that level determined consistent with State or Federal law.

GG. **Outfall:** The point where water flows out from a conduit, drain, or stream.

HH. **Outlet:** The stream or facility receiving the flow from a basin, drain, or other storm water management facility.

II. **Peak Rate of Discharge (Peak Flow):** The maximum calculated rate of storm water flow at a given point in a channel, water course or conduit resulting from a predetermined frequency storm or flood, measured in cubic feet per second (cfs).

JJ. **Permanent Soil Erosion and Sedimentation Control Measures:** Control measures which are installed or constructed to control soil erosion and sedimentation and which are maintained after project completion.

KK. **Receiving Body of Water:** Any lake, stream, river or wetland into which storm water runoff is directed.

LL. **Regional Detention Basin:** A basin to detain water flow from a number of development sites or a small watershed.

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MM. Retention Basin: An area which is constructed to capture surface water runoff and which does not discharge directly to a lake or stream through an outlet. Water leaves the basin only by infiltration and evaporation.

NN. Sediment: Solid particulate matter, including both mineral and organic matter, that is in suspension in water, is being transported, or has been removed from its site of origin by actions of wind, water, or gravity and has been deposited elsewhere.

OO. Site: Any tract, lot or parcel of land or combination of tracts, lots or parcels of land proposed for development or activity undergoing earth moving.

PP. Soil Erosion or Erosion: The wearing away of land by the action of wind, water, gravity or a combination thereof.

QQ. Soil Erosion, Sedimentation and Storm Water Runoff Control Permit*:* A signed, written statement issued under this Ordinance authorizing a landowner to engage in specified earth changes.

RR. Soil Erosion, Sedimentation and Storm Water Runoff Control Plan: The maps, plans and other written information for a proposed land use or earth change on a site which describe the way in which soil erosion and sedimentation and storm water runoff will be controlled, during and after completion of construction.

SS. Storm Water Design Guidelines: Those guidelines that correspond with this ordinance and specifically govern the process of any earth change activities occurring within the county.

TT. Storm Drain: A conduit, pipe, natural channel, or human-made structure which serves to transport storm water runoff.

UU. Stream: A river, creek, or other surface watercourse which may or may not be serving as a drain as defined in the Michigan Drain Code, and which has definite banks, a bed, and visible evidence of the continued flow or continued occurrence of water, including the connecting waters of the Great Lakes.

VV. Swale: Low-lying grassed area with gradual slopes which transports storm water, either on-site or off-site.

WW. Temporary Soil Erosion and Sedimentation Control Measures: Interim control measures which are installed or constructed to control soil erosion and sedimentation and which are not maintained after project completion.

XX. Vegetative Cover: Grasses, shrubs, trees, and other vegetation which holds and stabilizes soils.

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YY. Waters of the State: The Great Lakes and their connecting waters, inland lakes and streams, including drains, as defined under Part 301, Inland Lakes and Streams Act, being MCL 324.30101 *et seq*, and wetlands regulated under Part 303, Wetland Protection, being 324.30301 *et seq*, and the rules promulgated thereunder.

ZZ. Watershed: A land area, also known as a drainage area, which collects precipitation and contributes runoff to a receiving body of water or point along a watercourse.

AAA. Wetland: Land characterized by the presence of water at a frequency and duration sufficient to support, and that under normal circumstances does support, wetland vegetation or aquatic life, and is commonly referred to as a bog, swamp, or marsh and as regulated under Part 303, Wetland Protection, being 324.30301 et seq, and the rules promulgated thereunder.

BBB. Wetland Vegetation: Plants that exhibit adaptations to allow, under normal conditions, germination or propagation and to allow growth with at least their root systems in water or saturated soil.

VI. SOIL EROSION, SEDIMENTATION AND STORM WATER RUNOFF CONTROL PERMIT REQUIREMENTS

A. Jurisdiction for Permit Administration

1. County Enforcing Agency. The Drain Commissioner shall act as the County Enforcing Agency for regulated earth changes proposed within the boundaries of Grand Traverse County under Part 91.

2. Authorized Public Agencies. Earth changes carried out by authorized public agencies under Part 91 shall be exempt under this ordinance.

If any government agency loses its status as an Authorized Public Agency under Part 91, the government agency shall no longer be exempt from this Ordinance.

All Authorized Public Agencies shall notify the Drain Commissioner in writing of each proposed earth change pursuant to R 323.1706(4) of Part 91.

3. Municipal Enforcing Agencies. The land within the boundaries of a municipality approved as a Municipal Enforcing Agency under Section 9106 of Part 91 is exempt from this Ordinance.
If any municipality loses its status as a Municipal Enforcing Agency under Part 91, the land within the boundaries of the municipality shall no longer be exempt from this Ordinance.

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4. **Earth Changes Affecting Two or More Enforcing Agencies**. When earth changes are proposed on sites which are located in the jurisdiction of two or more local or county enforcing agencies, application review and permit issuance shall be the responsibility of the Michigan Department of Environmental Quality, which shall act as the enforcing agency.

B. Regulated Earth Changes

1. Except as provided in this Ordinance, earth changes that meet any of the following criteria require a Soil Erosion, Sedimentation and Storm Water Runoff Control Permit from the Drain Commissioner:

a. Which disturbs 1 or more acres of land.

b. Within 500 feet of the water's edge of a lake or stream.

c. Within an environmentally sensitive site.

d. The following sites regardless of size, location or environmental sensitivity:

1. Commercial use development.
2. Mobile home park or manufactured home development.
3. Multiple family residential development.
4. Site condominium or condominium developments as defined by Act 59 of the Public Acts of 1978, as amended.
5. Platted subdivision development.

2. The following activities which do not require a Soil Erosion Sedimentation and Storm Water Permit unless they meet the criteria specified in Section VI B, 1 c and d above:

a. A beach nourishment project permitted under Part 325 of Public Act 451 of 1994 as amended.

b. Normal road and driveway maintenance, such as grading or leveling, that does not increase the width of the road or driveway, and that will not contribute sediment to lakes or streams.

c. An earth change of a minor nature that is stabilized within 24 hours of the initial earth disturbance and that will not contribute sediment to lakes or streams as determined by the Drain Commissioner.

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d. Earth changes associated with well locations, surface facilities, flow lines or access roads relating to oil or gas exploration and development in conformance with the provisions of Section 9115(3) of Part 91 of Public Act 451 of 1994, as amended. (MCL 324.9115(3)).

e. All activities as set forth in Section 9115 of Part 91 of Public Act 451 of 1994 as amended. (MCL 324.9115)

C. Identification of Environmentally Sensitive Sites

1. Landowners or their designated agents are responsible for determining whether their sites are Environmentally Sensitive Sites as defined in this Ordinance. The Drain Commissioner may also determine that a site constitutes an Environmentally Sensitive Site.

2. Township, village, city and or county agencies shall be requested to provide assistance to Landowners in identifying earth changes and Environmentally Sensitive Sites subject to review by the Drain Commissioner.

D. Permit Application Submittal

1. Permit applications shall be submitted to the Drain Commissioner by the Landowner or Designated Agent.

2. A Landowner or Designated Agent shall submit with the application, one copy of the soil erosion and sedimentation and storm water runoff control plan unless additional copies are requested by the Drain Commissioner. Copies of the permit application form shall be made available by the Drain Commissioner.

3. Application for a permit shall be made prior to the start of any earth change requiring a permit under this Ordinance. Permit approval shall be given prior to the initiation of any work activity. Any unauthorized work shall be considered a violation of this Ordinance regardless of any later actions taken toward compliance.

4. Submission of an application for permit shall constitute consent by the Landowner for the Drain Commissioner or designated agent to enter upon the premises described in the application for purposes of inspections attendant to the application or any permit issued as a result thereof.

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E. Sequential Applications

1. Projects on a site which are so large or complex that a Soil Erosion, Sedimentation and Storm Water Runoff Control Plan encompassing all phases of the project cannot reasonably be prepared prior to initial ground-breaking, application for permit on successive major incremental earth change activities may be allowed. Requests for sequential applications shall be approved by the Drain Commissioner prior to submittal of the initial permit application.

2. Approval of sequential applications shall take place in two phases. First, the overall conceptual plan for the entire development shall be submitted for review and approval. Second, detailed plans for sections of the total project shall be submitted for review and approval upon the request of the Drain Commissioner.

3. All permits processed and issued for phases of a project shall be clearly defined as to the nature and extent of work covered. Each phase of the project must be reviewed and permitted by the Drain Commissioner prior to construction.

F. Permit Application Review

The Drain Commissioner shall approve, approve with conditions, disapprove, or require modification of an application and soil erosion, sedimentation and storm water runoff control plan within 30 days. The review period begins upon the receipt of a completed application, plans and fees.

1. **Approval.** Upon a determination by the Drain Commissioner that the permit applicant has met all of the requirements of this Ordinance and Part 91, the Drain Commissioner will issue a permit specifying the work approved. The Drain Commissioner shall notify the permit applicant of approval by first class mail or written approval delivered in person.

2. **Disapproval or Modification.** If the permit applicant has not met all of the requirements of this Ordinance and Part 91, the Drain Commissioner may either disapprove the application, request modification of the application or plan, or request additional information from the applicant. If an application is disapproved, the Drain Commissioner shall advise the applicant by certified mail or written statement delivered in person of the reasons for disapproval and conditions required for approval. An incomplete application constitutes grounds for disapproval.

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G. Permit Expiration or Revocation

1. **Permit Expiration.** Permits shall expire automatically upon the project completion date provided by the applicant on the application, not to exceed one (1) year. With the approval of the Drain Commissioner, a permit may be extended for a period not to exceed one (1) year upon request of the permit holder, provided the request for extension is made before the date of expiration of the permit setting forth, in writing, the reasons for the extension request.

2. **Permit Revocation**. Any permit issued by the Drain Commissioner under this Ordinance may be revoked or suspended for any of the following reasons:

a. A violation of a condition of the permit.

b. Misrepresentation or failure to fully disclose relevant facts in the application or soil erosion and storm water runoff control plan.

c. A change in a condition that requires a temporary or permanent change in the activity.

d. Authorized work is abandoned or suspended for a period of six months.

e. A violation of the setbacks established by the Guidelines.

The Drain Commissioner will provide the permit holder notice of any revocation and/or suspension of the permit, in writing, within 10 days of the revocation and/or suspension. The notice will be sent by first-class mail or served personally upon landowner or designated agent. The notice will specify the reason(s) for the revocation and/or suspension and will set forth the availability and time period for an appeal of the revocation and/or suspension.

H. Issuance Of Building Permits

1. A general law township, charter township, city, village or county agency which issues land use permits and/or building permits shall notify the Drain Commissioner upon receipt of an application involving an earth change subject to permit requirements under this Ordinance.

2. A township, city, village or county agency shall not issue a land use permit or building permit for an earth change subject to permit

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requirements until a soil erosion, sedimentation and storm water runoff control permit has been issued by the Drain Commissioner.

3. The Drain Commissioner shall notify the township, city, village or county agency after a permit decision has been made.

I. Permits and Approvals of Other Government Agencies

Approvals under this Ordinance or Part 91 shall not relieve a landowner of the need to obtain other applicable permits or approvals as required by federal, state, county and local agencies.

J. General Standards for Approval of Soil Erosion Sedimentation and Storm Water Runoff Control Plans

1. The Drain Commissioner shall approve or disapprove soil erosion sedimentation control permit applications and plans in accordance with this Ordinance, the guidelines promulgated under this Ordinance, as may be amended by the Drain Commissioner and Part 91.

2. All earth changes subject to review under the requirements of this Ordinance shall be designed, constructed, and maintained consistent with the guidelines and best management practices promulgated under this Ordinance to provide for the detention of runoff and to protect water quality.

3. Measures required for soil erosion, sedimentation and storm water runoff control shall take into consideration natural features, proximity of the site to lakes, streams and wetlands, applicable setback requirements, the extent of impervious surfaces, the potential for soil erosion and sedimentation and flooding, and the size of the site.

4. Storm water conveyance, storage, and infiltration facilities shall be designed to provide for non-erosive velocities of storm water runoff.

5. Alterations to natural drainage patterns shall not create downstream flooding or sedimentation or obstruct runoff from lands upstream from the project site or diminish capacity of watercourses, streams or drainage ways serving lands upstream of the project site.

6. When a proposed earth change is located in an area where a watershed plan has been approved by the Board of Commissioners, the standards for storm water detention and/or retention volumes, discharge rates, and storm water facility locations specified in the approved watershed plan shall be deemed to meet the requirements of this Ordinance, as it relates to storm water runoff requirements.

K. Soil Erosion Sedimentation and Storm Water Runoff Control Plan Requirements

A person shall prepare a soil erosion, sedimentation and storm water runoff control plan for any earth change identified in this Ordinance or in Part 91 that require a permit. A person shall design the plan to effectively reduce accelerated soil erosion and sedimentation and storm water runoff and shall identify factors that may contribute to soil erosion or sedimentation, or both. The plan shall include, but not be limited to, all of the following:

1. A map or maps at a scale of not more than 200 feet to the inch or as otherwise determined by the Drain Commissioner, including a legal description and site location sketch that includes the proximity of any proposed earth change to lakes, streams, and or wetlands; predominant land features; and contour intervals or slope description.

2. A soils survey or a written description of the soil types of the exposed land area contemplated for the earth change.

3. A description and the location of the physical limits of each proposed earth change.

4. A determination of all applicable setbacks.

5. The location of all lakes, streams and wetlands partially or completely contained within the boundaries of the site or within 50 feet of the site boundary.

6. A description and the location of all existing and proposed on-site storm water management and dewatering facilities.

7. The timing and sequence of each proposed earth change.

8. The location and description for installing and removing all proposed temporary soil erosion and sediment control measures.

9. A description and the location of all proposed permanent soil erosion and sedimentation control measures.

10. A program proposal for the continued maintenance of all permanent soil erosion and sediment control measures that remain after project completion, including the designation of the person responsible for the maintenance. Maintenance responsibilities shall become a part of any sales or exchange agreement for the land on which permanent soil erosion and sediment control measures are located.

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11. Other information which the Drain Commissioner requires to review the impact of the proposed earth change in relationship to the standards and requirements of this Ordinance and Part 91.

12. The Drain Commissioner may require that the soil erosion, sedimentation and storm water runoff control plan be prepared by one of the following registered professionals: civil engineer, land surveyor, architect, and/or landscape architect.

L. Earth Change Design, Installation and Removal Requirements

1. A person shall design, construct and complete an earth change in a manner that limits the exposed area of any disturbed land for the shortest possible period of time as determined by the Drain Commissioner.

2. A person shall remove sediment caused by accelerated soil erosion from runoff water before it leaves the site of the earth change.

3. A person shall design a temporary or permanent control measure that is designed and constructed for the conveyance of water around, through, or from the earth change area to limit the water flow to a nonerosive velocity.

4. A person shall install temporary soil erosion and sedimentation control measures before or upon commencement of the earth change activity and shall maintain the measures on a daily basis. A person shall remove temporary soil erosion and sedimentation control measures after permanent soil erosion measures are in place and the area is stabilized. A person shall stabilize the area with permanent soil erosion control measures under approved standards and specifications as outlined in this Ordinance as required by state law. Temporary and permanent soil erosion and sedimentation measures shall comply with the standards and specifications as set forth in Section VI M.

M. Standards and Specifications For Temporary and Permanent Soil Erosion Sedimentation and Storm Water Runoff Control Measures

1. A person shall complete all temporary and permanent erosion and sedimentation control measures according to the approved soil erosion, sedimentation and storm water runoff control plan.

2. A person shall install and maintain control measures in accordance with the standards and specifications of all of the following:

a. The product manufacturer.

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b. The Drain Commissioner as provided in storm water design guidelines published by the Drain Commissioner's office.

c. The Conservation District.

d. The Michigan Department of Environmental Quality.

e. The Michigan Department of Transportation.

If a conflict exists between the standards and specifications, then the Drain Commissioner shall determine which specifications are appropriate for the project.

N. Maintenance of Control Facilities and Measures

1. All soil erosion, sedimentation and storm water runoff control facilities and measures shall be maintained in accordance with this Ordinance, Part 91 and permit conditions.

2. The person(s) designated as responsible for maintenance under the soil erosion and storm water runoff control plan as required in this Ordinance shall be one of the following:

a. The landowner or recorded interest (easement holder).

b. The property owners association or other non-profit organization, provided that provisions requiring the maintenance outlined in the soil erosion and storm water runoff control plan and the financing of the maintenance are included in deed restrictions or other contractual agreements.

c. The Drain Commissioner, in accordance with the Michigan Drain Code, Public Act 40 of 1956, as amended.

3. Maintenance Agreements shall specify responsibilities for financing maintenance, performing emergency repairs and responsibility for violations of this Ordinance or Part 91.

4. The Drain Commissioner will make the final decision of what maintenance option is appropriate in a given situation. Considerations in making this decision will include, but not be limited to, natural features, proximity of site to lakes, streams and wetlands, extent of impervious surfaces, size and location of site, and potential need for ongoing maintenance activities.

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O. Off-Site Storm Water Control

1. **Waiver Option**. In lieu of on-site storm water facilities and measures, the use of off-site storm water facilities and measures, together with on-site soil erosion and sedimentation control measures, may be proposed. In such cases, the applicant shall request a waiver of the requirements for on-site storm water runoff control. The waiver request shall be submitted to the Drain Commissioner with a permit application and a soil erosion, sedimentation and storm water runoff control plan, including information specified in this Ordinance. This waiver option does not allow for changes in requirements for on-site soil erosion and sedimentation control measures.

2. **Shared Off-Site Storm Water Control Facilities.**

a. Off-site storm water runoff control areas may be shared between two or more landowners or developments, provided that maintenance agreements have been approved by the Drain Commissioner and storm water management easements have been obtained and recorded.

b. Storm water management easements are required for all areas for off-site storm water control unless an exception has been granted by the Drain Commissioner. Easements shall be recorded with the Grand Traverse County Register of Deeds prior to the approval of the final development plan by the Drain Commissioner.

P. Storm Water Management Easements

1. Storm water management easements shall be provided by the landowner if necessary for: (1) access for facility inspections and maintenance; and/or (2) preservation of storm water runoff conveyance, infiltration, and detention areas and facilities, including flood routes for the 100-year storm event. The purpose and the holder of the easement shall be specified in the maintenance agreement signed by the landowner.

2. Storm water management easements are required for all areas used for off-site storm water runoff control.

3. Easements shall be recorded with the Grand Traverse County Register of Deeds prior to the final inspection, approval and release of a building permit by the Drain Commissioner.

Q. Grand Traverse County Road Commission

The Road Commission may take all actions necessary to maintain its authorized public agency designation under Part 91 and may annually review its operational procedures with The Conservation District and the Drain Commissioner. A summary report of the previous year's activities and any noted deficiencies may be made and submitted to the Board of County Road Commissioners and the Board of Commissioners. The Drain Commissioner, the Board of Commissioners or the Board of County Road Commissioners may call for a review meeting with a seven (7) day notice if a deficiency is observed and not resolved in a reasonable method.

The Road Commission shall use its best effort to meet the goals and guidelines for storm water runoff control contained in this Ordinance on all new roads constructed on rights-of-way acquired after the adoption of this Ordinance. Storm water retention or detention shall be compatible to the current highway safety guidelines, geometric design standards, structural requirements, maintenance practices and general drain laws that govern natural surface water flow, concentration, location and/or velocity. When right-of-way is available on existing improved county roads, the Road Commission will review the feasibility of providing storm water runoff controls that are reasonable to be constructed and maintained at a nominal cost.

VII. INSPECTIONS

A. The Drain Commissioner or authorized representatives may enter at all reasonable times in or upon any private or pubic property for the purpose of inspection and investigating the conditions or practices that may be in violation of this Ordinance. Inspections may take place before, during, and/or after any earth change activity.

B. If upon inspection, existing site conditions are found to be in conflict with an approved permit or soil erosion, sedimentation and storm water runoff control plan, a cease and desist order may be issued. No earth moving shall be performed unless authorized for the purpose of protection until a revised soil erosion and storm water runoff control plan has been approved, and the permit modified.

C. Requests for revisions must be submitted to and approved by the Drain Commissioner in writing or approved by the Drain Commissioner or an authorized representative on-site before being effective. If approved, a revised site plan shall be submitted to the Drain Commissioner for review and approval.

VIII. FEES

All fees shall be paid to Grand Traverse County in accordance with the current fee schedule approved by the Grand Traverse County Board of Commissioners.

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IX. COMPLIANCE ASSURANCES

A. Performance Guarantees

1. As a condition of issuance of a permit, the Drain Commissioner may require the applicant to deposit cash, a certified check, or an irrevocable letter of credit acceptable to the Drain Commissioner in an amount sufficient to assure the installation and completion of such protective or corrective measures as may be required by the Drain Commissioner. Irrevocable letters of credit, if used as a performance guarantee, shall extend for a minimum of one year with the option of renewal. The required security shall be held in the office of the Drain Commissioner until authorized to be returned.

2. Performance guarantees will be returned to the applicant when:

a. The site is certified, by the licensed professional who designed the site, that the site is completely stabilized and was constructed as designed and approved by the Drain Commissioner; and

b. Following inspection, the Drain Commissioner determines that the site is completely stabilized and meets the requirements set forth by the Drain Commissioner.

B. Construction Certification by Registered Professional

For any sites that require a sealed site plan, a certification letter, with a registered professional's signature, shall be submitted after soil erosion and sedimentation and storm water runoff control facilities have been installed to affirm that construction has been completed in accordance with the approved soil erosion, sedimentation and storm water runoff plan. This certification letter can be prepared by one of the following registered professionals: civil engineer, land surveyor, architect, and/or landscape architect. If the Drain Commissioner specifies that a professional civil engineer prepare the plan, the certification must be submitted by the professional civil engineer that certifies construction.

If there are changes during the course of construction, the Drain Commissioner may require final "as built" drawings for final approval of the site work.

C. Certificate of Compliance

Upon receipt and approval of the certification letter, the Drain Commissioner shall issue a certificate of compliance to the landowner.

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X. ENFORCEMENT

Persons in violation of this Ordinance or Part 91, including earth changes exempt from permit requirements, may be subject to one or all of the following enforcement actions.

A. Notice of Violation

1. If the Drain Commissioner determines that soil erosion or sedimentation or flooding of adjacent properties or the waters of the state has or will reasonably occur from land in violation of this Ordinance or Part 91, the Drain Commissioner may seek to enforce a violation of this Ordinance or Part 91 by notifying the landowner, by mail, with return receipt requested, of its determination. The notice shall contain a description of the violation and what must be done to remedy the violation and shall specify a time to comply with the Ordinance and Part 91. If the Drain Commissioner determines that expenditures exceeding $10,000.00 must be made to meet compliance, the notice must state that conformance may result in expenditures above this amount.

2. Within 5 days after a Notice of Violation has been issued, the landowner shall implement and maintain soil erosion and sedimentation control measures in conformance with this Ordinance and Part 91.

B. Enforcement Actions

1. After a Notice of Violation has been mailed, if the Drain Commissioner determines that the condition of the land may result in or contribute to soil erosion and sedimentation or flooding of adjacent properties or to the waters of the state, and if soil erosion and sediment and storm water runoff control measures in conformance with this Ordinance and Part 91 are not in place, the Drain Commissioner may enter upon the land and construct, implement and maintain soil erosion and sedimentation and storm water runoff control measures in conformance with this Ordinance and Part 91.

2. The Drain Commissioner shall not expend more than $10,000.00 for the cost of the work, materials, labor and administration unless the Notice of Violation stated that an expenditure of more than $10,000.00 may be made and that the work may not begin until 10 days after the Notice of Violation was mailed.

3. Except as otherwise provided through Maintenance Agreements, all expenses incurred under this Ordinance by the Drain Commissioner to construct, implement, and maintain soil erosion and sedimentation control measures to bring land into conformance with this Ordinance and Part 91 shall be reimbursed to the Drain Commissioner by the landowner.

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4. The Drain Commissioner shall have a lien for the expenses incurred to bring the land into conformance. However, with respect to single-family or multiple family residential property, the lien for such expenses shall have priority over all liens and encumbrances filed or recorded after the date of such expenditure. With respect to all other property, the lien for such expenses shall be collected and treated in the same manner as provided for property tax liens under the General Property Tax Act, Public Act 206 of 1893, as amended.

C. Emergency Actions

When emergency actions are necessary to moderate a nuisance, to protect the public safety, health and welfare, and/or prevent the loss of life, injury or damage to property, the Drain Commissioner is authorized to carry out or arrange for all such emergency actions. Property owners shall be responsible for the cost of such measures made necessary as a result of a violation of this ordinance, and shall promptly reimburse the Drain Commissioner for all such costs.

D. Cease and Desist Orders

1. The Drain Commissioner may issue a Cease and Desist Order or revoke a permit upon the determination that there is a violation of this Ordinance or Part 91 or a finding that there is a violation of a permit or an approved soil erosion and sedimentation and storm water runoff control plan.

2. The Cease and Desist Order, when issued, shall require all specified earth change activities to be stopped.

3. A copy of the Cease and Desist Order shall immediately be submitted to other state and local agencies with regulatory jurisdiction.

E. Injunctive Relief

Notwithstanding any other remedy, the Drain Commissioner may maintain an action in a court of competent jurisdiction for an injunction or other process against a person to restrain or prevent violations of this Ordinance or Part 91.

F. Fines and Penalties

1. A person who violates this Ordinance or Part 91 is responsible for a municipal civil infraction and may be ordered to pay a civil fine of not more than $2,500.00.

2. A person who knowingly violates this Ordinance or Part 91 or knowingly makes a false statement in an application for permit or in a soil erosion and sedimentation and storm water runoff control plan is responsible for a

civil infraction and may be ordered to pay a civil fine of not more than $10,000.00 for each day of violation.

3. A person who knowingly violates this Ordinance or Part 91 after receiving a Notice of Violation is responsible for the payment of a civil fine of not less than $2,500.00 or more than $25,000.00 for each day of violation.

4. Civil fines collected under this Ordinance shall be deposited with Treasurer for Grand Traverse County.

5. A default in the payment of a civil fine or costs ordered under this Ordinance or an installment of the fine or costs may be remedied by any means authorized under the Revised Judicature Act of 1961, as amended.

G. Notification of Violation and Enforcement Actions

1. The Drain Commissioner shall notify the Michigan Department of Environmental Quality of all violations of this Ordinance and Part 91, including violations attributable to an earth changed created by an authorized public agency.

2. If a local unit of government has notice that a violation of this Ordinance or Part 91 has occurred within the boundaries of the local unit of government, including but not limited to a violation attributable to an earth change by an authorized public agency, the local unit of government shall notify the Drain Commissioner and the Michigan Department of Environmental Quality of the violation.

XI. WAIVER

The Drain Commissioner may waive certain requirements specified in this Ordinance upon being provided with demonstrable evidence of special circumstances warranting waiver so long as there is compliance with the purpose, intent and objectives of the ordinance utilizing the following criteria:

a. The relative extent of the public and private need for the proposed activity.

b. The availability of feasible and prudent alternative locations and methods to accomplish the expected benefits from the activity.

c. The extent and permanence of the beneficial or detrimental effects that the proposed activity may have on the public and private uses to which the area is suited.

d. The probable impact of each proposal in relation to the cumulative effect created by other existing and anticipated activities in the watershed.

The Drain Commissioner may not waive requirements that are specified in Part 91 of the Natural Resources and Environmental Protection Act, as amended or the rules promulgated there under.

XII. APPEALS

Any person aggrieved by the action or inaction of the Drain Commissioner related to this Ordinance may appeal to the Grand Traverse County Appeals Board for Building Code, Soil Erosion, Health and BOCA Fire. All requests for appeal shall be filed in writing within 30 days of the action or inaction appealed from and include the basis of the appeal.

The filing of an appeal does not preclude other remedies available to either party, nor does it act as a stay of any order from the Drain Commissioner for the installation of measures or controls to reduce or eliminate soil erosion or sedimentation pending the outcome of the appeal.

The affected Township Zoning Board of Appeals will have jurisdiction to hear a variance of the setbacks suggested when a zoning variance is concurrently considered.

XIII. SEVERABILITY

If any section, clause, provision or portion of this Ordinance is adjudged unconstitutional or invalid by a court of competent jurisdiction, the remainder of the Ordinance shall not be affected.

XIV. EFFECTIVE DATE

This Ordinance shall take effect on _____, 2003, and after publication according to statute.

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STATE OF MISSOURI

DEPARTMENT OF NATURAL RESOURCES

MISSOURI CLEAN WATER COMMISSION

MISSOURI STATE OPERATING PERMIT

GENERAL PERMIT

In compliance with the Missouri Clean Water Law, (Chapter 644 R.S. Mo. as amended, hereinafter, the Law), and the Federal Water Pollution Control Act (Public Law 92-500, 92nd Congress) as amended,

MO-R004000

is authorized to discharge from the facility described herein, in accordance with the effluent limitations and monitoring requirements as set forth herein:

FACILITY DESCRIPTION

All Outfalls

Discharges from Regulated Small Municipal Separate Storm Sewer Systems

This permit authorizes only wastewater, including storm waters, discharges under the Missouri Clean Water Law and the National Pollutant Discharge Elimination System; it does not apply to other regulated areas. This permit may be appealed in accordance with Section 644.051.6 of the Law.

March 10, 2003
Effective Date

Stephen M. Mahfood, Director, Department of Natural Resources
Executive Secretary, Clean Water Commission

March 9, 2008
Expiration Date

Jim Hull, Director of Staff, Clean Water Commission

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6. Standard Permit Conditions

7. Definitions

1 Coverage Under this Permit

1.1 Permit Area

This permit covers all areas served by a municipal separate storm sewer system (MS4) for which the applicant is identified as the continuing authority.

1.2 Eligibility

1.2.1 This permit authorizes discharges of storm water from regulated small MS4s, as defined in 10 CSR 20-6.200. The permittee, or co-permittee, is authorized to discharge under the terms and conditions of this general permit if the permittee:

1.2.1.1 Owns or operates a regulated small MS4 as defined in 10 CSR 20-6.200;

1.2.1.2 The regulated small MS4 is not a “large” or “medium” MS4 as defined in 10 CSR 20-6.200;

1.2.1.3 Submits a general permit application in accordance with Section 2 of this permit;

1.2.1.4 The regulated small MS4 is located fully or partially within an urbanized area as determined by the latest Decennial Census by the Bureau of Census or designated for permit authorization by the department pursuant to 10 CSR 20-6.200.

1.2.1.5 Complies with the terms of this general permit.

1.2.2 The following are types of discharges authorized by this permit:

1.2.2.1 *Storm water discharges.* This permit authorizes storm water discharges to waters of the State from the regulated small MS4s identified in Section 1.2.1, except as excluded in Section 1.3.

1.2.2.2 *Non-storm water discharges*. The permittee is authorized to discharge the following non-storm water sources provided that the permitting authority has not determined these sources to be substantial contributors of pollutants to the permittee’s MS4 that require a separate permit:

- Landscape irrigation
- Rising ground waters
- Uncontaminated ground water infiltration (infiltration is defined as water other than wastewater that enters a sewer system, including sewer service connections and foundation drains, from the ground through such means as defective pipes, pipe joints, connections, or manholes. Infiltration does not include, and is distinguished from, inflow.)
- Uncontaminated pumped ground water
- Discharges from potable water sources
- Foundation drains
- Air conditioning condensate
- Springs
- Water from crawl space pumps
- Footing drains
- Lawn watering
- Flows from riparian habitats and wetlands
- Street wash water
- Discharges or flows from fire fighting activities
- Individual residential car washing
- Dechlorinated residential swimming pool discharges

1.3 Limitations on Coverage

This permit does not authorize:

1.3.1 Discharges that are mixed with sources of non-storm water unless such non-storm water discharges are:

- In compliance with a separate NPDES permit, or
- Determined not to be a substantial contributor of pollutants to waters of the State.

1.3.2 Storm water discharges associated with industrial activities requiring separate NPDES permits as defined in 10 CSR 20-6.200.

1.3.3 Storm water discharges associated with construction activities requiring separate NPDES permits as defined in 10 CSR 20-6.200.

1.3.4 Storm water discharges currently covered under another permit.

1.3.5 Discharges that are likely to jeopardize the continued existence of any species that are listed as endangered or threatened under the Endangered Species Act (ESA) or result in the adverse modification or destruction of habitat that is designated as critical under the ESA.

1.3.6 Discharges that violate the National Historic Preservation Act.

1.3.7 Discharges that cause or contribute to a violation of instream water quality standards. The permittee's storm water management program must include a description of the BMPs that the permittee will use to ensure that violations will not occur. The department may require corrective action or an application for an individual permit or alternative general permit if an MS4 is determined to cause or create a significant potential for causing an instream exceedance of water quality standards.

1.3.8 Discharges of any pollutant into any water for which a Total Maximum Daily Load (TMDL) has been either established or approved by the EPA unless the permittee's discharge is consistent with that TMDL. This eligibility condition applies at the time the permittee submits an application for coverage. If conditions change after the permittee has permit coverage, the permittee may remain covered by the permit provided the permittee complies with the applicable requirements of Section 3. The permittee shall incorporate any limitations, conditions and requirements required by the TMDL, including monitoring frequency and reporting required, into the Storm Water Management Program in order to be eligible for permit coverage. For discharges for which the permittee is responsible but are not eligible for coverage under this permit, the permittee shall apply for and receive an individual or other applicable general NPDES permit prior to discharging.

1.3.9 Discharges that do not comply with state anti-degradation requirements for water quality standards as specified at 10 CSR 20-7.031(2).

1.4 Obtaining Authorization

1.4.1 To be authorized to discharge storm water from regulated small MS4s, the permittee shall submit an application and a description of the permittee's storm water management program in accordance with the deadlines presented in Section 2 of this permit.

1.4.2 The permittee shall submit the information required in Section 2 on the latest version of the application form (or photocopy thereof). The permittee's application shall be signed and dated.

1.4.3 Where the operator changes, or where a new operator is added after submittal of an application under Section 2, a new application shall be submitted in accordance with Section 2 prior to the change or addition.

2 Application Requirements

2.1 *Deadlines for Application.* If the permittee is automatically designated under 10 CSR 20-6.200 or designated by the department in this permit, then the permittee is required to submit an application and a description of the permittee's storm water management program or apply for an individual permit by March 10, 2003.

2.2 *Additional designations after the date of permit issuance.* If the permittee is designated by the department after the date of permit issuance, then the permittee is required to submit an application and a description of the permittee's storm water management program to the department within 180 days of notice.

2.3 *Submitting a Late application*. The permittee is not prohibited from submitting an application after the dates provided in Section 2.1. If a late, or modified application is submitted, the permittee's authorization is only for discharges that occur after permit coverage is granted. The department reserves the right to take appropriate enforcement actions for any unpermitted discharges.

3 Special Conditions

3.1 Discharges to Water Quality Impaired Waters

3.1.1 If discharges from the MS4 are upstream from a 303(d) listed (impaired) waterbody, the permittee shall, in consultation with the department:

3.1.1.1 Determine whether storm water discharges from any part of the MS4 significantly contributes measurable pollutants directly or indirectly to a 303(d) listed (i.e., impaired) waterbody. If the permittee has discharges meeting this criteria, the permittee shall comply with Section 3.1.2. If the permittee does not, Section 3.1 does not apply to the permittee.

3.1.1.2 Determine whether a Total Maximum Daily Load (TMDL) has been developed by the department and approved by EPA for the listed waterbody. If there is a TMDL, the permittee shall comply with both Sections 3.1.2 and 3.1.3. If no TMDL has been finalized, Section 3.1.3 will apply when the TMDL is finalized.

3.1.2 *Water Quality Controls for Discharges to Impaired Waterbodies*. The permittee's storm water management program (SWMP) required under Section 4 shall include a description of how the permittee's program will control the discharge of measurable pollutants of concern and ensure the permittee's discharges will not cause or contribute to instream exceedances of the water quality standards. This discussion shall specifically identify measures and BMPs that will collectively control the discharge of the pollutants of concern.

3.1.3 *Consistency with TMDL Allocations*. If a TMDL has been finalized for any waterbody into which the permittee discharge, the permittee must:

3.1.3.1 Determine whether the approved TMDL is for a pollutant likely to be found in storm water discharges from the permittee's MS4.

3.1.3.2 Determine whether the TMDL includes a pollutant wasteload allocation (WLA) or other performance requirements specifically for storm water discharge from the permittee's MS4.

3.1.3.3 Determine whether the TMDL address a flow regime likely to occur during periods of storm water discharge.

3.1.3.4 After the determinations above have been made and if it is found that the permittee's MS4 shall implement specific WLA provisions of the TMDL, assess whether the WLAs are being met through implementation of existing storm water control measures or if additional control measures are necessary.

3.1.3.5 Document all control measures currently being implemented or planned to be implemented. The permittee shall also include a schedule of implementation for all planned controls and shall document the calculations or other evidence that shows that the WLA will be met.

3.1.3.6 Describe a monitoring program to determine whether the storm water controls are adequate to meet the WLA.

3.1.3.7 If the evaluation shows that additional or modified controls are necessary, describe the measures to be taken and the schedule for their implementation. The permittee shall continue meeting the requirements of 3.1.3.4 through 3.1.3.7 until two continuous monitoring cycles show that the WLAs are being met or that water quality standards are being met.

3.2 Duty to Comply

3.2.1 The permittee shall comply with all conditions of this permit. Any permit noncompliance constitutes a violation of Missouri Clean Water Law and is grounds for enforcement action; permit termination, revocation and reissuance, or modification; or for denial of a permit renewal.

3.3 Continuation of the Expired General Permit

If this permit is not reissued or replaced prior to the expiration date, it will be administratively continued in accordance with 10 CSR 20-6.010 (10)(E) and remain in force and effect. Any permittee who was granted permit coverage prior to the expiration date will automatically remain covered by the continued permit until the earlier of:

- Reissuance or replacement of this permit, at which time the permittee shall comply with the application conditions of the new permit to maintain authorization to discharge;
- Notice of Termination;
- Issuance of an individual permit for your discharges; or
- A permit decision by the Director not to reissue this general permit, at which time the permittee shall seek coverage under an alternative general permit or an individual permit.

3.4 Need to Halt or Reduce Activity Not an Excuse

Actions by the permittee in an enforcement action to halt or reduce the permitted activity does not excuse compliance with this permit or any provision of the Missouri Clean Water Law.

3.5 Permit Transfers

This permit is not transferable to any person except after notice to the department. The department may require modification or revocation and reissuance of the permit to change the name of the permittee and incorporate such other requirements as may be necessary.

3.6 Procedures for Modification or Revocation

If at any time the Missouri Department of Natural Resources determines that the quality of waters of the state may be better protected by requiring the owner/operator of the permitted site to apply for a site specific permit, the department may require any person to obtain a site specific operating permit [10 CSR 20-6.010 (13) and 10 CSR 20-6.200(5)].

The department may require the permittee to apply for and obtain a site specific or different general permit if:

a. The permittee is not in compliance with the conditions of this general permit;
b. The discharge no longer qualifies for this general permit due to changed site conditions and regulations; or
c. Information becomes available that indicates water quality standards have been or may be violated.

The permittee will be notified in writing of the need to apply for a site specific permit or a different general permit. When a site specific permit or different general permit is issued to the authorized permittee, the applicability of this general permit to the permittee will be terminated upon the effective date of the site specific or different general permit, whichever the case may be. The permittee shall submit the appropriate forms to the department to terminate the permit that has been replaced.

3.7 Requiring an Individual Permit or an Alternative General Permit

3.7.1 *Decision by the department.* The department may require any person authorized by this permit to apply for and/or obtain either an individual NPDES permit or an alternative NPDES general permit. Any interested person may petition the department to require an individual permit. Where the department requires the permittee to apply for an individual NPDES permit, the department will notify the permittee in writing that a permit application is required. This notification shall include a brief statement of the reasons for this decision, an application form, a statement setting a deadline for the permittee to file the application, and a statement that on the effective date of issuance or denial of the individual NPDES permit or the alternative general permit. Coverage under this general permit shall automatically terminate in accordance with Section 3.6. The department may grant additional time to submit the application upon request of the applicant. If the permittee fails to submit an individual NPDES permit application in a timely manner as required by the department under this paragraph, then the applicability of this permit to the permittee is automatically terminated on the day specified by the department for application submittal.

3.7.2 *Request by permittee.* The permittee may apply for an individual permit in lieu of coverage under this general permit. In such cases, the permittee shall submit an application for the alternate permit in accordance with the requirements of 10 CSR 20-6.200, with reasons supporting the request. The request may be granted by issuance of any individual permit or an alternative general permit.

4 Storm Water Management Programs

4.1 Requirements

4.1.1 Reserved

4.1.1.1 The discharge of storm water shall not cause a violation of the state water quality standards, 10 CSR 20-7.031, which states, in part, that no water contaminant, by itself or in combination with other substances, shall prevent the waters of the state from meeting the following conditions:

a. Waters shall be free from substances in sufficient amounts to cause the formation of putrescent, unsightly or harmful bottom deposits or prevent full maintenance of beneficial uses;
b. Waters shall be free from oil, scum and floating debris in sufficient amounts to be unsightly or prevent full maintenance of beneficial uses;
c. Waters shall be free from substances in sufficient amounts to cause unsightly color or turbidity, offensive odor or prevent full maintenance of beneficial uses;
d. Waters shall be free from substances or conditions in sufficient amounts to have a harmful effect on human, animal or aquatic life.
e. There shall be no significant human health hazard from incidental contact with the water;
f. There shall be no acute toxicity to livestock or wildlife watering;
g. Waters shall be free from physical, chemical or hydrologic changes that would impair the natural biological community;
h. Waters shall be free from used tires, car bodies, appliances, demolition debris, used vehicles, or equipment and solid waste as defined in Missouri’s Solid Waste Law, Section 260.200, RSMo, except as the use of such materials is specifically permitted pursuant to Section 260.200-260.247.

4.1.1.2 For facilities under the control of the permittee good housekeeping practices shall be maintained to keep solid waste from entry into waters of the state to the maximum extent practicable.

4.1.1.3 All fueling facilities under the control of the permittee shall adhere to applicable federal and state regulations concerning underground storage, above ground storage, and dispensers, including spill prevention, control and counter measures.

4.1.1.4 Substances regulated by federal law under the Resource Conservation and Recovery Act (RCRA) or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) that are transported, stored, or used for maintenance, cleaning or repair by the permittee shall be managed according to the provisions of RCRA and CERCLA.

4.1.1.5 All paint, solvents, petroleum products and petroleum waste products (except fuels) under the control of the permittee shall be stored so that these materials are not exposed to storm water. Sufficient practices of spill prevention, control, and/or management shall be provided to prevent any spills of these pollutants from entering a water of the state. Any containment system used to implement this requirement shall be constructed of materials compatible with the substances contained and shall also prevent the contamination of groundwater.

4.1.2 The permittee shall develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from the permittee's regulated small MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Missouri Clean Water Law. The storm water management program should include management practices; control techniques and system, design, and engineering methods; and such other provisions as the permitting authority determines appropriate for the control of such pollutants. The permittee's storm water management program shall include the following information for each of the six minimum control measures described in Section 4.2 of this permit:

Note: These requirements do not supersede nor remove liability for compliance with county and other local ordinances.

4.1.2.1 A description of the best management practices (BMPs) that the permittee will implement for each of the storm water minimum control measures;

4.1.2.2 The measurable goals for each of the BMPs including, as appropriate, the months and years in which the permittee will undertake required actions, including interim milestones and the frequency of the action;

4.1.2.3 Individual(s) shall be designated by the permittee as responsible for environmental matters. The permittee shall inspect any structures that function to prevent pollution of storm water or to remove pollutants from storm water and of the facility in general to ensure that any Best Management Practices are continually implemented and effective;

4.1.3 In addition to the requirements listed above, the permittee shall provide a rationale for how and why the permittee selected each of the BMPs and measurable goals for the permittee's storm water management program. The information required for such a rationale is given in Section 4.2 for each minimum measure. The permittee shall develop and fully implement each measure within five (5) years of permit issuance.

4.2 Minimum Control Measures

The six (6) minimum control measures that shall be included in the permittee's storm water management program are:

4.2.1 **Public Education and Outreach on Storm Water Impacts**

4.2.1.1 *Permit requirement.* The permittee shall implement a public education program to distribute educational materials to the community or conduct equivalent outreach activities about the impacts of storm water discharges on water bodies and the steps that the public can take to reduce pollutants in storm water runoff.

4.2.1.2 *Decision process.* The permittee shall document the permittee's decision process for the development of a storm water public education and outreach program. The permittee's rationale statement shall address both their overall public education program and the individual BMPs, measurable goals and responsible persons for the permittee's program. The rationale statement shall include the following information, at a minimum:

4.2.1.2.1 How the permittee plans to inform individuals and households about the steps they can take to reduce storm water pollution.

4.2.1.2.2 How the permittee plans to inform individuals and groups on how to become involved in the storm water program (with activities such as local stream and beach restoration activities).

4.2.1.2.3 Identification of target audiences for the permittee's education program who are likely to have significant storm water impacts (including commercial, industrial and institutional entities) and an explanation why those target audiences were selected.

4.2.1.2.4 The target pollutant sources the permittee's public education program is designed to address.

4.2.1.2.5 The permittee's outreach strategy, including the mechanisms (e.g., printed brochures, newspapers, media, workshops, etc.) they will use to reach their target audiences, and how many people do they expect to reach by their outreach strategy over the permit term.

4.2.1.2.6 Identification of the person(s) responsible for overall management and implementation of the permittee's storm water public education and outreach program and, if different, the person responsible for each of the BMPs identified for this program.

4.2.1.2.7 How the permittee will evaluate the success of this minimum measure, including how the measurable goals for each of the BMPs were selected.

4.2.2 **Public Involvement/Participation**

4.2.2.1 *Permit requirement.* The permittee shall implement a public involvement/participation program that complies with State and local public notice requirements.

4.2.2.2 *Decision process.* The permittee shall document the decision process for the development of a storm water public involvement/participation program. The documentation shall provide rationale for how the overall public involvement/participation program was developed, and explain the individual BMPs, measurable goals, and responsible persons for the program. The rationale statement shall include the following information, at a minimum:

4.2.2.2.1 How the permittee has involved the public in the development and submittal of the application and storm water management program.

4.2.2.2.2 The permittee's plan to actively involve the public in the development and implementation of their program.

4.2.2.2.3 The target audiences for the permittee's public involvement program, including a description of the types of ethnic and economic groups engaged. The permittee is encouraged to actively involve all potentially affected stakeholder groups, including commercial and industrial businesses, trade associations, environmental groups, homeowners associations, and educational organizations, among others.

4.2.2.2.4 The types of public involvement activities included in the permittee's program. Where appropriate, the permittee must consider the following types of pubic involvement activities:

4.2.2.2.4.1 Citizen representatives on a storm water management panel

4.2.2.2.4.2 Public hearings

4.2.2.2.4.3 Working with citizen volunteers willing to educate others about the program

4.2.2.2.4.4 Volunteer monitoring or stream/beach clean-up activities

4.2.2.2.5 The person(s) responsible for the overall management and implementation of the permittee's storm water public involvement/participation program and, if different, the person responsible for each of the BMPs identified for this program.

4.2.2.2.6 The method for evaluating the success of this minimum measure, including how the permittee selected the measurable goals for each of the BMPs.

4.2.3 **Illicit Discharge Detection and Elimination**

4.2.3.1 *Permit requirement. The permittee* shall:

4.2.3.1.1 Develop, implement and enforce a program to detect and eliminate illicit discharges (as defined in 10 CSR 20-6.200) into the permittee's regulated small MS4;

4.2.3.1.2 Develop or submit, if not already completed, a storm sewer system map, showing the location of all outlets and the names and location of all waters of the State that receive discharges from those outlets;

4.2.3.1.3 To the extent allowable under State, or local law, effectively prohibit, through ordinance, or other regulatory mechanism, non-storm water discharges into the permittee's storm sewer system and implement appropriate enforcement procedures and actions;

4.2.3.1.4 Develop and implement a plan to detect and address non-storm water discharges, including illegal dumping, to the permittee's system;

4.2.3.1.5 Inform public employees, businesses, and the general public of hazards associated with illegal discharges and improper disposal of waste; and

4.2.3.1.6 Address the following categories of non-storm water discharges or flows (i.e., illicit discharges) only if the permittee identifies them as significant contributors of pollutants to the permittee's regulated small MS4: landscape irrigation, rising ground waters, uncontaminated ground water infiltration (as defined in 10 CSR 20-6.200), uncontaminated pumped ground water, discharges from potable water sources, foundation drains, air conditioning condensation, springs, water from crawl space pumps, footing drains, lawn watering, flows from riparian habitats and wetlands, and street wash water (discharges or flows from fire fighting activities are excluded from the effective prohibition against non-storm water and need only be addressed where they are significant sources of pollutants to waters of the State).

4.2.3.1.7 The permittee may also develop a list of other similar occasional incidental non-storm water discharges (e.g. non-commercial or charity car washes, etc.) that will not be addressed as illicit discharges. These non-storm water discharges shall not be reasonably expected (based on information available to the permittees) to be significant sources of pollutants to the MS4, because of either the nature of the discharges or conditions the permittee has established for allowing these discharges to the permittee's MS4 (e.g., a charity car wash with appropriate controls on frequency, proximity to sensitive waterbodies, BMPs on the wash water, etc.). The permittee shall document in their SWMP any local controls or conditions placed on the discharges. The permittee shall include a provision prohibiting any individual non-storm water discharge that is determined to be contributing significant amounts of pollutants to the permittee's MS4.

4.2.3.2 *Decision process.* The permittee shall document the decision process for the development of a storm water illicit discharge detection and elimination program. The permittee shall provide rationale for both the overall illicit discharge detection and elimination program and the individual BMPs, measurable goals, and responsible persons for the permittee's program. The rationale statement shall include the following information, at a minimum:

4.2.3.2.1 How the permittee will develop a storm sewer map showing the location of all outlets and the names and location of all receiving waters. The permittee shall describe the sources of information used for the maps, and how the permittee plans to verify the outlet locations with field surveys. If already completed, the permittee shall describe how the map was developed and how the map will be regularly updated.

4.2.3.2.2 The mechanism (ordinance or other regulatory mechanism) the permittee will use to effectively prohibit illicit discharges into the MS4 and why the permittee chose that mechanism. If the permittee needs to develop this mechanism, describe the permittee's plan and a schedule to do so. If the permittee's ordinance or regulatory mechanism is already developed, include a copy of the relevant sections with the permittee's program.

4.2.3.2.3 The permittee's plan to ensure through appropriate enforcement procedures and actions that the permittee's illicit discharge ordinance (or other regulatory mechanism) is implemented.

4.2.3.2.4 The permittee's plan to detect and address illicit discharges to the permittee's system, including discharges from illegal dumping and spills. The permittee's plan shall include dry weather field screening for non-storm water flows and field tests of selected chemical parameters as indicators of discharge sources. The plan shall also address on-site sewage disposal systems that flow into the permittee's storm drainage system. The permittee's description shall address the following, at a minimum:

4.2.3.2.4.1 Procedures for locating priority areas which includes areas with higher likelihood of illicit connections (e.g., areas with older sanitary sewer lines, for example) or ambient sampling to locate impacted reaches.

4.2.3.2.4.2 Procedures for tracing the source of an illicit discharge, including the specific techniques the permittee will use to detect the location of the source.

4.2.3.2.4.3 Procedures for removing the source of the illicit discharge.

4.2.3.2.4.4 Procedures for program evaluation and assessment.

4.2.3.2.5 How the permittee plans to inform public employees, businesses, and the general public of hazards associated with illegal discharges and improper disposal of waste. The permittee shall describe how this plan will coordinate with their public education minimum measure and the pollution prevention/good housekeeping minimum measure programs.

4.2.3.2.6 Identification of the person(s) responsible for overall management and implementation of the permittee's storm water illicit discharge detection and elimination program and, if different, the person responsible for each of the BMPs identified for this program.

4.2.3.2.7 How the permittee will evaluate the success of this minimum measure, including how they selected the measurable goals for each of the BMPs.

4.2.4 **Construction Site Storm Water Runoff Control**

4.2.4.1 *Permit requirement.* The permittee shall develop, implement, and enforce a program to reduce pollutants in any storm water runoff to their regulated small MS4 from construction activities that result in a land disturbance of greater than or equal to one acre. Reduction of storm water discharges from construction activity disturbing less than one acre shall be included in the program if that construction activity is part of a larger common plan of development or sale that would disturb one acre or more. The permittee's program shall include the development and implementation of, at a minimum:

4.2.4.1.1 An ordinance or other regulatory mechanism to require erosion and sediment controls, as well as sanctions to ensure compliance, to the extent allowable under State or local law;

4.2.4.1.2 Requirements for construction site operators to implement appropriate erosion and sediment control best management practices;

4.2.4.1.3 Requirements for construction site operators to control waste such as discarded building materials, concrete truck washout, chemicals, litter, and sanitary waste at the construction site that may cause adverse impacts to water quality;

4.2.4.1.4 Procedures for site plan review which incorporate consideration of potential water quality impacts;

4.2.4.1.5 Procedures for receipt and consideration of information submitted by the public; and

4.2.4.1.6 Procedures for site inspection and enforcement of control measures.

4.2.4.2 *Decision process.* The permittee shall document the permittee's decision process for the development of a construction site storm water control program. The permittee's rationale statement shall address both the permittee's overall construction site storm water control program and the individual BMPs, measurable goals, and responsible persons for the permittee's program. The rationale statement shall include the following information, at a minimum:

4.2.4.2.1 The mechanism (such as an ordinance or other regulatory mechanism) the permittee will use to require erosion and sediment controls at construction sites and why they chose that mechanism. If the permittee needs to develop this mechanism, the permittee shall describe the plan and schedule implementation. If the permittee's ordinance or regulatory mechanism is already developed, the permittee shall include a copy of the relevant sections with the permittee's storm water management program description.

4.2.4.2.2 The permittee's plan to ensure compliance with the permittee's erosion and sediment control regulatory mechanism, including the sanctions and enforcement mechanisms they will use to ensure compliance. The permittee shall describe the procedures for when the permittee will use certain sanctions. Possible sanctions include non-monetary penalties (such a stop work orders), fines, bonding requirements, and/or permit denials for non-compliance.

4.2.4.2.3 The permittee's requirements for construction site operators to implement appropriate erosion and sediment control BMPs and control waste at construction sites that may cause adverse impacts to water quality. Such waste includes discarded building materials, concrete truck washouts, chemicals, litter, and sanitary waste.

4.2.4.2.4 The permittee's procedures for considering the potential water quality impacts of pre-construction site plans. The permittee shall describe the procedures and the rationale for how the permittee will identify certain sites for site plan review, if all plans are not reviewed. The permittee shall describe the estimated number and percentage of sites that will have pre-construction site plans reviewed.

4.2.4.2.5 The permittee's procedures for receipt and consideration of information submitted by the public. Consider coordinating this requirement with the permittee's public education program.

4.2.4.2.6 The permittee's procedures for site inspection and enforcement of control measures, including how the permittee will prioritize sites for inspection.

4.2.4.2.7 Identification of the person(s) responsible for overall management and implementation of the permittee's construction site storm water control program and, if different, the person responsible for each of the BMPs identified for this program.

4.2.4.2.8 Describe how will the permittee evaluate the success of this minimum measure, including how the permittee selected the measurable goals for each of the BMPs.

4.2.5 **Post-Construction Storm Water Management in New Development and Redevelopment**

4.2.5.1 *Permit requirement.* The permittee shall:

4.2.5.1.1 Develop, implement, and enforce a program to address storm water runoff from new development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, that discharge into the permittee's regulated small MS4. The permittee's program shall ensure that controls are in place that would prevent or minimize water quality impacts;

4.2.5.1.2 Develop and implement strategies which include a combination of structural and/or non-structural best management practices (BMPs) appropriate for the permittee's community; and

4.2.5.1.3 Use an ordinance or other regulatory mechanism to address post-construction runoff from new development and redevelopment projects to the extent allowable under State, or local law; and

4.2.5.1.4 Ensure adequate long-term operation and maintenance of BMPs.

4.2.5.2 *Decision process.* The permittee shall document their decision process for the development of a post-construction storm water management program. The permittee's rationale statement shall address both their overall post-construction storm water management program and the individual BMPs, measurable goals, and responsible persons for their program. The rationale statement shall include the following information, at a minimum:

4.2.5.2.1 The permittee's program to address storm water runoff from new development and redevelopment projects. The permittee shall include in this description any specific priority areas for this program.

4.2.5.2.2 How the permittee's program will be specifically tailored for their local community, minimize water quality impacts, and attempt to maintain pre-development runoff conditions.

4.2.5.2.3 Any non-structural BMPs in the permittee's program, including, as appropriate:

4.2.5.2.3.1 Policies and ordinances that provide requirements and standards to direct growth to identified areas, protect sensitive areas such as wetlands and riparian areas, maintain and/or increase open space (including a dedicated funding source for open space acquisition), provide buffers along sensitive water bodies, minimize impervious surfaces, and minimize disturbance of soils and vegetation;

4.2.5.2.3.2 Policies or ordinances that encourage infill development in higher density urban areas, and areas with existing storm sewer infrastructure;

4.2.5.2.3.3 Education programs for developers and the public about project designs that minimize water quality impacts; and

4.2.5.2.3.4 Other measures such as minimization of the percentage of impervious area after development, use of measures to minimize directly connected impervious areas, and source control measures often thought of as good housekeeping, preventive maintenance and spill prevention.

4.2.5.2.4 Any structural BMPs in the permittee's program, including, as appropriate:

4.2.5.2.4.1 Storage practices such as wet ponds and extended-detention outlet structures;

4.2.5.2.4.2 Filtration practices such as grassed swales, bioretention cells, sand filters and filter strips; and

4.2.5.2.4.3 Infiltration practices such as infiltration basins and infiltration trenches.

4.2.5.2.5 Identification of the mechanisms (such as an ordinance or other regulatory mechanisms) the permittee will use to address post-construction runoff from new developments and redevelopments and why the permittee chose that mechanism. If the permittee needs to develop a mechanism, the permittee shall describe the plan and a schedule for implementation. If the permittee's ordinance or regulatory mechanism is already developed, the permittee shall include a copy of the relevant sections with the program.

4.2.5.2.6 How the permittee will ensure the long-term operation and maintenance (O&M) of their selected BMPs. Options to help ensure that future O&M responsibilities are clearly identified include an agreement between the permittee and another party such as the post-development landowners or regional authorities.

4.2.5.2.7 Identification of the person(s) responsible for overall management and implementation of the permittee's post-construction storm water management program and, if different, the person responsible for each of the BMPs identified for this program.

4.2.5.2.8 How the permittee will evaluate the success of this minimum measure, including how the permittee selected the measurable goals for each of the BMPs.

4.2.6 **Pollution Prevention/Good Housekeeping for Municipal Operations**

4.2.6.1 *Permit requirement.* The permittee shall:

4.2.6.1.1 Develop and implement an operation and maintenance program that includes a training component and has the ultimate goal of preventing or reducing pollutant runoff from municipal operations; and

4.2.6.1.2 Using training materials that are available from EPA, State, or other organizations, the permittee shall develop training to prevent and reduce storm water pollution from activities such as park and open space maintenance, fleet and building maintenance, new construction and land disturbances, and storm water system maintenance.

4.2.6.2 *Decision process.* The permittee shall document the permittee's decision process for the development of a pollution prevention/good housekeeping program for municipal operations. The permittee's rationale statement shall address both the permittee's overall pollution prevention/good housekeeping program and the individual BMPs, measurable goals, and responsible persons for the program. The rationale statement shall include the following information, at a minimum:

4.2.6.2.1 The permittee's operation and maintenance program to prevent or reduce pollutant runoff from their municipal operations. The permittee shall specifically list the municipal operations that are impacted by this operation and maintenance program. The permittee shall also include a list of industrial facilities the permittee owns or operates that are subject to EPA's Multi-Sector General Permit (MSGP) or individual NPDES permits for discharges of storm water associated with industrial activity that ultimately discharge to the permittee's MS4. The permittee shall include the permit number or a copy of the Industrial application form for each facility.

4.2.6.2.2 Any government employee training program the permittee uses to prevent and reduce storm water pollution from activities such as park and open space maintenance, fleet and building maintenance, new construction and land disturbances, and storm water system maintenance. The permittee shall describe any existing, available materials the permittee plans to use. The permittee shall describe how this training program will be coordinated with the outreach programs developed for the public information minimum measure and the illicit discharge minimum measure.

4.2.6.2.3 The permittee's program description shall specifically address the following areas:

4.2.6.2.3.1 Maintenance activities, maintenance schedules, and long-term inspection procedures for controls to reduce floatables and other pollutants to the permittee's regulated small MS4.

4.2.6.2.3.2 Controls for reducing or eliminating the discharge of pollutants from streets, roads, highways, municipal parking lots, maintenance and storage yards, waste transfer stations, fleet or maintenance shops with outdoor storage areas, and salt/sand storage locations and snow disposal areas the permittee operates.

4.2.6.2.3.3 Procedures for the proper disposal of waste removed from the permittee's MS4 and area of jurisdiction, including dredged material, accumulated sediments, floatables, and other debris.

4.2.6.2.3.4 Procedures to ensure that new flood management projects are assessed for impacts on water quality and existing projects are assessed for incorporation of additional water quality protection devices or practices.

4.2.6.2.4 Identification of the person(s) responsible for overall management and implementation of their pollution prevention/good housekeeping program and, if different, the person responsible for each of the BMPs identified for this program.

4.2.6.2.5 How the permittee will evaluate the success of this minimum measure, including how the permittee selected the measurable goals for each of the BMPs.

4.3 Sharing Responsibility

Implementation of one or more of the minimum measures may be shared with another entity, or another entity assume responsibility for the measure if:

4.3.1 The other entity, in fact, implements the control measure;

4.3.2 The particular control measure, or component of that measure, is at least as stringent as the corresponding permit requirement.

4.3.3 The other entity agrees to implement the control measure on permittee's behalf. Written acceptance of this obligation is required. This obligation shall be maintained as part of the description of the permittee's storm water management program. If the other entity agrees to report on the minimum measure, the permittee shall supply the other entity with the reporting requirements contained in Section 5.3 of this permit. If the other entity fails to implement the control measure on the permittee's behalf, then the permittee remains liable for any discharges due to that failure to implement.

4.4 Reviewing and Updating Storm Water Management Programs

4.4.1 *Storm Water Management Program Review:* The permittee shall do an annual review of the permittee's Storm Water Management Program in conjunction with preparation of the annual report required under Section 5.3

4.4.2 *Storm Water Management Program Update:* The permittee may change the Storm Water Management Program during the life of the permit in accordance with the following procedures:

4.4.2.1 Changes adding (but not subtracting or replacing) components, controls, or requirements to the Storm Water Management Program may be made at any time upon written notification to the department.

4.4.2.2 Changes replacing an ineffective or unfeasible BMP specifically identified in the Storm Water Management Program with an alternate BMP may be requested at any time. Unless denied by the department, changes proposed in accordance with the criteria below shall be deemed approved and may be implemented 60 days from submittal of the request. If request is denied, the department will send the permittee a written response giving a reason for the decision. The permittee's modification requests shall include the following:

4.4.2.2.1 An analysis of why the BMP is ineffective or infeasible (including cost prohibitive),

4.4.2.2.2 Expectations on the effectiveness of the replacement BMP, and

4.4.2.2.3 An analysis of why the replacement BMP is expected to achieve the goals of the BMP to be replaced.

4.4.2.3 Change requests or notifications must be made in writing and signed in accordance with Section 6.

4.4.3 *Storm Water Management Program Updates Required by the Department*: Changes requested by the department must be made in writing, set forth the time schedule for the permittee to develop the changes, and offer the permittee the opportunity to propose alternative program changes to meet the objective of the requested modification. All changes required by the department will be made in accordance with 10 CSR 20-6.200. The department may require changes to the Storm Water Management Program as needed to:

4.4.3.1 Address impacts on receiving water quality caused or affected by discharges from the Municipal Separate Storm Sewer System;

4.4.3.2 Include more stringent requirements necessary to comply with new federal or state statutory or regulatory requirements; or

4.4.3.3 Include such other conditions deemed necessary by the department to comply with the goals and requirements of the Missouri Clean Water Law.

4.4.4 *Transfer of Ownership, Continuing Authority, or Responsibility for Storm Water Management Program Implementation:* The permittee shall implement the Storm Water Management Program on all new areas added to the permittee's portion of the municipal separate storm sewer system (or for which the permittee becomes responsible for implementation of storm water quality controls) as expeditiously as practicable, but not later than one year from addition of the new areas. Implementation may be accomplished in a phased manner to allow additional time for controls that cannot be implemented immediately.

4.4.4.1 Within 90 days of a transfer of ownership, continuing authority, or responsibility for storm water management program implementation, the permittee shall submit a revised plan, if necessary, for implementing the revised Storm Water Management Program on all affected areas. The plan shall include revised schedules for implementation. Information on all new annexed areas and any resulting updates required to the Storm Water Management Program shall be included in the annual report.

4.4.4.2 Only those portions of the Storm Water Management Programs specifically required as permit conditions shall be subject to the modification requirements of 10 CSR 20-6.200. Addition of components, controls, or requirements by the permittee(s) and replacement of an ineffective or infeasible BMP implementing a required component of the Storm Water Management Program with an alternate BMP expected to achieve the goals of the original BMP shall be considered minor changes to the Storm Water Management Program and not modifications to the permit.

5 **Monitoring, Recordkeeping, and Reporting**

5.1 Monitoring

5.1.1 The permittee shall evaluate program compliance, the appropriateness of identified best management practices, and progress toward achieving identified measurable goals. If the permittee discharges to a water for which a TMDL has been approved, the permittee will have additional monitoring requirements under Section 3.1.3.6.

5.1.2 When the permittee conducts monitoring at the permittee's regulated small MS4, the permittee is required to comply with the following:

5.1.2.1 *Representative monitoring.* Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity.

5.1.2.2 *Test Procedures.* Monitoring results shall be conducted according to test procedures approved under 10 CSR 20-7.015.

5.1.3 Records of monitoring information shall include:

5.1.3.1 The date, exact place, and time of sampling or measurements;

5.1.3.2 The names(s) of the individual(s) who performed the sampling or measurements;

5.1.3.3 The date(s) analyses were performed;

5.1.3.4 The names of the individuals who performed the analyses;

5.1.3.5 The analytical techniques or methods used; and

5.1.3.6 The results of such analyses.

5.1.4 *Discharge Monitoring Report.* Monitoring results shall be reported on a Discharge Monitoring Report (DMR).

5.2 Record keeping

5.2.1 The permittee shall retain records of all activities requiring record keeping by the SWMP and monitoring information, including, all calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by this permit, copies of Discharge Monitoring Reports (DMRs), a copy of the NPDES permit, and records of all data used to complete the application for this permit, for a period of at least three years from the date of the sample, measurement, report or application, or for the term of this permit, whichever is longer. This period may be extended by request of the department at any time.

5.2.2 The permittee shall submit the permittee’s records to the department only when specifically asked to do so. The permittee shall retain a description of the Storm Water Management Program required by this permit (including a copy of the permit language) at a location accessible to the department. The permittee shall make the permittee’s records, including the application and the description of the storm water management program, available to the public if requested to do so in writing.

5.3 Reporting

The permittee shall submit annual reports to the Director by April 10 of each year of the permit term. The report shall include:

5.3.1 The status of the permittee’s compliance with permit conditions, an assessment of the appropriateness of the identified best management practices, progress towards achieving the statutory goal of reducing the discharge of pollutants to the MEP, and the measurable goals for each of the minimum control measures;

5.3.2 Results of information collected and analyzed, if any, during the reporting period, including monitoring data used to assess the success of the program at reducing the discharge of pollutants to the MEP;

5.3.3 A summary of the storm water activities the permittee plans to undertake during the next reporting cycle (including an implementation schedule);

5.3.4 Proposed changes to the permittee's storm water management program, including changes to any BMPs or any identified measurable goals that apply to the program elements; and

5.3.5.1 Notice that the permittee is relying on another government entity to satisfy some of the permittee's permit obligations (if applicable).

6 General Conditions

This permit includes General Permit Conditions attached as Part 1 to this permit.

7 Definitions

All definitions contained in 10 CSR 20-6.200 shall apply to this permit and are incorporated herein by reference. For convenience, simplified explanations of some regulatory/statutory definitions have been provided, but in the event of a conflict, the definition found in the regulation takes precedence.

Control Measure as used in this permit, refers to any Best Management Practice or other method used to prevent or reduce the discharge of pollutants to waters of the United States.

Director, refers to the Director of Staff, Water Pollution Control Program, Department Of Natural Resources.

Discharge, when used without a qualifier, refers to "discharge of a pollutant" as defined at 40 CFR 122.2.

Illicit Connection means any man-made conveyance connecting an illicit discharge directly to a municipal separate storm sewer.

Illicit Discharge refers to any discharge to a municipal separate storm sewer that is not entirely composed of storm water, except discharges authorized under an NPDES permit (other than the NPDES permit for discharges from the MS4) and discharges resulting from fire fighting activities.

MEP is an acronym for "Maximum Extent Practicable," the technology-based discharge standard for Municipal Separate Storm Sewer Systems to reduce pollutants in storm water discharges that was established by CWA §402(p). A discussion of MEP as it applies to regulated small MS4s is found at 40 CFR 122.34.

MS4 is an acronym for "Municipal Separate Storm Sewer System" and is used to refer to either a Large, Medium, or Small Municipal Separate Storm Sewer System (e.g. "the Dallas MS4"). The term is used to refer to either the system operated by a single entity or a group of systems within an area that are operated by multiple entities (e.g., the Houston MS4 includes MS4s operated by the city of Houston, the Texas Department of Transportation, the Harris County Flood Control District, Harris County, and others).

Outlet, refers to the point at which storm water exits an MS4 or enters waters of the state.

Permittee, as used in this permit refers to the permit holder.

Storm Water, means storm water runoff, snow melt runoff, and surface runoff and drainage.

Storm Water Management Program (SWMP) refers to a comprehensive program to manage the quality of storm water discharged from the municipal separate storm sewer system.

SWMP is an acronym for “Storm Water Management Program.”

N.J. Admin. Code tit. 7, § 8-1.2

NEW JERSEY ADMINISTRATIVE CODE
TITLE 7. DEPARTMENT OF ENVIRONMENTAL PROTECTION
CHAPTER 8. STORMWATER MANAGEMENT
SUBCHAPTER 1. GENERAL PROVISIONS

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7:8-1.2 Definitions

The following words and terms, when used in this chapter, shall have the following meanings unless the context clearly indicates otherwise.

"CAFRA Planning Map" means the geographic depiction of the boundaries for Coastal Planning Areas, CAFRA Centers, CAFRA Cores and CAFRA Nodes pursuant to N.J.A.C. 7:7E-5B.3.

"CAFRA Centers, Cores or Nodes" means those areas within boundaries accepted by the Department pursuant to N.J.A.C. 7:8E-5B.

"Compaction" means the increase in soil bulk density.

"Core" means a pedestrian-oriented area of commercial and civic uses serving the surrounding municipality, generally including housing and access to public transportation.

"County review agency" means an agency designated by the County Board of Chosen Freeholders to review municipal stormwater management plans and implementing ordinance(s). The county review agency may either be:

1. A county planning agency; or

2. A county water resources association created under N.J.S.A. 58:16A-55.5, if the ordinance or resolution delegates authority to approve, conditionally approve, or disapprove municipal stormwater management plans and implementing ordinances.

"Department" means the Department of Environmental Protection.

"Designated Center" means a State Development and Redevelopment Plan Center as designated by the State Planning Commission such as urban, regional, town, village, or hamlet.

"Design engineer" means a person professionally qualified and duly licensed in New Jersey to perform engineering services that may include, but not necessarily be limited to, development of project requirements, creation and development of project design and preparation of drawings and specifications.

"Development" means the division of a parcel of land into two or more parcels, the construction, reconstruction, conversion, structural alteration, relocation or enlargement of any building or structure, any mining excavation or landfill, and any use or change in the use of any building or other structure, or land or extension of use of land, for which permission is required under the Municipal Land Use Law, N.J.S.A. 40:55D-1 et seq.

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N.J. Admin. Code tit. 7, § 8-1.2

In the case of development on agricultural land, development means: any activity that requires a State permit; any activity reviewed by the County Agricultural Boards (CAB) and the State Agricultural Development Committee (SADC), and municipal review of any activity not exempted by the Right to Farm Act, N.J.S.A. 4:1C-1 et seq.

"Drainage area" means a geographic area within which stormwater runoff, sediments, or dissolved materials drain to a particular receiving waterbody or to a particular point along a receiving waterbody.

"Environmentally constrained area" means the following areas where the physical alteration of the land is in some way restricted, either through regulation, easement, deed restriction or ownership such as: wetlands, floodplains, threatened and endangered species sites or designated habitats, and parks and preserves. Habitats of endangered or threatened species are identified using the Department's Landscape Project as approved by the Department's Endangered and Nongame Species Program.

"Environmentally critical area" means an area or feature which is of significant environmental value, including, but not limited to: stream corridors; natural heritage priority sites; habitats of endangered or threatened species; large areas of contiguous open space or upland forest; steep slopes; and well head protection and groundwater recharge areas. Habitats of endangered or threatened species are identified using the Department's Landscape Project as approved by the Department's Endangered and Nongame Species Program.

"Empowerment Neighborhoods" means neighborhoods designated by the Urban Coordinating Council "in consultation and conjunction with" the New Jersey Redevelopment Authority pursuant to N.J.S.A. 55:19-69.

"Erosion" means the detachment and movement of soil or rock fragments by water, wind, ice or gravity.

"Impervious surface" means a surface that has been covered with a layer of material so that it is highly resistant to infiltration by water.

"Infiltration" is the process by which water seeps into the soil from precipitation.

"Lead planning agency" means one or more public entities having stormwater management planning authority designated by the regional stormwater management planning committee pursuant to N.J.A.C. 7:8-3.2, that serves as the primary representative of the committee.

"Major development" means any "development" that provides for ultimately disturbing one or more acres of land or increasing impervious surface by one-quarter acre or more. Disturbance for the purpose of this rule is the placement of impervious surface or exposure and/or movement of soil or bedrock or clearing, cutting, or removing of vegetation. Projects undertaken by any government agency which otherwise meet the definition of "major development" but which do not require approval under the Municipal Land Use Law, N.J.S.A. 40:55D-1 et seq., are also considered "major development."

"Municipality" means any city, borough, town, township, or village.

"Node" means an area designated by the State Planning Commission concentrating facilities and activities which are not organized in a compact form.

"Nutrient" means a chemical element or compound, such as nitrogen or phosphorus, which is essential to and promotes the development of organisms.

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N.J. Admin. Code tit. 7, § 8-1.2

"Person" means any individual, corporation, company, partnership, firm, association, political subdivision of this State and any state, interstate or Federal agency.

"Pollutant" means any dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, refuse, oil, grease, sewage sludge, munitions, chemical wastes, biological materials, medical wastes, radioactive substance (except those regulated under the Atomic Energy Act of 1954, as amended (42 U.S.C. §§ 2011 et seq.)), thermal waste, wrecked or discarded equipment, rock, sand, cellar dirt, industrial, municipal, agricultural, and construction waste or runoff or other residue discharged directly or indirectly to the land, groundwaters or surface waters of the State, or to a domestic treatment works. "Pollutant" includes both hazardous and nonhazardous pollutants.

"Recharge" means the amount of water from precipitation that infiltrates into the ground and is not evapotranspired.

"Sediment" means solid material, mineral or organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water or gravity as a product of erosion.

"Site" means the lot or lots upon which a major development is to occur or has occurred.

"Soil" means all unconsolidated mineral and organic material of any origin.

"State Development and Redevelopment Plan Metropolitan Planning Area (PA1)" means an area delineated on the State Plan Policy Map and adopted by the State Planning Commission that is intended to be the focus for much of the State's future redevelopment and revitalization efforts.

"State Plan Policy Map" is defined as the geographic application of the State Development and Redevelopment Plan's goals and Statewide policies, and the official map of these goals and policies.

"Stormwater" means water resulting from precipitation (including rain and snow) that runs off the land's surface, is transmitted to the subsurface, or is captured by separate storm sewers or other sewage or drainage facilities, or conveyed by snow removal equipment.

"Stormwater runoff" means water flow on the surface of the ground or in storm sewers, resulting from precipitation.

"Stormwater management basin" means an excavation or embankment and related areas designed to retain stormwater runoff. A stormwater management basin may either be normally dry (that is, a detention basin or infiltration basin), retain water in a permanent pool (a retention basin), or be planted mainly with wetland vegetation (most constructed stormwater wetlands).

"Stormwater management measure" means any structural or nonstructural strategy, practice, technology, process, program, or other method intended to control or reduce stormwater runoff and associated pollutants, or to induce or control the infiltration or groundwater recharge of stormwater or to eliminate illicit or illegal nonstormwater discharges into stormwater conveyances.

"Stormwater management planning agency" means a public body authorized by legislation to prepare stormwater management plans.

"Stormwater management planning area" means the geographic area for which a stormwater management

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planning agency is authorized to prepare stormwater management plans, or a specific portion of that area identified in a stormwater management plan prepared by that agency.

"Tidal Flood Hazard Area" means a flood hazard area, which may be influenced by stormwater runoff from inland areas, but which is primarily caused by the Atlantic Ocean.

"Urban Coordinating Council Empowerment Neighborhood" means a neighborhood given priority access to State resources through the New Jersey Redevelopment Authority.

"Urban Enterprise Zones" means a zone designated by the New Jersey Urban Enterprise Zone Authority pursuant to the New Jersey Urban Enterprise Zones Act, N.J.S.A. 52:27H-60 et seq.

"Urban Redevelopment Area" is defined as previously developed portions of areas:

1. Delineated on the State Plan Policy Map (SPPM) as the Metropolitan Planning Area (PA1), Designated Centers, Cores or Nodes;

2. Designated as CAFRA Centers, Cores or Nodes;

3. Designated as Urban Enterprise Zones; and

4. Designated as Urban Coordinating Council Empowerment Neighborhoods.

"Waters of the State" means the ocean and its estuaries, all springs, streams, wetlands, and bodies of surface or groundwater, whether natural or artificial, within the boundaries of the State of New Jersey or subject to its jurisdiction.

"Wetlands" or "wetland" means an area that is inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions, commonly known as hydrophytic vegetation.

Amended by R.1991 d.510, effective October 21, 1991.

See: 22 N.J.R. 2870(a), 23 N.J.R. 3134(b).

<General Materials (GM) - References, Annotations, or Tables>

N.J.A.C. 7:8-1.2, **NJ ADC 7:8-1.2**

NJ ADC 7:8-1.2

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7:8-1.6 Applicability to major development

(a) Except as provided in (b) below, all major development shall comply with the requirements of this chapter.

(b) The following major development shall be subject to the stormwater management requirements in effect on February 1, 2004, copies of which are available from the Department at the address specified in N.J.A.C. 7:8-1.3:

1. Major development which does not require any of the Department permits listed in (c) below and which has received one of the following approvals pursuant to the Municipal Land Use Law (N.J.S.A. 40:55D-1 et seq.) prior to February 2, 2004:

i. Preliminary or final site plan approval;

ii. Final municipal building or construction permit;

iii. Minor subdivision approval where no subsequent site plan approval is required;

iv. Final subdivision approval where no subsequent site plan approval is required; or

v. Preliminary subdivision approval where no subsequent site plan approval is required;

2. Major development which has received one of the approvals pursuant to the Municipal Land Use Law, N.J.S.A. 40:55D-1 et seq., in (b)1 above prior to February 2, 2004 and has secured at least one of the applicable permits listed in (c) below from the Department by February 2, 2004, and provided that the permit included a stormwater management review component; and

3. Major development undertaken by any government agency, which does not require approval under the Municipal Land Use Law, N.J.S.A. 40:55D-1 et seq., provided that the project has secured at least one of the applicable Department permits listed in (c) below prior to February 2, 2004, and provided that the permit included a stormwater management review component.

(c) For the purposes of this section, the term "permit" shall include transition area waivers under the Freshwater Wetlands Protection Act. In order to qualify under (b)2 or 3 above, the major development must have obtained at least one Department permit granted under the following statutes and, provided that the permit included a stormwater management review component, prior to February 2, 2004:

1. Flood Hazard Area Control Act, N.J.S.A. 58:16A-50 et seq.;

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2. Freshwater Wetlands Protection Act, N.J.S.A. 13:9B-1 et seq.;

3. Coastal Area Facility Review Act, N.J.S.A. 13:19-1 et seq.; or

4. Waterfront and Harbor Facilities Act, N.J.S.A. 12:5-3;

(d) An exemption provided by (b) above shall expire with the expiration, termination or other loss of duration or effect of either of the qualifying local approval or Department permit, whichever comes first. The expiration of local approvals under (b)1 above shall be governed by local ordinance. In the event there are multiple qualifying Department permits under (c) above, the expiration date is governed by that permit which expires last provided that the permit is still in effect. Once the exemption expires, the major development shall be subject to all requirements of this chapter upon reapplication for that permit and all subsequent permits or local approval(s) under the Municipal Land Use Law.

(e) An exemption under (b) above is limited to the land area and the scope of the project addressed by the qualifying approval(s) and permit(s). Exemptions under this section shall be deemed void if revisions are made to the qualifying approval or permit in (b) above, including approvals under the Municipal Land Use Law, unless upon application, the Department determines that each revision would have a de minimis impact on water resources. In making this determination, the Department shall consider the extent of any impacts on water resources resulting from the revision, including, but not limited to:

1. Increases in stormwater generated;

2. Increases in impervious surface;

3. Increases in stormwater pollutant loading;

4. Changes in land use;

5. New encroachments in special water resource protection areas; and

6. Changes in vegetative cover.

(f) In case of conflict with the Coastal Permit Program rules at N.J.A.C. 7:7-4.4(a)4, the requirements of this chapter shall supersede.

<General Materials (GM) - References, Annotations, or Tables>

N.J.A.C. 7:8-1.6, **NJ ADC 7:8-1.6**

NJ ADC 7:8-1.6
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N.J. Admin. Code tit. 7, § 8-5.2

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7:8-5.2 Stormwater management measures for major development

(a) Stormwater management measures for major development shall be developed to meet the erosion control, groundwater recharge, stormwater runoff quantity, and stormwater runoff quality standards at N.J.A.C. 7:8-5.4 and 5.5. To the maximum extent practicable, these standards shall be met by incorporating nonstructural stormwater management strategies at N.J.A.C. 7:8-5.3 into the design. If these measures alone are not sufficient to meet these standards, structural stormwater management measures at N.J.A.C. 7:8-5.7 necessary to meet these standards shall be incorporated into the design.

(b) The development shall incorporate a maintenance plan under N.J.A.C. 7:8- 5.8 for the stormwater management measures.

(c) Stormwater management measures shall avoid adverse impacts of concentrated flow on habitat for threatened and endangered species as documented in the Department's Landscape Project or Natural Heritage Database established under N.J.S.A. 13:1B-15.147 through 15.150, particularly *Helonias bullata* (swamp pink) and/or *Clemmys muhlnebergi* (bog turtle).

(d) The following linear development projects are exempt from the groundwater recharge, stormwater runoff quantity, and stormwater runoff quality requirements at N.J.A.C. 7:8-5.4 and 5.5:

1. The construction of an underground utility line provided that the disturbed areas are revegetated upon completion;

2. The construction of an aboveground utility line provided that the existing conditions are maintained to the maximum extent practicable; and

3. The construction of a public pedestrian access, such as a sidewalk or trail with a maximum width of 14 feet, provided that the access is made of permeable material.

(e) A waiver from strict compliance from the groundwater recharge, stormwater runoff quantity, and stormwater runoff quality requirements at N.J.A.C. 7:8- 5.4 and 5.5 may be obtained for the enlargement of an existing public roadway or railroad, or the construction or enlargement of a public pedestrian access, provided that the following conditions are met:

1. The applicant demonstrates that there is a public need for the project that cannot be accomplished by any other means;

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2. The applicant demonstrates through an alternatives analysis, that through the use of nonstructural and structural stormwater management strategies and measures, the option selected complies with the requirements of N.J.A.C. 7:8-5.4 and 5.5 to the maximum extent practicable;

3. The applicant demonstrates that, in order to meet the requirements at N.J.A.C. 7:8-5.4 and 5.5 existing structures currently in use, such as homes and buildings would need to be condemned; and

4. The applicant demonstrates that it does not own or have other rights to areas, including the potential to obtain through condemnation lands not falling under (e)3 above within the upstream drainage area of the receiving stream, that would provide additional opportunities to mitigate for requirements of N.J.A.C. 7:8-5.4 and 5.5 that were not achievable on-site.

<General Materials (GM) - References, Annotations, or Tables>

N.J.A.C. 7:8-5.2, **NJ ADC 7:8-5.2**

NJ ADC 7:8-5.2
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7:8-5.3 Nonstructural stormwater management strategies

(a) To the maximum extent practicable, the standards in N.J.A.C. 7:8-5.4 and 5.5 shall be met by incorporating nonstructural stormwater management strategies at N.J.A.C. 7:8-5.3 into the design. The person submitting an application for review shall identify the nonstructural strategies incorporated into the design of the project. If the applicant contends that it is not feasible for engineering, environmental, or safety reasons to incorporate any nonstructural stormwater management strategies identified in (b) below into the design of a particular project, the applicant shall identify the strategy and provide a basis for the contention.

(b) Nonstructural stormwater management strategies incorporated into site design shall:

1. Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss;

2. Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces;

3. Maximize the protection of natural drainage features and vegetation;

4. Minimize the decrease in the "time of concentration" from pre-construction to post-construction. "Time of concentration" is defined as the time it takes for runoff to travel from the hydraulically most distant point of the drainage area to the point of interest within a watershed;

5. Minimize land disturbance including clearing and grading;

6. Minimize soil compaction;

7. Provide low-maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers and pesticides;

8. Provide vegetated open-channel conveyance systems discharging into and through stable vegetated areas; and

9. Provide other source controls to prevent or minimize the use or exposure of pollutants at the site in order to prevent or minimize the release of those pollutants into stormwater runoff. These source controls include, but are not limited to:

i. Site design features that help to prevent accumulation of trash and debris in drainage systems;

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ii. Site design features that help to prevent discharge of trash and debris from drainage systems;

iii. Site design features that help to prevent and/or contain spills or other harmful accumulations of pollutants at industrial or commercial developments; and

iv. When establishing vegetation after land disturbance, applying fertilizer in accordance with the requirements established under the Soil Erosion and Sediment Control Act, N.J.S.A. 4:24-39 et seq., and implementing rules.

(c) Any land area used as a non-structural stormwater management measure to meet the performance standards in N.J.A.C. 7:8-5.4 and 5.5 shall be dedicated to a government agency, subjected to a conservation restriction filed with the appropriate County Clerk's office, or subject to Department approved or equivalent restriction that ensures that measure or an equivalent stormwater management measure approved by the reviewing agency is maintained in perpetuity.

(d) Guidance for nonstructural stormwater management strategies is available in the New Jersey Stormwater Best Management Practices Manual available from the Department through the address listed at N.J.A.C. 7:8-1.3.

<General Materials (GM) - References, Annotations, or Tables>

N.J.A.C. 7:8-5.3, **NJ ADC 7:8-5.3**

NJ ADC 7:8-5.3
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7:8-5.4 Erosion control, groundwater recharge and runoff quantity standards

(a) This section contains minimum design and performance standards to control erosion, encourage and control infiltration and groundwater recharge, and control stormwater runoff quantity impacts of major development.

1. The minimum design and performance standards for erosion control are those established under the Soil Erosion and Sediment Control Act, N.J.S.A. 4:24- 39 et seq. and implementing rules.

2. The minimum design and performance standards for groundwater recharge are as follows:

i. The design engineer shall, using the assumptions and factors for stormwater runoff and groundwater recharge calculations at N.J.A.C. 7:8-5.6, either:

(1) Demonstrate through hydrologic and hydraulic analysis that the site and its stormwater management measures maintain 100 percent of the average annual pre-construction groundwater recharge volume for the site; or

(2) Demonstrate through hydrologic and hydraulic analysis that the increase of stormwater runoff volume from pre-construction to post-construction for the two-year storm is infiltrated.

ii. This groundwater recharge requirement does not apply to projects within the "urban redevelopment area," or to projects subject to (a)2iii below.

iii. The following types of stormwater shall not be recharged:

(1) Stormwater from areas of high pollutant loading. High pollutant loading areas are areas in industrial and commercial developments where solvents and/or petroleum products are loaded/ unloaded, stored, or applied, areas where pesticides are loaded/unloaded or stored; areas where hazardous materials are expected to be present in greater than 'reportable quantities' as defined by the United States Environmental Protection Agency (EPA) at 40 CFR 302.4; areas where recharge would be inconsistent with Department approved remedial action work plan or landfill closure plan; and areas with high risks for spills of toxic materials, such as gas stations and vehicle maintenance facilities; and

(2) Industrial stormwater exposed to "source material." "Source material" means any material(s) or machinery, located at an industrial facility, that is directly or indirectly related to process,

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manufacturing or other industrial activities, which could be a source of pollutants in any industrial stormwater discharge to groundwater. Source materials include, but are not limited to, raw materials; intermediate products; final products; waste materials; by-products; industrial machinery and fuels, and lubricants, solvents, and detergents that are related to process, manufacturing, or other industrial activities that are exposed to stormwater.

iv. The design engineer shall assess the hydraulic impact on the groundwater table and design the site so as to avoid adverse hydraulic impacts. Potential adverse hydraulic impacts include, but are not limited to, exacerbating a naturally or seasonally high water table so as to cause surficial ponding, flooding of basements, or interference with the proper operation of subsurface sewage disposal systems and other subsurface structures in the vicinity or downgradient of the groundwater recharge area.

3. In order to control stormwater runoff quantity impacts, the design engineer shall, using the assumptions and factors for stormwater runoff calculations at N.J.A.C. 7:8-5.6, complete one of the following:

i. Demonstrate through hydrologic and hydraulic analysis that for stormwater leaving the site, post-construction runoff hydrographs for the two, 10 and 100- year storm events do not exceed, at any point in time, the pre-construction runoff hydrographs for the same storm events;

ii. Demonstrate through hydrologic and hydraulic analysis that there is no increase, as compared to the pre-construction condition, in the peak runoff rates of stormwater leaving the site for the two, 10 and 100-year storm events and that the increased volume or change in timing of stormwater runoff will not increase flood damage at or downstream of the site. This analysis shall include the analysis of impacts of existing land uses and projected land uses assuming full development under existing zoning and land use ordinances in the drainage area;

iii. Design stormwater management measures so that the post-construction peak runoff rates for the two, 10 and 100-year storm events are 50, 75 and 80 percent, respectively, of the pre-construction peak runoff rates. The percentages apply only to the post-construction stormwater runoff that is attributable to the portion of the site on which the proposed development or project is to be constructed; or

iv. In tidal flood hazard areas, stormwater runoff quantity analysis in accordance with (a)3i, ii and iii above shall only be applied if the increased volume of stormwater runoff could increase flood damages below the point of discharge.

(b) Any application for a new agricultural development that meets the definition of major development at N.J.A.C. 7:8-1.2 shall be submitted to the Soil Conservation District for review and approval in accordance with the requirements of this section and any applicable Soil Conservation District guidelines for stormwater runoff quantity and erosion control. For purposes of this section, "agricultural development" means land uses normally associated with the production of food, fiber and livestock for sale. Such uses do not include the development of land for the processing or sale of food and the manufacture of agriculturally related products.

<General Materials (GM) - References, Annotations, or Tables>

N.J.A.C. 7:8-5.4, **NJ ADC 7:8-5.4**

NJ ADC 7:8-5.4
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7:8-5.5 Stormwater runoff quality standards

(a) Stormwater management measures shall be designed to reduce the post-construction load of total suspended solids (TSS) in stormwater runoff generated from the water quality design storm by 80 percent of the anticipated load from the developed site, expressed as an annual average. Stormwater management measures shall only be required for water quality control if an additional one-quarter acre of impervious surface is being proposed on a development site. The requirement to reduce TSS does not apply to any stormwater runoff in a discharge regulated under a numeric effluent limitation for TSS imposed under the New Jersey Pollutant Discharge Elimination System (NJPDES) rules, N.J.A.C. 7:14A, or in a discharge specifically exempt under a NJPDES permit from this requirement. The water quality design storm is 1.25 inches of rainfall in two hours. Water quality calculations shall take into account the distribution of rain from the water quality design storm, as reflected in Table 1 below. The calculation of the volume of runoff may take into account the implementation of non-structural and structural stormwater management measures.

Table 1: Water Quality Design Storm Distribution

Time (Minutes)	Cumulative Rainfall (Inches)	Time (Minutes)	Cumulative Rainfall (Inches)
0	0.0000	65	0.8917
5	0.0083	70	0.9917
10	0.0166	75	1.0500
15	0.0250	80	1.0840
20	0.0500	85	1.1170
25	0.0750	90	1.1500
30	0.1000	95	1.1750
35	0.1330	100	1.2000
40	0.1660	105	1.2250
45	0.2000	110	1.2334
50	0.2583	115	1.2417
55	0.3583	120	1.2500
60	0.6250		

(b) For purposes of TSS reduction calculations, Table 2 below presents the presumed removal rates for certain BMPs designed in accordance with the New Jersey Stormwater Best Management Practices Manual. The BMP Manual may be obtained from the address identified in N.J.A.C. 7:8-1.3 or found on the Department's website at www.njstormwater.org.

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The BMP Manual and other sources of technical guidance are listed in N.J.A.C. 7:8-5.9(a). TSS reduction shall be calculated based on the removal rates for the BMPs in Table 2 below. Alternative removal rates and methods of calculating removal rates may be used if the design engineer provides documentation demonstrating the capability of these alternative rates and methods to the review agency. Where the Department is not the review agency, a copy of any approved alternative rate or method of calculating the removal rate shall be provided to the Department at the address at N.J.A.C. 7:8-1.3.

(c) If more than one BMP in series is necessary to achieve the required 80 percent TSS reduction for a site, the applicant shall utilize the following formula to calculate TSS reduction:

R = A + B-(AXB)/100

Where

R = total TSS percent load removal from application of both BMPs, and

A = the TSS percent removal rate applicable to the first BMP

B = the TSS percent removal rate applicable to the second BMP

Table 2: TSS Removal Rates for BMPs

Best Management Practice	TSS Percent Removal Rate
Bioretention Systems	90
Constructed Stormwater Wetland	90
Extended Detention Basin	40-60
Infiltration Structure	80
Manufactured Treatment Device	See N.J.A.C. 7:8-5.7(d)
Sand Filter	80
Vegetative Filter Strip	60-80
Wet Pond	50-90

(d) If there is more than one onsite drainage area, the 80 percent TSS removal rate shall apply to each drainage area, unless the runoff from the subareas converge on site in which case the removal rate can be demonstrated through a calculation using a weighted average.

(e) Stormwater management measures shall also be designed to reduce, to the maximum extent feasible, the post-construction nutrient load of the anticipated load from the developed site in stormwater runoff generated from the water quality design storm. In achieving reduction of nutrients to the maximum extent feasible, the design of the site shall include nonstructural strategies and structural measures that optimize nutrient removal while still achieving the performance standards in N.J.A.C. 7:8-5.4 and 5.5.

(f) Additional information and examples are contained in the New Jersey Stormwater Best Management Practices Manual, which may be obtained from the address identified in N.J.A.C. 7:8-1.3.

(g) In accordance with the definition of FW1 at N.J.A.C. 7:9B-1.4, stormwater management measures shall be designed to prevent any increase in stormwater runoff to waters classified as FW1.

(h) Special water resource protection areas shall be established along all waters designated Category One at N.J.A.C.

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7:9B and perennial or intermittent streams that drain into or upstream of the Category One waters as shown on the USGS Quadrangle Maps or in the County Soil Surveys, within the associated HUC 14 drainage. These areas shall be established for the protection of water quality, aesthetic value, exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, and exceptional fisheries significance of those established Category One waters. These areas shall be designated and protected as follows:

1. The applicant shall preserve and maintain a special water resource protection area in accordance with one of the following:

i. A 300-foot special water resource protection area shall be provided on each side of the waterway, measured perpendicular to the waterway from the top of bank outwards or from the centerline of the waterway where the bank is not defined, consisting of existing vegetation or vegetation allowed to follow natural succession is provided.

ii. Encroachment within the designated special water resource protection area under (h)1i above shall only be allowed where previous development or disturbance has occurred (for example, active agricultural use, parking area or maintained lawn area). The encroachment shall only be allowed where applicant demonstrates that the functional value and overall condition of the special water resource protection area will be maintained to the maximum extent practicable. In no case shall the remaining special water resource protection area be reduced to less than 150 feet as measured perpendicular to the top of bank of the waterway or centerline of the waterway where the bank is undefined. All encroachments proposed under this subparagraph shall be subject to review and approval by the Department.

2. All stormwater shall be discharged outside of but may flow through the special water resource protection area and shall comply with the Standard For Off-Site Stability in the "Standards for Soil Erosion and Sediment Control in New Jersey," established under the Soil Erosion and Sediment Control Act, N.J.S.A. 4:24-39 et seq. (see N.J.A.C. 2:90-1.3).

3. If stormwater discharged outside of and flowing through the special water resource protection area cannot comply with the Standard For Off-Site Stability in the "Standards for Soil Erosion and Sediment Control in New Jersey," established under the Soil Erosion and Sediment Control Act, N.J.S.A. 4:24- 39 et seq., (see N.J.A.C. 2:90-1.3), then the stabilization measures in accordance with the requirements of the above standards may be placed within the special water resource protection area, provided that:

i. Stabilization measures shall not be placed within 150 feet of the waterway;

ii. Stormwater associated with discharges allowed by this paragraph shall achieve a 95 percent TSS post construction removal rate;

iii. Temperature shall be addressed to ensure no impact on receiving waterway;

iv. The encroachment shall only be allowed where the applicant demonstrates that the functional value and overall condition of the special water resource protection area will be maintained to the maximum extent practicable;

v. A conceptual project design meeting shall be held with the appropriate Department staff and Soil Conservation District staff to identify necessary stabilization measures; and

vi. All encroachments proposed under this section shall be subject to review and approval by the Department.

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4. A stream corridor protection plan may be developed by a regional stormwater management planning committee as an element of a regional stormwater management plan, or by a municipality through an adopted municipal stormwater management plan. If a stream corridor protection plan for a waterway subject to this subsection has been approved by the Department, then the provisions of the plan shall be the applicable special water resource protection area requirements for that waterway. A stream corridor protection plan for a waterway subject to this subsection shall maintain or enhance the current functional value and overall condition of the special water resource protection area as defined above in (h)1i. In no case shall a stream corridor protection plan allow reduction of the Special Water Resource Protection Area to less than 150 feet as measured perpendicular to the waterway subject to this subsection.

5. This subsection does not apply to the construction of one individual single family dwelling that is not part of a larger development on a lot receiving preliminary or final subdivision approval on or before February 2, 2004, provided that the construction begins on or before February 2, 2009.

Petition for Rulemaking.

See: 36 N.J.R. 4995(b).

Petition for Rulemaking.

See: 37 N.J.R. 141(a).

<General Materials (GM) - References, Annotations, or Tables>

N.J.A.C. 7:8-5.5, **NJ ADC 7:8-5.5**

NJ ADC 7:8-5.5
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Project Name	Description	Analysis Date	BMP or LID Type
Sample Project	This is a test application	09/01/03	

Recharge BMP Input Parameters

Parameter	Symbol	Value	Unit
BMP Area	ABMP	6656.0	sq.ft
BMP Effective Depth, this is the design variable	dBMP	5.2	in
Upper level of the BMP surface (negative if above ground)	dBMPu	-5.2	in
Depth of lower surface of BMP, must be>=dBMPu	dEXC	0.0	in
Post-development Land Segment Location of BMP , Input Zero if Location is distributed or undetermined	SegBMP	0	unitless

Root Zone Water capacity Calculated Parameters

Parameter	Symbol	Value	Unit
Empty Portion of RWC under Post-D Natural Recharge	ERWC	0.93	in
ERWC Modified to consider dEXC	EDRWC	0.93	in
Empty Portion of RWC under Infilt. BMP	RERWC	0.74	in

Recharge Design Parameters

Parameter	Symbol	Value	Unit
Inches of Runoff to capture	Qdesign	0.54	in
Inches of Rainfall to capture	Pdesign	0.67	in
Recharge Provided Avg. over Imp. Area		19.0	in
Runoff Captured Avg. over imp. Area		24.8	in

BMP Calculated Size Parameters

ABMP/Aimp	Aratio	0.10	unitless
BMP Volume	VBMP	2,873	cu.ft

Parameters from Annual Recharge Worksheet

Post-D Deficit Recharge (or desired recharge volume)	Vdef	103,435	cu.ft
Post-D Impervious Area (or target Impervious Area)	Aimp	65,340	sq.ft
Root Zone Water Capacity	RWC	3.94	in
RWC Modified to consider dEXC	DRWC	3.94	in
Climatic Factor	C-factor	1.53	no units
Average Annual P	Pavg	47.8	in
Recharge Requirement over Imp. Area	dr	19.0	in

System Performance Calculated Parameters

Annual BMP Recharge Volume		103,435	cu.ft
Avg BMP Recharge Efficiency		76.7%	Represents % Infiltration Recharged
%Rainfall became Runoff		78.3%	%
%Runoff Infiltrated		66.2%	%
%Runoff Recharged		50.8%	%
%Rainfall Recharged		39.7%	%

CALCULATION CHECK MESSAGES

Volume Balance-> OK
dBMP Check---> OK
dEXC Check---> OK

BMP Location---> Location is selected as distributed or undetermined

OTHER NOTES

Pdesign is accurate only after BMP dimensions are updated to make rech volume= deficit volume. The portion of BMP infiltration prior to filling and the area occupied by BMP are ignored in these calculations. Results are sensetive to dBMP, make sure dBMP selected is small enough for BMP to empty in less than 3 days. For land Segment Location of BMP if you select "impervious areas" RWC will be minimal but not zero as determined by the soil type and a shallow root zone for this Land Cover allowing consideration of lateral flow and other losses

How to solve for different recharge volumes: By default the spreadsheet assigns the values of total deficit recharge volume "Vdef" and total proposed impervious area "Aimp" from the "Annual Recharge" sheet to "Vdef" and "Aimp" on this page. This allows solution for a single BMP to handle the entire recharge requirement assuming the runoff from entire impervious area is available to the BMP.
To solve for a smaller BMP or a LID-IMP to recharge only part of the recharge requirement, set Vdef to your target value and Aimp to impervious area directly connected to your infiltration facility and then solve for ABMP or dBMP. To go back to the default configuration clik the "Default Vdef & Aimp" button.

Tier A Municipal Stormwater General Permit
(NJ0141852)
Major Modification
Effective Date of Permit Modification: September 1, 2005

PART I
NARRATIVE REQUIREMENTS:

A. Authorization Under this Permit

1. Permit Area

a. This permit applies to all areas of the State of New Jersey.

2. Eligibility

a. This permit may authorize all new and existing stormwater discharges to surface water and groundwater from small municipal separate storm sewer systems (MS4s) owned or operated by municipalities assigned to Tier A under N.J.A.C. 7:14A-25.3(a)1 (Tier A Municipalities), except as provided in A.5 below.

b. On a case-by-case basis, the Department may use this permit to authorize new and existing stormwater discharges to surface water and groundwater from small MS4s (or portions of small MS4s) owned or operated by Tier B Municipalities. As used in this permit, the term "Tier A Municipality" includes Tier B Municipalities that seek or obtain authorization pursuant to this provision of this permit.

c. After the Effective Date of Permit Authorization (EDPA), the permit authorizes the following new and existing non-stormwater discharges from small MS4s owned or operated by Tier A Municipalities:

i. Water line flushing and discharges from potable water sources

ii. Uncontaminated ground water (e.g., infiltration, crawl space or basement sump pumps, foundation or footing drains, rising ground waters)

iii. Air conditioning condensate (excluding contact and non-contact cooling water)

iv. Irrigation water (including landscape and lawn watering runoff)

v. Flows from springs, riparian habitats and wetlands, water reservoir discharges and diverted stream flows

vi. Residential car washing water, and residential swimming pool discharges

vii. Sidewalk, driveway and street wash water

viii. Flows from fire fighting activities including the washing of fire fighting vehicles

ix. Vehicle and equipment washwater from municipal operations pursuant to Part I, Section F.8.e of the permit

x. Flows from rinsing of the following equipment with clean water:

- Beach maintenance equipment immediately following their use for their intended purposes; and
- Equipment used in the application of salt and de-icing materials immediately following salt and de-icing material applications. Prior to rinsing with clean water, all residual salt and de-icing materials must be removed from equipment and vehicles to the maximum extent practicable using dry cleaning methods (e.g., shoveling and sweeping). Recovered materials are to be returned to storage for reuse or properly discarded.

  Rinsing of equipment in the above situations is limited to exterior, undercarriage, and exposed parts and does not apply to engines or other enclosed machinery.

d. If any of the discharges listed in 2.c above are identified by the municipality as a significant contributor of pollutants to or from the MS4, the Tier A Municipality must address the discharge as an illicit connection or as an improper disposal of waste as specified in Part I, Section F of this permit

3. Authorization

a. In order to obtain authorization under this permit (except for automatic renewal of authorization under A.4 below) a complete Request for Authorization (RFA) shall be submitted in accordance with the requirements of this permit. Upon review of the RFA, the Department may, in accordance with N.J.A.C. 7:14A-6.13, either:

i. Issue notification of authorization under this permit, in which case, authorization is deemed effective the first day of the following month of the date of the notification of authorization;

ii. Deny authorization under this permit and require submittal of an application for an individual permit; or

iii. Deny authorization under this permit and require submittal of an RFA for another general permit.

b. For discharges from a small MS4 authorized by this permit, the Tier A Municipality is exempt from N.J.A.C. 7:14A-6.2(a)2. This exemption means that the discharge of any pollutant not specifically regulated in the NJPDES permit or listed and quantified in the NJPDES application or RFA shall not constitute a violation of the permit.

c. Authorization under this permit shall cease to be effective under N.J.A.C. 7:14A-6.13(f), (h), (j) and (o), where applicable.

4. Automatic Renewal of Authorization

a. Authorization under this permit will be automatically renewed when this general permit is reissued as provided by N.J.A.C. 7:14A-6.13(d)9 and 25.4(a)3 so long as the discharge authorized under the general permit continues to be eligible. The Department shall issue a notice of renewed authorization to the Tier A Municipality.

b. If the Tier A Municipality is aware of any information in the most recently submitted RFA that is no longer true, accurate, and/or complete, the Tier A Municipality shall provide the correct information to the Department within 90 days of the effective renewal authorization notice.

5. Stormwater Discharges Not Authorized

a. This permit does not authorize "stormwater discharge associated with industrial activity" as defined in N.J.A.C. 7:14A-1.2. Types of facilities that a Tier A Municipality may operate and that are considered to be engaging in "industrial activity" include but are not limited to certain landfills and recycling facilities, certain transportation facilities (including certain local passenger transit and air transportation facilities), certain facilities handling domestic sewage or sewage sludge, steam electric power generating facilities, and construction activity that disturbs five acres or more (see N.J.A.C. 7:14A-1.2 for the full definition of "stormwater discharge associated with industrial activity"). Any municipality that operates an industrial facility with such a discharge must submit a separate request for authorization (RFA) or individual permit application for that discharge. An RFA submitted for the Tier A Municipal Stormwater General Permit does not qualify as an RFA for such a discharge.

i. Deadlines to apply for a NJPDES permit for "stormwater discharge associated with industrial activity" are set forth in N.J.A.C. 7:14A-24.4(a)1. If such a discharge is from a facility (other than an airport, powerplant, or uncontrolled sanitary landfill) that is owned or operated by a municipality with a population of less than 100,000, the municipality shall submit the RFA or individual permit application by March 3, 2004. If such a discharge is from any other industrial facility, N.J.A.C. 7:14A-24.4(a)1 specifies earlier deadlines to apply.

b. This permit does not authorize "stormwater discharge associated with small construction activity" as defined in N.J.A.C. 7:14A-1.2. In general, this is the discharge to surface water of stormwater from construction activity that disturbs at least one but less than five acres (see N.J.A.C. 7:14A-1.2 for the full definition). Any municipality that operates a construction site with such a discharge must submit a separate RFA or individual permit application for that discharge. An RFA submitted for the Tier A Municipal Stormwater General Permit does not qualify as an RFA for such a discharge.

c. This permit does not authorize any stormwater discharge that is authorized under another NJPDES permit. A municipality does not have to implement measures contained in this NJPDES permit for stormwater discharges at facilities owned or operated by that municipality that are regulated under a separate NJPDES stormwater permit authorizing those discharges.

d. This permit does not authorize stormwater discharges from projects or activities that conflict with an adopted areawide or Statewide WQM plan.

B. Requests for Authorization Requirements

1. Deadline for Requesting Authorization for an Existing Discharge

a. An RFA for the existing discharges from the small MS4 owned or operated by a Tier A Municipality must be submitted to the Department on or before March 3, 2004, except as provided below.

i. If a municipality receives notice from the Department that it has been reassigned from Tier B to Tier A, or that a special designation is made under N.J.A.C. 7:14A-25.2(a)4, the deadline to submit an RFA is 180 days after the receipt of that notice, unless the Department approves a later date.

ii. The Department may, in its discretion, accept an RFA submitted after the foregoing deadline; however, the municipality may still be held liable for violating the deadline to apply in accordance with N.J.A.C. 7:14A-25.4 and for discharging pollutants without a valid NJPDES permit in accordance with N.J.A.C. 7:14A-2.1(d).

2. Deadline for Requesting Authorization for a New Discharge

a. An RFA for discharges from a new small MS4 owned or operated by a Tier A Municipality must be submitted to the Department at least ninety (90) days prior to the operation of the new MS4 system.

i. A Tier A Municipality that already has authorization to discharge from a small MS4 under the Tier A Municipal Stormwater Permit does not need to submit an additional RFA for the expansion of an existing small MS4.

ii. A new small MS4 is a small MS4 that did not exist on March 3, 2004 and results in a new discharge to surface or ground waters of the State.

3. Requesting Authorization

a. A separate RFA shall be submitted by each Tier A Municipality applying for authorization under this permit.

b. A single RFA is required for the entire stormwater discharge from the small MS4 owned or operated by and located within a single municipality. Multiple RFAs are not required for multiple municipal operations (e.g., municipally owned and operated maintenance facilities, garages, and/or offices).

4. Contents of the Request for Authorization

a. A completed RFA shall include all of the following information regarding the Tier A Municipality and shall be completed using the Department's RFA form:

i. The name of the municipality that operates the small MS4, county it is located in, and the address of the main municipal office (e.g., city hall, town hall, or municipal building).

ii. The name and mailing address of the Municipal Stormwater Program Coordinator who will submit any reports or certifications required by the permit and to whom the Department shall send all correspondence concerning the permit.

iii. A certification acknowledging the best management practices and measurable goals specified in the permit.

iv. Additional information may be required by the Department to be included as part of the RFA if the Department determines that such additional information (including other data, reports, specifications, plans, permits, or other information) is reasonably necessary to determine whether to authorize the discharge under this permit.

5. Where to Submit

a. A completed and signed RFA shall be submitted to the Department at the address specified on the Department's RFA form.

C. Definitions

1. The following definitions apply to this permit.

a. "Catch Basin" means a cistern, vault, chamber or well that is usually built along a street as part of the storm sewer system.

b. "EDPA" means Effective Date of Permit Authorization.

c. "Illicit connection" means any physical or non-physical connection that discharges the following to a municipal separate storm sewer system, unless that discharge is authorized under a NJPDES permit other than the NJPDES permit for discharges from that system (non-physical connections may include, but are not limited to, leaks, flows, or overflows into the municipal separate storm sewer system):

i. Domestic sewage;

ii. Non-contact cooling water, process wastewater, or other industrial waste (other than stormwater); or

iii. Any category of non-stormwater discharges that the Tier A Municipality identifies as a source or significant contributor of pollutants pursuant to 40 C.F.R. 122.34(b)(3)(iii).

d. "MS4" means a municipal separate storm sewer system.

e. "Municipality" means a "municipality" as defined in the Municipal Land Use Law at N.J.S.A. 40:55D-5, that is, any city, borough, town, township, or village.

f. "Municipal separate storm sewer" means a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains):

iv. Owned or operated by the United States, an interstate agency, a State, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State law) having jurisdiction over disposal of sewage, industrial wastes, stormwater, or other wastes, including special districts under State law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe organization, or a designated and approved management agency under section 208 of the CWA that discharges to surface water or groundwater;

v. Designed and used for collecting or conveying stormwater;

vi. Which is not a combined sewer;

vii. Which is not part of a POTW; and

viii. Which is not either of the following:

- A separate storm sewer(s) that is at an industrial facility, and that collects or conveys stormwater discharges associated with industrial activity that occurs at that facility; or

- A separate storm sewer(s) that is at a construction site, and that collects or conveys stormwater discharges associated with small construction activity that occurs at that site.

g. "Small municipal separate storm sewer system" or "small MS4" means all municipal separate storm sewers (other than "large" or "medium" municipal separate storm sewer systems as defined in N.J.A.C. 7:14A-1.2) that are:

i. Owned or operated by municipalities described under N.J.A.C. 7:14A-25.1(b);

ii. Owned or operated by county, State, interstate, or Federal agencies, and located at public complexes as described under N.J.A.C. 7:14A-25.2(a)2; or

iii. Owned or operated by county, State, interstate, or Federal agencies, and located at highways and other thoroughfares as described under N.J.A.C. 7:14A-25.2(a)3; or

iv. Owned or operated by county, State, interstate, Federal, or other agencies, and receive special designation under N.J.A.C. 7:14A-25.2(a)4.

h. "Solid and floatable materials" means sediment, debris, trash, and other floating, suspended, or settleable solids.

i. "Stormwater" means water resulting from precipitation (including rain and snow) that runs off the land's surface, is transmitted to the subsurface, is captured by separate storm sewers or other sewerage or drainage facilities, or is conveyed by snow removal equipment.

D. Special Conditions

1. Sharing of Responsibilities

a. A Tier A Municipality may rely on another governmental, private, or nonprofit entity (for example, a watershed association) to satisfy the municipality's NJPDES permit obligations to implement one or more control measures (or components (s) thereof) pursuant to N.J.A.C. 7:14A-25.7(a) if:

i. The other entity, in fact, implements the measure(s), or component(s) thereof;

ii. The particular measure(s), or component(s) thereof, is at least as stringent as the corresponding NJPDES permit requirement;

iii. The other entity agrees in writing (or is required by law) to implement the measure(s), or component(s) thereof, on the Tier A Municipality's behalf. The municipality is responsible for compliance with this permit if the other

entity fails to implement the measure(s), or component(s) thereof. In the annual reports the municipality must submit under Part I, Section H.3, the municipality shall specify that it is relying on another entity to satisfy some of the Tier A Municipality's NJPDES permit obligations.

iv. If the municipality is relying on another entity regulated under the NJPDES permit program to satisfy all of that Tier A Municipality's NJPDES permit obligations, including that municipality's obligation to file these annual reports, the municipality shall notify the Department of this reliance in writing, and shall also note this reliance in the municipality's SPPP.

E. Stormwater Program and Stormwater Pollution Prevention Plan

1. Stormwater Program

a. Tier A Municipalities are required to develop, implement, and enforce a stormwater program. This program shall be designed to reduce the discharge of pollutants from the municipality's small MS4 to the maximum extent practicable, to protect water quality, and to satisfy the appropriate water quality requirements of the Federal Act and the State Act by including the Statewide Basic Requirements (SBRs) set forth in Part I, Section F and any Additional Measures (AMs) required under Part I, Section G below. At the municipality's discretion, the stormwater program may also include Optional Measures (OMs) also in accordance with Part I, Section G below.

2. Stormwater Pollution Prevention Plan (SPPP)

a. Tier A Municipalities shall prepare and implement a written Stormwater Pollution Prevention Plan (SPPP) that describes the Tier A Municipality's stormwater program and serves as the mechanism for the implementation of the Statewide Basic Requirements. The SPPP must address stormwater quality issues related to new development, redevelopment and existing development. The SPPP shall be prepared and implemented in accordance with the deadlines specified in Part I, Section H. The SPPP shall include, at a minimum, all of the information and items identified in Attachment A.

i. The SPPP shall be signed, dated and retained by the Municipal Stormwater Program Coordinator.

b. For any projects or activities which the municipality contracts out to private contractors after the EDPA, the awarded contract must contain conditions that the contractor must conduct such projects or activities in such a manner that is in compliance with the municipality's SPPP and this permit's conditions. The municipality is responsible for any violations of this permit resulting from a contractor's noncompliance.

c. SPPPs may be amended so long as they continue to meet the requirements of this permit. Any amended SPPPs shall be signed, dated, implemented, retained, and otherwise treated in the same manner as the original SPPP. The Tier A Municipality shall retain each previous SPPP for a period of at least five years from the date of that previous SPPP. This period may be extended by written request of the Department at any time.

F. Statewide Basic Requirements (SBRs)

1. Stormwater quality issues related to new development, redevelopment and existing development are to be addressed through the implementation of the following Statewide Basic Requirements (SBRs). The permit specifies the BMPs that will be implemented for those SBRs. These SBRs and related BMPs are to be detailed in the municipality's SPPP.

a. Additional information is provided and each of the SBRs and related BMPs are described in more detail in the Department's Tier A Municipal Stormwater Permit Guidance Document.

2. Public Notice

a. Minimum Standard - Tier A Municipalities shall comply with applicable State and local public notice requirements when providing for public participation in the development and implementation of the Tier A Municipality's stormwater program.

b. Measurable Goal - Tier A Municipalities shall certify annually that all applicable State and local public notice requirements were followed.

c. Implementation – Upon the effective date of permit authorization (EDPA).

3. Post-Construction Stormwater Management in New Development and Redevelopment

a. Minimum Standard - To prevent or minimize water quality impacts, the Tier A Municipality shall develop, implement, and enforce a program to address stormwater runoff from new development and redevelopment projects (including projects operated by the municipality itself) that disturb one acre or more, including projects less than one acre that are part of a larger common plan of development or sale, that discharge into the municipality's small MS4. The municipality shall in its post-construction program:

i. Adopt and reexamine a municipal stormwater management plan (or adopt amendments to an existing municipal stormwater management plan) in accordance with N.J.A.C. 7:8-4.

ii. Adopt and implement a municipal stormwater control ordinance or ordinances in accordance with N.J.A.C. 7:8-4. The ordinance(s) will control stormwater from non-residential development and redevelopment projects.

iii. Ensure that any residential development and redevelopment projects that are subject to the Residential Site Improvement Standards for stormwater management (N.J.A.C. 5:21-7) comply with those standards (including any exception, waiver, or special area standard that was approved under N.J.A.C. 5:21-3).

iv. Where necessary to implement the municipal stormwater management plan, the municipal stormwater control ordinance(s) will also:

- Control aspects of residential development and redevelopment projects that are not pre-empted by the Residential Site Improvement Standards; and
- Set forth special area standards approved by the Site Improvement Advisory Board for residential development or redevelopment projects under N.J.A.C. 5:21-3.5.

v. Ensure adequate long-term operation and maintenance of BMPs.

vi. Enforce, through the stormwater control ordinance(s) or a separate ordinance, compliance with standards set forth in Attachment C of the permit to control passage of solid and floatable materials through storm drain inlets.

vii. This post-construction program shall also require compliance with the applicable design and performance standards established under N.J.A.C. 7:8 for major development, unless:

- Those standards do not apply because of a variance or exemption granted under N.J.A.C. 7:8; or
- Alternative standards are applicable under an areawide or Statewide Water Quality Management Plan adopted in accordance with N.J.A.C. 7:15.

b. Measurable Goal – Tier A Municipalities shall certify annually that that they have developed, implemented, and are actively enforcing a program to address stormwater runoff from new development and redevelopment projects that discharge into the Tier A Municipality's small MS4 in accordance with the minimum standard.

c. Implementation

i. Upon the effective date of permit authorization, Tier A Municipalities shall for new development and redevelopment projects:

- Ensure that any residential development and redevelopment projects that are subject to the Residential Site Improvement Standards for stormwater management (N.J.A.C. 5:21-7) comply with those standards (including any exception, waiver, or special area standard that was approved under N.J.A.C. 5:21-3).
- Ensure adequate long-term operation and maintenance of BMPs on property owned or operated by the municipality.

ii. Within 12 months from the effective date of permit authorization, Tier A Municipalities shall:

- Adopt a municipal stormwater management plan (or adopt amendments to an existing municipal stormwater management plan) pursuant to the Stormwater Management Rules (N.J.A.C. 7:8-4) except as provided in iii below;
- Comply with the standards set forth in Attachment C of the permit to control passage of solid and floatable materials through storm drain inlets for storm drain inlets the municipality installs within the Tier A Municipality's small MS4.

iii. Within 3 months from the date the Department provides a draft model "Pinelands" Municipal Stormwater Control Ordinance, Tier A Municipalities within the Pinelands Area as defined by N.J.S.A. 13:18A-11 shall adopt a municipal stormwater management plan (or adopt amendments to an existing

municipal stormwater management plan) pursuant to the Stormwater Management Rules (N.J.A.C. 7:8-4) for those areas of the municipality within the Pinelands Area.

Tier A Municipalities partially within the Pinelands Area shall adopt a municipal stormwater management plan (or adopt amendments to an existing municipal stormwater management plan) pursuant to the Stormwater Management Rules (N.J.A.C. 7:8-4) within 12 months from the effective date of permit authorization for those areas of the municipality not within the Pinelands Area.

iv.Within 12 months from the adoption of the municipal stormwater management plan, Tier A Municipalities shall adopt a stormwater control ordinance(s) to implement that plan, and shall submit the adopted municipal stormwater management plan and ordinance(s) to the appropriate county review agency for approval pursuant to N.J.A.C. 7:8-4.4 (and, where N.J.A.C. 7:50-3 is applicable, to the Pinelands Commission for certification).

- If a county review agency conditionally approves the adopted municipal stormwater management plan and ordinance(s) the Tier A Municipality shall, within 180 days of the conditional approval, adopt the amendments to the municipal stormwater management plan and ordinance(s) specified by the county review agency and resubmit the amended municipal stormwater management plan and ordinance(s).

- If a county review agency disapproves the adopted municipal stormwater management plan and ordinance(s) the Tier A Municipality shall, within 180 days of the disapproval, resubmit an amended municipal stormwater management plan and ordinance(s) to the county review agency.

- If the Pinelands Commission disapproves or conditionally certifies the adopted municipal stormwater management plan and ordinance(s) the Tier A Municipality shall submit its modified plan and ordinance(s) to the Pinelands Commission in accordance with N.J.A.C. 7:50-3.

v. Tier A Municipalities shall enforce stormwater control ordinance(s) when approved by the county review agency (and, where N.J.A.C. 7:50-3 is applicable, certified by the Pinelands Commission) or shall enforce stormwater control ordinance(s) when conditionally approved by the county review agency upon adoption by the municipality of the amendments specified by the county review agency (and, where N.J.A.C. 7:50-3 is applicable, certified by the Pinelands Commission) in accordance with N.J.A.C. 7:8-4.

vi. Within 24 months from the effective date of permit authorization Tier A Municipalities shall:

- Ensure adequate long-term operation and maintenance of BMPs on property not owned or operated by the municipality;

- Enforce, through the stormwater control ordinance(s) or a separate ordinance compliance with the standards set forth in Attachment C of the permit to control passage of solid and floatable materials through storm drain inlets for storm drain inlets not installed by the Tier A Municipality.

4. Local Public Education

a. Local Public Education Program

i. Minimum Standard – The Local Public Education Program shall describe how the Tier A Municipality will distribute educational information and specifics on how educational activities, including the educational event, will be conducted to satisfy this minimum standard. The following SBR and/or BMP topics shall be included in the Local Public Education Program:

- Stormwater/Nonpoint Source Education – impact of stormwater discharges on surface and ground waters of the State and steps that the public can take to reduce pollutants in stormwater runoff.
- Storm Drain Inlet Labeling – hazards of dumping materials into the storm drain, and fact that storm drains are usually connected to water bodies and do not receive treatment.
- Fertilizer/Pesticide Education –proper application, storage and disposal of pesticides and fertilizers, and the benefits of using native or well adapted vegetation that requires little or no fertilization.
- Waste Disposal Education – identification, proper handling and proper disposal of wastes (including the locations of hazardous waste collection facilities in the area) and the hazards associated with illicit connections and improper disposal of waste.
- Pet Waste Ordinance – information regarding the pet waste ordinance and the benefits of proper disposal of pet waste.
- Litter Ordinance - information regarding litter control and fines associated with littering
- Improper Disposal of Waste Ordinance - information regarding this ordinance.
- Wildlife Feeding Ordinance - information regarding the wildlife feeding prohibition.
- Yard Waste - information regarding home composting and yard waste recycling.

Tier A Municipalities shall provide for the duplication and annual mailing (or other means of delivery) to all residents and businesses within the municipality of the informational brochure provided by the Department. The informational brochure covers all the topics above. The Department may periodically provide the Tier A Municipality with an updated brochure for duplication and distribution.

As part of this program, Tier A Municipalities shall also conduct each year, at minimum, one education effort in the form of an "event." An event may be an activity established primarily to satisfy this requirement or may be part of a bigger existing event such as municipal festivals, county fairs, or an Earth Day, Arbor Day or 4th of July celebration. During this event, the informational brochure shall also be made available to the public.

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the Local Public Education Program minimum standard and shall provide the date(s) of the annual mailing (or other means of delivery) and annual event (including a description of the event).

iii. Implementation - Within 12 months from the effective date of permit authorization, Tier A Municipalities shall have developed and begun implementing the Local Public Education Program minimum standard.

b. Storm Drain Inlet Labeling

i. Minimum Standard - Tier A Municipalities shall establish a storm drain inlet labeling program and label all storm drain inlets that are along municipal streets with sidewalks, and all storm drain inlets within plazas, parking areas, or maintenance yards that are operated by the municipality. The program shall establish a schedule for labeling, develop a long term maintenance plan, and when possible, coordinate efforts with watershed groups and volunteer organizations.

ii. Measurable Goal - Tier A Municipalities shall certify annually that a storm drain inlet labeling program has been developed or is being implemented, and shall identify the number of storm drain inlets labeled within each year.

iii. Implementation - Within 12 months from the effective date of permit authorization, Tier A Municipalities shall develop an inlet labeling program for the storm drains identified in the minimum standard. Tier A Municipalities must either:

- Label a minimum of 50% of the storm drain inlets within 36 months from the EDPA; and label all remaining storm drain inlets on or before 60 months from EDPA; or

- Divide the municipality into two sectors for the purposes of storm drain inlet labeling and include a map of the two sectors in the SPPP. Label the storm drain inlets in one sector within 36 months from the EDPA; and label all remaining storm drain inlets on or before 60 months from EDPA.

5. Improper Disposal of Waste

a. Pet Waste Ordinance

i. Minimum Standard - Tier A Municipalities shall adopt and enforce an ordinance that requires pet owners or their keepers to immediately and properly dispose of their pet's solid waste deposited on any property, public or private, not owned or possessed by that person. Information on the Pet Waste Ordinance

and the benefits of proper disposal of pet solid waste shall be distributed with pet licenses.

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the Pet Waste Ordinance minimum standard.

iii. Implementation - Within 18 months from the effective date of permit authorization, Tier A Municipalities shall have fully implemented the Pet Waste Ordinance minimum standard.

b. Litter Ordinance

i. Minimum Standard - Tier A Municipalities shall adopt and enforce a litter ordinance or enforce the existing State litter statute (N.J.S.A 13:1E-99.3).

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the Litter Ordinance minimum standard.

iii. Implementation - Within 18 months from the effective date of permit authorization, Tier A Municipalities shall have fully implemented the Litter Ordinance minimum standard.

c. Improper Disposal of Waste Ordinance

i. Minimum Standard - Tier A Municipalities shall adopt and enforce an ordinance prohibiting the improper spilling, dumping, or disposal of materials other than stormwater into the small MS4 (excluding those authorized in Part I, Section A.2.c).

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the Improper Waste Disposal Ordinance minimum standard.

iii. Implementation - Within 18 months from the effective date of permit authorization, Tier A Municipalities shall have fully implemented the Improper Disposal of Waste Ordinance minimum standard.

d. Wildlife Feeding Ordinance

i. Minimum Standard - Tier A Municipalities shall adopt and enforce an ordinance that prohibits the feeding in any public park or on any other property owned or operated by the Tier A Municipality of any wildlife (excluding confined animals, for example, wildlife confined in zoos, parks, or rehabilitation centers or unconfined wildlife at environmental education centers, or feral cats as part of an approved Trap-Neuter-Release (TNR) program).

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the Wildlife Feeding Ordinance minimum standard.

iii. Implementation - Within 18 months from the effective date of permit authorization, Tier A Municipalities shall have fully implemented the Wildlife Feeding Ordinance minimum standard.

e. Yard Waste Ordinance / Collection Program

i. Minimum Standard - Tier A Municipalities shall either adopt and enforce an ordinance that prohibits placing non-containerized yard wastes in the cartway of the street or shall develop a yard waste collection and disposal program. A

yard waste collection program shall include the adoption and enforcement of an ordinance prohibiting all yard wastes from being placed within the cartway more than seven (7) days prior to scheduled collection or the placing of yard waste closer than 10 feet from any storm sewer inlet along the street, unless they are bagged or otherwise containerized. The frequency of pickups shall be determined at the discretion of the Tier A Municipality. Any area, which the municipality determines to have no yard waste, will be exempt from the collections.

For the purposes of this minimum standard "yard waste" means loose leaves and grass clippings.

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the Yard Waste minimum standard.

iii. Implementation – Within 18 months from the effective date of permit authorization, Tier A Municipalities shall have either developed and begun implementing a Yard Waste Collection Program or have fully implemented the Yard Waste Ordinance in accordance with the Yard Waste Ordinance / Collection Program minimum standard.

6. Illicit Connection Elimination and MS4 Outfall Pipe Mapping

a. Minimum Standard

i. Storm Sewer Outfall Pipe Mapping – Tier A Municipalities must develop a map showing the location of the end of all MS4 outfall pipes that are operated by the Tier A Municipality, and that discharge within the Tier A Municipality's jurisdiction to a surface water body (e.g., a lake, ocean, or stream including an intermittent stream). This map shall also show the location (and name, where known to the Tier A Municipality) of all surface water bodies receiving discharges from those outfall pipes. Each outfall pipe mapped shall be given an individual alphanumeric identifier, which shall be noted on the map. The outfall pipes shall be mapped on either a tax map prepared in accordance with Title 18, Chapter 23A of the New Jersey Administrative Code or on another map drawn to equal or larger (more detailed) scale. A municipality regulated under the Sewage Infrastructure Improvement Act (SIIA) regulations (N.J.A.C. 7:22A) may use a preliminary or final map prepared pursuant to those regulations. The Tier A Municipality shall submit a copy of its outfall pipe map to the Department upon request.

ii. Ordinance Prohibiting Illicit Connections - Each Tier A Municipality shall, to the extent allowable under State law, effectively prohibit through ordinance, illicit connections to the Tier A Municipality's small MS4, and implement appropriate enforcement procedures and actions.

iii. Illicit Connection Elimination Program - Each Tier A Municipality must develop and implement a program to detect and eliminate illicit connections into the Tier A Municipality's small MS4. The program, at minimum, must include an initial physical inspection of all its outfall pipes. All outfall pipes that are found to have dry weather flow are to be further investigated.

The inspections of outfall pipes and investigations of dry weather flows are to be conducted in accordance with the procedures for detecting, investigating, and eliminating illicit connections contained in Attachment B of the permit. Results of the inspections of outfall pipes and dry weather flows are to be recorded on the Department's Illicit Connection Inspection Report form. Inspection reports for dry weather flows discovered as a result of initial physical inspections or as part of the ongoing program must be submitted to the Department with the annual certification. If the dry weather flow is intermittent the Tier A Municipality must perform, at minimum, three (3) additional investigations in an attempt to locate the illicit connection. If an illicit connection cannot be located or is found to emanate from another public entity, Tier A Municipalities must submit to the Department a written explanation detailing the results of the investigation and notify that public entity. The Department will determine if such measures were adequate and will notify the Tier A Municipality of the determination. All illicit connections found and subject to the ordinance prohibiting illicit connections must be eliminated within six (6) months of the discovery.

After the completion of the initial physical inspection of all outfall pipes, Tier A Municipalities must maintain an ongoing program to detect and eliminate illicit connections. The ongoing program will respond to complaints and reports of illicit connections, including those from operating entities of interconnected small MS4s, and continue to investigate dry weather flows discovered during routine inspections and maintenance of the small MS4.

b. Measurable Goal

i. Tier A Municipalities shall certify annually that an outfall pipe map has been completed or is being prepared in accordance with permit conditions and shall report the number of outfall pipes mapped within the year being reported and the total number of outfall pipes mapped to date.

ii. Tier A Municipalities shall submit an annual certification to the Department certifying that an ordinance prohibiting illicit connections is in place and is being actively enforced.

iii. Tier A Municipalities shall certify annually that an illicit connection elimination program has been developed in accordance with permit conditions to detect and eliminate illicit connections into the Tier A Municipalities' small MS4. Annual certifications shall also include the number of outfalls physically inspected, the number of outfalls found to have dry weather flow, the number of illicit connections found and the number of illicit connections eliminated. Copies of inspection reports shall be submitted with the annual certification for those outfalls found to have dry weather flow.

c. Implementation

i. Storm Sewer Outfall Pipe Mapping – Tier A Municipalities shall divide the municipality into two (2) sectors for the purposes of outfall mapping. A diagram of the municipality showing the two (2) sectors shall be part of the Tier A Municipality's SPPP. Tier A Municipalities shall map the location of the end

of small MS4 outfall pipes in one sector 36 months from the EDPA; and map the location of the end of all small MS4 outfall pipes on or before 60 months from the EDPA.

ii. Ordinance Prohibiting Illicit Connections - Within 18 months from the EDPA, Tier A Municipalities shall effectively prohibit through ordinance, illicit connections to the Tier A Municipality's small MS4, and implement appropriate enforcement procedures and actions.

iii. Illicit Connection Elimination Program - Within 18 months from the effective date of permit authorization, Tier A Municipalities shall have developed and begun implementing a program to detect and eliminate illicit connections into the Tier A Municipality's small MS4. Tier A Municipalities shall perform an initial physical inspection of all outfall pipes using the Department's Illicit Connection Inspection Report form within 60 months from the EDPA.

7. Solids and Floatable Controls

a. Monthly Sweeping of Certain Streets in Predominantly Commercial Areas

i. Minimum Standard - Tier A Municipalities shall sweep, at a minimum of once per month (weather and street surface conditions permitting) all streets (including roads or highways) that meet all of the following criteria:
- the street is owned or operated by the municipality;
- the street is curbed and has storm drains;
- the street has a posted speed limit of 35 mph or less;
- the street is not an entrance or exit ramp; and
- the street is in a predominantly commercial area.

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the Street Sweeping minimum standard. Tier A Municipalities must maintain records including the date and areas swept, number of miles of streets swept and the total amount of materials collected. Information shall be reported to the Department in the annual report and certification.

iii. Implementation - Beginning 12 months after the effective date of permit authorization Tier A Municipalities shall have developed and begun implementing a street sweeping program that meets the minimum standard above.

b. Storm Drain Inlets

i. Minimum Standard - Retrofitting of existing storm drain inlets to meet the standard contained in Attachment C of the permit is required where such inlets are in direct contact with repaving, repairing (excluding repair of individual potholes), reconstruction or alterations of facilities owned or operated by the Tier A Municipality. For exemptions to this standard, refer to "Exemptions" in Attachment C.

ii. Measurable Goal – Tier A Municipalities shall certify annually that such storm drain inlets have been retrofitted to meet the minimum standard contained in Attachment C, unless otherwise exempted.

iii. Implementation - Within 12 months of effective date of permit authorization and thereafter, Tier A Municipalities shall retrofit all such storm drain inlets in accordance with the Storm Drainage Inlets minimum standard.

c. Stormwater Facility Maintenance

i. Minimum Standard - Tier A Municipalities shall develop and implement a stormwater facility maintenance program for cleaning and maintenance of all stormwater facilities operated by the Tier A Municipality. Stormwater facilities include, but are not limited to: catch basins, detention basins, filter strips, riparian buffers, infiltration trenches, sand filters, constructed wetlands, wet basins, bioretention systems, low flow bypasses, and stormwater conveyances. The stormwater facility maintenance must be performed as required to ensure the proper function and operation of the stormwater facility. Tier A Municipalities shall also clean all catch basins annually to remove accumulated sediment, trash and debris.

ii. Measurable Goal - Tier A Municipalities shall certify annually that all stormwater facilities are properly functioning and that all catch basins have been cleaned in accordance with the minimum standard. If stormwater facilities were found not to be functioning properly and repairs were not made, a schedule for such repairs shall be included in the annual report and certification. Tier A Municipalities shall also maintain records of inspections, maintenance and repairs that were performed which shall be reported in the annual report and certification.

iii. Implementation - Within 12 months from the effective date of permit authorization, Tier A Municipalities shall have developed and begun implementing a stormwater facility maintenance program in accordance with the minimum standard.

d. Road Erosion Control Maintenance

i. Minimum Standard - Tier A Municipalities shall develop a roadside erosion control maintenance program to identify and repair erosion along streets (including roads or highways) operated by the municipality. Tier A Municipalities are also required to regularly inspect and maintain the stability of shoulders, embankments, ditches and soils along these streets to ensure that they are not eroding and contributing to sedimentation of receiving waters. Repairs shall be made in accordance with the Standards for Soil Erosion and Sediment Control in New Jersey (N.J.A.C. 2:90-1).

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have developed and are implementing a Roadside Erosion Control Maintenance program. The certification shall also indicate the locations of all problem areas corrected and any maintenance done during that year. The dates of all inspections and employee training sessions shall also be reported in the annual report and certification.

iii. Implementation - Within 18 months from the effective date of permit authorization, Tier A Municipalities shall have developed and begun

implementing a roadside erosion control maintenance program in accordance with the minimum standard.

e. Outfall Pipe Stream Scouring Remediation

i. Minimum Standard - Tier A Municipalities shall develop and implement a stormwater outfall pipe scouring detection, remediation and maintenance program to detect and control localized stream and stream bank scouring in the vicinity of outfall pipes operated by the municipality. This program shall identify all areas where localized stream and bank scouring occurs as a result of stormwater discharges from the Tier A Municipality's MS4. These areas shall then be prioritized and repairs shall be scheduled and completed. Repairs shall be made in accordance with the Standards for Soil Erosion and Sediment Control in New Jersey at N.J.A.C. 2:90-1 (e.g., Conduit Outlet Protection 12-1).

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the Outfall Pipe Stream Scouring Remediation minimum standard. In addition, the Tier A Municipality shall list the location of outfall scouring identified, the dates control measures are to begin, and the dates any control measures were completed.

iii. Implementation - Within 18 months of the effective date of permit authorization, Tier A Municipalities shall have developed and begun implementing an outfall pipe stream scouring detection, remediation and maintenance program. This program shall identify and prioritize all stormwater outfall pipes needing repairs, and then schedule and complete the repairs.

8. Maintenance Yard Operations (including maintenance activities at Ancillary Operations)

a. De-icing Material Storage

i. Minimum Standard - Tier A Municipalities must construct a permanent structure (a permanent building or permanent structure that is anchored to a permanent foundation with an impermeable floor, and that is completely roofed and walled) for the storage of salt, and other de-icing materials. Once completed, Tier A Municipalities shall perform regular maintenance and inspections of the permanent structure. Seasonal tarping shall be used as an interim BMP until the permanent structure is completed. Sand may be stored outside and uncovered if a 50-foot setback is maintained from storm sewer inlets, ditches or other stormwater conveyance channels, and surface water bodies.

ii. Measurable Goal - Tier A Municipalities shall certify annually that they have met the De-icing Material Storage minimum standard.

iii. Implementation - Within 12 months from the effective date of permit authorization, Tier A Municipalities shall implement the interim seasonal tarping BMP. Within 12 months of the effective date of permit authorization, Tier A Municipalities will comply with the 50-foot buffer requirement for the outside storage of sand. Within 36 months from the effective date of permit authorization Tier A Municipalities shall store all salt and de-icing materials in a permanent structure.

b. Fueling Operations

i. Minimum Standard - Tier A Municipalities must develop and implement standard operating procedures for vehicle fueling, and receiving of bulk fuel deliveries at maintenance yard operations. The standard operating procedures shall incorporate the required practices listed in Attachment D.

ii. Measurable Goal - Tier A Municipalities must certify annually that there is a vehicle fueling and bulk receiving standard operating procedures in place.

iii. Implementation - Within 12 months of the effective date of permit authorization, Tier A Municipalities shall have developed and begun implementing the required standard operating procedures for fueling operations.

c. Vehicle Maintenance

i. Minimum Standard - Tier A Municipalities shall develop and implement a standard operating procedure (SOP) for vehicle maintenance and repair activities that occur at municipal maintenance yard operations. The SOP shall include the required practices listed in Attachment D. The SOP shall include regular inspections of all maintenance areas and activities.

ii. Measurable Goal - Tier A Municipalities must certify annually that there is a vehicle maintenance standard operating procedure in place and that regular inspections and maintenance are being performed.

iii. Implementation - Within 12 months of the effective date of permit authorization, Tier A Municipalities shall have developed and begun implementing the required standard operating procedures for Vehicle Maintenance.

d. Good Housekeeping Practices

i. Minimum Standard - Tier A Municipalities must implement good housekeeping procedures for all materials or machinery listed in the Inventory Requirements for Municipal Maintenance Yard Operations prepared in accordance with Attachment D. These good housekeeping procedures include, but not limited to, the required practices listed in Attachment D at all municipal maintenance yard operations (including maintenance operations at ancillary operations).

ii. Measurable Goal - Tier A Municipalities must certify annually that they have met the Good Housekeeping Practices minimum standard.

iii. Implementation - Within 12 months of the effective date of permit authorization, Tier A Municipalities shall have developed and begun implementing the required standard operating procedures for Good Housekeeping.

e. Equipment and Vehicle Washing

i. Minimum Standard - Tier A Municipalities must eliminate the unpermitted discharge of equipment and vehicle wash wastewater to the waters of the State from municipal maintenance yard operations by either installing a vehicle wash reclaim system, capturing and hauling the wastewater for proper

disposal, connecting to sanitary sewer (where applicable and approved by local authorities), ceasing the activity and/or applying for and obtaining a separate NJPDES permit.

ii. Measurable Goal - After implementation, Tier A Municipalities must certify annually that there is no unpermitted discharge from vehicle and equipment washing activities at their municipal maintenance yard operations and describe the BMP option implemented at each of the locations where vehicle and equipment washing activities occur.

iii. Implementation – This permit authorizes existing discharges of equipment and vehicle wash water from municipal maintenance yard operations until February 28, 2009. On or before February 28, 2009 Tier A Municipalities shall have a BMP option implemented and shall have no unpermitted discharge of equipment and vehicle wash wastewater to the waters of the State.

9. Employee Training

a. Minimum Standard - Tier A Municipalities shall develop and conduct an annual employee training program for appropriate employees on appropriate topics. At a minimum, annual employee training will include the following topics:

i. Waste Disposal Education –Training shall include how to respond to inquires regarding proper waste disposal.

ii. Municipal Ordinances – Training shall include an overview of the Pet Waste Ordinance, Litter Ordinance, Illicit Connection Ordinance and Improper Waste Disposal Ordinance, Wildlife Feeding Ordinance, and Yard Waste Ordinance (if applicable), their requirements, enforcement policy, and hazards associated with improper waste disposal.

iii. Yard Waste Collection Program (if applicable) – Training shall include frequency of yard waste pickups and schedule, policy for when yard waste can be placed curbside, and alternatives such as composting and recycling.

iv. Illicit Connection Elimination and Outfall Pipe Mapping – Training shall include information regarding the hazards associated with illicit connections and details of the program including investigation techniques, physical observations, field sampling, and mapping procedures.

v. Monthly Sweeping of Certain Streets in Predominantly Commercial Areas – Training shall include sweeping schedules and record keeping requirements.

vi. Stormwater Facility Maintenance - Training shall include catch basin cleaning schedules and record keeping requirements.

vii. Road Erosion Control and Outfall Pipe Stream Scouring Remediation – Training shall include identifying road erosion and outfall pipe scouring and repairs.

viii. Maintenance Yard Operations (including Ancillary Operations) – Training shall include de-icing material storage, fueling, vehicle maintenance, equipment/vehicle washing and good housekeeping SOPs.

ix. Construction Activity / Post-Construction Stormwater Management in New Development and Redevelopment – Training shall include information regarding the requirement to obtain a NJPDES construction activity stormwater permit (see Part I, Section A.5.a and A.5.b of this permit) and requirements for Post-Construction Stormwater Management in New Development and Redevelopment (See Part I, Section F.3 of this permit) for the permittee's own construction activities and projects that disturb one acre or more.

b. Measurable Goal - Tier A Municipalities must certify annually the date of the annual employee training.

c. Implementation – Training shall begin 12 months from the effective date of permit authorization.

10. Construction Site Stormwater Runoff Control

a. Pursuant to N.J.A.C. 7:14A-25.6(b)2 and 25.7(b), the Department is responsible for developing, implementing, and enforcing a NJPDES permit program to reduce pollutants in stormwater runoff to small MS4s from construction activities. The Tier A Municipality is not required to include this SBR in its stormwater program or discuss this SBR in its SPPP.

G. Additional Measures and Optional Measures

1. Additional Measures

a. Additional Measures (AMs) are non-numeric or numeric effluent limitations that are expressly required to be included in the stormwater program by an adopted areawide or Statewide Water Quality Management Plan (WQM plan). AMs may modify or be in addition to SBRs. AMs may be required by a TMDL approved or established by USEPA, a regional stormwater management plan, or other elements of adopted areawide or Statewide WQM plans.

b. The Department will provide written notice of the adoption of an AM to each Tier A Municipality whose stormwater program will be affected, and will list each adopted AM in the permit by making a minor modification to the permit. The AMs, other than numeric effluent limitations, will specify the BMPs that must be implemented and the measurable goals for each BMP. The AMs will also specify time periods for implementation.

2. Optional Measures

a. At the Tier A Municipality's discretion, the stormwater program may also include Optional Measures (OMs), which are BMPs that are not implemented for SBRs or AMs but that prevent or reduce the pollution of the waters of the State.

H. Deadlines and Certifications

1. Stormwater Pollution Prevention Plan

a. Within twelve (12) months from the effective date of permit authorization, the Tier A Municipality shall prepare an SPPP.

b. The SPPP shall include, at a minimum, all of the information and items identified in Attachment A. The SPPP shall be signed, dated and retained by the Tier A Municipality.

2. Statewide Basic Requirements

a. Each SBR contained in Part I, Section F of the permit has a specific implementation schedule based on the effective date of permit authorization. Each SBR shall be implemented in accordance with that schedule. Tier A Municipalities shall certify in the Annual Report and Certification the status of the implementation of each SBR and the date implementation was completed, as appropriate.

i. The Department may grant a six-month extension to the deadlines contained in an implementation schedule for any of the SBRs if the Tier A Municipality submits a written request for such extension, at least 30 days prior to the deadline, establishing to the Department's satisfaction that the Federal, State and local permits and approvals necessary for the construction of best management practices could not with due diligence be obtained within the time period set forth in Section F above. The written request shall be submitted to:

NJDEP
Division of Water Quality
Bureau of Nonpoint Pollution Control
Municipal Stormwater Regulation Program
P.O. Box 029
Trenton, NJ 08625-0029

3. Annual Report and Certification

a. Tier A Municipalities shall complete an Annual Report (on a form provided by the Department) summarizing the status of compliance with this permit including measurable goals and the status of the implementation of each SBR contained in Part I, Section F of the permit. This report shall include a certification that the municipality is in compliance with its stormwater program, SPPP and this permit, except for any incidents of noncompliance. Any incidents of noncompliance with permit conditions shall be identified in the Annual Report and Certification. A copy of each Annual Report and Certification shall be kept at a central location and shall be made available to the Department for inspection.

i. If there are incidents of noncompliance, the report shall identify the steps being taken to remedy the noncompliance and to prevent such incidents from recurring.

ii. The Annual Report and Certification shall be signed and dated by the Tier A Municipality, and shall be maintained for a period of at least five years. This period may be extended by written request of the Department at any time.

b. The Annual Report and Certification shall be submitted to the Department pursuant to the following submittal schedule:

i. Submit an Annual Report and Certification: on or before May 2, 2005 and every 12 months thereafter.

I. Standard Conditions

1. The following general conditions are incorporated by reference. The Tier A Municipality is required to comply with the regulations, which were in effect as of March 2, 2004.

a. General Permits N.J.A.C. 7:14A-6.13
b. Penalties for Violations N.J.A.C. 7:14-8.1 et seq.
c. Incorporation by Reference N.J.A.C. 7:14A-2.3
d. Toxic Pollutants N.J.A.C. 7:14A-6.2(a)4i
e. Duty to Comply N.J.A.C. 7:14A-6.2(a)1 & 4
f. Duty to Mitigate N.J.A.C. 7:14A-6.2(a)5 & 11
g. Inspection and Entry N.J.A.C. 7:14A-2.11(e)
h. Enforcement Action N.J.A.C. 7:14A-2.9
i. Duty to Reapply N.J.A.C. 7:14A-4.2(e)3
j. Signatory Requirements for Applications and Reports N.J.A.C. 7:14A-4.9
k. Effect of Permit/Other Laws N.J.A.C. 7:14A-6.2(a)6 & 7 & 2.9(c)
l. Severability N.J.A.C. 7:14A-2.2
m. Administrative Continuation of Permits N.J.A.C. 7:14A-2.8
n. Permit Actions N.J.A.C. 7:14A-2.7(c)
o. Reopener Clause N.J.A.C. 7:14A-6.2(a)10, 16.4(b) & 25.7(b)
p. Permit Duration and Renewal N.J.A.C. 7:14A-2.7(a) & (b)
q. Consolidation of Permit Process N.J.A.C. 7:14A-15.5
r. Confidentiality N.J.A.C. 7:14A-18.2 & 2.11(g)
s. Fee Schedule N.J.A.C. 7:14A-3.1
t. UIC Corrective Action N.J.A.C. 7:14A-8.4
u. Additional Conditions Applicable to UIC Permits N.J.A.C. 7:14A-8.9
v. UIC Operating Criteria N.J.A.C. 7:14A-8.16

2. Operation And Maintenance

a. Need to Halt or Reduce not a Defense N.J.A.C. 7:14A-2.9(b)
b. Proper Operation and Maintenance N.J.A.C. 7:14A-6.12

3. Monitoring And Records

a. Monitoring N.J.A.C. 7:14A-6.5
b. Recordkeeping N.J.A.C. 7:14A-6.6
c. Signatory Requirements for Monitoring Reports N.J.A.C. 7:14A-6.9

4. Reporting Requirements

a. Planned Changes N.J.A.C. 7:14A-6.7
b. Reporting of Monitoring Results N.J.A.C. 7:14A-6.8
c. Noncompliance Reporting N.J.A.C. 7:14A-6.10 & 6.8(h)
d. Hotline/Two Hour & Twenty-four Hour Reporting N.J.A.C. 7:14A-6.10(c) & (d)
e. Written Reporting N.J.A.C. 7:14A-6.10(e) &(f) & 6.8(h)
f. Duty to Provide Information N.J.A.C. 7:14A-2.11, 6.2(a)14 & 18.1

g. Compliance Schedules N.J.A.C. 7:14A-6.4
h. Transfer N.J.A.C. 7:14A-6.2(a)8 & 16.2

5. Copies of the NJPDES rules may be purchased by contacting West Group, St. Paul, Minnesota, 1-800-808-WEST.

J. Additional Conditions

1. Agency and Public Review

a. The Tier A Municipality shall make the SPPP available upon request to an authorized representative of the Department and to the owner of and operating entity for any municipal separate storm sewer system that receives discharges from the Tier A Municipality's small MS4.

b. Upon review by an authorized representative, the Department may notify the Tier A Municipality at any time that the SPPP does not meet one or more of the minimum requirements. Within 30 days after receiving such notification (unless otherwise specified by the Department), the SPPP shall be amended to adequately address all deficiencies, and written certification of such amendments shall be submitted to the Department.

c. Tier A Municipalities shall make records required by this permit, including its SPPP, available to the public at reasonable times during regular business hours (see N.J.A.C. 7:14A-18 for confidentiality provisions).

2. Other Laws

a. In accordance with N.J.A.C. 7:14A-6.2(a)7, this permit does not authorize any infringement of State or local law or regulations, including, but not limited to the Pinelands rules (N.J.A.C. 7:50), N.J.A.C. 7:1E (Department rules entitled "Discharges of Petroleum and other Hazardous Substances"), the New Jersey Register of Historic Places Rules (N.J.A.C. 7:4), and all other Department rules. No discharge of hazardous substances (as defined in N.J.A.C. 7:1E-1.6) resulting from an onsite spill shall be deemed to be "pursuant to and in compliance with [this] permit" within the meaning of the Spill Compensation and Control Act at N.J.S.A. 58:10-23.11c.

3. Operations and Maintenance Manual

a. In accordance with N.J.A.C. 7:14A-6.12(c), for a discharge authorized by this permit, the Tier A Municipality is exempt from the requirement to prepare an operations and maintenance manual.

Attachment A
CONTENTS OF THE STORMWATER POLLUTION PREVENTION PLAN

A. SPPP Team

1. The Stormwater Pollution Prevention Plan (SPPP) shall identify the person or persons responsible for implementing or coordinating the SPPP activities (including at the Tier A Municipality's discretion, OMs).

B. Description of Required Best Management Practices

1. The SPPP shall identify and discuss each Statewide Basic Requirement (SBR) and best management practice (BMP) required by the Tier A Municipal Stormwater General Permit.
2. The SPPP shall identify and discuss each Additional Measure (AM), if any, required by the Tier A Municipal Stormwater General Permit.
3. The SPPP shall identify and discuss any Optional Measures (OMs) the Tier A Municipality chooses to include in its stormwater program.
4. For each SBR, AM, or OM included in the Tier A Municipality's stormwater program, the SPPP shall:
    a. Describe the method of implementation;
    b. Include detailed record keeping, as appropriate or as required;
    c. Include an implementation schedule consistent with permit requirements, including interim milestones;
    d. Include any special diagrams required by the permit (i.e., Storm Drain Inlet Labeling and Illicit Connection Elimination and MS4 Outfall Pipe Mapping);
    e. Sharing responsibilities (If the Tier A Municipality wants to share responsibilities for implementing one or more control measures (other than OMs) with one or more other entities pursuant to N.J.A.C. 7:14A-25.7(a), the SPPP must describe which measure(s) the Tier A Municipality will implement, and identify the entity(ies) that will implement the other measure(s));
    f. Include maintenance schedules, as appropriate; and
    g. Include inspection schedules, as appropriate.

C. Identifying Areas Served by Combined Sewer

1. Tier A Municipalities that want to exclude any "combined sewer area" from the stormwater program must include a map showing the boundaries of the combined sewer area. A "combined sewer area" is an area that is excluded because all stormwater from that area (and operated by the municipality) is discharged to combined (or sanitary) sewer systems.

Attachment B
PROCEDURES FOR DETECTING, INVESTIGATING, AND ELIMINATING ILLICIT CONNECTIONS

Detection

An illicit connection for the purposes of this permit, is any physical or non-physical connection that discharges domestic sewage, non-contact cooling water, process wastewater, or other industrial waste (other than stormwater) to the Tier A Municipality's small MS4, unless that discharge is authorized under a NJPDES permit other than this Tier A Municipal Stormwater General Permit (non-physical connections may include, but are not limited to, leaks, flows, or overflows into the municipal separate storm sewer system). An illicit connection is also any category of non-stormwater discharges that a Tier A Municipality identifies as a source or significant contributor of pollutants pursuant to 40 C.F.R. 122.34(b)(3)(iii).

MS4 outfall pipes, for the most part, should not be discharging during substantial dry periods (72 hours after a rain event). Such flow is frequently referred to as "dry weather flow", which may be the result of an illicit connection. All dry weather flows are generally non-stormwater discharges, however not all dry weather flows are illicit connections. Some non-stormwater flows result from the improper disposal of waste (e.g., radiator flushing, engine degreasing, improper disposal of oil) and some may be the result of allowable discharges such as residential car washing, irrigation runoff, permitted (NJPDES) discharges and natural waters (e.g., spring water and groundwater infiltration). By using the Department's Illicit Connection Inspection Report form and making physical observations, a Tier A Municipality will compile information that will help determine if the dry weather flow is an illicit connection and the most likely source of the illicit connection. After making these physical observations, additional chemical field testing will enable a Tier A Municipality to further narrow the potential source(s) of the illicit connection.

The first physical observation is to observe if there is a dry weather flow. Some dry weather discharges are continuously flowing and some are intermittent. Observations will allow the Tier A Municipality to establish with reasonable certainty if there is an intermittent flow. If there are indications of intermittent flows (staining, odors, deterioration of outfall structure) follow-up investigations are required (see Investigation section). An estimate of the flow rate of the discharge shall also be noted (flow rate can be estimated by various methods, including timing how long it takes to fill a container of a known size). Additional physical observations and measurements shall be made for odor, color, turbidity, floatable matter, temperature, deposits and stains, vegetation and algal growth and condition of outfall structure (see Illicit Connection Inspection Report form). Information compiled from physical observations and field monitoring should be used to help identify potential sources. These observations are very important since they are the simplest method of identifying grossly contaminated dry weather flows. If physical observations alone are sufficient to warrant further investigation, then field testing is not required.

If a dry weather flow exists, and after making all physical observations (unless physical observations are enough to warrant further investigation), the Tier Municipality shall field test for surfactants (detergents). If these flows contain surfactants in excess of the detection limit, Tier A Municipalities shall field test for ammonia (as N) and potassium to help distinguish sanitary wastewater sources from other non-stormwater flows that contain detergents. Non-stormwater discharges that are absent of surfactants shall be tested for fluoride to help distinguish potable from

non-potable sources. Municipalities should refer to the Tier A Stormwater General Permit Guidance Manual for assistance and interpretation of field testing results.

All of the tests for the tracing of illicit connections may be performed in the field by employees of the Tier A Municipality or may be contracted out. Lab certification for those parameters is **not** required, however all person(s) responsible for calibrating, maintaining, and taking field samples shall be trained in the use of the equipment and appropriate field testing protocol.

Investigation

Any storm sewer outfall pipe found during the initial inspection or on any subsequent inspection to have a non-stormwater discharge or indications of an intermittent non-stormwater discharge requires further investigation by the Tier A Municipality to identify and locate the specific source. Non-stormwater discharges suspected of being sanitary sewage and/or significantly contaminated shall be prioritized and investigated first. Investigations of non-stormwater discharges suspected of being cooling water, washwater, or natural flows may be delayed until after all suspected sanitary sewage and/or significantly contaminated discharges have been investigated, eliminated and/or resolved.

Dry weather flows believed to be an immediate threat to human health or the environment shall be reported immediately to the Department's Action Hotline at 1-877-WARNDEP (1-877-927-6337).

Physical observations and field testing can help narrow the identification of potential sources of a non-stormwater discharge. However it is unlikely that either will pinpoint the exact source. Therefore, Tier A Municipalities will need to perform investigations "upstream" to identify illicit connections to systems with identified problem outfalls.

All non-stormwater discharges, whether continuous or intermittent must be investigated by the Tier A Municipality. All investigations must be resolved. If the source is found to be a non-stormwater discharge authorized under Part I, Section A.2.c of the permit, no further action is required. If a non-stormwater discharge is found but no source is able to be located within six (6) months of beginning the investigation, then the Tier A Municipality shall submit to the Department a Closeout Investigation form to close out the investigation. The Tier A Municipality must document that a good faith effort was made to find the source of the dry weather discharge and document each phase of the investigation. If the observed discharge is intermittent the Tier A Municipality must document, in the Illicit Connection Inspection Report form, that a minimum three (3) separate investigations were made to observe the discharge when it is flowing. If these attempts are unsuccessful, the Tier A Municipality shall submit to the Department the Closeout Investigation form noted above. However, since this is an ongoing program, the Tier A municipality should periodically recheck these suspected intermittent discharges.

Elimination

Non-stormwater discharges traced to their source and found to be illicit connections subject to the ordinance prohibiting illicit connections shall be eliminated. At the time the illicit connection is detected the responsible party shall be cited for violation of the municipal ordinance prohibiting illicit connections and given thirty (30) days to cease the non-stormwater discharge. The responsible party may apply for a NJPDES permit for the discharge, but the discharge shall be

ceased until a valid NJPDES permit has been issued by the Department. Tier A Municipalities are required to verify that the illicit discharge was eliminated by the responsible party within the specified timeframe and ensure that measures taken to eliminate the discharge are permanent and are not done in such a manner that would allow easy reconnection to the MS4.

When a responsible party fails to eliminate the discharge, Tier A Municipalities shall take the necessary steps to enforce their ordinance, including court action. In such instances the Department shall be notified by written correspondence so it is aware of any pending action and is able to provide assistance if needed.

If an illicit connection cannot be located or is found to emanate from another public entity, Tier A Municipalities must submit to the Department a written explanation detailing the results of the investigation and notify that public entity.

Attachment C
DESIGN STANDARD - STORM DRAIN INLETS

This standard applies to storm drain inlets installed as part of new development and redevelopment projects (public or private) that disturb one acre or more. In addition, retrofitting of existing storm drain inlets to this standard is required where such inlets are in direct contact with repaving, repairing (excluding repair of individual potholes), reconstruction or alterations of facilities owned or operated by the Tier A Municipality. For exemptions to this standard see "Exemptions" below.

Grates in Pavement or Other Ground Surfaces

Design engineers shall use either of the following grates whenever they use a grate in pavement or another ground surface to collect stormwater from that surface into a storm drain or surface water body under that grate:

1. The New Jersey Department of Transportation (NJDOT) bicycle safe grate, which is described in Chapter 2.4 of the NJDOT Bicycle Compatible Roadways and Bikeways Planning and Design Guidelines (April 1996).

2. A different grate, if each individual clear space in that grate has an area of no more than seven (7.0) square inches, or is no greater than 0.5 inches across the smallest dimension.

   (In regard to whether the different grate must also be bicycle safe, the Residential Site Improvement Standards include requirements for bicycle-safe grates.)

Examples of grates subject to this standard include grates in grate inlets, the grate portion (non-curb-opening portion) of combination inlets, grates on storm sewer manholes, ditch grates, trench grates, and grates of spacer bars in slotted drains. Examples of ground surfaces include surfaces of roads (including bridges), driveways, parking areas, bikeways, plazas, sidewalks, lawns, fields, open channels, and stormwater basin floors.

Curb-Opening Inlets (Including Curb-Opening Inlets in Combination Inlets)

Whenever design engineers use a curb-opening inlet, the clear space in that curb opening (or each individual clear space, if the curb opening has two or more clear spaces) shall have an area of no more than seven (7.0) square inches, or be no greater than two (2.0) inches across the smallest dimension.

Exemptions

Retrofitting Exemptions

1. Repaving, repairing, reconstruction or alterations projects that began construction prior to March 3, 2004, and projects that were awarded bid prior to March 3, 2004, are exempted from the storm drain inlet design standard.

2. Existing curb-opening inlets do not need to be retrofitted to meet the design standard if each individual clear space in the curb opening has an area of no more than nine (9.0) square inches.

Hydraulic Performance Exemptions

1. New Development and Redevelopment Projects - Where the review agency determines that this standard would cause inadequate hydraulic performance that could not practicably be overcome by using additional or larger storm drain inlets that meet these standards.

2. Retrofitting of existing storm drain inlets - Where the review agency determines that this standard would cause inadequate hydraulic performance.

Alternative Device Exemptions

1. Where flows from the water quality design storm as specified in N.J.A.C. 7:8 are conveyed through any device (e.g., end of pipe netting facility, manufactured treatment device, or a catch basin hood) that is designed, at a minimum, to prevent delivery of all solid and floatable materials that could not pass through one of the following:

    a. A rectangular space four and five-eighths inches long and one and one-half inches wide (this option does not apply for outfall netting facilities); or

    b. A bar screen having a bar spacing of 0.5 inches.

2. Where flows are conveyed through a trash rack that has parallel bars with one-inch (1") spacing between the bars, to the elevation of the water quality design storm as specified in N.J.A.C. 7:8.

Note - The preceding exemptions do not authorize any infringement of requirements in the Residential Site Improvement Standards for bicycle-safe grates in new residential development (N.J.A.C. 5:21-4.18(b)2 and 7.4(a)).

Historic Places Exemption

Where the Department determines, pursuant to the New Jersey Register of Historic Places Rules at N.J.A.C. 7:4-7.2(c), that action to meet this standard is an undertaking that constitutes an encroachment or will damage or destroy the New Jersey Register listed historic property.

Attachment D
REQUIRED PRACTICES FOR FUELING OPERATIONS, VEHICLE MAINTENANCE, AND GOOD HOUSEKEEPING SBRs

A. The following BMPs must be implemented at maintenance yards including maintenance activities at ancillary operations (for example, impound yards, solid waste transfer stations, mobile fueling), where applicable, operated by Tier A Municipalities:

1. Inventory Requirements for Municipal Maintenance Yard Operations (including Ancillary Operations)

a. Tier A Municipalities shall include for municipal maintenance yard operations an inventory that includes the following:

i. A list to be made part of the SPPP of general categories of all materials or machinery located at the municipal maintenance yard, which could be a source of pollutants in a stormwater discharge. The materials in question include, but are not limited to: raw materials; intermediate products; final products; waste materials; by-products; machinery and fuels; and lubricants, solvents, and detergents that are related to the municipal maintenance yard operations or ancillary operations. Materials or machinery that are not exposed to stormwater or that are not located at the municipal maintenance yard or related to its operations do not need to be included.

2. Fueling

a. No topping off vehicles, mobile fuel tanks, and storage tanks. Drip pans must be used under all hose and pipe connections and other leak-prone areas during bulk transfer of fuels.

b. Block storm sewer inlets, or contain tank trucks used for bulk transfer, with temporary berms or temporary absorbent booms during the transfer process. If temporary berms are being used instead of blocking the storm sewer inlets, all hose connection points associated with the transfer of fuel must be within the temporary berms during the loading/unloading of bulk fuels. A trained employee must always be present to supervise during bulk fuel transfer.

c. Clearly post, in a prominent area of the facility, instructions for safe operation of fueling equipment, and appropriate contact information for the person(s) responsible for spill response.

d. Any equipment, tanks, pumps, piping and fuel dispensing equipment found to be leaking or in disrepair must immediately be repaired or replaced.

3. Vehicle Maintenance

a. Perform all vehicle and equipment maintenance at an indoor location with a paved floor whenever possible. For projects that must be performed outdoors that last more than one day, portable tents or covers must be placed over the equipment being serviced when not being worked on, and drip pans must be used.

4. General Good Housekeeping

a. Properly mark or label all containers. Labels must be kept clean and visible. All containers must be kept in good condition and tightly closed when not in use. When practical, containers must be stored indoors. If indoor storage is not practical, containers may be stored outside as long as they are covered and placed on spill platforms. An area that is graded and/or bermed that prevents run-through of stormwater may be used in place of spill platforms. Outdoor storage locations must be regularly maintained.

b. Conduct cleanups of any spills or liquids or dry materials immediately after discovery. Clean all maintenance areas with dry cleaning methods only. Spills shall be cleaned up with a dry, absorbent material (i.e., kitty litter, sawdust, etc.) and the rest of the area is to be swept. Collected waste is to be disposed of properly. Clean-up materials, spill kits and drip pans must be kept near any liquid transfer areas, protected from rainfall.

5. Good Housekeeping Practices for Salt and De-icing Material Handling

a. The SPPP for De-icing Material Storage shall include the following required practices to ensure that Municipal Maintenance Yard Operations prevent or minimize the exposure of salt and de-icing materials to stormwater runoff from storage, loading and unloading areas and activities:

i. Prevent and/or minimize the spillage of salt and de-icing materials during loading and unloading activities.

ii. At the completion of loading and unloading activities, spilled salt and de-icing materials shall be removed using dry cleaning methods and either reused or properly discarded.

iii. Sweeping by hand or mechanical means of storage and loading/unloading areas shall be done on a regular basis. More frequent sweeping is required following loading/unloading activities. Sweeping shall also be conducted immediately following, as practicable, loading/unloading activities.

iv. Tracking of materials from storage and loading/unloading areas shall be minimized.

v. Minimize the distance salt and de-icing materials are transported during loading/unloading activities.

b. Interim Seasonal Tarping - All Tier A Municipalities must tarp all de-icing materials until a permanent structure is built. Interim storage measures must include, but are not limited to the following:

i. Tarping materials that are not actively being used.

ii. The storage of de-icing materials (salt and de-icing products) outside is limited to October 15th through April 30th. All salt and de-icing materials must be removed from the site prior to May 1st and may not be stored outside again until October 15th.

iii. The implementing of a regular inspection, sweeping and housekeeping program to ensure that the material is maintained and stored in a proper manner.

6. Inspections

a. Inspections of all Municipal Maintenance Yard Operations shall be conducted regularly.

b. Discharge of Stormwater from Secondary Containment

i. The discharge pipe/outfall from a secondary containment area must have a valve and the valve must remain closed at all times except as described below. A municipality may discharge stormwater that accumulated in the secondary containment area if a visual inspection is performed to ensure that the contents of aboveground storage tank have not come in contact with the stormwater to be discharged. Visual inspections are only effective when dealing with materials that can be observed, like petroleum. If the contents of the tank are not visible in stormwater, the municipality must rely on previous tank inspections to determine with some degree of certainty that the tank has not leaked. If the municipality cannot make a determination with reasonable certainty that the stormwater in the secondary containment area is uncontaminated by the contents of the tank, then the stormwater shall be hauled for proper disposal.

NJDEP Nonstructural Strategies Points System (NSPS)

Version: January 31, 2006

Note: Input Values in Yellow Cells Only

Project:

Date:

User:

Notes:

Step 1 - Provide Basic Major Development Site Information

A. Specify Total Area in Acres of Development Site Described in Steps 2 and 3 = **Acres**

B. Specify by Percent the Various Planning Areas Located within the Development Site:

State Plan Planning Area:	PA-1	PA-2	PA-3	PA-4	PA-4B	PA-5	Total % Area
Percent of Each Planning Area within Site:							

Note: See User's Guide for Equivalent Zones within Designated Centers and the NJ Meadowlands, Pinelands, and Highlands Districts

Step 2 - Describe Existing or Pre-Developed Site Conditions

A. Specify Existing Land Use/Land Cover Descriptions and Areas:

Site Segment	Land Use/Land Cover Description	Specify Land Use/Land Cover in Acres for Each HSG: HSG A	HSG B	HSG C	HSG D	Use/Cover Subtotals	Points
1	Wetlands and Undisturbed Stream Buffers					0.0	0
2	Lawn and Open Space					0.0	0
3	Brush and Shrub					0.0	0
4	Meadow, Pasture, Grassland, or Range					0.0	0
5	Row Crop					0.0	0
6	Small Grain and Legumes					0.0	0
7	Woods - Indigenous					0.0	0
8	Woods - Planted					0.0	0
9	Woods and Grass Combination					0.0	0
10	Ponds, Lakes, and Other Open Water					0.0	0
11	Gravel and Dirt					0.0	0
12	Porous and Permeable Paving					0.0	0
13	Directly Connected Impervious					0.0	0
14	Unconnected Impervious with Small D/S Pervious					0.0	0
15	Unconnected Impervious with Large D/S Pervious					0.0	0
	HSG Subtotals (Acres):	0.0	0.0	0.0	0.0	**Total Area:**	0.0
	HSG Subtotals (%):	0.0%	0.0%	0.0%	0.0%	**Total % Area:**	0.0%

Points Subtotal: **0**

Total Existing Site Points: **0**

Step 3 - Describe Proposed or Post-Developed Site Conditions

A. Specify Proposed Land Use/Land Cover Descriptions and Areas:

Site Segment	Land Use/Land Cover Description	Specify Land Use/Land Cover in Acres for Each HSG				Use/Cover Subtotals	Points
		HSG A	HSG B	HSG C	HSG D		
1	Wetlands and Undisturbed Stream Buffers					0.0	0
2	Lawn and Open Space					0.0	0
3	Brush and Shrub					0.0	0
4	Meadow, Pasture, Grassland, or Range					0.0	0
5	Row Crop					0.0	0
6	Small Grain and Legumes					0.0	0
7	Woods - Indigenous					0.0	0
8	Woods - Planted					0.0	0
9	Woods and Grass Combination					0.0	0
10	Ponds, Lakes, and Other Open Water					0.0	0
11	Gravel and Dirt					0.0	0
12	Porous and Permeable Paving					0.0	0
13	Directly Connected Impervious					0.0	0
14	Unconnected Impervious with Small D/S Pervious					0.0	0
15	Unconnected Impervious with Large D/S Pervious					0.0	0
	HSG Subtotals (Acres):	0.0	0.0	0.0	0.0	**Total Area:**	0.0
	HSG Subtotals (%):	0.0%	0.0%	0.0%	0.0%	**Total % Area:**	0.0%
						Points Subtotal:	**0**

B. Compare Proposed Impervious Coverage with Maximum Allowable Impervious Coverage:

Total Directly Connected Impervious Coverage =	0%	% of Site
Total Unconnected Impervious Coverage with Small D/S Pervious =	0%	% of Site
Total Unconnected Impervious Coverage with Large D/S Pervious =	0%	% of Site
Total Site Impervious Coverage =	0%	% of Site
Effective Site Impervious Coverage =	0%	% of Site
Specify Source of Maximum Allowable Impervious Coverage:	None	(None or Table)

Points Subtotal: 0

C. Compare Proposed Site Disturbance with Maximum Allowable Site Disturbance:

Total Proposed Site Disturbance =		% of Site
Maximum Allowable Site Disturbance by Municipal Ordinance =		% of Site

Points Subtotal: 0

D. Describe Proposed Runoff Conveyance System:

Total Length of Runoff Conveyance System =		Feet
Length of Vegetated Runoff Conveyance System =		Feet
% of Total Runoff Conveyance System That is Vegetated =	0%	

Points Subtotal: 0

E. Residential Lot Clustering:

Percent of Total Site Area that will be Clustered =		% of Site
Minimum Standard Lot Size as Per Zoning (Note: 1/2 Acre or Greater) =		Acres
Maximum Proposed Cluster Lot Size (Note:1/4 Acre or Less) =		Acres
Percent of Clustered Portion of Site to be Preserved as Vegetated Open Space =		% of Clustered Site Portion

Points Subtotal: 0

F. Will the Following be Utilized to Minimize Soil Compaction?

Proposed Lawn Areas will be Graded with Lightweight Construction Equipment:	No	(Yes or No)
Percent of Proposed Lawn Areas to be Graded with Such Equipment:		% of Lawn Areas

Points Subtotal: 0

G. Are Any of the Following Stormwater Management Standards Met Using Only Nonstructural Strategies and Measures?

Groundwater Recharge Standards (NJAC 7:8-5.4-a-2):	No	(Yes or No)
Stormwater Runoff Quality Standards (NJAC 7:8-5.5):	No	(Yes or No)
Stormwater Runoff Quantity Standards (NJAC 7:8-5.4-a-3):	No	(Yes or No)

Points Subtotal: 0

Note: If the Answers to All Three Questions at G Above are "Yes", Adequate Nonstructural Measures have been Utilized.

Total Proposed Site Points: 0

Ratio of Proposed to Existing Site Points:

Required Site Points Ratio:

Nonstructural Point System Results:

New Jersey Nonstructural
Stormwater Management Strategies Point System (NSPS)

User's Guide

January 31, 2006

Introduction

The New Jersey Stormwater Management Rules at N.J.A.C. 7:8-5.2(a) require nonstructural stormwater management strategies to be incorporated into the site design of a major development. A total of nine strategies are to be used to the maximum extent practicable to meet the groundwater recharge, stormwater quality, and stormwater quantity requirements of the Rules prior to utilizing structural stormwater management measures. The New Jersey **N**onstructural Stormwater Management **S**trategies **P**oint **S**ystem (NSPS) described herein provides a tool to assist planners, designers, and regulators in determining that the strategies have been used to the "maximum extent practicable" at a major development as required by the Rules.

The nine mandatory nonstructural strategies contained in the Stormwater Management Rules are presented below:

1. Protect areas that provide water quality benefits or areas particularly susceptible to erosion;
2. Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces;
3. Maximize the protection of natural drainage features and vegetation;
4. Minimize the decrease in the "time of concentration" from pre-construction to post-construction. "Time of concentration" is defined as the time it takes for runoff to travel from the hydraulically most distant point of the drainage area to the point of interest within a watershed;
5. Minimize land disturbance including clearing and grading;
6. Minimize soil compaction;
7. Provide low-maintenance landscaping that encourages the retention and planting of native vegetation and minimizes the use of lawns, fertilizers and pesticides;
8. Provide vegetated open-channel conveyance systems discharging into and through stable vegetated areas; and
9. Provide other source controls to prevent or minimize the release of those pollutants into stormwater runoff. These source controls include, but are not limited to:

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i. Site design features that help to prevent accumulation of trash and debris in drainage systems;
ii. Site design features that help to prevent discharge of trash and debris from drainage systems;
iii. Site design features that help to prevent and/or contain spills or other harmful accumulations of pollutants at industrial or commercial developments; and
iv. When establishing vegetation after land disturbance, applying fertilizer in accordance with the requirements established under the Soil Erosion and Sediment Control Act, N.J.S.A. 4:24-39 et seq., and implementing rules.

These mandatory strategies are implemented through a variety of nonstructural stormwater management measures. When properly integrated into the site design, these nonstructural measures can be effective in reducing development-induced increases in runoff volumes, rates, pollutant loads, and concentrations. The New Jersey Stormwater Best Management Practices (BMP) Manual contains guidelines for the design of individual nonstructural measures.

Important Note: If the NSPS demonstrates that sufficient nonstructural stormwater management measures have been utilized at a major development, no further proof of compliance with the maximum extent practicable requirement shall be required. However, if the NSPS fails to demonstrate such compliance, such results shall not be used to disapprove any permit application sought by a proposed major development. Instead, the applicant for such permit will be required to demonstrate compliance through other and/or additional means. This includes the Low Impact Development (LID) Checklist contained in Appendix A of the New Jersey Stormwater Best Management Practices Manual, which includes a rigorous alternatives analysis for each measure. Finally, it should be noted that the NSPS is not presently intended for use on roadway construction, improvement, and other linear development projects. As a result, other means, including the LID Checklist, should be used for such projects.

NSPS Overview

The New Jersey NSPS is a Microsoft Excel-based computer spreadsheet program that can be used to demonstrate that sufficient nonstructural stormwater management measures have been incorporated into the design of a major land development project to the meet the maximum extent practicable requirement for nonstructural strategies in the Stormwater Management Rules. The NSPS assigns points based upon the existing and proposed conditions at the development site. A specific percentage of existing or pre-developed points must be achieved under proposed or post-developed conditions in order to demonstrate compliance through the NSPS. As described in detail below, the required percentage of existing points

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varies according to the size of project site and the State Planning Area in which it is located.

To use the NSPS, the user begins by providing basic information about the proposed major development project. Next, the user describes the project site under existing or pre-developed conditions. This is accomplished by specifying in tabular form the various land uses and/or covers for each type of soil present at the existing site. From the user's input data, the NSPS computes a nonstructural point total that reflects the site's existing or pre-development stormwater runoff condition. The computations are based upon the USDA Natural Resources Conservation Service (NRCS) Runoff Equation and on a variation of the NRCS Runoff Curve Number (CN). The NSPS then determines what percentage of this existing point total must be retained or achieved under proposed or post-developed conditions to demonstrate compliance with the nonstructural requirements of the Rules.

To complete the analysis, the user describes the project site under proposed or post-developed conditions. This includes the proposed land uses and/or covers that will exist following site construction in the same tabular format as the existing uses and covers were specified. In addition, the user provides information regarding any additional nonstructural stormwater management measures that will be used at the proposed development site. These include minimizing and disconnecting impervious surfaces, minimizing ground disturbance and soil compaction, utilizing vegetated runoff conveyance systems, and residential lot clustering. The user provides this information by responding to a series of program questions concerning critical aspects of each proposed measures. The NSPS then computes a nonstructural point total for proposed site conditions by combining the proposed land use/land cover points with those for the various additional nonstructural measures. The program then computes the actual ratio of proposed to existing nonstructural points and compares the result to the percentage of existing nonstructural points required for approval. Based upon this comparison, the NSPS reports whether the proposed nonstructural measures for the development site are adequate or that further effort is necessary to demonstrate compliance with the Stormwater Management Rules' nonstructural requirements.

It should be noted that all of the required input data described above is provided on a single worksheet in the NSPS titled "NSPS Computations", which is the first of seven worksheets in the overall program. Detailed instructions for entering program input data is presented below.

Entering NSPS Input Data

As noted above, all input data to the NSPS is entered on the NSPS Computations worksheet. At the top of the worksheet, the user can enter a project name, date, user name, and information about the project or NSPS run. This information is

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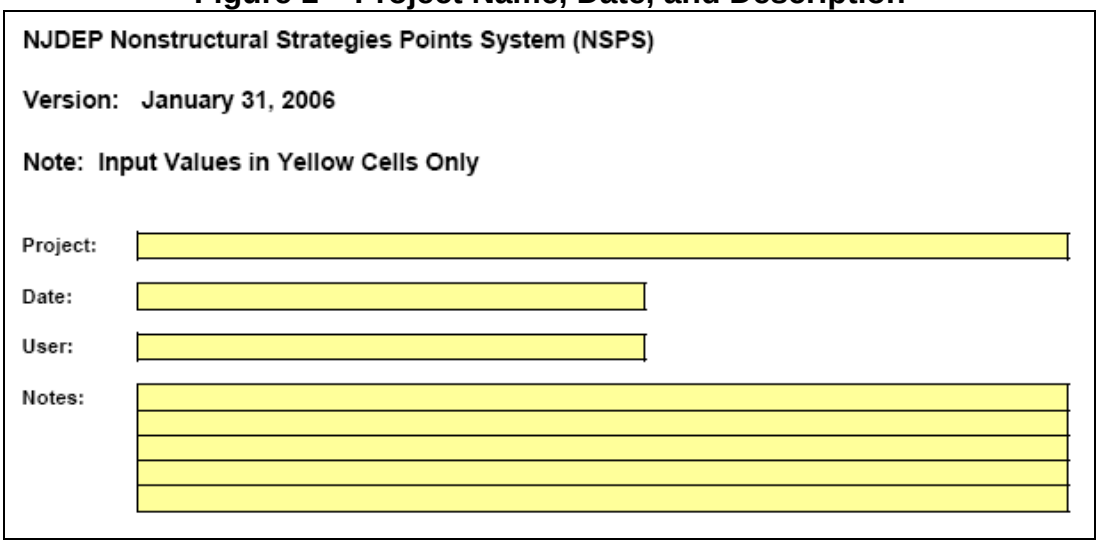
purely descriptive and is not included in any point computations. This portion of the NSPS Computations worksheet is shown in Figure 1 below. It should be noted that all NSPS input data can only be entered in cells shaded in yellow, while all NSPS results are presented in cells shaded in green.

Figure 1 – Project Name, Date, and Description

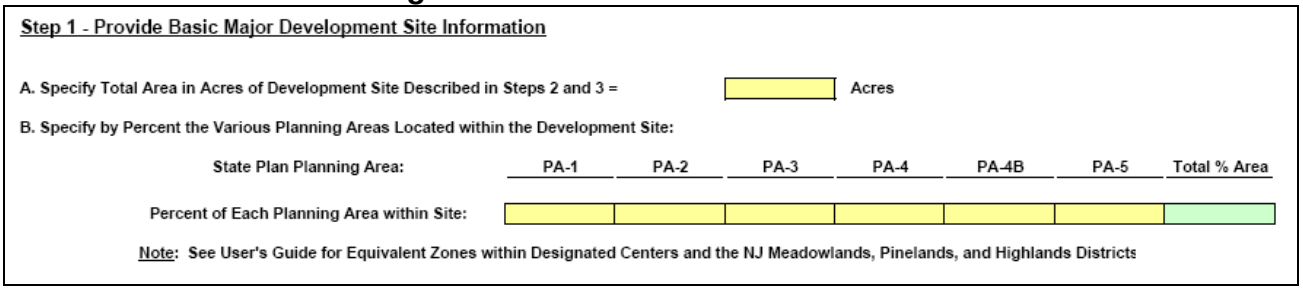


Step 1: Provide Basic Site Information

The Basic Site Information portion of the NSPS Computation worksheet is duplicated in Figure 2 below. Entering the required basic site information begins with the total area of the development site in acres (Cell E24). This area will be used at numerous locations throughout the NSPS and, therefore, should be the first input data entered. Failure to enter the total site area will prevent the computation of any existing or proposed nonstructural points.

Next, the user must designate the State Plan Planning Area(s) in which the site is located. Planning Area coverage is specified by the percentage of the total site area within each Planning Area (Cells C30 to H30). The sum of all input percentages for the Planning Areas must equal 100 percent. To help prevent errors, a warning message will appear if the total percentage does not equal 100 percent.

Figure 2 – Basic Site Information



Determination of the appropriate State Plan Planning Areas should be based upon the State Plan Policy Map from the March 1, 2002 New Jersey State Development and Redevelopment Plan. State Plan Planning Areas PA1, PA2, PA3, PA4, PA4B and PA5 are currently included in the NSPS. For sites within other planning or development areas, the following guidelines should be used to determine the equivalent NSPS planning area:

- If the site is located within a Designated Centers, use PA1 in the NSPS.
- If the site is located in PA5B, use PA5 in the NSPS.
- If the site is located in PA6, PA7, or PA8, use the largest of planning areas PA1 through PA5 located immediately adjacent to the site in the NSPS.
- If the site is located in a Highlands Preservation Area, use PA5 in the NSPS.
- If the site is located in a Highlands Planning Area, use the Planning Area in the State Development and Redevelopment Plan unless superseded by the Highlands Regional Master Plan.
- If the site is located in the New Jersey Meadowlands District, use PA1 in the NSPS.
- If the site is located in a New Jersey Pinelands Management Area, use the guidance in the table below:

Pinelands Management Area	NSPS Planning Area
Pinelands Towns, Pinelands Villages	PA1
Regional Growth Area	PA2
Rural Development Area	PA3
Agricultural Production Area and Forest Area	PA4
Special Agricultural Production Area and Agricultural Production Area	PA4B
Forest Area, Preservation Area and Special Agricultural Production Area	PA5

The March 1, 2002 New Jersey State Development and Redevelopment Plan is available through the Office of Smart Growth at the New Jersey Department of Community Affairs and at http://www.nj.gov/dca/osg/plan/. The Pinelands Comprehensive Management Plan is available through the New Jersey Pinelands Commission and at http://www.state.nj.us/pinelands/cmp/.

As noted above, the NSPS uses both the site's total area and State Plan Planning Area to compute the percentage of existing or pre-development nonstructural site points that must be achieved under proposed or post-development conditions in order to demonstrate compliance with the nonstructural requirements of the Stormwater Management Rules. In considering the site's area, the NSPS applies the

user-specified value to a sliding scale ranging from 0.1 to 10 acres. This value is combined with a value for the site's Planning Area based upon the percentages shown in Table 1 below. For site within multiple Planning Areas, the final value is based upon a weighted average of the various Planning Area percentages specified by the user.

Table 1 - Required Percentage of Existing Nonstructural Site Points

Site Area	PA-1	PA-2	PA-3	PA-4	PA-4B	PA-5
0.1 - 2 Acres	60% - 69%	75% - 84%	80% - 89%	84% - 93%	89% - 98%	95% - 104%
2 -10 Acres	69% - 80%	84% - 95%	89% - 100%	93% - 104%	98% - 109%	104% - 115%
>10 Acres	80%	95%	100%	104%	109%	115%

As shown in the Table, the required percentage of existing condition nonstructural site points for a given site increases as the site location changes from Planning Area 1 to Planning Area 5. For example, a 2-acre development site in Planning Area 1 must achieve 69 percent of its existing nonstructural points, while the same site in Planning Area 4 must achieve 84 percent of its existing nonstructural points. The required percentage also increases as the site area increases. A 15-acre development site in Planning Area 1 must achieve 80 percent of its existing nonstructural points, as opposed to a 2-acre site within the same Planning Area that must achieve 69 percent. Due to the sliding site area scale, the required percentage is interpolated within each Site Area and Planning Area category shown in Table 1 for site areas less than 10 acres. For example, the required percentage of existing nonstructural points for a 5-acre development site in Planning Area 1 is 73 percent, as opposed to 69 percent for a 2-acre site.

Step 2: Describe Existing or Pre-Developed Site Conditions

As described above, a development site's existing or pre-developed nonstructural points are based on the land use/land cover and soil data for existing site conditions provided by the user in Step 2. This portion of the NSPS Computations worksheet is shown below in Figure 3. The land use/land cover categories contained in the NSPS are shown below in Table 3. The site soil data in the NSPS is based upon the four NRCS Hydrologic Soil Groups A, B, C, and D. Also shown in Table 3 are the nonstructural points assigned to each combination of land use/land cover and Hydrologic Soil Group. It should be noted that these nonstructural points are also used for proposed or post-developed site conditions in Step 3.

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Figure 3 – Existing or Pre-Developed Site Conditions

Step 2 - Describe Existing or Pre-Developed Site Conditions

A. Specify Existing Land Use/Land Cover Descriptions and Areas:

Site Segment	Land Use/Land Cover Description	Specify Land Use/Land Cover in Acres for Each HSG: HSG A	HSG B	HSG C	HSG D	Use/Cover Subtotals	Points
1	Wetlands and Undisturbed Stream Buffers					0.0	0
2	Lawn and Open Space					0.0	0
3	Brush and Shrub					0.0	0
4	Meadow, Pasture, Grassland, or Range					0.0	0
5	Row Crop					0.0	0
6	Small Grain and Legumes					0.0	0
7	Woods - Indigenous					0.0	0
8	Woods - Planted					0.0	0
9	Woods and Grass Combination					0.0	0
10	Ponds, Lakes, and Other Open Water					0.0	0
11	Gravel and Dirt					0.0	0
12	Porous and Permeable Paving					0.0	0
13	Directly Connected Impervious					0.0	0
14	Unconnected Impervious with Small D/S Pervious					0.0	0
15	Unconnected Impervious with Large D/S Pervious					0.0	0
	HSG Subtotals (Acres):	0.0	0.0	0.0	0.0	**Total Area:**	0.0
	HSG Subtotals (%):	0.0%	0.0%	0.0%	0.0%	**Total % Area:**	0.0%
						Points Subtotal:	0

As noted above, the points shown in Table 3 are based upon a variation of the NRCS Runoff Curve Numbers (CNs) contained in Technical Release 55 – Urban Hydrology for Small Watersheds (TR-55). However, as shown in Table 3, it is important to note that six additional Land Use/Land Cover categories (and their associated points) have been included in the NSPS. These six additional categories are: Wetlands and Stream Buffers; Woods - Planted; Ponds, Lakes, and Other Open Waters; Porous and Permeable Paving; Unconnected Impervious with Small D/S Pervious, and Unconnected Impervious with Large Downstream Pervious. A description of each of these additional land use/land cover categories is presented below along with guidance on describing the surface areas of various structural stormwater BMPs.

Table 2 - Nonstructural Points for Land Use/Cover and Hydrologic Soil Group

Land Use/Cover Descriptions:	Land Use/Land Cover Points A	B	C	D
Wetlands and Undisturbed Stream Buffers	900.000	600.000	410.000	330.000
Lawn and Open Space	500.000	331.000	230.450	180.750
Brush and Shrub	550.000	364.100	253.495	198.825
Meadow, Pasture, Grassland, or Range	650.000	430.300	299.585	234.975
Row Crop	400.000	264.800	184.360	144.600
Small Grain and Legumes	450.000	297.900	207.405	162.675
Woods - Indigenous	700.000	463.400	322.630	253.050
Woods - Planted	650.000	430.300	299.585	234.975
Woods and Grass Combination	600.000	397.200	276.540	216.900
Ponds, Lakes, and Other Open Water	700.000	463.400	322.630	253.050
Gravel and Dirt	300.000	198.600	138.270	108.450
Porous and Permeable Paving	500.000	331.000	230.450	180.750
Directly Connected Impervious	0.000	0.000	0.000	0.000
Unconnected Impervious with Small D/S	150.000	99.300	69.135	54.225
Unconnected Impervious with Large D/S	400.000	264.800	184.360	144.600

Wetlands and Undisturbed Stream Buffers: This NSPS land use/land cover category should be used for 1) undisturbed portions of a Special Water Resource Protection Area (SWRPA) buffer; 2) wetland areas regulated under the Freshwater Wetlands Protection Act or the Wetlands Act of 1970; 3) contiguous undisturbed buffers within 75 feet of streams with a bed and bank or a contributory drainage area of 50 acres. Wetland areas include both natural and constructed wetlands but do not include transition areas. With regards to stream buffers, it is important to emphasize that this category should only be used for the undisturbed portions of those buffers described above. For disturbed portions of these buffers, an appropriate NSPS land use/land cover that best characterizes the disturbed land cover should be used. Similarly, when a disturbed buffer area is proposed to be restored, the appropriate NSPS land use/land cover for the restored area should be used.

Woods - Planted: This NSPS land use/land cover category should be used to describe an area of the development site that has been or will be planted with trees to create a woods. The planted woods category has somewhat lower nonstructural points than indigenous wood in recognition of the fact that, while a planted woods may be hydrologically beneficial, it typically is not as effective as a mature, indigenous woods.

Ponds, Lakes, and Other Open Waters: This NSPS land use/land cover category should be used for any areas of ponded water on the development site. This

includes both natural and man-made impoundments, including wet ponds and other structural BMPs with permanent pools.

Porous and Permeable Paving: This NSPS land use/land cover category should be used to describe any porous or permeable paving area that will include a subsurface stone bed with sufficient storage capacity to contain, at a minimum, the New Jersey Stormwater Quality Storm runoff from the paving. Details of such paving can be found in Chapter 9 of the New Jersey Stormwater Best Management Practices Manual.

Unconnected Impervious with Large Downstream Pervious: This NSPS land use/land cover category should be used to describe any impervious area that meets all of the requirements of an unconnected impervious area contained in Chapter 5 of the New Jersey Stormwater Best Management Practices Manual. This includes the requirement for a minimum downstream pervious sheet flow length of 25 feet.

Unconnected Impervious with Small Downstream Pervious: This NSPS land use/land cover category should be used to describe any impervious area that meets all of the requirements of an Unconnected Impervious Area with Large Downstream Pervious area but which only has a minimum downstream pervious flow length of 10 feet,

Structural Stormwater BMPs: The area occupied by a structural stormwater BMP should be described by the NSPS land use/land cover category that best characterizes the dominant cover in the BMP. For example, a dry detention basin with a grassed surface should be included in the Lawn and Open Space category, while sand filters and infiltration basins with sand bottoms should be included in the Gravel and Dirt category. Bioretention basins should be included in either the Brush and Shrub, Meadow and Pasture, or Woods – Planted category depending again on the dominant type of vegetation in the basin. As noted above, wet ponds should be included in the Ponds, Lakes, and Open Waters category and constructed wetlands should be included in the Wetlands and Undisturbed Buffers category.

Roofs with Drywells: The area occupied by roofs that discharge their runoff to drywells with sufficient capacity to contain, at a minimum, the roofs' groundwater recharge storm should be included in the Unconnected Impervious with Large Downstream Pervious category.

Vegetated Roofs: The area occupied by a building with vegetated roofs should be included in the Unconnected Impervious with Large Downstream Pervious category.

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Finally, it is important to note that the above land use/land cover characterizations have been made only for the purposes of the NSPS and should be not used in any direct rainfall-runoff computations,

Step 3: Describe Proposed or Post-Developed Site Conditions

As noted above, the total nonstructural points for a development site under proposed or post-developed conditions is a combination of the points earned by the site's proposed land use/land cover (Step 3A) and additional nonstructural stormwater management measures proposed for the development (Steps 3B to 3G). These additional measures in the NSPS represent nonstructural strategies that minimize site disturbance, minimize and/or disconnect impervious surfaces, minimize soil compaction, utilize vegetated stormwater conveyances, or cluster residential development.

Step 3A – Proposed Land Use/Land Cover Description: Characterization of the site's proposed land use/land cover and Hydrologic Soil Group data in Step 3A is performed in the same manner described above for existing or pre-developed site conditions in Step 2. This includes the guidance provided for the additional NSPS land use/land cover categories, structural stormwater BMPs, and roofs with drywells. The portion of the NSPS Computations worksheet for proposed land use/land cover and soil data in Step 3A is shown below in Figure 4.

Figure 4 – Proposed or Post-Developed Site Conditions

Step 3 - Describe Proposed or Post-Developed Site Conditions

A. Specify Proposed Land Use/Land Cover Descriptions and Areas:

Site Segment	Land Use/Land Cover Description	Specify Land Use/Land Cover in Acres for Each HSG: HSG A	HSG B	HSG C	HSG D	Use/Cover Subtotals	Points
1	Wetlands and Undisturbed Stream Buffers					0.0	0
2	Lawn and Open Space					0.0	0
3	Brush and Shrub					0.0	0
4	Meadow, Pasture, Grassland, or Range					0.0	0
5	Row Crop					0.0	0
6	Small Grain and Legumes					0.0	0
7	Woods - Indigenous					0.0	0
8	Woods - Planted					0.0	0
9	Woods and Grass Combination					0.0	0
10	Ponds, Lakes, and Other Open Water					0.0	0
11	Gravel and Dirt					0.0	0
12	Porous and Permeable Paving					0.0	0
13	Directly Connected Impervious					0.0	0
14	Unconnected Impervious with Small D/S Pervious					0.0	0
15	Unconnected Impervious with Large D/S Pervious					0.0	0
	HSG Subtotals (Acres):	0.0	0.0	0.0	0.0	Total Area:	0.0
	HSG Subtotals (%):	0.0%	0.0%	0.0%	0.0%	Total % Area:	0.0%

Step 3B – Compare Proposed and Maximum Impervious Coverages: Additional nonstructural points may be earned under proposed site conditions if the amount of proposed impervious surface at the development site is less than maximum allowable percentages on the Maximum Impervious Cover Table worksheet. This worksheet immediately follows the NSPS Computations worksheet in the NSPS. A copy of the Table, including the maximum allowable impervious cover for each NSPS land use/land cover category, is shown below in Figure 5.

To determine the maximum impervious site coverage for the proposed development site and the amount of additional nonstructural points (if any) earned due to the amount of proposed impervious site coverage specified in Step 3A, the user must select "Table" in Cell E110 on the NSPS Computations worksheet and then complete the table on the Maximum Impervious Cover Table worksheet. In doing so, the user must insure that the sum of the various Land Use Zone areas entered in the table must equal the total site area specified in Cell E24 of the NSPS Computations worksheet (and reproduced in Cell B7 on the Maximum Impervious Cover Table worksheet). Failure to do so will prevent to computation of a maximum impervious coverage in Cell D28 as well as produce a warning message at the bottom of the table. As a result, the entire development site must be characterized in the table. For actual site land use zones not listed in the table, the user should select a listed land use zone that has a maximum impervious cover similar to the actual zone.

Figure 5 – Maximum Impervious Cover Table

NJDEP Nonstructural Strategies Points System (NSPS)

Maximum Impervious Cover Table

Project:

Total Site Area: Acres Date:

Land Use Zone	Planning Areas PA-1 and PA-2		Planning Areas PA-3, PA-4, PA-4B, and PA-5	
	Maximum % Impervious	Zone Area (Acres)	Maximum % Impervious	Zone Area (Acres)
Single Family Residential:				
1/8 Acres or Less	65%		12%	
Greater than 1/8 to 1/4 Acre	38%		12%	
Greater than 1/4 to 1/3 Acre	30%		12%	
Greater than 1/3 to 1/2 Acre	25%		12%	
Greater than 1/2 to 1 Acre	20%		12%	
Greater than 1 to 2 Acres	12%		12%	
Greater than 2 Acres	10%		10%	
Commercial	85%		12%	
Business	85%		12%	
Industrial	72%		12%	
Institutional	72%		12%	
Multi-Family Residential	65%		12%	
Total Zone Areas (Acres) =		0.0		0.0
Maximum % Impervious =			0%	

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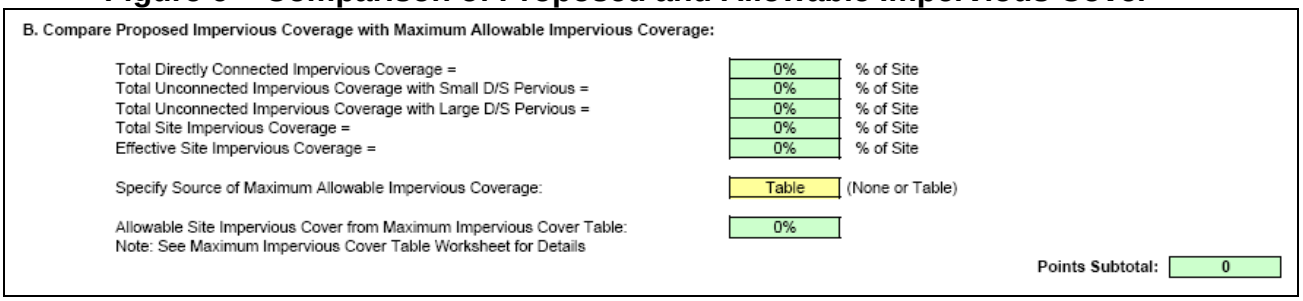
Upon completion of the above steps, the NSPS will determine whether the proposed site impervious cover specified in Step 3A is less than the maximum impervious cover computed in the Maximum Impervious Cover Table and, if so, will compute additional nonstructural points for the proposed site. These points will be displayed in Cell I114 on the NSPS Computations worksheet. A copy of this portion of the worksheet is shown below in Figure 6.

Figure 6 – Comparison of Proposed and Allowable Impervious Cover

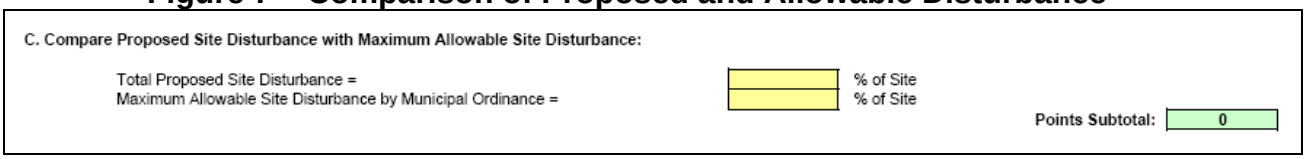


As noted above, the NSPS will automatically compute the actual proposed impervious cover at the development site. This computation will be based upon the Directly Connected Impervious, Unconnected Impervious with Large Downstream Pervious, and Unconnected Impervious with Small Downstream areas entered in the proposed land use/land cover and soil table in Step 3A. In addition, the NSPS will also compute an effective site impervious cover for the proposed site based upon a weighted average of these three impervious surfaces. The NSPS will then use this effective impervious cover in the computation of any nonstructural points.

Weighting factors for the Directly Connected Impervious, Unconnected Impervious with Large Downstream Pervious, and Unconnected Impervious with Small Downstream Pervious surfaces are 1.0, 0.5, and 0.85, respectively. As a result, it can be seen that increased use of unconnected impervious surface will result in a lower effective impervious cover for the development site and potentially greater nonstructural points. For example, one acre of Unconnected Impervious with Large Downstream Pervious will only count as one half acre of effective impervious surface.

Step 3C – Compare Proposed and Maximum Disturbances: Additional nonstructural points may be earned under proposed site conditions if the amount of proposed disturbance at the development site is less than maximum allowed by municipal ordinance. A copy of this portion of the NSPS Computations worksheet is shown below in Figure 7.

Figure 7 – Comparison of Proposed and Allowable Disturbance

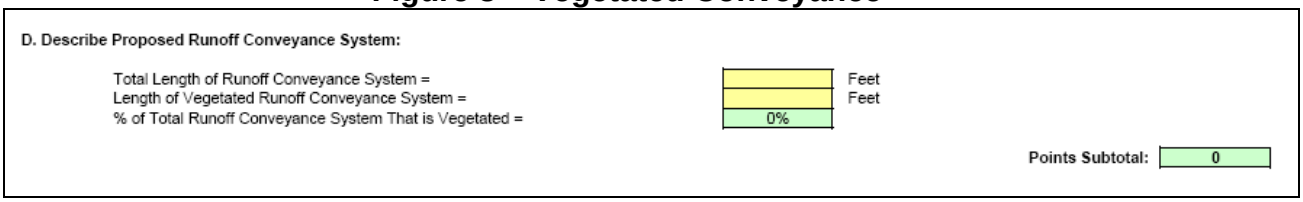


To complete Step 3C, as shown in Figure 7, the user must specify both the proposed (Cell E119) and maximum allowable (Cell E121) site disturbance at the development site. The maximum allowable site disturbance must be based upon an applicable ordinance of the municipality in which the project is located. As a result, additional nonstructural points can only be computed under this Step if such an ordinance and maximum site disturbance exists.

The proposed site disturbance is the sum of all areas that will be temporarily or permanently disturbed during the construction of the proposed site. This area is generally included within the development's proposed limit of disturbance line and should include all impervious surfaces, lawns, landscaped areas, and construction clearing, access, staging, and stockpile areas.

Step 3D – Vegetated Conveyance: Additional nonstructural points may be earned under proposed site conditions if vegetated conveyance measures such as swales and channels are used at the proposed development site. A copy of this portion of the NSPS Computations worksheet is shown below in Figure 8.

Figure 8 – Vegetated Conveyance



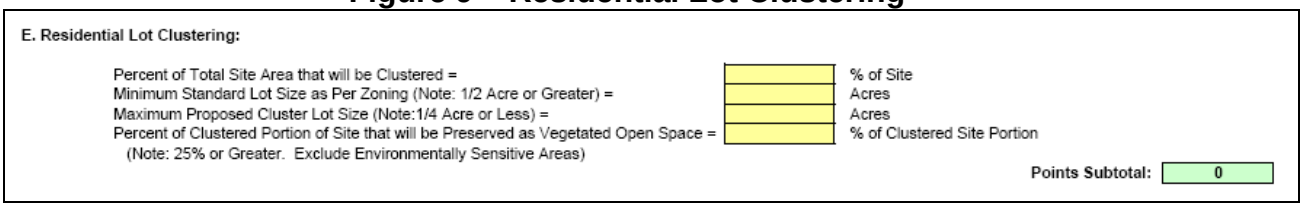
To complete Step 3D, as shown in Figure 8, the user must specify the total length of the development's proposed runoff conveyance system (Cell E127) as well the length of that portion that will be vegetated (Cell E128). In measuring both of these lengths, upstream system limits are to be established at those points where the drainage area to the system are comprised of at least one acre of pervious surface or 0.1 acre of impervious surface. For drainage areas that include both pervious and impervious surfaces, the following equation should be used to determine the minimum amount of each surface:

$$(\text{Impervious Area} * 10) + \text{Pervious Area} \geq 1.0 \text{ Acres}$$

Finally, it should be noted that swales created during normal site grading (such as those created along property lines between adjacent single family residential lots) should not be considered part of the development's proposed runoff conveyance system regardless of the size of the pervious or impervious area draining to them.

Step 3E – Residential Lot Clustering: Additional nonstructural points may be earned under proposed site conditions at residential developments if lot clustering is utilized. A copy of this portion of the NSPS Computations worksheet is shown below in Figure 9.

Figure 9 – Residential Lot Clustering



To complete Step 3E, as shown in Figure 9, the user must specify the following information:

1. The percent of the total site area that will be clustered (Cell E136).
2. Minimum standard residential lot size in clustered portion of site in acres (Cell E137).
3. Maximum proposed clustered lot size in acres (Cell E138)
4. Percent of clustered portion of site that will be preserved as open space (Cell E139).

In providing the above information, the following NSPS conditions must be met.

1. The minimum standard residential lot size as specified in the municipality's zoning ordinance must be ½ acre or greater.
2. The maximum proposed clustered lot size must be ¼ acre or smaller. This requirement is independent of any lot size requirements contained in the municipality's cluster ordinance.
3. The percentage of the clustered portion of the site that will be preserved as open space must be 25 percent or greater. This requirement is independent of any open space requirements contained in the municipality's cluster ordinance.
4. The preserved open space must be permanently vegetated and may not include any areas such as wetlands, transition areas, stream buffers, and floodways that are already protected from development.

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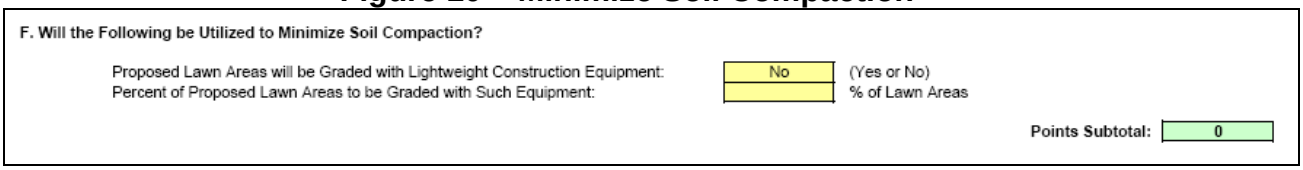
Step 3F – Soil Compaction: Additional nonstructural points may be earned under proposed site conditions if measures are taken during construction to minimize soil compaction that can increase runoff volumes and rates and adversely impact the growth of vegetation. A copy of this portion of the NSPS Computations worksheet is shown below in Figure 10.

Figure 10 – Minimize Soil Compaction



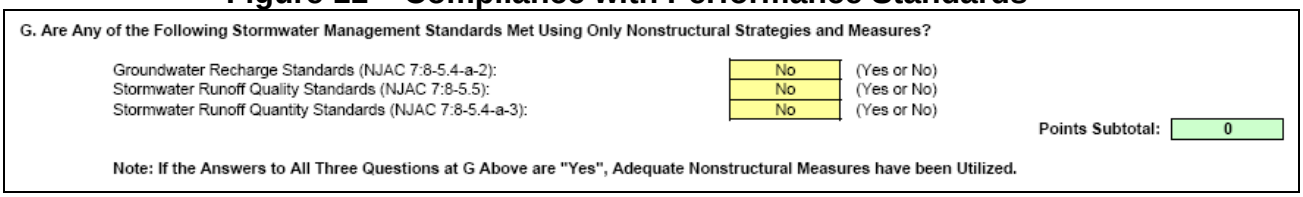
To complete Step 3F, the user must agree to use lightweight, low impact earth moving equipment for the final grading of proposed lawn areas (Cell E145). To qualify as lightweight and low impact, this equipment must exert a maximum pressure of eight pounds per square inch on the ground surface during grading operations. The percentage of the proposed lawn areas where such equipment will be utilized must also be specified (Cell E146).

In providing the above information, the following NSPS conditions must be met:

1. The approved plans must include appropriate notes and/or drawings specifying the lightweight grading equipment requirements and designating the limits of the proposed lawn areas on which it shall be used.
2. If during construction inspection it is found that equipment that exceeds the maximum eight pounds per square inch requirement has been used for backfilling or final grading of designated lawn areas, the applicant agrees to modify the affected lawn areas to a minimum of 18 inches below finished grade. Procedures to restoration of the permeability of the upper 18 inches of compacted soil shall be site-specific, and subject to the approval of the reviewing authority.

Step 3G – Compliance with Performance Standards: Additional nonstructural points may be earned under proposed site conditions if the performance standards for groundwater recharge, runoff quality, and/or runoff quantity in the Stormwater Management Rules are achieved entirely through nonstructural measures. A copy of this portion of the NSPS Computations worksheet is shown below in Figure 11.

Figure 11 – Compliance with Performance Standards



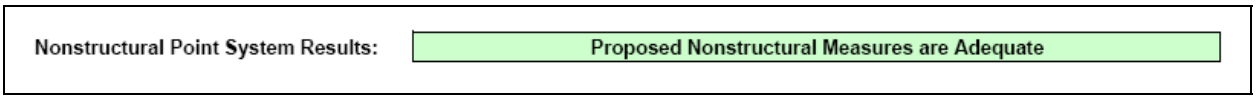
To complete Step 3G, the user must indicate which of the performance standards have been achieved entirely through nonstructural measures at the proposed development site. For each standard met in this way, the site will earn 1/3 of the proposed nonstructural points necessary to demonstrate compliance with nonstructural requirements of the Stormwater Management Rules. As such, meeting all three performance standards entirely through nonstructural measures will automatically demonstrate compliance with the nonstructural requirements of the Rules.

It should be noted that supporting computations and plans must accompany any claim of compliance indicated in Step 3G. In addition, the use of the NSPS is, of course, optional if compliance with all three performance standards through entirely nonstructural measures has in fact been achieved.

NSPS Results

As the user completes the required input for any of Steps 3A to 3G, the NSPS automatically updates the total nonstructural points for proposed site conditions and computes the ratio of this total to total existing nonstructural points computed in Step 2. The NSPS then compares this ratio to the required existing nonstructural points ratio also computed in Step 2 to determine if the proposed site meets the nonstructural requirement of the Stormwater Management Rules.

If the ratio of proposed to existing nonstructural points equals or exceeds the required ratio, the NSPS will provide the following result:



As described in the Introduction, achieving this result means that no additional demonstration of compliance with the nonstructural requirements of the Stormwater Management Rules is necessary.

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However, if the ratio of proposed to existing nonstructural points is less than the required ratio, the NSPS will provide the following result:

Nonstructural Point System Results:	Further Review of Proposed Nonstructural Measures is Necessary

As described in the Introduction, this result indicates that other and/or additional justification must be provided to demonstrate compliance with the nonstructural requirements of the Stormwater Management Rules. This includes the Low Impact Development (LID) Checklist contained in Appendix A of the New Jersey Stormwater Best Management Practices Manual. However, this result shall not be used to disapprove any permit application sought by a proposed major development.

Additional NSPS Worksheets

In addition to the NSPS Computations and Maximum Impervious Cover Table worksheets described above, the NSPS contains five additional worksheets.

The Site Comparison Table worksheet, shown below in Figure 12, provides the user with a summary of the existing and proposed areas and nonstructural points for each land use/land cover and soil category specified in the NSPS Computations worksheet. This summary allows the user to identify how the areas and nonstructural points of each existing land use/land cover changes under proposed conditions. In addition, the Site Comparison Table displays the difference between the total exiting and proposed nonstructural points as well as the target or required point difference necessary to achieve compliance. This information is intended to assist the user in selecting the most effective nonstructural strategies for the proposed development site.

Finally, the remaining four worksheets in the NSPS include:

1. The Data and Formulas worksheet, which contains the nonstructural points tables associated with each NSPS Planning Area and land use/land cover category as well as the equations and other input data necessary to compute the various NSPS results.
2. The Planning Area Points worksheet, which displays in tabular and graphical form the required percentage of existing nonstructural points for each NSPS Planning Area.
3. The Impervious and Disturbance Effects worksheets, which display in tabular and graphical form the relative effects of reducing proposed site impervious cover and disturbance, respectively, on a site's proposed nonstructural points.

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It is important to note that these five additional worksheets do not contain any user input cells. Therefore, the NSPS user should not attempt to input or alter any data or other information on these worksheets.

Figure 12 – Site Comparison Table

NJDEP Nonstructural Strategies Points System (NSPS)

Pre- and Post-Developed Site Comparison Table

Project:

Date: Total Site Area: Acres

Site Segment	Land Use/Land Cover Description	Existing Area (Acres)	Proposed Area (Acres)	Change (Acres)	Existing Points	Proposed Points	Change in Points
1	Wetlands and Undisturbed Stream Buffers	0.0	0.0	0.0	0	0	0
2	Lawn and Open Space	0.0	0.0	0.0	0	0	0
3	Brush and Shrub	0.0	0.0	0.0	0	0	0
4	Meadow, Pasture, Grassland, or Range	0.0	0.0	0.0	0	0	0
5	Row Crop	0.0	0.0	0.0	0	0	0
6	Small Grain and Legumes	0.0	0.0	0.0	0	0	0
7	Woods - Indigenous	0.0	0.0	0.0	0	0	0
8	Woods - Planted	0.0	0.0	0.0	0	0	0
9	Woods and Grass Combination	0.0	0.0	0.0	0	0	0
10	Ponds, Lakes, and Other Open Water	0.0	0.0	0.0	0	0	0
11	Gravel and Dirt	0.0	0.0	0.0	0	0	0
12	Porous and Permeable Paving	0.0	0.0	0.0	0	0	0
13	Directly Connected Impervious	0.0	0.0	0.0	0	0	0
14	Unconnected Impervious with Small D/S Pervious	0.0	0.0	0.0	0	0	0
15	Unconnected Impervious with Large D/S Pervious	0.0	0.0	0.0	0	0	0
				Total Points =	0	0	0

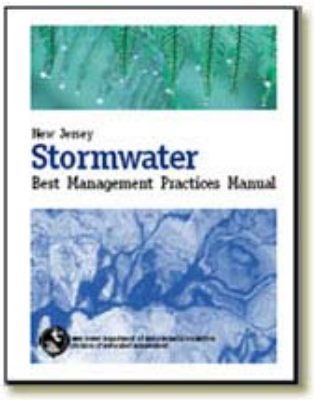
Additional Points for Other Nonstructural Measures = 0

Total Point Difference = 0

Target Point Difference = 0

Stormwater and Nonpoint Source Pollution
njstormwater.org

NJ Stormwater Best Management Practices Manual



The Stormwater Management rules, N.J.A.C. 7:8 specify stormwater management standards that are mandatory for new major development. The New Jersey Stormwater Best Management Practices Manual (BMP manual) is developed to provide guidance to address the standards in the proposed Stormwater Management Rules, N.J.A.C. 7:8. The BMP manual provides examples of ways to meet the standards contained in the rule. The methods referenced in the BMP manual are one way of achieving the standards. An applicant is welcome to demonstrate that other proposed management practices will also achieve the standards established in the rules. The BMP Manual is a developed by the New Jersey Department of Environmental Protection, in coordination with the New Jersey Department of Agriculture, the New Jersey Department of Community Affairs, the New Jersey Department of Transportation, municipal engineers, county engineers, consulting firms, contractors, and environmental organizations.

The BMP manual has been drafted to assist review agencies and the regulated community. The methods in the BMP manual can be utilized without need for additional documentation to address the performance standards in the rule. The Department anticipates providing guidance on additional best management practices and new information on already included practices as research and development occurs in this field.

Technical information regarding updates of the New Jersey Stormwater Best Management Practices Manual will be available at www.njstormwater.org.

Future versions of the New Jersey Stormwater Best Management Practices Manual will reflect the technical updates found on the website. Notices regarding future versions of the manual will be also be found at this www.njstormwater.org.

Future versions of the manual are expected to occur at most once a year.

If you have any question or comments on the content of this Manual, please e-mail your questions and comments to: swbmpmanual@dep.state.nj.us

BMP MANUAL - April 2004

- Cover and Contents: Includes the cover pages, Notes on Technical Updates, Acknowledgements, and Table of Contents.

SARB_006996

Chapter One: Impacts of Development on Runoff discusses the impact of development on the quality and quantity of stormwater runoff.

Chapter Two: Low Impact Development Techniques provides information how to use structural and nonstructural to provide lower impact development.

Chapter Three: Regional and Municipal Stormwater Management Plans presents guidance on the development of regional and municipal stormwater management plans.

Chapter Four: Stormwater Pollutant Removal Criteria provides guidance on how to meet the water quality performance standards.

Chapter Five: Computing Stormwater Runoff Rates and Volumes presents the mathematical methods for the stormwater runoff rates, volumes, and the stormwater quality and quantity design storms. This chapter provides information computations for unconnected impervious areas, and also contains an overview of various stormwater pollutant loading models.

Chapter Six: Groundwater Recharge discusses the groundwater recharge methodology, the groundwater recharge design storm, and the details of the New Jersey Groundwater Recharge Spreadsheet (NJGRS).

- Download the NJGRS in Excel 97 format
- Download the NJGRS in Excel 2002 format

Chapter Seven: Landscaping provides information on vegetation and landscaping for stormwater management measures.

Chapter Eight: Maintenance and Retrofit of Stormwater Management Measures provides information to be included and considered in a maintenance plan, and discusses retrofit of stormwater management facilities.

Chapter Nine: provides general information on Structural Stormwater Management Measures

- Chapter 9.1 Standard for Bioretention Systems
- Chapter 9.2 Standard for Constructed Stormwater Wetlands
- Chapter 9.3 Standard for Dry Wells
- Chapter 9.4 Standard for Extended Detention Basins
- Chapter 9.5 Standard for Infiltration Basins
- Chapter 9.6 Standard for Manufactured Treatment Devices
- Chapter 9.7 Standard for Pervious Paving Systems
- Chapter 9.8 Standard for Rooftop Vegetated Cover (reserved)
- Chapter 9.9 Standard for Sand Filters
- Chapter 9.10 Standard for Vegetative Filters

- Chapter 9.11 Standard for Wet Ponds

Appendix A: Low Impact Development Checklist provides information to assist reviewers and designers in the demonstration that nonstructural stormwater management measures have been implemented in a project.

- Download Appendix A in Word Format.

Appendix B: Municipal Regulations Checklist provides information to assist municipalities in incorporating nonstructural stormwater management measures into the master plan, land use and zoning ordinances.

Appendix C: Sample Municipal Stormwater Management Plan provides an example as well as guidance on the municipal plan required to be developed by every municipality.

- Download Appendix C in Word Format.

Appendix D: Model Municipal Stormwater Control Ordinance for Municipalities provides a sample stormwater ordinance consistent with the requirements of the Stormwater Management Rules.

- Download Appendix D in Word Format.

The documents and maps linked to this page are available in Adobe Acrobat "pdf" format only. You will need a "pdf" reader such as the free Adobe Acrobat Reader to view these files.

Back to Home Page

Comments or suggestions on the Stormwater web site? Please contact John Laurita.

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P. O. Box 402
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Last Updated: April 23, 2007

SARB_006998



New Jersey
Stormwater
Best Management Practices Manual



New Jersey Department of Environmental Protection
Division of Watershed Management

SARB_006999

New Jersey Stormwater Best Management Practices Manual

April 2004

State of New Jersey

James E. McGreevey, Governor

Department of Environmental Protection

Bradley M. Campbell, Commissioner

Land Use Management

Ernest P. Hahn, Assistant Commissioner

Division of Watershed Management

Larry Baier, Director

In cooperation with

New Jersey Department of Agriculture
New Jersey Department of Community Affairs
New Jersey Department of Transportation

New Jersey Department of Environmental Protection

Division of Watershed Management
PO Box 418
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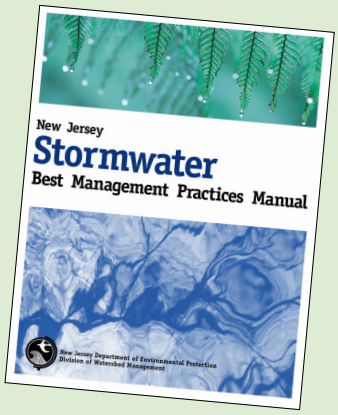
Updates and Future Versions of the Stormwater BMP Manual

Technical information regarding updates of the New Jersey Stormwater Best Management Practices Manual will be available at www.njstormwater.org
Future versions of the New Jersey Stormwater Best Management Practices Manual will reflect the technical updates found on the website.
Notices regarding future versions of the manual will be posted at this website.
Future versions of the manual are expected to occur at most once a year.

www.njstormwater.org



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Participating State Departments

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CHAPTER 1

Impacts of Development on Runoff

This chapter describes the adverse impacts unmanaged land development can have on groundwater recharge and stormwater runoff quality and quantity both at and downstream of a development site. The chapter also reviews the fundamental physical, chemical, and biological aspects of the rainfall-runoff process and how they can be altered by development. In doing so, the chapter demonstrates the need for the NJDEP Stormwater Management Rules at N.J.A.C. 7:8, which have been developed to directly address these adverse impacts. In addition, the chapter seeks to increase understanding of these physical, chemical, and biological processes in order to improve the design of structural and non-structural measures mandated by the Rules' groundwater recharge, stormwater quality, and stormwater quantity requirements.

Runoff Quantity

Development can dramatically alter the hydrologic response of an area and, ultimately, an entire watershed. Prior to development, native vegetation can either directly intercept precipitation or evapotranspirate that portion that has infiltrated into the ground back into the atmosphere. Development can remove this beneficial vegetation and replace it with turf grass lawns and impervious roofs, driveways, parking lots, and roads, thereby reducing the site's pre-developed evapotranspiration and infiltration rates. In addition, clearing and grading can remove surface depressions that store rainfall. Construction activities may also compact the soil and diminish its infiltration rate, resulting in increased rates and volumes of stormwater runoff from the development site.

Impervious areas directly connected to gutters, channels, and storm sewers can transport runoff more quickly than natural, vegetated conveyances. This shortening of the transport or travel time quickens the rainfall-runoff response of the site, causing flow in downstream waterways to peak faster and higher than under natural or predeveloped site conditions. These increases can create new and aggravate existing downstream flooding and erosion problems and can increase the quantity of sediment and other pollutants in the waterways.

Filtration of runoff and removal of pollutants by natural surface and channel vegetation is eliminated by storm sewers that discharge runoff directly into waterways. Increases in impervious area can also decrease

opportunities for infiltration and reduce stream base flow and groundwater recharge. Reduced base flows and increased peak flows produce greater fluctuations between normal and storm flow rates, which can increase channel erosion and adversely impact aquatic organisms and habitats. Reduced base flows can negatively impact the hydrology of adjacent wetlands and the health of biological communities that depend on these base flows.

To address these impacts, planners, engineers, reviewers, and other participants in the design of stormwater management measures must rethink traditional approaches to both land development itself and the environmental problems it can cause. New approaches such as those described in this manual must be taken. For example, nonstructural stormwater management principles provide a prevent-minimize-mitigate approach that is preferred by the NJDEP Stormwater Management Rules. Under these Rules, nonstructural stormwater management techniques are a requirement for new land development projects. Nonstructural stormwater management measures, also known as Low Impact Development Best Management Practices (LID-BMPs), include reduction of impervious cover, maintenance of natural vegetation, and reduction of nutrient inputs. LID-BMP techniques can significantly reduce and even prevent the negative effects of land development on stormwater runoff described above. Nonstructural stormwater management practices are covered in detail in *Chapter 2: Low Impact Development Techniques.*

During heavy rainfall, many land developments increase the rate or volume of stormwater runoff, even those with well-designed LID techniques. Historically, this increased runoff was managed through state and/or local regulations that required peak runoff rates leaving a site after development to be equal to those that existed prior to development. It was believed that if the peak rate of runoff was maintained, the downstream waterways could assimilate the runoff in the same manner as before development. This control was accomplished using detention and retention basins that store and then gradually release the runoff.

However, this control methodology failed to account for the increased volume of runoff caused by land development. Watershed studies in New Jersey have demonstrated that this additional volume resulted in extended peak rates and increases in non-peak flows that increased flooding and erosion problems downstream. These same watershed studies determined that, by reducing peak post-development site runoff to rates less than pre-developed site conditions throughout the watershed, the volume of post-development runoff was redistributed and pre-development peaks were maintained or reduced throughout the watershed.

The Stormwater Management Rules incorporate these peak flow reduction requirements, which are similar to those previously published in the NJDEP Flood Hazard Area Control Act Rules and the New Jersey Department of Community Affairs (NJDCA) Residential Site Improvement Standards (RSIS).

Runoff Quality

In addition to increases in runoff volume, land development often results in the accumulation of pollutants on the land surface that runoff can mobilize and transport to streams. New impervious surfaces and cleared areas created by development can accumulate a variety of pollutants from the atmosphere, fertilizers, animal wastes, and leakage and wear from vehicles. Pollutants can include metals, suspended solids, hydrocarbons, pathogens, and nutrients. Common pollutants found in stormwater runoff are shown in Table 1-1.

In addition to increased pollutant loading, land development can adversely affect water quality and stream biota in more subtle ways. For example, stormwater falling on impervious surfaces or stored in detention or retention basins can become heated and raise the temperature of the downstream waterway, adversely affecting cold water fish species such as trout. Development can remove trees along streambanks that normally provide shading, stabilization, and leaf litter that falls into streams and becomes food for the aquatic community.

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Table 1-1: Typical Stormwater Pollutants

Pollutant	Typical Concentration
Total suspended solids [a]	80 mg/l
Total phosphorus [b]	0.30 mg/l
Total nitrogen [a]	2.0 mg/l
Total organic carbon [d]	12.7 mg/l
Fecal coliform bacteria [c]	3600 MPN/100ml
E. Coli bacteria [c]	1450 MPN/100ml
Petroleum hydrocarbons [d]	3.5 mg/l
Cadmium [e]	2 ug/l
Copper [a]	10 ug/l
Lead [a]	18 ug/l
Zinc [e]	140 ug/l
Chlorides [f] (winter only)	230 mg/l
Insecticides [g]	0.1 to 2.0 ug/l
Herbicides [g]	to 5.0 ug/l

Notes

1. Data sources: [a] Schueler (1987), [b] Schueler (1995), [c] Schueler (1997), [d] Rabanal and Grizzard (1996), [e] USEPA (1983), [f] Oberts (1995), [g] Schueler (1996).
2. Concentrations represent mean or median storm concentrations measured at typical sites and may be greater during individual storms. Mean or median runoff concentrations from stormwater hotspots are higher than those shown.
3. Units: mg/l = milligrams/liter ug/l = micrograms/liter MPN = Most Probable Number

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The following sections provide basic information on the most common pollutants associated with stormwater runoff from a broad range of land uses.

1. Solids/Floatables

Solids/floatables are primarily a surface water pollution concern. They are defined by the NJDEP as wastes or debris floating, suspended or otherwise contained in wastewater or waters of the state (N.J.A.C. 7:22A-1.4 et seq.). These materials include debris such as bottles, jars, cans, cardboard boxes, paper bags, newspapers, plastic containers and wrappings, condoms, hypodermic needles, leaves, and branches.

Solid/floatable materials are wastes that are inadvertently or purposefully disposed of either on land or directly into stormwater conveyances. Runoff transports this material to receiving waters where it can disperse, float, wash ashore onto beaches or embankments, or settle onto waterway bottoms. Solid/floatable material can create odors, aesthetic problems, and even toxic or corrosive gases that can emanate from bottom mud deposits.

2. Sediment

Sediment is one of the most significant pollutants created by development and transferred by its runoff. Sediments consist largely of soil materials eroded from uplands as a result of natural processes and human activities.

The greatest sediment loads are exported during the construction phase of land development. Adequate sediment and erosion control must be installed and maintained at the site to prevent the delivery of large quantities of sediment into downstream waterways and water bodies. Other pollutants such as nutrients and organic matter attached to the sediment can also be delivered. Requirements for appropriate erosion controls are available in the Standards for Soil Erosion and Sediment Control in New Jersey available from the State Soil Conservation Committee (SSCC) or local Soil Conservation Districts.

Sediment and other nonpoint source pollution from agricultural sources is also a major contributor to water quality problems in the state. Sediment from croplands clogs lakes, road ditches, canals, and culverts, particularly during and just after active tilling.

High concentrations of suspended sediment in streams and lakes cause many adverse consequences including increased turbidity, reduced light penetration, reduced prey capture for sight-feeding predators, clogged fish gills/filters, and reduced angling success. Additional impacts can result after sediment is deposited in slower moving waters. These include the smothering of benthic communities, alterations in the composition of the bottom substrate, and the rapid filling-in of small impoundments that create the need for costly dredging and reductions in the overall aesthetic value of the water resource. Sediment is also an efficient carrier of toxins and trace metals. Once deposited, pollutants in these enriched sediments can be remobilized under suitable environmental conditions and threaten benthic life.

3. Nutrients

Phosphorus and nitrogen are nutrients used by plants during photosynthesis. Phosphorus in natural waters occurs as phosphate in three classifications: orthophosphates (P04), polyphosphates (polymers of phosphoric acid), and organically bound phosphates. The most common forms of nitrogen are gaseous (N2), ammonia (NH3 or NH4), nitrite (NO2), nitrate (NO3), and nitrogen bound in organic compounds. Pollution from inorganic phosphorus (orthophosphates) and inorganic nitrogen (nitrates and ammonia) are of chief concern in New Jersey.

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In general, undeveloped land produces relatively few nutrients; agricultural, residential, industrial, and commercial areas produce more nutrient loadings. In rural and residential areas, substantial amounts of nutrients originate from commercial fertilizers, manure from livestock feeding operations, or dairy farming. Fertilizer spread on lawns and farmland during the winter can contribute nutrients to runoff in the springtime. Pet wastes contribute nutrients to runoff in residential areas. Detergents and raw sanitary waste also contribute to nutrient loading.

The action of phosphates and nitrates can be quite different. Although both can be transported by groundwater, phosphorus often combines with fine soil particles and remains locked in the soil until it is either utilized by plant life or eroded away with the soil. In the latter case, the phosphorus will flow along with the soil particles as suspended sediment. Nitrates in the soil remain much more soluble. During the late winter and occasionally in midseason following exceptionally heavy rainfall, nitrates may pass below the root zone into the groundwater. This movement of nitrates into groundwater may cause a public health hazard because high nitrate concentrations in drinking water can cause infant methemoglobinemia (Blue Baby Syndrome).

Under normal conditions, phosphorus and nitrogen are not generally regarded as problem chemicals. However, in excessive amounts, phosphorus and nitrogen present a problem by over-stimulating plant growth within the aquatic environment. When excessive concentrations (especially phosphorus) pass into surface fresh waters, they can contribute to eutrophication in slower moving water bodies and to dense algal growths on substrates within flowing water systems.

The greatest risk of eutrophication is in small agricultural ponds, urban lakes, and impoundments that have retention times of two weeks or more. Under optimal growing conditions, these lake systems can experience chronic and severe eutrophic symptoms such as surface algal scums, water discoloration, strong odors, depressed oxygen levels (as the bloom decomposes), release of toxins, and reduced palatability of fishery resources. High nutrient levels also promote the growth of dense mats of green algae that attach to rocks and cobbles in shallow, unshaded headwater streams. This phenomenon is present in many residential areas with recreational water bodies bordered by extensive, improperly fertilized lawn.

Coastal waters and estuaries in New Jersey also suffer from increased incidences of phytoplankton blooms, e.g., Barnegat Bay has been the site of several algal bloom problems including brown tide. Concern exists that this problem is caused, in part, by inputs from nutrient-enriched fresh waters; however, the relationship between high nutrient levels and algal production is extremely complex and is not fully understood.

4. Pesticides

Pesticides, which include insecticides, herbicides, rodenticides, and fungicides, are among the few toxic substances deliberately introduced to the environment. These substances are used routinely for agricultural purposes and in residential and commercial property maintenance to biochemically affect specific unwanted organisms. However, these substances can produce unintended toxic effects on ecosystems and human life by contaminating soil, water, and air. Numerous acute and chronic effects on humans and other organisms are associated with pesticide exposure. Pesticides can enter an organism through inhalation, ingestion, or skin contact. They have caused decreases in aquatic populations either directly, through damage to the food chain by decreasing reproductive success, or indirectly, by reducing oxygen levels in the water through a reduction in the populations of higher plants and phytoplankton. Some pesticides, such as DDT, dieldrin, and chlordane, are no longer in use but persist in the food chain and in the human body. Other commonly used pesticides, such as malathion, are suspected carcinogens and are hazardous more through direct contact than indirect contact via the food chain.

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Pesticides are carried in stormwater from application sites by becoming dissolved or suspended in runoff or by binding to particulate matter carried in runoff. These pesticides can contaminate surface or groundwater through infiltration devices or overflow. The fate and transport of pesticides are dependent on their physical and chemical properties and their chemical interactions with the environment. Processes that determine the path of pesticides in the environment are primarily photolysis (degradation in light), hydrolysis (degradation in the presence of water), and sorption reactions that are dependent on the chemical nature and solubility of the pesticide and the percentage of particulate and organic matter present in the sediment. Some pesticides, such as aldicarb, are highly soluble in water and are easily flushed into aquatic ecosystems or groundwater. Pesticides with low solubility may accumulate in sediments by adhering to particulate matter. Adsorption and absorption increase with the amount of organic matter present. These factors and the resistance to degradation of certain pesticides (expressed as the half-life) increase the persistence of these substances in the environment.

5. Metals

The permissible concentrations of metals in water are established directly by numerical criteria under the surface and groundwater quality standards and indirectly by standards under the Safe Drinking Water Act. Concentrations of metals found in water can have adverse effects upon public health as well as upon aquatic biota. Lead, arsenic, copper, cadmium, mercury, and some forms of chromium are all metals of concern.

Metals can occur naturally in soil or result from human activity. The quantities of metals leaching into water from natural sources are influenced largely by the water's pH. Acid rain and the low pH water often found in swamps may increase the solution of metals into water. Although mercury and copper have been shown to cause serious health problems, lead is of primary public health concern. It has a cumulative, toxic neurological effect and may be particularly harmful to children. One of the principal sources of lead in stormwater runoff has been the tetraethyl lead in gasoline, but pollution from this source is rapidly declining due to stringent federal controls over lead in gasoline.

6. Road Salt

Road salt, primarily composed of sodium chloride (common salt), has the potential to impair land vegetation, water quality, and aquatic ecosystems. This material is commonly used throughout the state as a low-cost substance for melting snow and ice. Road salt entering stormwater runoff generally originates from salt stockpiles or from salt application to roadways and other impervious surfaces. Precipitation falling on salted surfaces creates runoff containing dissolved salt. The increasing amount of urban and suburban development in New Jersey has resulted in increased roadways and other impervious surfaces such as parking lots, which has increased the use of road salt.

The primary problem with road salt is the contamination of ground and surface waters, which may render them unusable or require expensive treatment procedures. Increased sodium chloride concentrations in water create aesthetically displeasing drinking water and interfere with pristine manufacturing processes. High levels of sodium consumed in drinking water can elevate blood pressure and impair kidney function in susceptible individuals.

Because of salt's long residence time, salt water often tends to build up concentration in groundwater. Due to a seasonal effect, the highest levels of chloride ions appear in the summer months. This effect is attributed to the slow movement of groundwater (reacting to winter applications) and high summer evapotranspiration rates.

Excessive salt or saline input to fresh surface waters can cause significant use impairment. The input of highly concentrated saline water into fresh water lakes can retard springtime mixing. The density of the bottom layer of water increases, thereby overriding the normal thermal density gradients responsible for

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vertical mixing. This saline buildup can decrease oxygen levels and cause high mortality among bottom-dwelling organisms. Increased salt loading to bays and estuaries can alter natural saline concentrations and disrupt shellfish reproduction and fish spawning. Surface water effects are dependent on the concentrations of sodium chloride entering the system, the amount of dilution, and the sensitivity of the aquatic ecosystem.

Aside from contaminating surface and groundwater, high levels of sodium chloride can kill roadside vegetation and corrode infrastructure such as bridges, roads, and stormwater management devices. In addition, some industrial operations can be impaired by an increase in the salinity of intake water.

7. Petroleum Hydrocarbons

Petroleum hydrocarbons in water are considered very harmful to natural biota. In addition, some constituents are carcinogenic and toxic to humans. No numerical criteria exist for petroleum hydrocarbons in ground or surface water quality standards. In both cases and in most waters, the basic criterion is "none noticeable."

Additional requirements for surface water prohibit hydrocarbons on aquatic substrata, along the shore in quantities detrimental to the natural biota, and where they would render waters unsuitable for their designated uses. The same standards are generally applicable to oil and grease, which, except for petroleum hydrocarbons, are not considered especially dangerous. Control efforts are mainly directed toward hydrocarbons.

Although the hydrocarbons harmful to water quality are mostly liquid at ambient temperatures, they are absorbed and adsorbed onto solid particles of sediment so rapidly that they are found mainly as particulates in runoff. Only considerable masses of oil will remain in liquid form in the larger storm drains. Petroleum hydrocarbons are also biodegradable in an aerobic environment, although at a relatively slow rate.

8. Pathogens

Pathogens (viral and bacterial) and non-pathogenic bacteria are found in the intestinal tracts of humans and other warm-blooded animals and are excreted with fecal wastes. A number of human diseases can be transmitted by runoff contaminated by fecal sources. Some well-documented bacterial agents include the *Salmonella* group responsible for typhoid fever, paratyphoid fever, and intestinal fever; the *Shigella* group causing bacillary dysentery; *Vibrio cholerae* responsible for cholera; and *Escherichia coli (E. coli)* causing gastroenteritis. In humans, gastroenteritis is the leading waterborne infectious disease in the United States. Deficient water treatment and groundwater contamination of wells are responsible for most of the outbreaks (65 percent) and cases (63 percent). The ingestion of shellfish harvested from contaminated waters can lead to disease as well.

Human fecal contamination is primarily a sewage treatment problem complicated by cross-connections or interconnections between sanitary and storm sewers, where combined sewer overflows degrade surface waters and where faulty, improperly sized, or improperly located septic systems contaminate groundwater. Animal fecal material from livestock operations, domestic pet populations, and concentrated wildlife populations contaminate surface waters via overland runoff and stormwater sewer discharges. Groundwater contamination occurs in areas with very permeable soils and/or high groundwater tables and where sinkholes, fractured rock, and well casings provide possible entry routes.

It is generally accepted that urban runoff will exceed desired bacterial limits. When considering stormwater contributions to the flow in a combined sewer system, the importance of stormwater control for bacterial water quality should be considered.

While not directly responsible for disease, fecal coliform bacteria have traditionally served as the microbiological indicators for the potential presence of waterborne pathogens. Enterococci appear to be a more accurate indicator than coliform bacteria, especially in saltwater where their resistance time and

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survival rate is similar to that of pathogenic bacteria. Research is being conducted on the use of bacteriophages as viral indicators. Until regulations are revised, however, the state will continue to rely on traditional indicators (total and fecal coliforms) as well as enterococci.

Compared to other pollutants, bacteria and pathogens have relatively low residence times in the environment. Survival in surface waters varies with environmental factors such as temperature, light intensity, salinity, nutrient levels, bacteriophages and predation, absorption, sedimentation, and the presence of toxic substances.

Bacteria and viruses, when introduced to the subsurface environment, can undergo a natural die-off, be retained in the soil, or be transported to groundwater. Survival rates of both bacteria and viruses decrease with increasing temperature, decreasing soil moisture, and increasing competition with native soil microflora. Bacteria can be effectively retained in soils by the filtering action of fine particle soils with small pore size. The finer the soil grain, the greater its capability to filter out microorganisms. Adsorption, however, is the principal mechanism by which viruses are retained in the soil, and it can be a factor for retaining bacteria. Adsorption may be temporary; viruses may remain on the soil particle and be returned to subsurface flow during intense rainfall.

Groundwater is less likely to be contaminated by bacteria than surface waters. Bacteria and pathogens are generally filtered, adsorbed by soil, or dead before reaching the groundwater.

There is presently limited information that specifically addresses the survivability and transport of bacteria in stormwater runoff. The exact distances bacteria would be transported vary with soil properties, climate, and vegetation.

Parasites are an additional concern under this general category of pollutants. A number of infectious diseases are transmissible to humans via ordinary parasites. Common causes of these diseases are dog and cat parasites such as roundworms and hookworms shed in animal feces. The intimate relationships that household pets have with people, combined with the large pet population, greatly increase the potential for transmission of pathogens. This also appears to be true for bacteria and viruses, many of which have long survival times when infected pet waste is washed into receiving waters via stormwater.

Two relatively common protozoa that cause intestinal disorders in humans are also of great concern. The first is *Cryptosporidium Spp.,* which often causes diarrhea and may be accompanied by fever, abdominal pain, nausea, constipation, and/or weight loss. Most infections occur after contact with infected people. The other is *Giardia Spp.,* which causes many of the same symptoms as cryptosporidiosis. Its major reservoirs appear to be water and food contaminated by infected animals and people. A worrisome feature of these organisms is their resistance to environmental influences and disinfectants.

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CHAPTER 2

Low Impact Development Techniques

As described in Chapter 1, land development can have severe adverse stormwater impacts, particularly if the land is converted from woods, meadow, or other natural condition to a highly disturbed area with large percentages of impervious and non-native vegetated covers. Such impacts typically include an increase in stormwater runoff volume, rate, velocity, and pollutants and a corresponding decrease in the quality of runoff and stream flow. Frequently, management of these impacts has focused on collecting and conveying the runoff from the entire site through a structural conveyance system to a centralized facility (e.g., detention basin, wet pond) where it is stored and treated prior to discharge downstream. In effect, such practices first allow the adverse runoff impacts to occur throughout the site and then provide remedial and/or restorative measures immediately prior to releasing the runoff downstream.

Since the 1960s, the range of remedial measures provided in centralized treatment facilities has increased from merely 100-year peak flow attenuation to the range of peak flow, volume, and nonpoint source pollutant controls required by New Jersey's current Stormwater Management Rules at N.J.A.C. 7:8. This has required modifications to established methods of runoff computation and the development of alternative treatment methods to be used in centralized facilities.

However, with the increasing emphasis on nonpoint source pollution and concerns over the environmental impacts of land development, it has become necessary to develop effective alternatives to the centralized conveyance and treatment strategy that has been the basis for much of the stormwater management systems and programs in the state. New strategies must be developed to minimize and even prevent adverse stormwater runoff impacts from occurring and then to provide necessary treatment closer to the origin of those impacts. Such strategies, known collectively as Low Impact Development or LID, seek to reduce and/or prevent adverse runoff impacts through sound site planning and both nonstructural and structural techniques that preserve or closely mimic the site's natural or pre-developed hydrologic response to precipitation. Rather than responding to the rainfall-runoff process like centralized structural facilities, low impact development techniques interact with the process, controlling stormwater runoff and pollutants closer to the source and providing site design measures that can significantly reduce the overall impact of land development on stormwater runoff. As such, low impact development promotes the concept of designing with nature.

Effective low impact development includes the use of both nonstructural and structural stormwater management measures that are a subset of a larger group of practices and facilities known as Best Management Practices or BMPs. As noted above, the BMPs utilized in low impact development, known as LID-BMPs, focus first on minimizing both the quantitative and qualitative changes to a site's pre-developed hydrology through nonstructural practices and then providing treatment as necessary through a network of structural facilities distributed throughout the site. In doing so, low impact development places an emphasis on nonstructural stormwater management measures, seeking to maximize their use prior to utilizing structural BMPs.

Nonstructural BMPs used in low impact development seek to reduce stormwater runoff impacts through sound site planning and design. Nonstructural LID-BMPs include such practices as minimizing site disturbance, preserving important site features, reducing and disconnecting impervious cover, flattening slopes, utilizing native vegetation, minimizing turf grass lawns, and maintaining natural drainage features and characteristics. Structural BMPs used to control and treat runoff are also considered LID-BMPs if they perform these functions close to the runoff's source. As such, they are typically smaller in size than standard structural BMPs. Structural LID-BMPs include various types of basins, filters, surfaces, and devices located on individual lots in a residential development or throughout a commercial, industrial, or institutional development site in areas not typically suited for larger, centralized structural facilities.

Finally, low impact development promotes the view of rainwater as a resource to be preserved and protected, not a nuisance to be eliminated. For example, with low impact development, roof runoff can be captured and stored in rain barrels for plant watering or other uses. Runoff can also be directed to small on-lot bioretention or infiltration basins, also known as rain gardens, to provide both runoff treatment and landscape enhancements.

Unfortunately, low impact development techniques and strategies are considered by some to be applicable only to land development sites with limited impervious cover. However, it has been clearly demonstrated that low impact development techniques can be applied to virtually any development site, regardless of impervious coverage, to produce enhanced site designs and "lower" stormwater impacts.

The use of nonstructural and structural LID-BMPs can be a significant improvement over the more centralized approach to stormwater management traditionally used in New Jersey. Even in those instances where centralized structural BMPs are still required to fully provide downstream areas with effective pollution, erosion, and flood protection, LID-BMPs can help to reduce the number and/or size of such facilities, further reducing site disturbance. And, in certain instances, it may be possible to satisfy all stormwater management requirements through the use of nonstructural LID-BMPs alone, thereby eliminating the need for any structural BMPs. In all instances, specific site and downstream conditions must be evaluated to determine the range of standard and low impact development BMPs that can be utilized at a land development site.

It is also important to note that, since low impact development typically relies on an array of nonstructural and relatively small structural BMPs distributed throughout a land development site, ownership and maintenance of the various BMPs may be similarly distributed over an array of property owners. As such, it is vital to have public understanding of and support for the various LID-BMPs officially authorized for use in a particular municipality. Such understanding and support must include an appreciation for the role that the LID-BMPs play in the site's or watershed's stormwater management program and a commitment to preserve and maintain them. Additional information regarding this issue is presented in the *Additional Considerations* section below.

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The use of both nonstructural and structural BMPs in low impact development is governed by certain principles, objectives and requirements. A discussion of each of these factors is presented below, along with details of each type of LID-BMP. It should be noted that, while consideration of nonstructural stormwater management techniques at land development sites is required by the NJDEP Stormwater Management Rules at N.J.A.C. 7:8, the NJDEP believes that effective, state-wide use of such practices can be best achieved through municipal master plans and land development ordinances that mandate specific LID goals and authorize the use of specific LID-BMPs. For this reason, the Stormwater Management Rules require municipalities to review their master plans and ordinances in order to incorporate LID practices into their land development regulations to the maximum extent practicable. A detailed discussion of the NJDEP Stormwater Management Rules is presented below, along with guidelines on the development of municipal LID regulations and the selection of practical and reliable LID-BMPs.

Nonstructural Stormwater Management Strategies

As described above, effective low impact development includes the use of both nonstructural and structural stormwater management measures known as LID-BMPs. Of the two, nonstructural LID-BMPs play a particularly important role. The proposed NJDEP Stormwater Management Rules at N.J.A.C. 7:8 require in Section 5.2(a) that the design of any development that disturbs at least 1 acre of land or increases impervious surface by at least 1/4 acre must incorporate nonstructural stormwater management strategies "to the maximum extent practicable." Such a development is defined in the Rules as a "major development." As such, nonstructural LID-BMPs are to be given preference over structural BMPs. Where it is not possible to fully comply with the Stormwater Management Rules solely with nonstructural LID-BMPs, they should then be used in conjunction with LID and standard structural BMPs to meet the Rules' requirements.

More precisely, to achieve the Rules' design and performance standards, Subchapter 5 of the NJDEP Stormwater Management Rules requires the maximum practical use of the following nine nonstructural strategies at all major developments:

1. Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss.
2. Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces.
3. Maximize the protection of natural drainage features and vegetation.
4. Minimize the decrease in the pre-construction "time of concentration."
5. Minimize land disturbance including clearing and grading.
6. Minimize soil compaction.
7. Provide low maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers, and pesticides.
8. Provide vegetated open-channel conveyance systems discharge into and through stable vegetated areas.
9. Provide preventative source controls.

In addition, Subchapter 5 further requires an applicant seeking approval for a major development to specifically identify which and how these nine nonstructural strategies have been incorporated into the development's design. Finally, for each of those nonstructural strategies that were not able to be incorporated into the development's design due to engineering, environmental, or safety reasons, the applicant must provide a basis for this contention.

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While the nonstructural stormwater management strategies listed above represent a wide range of both objectives and practices, Strategies 1 through 8 can be directly addressed through the use of specific nonstructural LID-BMPs that can be grouped into four general categories:

1. Vegetation and Landscaping;
2. Minimizing Site Disturbance;
3. Impervious Area Management; and
4. Time of Concentration Modifications.

Information on the specific nonstructural LID-BMPs included in each of these categories is presented below. A Nonstructural Stormwater Management Checklist is provided in Appendix A to assist applicants and reviewers in demonstrating that the Stormwater Management Rules' nine nonstructural stormwater management strategies have been utilized throughout the land development site to the maximum extent practicable.

Prior to utilizing any of the specific nonstructural LID-BMPs described below, applicants are urged to review the land development regulations of the municipality and/or agency from which they are seeking development approval. Despite low impact development being a relatively new aspect of stormwater management, many municipalities and agencies have already incorporated low impact development goals and strategies into their own regulations and, with the advent of the NJDEP Stormwater Management Rules, those that haven't will be required to do so. Therefore, additional nonstructural strategies and/or specific nonstructural LID-BMPs aside from those described in this chapter may have already been incorporated into a municipality's land development regulations or will be in the near future. In light of the site specific nature of LID-BMPs, these regulations may also discourage or prohibit the use of specific LID-BMPs for engineering, safety, or maintenance reasons. Consideration should also be given to having a pre-design meeting and/or site walk with pertinent regulators and technical reviewers to review local regulations and optimize the site's nonstructural stormwater management design.

Finally, engineers and site designers should recognize the importance of accurately computing existing or predeveloped runoff at a land development site. While this is an important computation at all development sites, it is particular important at those sites where nonstructural LID-BMPs will be utilized. This is because, to a large degree, these nonstructural measures will utilize and/or mimic the predeveloped site's rainfall-runoff response. As such, accurate computation of predeveloped hydrologic conditions is vital to successful LID-BMP use. It is recommended that engineers and site designers consult with regulatory entities, such as the State, municipality, or local soil conservation district, regarding predeveloped hydrologic conditions.

1. Vegetation and Landscaping

As a nonstructural LID technique, the management of existing and proposed vegetation at a land development site can significantly reduce the site's impact on downstream waterways and water bodies. As discussed in detail in Chapter 5, pervious vegetated areas reduce runoff volumes and peaks through infiltration, surface storage, and evapo-transpiration. Vegetated areas also provide a pervious surface for groundwater recharge, particularly during dormant or non-growing seasons. In addition, vegetation can remove pollutants from the runoff flowing through it through both filtration and biological uptake.

Information regarding three key nonstructural LID-BMPs that utilize vegetation and landscaping to manage stormwater runoff are presented below. A review of this information demonstrates how the features of all three are closely inter-related.

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A. Preservation of Natural Areas

The preservation of existing natural vegetated areas is a nonstructural LID-BMP that must be considered throughout the design of a land development. This is especially true for areas with significant hydrologic functions such as forested areas, riparian corridors, and high groundwater or aquifer recharge capabilities. When applying for development approval from a regulatory agency or board, a plan showing natural vegetated areas on the pre-developed site, along with a narrative and photographs describing each area's vegetated and hydrologic characteristics, should be included in the application package. The narrative should also discuss the alternatives and choices made to preserve the natural vegetated areas.

In addition to identifying natural areas to be preserved at a development site, specific legal and/or procedural measures must be specified to ensure that such areas remain preserved in the future. This may include the establishment of easements or deed restrictions on specific portions of a parcel or lot that prohibit any disturbance or alteration. Other measures may not designate a particular portion of a parcel or lot but instead mandate through deed restrictions that an overall percentage of the parcel or lot must remain in natural, vegetated cover. This method allows greater flexibility but can be used only where the exact location of the preserved natural area is not critical to the success of the development's stormwater management system. In either case, the amount of natural area to be preserved must be the maximum amount feasible.

B. Native Ground Cover

Research has demonstrated that areas covered with turf grass typically generate more runoff than other types of vegetation. This is especially true when comparing grass areas with naturally wooded areas or forests. Therefore, in keeping with the goals of nonstructural LID-BMPs contained in the NJDEP Stormwater Management Rules, the amount of lawns and other grass areas at land development sites should be minimized. Instead, alternative vegetation, particularly native plants, should be used to revegetate disturbed site areas.

The use of native plants can provide a low-maintenance alternative to turf grass, resulting in lower fertilizer and water needs. The use of native ground cover, shrubs, and trees instead of turf grass can create infiltration characteristics similar to those of natural areas. These plants can also provide better habitat and create food sources for songbirds and small animals. Native landscaping can also be used to provide property screening, summer shade, and year-round landscaping interest.

In addition to revegetating site areas disturbed by construction, native plants can be used to improve or enhance the hydrologic characteristics of existing site areas. Such areas may include existing agricultural fields, developed areas, access roads, and other previously disturbed portions of the site as well as degraded natural areas. Naturally wooded areas or forests should also be restored or reestablished at land development sites wherever practical. This is also consistent with the goals of nonstructural LID-BMPs. In doing so, it is often necessary to provide stable interim vegetative cover in such restored areas.

In selecting native vegetation, consideration should be given to height, density, and other growth patterns, visual appearance, anticipated use of the planted area, and fertilizer, irrigation, and other maintenance needs. Additional information on native vegetation and landscaping is presented in Chapter 7.

C. Vegetative filters and Buffers

Both native ground cover and grass areas can provide a vegetated buffer to help filter stormwater runoff and provide locations for runoff from impervious areas to re-infiltrate. As described above, water flowing as sheet flow across a vegetated area is slowed, filtered and, depending on soil conditions, given the opportunity to re-infiltrate into the soil. Dense vegetative cover, long flow path lengths, and low surface slopes provide the most effective vegetated filters. Maximizing the use of such nonstructural LID-BMPs

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helps demonstrate compliance with the nonstructural stormwater management requirements of the NJDEP Stormwater Management Rules.

Vegetative filters and buffers can be created by preserving existing vegetated areas over which runoff will flow or by planting new vegetation. Vegetative filters located immediately downstream of impervious surfaces such as roadways and parking lots can achieve pollutant removal, groundwater recharge, and runoff volume reduction. Vegetated buffers adjacent to streams, creeks, and other waterways and water bodies can also help mitigate thermal runoff impacts, provide wildlife habitat, and increase site aesthetics. Further information and detailed design procedures for vegetative filters are presented in Chapter 9.

2. Minimizing Land Disturbance

Minimizing land disturbance at a development site is a nonstructural LID-BMP that can be used during all phases of a land development project. Similar to the preservation of natural areas (see *1. Vegetation and Landscaping* above), minimizing land disturbance can help reduce post-development site runoff volumes and pollutant loads and maintain existing groundwater recharge rates and other hydrologic characteristics by preserving existing site areas. However, as a strategy, minimizing land disturbance can also be applied during a project's construction and post-construction phases.

Minimum disturbance begins during the project's planning and design phases by fitting the development into the terrain, as opposed to changing the terrain to fit the development. Also known as site fingerprinting, minimal disturbance techniques are first applied during the planning and design stages to evaluate existing site characteristics and constraints. The goal of this process is to limit clearing, grading, and other land disturbance necessary for buildings, houses, roadways, parking lots, and other proposed features and facilities. Roadway and building patterns that match the existing land forms and limit the amount of required clearing and grading should be chosen.

Site-specific conditions such as slope, soil type, drainage area, and other site conditions and constraints must be considered, including the identification of effective groundwater recharge and runoff storage areas. Wherever feasible, development should be concentrated on soils with low permeability rates to minimize the increase in runoff and to retain high permeability areas for groundwater recharge. The selection of the location of the development due to the soil type can have a significant impact on the resulting increases in runoff. Existing runoff storage areas should also be preserved to help retain the site's hydrologic character. Strict adherence to a minimum land disturbance strategy during a development's planning and design stages can also be an effective way to minimize soil compaction at those sites where there is a potential for it to occur.

In addition, the identification and evaluation of site constraints such as wetlands, Karst topography, and floodplains are critical to the effective implementation of LID designs. For example, additional analysis and provisions are applicable for development in Karst areas. It is interesting to note that the New Jersey Geological Survey's recommendations for Karst areas presented below are very similar to those for low impact development:

1. Do not concentrate flows.
2. Minimize grading.
3. Build within landscape (design around existing topography).
4. Do not alter natural drainage areas.
5. Minimize the amount of imperviousness.
6. Increased structural loads at the site can contribute to ground failures.
7. Changes to existing soil profile, including cuts, fills, and excavations, should be minimized.

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Additional information on development in Karst areas can be found in Appendix A-10 of the New Jersey Department of Agriculture's Soil Erosion and Sediment Control Standards or from either the State Soil Conservation Committee (SSCC) at (609) 292-5540 or the New Jersey Geological Survey (NJGS) at (609) 292-2576. Information may also be available from the local Soil Conservation District or municipal engineer.

As noted above, land disturbance can also be minimized during a project's construction and post-construction stages. For example, during a development's construction phase, construction areas, access roads, and material and equipment storage areas can be minimized and strictly regulated. In addition, lighter-weight, rubber-tired construction equipment can be used whenever possible, with their movements limited to a few repetitive routes. Construction can also be phased to minimize the site area that will be disturbed at any given time. To help ensure compliance, such practices and requirements should be included in soil erosion and sediment control plans, construction plans, and contract documents.

Following construction, limits can be placed on the expansion of homes, buildings, driveways, parking, and other disturbed areas through deed restrictions, approving resolutions, owners' agreements, and zoning ordinances. Specific portions or percentages of a parcel or lot can be designated to remain undisturbed through deed restrictions or easements. As such, it can be seen that minimizing land disturbance should not only be one of the first nonstructural LID-BMPs applied to a land development's design, but it should also be continually reapplied throughout the life of the project.

It should also be noted that, in addition to the measures described above for minimizing soil compaction, measures can be taken to remediate a soil compaction problem. If compaction should be a problem, the Standards for Soil Erosion and Sediment Control in New Jersey recommends that, prior to topsoil and seed application, the surface of all compacted areas be scarified 6 to 12 inches.

3. Impervious Area Management

Impervious areas in a watershed have been cited in studies as an indicator of stream health. Increases in watershed imperviousness have been linked in these studies to degradation of water quality, especially in areas where the impervious surface is directly connected to a water body. Increases in impervious cover in a watershed can be directly correlated to increased runoff volumes and rates as well as waterway velocities, erosion, and flooding. Impervious areas can also accumulate nonpoint source pollutants that can significantly impact waterways when washed off by runoff.

Fortunately, comprehensive management of impervious areas at a land development site can help reduce the impervious area impacts described above. This section discusses the nonstructural LID-BMPs that can reduce the volume and peak rate of runoff from impervious surfaces by limiting their total area or disconnecting them from the site's stormwater conveyance system. Reductions in impervious area translate into more surface storage, infiltration and groundwater recharge, less stormwater runoff, and reduced storm sewer construction, maintenance, and repair costs. It is important to note that all reductions in the amount and dimensions of impervious surfaces at a land development site must also recognize safety and the level of use of the impervious surfaces.

A. Streets and Sidewalks

Street Widths: Street widths are typically based on traffic density, emergency vehicle movement, and the need for roadside parking. Street widths in residential areas are specified in Subchapter 4: Streets and Parking of the Residential Site Improvement Standards at N.J.A.C. 5:21 (RSIS). In such developments, efforts should be made to utilize the minimum pavement or cartway width consistent with the Standards. Similarly, in all other development types, the widths of all streets should be evaluated to demonstrate that the proposed width is the narrowest possible consistent with safety and traffic concerns and requirements.

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Street Features: The design of certain streets or portions thereof may include features or areas that can be covered with pervious material, landscaped, and/or designed to receive runoff. For example, traffic calming measures such as circles, rotaries, medians, and islands can be vegetated or landscaped. Such features reduce the amount of impervious cover and provide an opportunity to store and possibly infiltrate runoff from adjacent impervious street surfaces. When curbs are necessary to maintain traffic safety and/or meet existing regulations, street runoff may be directed to these features through curb cuts.

Sidewalks: Sidewalk requirements within residential areas are also specified in Subchapter 4 of the RSIS and are based on the street type and development intensity. Municipal regulations often dictate the requirements for sidewalks in non-residential development to provide safe pedestrian movement. Pedestrian traffic patterns considered when determining the placement of sidewalks include the presence of schools, shopping centers, recreational facilities, handicap access, and public transportation facilities. Sidewalks can be made of pervious material, such as porous pavement or concrete, or designed to provide runoff storage and infiltration in their stone base. Where impervious material is used, sidewalks can be disconnected from the drainage system, which allows some of the runoff from them to re-infiltrate in adjacent pervious areas. Additional details regarding unconnected impervious surface is presented below.

B. Parking and Driveway Areas

Similar to street widths, the size of parking areas and driveways contributes to the total amount of impervious surface at a development site. In New Jersey, parking area and driveway requirements are typically mandated by municipal regulations and, in the case of residential areas, the RSIS. In Section 4.14, the RSIS states:

> *Alternative parking standards… shall be accepted if the applicant demonstrates these standards better reflect local conditions. Factors affecting minimum number of parking spaces include household characteristics, availability of mass transit, urban vs. suburban location, and available off-site parking resources.*

As such, the RSIS provides flexibility in selecting parking and driveway size, provided that supporting local data is available.

The RSIS further states:

> *When housing is included in a mixed-use development, a shared parking approach to the provision of parking shall be permitted.*

From the above, it can be seen that a mix of residential and nonresidential uses at a development site can share parking areas, thereby reducing the total parking area and impervious cover. The RSIS also allows a reduction in the standard 18 foot parking space length provided that room is provided for overhang by the vehicle. The overhang area can then be vegetated to further reduce (and possibly help disconnect) impervious surfaces. Non-residential developments can use these same ideas where permitted by local regulations.

At all development sites, consideration should be given to constructing some or all driveways and parking areas from pervious paving material. This is particularly true for overflow parking areas as well as driveways (and other access roadways) that are used relatively infrequently by maintenance and emergency vehicles. See below and Chapter 9 for more information on pervious paving materials. Parking can also be located underground or beneath buildings, which can help reduce the site's overall impervious coverage. Finally, parking decks can reduce overall impervious coverage by concentrating the total required parking area into a smaller footprint.

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C. Pervious Paving Materials

Pervious paving materials can be used at many site locations to replace standard impervious pavement. These locations may include parking spaces, driveways, access roadways, and sidewalks. Pervious material can include pavers (interlocking concrete blocks or bricks), porous pavement (concrete or asphalt), gravel, and reinforced lawn. While brick pavers, concrete block pavers, and gravel are themselves impervious, their use can reduce impervious areas by providing gaps between individual pieces through which runoff can reach a pervious base course and/or subsoil. Turf blocks (open cells made of concrete, plastic, or composite materials that are filled with soil and planted with grass) may also be utilized to replace traditionally paved areas. Porous concrete and porous asphalt are generally considered fully pervious and may be viable options for areas that need to be fully paved. Municipal regulations must be reviewed to determine whether the use of pervious paving materials is permissible at a development site. It may also be appropriate to discuss the use of pervious paving materials with local officials and Soil Conservation Districts.

In selecting the type of pervious paving material to be used at a development site, consideration must be given to anticipated character and intensity of use of the material's surface. This will include the type, weight and size of vehicle, and the traffic rate and frequency. For example, due to their non-monolithic character, pavers, turf blocks, and gravel can achieve significant infiltration but may not be able to withstand regular traffic loads. As such, these materials may be more appropriate for overflow parking areas and emergency or maintenance access roads. Since its monolithic character is similar to standard impervious paving, porous pavement will have more general use, provided that adequate subsurface drainage is available. In all cases, consideration must be given to the effects of snow plowing and other maintenance activities. Additional information regarding pervious paving is available in Chapter 9.

D. Unconnected Impervious Areas

Unconnected impervious areas are impervious surfaces that are not directly connected to a site's drainage system. Instead, runoff from an unconnected impervious area is allowed to sheet flow from the impervious area across a downstream pervious surface, where it has the opportunity to re-infiltrate into the soil, thereby reducing the total runoff volume. An unconnected impervious surface may be on-grade (e.g., a parking lot) or above-grade (e.g., a roof). While impervious area disconnection is most applicable to low density development where pervious open space is readily available to accept impervious area runoff, opportunities to utilize unconnected impervious area can usually be found even at highly impervious development sites.

In most circumstances, impervious areas can be considered unconnected under the following conditions:

1. All runoff from the unconnected impervious area must be sheet flow.
2. Upon entering the downstream pervious area, all runoff must remain as sheet flow.
3. Flow from the impervious surface must enter the downstream pervious area as sheet flow or, in the case of roofs, from downspouts equipped with splash pads, level spreaders, or dispersion trenches that reduce flow velocity and induce sheet flow in the downstream pervious area.
4. All discharges onto the downstream pervious surfaces must be stable and nonerosive.
5. The shape, slope, and vegetated cover in the downstream pervious area must be sufficient to maintain sheet flow throughout it length. Maximum slope of the downstream pervious area is 8 percent.
6. The maximum roof area that can be drained by a single downspout is 600 square feet.

Methods to compute the resultant runoff volumes and peak runoff rates from unconnected impervious areas are presented in Chapter 5 of this manual. This includes parameters and procedures for determining the effective size of the downstream pervious area that receives the runoff from an unconnected impervious area.

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Curb requirements included in the RSIS and many municipal regulations are often cited as a limiting factor in the use of unconnected impervious areas. However, residential curb requirements in the current RSIS provide flexibility to limit curbing, and also allow the use of curb cuts to disconnect impervious areas. The RSIS states in Section 4.3 (d):

> *Curb requirements may be waived by the appropriate municipal approving agency, and shoulders and/or drainage swales used when it can be shown that: shoulders are required by CAFRA; soil and/or topography make the use of shoulders and/or drainage swales preferable; and/or the community desires to preserve its rural character by using shoulders and/or drainage swales instead of curbs.*

In addition, the top of the curbing may be set level with the impervious and downstream pervious surfaces to allow sheet flow from one to the other. Similar opportunities to use level curbs and/or curb cuts may also exist at nonresidential developments.

It is important to note that, in designing and utilizing unconnected impervious areas, consideration must be given, on a case-by-case basis, to sensitive or limiting geographic conditions such as Karst topography and rough, irregular topography.

E. Vegetated Roofs

Vegetated roofs, also known as green roofs, are an innovative way to reduce impervious surfaces at development sites in New Jersey. They have been used successfully in several European countries, including Germany. A vegetated or green roof consists of a lightweight vegetated planting bed that is installed on a new or existing roof. This enables the roof to retain precipitation on and within the planting bed and on the surface of the vegetation. This stored water is later released through evapotranspiration, thereby reducing the volume of runoff from the roof. The exact amount of rainfall storage (and runoff reduction) will depend upon the depth and porosity of the planting bed and, to a lesser degree, the type and density of vegetation.

Vegetated roofs can be implemented using specialized commercial products. A common arrangement consists of an impervious synthetic underdrain system that allows drainage of water from the roof surface (known as a geomembrane) and a 1 to 6-inch thick layer of lightweight planting media. The type of vegetation to be used should be based on access and maintenance requirements and secondary uses of specific roof areas. Except for periodic fertilization and watering, a meadow-like planting of perennial plants can require minimal maintenance.

When designing new systems or converting existing roofs to green roofs, adequate capacity and easy access to gutters, underdrains, downspouts, and other components of the roof's drainage system must be provided. Clogging of underdrains must be prevented through a combination of sound design and regular inspection and maintenance. Overflows must also be provided to address drainage system malfunctions and rainfalls that exceed the system's design storm. Green roofs will be most effective during the spring and summer growing season, with somewhat reduced effectiveness during the late fall and winter months. Depending on the type of vegetation selected and the amount of rainfall, there may be a need for occasional watering and perhaps fertilization of the vegetative cover. Therefore, special provisions must be provided to readily enable such activities.

The structural integrity of the roof and the building must support any loading resulting from the vegetation, soil, and rainfall stored in the rooftop. In general, the slope (horizontal to vertical) of the roof can vary between 12:1 and 4:1. Steeper roofs will usually require erosion protection to hold the planting media in place at least until the plants become established. The roof slope must not exceed 1:1. Relatively flat roofs require an underdrain layer, while steeper roofs can drain by gravity.

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4. Time of Concentration Modifications

Time of concentration (Tc) is technically defined as "the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed."[1] Stated more simply, it represents the time needed to drain runoff from an area. Changes in peak flow result from changes in Tc from drainage areas, with longer times yielding smaller peak runoff rates and shorter times causing greater ones. Site factors that affect a drainage area's time of concentration include flow length, flow regime, surface roughness, channel shape, and slope.[2] Typically, land development modifies most if not all of these factors in ways that cause the time of concentration of a drainage area to be shorter (and, therefore the peak runoff rates to be greater) after development than prior to development.

However, during site design, it may be possible to avoid or minimize this decrease in time of concentration by controlling the various site factors that affect it. Considerations for three factors are presented below. In reviewing these considerations, it must be remembered that, although the time of concentration of a drainage area is computed for a specific flow path (as determined by the technical definition above), it is actually a representative time for an entire drainage area. As such, the modifications discussed below that pertain to sheet flow from a drainage area to a more defined conveyance system (such as a channel or storm sewer) must not only be applied along the specific Tc route, but throughout the entire area where the sheet flow is occurring.

For certain areas in New Jersey, such as those with Karst topography, the flat topography of the Pinelands and shore areas, and the rough terrain of the northwest, the development of a time of concentration may be difficult. In such cases, the designer should confer with the applicable review agencies in order to develop a representative Tc route and time.

A. Surface Roughness Changes

Based upon hydraulic theory, surface roughness coefficients used in sheet flow computations are based on the land cover of a drainage area, with areas of dense vegetation having generally higher coefficients (and longer times of concentration) than smoother surfaces such as paved or grassed areas. This surface roughness can also vary with season and degree of maintenance, particularly for turf grass areas. Therefore, site designers should preserve existing native vegetation or use native plants to restore disturbed areas (as discussed above in *1. Vegetation and Landscaping*) in order to increase surface roughness and time of concentration, and consequently reduce the peak flows from a drainage area.

B. Slope Reduction

As noted above, ground slope is another important factor in determining a drainage area's time of concentration and peak discharge. Reducing slopes in graded areas can help minimize Tc reductions and peak flow increases. In addition, terraces and reduced slope channels can be constructed on a sloping area to provide additional travel time. Terraces can also be used to redirect runoff to flow along rather than across the slope, decreasing the slope and increasing the flow length and, subsequently, the time of concentration. Care should also be taken to ensure that the grading of vegetated areas is sufficient to allow for positive drainage as required by local or state regulations, particularly adjacent to buildings and other structures.

[1] USDA Soil Conservation Service Technical Release 55, June 1986, Urban Hydrology for Small Watersheds.

[2] Ibid.

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C. Vegetated Conveyance

The use of vegetated conveyance measures such as channels and swales can increase the surface roughness along the Tc flow path and increase the overall Tc. Grade stabilization structures can also be added to further decrease the flow velocity. In addition, vegetated channels can provide opportunities for runoff treatment, runoff infiltration, and groundwater discharge. Such measures can replace conventional storm sewer systems in small drainage areas. Site specific conditions such as slope, soil type, drainage area, and site constraints must be considered in the design of a vegetated channel or swale. Additional requirements are presented in the Standards for Soil Erosion and Sediment Control in New Jersey. The local Soil Conservation District will review the project to ensure stability.

In designing vegetated conveyance measures, care should be taken to protect transitions to and from culverts from erosion caused by flow acceleration and turbulence. In addition, vegetated channels and swales should be constructed only in areas with sufficient sunlight to adequately maintain vegetation. The channels must also be able to drain and dry out between storm events. As an alternative to grasses, the channel could be planted with ground covers that tolerate frequent short-duration flooding. The vegetation must be tolerant of the hydrologic regime associated with the channel.

In the design of any site features to control or modify time of concentration, it should be noted that the effectiveness of the design may vary with runoff rate and, therefore, storm frequency. As a result, modifications to such factors as slope or surface roughness may have a significant effect on the time of concentration for a one-year storm event, but little or no effect on a larger 10 or 100-year event. Therefore, it may be necessary (and even prudent) to vary Tc with storm frequency, utilizing the longer one for the frequent events associated with stormwater quality and the shorter (and more conservative) one for the more extreme erosion and flood control storms. Care should also be taken when analyzing a time of concentration to ensure that the watershed it represents is relatively homogenous. Otherwise, the drainage area may need to be divided into subareas with a separate Tc computed for each.

Structural Stormwater Management Measures

In addition to the nonstructural LID-BMPs presented in the previous section, structural stormwater management measures can also be used to implement low impact development. Known as structural LID-BMPs, these structural measures are identified as low impact BMPs by storing, infiltrating, and/or treating runoff close to its source. Unlike typical structural BMPs that are centrally located along a site's drainage system, structural LID-BMPs are normally dispersed throughout a development site and, like the nonstructural LID measures discussed above, provide ways to more closely mimic the site's predeveloped hydrology than standard structural BMPs.

As structural facilities, however, the configuration, operation, and maintenance of structural LID-BMPs are similar to standard structural BMPs, although their location closer to the runoff source typically allows them to be smaller in size. An example of this relationship is the use of bioretention basins as structural LID-BMPs in a residential subdivision. Also known as raingardens, they are typically located on each lot in the subdivision and, as such, each receives considerably less runoff than would a single, centralized bioretention basin. Nevertheless, similar to the centralized bioretention basin, each basin would be designed and constructed in accordance with the technical standards presented in Chapter 9. Designers should take care to ensure that sufficient setbacks are provided to protect adjacent structures from impacts due to the anticipated functioning of LID-BMPs.

The integration of bioretention basins and other structural BMPs throughout a development site can be viewed as applying low impact development techniques. Many standard BMPs can be done at an LID scale. Drywells, infiltration systems, bioretention basins, and both surface and subsurface detention basins can all be downsized to address stormwater runoff close to its source, as opposed to a centralized location at the end of a stormwater collection and drainage system. Detailed design, construction, and maintenance information on various structural BMPs is presented in Chapter 9.

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Preventative Source Controls

The most effective way to address water quality concerns is by preventing pollutants from being part of stormwater runoff. Pollution prevention techniques should be incorporated into site designs, especially at commercial and light industrial sites, to minimize the potential impact those activities may have on stormwater runoff quality. Preventative source controls, while more limited, can also be applied in residential development, particularly in preventing floatables (trash and debris) from entering storm sewer drainage systems.

Preventative source controls can prevent the accumulation of trash and debris in drainage systems by providing trash receptacles at appropriate locations throughout the site. The benefits are realized only if regular trash collection is provided; this should be included as part of the site maintenance plan. The installation of litter fences, especially at commercial properties, to prevent the blowing of litter off the site is another measure that addresses the accumulation of trash and debris. At industrial/commercial sites, maintenance plans should include regular sweeping or manual collection of litter. In residential developments, the inclusion of "pet waste stations" in the site design of dense housing developments such as apartment, townhouse and condominium communities prevents pollutants from entering the stormwater system. Pet waste stations should include bags for picking up pet waste and containers for pet waste disposal. Providing these stations will increase the likelihood that pet waste is properly disposed and prevent it from being washed into streams as part of stormwater runoff.

Site design features can also prevent the discharge of trash and debris into receiving streams. Storm drain inlets, trash racks, or structural BMPs are types of features that prevent the discharge of trash and debris. The New Jersey Pollutant Discharge Elimination System stormwater general permits issued under the Municipal Stormwater Regulation Program provide information on storm drain inlets that are designed specifically to prevent the discharge of large trash and debris from drainage systems by reducing the size of each individual clear space in both the grate and curb opening. Where allowed and consistent with the design standard, alternative devices may be substituted for these storm drain inlets.

Some site design features help to prevent or contain spills and other harmful accumulations of pollutants at industrial or commercial developments. These include roofs, overhangs, knee walls, berms, secondary containment, stormwater diversion devices, oil/grit separators and other manufactured treatment devices, and indoor storage. Specifically, berms and secondary containment can contain spills of fuels or other chemicals, and roofs and walls can prevent or minimize exposure of stormwater to activities and materials such as fueling and maintenance, trash, waste motor oil, storage or handling of landscape and garden chemicals (including fertilizers and pesticides) at retail stores, and storage or handling of raw materials, intermediate products, final products, and by-products at warehouses or manufacturing plants. Stormwater diversion devices, such as curbing and berms, can divert stormwater away from areas where it may come into contact with materials or activities that could affect stormwater quality. Oil/grit separators and other manufactured treatment devices may contain certain spills and treat stormwater that has come into contact with spills or residual material from spills. Also, the inclusion in the site design of adequate indoor storage of raw materials, intermediate products, final products, and by-products at commercial and industrial sites is the best method for preventing potential stormwater quality issues.

Stormwater as a Resource

Stormwater runoff from precipitation is often viewed as a nuisance. However, an increase in stormwater runoff is an indicator of reduced infiltration and recharge to groundwater. As such, this negative view of stormwater runoff must be corrected to more accurately consider stormwater as a resource vital to achieving more sustainable development.

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For example, stormwater runoff from roofs can be captured for future re-use using a variety of collection and storage devices. These systems can be installed above or below ground. Above ground systems could be simple rain barrels that overflow onto a splash pad. Underground systems may be concrete structures requiring a pump to empty them or, if the topography allows it, they may drain by gravity. The size of this BMP depends on the contributing roof area. In commercial or high-density residential applications, roof water cisterns can be incorporated into landscaping features such as water fountains and ponds. Where space permits, underground cisterns can discharge to an infiltration trench.

It is important to note that all collection and storage devices must be emptied between storm events in order to be considered effective in reducing site runoff volumes. In addition, the total system storage volume must be evaluated to determine its effectiveness as a runoff volume control measure. Nevertheless, re-use of the collected stormwater in place of potable water from an onsite well or public water supply will help minimize the site's over environmental impacts, reduce site operating costs, and help achieve a more sustainable environment.

Additional Considerations

As described above, low impact development typically relies on an array of nonstructural and relatively small structural BMPs distributed throughout a land development site to manage stormwater runoff quantity and quality. This distributed approach to stormwater management contrasts with the more traditional use of centralized stormwater facilities in New Jersey. However, as discussed briefly at the beginning of this chapter, this distributed approach means that the responsibility for successful operation and maintenance of the various LID-BMPs will not be centrally located at a municipality or other government entity. Instead, such responsibility will be distributed over a variety of property owners with varying interests, knowledge, abilities, and resources. As such, it is vital to have public understanding of and support for the various LID-BMPs that a municipality authorizes for use in its stormwater management program and land development regulations. Such understanding and support must include both an appreciation for the necessary role that the LID-BMPs play in meeting a development site's stormwater obligations and a strong, enforceable commitment to preserve and maintain them.

This is particularly true for nonstructural LID-BMPs, which may rely on such techniques as preserving existing or planting new vegetation, minimizing building footprints, and limiting lot impervious cover and/or disturbance limits to effectively manage stormwater runoff and prevent downstream environmental and property damage. The Stormwater Rule at Section 5.3(c) requires the deed restriction of LID-BMPs since such practices may not be readily recognized by property owners as stormwater management measures or facilities, and they may be more prone to neglect, abandonment, or removal than centralized structural BMPs unless the property owners fully recognize, understand, and support their use.

Similar problems may also arise with structural LID-BMPs which, due to their smaller size and their location on individual lots much closer to homes than larger, centralized facilities, may be overlooked as vital stormwater management measures and similarly neglected or abandoned. In the worst case, a resident or property owner may remove a vital structural LID-BMP located on their property. Such action may occur due to an alternative need for the land (e.g., house addition, driveway expansion, storage shed), adverse aesthetic impacts, or excessive maintenance demands. Regardless of the reasons, a municipality may find it extremely difficult to have the eliminated LID-BMP either restored or replaced by a centralized facility.

Therefore, it is vital that each municipality critically evaluate the range of available nonstructural and structural LID-BMPs presented in this manual and elsewhere and authorize the use of only those that they can rely on to be properly operated, maintained, and preserved by their residents, property owners, and municipal employees. Failure to achieve such acceptance, operation, and maintenance can lead to flooding, erosion, and runoff pollution; damage to downstream waterways and property; and threats to public safety.

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To assist in this evaluation, physical details and operation and maintenance requirements for a range of structural BMPs are presented in Chapter 9.

When evaluating LID-BMPs for authorization and incorporation into their land development ordinances and standards (as required by the NJDEP Stormwater Management Rules), a municipality should consider the following:

1. Permitting the use of certain LID-BMPs to manage the runoff from small, frequent storm events (such as those required by the NJDEP Stormwater Management Rules for groundwater recharge and stormwater quality), but prohibiting their consideration when addressing erosion and flood control requirements that typically involve larger, less frequent but more hazardous events. For example, a municipality may allow a site designer to use rain barrels and/or small, on-lot infiltration basins (also known as raingardens) to meet groundwater recharge and stormwater quality requirements, but may also require that such measures be ignored when meeting erosion and flood control standards.
2. Requiring deed restrictions or adopting ordinances that prohibit the alteration or elimination of on-lot LID-BMPs approved for use at a land development and officially identified as such. Such restrictions and ordinances should clearly define the right of the municipality to restore such LID-BMPs and the means by which it will be accomplished and financed.
3. Requiring deed restrictions or adopting ordinances that require land owners to properly maintain structural LID-BMPs located on their properties.
4. Requiring signage of LID-BMPs to indicate their function and use.
5. Preparing leaflets, brochures, and/or manuals for property owners on the function and importance of LID-BMPs and their maintenance and preservation. Similar efforts targeting such activities as proper septic system operation, recycling, lawn fertilization, and pet waste disposal have proven successful in many municipalities. Soil test kits and information regarding lawn fertilization are available for homeowners from the Rutgers Cooperative Extension.

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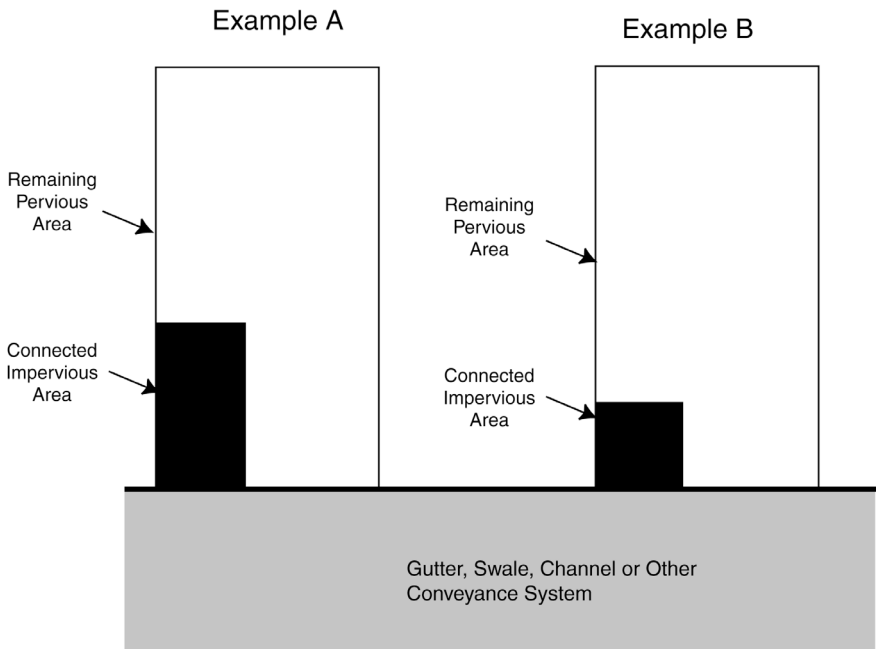
Low Impact Development Example Calculations

Figure 2-1: Schematic of Lot with Connected Impervious Areas



Reduction of Runoff Volumes Due to Reduced Impervious Surfaces

Note: The computations were done by evaluating the runoff from the pervious and the impervious areas separately, and summing the volumes.

Example A

Given: A 32670 sf lot with 27470 sf lawn, HSG "B", CN = 61, 5200 sf impervious surface, CN = 98.
No impervious cover is disconnected
P_2 = 3.3 inches, P_{10} = 5.2 inches, and P_{100} = 7.5 inches

From the NRCS Runoff Equation, the following runoff volumes are generated:

2-year = 2444 cf
10-year = 5567 cf
100-year = 10175 cf

Example B

Given: A 32670 sf lot with 29870 sf lawn, HSG "B", CN = 61, 2800 sf impervious surface, CN = 98.
No impervious cover is disconnected
P_2 = 3.3 inches, P_{10} = 5.2 inches, and P_{100} = 7.5 inches

From the NRCS Runoff Equation, the following runoff volumes are generated:

2-year = 1927 cf
10-year = 4872 cf
100-year = 9336 cf

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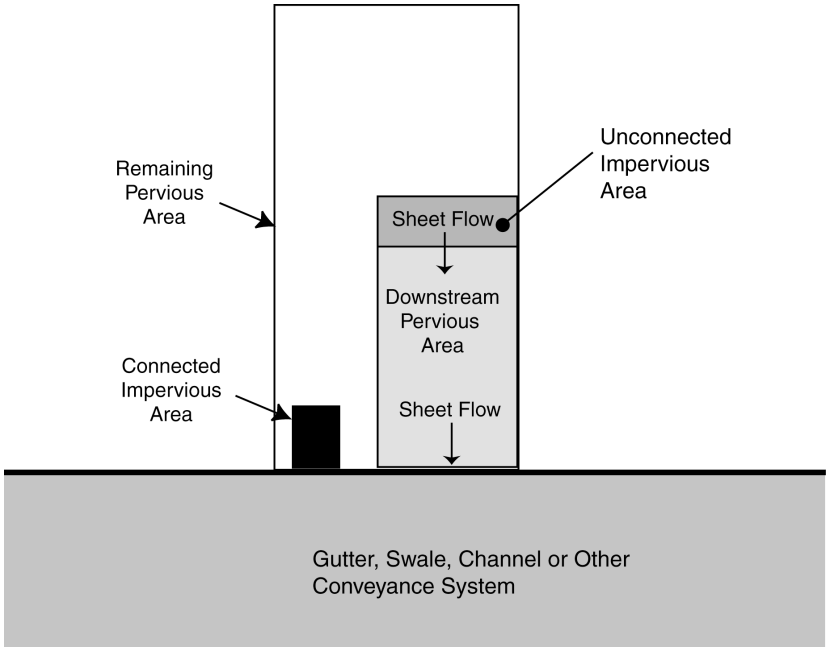
Figure 2-2: Schematic of Lot with Connected and Unconnected Impervious Areas



Changes in Runoff Volumes Due to Disconnection of Impervious Surfaces

Example C

Given: A 32670 sf lot with 29870 sf lawn, HSG "B", CN = 61, 2800 sf impervious surface of total impervious area, CN = 98.
2000 sf of impervious area discharges to 8900 sf of lawn, and 800 sf impervious area is directly connected
P_2 = 3.3 inches, P_{10} = 5.2 inches, and P_{100} = 7.5 inches

**NRCS Method:

2-year = 1625 cf
10-year = 4515 cf
100-year = 8947 cf

Two-Step Method (discussed in Chapter 5):

2-year = 1650 cf
10-year = 4580 cf
100-year = 9055 cf

**Note: The computations were done by evaluating the runoff from the pervious, impervious, and unconnected impervious areas separately, and summing the volumes. The equation for Figure 2-4, shown in Appendix F of the USDA Urban Hydrology for Small Watersheds, was used for the volume of unconnected impervious areas.

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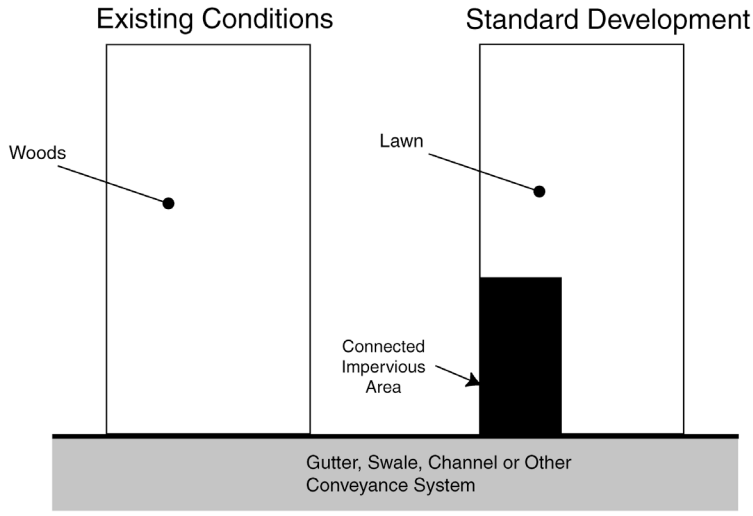
Figure 2-3: Schematic of Existing Lot and Standard Development Lot



Comparison of Changes in Runoff Due to Low Impact Development Techniques

Predeveloped Condition

0.75 acre lot
20,650 sf woods, HSG "B"
12,020 sf woods, HSG "C"
P_2 = 3.3 inches, P_{10} = 5.2 inches, and P_{100} = 7.5 inch

Tc = 0.52 hours
125 lf sheet flow, 1.3% slope, n = 0.40
135 lf shallow concentrated flow, 1.4% slope, unpaved

Postdeveloped Condition (Standard Development Lot)

0.75 acre lot
5200 sf of total impervious area, directly connected, Tc = 0.1 hours
P_2 = 3.3 inches, P_{10} = 5.2 inches, and P_{100} = 7.5 inch

Vegetated Area, Tc = 0.32 hours
125 lf sheet flow, 1.6% slope, n = 0.24
135 lf shallow conc flow, 1.4% slope, unpaved

Area (sf)	Land Use	HSG
17214	Lawn (good condition)	B
10256	Lawn (good condition)	C
3436	Impervious (directly connected)	B
1764	Impervious (directly connected)	C

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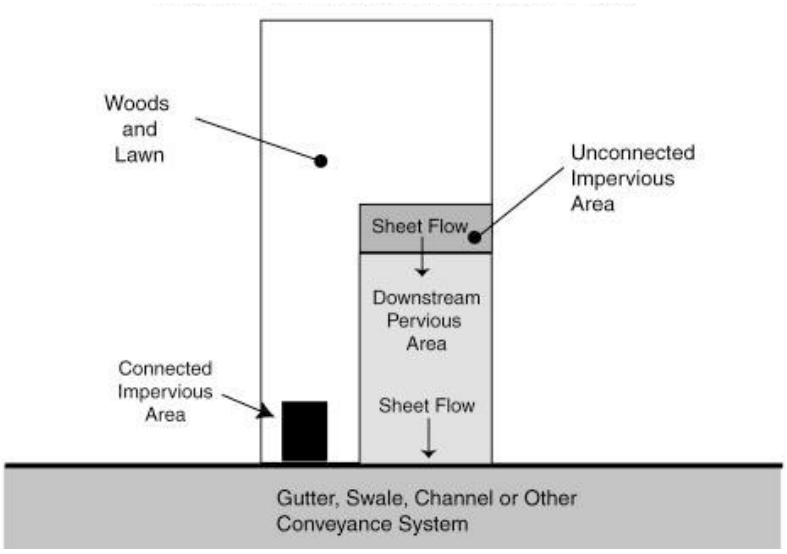
Figure 2-4: Schematic of Lot With LID Techniques



Postdeveloped Condition (With LID Techniques)

0.75 acre lot, 2800 sf of total impervious area

800 sf of impervious area, directly connected, Tc = 0.1 hours

2000 sf of impervious area, unconnected, discharging to 8906 sf of lawn

P_2 = 3.3 inches, P_{10} = 5.2 inches, and P_{100} = 7.5 inch

Nonstructural stormwater management strategies used: minimized land disturbance; minimized compaction; maximized the protection of vegetation; minimized the decrease in post-development time of concentration through retaining existing wooded area; and minimized and disconnected impervious cover.

Vegetated Area, Tc = 0.52 hours

125 lf sheet flow, 1.3% slope, n = 0.40

135 lf shallow conc flow, 2.1% slope, unpaved

Area (sf)	Land Use	HSG
17524	Woods (good condition)	B
1564	Lawn (good condition)	B
1876	Lawn (good condition)	C

Unconnected Impervious Area, Tc = 0.23 hours

100 lf sheet flow, 2.1% slope, n = 0.24

Note: The time of concentration was developed from the receiving pervious area alone.

Distribution of Pervious Areas Receiving Unconnected Impervious Area Runoff		
Area (sf)	**Land Use**	**HSG**
1562	Lawn (good condition)	B
7344	Lawn (good condition)	C

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Peak Flow Rates and Volumes

	Existing Conditions	Proposed Conditions (Standard Development)	Proposed Conditions (Nonstructural Stormwater Management Strategies)	
			Two-Step Method	NRCS Method
2-year	0.15 cfs 0.030 ac-ft	0.48 cfs 0.067 ac-ft	0.29 cfs 0.043 ac-ft	0.27 cfs 0.041 ac-ft
10-year	0.62 cfs 0.093 ac-ft	1.18 cfs 0.150 ac-ft	.81 cfs 0.116 ac-ft	.78 cfs 0.109 ac-ft
100-year	1.35 cfs 0.192 ac-ft	2.19 cfs 0.261 ac-ft	1.61 cfs 0.214 ac-ft	1.58 cfs 0.211 ac-ft

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New Jersey Stormwater Best Management Practices Manual

February 2004

CHAPTER 3

Regional and Municipal Stormwater Management Plans

Regional Stormwater Management Plans

Regional stormwater management planning is a water resource management strategy that identifies and develops solutions to problems that can be managed most effectively on a regional basis. The product of this planning process, the regional stormwater management plan (RSWMP), spans the boundaries of individual properties, neighborhoods, municipalities, and even county borders. A plan may address an existing water quantity issue, such as localized flooding; an existing water quality issue, such as excess pollutant loading; or issues of water quantity and quality that may be generated by future development. Regional stormwater planning creates a combination of regulations and actions tailored to the specific needs of a drainage area, but it does not reduce environmental protection. Rather, it allows regulations more flexibility to match the concerns, conditions, and features of regions that are connected by a common drainage area.

Well-designed RSWMPs share common elements. First, they are collaborative. Adoption and implementation of an RSWMP depends on the cooperation of county and municipal governing bodies, regulatory agencies, and environmental organizations. Any plan designed without their active involvement and consent has dim prospects for adoption. Second, they focus on identifying and solving specific problems. Shared regional problems, such as recurring flooding, unswimmable lakes, reduced stream flows, or contaminated public water supplies, can drive the collaboration needed to trigger and sustain the planning and adoption process. Specific problems also lend themselves to specific, measurable, and quantifiable implementation steps. For example, an RSWMP can spell out the specific measures required to reduce pollutant loads determined by the TMDL (total maximum daily load) process. Third, an RSWMP's recommendations are based on sound engineering and science geared to local land use conditions. All measures included in an RSWMP must be supported by a rationale that includes a feasibility analysis for achieving specific objectives as well as a monitoring plan to gauge long-run effectiveness of each measure. Plans must be reviewed every five years at a minimum. Fourth and finally, RSWMPs include a strong emphasis on maintenance and monitoring to ensure long-term functioning of the structures, measures, and programs recommended by the plan.

Regional stormwater management planning represents a fundamental shift in thinking – and execution. Traditionally, stormwater has been planned for and managed on a site-by-site basis, with the combined effect of thousands of individual stormwater management decisions in one watershed creating unintended consequences. For example, a detention or retention basin may make perfect sense to manage stormwater for an individual property. Typically, these basins were designed to ensure that peak runoff rates from a site did not increase after the property was developed. However, when hundreds of such basins simultaneously retain and then release stormwater in a regional drainage area, they can actually increase flooding and downstream erosion by extending peak runoff rates and increasing non-peak flows. As development increase in a drainage area, this site-by-site planning failed to account for the increased volume of runoff caused by regional increases in development. To address these increased volumes, recent regulations, including the Stormwater Management Rules, require stormwater management plans to reduce peak flows leaving a site. The regulations are based on analyses that demonstrate how to prevent increases in the flows that cause both flooding and erosion. However, this statewide method for addressing flooding and erosion may not be the optimum solution for managing runoff for a specific drainage area. For example, an RSWMP may recommend longer detention times at the top of a watershed to release water more slowly into local streams, and the plan may call for reduced detention times in more urbanized sections of the watershed where storage space is limited.

RSWMPs optimize flexible use of stormwater management measures by providing the authority to create new, customized regulatory requirements and by setting priorities for actions that address the specific stormwater quality, quantity, and recharge objectives within the planning area. Although performance standards can be changed from those proposed in the Stormwater Management Rules, RSWMPs must avoid adverse impacts downstream of the planning area. Regional planning also creates more options for groundwater recharge. Local topography, geology, and soil conditions that restrict infiltration may present daunting design challenges for some sites and municipalities, while well-suited recharge sites may lie just up- or downstream. In each case, better solutions become available with regional planning.

Sizing an RSWMP

Determining the size of a drainage area is one of the first technical challenges in creating an RSWMP. Regional stormwater management is fundamentally a problem-centered planning process, so the size of an RSWMP drainage area may depend on the nature and location of previously identified local concerns such as water quality impairment, erosion damage, reduced stream flows, sedimentation, inadequate groundwater recharge, or flooding. RSWMPs are created to address existing problems or to anticipate and avoid future ones. Local interest groups may already have specific concerns that can be addressed with a regional plan. TMDL implementation plans may identify regional stormwater management plans as a long-term management measure to address impairment for a specific stream segment.

A build-out analysis may identify additional problems during the assessment portion of regional plan development. A regional plan developed for the Jackson Brook in Morris County, for example, was driven initially by flooding concerns, but it also proposes improvements to reduce pollutant loads projected under full development conditions. A regional plan proposed for the Mulhockaway Creek seeks to anticipate and address concerns about development in an environmentally sensitive area of the South Branch of the Raritan River. A plan proposed for the Cedar Grove Brook in Franklin Township is targeting water quality issues in an urbanized area just upstream from water supply intakes.

Available funding is a key variable in determining the size of a regional area for a plan. Budgets for developing RSWMPs typically exceed $100,000 because they often require extensive collection and complex analysis of field data. Those costs tend to limit the size of the drainage area to be studied, and the regional plans completed or proposed in New Jersey tend to fall between 5 and 20 square miles. The budget for a

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12-square-mile drainage area around the Mulhockaway Creek drainage area, for example, is projected at $300,000. The budget to develop the plan for the 5-square-mile drainage area around Cedar Grove Creek was $200,000. The cost of implementing an RSWMP, of course, depends on its findings and recommendations. If writing a plan can easily run into six figures, implementing one can easily exceed $1 million if construction of large stormwater management structures is called for in the plan. These costs, however, are dependent on the goals and objectives of the plan and the specific conditions of the area; therefore, costs can vary significantly between regional stormwater management plans.

In New Jersey, with its history of municipal autonomy know as "home rule," smaller drainage areas tend to be more politically feasible. Regional stormwater planning requires municipalities to align their zoning and development standards with the plan, so drainage areas that involve three or four neighboring municipalities with a common concern may have a realistic chance of aligning development standards to solve their shared problem. That possibility would likely diminish dramatically if the regional plan involves tens of municipalities lacking a common, immediate problem.

Beginning the Process

By law and by definition, the development of a regional stormwater management plan is a participatory process. In fact, N.J.A.C. 7:8-3, the regulations authorizing optional regional plans require the creation of a broadly representative regional planning committee as the first step in the process. That committee then designates a lead planning agency to marshal the technical and administrative resources required to develop and implement a regional plan.

From a technical standpoint, plan development begins with characterizing and assessing the drainage area by gathering and reviewing all relevant water quality and quantity information currently available. This requires scouring for all available data from sources including:

- state and Federal Emergency Management Agency (FEMA) floodplain maps;
- hydraulic analysis and stream cross section data from stream encroachment permits;
- topographic data from aerial photos with two-foot contours;
- water quality data from New Jersey Pollution Discharge Elimination System (NJPDES) permits or intake waters from local water treatment facilities; and
- monitoring data from the U.S. Geological Survey, the Environmental Protection Agency's STORET database, the NJDEP, local health departments, environmental commissions, or watershed associations.

In New Jersey, local Soil Conservation Districts are a valuable source of field observations on streambanks, erosion, and scouring that can be collected only from walking along stream corridors. Additional information regarding local conditions may be available from the Division of Watershed Management and local environmental organizations. Recent watershed characterization studies, if available, also provide data to focus planning efforts on water quality issues.

If a watershed characterization study is not available, consider performing a relatively quick and inexpensive Geographic Information Systems (GIS) analysis that matches water supply sources with reported water quality degradations and potential pollutant sources.

The full range of steps and requirements for creating, implementing, and adopting an RSWMP are included in N.J.A.C. 7:8-3. A summary of those requirements is outlined in this chapter, including:

- a written statement from each public entity on the committee confirming the authority of each to develop and implement a stormwater management plan;
- a discussion of both the majority and minority positions, if portions of the plan do not represent a consensus of the committee;

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- characterization and evaluation of the planning committee's drainage area;
- specific objectives for water quality, groundwater recharge, and water quantity for the planning committee's drainage area;
- specific performance standards for water quality, groundwater recharge, and water quantity for the committee's planning area; and
- stormwater management measures selected by the planning committee and an explanation of why they were chosen.

Steps to Create, Implement and Adopt an RSWMP

Planning the RSWMP Process

Because an RSWMP is both a technical planning procedure and a regulatory process, it requires active participation from organizations that would likely be affected by the plan. In fact, the first step in the RSWMP process is to create a regional stormwater management planning committee and select a lead planning agency for the express purpose of developing a regional plan. The committee is charged with soliciting information from the following interested groups and organizations:

- government agencies at all levels, including Soil Conservation Districts;
- local and regional environmental groups and organizations including lake associations, watershed associations, and environmental commissions;
- water supply and wastewater treatment utilities, authorities, and agencies, and watershed management planning agencies; and
- residents in the drainage area.

The planning committee must designate a lead planning agency to serve as the primary contact for the committee. The Lead Agency must submit a request for the recognition of the regional stormwater plan committee to the NJDEP. This request must include a draft work plan, schedule of activities, and the information used to invite organizations to participate in the planning committee. The NJDEP has 45 days to approve or deny the request or ask for more information.

Data Gathering and Priority Setting

Data gathering and priority setting can be the most expensive steps in the process because they often require time-intensive collection of field data on variables such as stream elevations, erosion hot spots, and water quality. To minimize the cost of gathering this data, the NJDEP encourages planners to make maximum use of existing information, including information on the department's GIS web site (www.state.nj.us/dep/gis) or developed through the watershed management process. This task is ideally suited for analysis and display on Geographic Information Systems, and all maps developed must meet New Jersey's digital data standards in N.J.A.C. 7:1D. The following items should be included in the assessment unless they are not pertinent to a specific analysis.

Maps

The maps must first clearly delineate the drainage area boundaries, showing both existing and projected land uses assuming full development under current zoning. The following layers of information should be included: soils, topography, flood hazard areas, well protection, and groundwater recharge areas. All water bodies designated as water quality-limited surface water as well as environmentally sensitive areas or special classifications should be identified, including river areas designated under the New Jersey Wild and Scenic

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Rivers Act or the Federal Wild and Scenic Rivers Act. These maps must identify stormwater management structures, surface water intakes, and public water supply reservoirs in addition to features that are outside the regional planning areas but discharge or flow into the drainage area.

Key Stormwater Management Features

The assessment must include an inventory of all key stormwater management features, including slopes, swales, outfall structures, culverts, and impoundment areas pertinent to stormwater management and required for analyzing the drainage area. Often this data can be gathered only by physically walking stream corridors to record features such as stream widths, streambank conditions, pollutant sources, eroded areas, and other relevant data. This data collection requires trained eyes in the field and often accounts for a substantial portion of the cost of developing an RSWMP.

Modeling and Analysis

Analysis of the drainage area or a water quality, groundwater recharge and water quantity hydrologic and hydraulic model may need to be performed if new performance standards are being proposed. This analysis is critical to identifying the current or potential concerns that drive the entire plan. The analysis must include existing and projected land uses assuming full development under current zoning.

Relevant Current Regulations

The assessment must identify and evaluate existing municipal, county, state, federal, and other regulations related to stormwater management, groundwater recharge, and water quality and quantity, including programs to develop total maximum daily load (TMDLs).

Once the characterization and assessment of the drainage area is complete, the RSWMP must identify current stormwater-related water quality concerns and forecast future ones, assuming full development under current zoning. The inventory should include current and potential stormwater pollutant sources in the regional planning area including urban and suburban development, roads, storm sewers, agricultural or mining operations, and waterfront development. The New Jersey Integrated Water Quality Monitoring and Assessment Report (305(b) and 303(d)) (Integrated List) is required by the Federal Clean Water Act to be prepared biennially and is a valuable source of water quality information. This combined report presents the extent to which New Jersey waters are attaining water quality standards, and identifies waters that are impaired. Sublist 5 of the Integrated List constitutes the list of waters impaired or threatened by pollutants for which one or more TMDLs are needed.

Once identified, these water-quality concerns must be ranked based on criteria determined by the planning committee. They can include: threat to public health, safety and welfare; damage to water supplies; risk of damage to the biological integrity of water bodies; mosquito control; groundwater depletion; or impacts to the ecosystem, among others.

If a TMDL has been adopted for any part of a water body in the planning area, these water-quality objectives must incorporate the loading reductions established in the TMDL for stormwater runoff. If any part of a water body is on Sublist 5 of the Integrated List due to stormwater-related impacts, the plan's objectives must specifically address those pollutants of concern.

Regional stormwater management plans must also identify and rank issues of water quantity and groundwater recharge as well as water quality. Thus, the broad goal of the plan is to eliminate, reduce, or minimize stormwater-related impacts associated with current and future land use. The minimum standard of protection is the level that would be achieved by conforming to New Jersey's Design and Performance Standards for Stormwater Management Measures when implemented throughout the regional stormwater management planning area.

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Designing Regional Stormwater Solutions

An RSWMP must include design and performance standards to meet the New Jersey water quality, water quantity, and groundwater recharge standards in N.J.A.C. 7:8-3.5. However, because an RSWMP addresses concerns on a regional basis, the design and performance standards need not be uniform throughout the planning area if they satisfy N.J.A.C. 7:8-5 when considered as a whole. Any alternative standards must be at least as protective when implemented throughout the regional stormwater management planning area.

Once the objectives and performance standards have been identified, an RSWMP must outline the stormwater management measures needed to achieve the objectives. The plan may include the following guidelines for new or existing land uses or other measures: design and performance standards for storm water quality, stormwater quantity, or groundwater recharge for new development; modifications to existing stormwater management structural controls; elimination of illegal or illicit discharges; prevention or minimization of the exposure of pollutants to stormwater; or control of floatables. The plan may also include measures to enhance, protect, or preserve land or water areas for purposes of flood control, water quality protection, or conservation of natural resources. And, because many stormwater management concerns can be traced directly to the lifestyle choices of watershed residents, a plan may choose to emphasize public education programs that address root causes of water quantity and quality impacts.

Whatever measures are selected, the plan must include two important additional features. First, the plan must explain the committee's rationale for including the selected measure. The rationale should include a feasibility and cost/benefit analysis, an estimate of reduction in pollutant loads, and a projection of performance longevity. Second, the plan must specifically address maintenance requirements for each stormwater management measure, including preventative and corrective maintenance, a long-term maintenance implementation schedule, and clear identification of the organization or entity responsible for implementation and maintenance.

Implementation and Evaluation Strategies

The implementation strategy begins by identifying the agency assigned to coordinate plan implementation, including long-term monitoring requirements. The plan must identify the agency appointed to implement and monitor each measure in the plan along with a timetable for implementation. It must include a process to evaluate the entire plan at least once every five years and should include a budget that projects both long- and short-term costs for each measure. The strategy should identify possible current and potential funding sources to implement the RSWMP.

The long-term monitoring program should provide information about land use, water quality, water quantity, groundwater, and riparian and aquatic habitat conditions. Monitoring data may include information from watershed management agencies and monitoring programs operated by other agencies, including volunteer programs.

Once complete, an RSWMP will be submitted for review to the NJDEP and, if applicable, to the designated water quality management planning agency as an amendment to areawide water quality management plans. If the plan is approved, the NJDEP will propose to amend the areawide water quality management plan as outlined in N.J.A.C. 7:15-3.4(g). Any performance standards developed under an RSWMP adopted by the NJDEP in effect supersedes the minimum design and performance standards in N.J.A.C. 7:8-5 of the Stormwater Management Rules. NJDEP will use the plan requirements to review stormwater management requirements for activities currently regulated by the Freshwater Wetland Protection Act, Coastal Zone Management Rules, Flood Hazard Area Control Act Rules, New Jersey Pollution Discharge Elimination System Rules, and Dam Safety Standards. Each municipality in the regional stormwater management planning area must incorporate the applicable provisions of the plan into a new or amended municipal stormwater management plan. In addition, the stormwater management review for residential developments, which are based on the Residential Site Improvement Standards, will be based on the regional stormwater management plan. The requirements of the plan apply only to stormwater management criteria of other regulatory programs; additional requirements may be imposed as necessary under each program.

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Municipal Stormwater Management Plans

A municipal stormwater management plan (MSWMP) documents the strategy of a specific municipality to address stormwater-related impacts. MSWMPs provide the structure and process for addressing stormwater management in the municipality. They are required by the Environmental Protection Agency's Phase II Stormwater Permitting Rules; the mandatory elements of the plan are described in the Stormwater Management Rules.

The municipal plan must address and achieve the goals of stormwater management discussed in N.J.A.C. 7:8-2. For new development, the plan must incorporate the performance standards for water quantity, water quality, and groundwater recharge in the Stormwater Management Rules at N.J.A.C. 7:8-5. If alternate standards have been established by an adopted regional stormwater management plan (RSWMP), the MSWMP must be consistent with it. A copy of the ordinances incorporating the performance standards must be included in the plan.

The MSWMP must be coordinated and consistent with other regulations on stormwater management issues such as those of the Soil Conservation Districts and the Residential Site Improvement Standards. The MSWMP may also address existing stormwater issues such as those identified in an RSWMP. In addition to specific design criteria, maintenance and safety requirements are a critical component. Preventative and corrective maintenance strategies must be included in the plan to ensure long-term effectiveness of stormwater management facilities. Safety standards discussed in Subchapter 6 of the Stormwater Management Rules must also be included in the MSWMP.

The plan must provide a view of the impacts of existing zoning and environmentally constrained areas on the municipality's landscape. In addition, the plan must include: maps of existing streams, groundwater recharge, and wellhead protection areas; build-out conditions based on existing zoning; and an evaluation of the existing master plan and land use ordinances that identifies areas to be amended to enable the implementation of nonstructural stormwater management techniques identified in the Rules. In order for the municipality to grant variances or exemptions from the design and performance standards for groundwater recharge and stormwater runoff quality and quantity, the municipality must provide a mitigation strategy in the MSWMP. The municipality should use the information provided in the plan to ensure that stormwater management objectives are completely addressed in the implementation of the municipal plan and ordinances.

MSWMPs are subject to review by county planning agencies to determine whether they meet the standards required by the Stormwater Management Rules. A copy of the proposed plan must also be sent to the Department of Environmental Protection, Division of Watershed Management. The county must approve, conditionally approve, or disapprove the plan in writing within 60 days. Generally, the plan becomes effective upon approval by the county; however, in the case of conditional approvals, the plan becomes effective after the municipality meets the conditions of approval.

A sample municipal stormwater management plan is provided in Appendix C.

Mitigation

Municipal stormwater management plans must incorporate design and performance standards that are as protective as those outlined in the Stormwater Management Rules or alternative standards in an adopted regional stormwater management plan. These design and performance standards focus on three areas: maintaining groundwater recharge from proposed development, minimizing the proposed development's impact on flooding, and minimizing the proposed development's water quality impact on state waters. Some projects have unique, site-specific conditions that prevent them from strict compliance with the performance standards. In order for the municipality to grant a waiver or exemption from strict compliance

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with the groundwater recharge and stormwater runoff quality and quantity requirements, the MSWMP must include a mitigation process documented in a mitigation plan contained within the larger MSWMP.

The mitigation plan must identify the measures required to offset any potential impact created by granting the variance or exemption to the performance standards. Several strategies can be used to mitigate a development project and its impacts. Applicants can: identify, design, and implement a compensating measure to mitigate impacts; complete a project identified by the municipality as equivalent to the environmental impact created by the exemption or variance; or, provide funding for municipal projects that would address existing stormwater impacts.

The preferred option is to identify a mitigation project within the drainage area that directly compensates for the projected impact of the variance or exception. For example, because of natural site constraints, a proposed development might be unable to fully meet the groundwater recharge criteria, with the projected impact being an annual net loss of 50,000 cubic feet of groundwater recharge volume. In this case, a mitigation plan might require recovery of the lost recharge volume by capturing existing runoff from an impervious area on a site within the same drainage basin. Applicants can be directed to identify potential properties suitable for the mitigation project and secure the easements necessary to implement the projects.

Municipalities can plan for mitigation by identifying property owned by the municipality or by securing easements, as conditions of planning and zoning board approvals, that would allow implementation of future mitigation measures. Municipalities should develop a list of projects that need to be implemented throughout the municipality that would compensate for groundwater recharge, stormwater quality, and stormwater quantity impacts. Project mitigation is simplified when the municipality identifies and ranks a series of projects an applicant can select, especially on land owned or controlled by the municipality. The selection process should be clearly stated so the applicant and the municipality have predictability in the mitigation process. In its mitigation plan, a municipality can assign credits for proposed projects that address groundwater recharge and stormwater runoff quantity and quality problems within the drainage area.

If direct mitigation for the projected environmental impact is not feasible, an MSWMP may permit a non-equivalent project mitigation. Using the development example above, a mitigation plan may require a project that helps alleviate an existing impairment, such as fecal contamination in local streams, rather than one that compensates for the loss of groundwater recharge. Non-equivalent mitigation projects allow a municipality to target issues of greatest concern within a drainage area and secure the resources to correct them. In this example, the non-equivalent mitigation option might be pursued if close examination of local water resources indicates that fecal impairment is a more critical parameter in the receiving stream than small losses in groundwater recharge and baseflow. Clearly, the non-equivalent mitigation option must be cautiously approached; in this example, the long-term impacts of cumulative losses in groundwater recharge on the aquifer and baseflow must be carefully considered before granting a variance or exception.

The third, and least preferred, mitigation option is to require funding for specific projects within the municipality that would retrofit existing groundwater recharge and stormwater quality or quantity issues. In urban redevelopment areas, funding projects that address stormwater impacts on a regional basis, such as the development or implementation of regional stormwater management plans, may be more effective than a project that provides direct compensation for the performance standard. Planners implementing this option should ensure that the funding results in projects that provide adequate protection to compensate for the impact created by failing to strictly comply with the performance standards in the Stormwater Management Rules.

All mitigation plans and reviews should consider the location of mitigation projects in relation to the property where the projected damage will occur. For example, if a project is unable to achieve the stormwater quantity performance standards upstream of an inadequate culvert, a mitigation project downstream of that culvert would not offer similar protection. If the groundwater recharge is the major contributor to a wetlands area, the new project should continue to provide recharge to the wetlands area. A municipality can develop a mitigation plan that includes any or all of the options discussed above. Plans can

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be as simple or as complex as the municipality chooses, provided they afford sufficient protection of the water resources. However, mitigation should not be an option until it is clearly demonstrated that on-site compliance is not practical.

Mitigation requirements should include a hierarchy of options that clearly offset the effect on groundwater recharge, stormwater quantity control, and/or stormwater quality control that was created by granting the variance or exemption. Mitigation must occur within the same drainage basin as that of the proposed development so that it provides benefits and protection similar to those that would have been achieved if the stormwater and recharge performance standards had been completely satisfied. Because these problems span political boundaries, mitigation projects could be located in adjacent municipalities within the drainage area with the cooperation of the municipalities, especially if a regional stormwater management plan has been developed for the drainage basin. The mitigation planning and approval process must ensure that long-term maintenance is achieved by clearly assigning responsibility for maintenance and by securing the funding and resources required to perform it.

Mitigation plans can differ greatly from municipality to municipality. As part of the mitigation plan development, consideration should be given to a specific municipality's water resource needs and ability to implement the plan. The following text is an example of a mitigation plan.

If a proposed development requests a variance or exemption from strict compliance with the groundwater recharge, stormwater quantity and stormwater quality requirements outlined in the Municipal Stormwater Management Plan and ordinances, the applicant must provide mitigation in accordance with the following:

1. A mitigation project must be implemented in the same drainage area as the proposed development. The project must provide additional groundwater recharge benefits, or protection from stormwater runoff quality and quantity from previously developed property that does not currently meet the design and performance standards outlined in the Municipal Stormwater Management Plan.
   - The applicant can select a project listed on the Municipal Stormwater Management Plan to compensate for the deficit from the performance standards resulting from the proposed project.
   - The applicant can obtain the necessary agreements to create a project to compensate for the deficit from the performance standards resulting from the proposed project.
   - The applicant must ensure the long-term maintenance of the project including the maintenance requirements under Chapters 8 and 9.
2. If a suitable mitigation site cannot be located in the same drainage area as the proposed development, as discussed under Option 1, the municipality may allow the applicant to provide funding to the municipality for an environmental enhancement project that has been identified in this Municipal Stormwater Management Plan. *[This option would be available only if the MSWMP includes a list of environmental enhancement projects that provide groundwater recharge, control flooding, or control nonpoint source pollution.]* The funding must be equal to or greater than the cost to implement the mitigation outlined above, including the costs associated with purchasing the property or easement for mitigation and the costs associated with the long-term maintenance requirements of the mitigation measure.

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Build-Out

A build-out analysis allows a municipality to project future development based on existing zoning and land-use regulations. It develops a picture, projected visually on a map, of what will happen if land is developed to the maximum extent allowed by law. A build-out analysis is not only useful for communities with undeveloped land. Areas with significant redevelopment potential should be considered in developing a build-out analysis. Many urban and older suburban municipalities contain properties that are not developed to the full extent allowed under current zoning. For example, properties zoned for industrial use may contain residential developments. Or, a developer might assemble several small residential and retail properties for demolition and redevelopment as an office complex. A build-out analysis can identify those properties and project impacts of their potential redevelopment.

Each municipal stormwater management plan is required to include a build-out analysis with information about the municipality based on the HUC14 boundaries. A hydrologic unit code 14 (HUC14) is a specific drainage area defined by the U.S. Geological Survey. For every individual HUC14 area in the municipality, the full development impervious cover and the anticipated pollutant loading based on full development must be determined.

A build-out analysis has two phases. The first visually depicts changes on a map and is best performed using a Geographic Information System (GIS), which is a computerized system for developing, analyzing, and displaying locational data. GIS allows planners to combine data sources such as zoning maps, tax maps, HUC14, and topographic maps, into "layers" that can be displayed on one map.

- Begin by constructing a base map of your community that includes the municipal boundary, existing roads, surface water bodies, HUC14 boundaries, impervious cover, existing development by land use types, groundwater recharge areas, and wellhead protection area layers. Existing GIS information sources may be helpful in the development of this plan, such as the NJDEP-GIS website at http://www.state.nj.us/dep/gis. Counties, watershed associations, and universities may also have information useful for the development of the base map.
- Identify and delineate land that cannot be developed because of legal restrictions, physical constraints, or environmental sensitivity. Examples include lands in permanently preserved open space, public ownership, deed restrictions, utility easements, steep slopes, wetlands, floodplains, and Category 1 Waters with the associated special water resource protection areas.
- Identify and delineate developable land under current zoning and land use regulations, as well as land that is not currently developed or restricted as discussed above. Identify and delineate developed areas within the municipality that have significant redevelopment potential and that have not been developed to the maximum allowed. For these undeveloped and underdeveloped areas, determine maximum future development by projecting the largest number of housing units allowed in residential zones and the largest number of buildings and most intensive land uses in commercial and industrial zones.

The second phase quantifies the impact of the changes based on information provided by the maps. This includes calculations of percentage of impervious surfaces, number of housing units and their density, and remaining farmland and open space acreage. GIS can also assist in this computation by providing values for specific sets of layers such as the combination of the municipality, HUC14, and impervious area layers. This set of variables can provide the impervious cover for each HUC14 required by the Stormwater Management Rules. Values can be exported to other programs from GIS for more comprehensive computations, including the pollutant loading calculations also required by the regulations.

The pollutant load computation is a planning tool that helps municipalities evaluate anticipated pollutant loads from future development. Nonpoint source pollutant loads from current conditions should be compared to build-out conditions. If BMPs are required for the development of undeveloped or

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underdeveloped areas by regulation, the implementation of BMPs and their impacts on loading should be incorporated into the analysis.

To calculate pollutant loads from land uses for both current and build-out conditions, the table of values below for total suspended solids, nitrogen, and phosphorus can be used for a broad perspective on a municipal level. To utilize the table, relate the zones on the zoning map to the listed land uses. Other pollutant loading values may also be used provided that the values are a better depiction of the municipality. Pollutant loads are required for each HUC14 in the municipality. For each land use within the HUC14, multiply the total acreage by the assigned load factor, which is given in pounds per acre per year. The total pollutant load for the HUC14 will be the sum of the loads for each land use.

Table 3-1: Pollutant Loads by Land Cover

Land Cover	TP load (lbs/acre/yr)	TN load (lbs/acre/yr)	TSS load (lbs/acre/yr)
High, Medium Density Residential	1.4	15	140
Low Density, Rural Residential	0.6	5	100
Commercial	2.1	22	200
Industrial	1.5	16	200
Urban, Mixed Urban, Other Urban	1.0	10	120
Agriculture	1.3	10	300
Forest, Water, Wetlands	0.1	3	40
Barrenland/Transitional Area	0.5	5	60

Note: References for Table 3-1 are provided at the end of this chapter.

The build-out analysis can go further than the requirements in the regulations. In addition to pollutant loads and impervious surfaces, the analysis can be used to assess open space plans, and to project school population and demand on municipal services. The build-out analysis can greatly benefit a municipality by envisioning its future so that steps can be taken to prevent unwanted impacts or plan for future needs. Finally, the build-out analysis should include a summary with critical findings, conclusions, and recommendations.

It is important to note that, although the pollutant loads for agricultural lands are higher than those for low density residential for the parameters in Table 3-1, converting agricultural lands to residential typically results in an increase in pollutant loads for metals and petroleum hydrocarbons; it is recommended that each municipality calculate build-out pollutant loads for each. Also, the total load of suspended solids due to stormwater runoff may decrease due to the conversion of agricultural lands to low density residential, but the percentage of impervious surfaces increases dramatically. If increases in stormwater runoff flows, due to the increase of impervious surfaces, are not managed properly, these high flows will increase stream bank erosion, thereby increasing sediment loads to the receiving waters.

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Evaluation of Master Plan and Municipal Ordinances

The master plan and ordinances of the municipality must be analyzed as part of the requirements for the municipal stormwater management plan. They must be assessed to determine which aspects of the master plan and ordinances limit the use of nonstructural stormwater management strategies, as discussed in N.J.A.C. 7:8-5.3. These strategies include minimum disturbance, disconnection and minimization of impervious surfaces, pollution prevention techniques, and minimization of lawns. Elements of the plan and ordinances to be evaluated can include items such as minimum parking spaces, curbing, minimum lawn areas, and landscaping. Recommendations for revisions to the master plan and ordinances should be included in the MSWMP.

To fulfill the requirement that nonstructural stormwater management strategies be incorporated into local regulations and plans, as outlined in N.J.A.C. 7:8-5.3(b), municipal engineers and municipal planners must work together. This allows the municipality to address the issue cost-effectively using expertise already on staff.

In essence, this task requires that municipalities review and update their master plans (including the land use plan element), official maps, and development regulations (including zoning ordinance) to implement the principles of the nine nonstructural stormwater strategies in N.J.A.C. 7:8-5.3(b). *Chapter 2: Low Impact Development Techniques* can assist municipalities in the review of these documents to determine where changes should be made. A checklist is also provided in *Appendix B: Municipal Regulations Checklist – A Checklist for Incorporating Nonstructural Stormwater Management Strategies into Local Regulations.*

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Database of Total Phosphorus, Total Nitrogen, and Total Suspended Solids Export Coefficients

A database of literature values was assembled that includes approximately 4,000 values accompanied by site-specific characteristics such as location, soil type, mean annual rainfall, and site percent-impervious. In conjunction with the database, the contractor reported on recommendations for selecting values for use in New Jersey. Analysis of mean annual rainfall data revealed noticeable trends, and, of the categories analyzed, was shown to have the most influence on the reported export coefficients. Incorporating this and other contractor recommendations, the NJDEP took steps to identify appropriate export values by first filtering the database to include only those studies whose reported mean annual rainfall was between 40 and 51 inches. From the remaining studies, total phosphorus, total nitrogen, and total suspended solids values were selected based on best professional judgment for eight land use categories.

The sources incorporated in the database include a variety of governmental and non-governmental documents. All values used to develop the database and the total phosphorus values in this document are included in the following reference list.

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CHAPTER 4

Stormwater Pollutant Removal Criteria

This chapter presents the criteria and methodologies necessary to determine the pollutant removal rates of stormwater management measures used individually and in series to meet the stormwater quality requirements of the Stormwater Management Rules at N.J.A.C. 7:8. According to these Rules, a "major development" project that creates at least 0.25 acres of new or additional impervious surface must include stormwater management measures that reduce the average annual total suspended solids (TSS) load in the development site's post-construction runoff by 80 percent. This 80 percent requirement has been based, in part, upon Section 6217(g) of the 1990 Coastal Zone Management Act Reauthorization Amendments as enforced by the U.S. Environmental Protection Agency. In addition, these stormwater management measures must reduce the average annual nutrient load in the post-construction runoff by the maximum extent feasible. This requirement has been included in the Stormwater Management Rules because nutrients, consisting primarily of various forms of nitrogen and phosphorous, are recognized as a major class of stormwater pollutants from land development.

The stormwater management measures used to reduce the average annual TSS and nutrient loads can be structural and/or nonstructural in nature. To achieve the reduction requirements, they must be designed to treat the runoff from the stormwater quality design storm, a 1.25-inch/2-hour variable rate rainfall event. Details of the stormwater quality design storm are presented in *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. Details of nonstructural and structural stormwater management measures, also known as Best Management Practices (BMPs), are presented respectively in *Chapter 2: Low Impact Development Techniques* and *Chapter 9: Structural Stormwater Management Measures*.

TSS Removal Rates for Individual BMPs

As noted above, the Stormwater Management Rules require an 80 percent TSS reduction in the post-construction runoff from a land development site that increases impervious surface by 0.25 acres or more. This reduction is to be achieved by conveying the site's runoff through one or more onsite BMPs that have the ability to remove a portion of the TSS load. To demonstrate compliance with this requirement, the NJDEP has adopted official TSS removal rates for each of the BMPs described in detail in Chapter 9. These BMPs and their adopted TSS removal rates are presented below in Table 4-1. Different removal rates and BMPs may be utilized if supporting information is provided and accepted by the applicable review agencies.

It is important to note that the TSS removal rates shown in Table 4-1 have been based upon several sources of BMP research and monitoring data as well as consultation with numerous stormwater management experts. As demonstrated by that research, actual TSS removals at specific BMPs during specific storm events will depend upon a number of site factors and can be highly variable. As such, the TSS removal rates presented in Table 4-1 are considered representative values that are based upon a recognition of this variability and the state's need to develop and implement a statewide stormwater management program. Furthermore, the TSS removal rates are also considered to accurately represent the relative TSS removal efficiencies of the various BMPs listed in the table.

Table 4-1: TSS Removal Rates for BMPs

Best Management Practice (BMP)	Adopted TSS Removal Rate (%)
Bioretention System	90
Constructed Stormwater Wetland	90
Dry Well	Volume Reduction Only[1]
Extended Detention Basin	40 to 60[2]
Infiltration Structure	80
Manufactured Treatment Device	See N.J.A.C. 7:8-5.7(d)[3]
Pervious Paving System	Volume Reduction Or 80[4]
Sand Filter	80
Vegetative Filter	60-80
Wet Pond	50-90[5]

[1] See text below.
[2] Final rate based upon detention time. See Chapter 9.
[3] To be determined through testing on a case-by-case basis. See text below.
[4] If system includes a runoff storage bed that functions as an infiltration basin. See Chapter 9.
[5] Final rate based upon pool volume and detention time. See Chapter 9.

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As shown in Table 4-1, a dry well and certain types of pervious paving do not have an adopted TSS removal rate. This is due to the fact that, as described in Chapter 9, a dry well is intended to infiltrate runoff only from a roof and other impervious area with minimal TSS loading. A pervious paving system without a runoff storage bed can reduce the runoff volume from standard paving, but is not used to treat runoff from other impervious areas. As such, these systems are not considered to be effective in reducing the overall TSS load from a development site. However, in recognition of their infiltration ability, both BMPs can be used to reduce the volume of development site runoff and, consequently, the size and cost of other onsite BMPs. Use of these "volume reduction" BMPs are illustrated in Example 4-2 below and described in detail in Chapter 5.

In addition, Table 4-1 also indicates that the adopted TSS removal rates for manufactured treatment devices must be determined on a case-by-case basis. Manufactured treatment devices are proprietary water quality devices that use a variety of stormwater treatment techniques. They have and continue to be developed by a variety of companies. As such, the actual TSS removal rate for a specific device will depend on a number of factors, and a single representative TSS removal rate cannot be developed. Instead, the NJDEP's Division of Science, Research & Technology (DSRT) is responsible for certifying final pollutant removal rates for all manufactured treatment devices. This certification process is described in detail in Chapter 9.

Finally, as noted in Table 4-1, the adopted TSS removal rates for extended detention basins and wet ponds will vary depending on such specific features as detention time and permanent pool volume. Details for each BMP are also provided in Chapter 9.

TSS Removal Rates for BMPs in Series

The TSS removal rates specified in Table 4-1 for certain BMPs range as low as 40 percent, which indicates that these BMPs will not be able to meet the 80 percent TSS reduction requirement by themselves. As such, it will be necessary at times to use a series of BMPs in a treatment train to achieve the required 80 percent TSS removal rate. In such cases, the total removal rate of the BMP treatment train is based on the removal rate of the second BMP applied to the fraction of the TSS load remaining after the runoff has passed through the first BMP (Massachusetts DEP, 1997).

A simplified equation for the total TSS removal rate (R) for two BMPs in series is:

$$R = A + B - [(A \times B) / 100] \qquad \text{(Equation 4-1)}$$

Where:

R = Total TSS Removal Rate

A = TSS Removal Rate of the First or Upstream BMP

B = TSS Removal Rate of the Second or Downstream BMP

The use of this equation is demonstrated in Example 4-1 below.

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Example 4-1: Total TSS Removal Rate for BMPs in Series

A stormwater management system consists of both a vegetative filter and an extended detention basin to collect and treat runoff from a small commercial parking lot. Runoff from the parking lot will sheet flow off the parking lot through the filter strip, which will have a turf grass surface cover, before being discharged to the extended detention basin. The extended detention basin will have a detention time of 18 hours.

From Table 4-1 and Chapter 9, the adopted TSS removal rates for these individual BMPs are:

Turf Grass Vegetative Filter = 60%

Extended Detention Basin with 18-Hour Detention Time = 50%

From Equation 4-1,

$R = A + B - [(A \times B) / 100]$

$R = 60 + 50 - [(60 \times 50) /100] = 110 - 30 = 80\%$ Total TSS Removal Rate

It should be noted that the total TSS removal rate of the stormwater management system described in Example 4-1 above can also be computed by the following technique:

Initial TSS Load Upstream of Vegetated Filter Strip = 1.0

TSS Load Removed by Vegetated Filter Strip = 1.0 X 60% Removal Rate = 0.6

Remaining TSS Load Downstream of Vegetated Filter Strip = 1.0 – 0.6 = 0.4

TSS Load Removed by Extended Detention Basin = 0.4 X 50% Removal Rate = 0.2

Final TSS Load Downstream of Extended Detention Basin = 0.4 – 0.2 = 0.2

Total TSS Removal Rate = 1.0 – 0.2 = 0.8 or 80%

This technique can also be used in place of Equation 4-1 when there are more than two BMPs in series.

Guidelines for Arranging BMPs in Series

As described in Example 4-1, it may be necessary or desirable to use a series of BMPs in a treatment train to provide adequate TSS removal. In selecting the order or arrangement of the individual BMPs, the following general guidelines should be followed:

1. Arrange the BMPs from upstream to downstream in ascending order of TSS removal rate. In this arrangement, the BMP with the lowest TSS removal rate would be located at the upstream end of the treatment train. Downstream BMPs should have progressively higher TSS removal rates.
2. Arrange the BMPs from upstream to downstream in ascending order of nutrient removal rate. Similar to 1 above, the BMP with the lowest nutrient removal rate would be located at the upstream end of the treatment train in this arrangement. Downstream BMPs should have progressively higher nutrient removal rates.
3. Arrange the BMPs from upstream to downstream by their relative ease of sediment and debris removal. In this arrangement, the BMP from which it is easiest to remove collected sediment and debris would be located at the upstream end of the treatment train. In downstream BMPs, it should be progressively more difficult to remove sediment and debris.

In applying these guidelines, it is recommended that they generally be applied in the order presented above. As such, a series of BMPs would be preliminarily arranged in accordance with their relative TSS removal rates (Guideline 1). This preliminary arrangement would then be refined by the BMPs' relative nutrient removal rate (Guideline 2) and then their ease of sediment and debris removal (Guideline 3). Two or more

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iterations may be necessary to select the optimum arrangement, which should also include consideration for site conditions and the abilities and equipment of the party responsible for the BMPs' maintenance.

Finally, it should be noted that, unless otherwise approved by the applicable reviewing agencies or specifically indicated in the certification of a specific manufactured treatment device, all manufactured treatment devices that achieve TSS removal primarily through swirling and/or baffles should be placed at the upstream end of a treatment train.

Sites with Multiple Discharge Points and Subareas

In general, if runoff is discharged from a site at multiple points, the 80 percent TSS removal requirement will have to be applied at each discharge point. However, the application of this requirement will depend upon the exact amount of physical and hydraulic separation between the various discharge points. If the runoff from two or more discharge points combine into a single waterway or conveyance system before leaving the site, these separate discharge points can be considered as a single one for purposes of computing TSS removal.

In addition, where there are multiple onsite subareas to a single discharge point, the removal rates for the subareas can be combined through a weighted averaging technique. It should be noted that the averaging of TSS removal rates is applicable only where the anticipated pollutant loadings from each of the subareas are similar. As such, the TSS removal rate for an onsite BMP receiving runoff from a commercial parking lot cannot be averaged with a second onsite BMP serving a lawn or landscaped area.

Example 4-2 below provides further explanations of the procedures described above for computing TSS removal rates at sites with both multiple discharge points and subareas.

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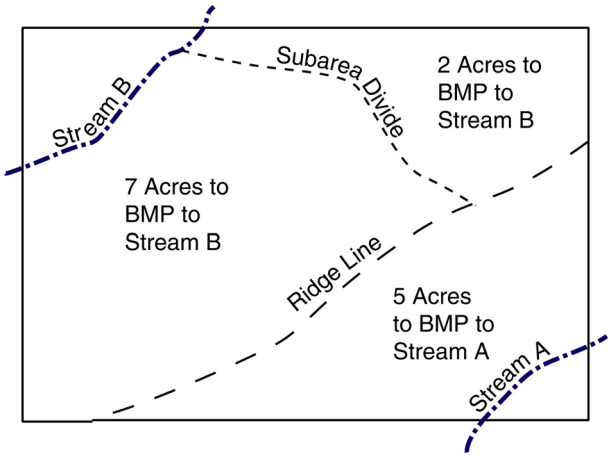
Example 4-2: TSS Removal Rates at Sites with Multiple Discharge Points and Subareas

A 15-acre site has a ridge running through it from northeast to southwest. Five acres of the site drain in a southeasterly direction to Stream A, while the remaining 10 acres drain in a northwesterly direction to Stream B. Since Stream A and B do not join on the site, each portion of the site will have to be evaluated separately for compliance with the 80 percent TSS removal requirement.

Southeast Drainage to Stream A

The site runoff to Stream A will first be routed through a bioretention system.

The bioretention system TSS removal rate is 90 percent. This exceeds the 80 percent removal requirements and meets the TSS removal requirement for the southeast drainage area.



Northwest Drainage to Stream B

One acre of rooftop runoff from the stormwater quality design storm will be directed to dry wells, thereby reducing the drainage area to be served by other BMPs by 1 acre. The remaining 9 acres to Stream B are divided into two subareas of 2 and 7 acres, respectively. A vegetative filter will treat the runoff from one of the subareas, while a constructed stormwater wetland will treat the runoff from other. The anticipated pollutant loadings from each subarea are similar.

The TSS removal rate for a vegetative filter with meadow is 70 percent, which is not sufficient by itself to meet the 80 percent TSS removal requirement. However, the constructed stormwater wetland TSS removal rate is 90 percent, which exceeds the 80 percent TSS removal requirement. By averaging of removal rates, the use of these two BMPs may be sufficient to meet the 80 percent removal requirement for this portion of the site.

Two alternatives to address the TSS load in the runoff from the northwest portion of the site to Stream B are presented below.

OPTION A: The meadow vegetative filter will be used to treat the runoff from the 7 acre subarea, while the constructed stormwater wetland will be used in the 2 acre subarea.

Apply the various TSS removal rates to the areas to be treated by each BMP and determine the average TSS removal rate for the entire northwest portion of the site.

7 Acres X 70% TSS Removal for Vegetative Filter= 4.9

2 Acres X 90% TSS Removal for Wetland = 1.8

Total Acreage-Removal Rate = 4.9 + 1.8 = 6.7

6.7 Total Acreage-Removal Rate / 9 Acres = 0.74 or 74% Average TSS Removal Rate

Therefore, for Option A, the northwest portion of the site does not meet the 80 percent TSS removal requirement.

OPTION B: The vegetative filter will be used to treat the runoff from the 2 acre subarea, while the constructed stormwater wetland will be used in the 7 acre subarea.

Once again, apply the various TSS removal rates to the areas to be treated by each BMP and determine the average TSS removal rate for the entire northwest portion of the site.

2 Acres X 70% TSS Removal for Vegetative Filter = 1.4

7 Acres X 90% TSS Removal for Wetland = 6.3

Total Acreage-Removal Rate = 1.4 + 6.3 = 7.7

7.7 Total Acreage-Removal Rate / 9 Acres = 0.86 or 86% Average TSS Removal Rate

Therefore, for Option B, the northwest portion of the site does meet the 80 percent TSS removal requirement.

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Nutrients

In addition to TSS removal, the Stormwater Management Rules also require the reduction of post-construction nutrients to the maximum extent feasible. In general, to demonstrate compliance with this requirement, a two step approach should be used. First, the input of nutrients to the drainage area should be limited as much as feasible. Second, when selecting a stormwater management measure to address the TSS removal requirement, the measure with the best nutrient removal rate that also best meets the site's constraints should be chosen. Details of each step in this approach are provided below.

Reducing Nutrient Input

A significant amount of nutrients are in stormwater runoff due to fertilization of lawns. As described in Chapter 2, lawns should be minimized in favor of other vegetated cover. Existing site areas with desirable vegetation communities should be left in a natural state and forested areas and meadows should be considered as alternatives to the standard lawn. Ground covers provide aesthetically pleasing, innovative landscapes that are adaptable to the local environment. These types of land cover reduce lawn area and the consequent need for fertilization. A landscape design that minimizes the use of lawn can be beneficial in preventing pesticides, as well as nutrients from fertilizers, from stormwater runoff.

Soil testing determines the soil nutrient level as well as pH. Using the test results to determine the appropriate application of lime and fertilizer required for lawn areas will increase efficient uptake and decrease associated costs of lawn maintenance as well as minimize nutrient input. Low or no phosphorous fertilizers may be adequate to maintain the health of the landscape after the vegetation has fully established. Soil test kits are available at most lawn and garden care centers as well as through the Rutgers Cooperative Extension county offices. Fertilization specifications must be included in the maintenance manual.

Pet waste is another source of nutrients in stormwater runoff. To prevent or minimize pet waste problems, residents must be required to pick up after their animal and dispose of the material in the toilet or garbage. Homeowner associations must include this condition in homeowner's agreements. Signage should be located strategically throughout the development to reinforce this criterion. Education is critical to successful pet waste management.

Nutrient Removal Rates

Site conditions and the need to reduce post-construction TSS by 80 percent are primary factors in the selection of appropriate BMPs for a development site. However, removal of nutrients such as phosphorous and the various forms of nitrogen must also be considered in this selection process. The chosen BMP must meet the TSS criteria, but must also maximize nutrient removal for the site. To assist with the selection of BMPs for nutrients, information regarding estimated nutrient removal rates is provided in Table 4-2.

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Table 4.2 – Typical Phosphorous and Nitrogen Removal Rates for BMPs

Best Management Practice (BMP)	Total Phosphorous Removal Rate (%)	Total Nitrogen Removal Rate (%)
Bioretention Basin	60	30
Constructed Stormwater Wetland	50	30
Extended Detention Basin	20	20
Infiltration Basin	60	50
Manufactured Treatment Devices	See N.J.A.C. 7:8-5.7(d)	See N.J.A.C. 7:8-5.7(d)
Pervious Paving[2]	60	50
Sand Filter	50	35
Vegetative Filter	30	30
Wet Pond	50	30

The nutrient removal rates presented in Table 4-2 should be considered typical values based upon data from a range of research studies. Due to the multiple forms and complex behavior of nutrients in stormwater runoff and the similarly complex processes by which nutrient loading is altered by BMPs, actual removal rates for specific BMPs and development sites may vary.

The nutrient removal data in Table 4-2 is intended to assist designers in the selection of appropriate BMPs to meet both the 80 percent TSS and maximum feasible nutrient removal requirements in the NJDEP Stormwater Management Rules. During this selection process, primary consideration should be given to achieving the Rules' 80 percent TSS removal requirement with one or more BMPs that are compatible with and responsive to site conditions and constraints, maintenance needs, and safety concerns. The selection process should then be further refined to achieve the Rules' maximum feasible nutrient requirement utilizing the structural BMP data in Figure 4.2 and, as necessary, other appropriate resources. In doing so, it should be remembered that many nonstructural BMPs can also help achieve the nutrient removal requirement, and must be considered prior to the use of structural BMPs.

The nutrient removal data in Table 4-2 can also be used to optimize existing BMP retrofits.

Additional Considerations

From the information presented in this chapter, it should be evident that BMPs are intended to reduce the pollutants in stormwater runoff. However, sometimes an unintended consequence of stormwater management facilities is their attractiveness to waterfowl, such as Canada geese. Canada geese are attracted to lawn areas adjacent to water bodies. As such, wet ponds and other stormwater management structures can appeal to these waterfowl, whose resulting fecal input can result in an increase in nutrient loading to systems that are intended to reduce such pollutants. As a result, adjustments to a BMP's design and/or maintenance plan may be necessary to discourage waterfowl from contributing pollutants to the stormwater measure. Additional guidance on Canada geese is available in Management of Canada Geese in Suburban Areas: A Guide to the Basics, available at http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/Goosedraft.pdf.

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CHAPTER 5

Computing Stormwater Runoff Rates and Volumes

This chapter discusses the fundamentals of computing stormwater runoff rates and volumes from rainfall through the use of various mathematical methods. To do so effectively, the chapter also describes the fundamentals of the rainfall-runoff process that these methods attempt to simulate. Guidance is also provided in the use of the Natural Resources Conservation Service, Rational, and Modified Rational Methods that are specifically recommended and/or required by the NJDEP Stormwater Management Rules at N.J.A.C. 7:8. This guidance includes use of the methods to comply with the Rules' groundwater recharge, stormwater quality, and stormwater quantity requirements.

Fundamentals

The actual physical processes that convert rainfall to runoff are both complex and highly variable. As such, these processes cannot be replicated mathematically with exact certainty. However, through the use of simplifying assumptions and empirical data, there are several mathematical models and equations that can simulate these processes and predict resultant runoff volumes and rates with acceptable accuracy.

The selection of the appropriate model or equation depends upon a number of factors.

Desired Results

Some methods, such as the Rational Method, can be used to produce estimates of peak runoff rates, but cannot predict total runoff volumes. Other methods, conversely, can only produce estimates of total runoff volumes, while others, such as the Natural Resources Conservation Service (NRCS) methods, can accurately predict both total runoff volume and peak rate, and even entire runoff hydrographs.

Drainage Area Size

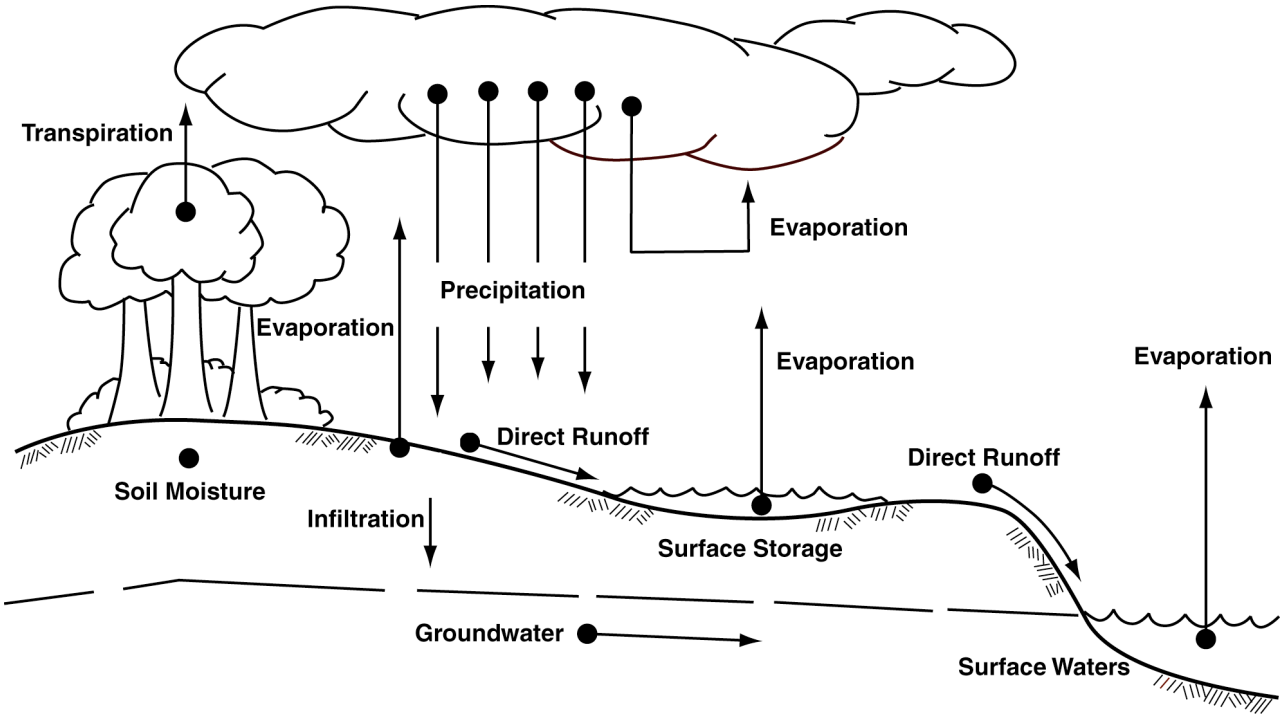
Due to their assumptions and/or theoretical basis, some methods can accurately predict runoff volumes or rates only for single drainage areas of 20 acres or less, while other methods can be applied to watersheds of 20 square miles or more with 100 or more subareas.

Data Availability

Simple methods, such as the Rational or Modified Rational Methods, require limited rainfall and drainage area data, while other, more sophisticated methods have extensive data needs, including long-term rainfall and temperature data as well as drainage area soils, subsoil, and ground cover information. In general, the more data-intensive models can produce more comprehensive runoff predictions.

In general, stormwater runoff can be described as a by-product of rainfall's interaction with the land. This interaction is one of several processes that the earth's water may go through as it continually cycles between the land and the atmosphere. In addition, stormwater runoff is only one of many forms water may take during one of these cycles, known scientifically as the hydrologic cycle. Shown in Figure 5-1 below, the hydrologic cycle depicts both the primary forms that water can take and the cyclical processes that produce them. In addition to runoff, these processes include precipitation, evaporation from surfaces or the atmosphere, evapotranspiration by plants, and infiltration into the soil or groundwater. As such, water that precipitates as rainfall can wind up or at least spend time on ground or plant surfaces, in the atmosphere, within the various soil layers, or in waterways and water bodies.

Figure 5-1: The Hydrologic Cycle



Source: Fundamentals of Urban Runoff Management.

In general, all runoff computation methods are, to some degree, mathematical expressions of the hydrologic cycle. However, most transform its cyclical character to a linear one, treating rainfall as an input and producing runoff as an output. During this transformation, each method uses mathematical approximations of the real rainfall-runoff processes to produce its estimates of runoff volume and/or rate. As described above, each method has its own complexity, data needs, accuracy, and range of results.

As the key input, rainfall is generally characterized by its size, intensity, and the frequency of its occurrence. The size of a rain storm is the total precipitation that occurs over a particular duration. How

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often this size of storm is likely to reoccur is called its recurrence interval. For instance, a rainfall of certain duration that occurs, on average, once every 25 years would have an average recurrence interval of 25 years or be called a 25-year storm.

Since storms have been shown to be mathematically random events, their recurrence can also be specified as an annual probability. The equation for converting between recurrence interval and annual probability is:

Annual probability (in percent) = 100/recurrence interval (in years)

For example, the 25-year storm noted above could also be described as having a probability of 4 percent (=100/25) or a 4 percent chance of being equaled or exceeded in any given year. Similarly, a 2-year storm has a 50 percent chance (=100/2), a 10-year storm has a 10 percent chance (=100/10), and a 100-year storm has a 1 percent chance (=100/100) of being equaled or exceeded in a given year. Resultant runoff peak rates and volumes events can also be described in such terms.

Runoff volumes are influenced primarily by the total amount of rainfall. However, runoff rates resulting from a given rainfall, including the peak rate or discharge, are influenced primarily by the rainfall's distribution, which is how the rainfall rate or intensity varies over a period of time. Studies of rainfall records show that actual storm distributions and durations can vary considerably from event to event. A rainfall may be evenly distributed over a time period or can vary widely within that same period. Its duration can also be long or very short. These different types of rain events can produce extremely different runoff volumes and peak discharges.

Runoff computation methods deal with this rainfall variability in one of two general ways. Many methods, including the Rational and NRCS methods, rely on a hypothetical rain event known as a design storm for their rainfall input. This single, hypothetical storm event is based on a compilation of local or regional rainfall data recorded over an extended time period. To use a design storm, the user must make some assumptions about the antecedent ground and waterway conditions that exist at its start. Most runoff computations are based on average antecedent conditions, although wetter or drier conditions can also be used depending upon the user's interests and concerns.

Instead of compiling long-term rainfall data into a single design storm, other runoff computation methods address the variability of real rain events by analyzing a long series of them, computing runoff rate and volume estimates for each. While such methods need only the exact antecedent conditions that existed prior to the first storm, they must mathematically account for changes in ground and waterway conditions during intervening dry periods. Therefore, such methods are generally more complex than design storm methods and, obviously, require extensive rainfall data for the drainage area or watershed under analysis. Their results, however, are based on the actual long-term rainfall history of the watershed instead of a single, hypothetical design storm.

In addition to rainfall and antecedent conditions, other factors that can significantly affect both runoff volume and peak discharge are the hydrologic characteristics of the soils in the watershed and the type of surface that covers those soils. This cover may vary from pervious surfaces such as woods and grass to impervious surfaces such as roofs, roadways, and parking lots. Another factor that can greatly influence the peak runoff rate or discharge is the time of concentration (Tc). This is a measure of how quickly or slowly a watershed will respond to rainfall input and is usually measured as the time required for runoff to travel from the hydraulically most distant point in the watershed to the point of analysis at the watershed's lower end. Factors such as surface roughness, irregularity, length, and slope generally affect a watershed's Tc.

In summary, runoff computation methods attempt to mathematically reproduce or simulate the hydrologic cycle. They treat rainfall as an input, converting it into estimates of resultant runoff volume and/or rate. There are certain characteristics of both the rainfall event and the area upon which it falls that can influence the resulting runoff. These include:

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1. High intensity rainfall will generally produce a greater peak discharge than a rainfall that occurs over a longer time period.
2. Highly porous or permeable soils that can rapidly infiltrate rainfall generally produce less runoff volume than soils with more restrictive infiltration.
3. Dense vegetation such as woodland intercepts and help infiltrates rainfall, thereby reducing runoff volumes and rates.
4. Conversely, impervious areas such as roadways and rooftops prevent infiltration and increase runoff volumes and rates.
5. Drainage areas with shorter times of concentration will have higher peak runoff rates than those with a longer Tc.

Runoff Computation Methods

As described in the Stormwater Management Rules, the NJDEP has specified that one of two general runoff computation methods be used to compute runoff rates and volumes. These are the NRCS methodology, which consists of several components, and the Rational Method (and the associated Modified Rational Method), which are generally limited to drainage areas less than 20 acres. A general description of each method is provided below.

NRCS Methodology

The USDA Natural Resources Conservation Service (NRCS) methodology is perhaps the most widely used method for computing stormwater runoff rates, volumes, and hydrographs. It uses a hypothetical design storm and an empirical nonlinear runoff equation to compute runoff volumes and a dimensionless unit hydrograph to convert the volumes into runoff hydrographs. The methodology is particularly useful for comparing pre- and post-development peak rates, volumes, and hydrographs. The key component of the NRCS runoff equation is the NRCS Curve Number (CN), which is based on soil permeability, surface cover, hydrologic condition, and antecedent moisture. Watershed or drainage area time of concentration is the key component of the dimensionless unit hydrograph.

Several runoff computation methods use the overall NRCS methodology. The most commonly used are the June 1986 *Technical Release 55 – Urban Hydrology for Small Watersheds* (TR-55), the April 2002 *WinTR-55 – Small Watershed Hydrology* computer program, and *Technical Release 20 – Computer Program for Project Formulation: Hydrology* (TR-20) published by the NRCS. The computer programs *HEC-1 Flood Hydrograph Package* and *HEC-HMS Hydrologic Modeling System* published by the U.S. Army Corps of Engineers' Hydrologic Engineering Center also contain components of the NRCS methodology. A complete description of the NRCS methodology can be found in the NRCS *National Engineering Handbook Section 4 – Hydrology* (NEH-4).

Rational Method

The Rational Method uses an empirical linear equation to compute the peak runoff rate from a selected period of uniform rainfall intensity. Originally developed more than 100 years ago, it continues to be useful in estimating runoff from simple, relatively small drainage areas such as parking lots. Use of the Rational Method should be limited to drainage areas less than 20 acres with generally uniform surface cover and topography. It is important to note that the Rational Method can be used only to compute peak runoff rates. Since it is not based on a total storm duration, but rather a period of rain that produces the peak runoff rate, the method cannot compute runoff volumes unless the user assumes a total storm duration. Complete descriptions of the Rational Method can be found in many hydrology and drainage textbooks.

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Modified Rational Method

The Modified Rational Method is a somewhat recent adaptation of the Rational Method that can be used to not only compute peak runoff rates, but also to estimate runoff volumes and hydrographs. This method uses the same input data and coefficients as the Rational Method along with the further assumption that, for the selected storm frequency, the duration of peak-producing rainfall is also the entire storm duration. Since, theoretically, there are an infinite number of rainfall intensities and associated durations with the same frequency or probability, the Modified Rational Method requires that several of these events be analyzed in the method to determine the most severe. Similar to the Rational Method, there are several urban hydrology and drainage publications that contain descriptions of the Modified Rational Method, including Appendix A-9 of the *Standards for Soil Erosion and Sediment Control in New Jersey* published by the New Jersey State Soil Conservation Committee. Use of the Modified Rational Method should also be limited to drainage areas less than 20 acres with generally uniform surface cover and topography.

Design Storms

To fully comply with the NJDEP Stormwater Management Rules, stormwater runoff must be computed for three types of rainfall or storm events. These storms are associated with the groundwater recharge, stormwater quality, and stormwater quantity requirements in the Rules. A description of each storm and the techniques used to model it in the NRCS, Rational and Modified Rational methods are presented below.

Groundwater Recharge Design Storm

As described in detail in *Chapter 6: Groundwater Recharge*, the NJDEP's groundwater recharge requirements are actually met through the analysis of a series of rainfall events derived from long-term New Jersey data. However, these events can also be expressed by an equivalent groundwater recharge design storm that represents the largest rainfall that must be controlled by a groundwater recharge facility. Due to the relatively small size of both the statistical rainfall series and the equivalent Design Storm, the NJDEP has developed specialized equations to compute the resultant runoff volume from each. The basis and use of these equations are described in detail in *Chapter 6: Groundwater Recharge*.

Stormwater Quality Design Storm

This is the rainfall event used to analyze and design structural and nonstructural stormwater quality measures (known as Best Management Practices or BMPs). As described in the Stormwater Management Rules, the NJDEP stormwater quality design storm has a total rainfall depth of 1.25 inches and a total duration of two hours. During its duration, the rain falls in a nonlinear pattern as depicted in Figure 5-2 below. This rainfall pattern or distribution is based on Trenton, New Jersey rainfall data collected between 1913 and 1975 and contains intermediate rainfall intensities that have the same probability or recurrence interval as the storm's total rainfall and duration. As such, for times of concentration up to two hours, the stormwater quality design storm can be used to compute runoff volumes, peak rates, and hydrographs of equal probability. This ensures that all stormwater quality BMPs, whether they are based on total runoff volume or peak runoff rate, will provide the same level of stormwater pollution control.

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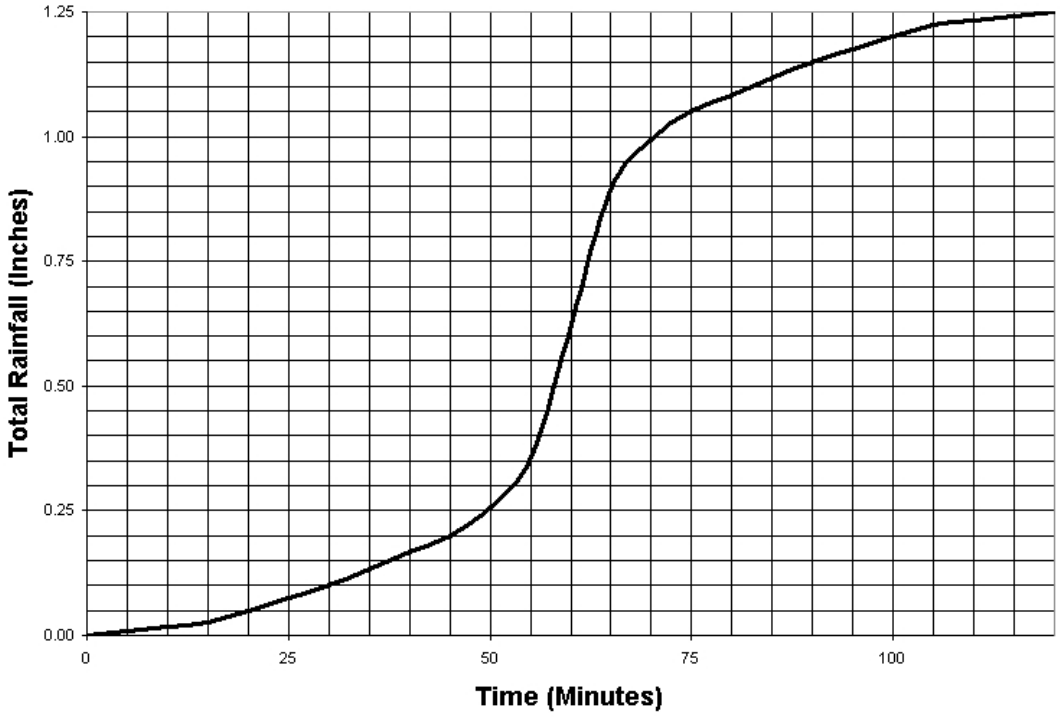
Figure 5-2: NJDEP 1.25-Inch/2-Hour Stormwater Quality Design Storm



The NJDEP stormwater quality design storm can be used to analyze and design stormwater quality BMPs based on the Rational, Modified Rational, or NRCS methods. Selection of the appropriate method will depend on the type of BMP selected and its required design data. BMPs that essentially store, treat, and slowly release the stormwater quality design storm runoff (such as extended detention basins, wet ponds, constructed stormwater wetlands, and sand filters) generally require a runoff volume at the very least and, ideally, an entire runoff hydrograph. This mandates the use of either the NRCS methodology or Modified Rational Method. However, BMPs that treat the stormwater quality design storm runoff as it is conveyed through them (such a filter strip, buffer or manufactured treatment device) generally require only a peak runoff rate. This can be computed using either the NRCS or Rational Methods. Further information on the use of these methods is presented below. When using either the Rational or Modified Rational Methods, it is important to remember their 20-acre drainage area limitations.

Table 5-1 was prepared for those using the NRCS methodology to compute stormwater quality design storm runoff peaks or hydrographs. It contains cumulative and incremental rainfall values for the stormwater quality design storm in five minute increments. These values can be used in computer programs such as TR-20, HEC-1, HEC-HMS, and other programs that both contain the NRCS methodology and allow user-specified rainfalls.

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Table 5-1: NJDEP 1.25-Inch/2-Hour Stormwater Quality Design Storm Cumulative and Incremental Rainfall Distributions

Time (minutes)	Cumulative Rainfall (inches)	Incremental Rainfall (inches)	Time (minutes)	Cumulative Rainfall (inches)	Incremental Rainfall (inches)
0	0.0000	0.0000	65	0.8917	0.2667
5	0.0083	0.0083	70	0.9917	0.1000
10	0.0166	0.0083	75	1.0500	0.0583
15	0.0250	0.0084	80	1.0840	0.0340
20	0.0500	0.0250	85	1.1170	0.0330
25	0.0750	0.0250	90	1.1500	0.0330
30	0.1000	0.0250	95	1.1750	0.0250
35	0.1330	0.0330	100	1.2000	0.0250
40	0.1660	0.0330	105	1.2250	0.0250
45	0.2000	0.0340	110	1.2334	0.0084
50	0.2583	0.0583	115	1.2417	0.0083
55	0.3583	0.1000	120	1.2500	0.0083
60	0.6250	0.2667			

Note: See Figure 5-1 for plot of cumulative rainfall distribution.

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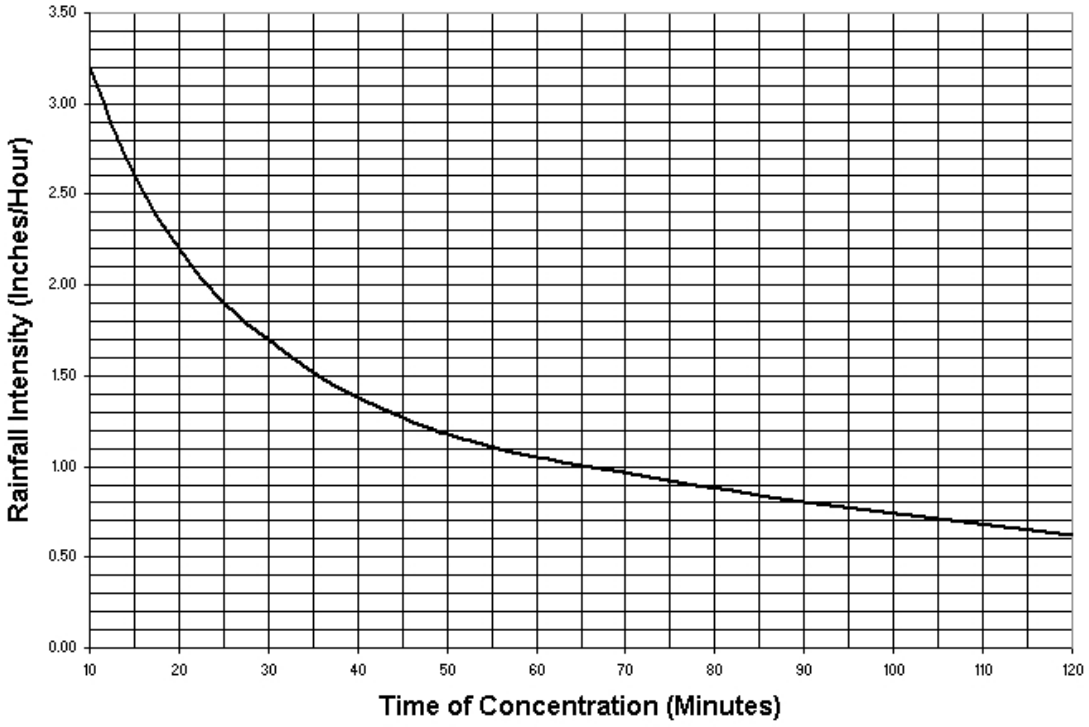
Figure 5-3 was prepared for those using the Rational Method to compute stormwater quality design storm runoff peaks. It presents the stormwater quality design storm as a rainfall intensity-duration curve that allows the user to determine the appropriate rainfall intensity for the selected time of concentration.

Figure 5-3: NJDEP 1.25-Inch/2-Hour Stormwater Quality Design Storm Rainfall Intensity-Duration Curve



Finally, when using the Modified Rational Method to compute a stormwater quality design storm hydrograph, the entire 2-hour storm duration at an average intensity of 0.625-inches/hour can be used. Example 5-1 below demonstrates this procedure.

Important Note: While the stormwater quality design storm actually falls in a variable pattern, use of the 2-hour average rate described above and demonstrated in Example 5-1 is consistent with the assumptions of the Modified Rational Method. In addition, analysis and experience has shown that the structural BMPs that store and slowly release the stormwater quality design storm hydrograph (such as extended detention basins, wet ponds, bioretention facilities, constructed wetlands, and sand filters) are not particularly sensitive to rainfall pattern. If such sensitivity does exist for a particular BMP, the designer should use the NRCS methodology, which allows for consideration of the stormwater quality design storm's variable rainfall pattern.

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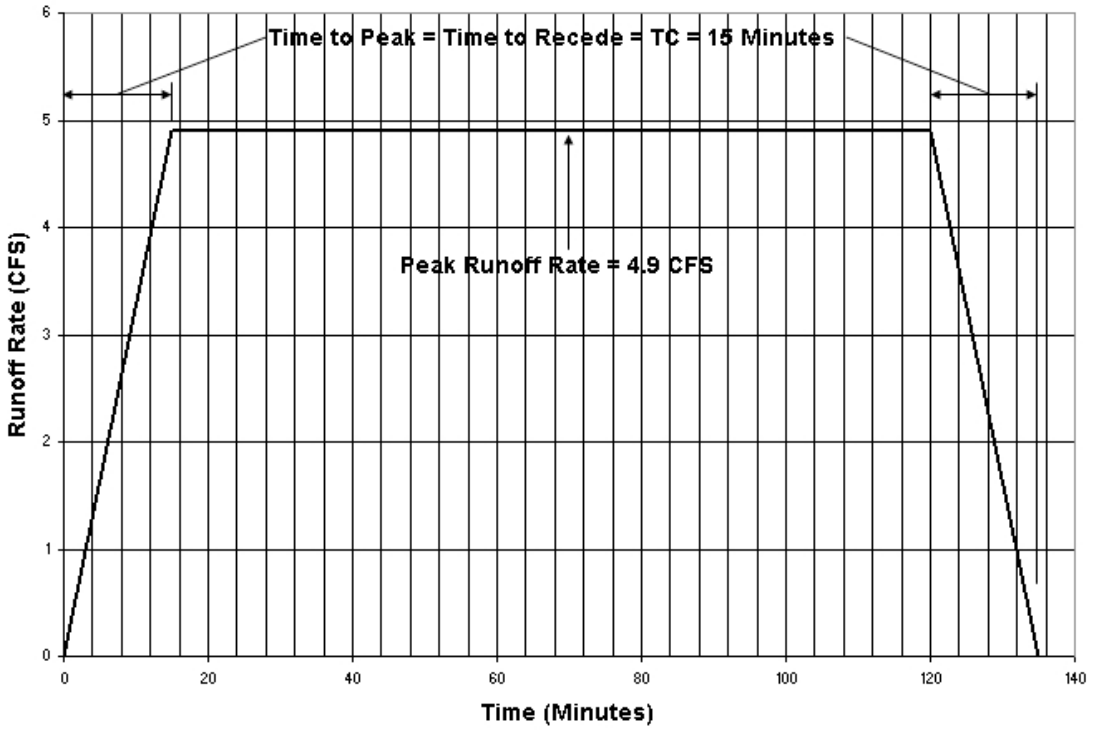
Example 5-1: NJDEP 1.25-Inch/2-Hour Stormwater Quality Design Storm Hydrograph Computation with Modified Rational Method

Description: A 10-acre development site has a Rational C value of 0.78 and a time of concentration of 15 minutes. Construct a runoff hydrograph from the site for the 1.25-inch/2-hour stormwater quality design storm using the Modified Rational Method.

C = 0.78 Average I = 1.25-inches/2-hours = 0.625 inches per hour
Area = 10 acres Tc = 15 minutes Storm duration = 2 hours

Q = runoff rate (cubic feet per second) = CIA
C = Rational Method runoff coefficient
I = rainfall intensity (inches per hour)
A = drainage area (acres)
D = storm duration (hours)
Q = (0.78) (0.625 inches per hour)(10 acres) = 4.9 CFS

In the Modified Rational Method, the runoff hydrograph is then constructed as shown here:



Finally, the total runoff volume is equal to the area under the hydrograph, which is equal to the peak runoff rate times the duration of the storm.

V = peak runoff rate x storm duration = Q x D

V = 4.9 cubic feet/second x 2 hours x 3600 seconds/hour

V = 35280 cubic feet = 0.81 acre-feet

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Stormwater Quantity Storms

As described in the Stormwater Management Rules, the three storm frequencies of primary concern for stormwater quantity control are the 2, 10, and 100-year events. These storms are of such concern due to their potential to cause or aggravate downstream erosion and/or flooding. In certain instances, however, additional storm frequencies may need to be analyzed to ensure that downstream peak runoff rates and/or velocities are not increased by a land development or redevelopment project.

Selection of the appropriate stormwater quantity storm data will depend on the runoff estimation method being used. When using the NRCS methodology, the NRCS Type III Storm distribution should be selected. Details and data regarding this distribution can be found in the NRCS *Technical Release 55 – Urban Hydrology for Small Watersheds*. When using the Rational Method, the rainfall intensity-duration-frequency (IDF) curves shown in Figure 5-4 may be used. These curves were developed from Trenton area rainfall data between 1913 and 1975 and were adapted from Figure 2.1-2 in the *Technical Manual for Stream Encroachment Permits* prepared by the NJDEP Land Use Regulation Program. IDF curves based on rainfall data collected closer to an actual land development or redevelopment site may also be used if such data covers a sufficiently long time period and is analyzed by appropriate statistical methods.

Use of Long Term or Single Event Rainfall Data

As discussed in the *Fundamentals* section above, long term rainfall data for a watershed or development site may be used in certain runoff computations methods. Long term data can be used as input to the rainfall-runoff computations in place of a hypothetical, statistically-based design storm and, in certain instances, may be a more accurate or representative form of this input. In other instances, rainfall records from a significant historic storm in the watershed may also be used to test or verify a runoff computation or BMP design initially based on a hypothetical design storm. While the use of long term or single event rainfall data is not specifically required in the NJDEP Stormwater Management Rules, it is also not prohibited, since such uses may improve the effectiveness and/or reliability of a runoff computation or BMP design. Analysts and designers wishing to use such data should confer with the relevant review agencies prior to such use to ensure the suitability and acceptability of both the data and the computation method.

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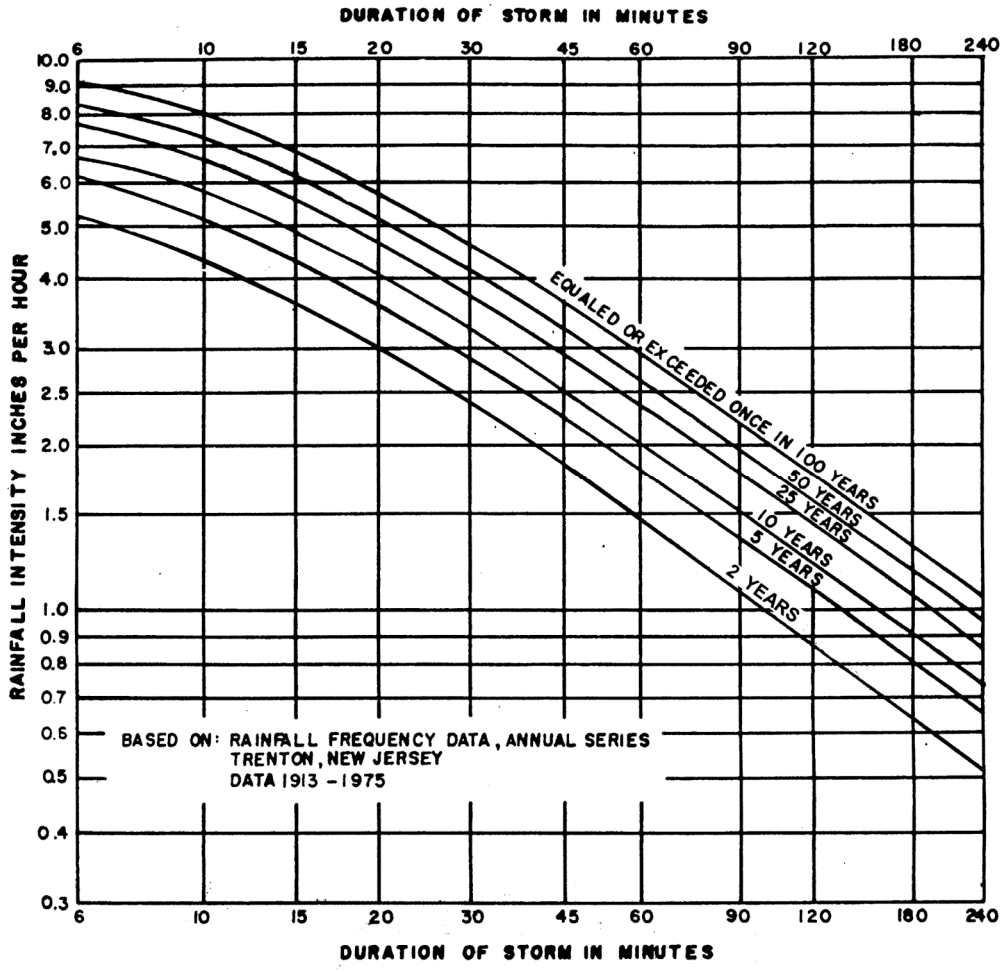
Figure 5-4: Rainfall Intensity-Duration-Frequency Curves



Note: Adapted from Figure 2.1-2 in the NJDEP *Technical Manual for Stream Encroachment Permits*.

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Modeling Various Site Conditions

This section provides guidance for modeling various site conditions within a drainage area or watershed that may be encountered in the analysis and/or design of structural and nonstructural BMPs. This guidance is provided, where applicable, for the NRCS, Rational, and Modified Rational Methods and is intended to facilitate computation of required runoff volumes, peak rates, and hydrographs. A summary of the guidance for each computation method is presented at this end of this section in Table 5-2.

Pre-Developed Site Land Cover and Hydrologic Condition

As specified in the NJDEP Stormwater Management Rules, the predeveloped land cover at a development site must be assumed to be woods unless it can be verified that a different land cover has existed for at least five years prior to the analysis. Similarly, the predeveloped land cover must be assumed to be in good hydrologic condition for all land covers.

Sites With Pervious and Directly Connected Impervious Cover

It is virtually inevitable that a land development or redevelopment site will have a mixture of pervious and directly connected impervious surfaces, particularly under post-development conditions. As defined by the NRCS and others, impervious surfaces are directly connected when runoff from them can flow as shallow concentrated, channel, or pipe flow directly to the downstream drainage system. While such conditions pose no significant modeling problems for simple, linear methods such as the Rational and Modified Rational Methods, inaccuracies may occur for small rainfall depths when using more detailed, nonlinear methods such as the NRCS methodology. Analysis of such conditions using each method is presented here.

- **Rational and Modified Rational Methods:** Due to the linear character of the basic Rational Equation, a representative Rational Runoff Coefficient (C) can be computed for the entire site by standard area weighting techniques.
- **NRCS Methodology:** Due to the nonlinear character of the NRCS runoff equation and, primarily, the presence of the initial abstraction term Ia, inaccurate runoff estimates can result when the mixture of pervious and directly connected impervious surfaces within a drainage area or watershed are modeled with a weighted average NRCS Curve Number (CN). As discussed in the NRCS' TR-55, "the combination of impervious areas with pervious areas can imply a significant initial loss that may not take place." This problem will be particularly acute for small rainfalls less than an inch or two where the large (but incorrect) initial loss can be 50 percent or more of the total rainfall.

To avoid these errors, it is recommended that runoff volumes be computed separately from the pervious and directly connected impervious portions of the drainage area and then combined into a weighted average runoff volume. This volume averaging technique produces more accurate estimates of total runoff volume than the standard average Curve Number approach. At a minimum, it should generally be used for all rainfalls less than approximately 4 inches in depth. This would include the 1.25-inch/2-hour stormwater quality design storm and the 1-year and 2-year 24-hour storms. The technique can also be used for larger rainfall depths at the designer's discretion.

Example 5-2 below further illustrates this problem and the recommended volume averaging solution for the stormwater quality design storm.

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Example 5-2: Site With Pervious and Directly Connected Impervious Cover Runoff Volume Computation Using NRCS Methodology

Description: A 3-acre development site is comprised of 1 acre of impervious surface and 2 acres of lawn and woods with an NRCS Curve Number (CN) of 65. The entire impervious surface is directly connected to the site's drainage system. Compute the site's total runoff volume for the 1.25-inch stormwater quality design storm using the Weighted Average CN technique. Compare the results with the Weighted Average Volume technique.

Stormwater Quality Design Storm = P = 1.25 inches

Total drainage area = 3 acres

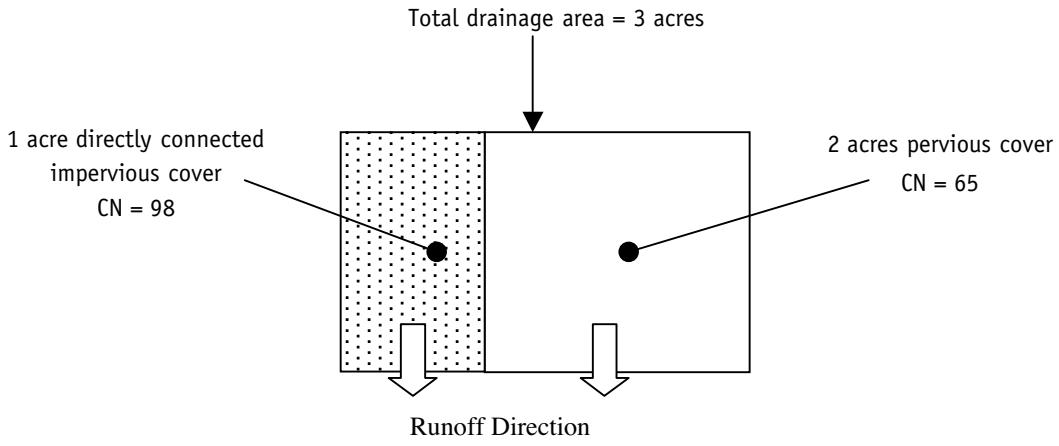
Impervious area = 1 acre (1/3 of total area)

Pervious area = 2 acres (2/3 of total area)

Pervious cover = mixture of lawn and woods Pervious CN = 65

Impervious cover = asphalt Impervious CN = 98

Note: All impervious cover is connected to the drainage system



1. Using Weighted Average Curve Number Technique

Weighted CN = (65)(2/3) + (98)(1/3) = 76

$$\text{Average } S = \frac{1000}{CN} - 10 = \frac{1000}{76} - 10 = 3.16 \text{ inches}$$

Average initial abstraction = Ia = 0.2S = (0.2)(3.16) = 0.63 inches

0.8S = (0.8)(3.16) = 2.53 inches

$$\text{Runoff volume} = Q = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(1.25 - 0.63)^2}{1.25 + 2.53} = 0.10 \text{ inches}$$

Runoff volume = (0.10 inches/12 inches per foot)(3 acres)(43,560 sf per acre)

Total site runoff volume = 1089 cubic feet

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2. Using Weighted Average Volume Technique

Impervious Area

$$\text{Impervious area } S = \frac{1000}{CN} - 10 = \frac{1000}{98} - 10 = 0.20 \text{ inches}$$

$$\text{Impervious area initial abstraction} = 0.2S = (0.2)(0.20) = 0.04 \text{ inches}$$

$$0.8S = (0.8)(0.20) = 0.16 \text{ inches}$$

$$\text{Impervious area runoff volume} = Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} = \frac{(1.25 - 0.04)^2}{1.25 + 0.16} = 1.04 \text{ inches}$$

Runoff volume = (1.04 inches/12 inches per foot)(1 acre)(43,560 sf per acre)

Impervious area runoff volume = 3775 cubic feet

Pervious Area

$$\text{Pervious area } S = \frac{1000}{CN} - 10 = \frac{1000}{65} - 10 = 5.38 \text{ inches}$$

$$\text{Pervious area initial abstraction} = 0.2S = (0.2)(5.38) = 1.08 \text{ inches}$$

$$0.8S = (0.8)(5.38) = 4.30 \text{ inches}$$

$$\text{Pervious area runoff volume} = Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} = \frac{(1.25 - 1.08)^2}{1.25 + 4.30} = 0.005 \text{ inches}$$

Runoff volume = (0.005 inches/12 inches per foot)(2 acres)(43,560 sf per acre)

Pervious area runoff volume = 36 cubic feet

Total site runoff volume = 3775 + 36 = 3811 cubic feet
(vs. 1089 cubic feet using weighted average CN)

As can be seen in Example 5-2 above, the weighted average CN technique produced an estimated stormwater quality design storm runoff volume that was less than 30 percent of the volume produced by the weighted average volume technique. Perhaps more significantly, the example also demonstrates how virtually the entire site runoff for the stormwater quality design storm comes from the impervious portion and that very little comes from the pervious portion (i.e., 3775 cubic feet vs. 36 cubic feet). The significant but erroneous initial loss that the NRCS cautions about in TR-55 can also be seen in the 0.63 inch initial abstraction for the entire site (including 1 acre of impervious surface) produced by the weighted average CN technique.

It is important to note that, in computing a weighted average runoff volume from the development site, Example 5-2 does not address the resultant peak discharge or hydrograph from the site. If both the pervious and directly connected impervious site areas will have the same time of concentration, the weighted runoff volume can then be used directly to compute the peak site discharge or hydrograph. However, if these areas will respond to rainfall with different times of concentration, separate hydrographs should be computed for each and then combined to produce the peak site discharge or hydrograph.

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Sites with Unconnected Impervious Cover

As described in detail in *Chapter 2: Low Impact Development Techniques*, an important nonstructural BMP will be new impervious cover that is not directly connected to a site's drainage system. Instead, runoff from these impervious areas will sheet flow onto adjacent pervious areas, where a portion of the impervious area runoff will be given a second opportunity to infiltrate into the soil. Under certain conditions described below, this can help provide both groundwater recharge and stormwater quality treatment for small rainfalls as well as reduce the overall runoff volume that must be treated and/or controlled in a structural BMP downstream. Unconnected impervious areas may either by on-grade (e.g., a parking lot) or above-grade (e.g., a roof), while downstream pervious areas may either be constructed (e.g., lawn) or natural (e.g., woods or meadow).

In most circumstances, impervious areas can be considered unconnected under the following conditions:

1. All runoff from the unconnected impervious area must be sheet flow.
2. Upon entering the downstream pervious area, all runoff must remain as sheet flow.
3. Flow from the impervious surface must enter the downstream pervious area as sheet flow or, in the case of roofs, from downspouts equipped with splash pads, level spreaders, or dispersion trenches that reduce flow velocity and induce sheet flow in the downstream pervious area.
5. All discharges onto the downstream pervious surfaces must be stable and nonerosive.
6. The shape, slope, and vegetated cover in the downstream pervious area must be sufficient to maintain sheet flow throughout it length. Maximum slope of the downstream pervious area is 8 percent.
7. The maximum roof area that can be drained by a single downspout is 600 square feet.

To determine the hydrologic effects of unconnected impervious cover, the combined effects of the impervious area disconnection and the subsequent infiltration in downstream pervious areas must be quantified. Techniques to do so are presented below.

- **Rational and Modified Rational Methods:** Due to the character of the basic Rational Equation, there is currently no technique for addressing the effects of unconnected impervious cover. As such, neither the Rational nor Modified Rational Methods can be recommended at this time for use at sites with unconnected impervious areas.
- **Methodology Using NRCS Equations:** Computation of the resultant runoff from unconnected impervious areas can be performed using two different methods. The first method is described in the NRCS TR-55. The second method is a two-step technique using the NRCS runoff equation. Both methods are discussed in detail below. Additional discussion and computed examples of unconnected impervious cover are presented in *Chapter 2: Low Impact Development Techniques*.
    - **NRCS TR-55 Methodology:** This method is based on the procedures to compute runoff from unconnected impervious surfaces described in the NRCS TR-55. Complete details of these procedures are described in Chapter 2 of TR-55. It should be noted that the TR-55 procedures are applicable only to sites with less than 30 percent total impervious coverage. In addition, the size of the downstream pervious area must be at least twice as large as the unconnected impervious area.
    - **Two-Step Technique:** This method is a two-step technique using the NRCS runoff equation. First, the resultant runoff from the unconnected impervious area should be computed separately, using the NRCS runoff equation in a manner similar to the technique described above for impervious surfaces. However, once the runoff from the unconnected impervious area is computed, it should then be considered as additional rainfall on the downstream pervious area it sheet flows onto. As a result, these pervious areas will effectively be subject to

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their own direct rainfall as well as the "rainfall" flowing from the upstream unconnected impervious areas. The resultant runoff from the downstream pervious areas in response to this combined rainfall can then be computed using the NRCS runoff equation again.

Example 5-3 illustrates this two-step runoff computation technique for unconnected impervious areas. In reviewing the example, it is important to note that the unconnected impervious area runoff depth must be converted to an equivalent uniform rainfall depth over the entire downstream pervious area based on the relative sizes of the unconnected impervious and downstream pervious areas.

Example 5-3: Site With Unconnected Impervious Cover Runoff Volume Computation Using Two-Step Technique

Description: A 3-acre development site is comprised of 1 acre of impervious surface and 2 acres of lawn and woods with an NRCS Curve Number (CN) of 65. Runoff from the entire impervious surface sheet flows onto to the pervious portion of the site before entering the site's drainage system. Compute the total runoff volume for the 1.25-inch stormwater quality design storm using the NRCS methodology.

Stormwater Quality Design Storm = P = 1.25 inches

Total drainage area = 3 acres

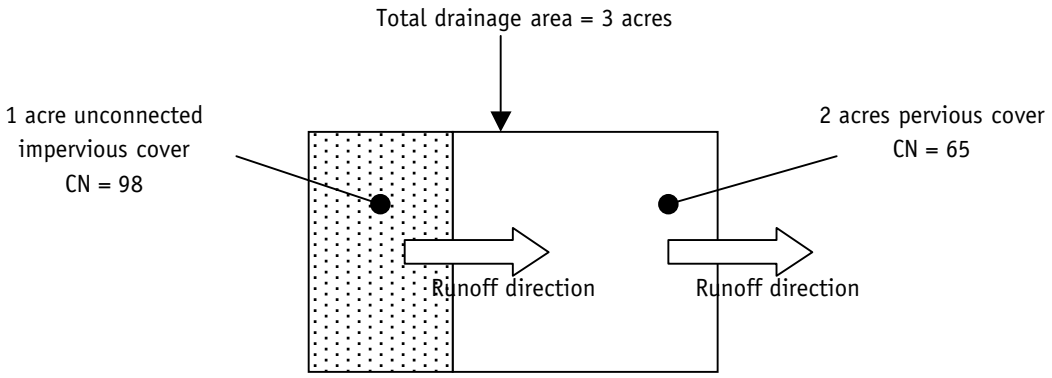
Impervious area = 1 acre (1/3 of total area)

Pervious area = 2 acres (2/3 of total area)

Pervious cover = mixture of lawn and woods pervious CN = 65

Impervious cover = asphalt impervious CN = 98

Note: All impervious area runoff sheet flows onto downstream pervious area



Impervious Area

$$\text{Impervious area } S = \frac{1000}{CN} - 10 = \frac{1000}{98} - 10 = 0.20 \text{ inches}$$

Impervious area initial abstraction = 0.2S = (0.2)(0.20) = 0.04 inches

0.8S = (0.8)(0.20) = 0.16 inches

$$\text{Impervious area runoff volume} = Q = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(1.25 - 0.04)^2}{1.25 + 0.16} = 1.04 \text{ inches}$$

Runoff volume = (1.04 inches/12 inches per foot)(1 acre)(43,560 sf per acre)

Impervious area runoff volume = 3775 cubic feet

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Equivalent rainfall depth on downstream pervious area =

(3775 cubic feet)/(2 acres)(43,560 sf per acre) = 0.043 feet = 0.52 inches

Pervious Area

Total effective rainfall = direct rainfall + unconnected impervious area runoff

= 1.25 inches + 0.52 inches = 1.77 inches total

$$\text{Pervious area } S = \frac{1000}{CN} - 10 = \frac{1000}{65} - 10 = 5.38 \text{ inches}$$

Pervious area initial abstraction = 0.2S = (0.2)(5.38) = 1.08 inches

0.8S = (0.8)(5.38) = 4.30 inches

$$\text{Pervious area runoff volume} = Q = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(1.77 - 1.08)^2}{1.77 + 4.30} = 0.08 \text{ inches}$$

Runoff volume = (0.08 inches/12 inches per foot)(2 acres)(43,560 sf per acre)
= 581 cubic feet

Pervious area runoff volume = total runoff volume = 581 cubic feet

From the above example, it can be seen that a key parameter in the two-step runoff computation technique for unconnected impervious cover is the effective size of the downstream pervious area. The following three criteria, in conjunction with the seven requirements for all unconnected impervious areas shown above, should be used to determine the effective size of this downstream area:

1. The minimum sheet flow length across the downstream pervious area is 25 feet.
2. The maximum sheet flow length across the unconnected impervious area is 100 feet.
3. While the total flow length area may be greater, the maximum sheet flow length across the downstream pervious area that can be used to compute the total resultant runoff volume is 150 feet.

These criteria are illustrated below in Figures 5-5 and 5-6 for both on-grade and above-grade unconnected impervious areas, respectively. Additional criteria for determining the lower limits of the downstream pervious area are presented in Figure 5-7. When using Figure 5-6 with overlapping pervious areas downstream of roof downspouts, the overlapping areas should be counted only once in the computation of the total pervious area downstream of the roof.

Finally, when computing the peak runoff rate or hydrograph from an area with unconnected impervious cover, the time of concentration of the combined impervious and downstream pervious area should be based upon the Tc of the downstream pervious area only, with the Tc route beginning as sheet flow at the upper end of the pervious area.

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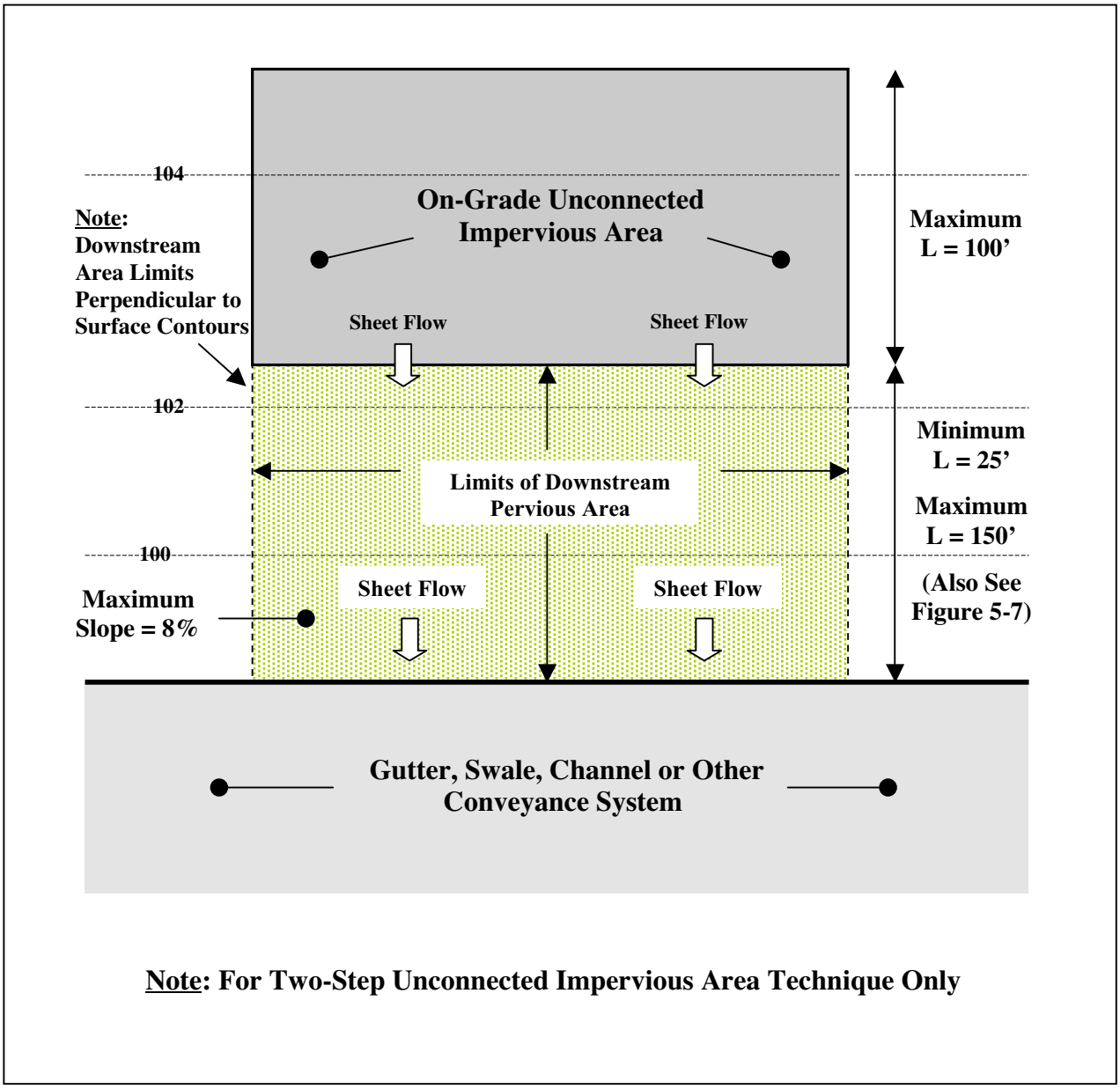
Figure 5-5: Downstream Pervious Area Criteria for On-Grade Unconnected Impervious Area



Note: For Two-Step Unconnected Impervious Area Technique Only

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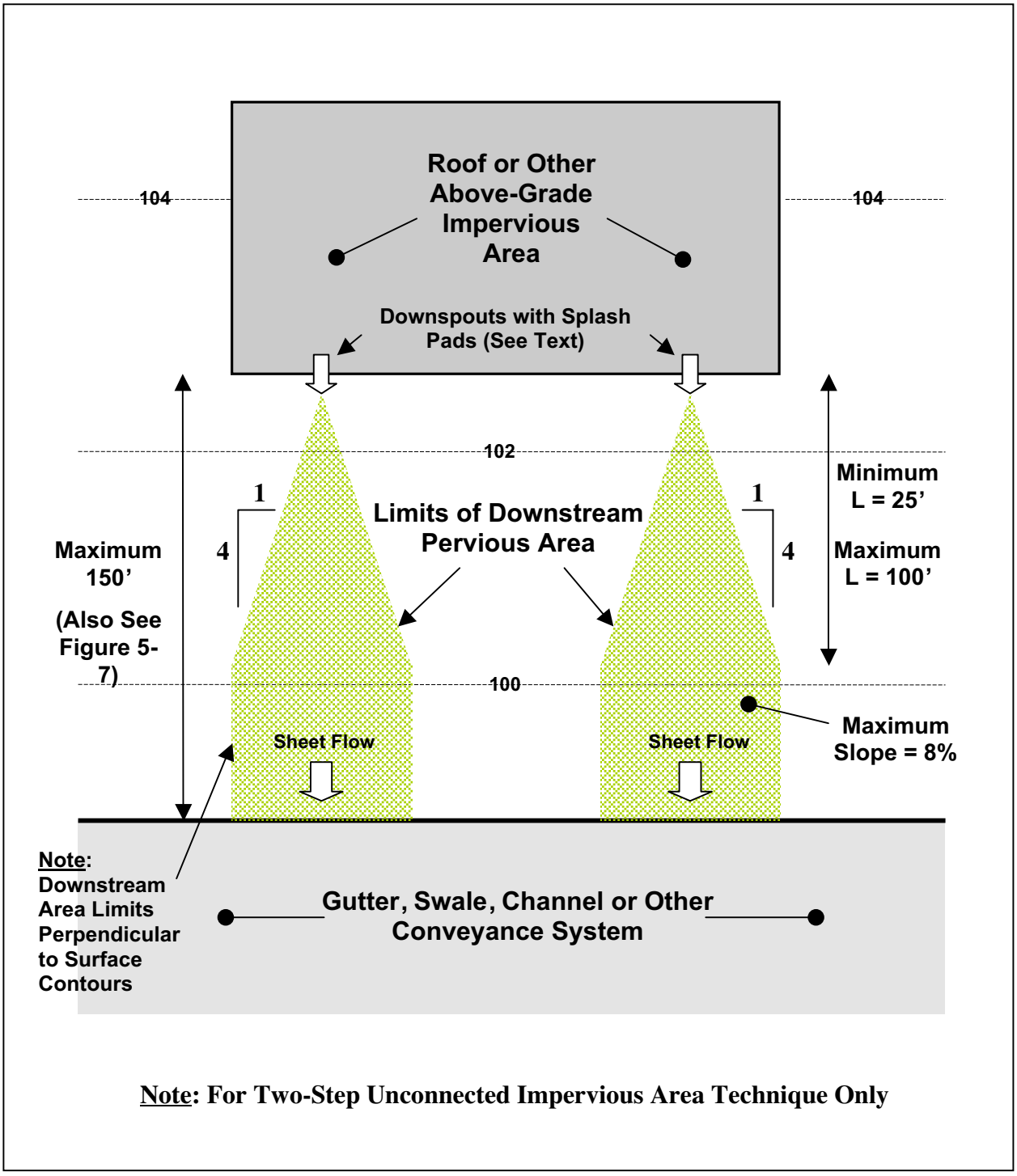
Figure 5-6: Downstream Pervious Area Criteria for Above-Grade Unconnected Impervious Area



Note: For Two-Step Unconnected Impervious Area Technique Only

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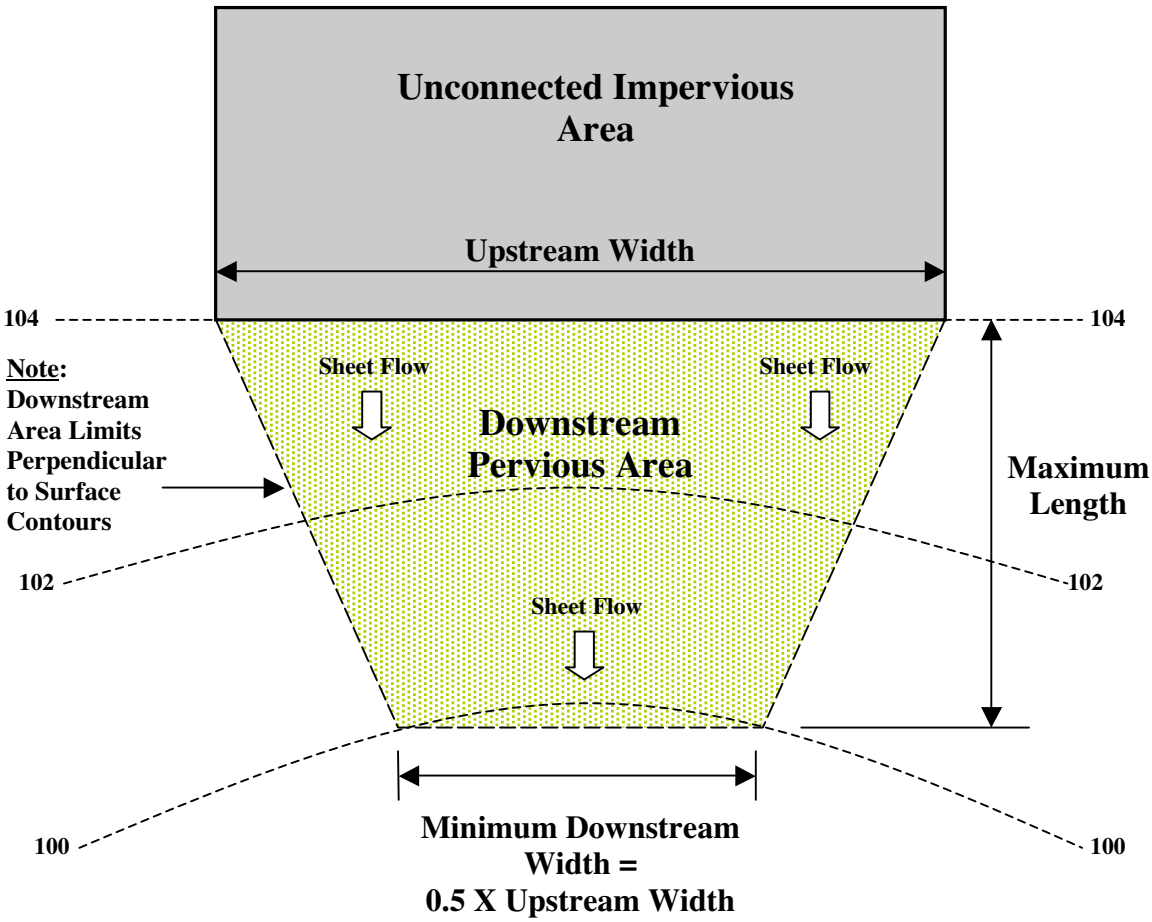
Figure 5-7: Additional Downstream Pervious Area Length and Effective Size Criteria



Note: In determining maximum length and effective size of downstream impervious area, downstream area width cannot be less than one half of upstream width regardless of distance to downstream conveyance system.

Note: For Two-Step Unconnected Impervious Area Technique Only

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Sites With Groundwater Recharge

As required by the NJDEP Stormwater Management Rules and described in detail in *Chapter 6: Groundwater Recharge*, land development projects must maintain 100 percent of the site's annual pre-developed groundwater recharge. At most sites, this will require the design and construction of a groundwater recharge BMP that allows the runoff from the groundwater recharge design storm to infiltrate into the site's subsoil. This amount of infiltration can also be used by a designer to help meet the stormwater quality requirements of the Rules. Techniques to do so are presented below. However, to ensure downstream safety and channel stability, the amount of groundwater recharge provided at a development site *cannot* be considered when complying with the Rules' stormwater quantity requirements (i.e., control of the 2, 10, and 100-year storms).

Rational and Modified Rational Methods

When computing a peak runoff rate for the stormwater quality design storm using the Rational Method, the size of that portion of the site that contributes runoff to the groundwater recharge BMP can be reduced by the ratio of the total groundwater recharge design storm to the 1.25-inch stormwater quality design storm. Similar procedures can be used in most instances to construct a reduced inflow hydrograph for use in the Modified Rational Method. Examples 5-4 and 5-5 below demonstrate these techniques.

Example 5-4: Sites With Groundwater Recharge
Stormwater Quality Design Storm Peak Flow Computation Using Rational Method

Description: A 3-acre development site is comprised of 1 acre of impervious surface (Rational C = 0.99) and 2 acres of lawn and woods (Rational C = 0.40). The post-development time of concentration (Tc) is 20 minutes. All runoff from a 0.5-inch recharge design storm on the impervious surface is recharged. Runoff from larger storms on the impervious surface flows directly to the site's drainage system. Compute the site's total peak runoff rate for the 1.25-inch stormwater quality design storm using the Rational Method.

Recharge Design Storm = 0.5 inches on impervious cover only
Total Stormwater Quality Design Storm = 1.25 inches on entire site
Post-developed Tc = 20 minutes
Maximum Stormwater Quality Design Storm I = 2.2 inches (see Figure 5-3)

Total drainage area = 3 acres
Impervious area = 1 acre (1/3 of total area)
Pervious area = 2 acres (2/3 of total area)
Pervious cover = mixture of lawn and woods pervious C = 0.40
Impervious cover = asphalt impervious C = 0.99
Note: All impervious cover is directly connected to the drainage system

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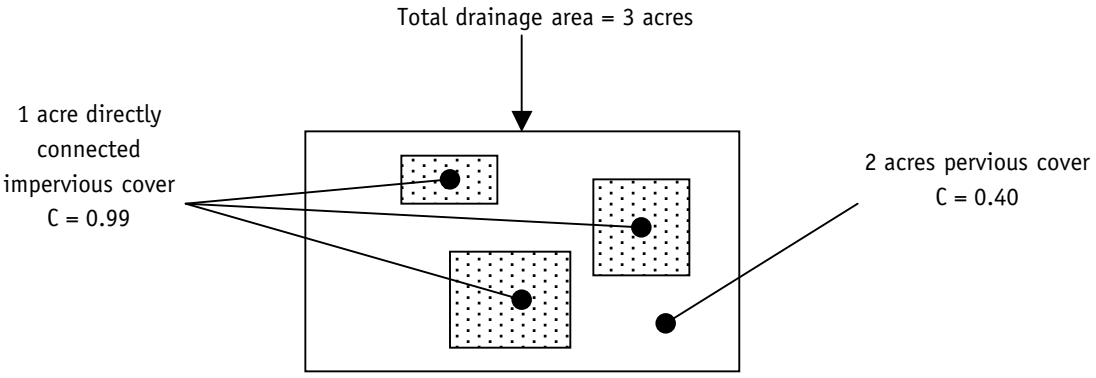

Adjusted impervious area due to recharge =

$$\text{Total impervious area} \times \frac{\text{Stormwater Quality Design Storm} - \text{Groundwater Recharge Design Storm}}{\text{Stormwater Quality Design Storm}}$$

$$= 1 \text{ acre} \times \frac{1.25 \text{ inches} - 0.5 \text{ inches}}{1.25 \text{ inches}}$$

$$= 1 \text{ acre} \times \frac{0.75 \text{ inches}}{1.25 \text{ inches}} = 1 \text{ acre} \times 0.6 = 0.6 \text{ acres}$$

Adjusted total site area = 0.6 acres impervious + 2.0 acres pervious = 2.6 acres

$$\text{Composite site C} = \frac{(0.6 \text{ acres impervious} \times 0.99) + (2.0 \text{ acres pervious} \times 0.40)}{2.6 \text{ acres total}}$$

$$= \frac{0.59 + 0.8}{2.6} = \frac{1.39}{2.6} = 0.53$$

Peak Stormwater Quality Design Storm runoff rate = C I A
= 0.53 x 2.2 inches per hour x 2.6 acres = 3.0 CFS

Note: Without considering groundwater recharge credit, the peak rate would be:

Total area = 3.0 acres

$$C = \frac{(1.0 \times 0.99) + (2.0 \times 0.40)}{3.0} = \frac{1.79}{3.0} = 0.60$$

Peak stormwater quality runoff rate = 0.60 x 2.2 x 3.0 = 4.0 CFS

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Example 5-5: Sites With Groundwater Recharge
Stormwater Quality Design Storm Hydrograph Using Modified Rational Method

Description: For land development site described in Example 5-4 above, compute runoff hydrograph for entire site using Modified Rational Method.

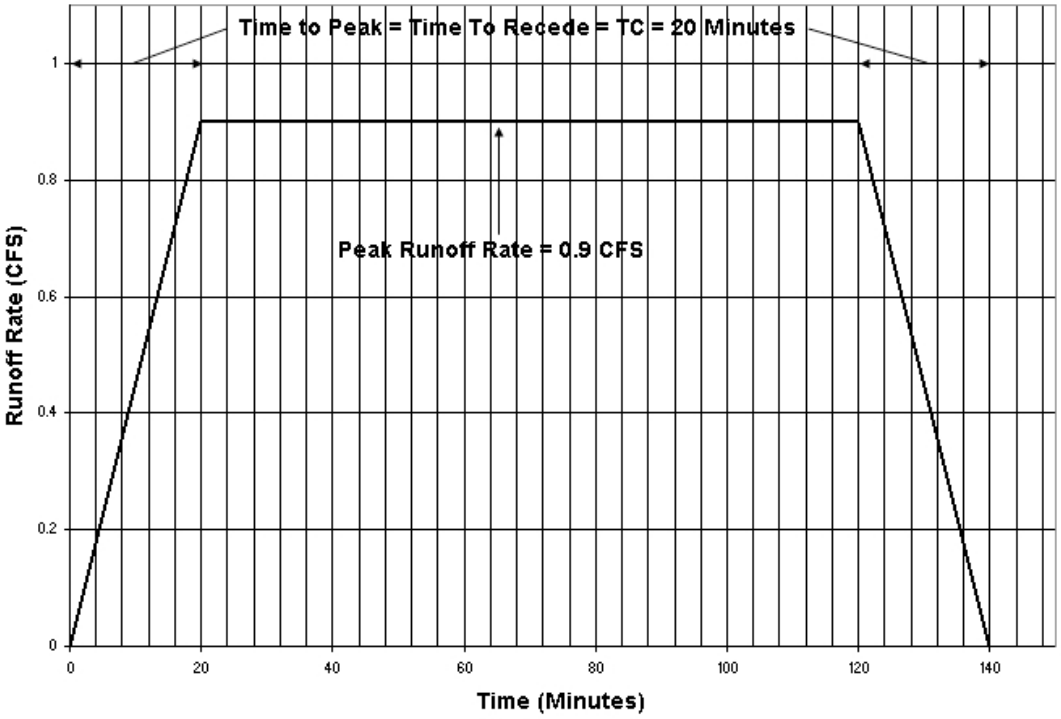
Adjusted total site area = 2.6 acres

Composite site C = 0.54

Average Stormwater Quality Design Storm I = 1.25-inches/2- hours = 0.625 inches per hour

Q = C I A = 0.54 x 0.625 x 2.6 Acres = 0.9 CFS

The Modified Rational Method runoff hydrograph is then constructed as shown below:



Note: See Example 5-1 for procedures to construct Modified Rational Method runoff hydrograph. Also see Important Note on page 5-8 regarding use of Modified Rational Method to compute a runoff hydrograph for the stormwater quality design storm.

It is important to note in Examples 5-4 and 5-5 that runoff from only a portion of the site was recharged during the 0.5-inch groundwater recharge design storm and that those areas were distributed throughout the site. This means that the remaining site areas would still be capable of generating runoff and that the overall site would produce runoff throughout the entire stormwater quality design storm. These conditions permitted the assumptions inherent in the Rational and Modified Rational Methods to be reasonably met when computing both the peak runoff rate and hydrograph from the larger, 1.25-inch stormwater quality design storm. Such site conditions are expected to be typical of most land developments.

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However, in cases where the groundwater recharge design storm runoff from the entire drainage area is recharged, the assumptions of the Rational and Modified Rational Methods cannot be met. As such, neither method can be recommended for computing the peak site runoff if the recharge volume is to be considered. In such cases, the designer can either continue to use either method without considering the recharge volume or use the NRCS methodology with the actual, nonlinear stormwater quality design storm as shown in Figure 5-2 and Table 5-1.

NRCS Methodology

When using the NRCS methodology to compute the total stormwater quality design storm runoff volume from a development site where all or a portion of the site's groundwater recharge design storm runoff is recharged, the relative amount of recharged runoff volume can be deducted from the total stormwater quality design storm volume. However, due to the nonlinearity of the NRCS runoff equation, such a deduction must be based on the *volume* of groundwater recharge design storm runoff from the recharged area and not simply the size of the recharged areas. Example 5-6 below describes this technique. When computing the peak stormwater quality design storm runoff rate or hydrograph from such a site with the NRCS methodology, it will be necessary to route the stormwater quality design storm hydrograph through the recharge facility. Since the recharge facility will be designed to contain only the normally smaller groundwater recharge design storm, an accurate stage-discharge relationship for the facility's overflow must be included in the routing computations in order to obtain an accurate peak runoff rate or hydrograph.

Example 5-6: Sites With Groundwater Recharge
Stormwater Quality Design Storm Volume Using NRCS Methodology

Description: A 3-acre development site is comprised of 1 acre of impervious surface and 2 acres of lawn and woods with an NRCS Curve Number (CN) of 65. Runoff from the entire impervious surface is recharged during a 0.5-inch groundwater recharge design storm. Runoff from larger storms on the impervious surface flows directly to the site's drainage system. Compute the total stormwater quality design storm runoff volume from the site using the NRCS methodology.

Groundwater Recharge Design Storm = 0.5 inches on impervious cover only
Total Stormwater Quality Design Storm = 1.25 inches on entire site

Total drainage area = 3 acres
Impervious area = 1 acre (1/3 of total area)
Pervious area = 2 acres (2/3 of total area)
Pervious cover = mixture of lawn and woods pervious CN = 65
Impervious cover = asphalt impervious CN = 98

Note: All impervious cover is directly connected to the drainage system

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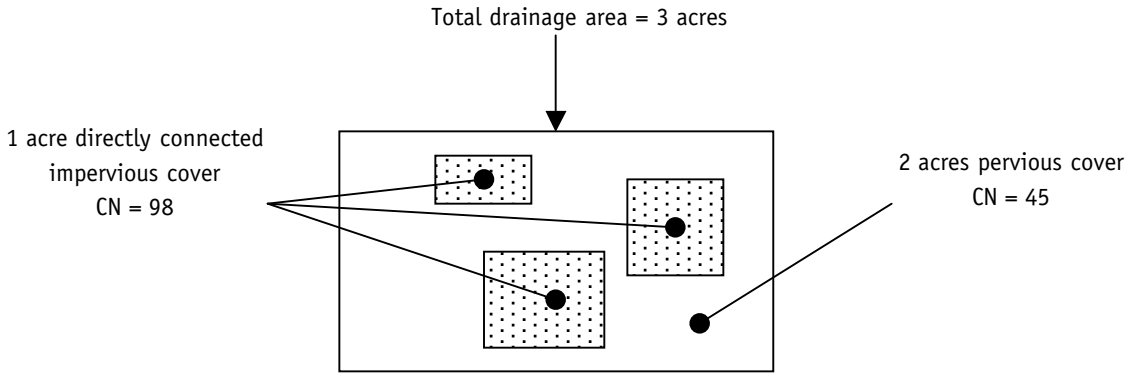

Impervious Area

$$\text{Impervious area } S = \frac{1000}{CN} - 10 = \frac{1000}{98} \pm 10 = 0.20 \text{ inches}$$

Impervious area initial abstraction = 0.2S = (0.2)(0.20) = 0.04 inches

0.8S = (0.8)(0.20) = 0.16 inches

Groundwater Recharge Design Storm = 0.5 inches

$$\text{Recharged runoff volume for Groundwater Recharge Design Storm} = Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S}$$

$$= \frac{(0.50 - 0.04)^2}{0.50 + 0.16} = 0.32 \text{ inches}$$

Stormwater Quality Design Storm = 1.25 inches

$$\text{Runoff volume for Stormwater Quality Design Storm} = Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S}$$

$$= \frac{(1.25 - 0.04)^2}{1.25 + 0.16} = 1.04 \text{ inches}$$

Difference in runoff volumes = 1.04 inches - 0.32 inches = 0.72 inches

Net impervious area runoff volume =

(0.72 inches/12 inches per foot)(1 acre)(43,560 SF per acre)

= 2614 cubic feet

Pervious Area

$$\text{Pervious area } S = \frac{1000}{CN} - 10 = \frac{1000}{65} \pm 10 = 5.38 \text{ inches}$$

Pervious area initial abstraction = 0.2S = (0.2)(5.38) = 1.08 inches

0.8S = (0.8)(5.38) = 4.30 inches

$$\text{Pervious area runoff volume} = Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} = \frac{(1.25 \pm 1.08)^2}{1.25 + 4.30} = 0.005 \text{ inches}$$

Runoff volume = (0.005 inches/12 inches per foot)(2 acres)(43,560 SF per acre)

Total pervious area runoff volume = 36 cubic feet

Total site runoff volume = 2614 + 36 = 2650 cubic feet

Note: in Example 5-2, where none of the impervious surface runoff was recharged, the same site produced 3811 cubic feet of runoff for the stormwater quality design storm.

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Time of Concentration Considerations

Computation of a peak runoff rate or hydrograph will require an estimate of a drainage area's time of concentration (Tc). In performing Tc calculations, designers should consider the following factors.

- **Maximum sheet flow length:** When using the segmental Tc procedures contained in Chapter 3 of the NRCS *Technical Release 55 – Urban Hydrology for Small Watersheds* (TR-55), the maximum sheet flow length recommended by the NRCS is 150 feet. According to the NRCS, longer lengths may be used only in special cases, such as smooth, uniformly graded parking lots or athletic fields. In addition, it may be appropriate to use a longer sheet flow length in wooded areas with Hydrologic Soil Group A or B soils and ground slopes of 2 percent or flatter. In such areas, high infiltration rates, low sheet flow velocities, and the presence of surface irregularities that store and reinfiltrate runoff may limit the generation of runoff to such an extent that a larger than normal area (and therefore a longer than normal sheet flow length) is needed to produce sufficient runoff rates to exceed sheet flow depths and create shallow concentrated flow.
- **Maximum sheet flow roughness coefficient:** According to the NRCS, the maximum Manning's Roughness Coefficient (n) to be used in the Sheet Flow Equation in Chapter 3 of TR-55 is 0.040.
- **Tc routes:** Consideration must be given to the hydraulic conditions that exist along a selected Tc route, particularly in pre-developed drainage areas. Tc routes should not cross through significant flow constrictions and ponding areas without considering the peak flow and time attenuation effects of such areas. As noted in the NJDEP Stormwater Management Rules, such areas can occur at hedgerows, undersized culverts, fill areas, sinkholes, and isolated ponding areas. In general, a separate subarea tributary to such areas should be created and its runoff routed through the area before combining with downstream runoff.
- In certain areas with highly irregular topography, large surface storage volumes, high soil infiltration rates, and/or Karst topography, the segmental Tc method described in Chapter 3 of TR-55 may not be appropriate. In such areas, alternative Tc methods should be used.

Table 5-2: Summary of Modeling Guidance for Various Site Conditions
Rational, Modified Rational and NRCS Methods[1]

Site Condition or Parameter	Rational Method	Modified Rational Method	NRCS-Based Methods
Mixture of pervious and directly connected impervious surface	Use standard procedures	Use standard procedures	Use weighted average runoff volume
Unconnected impervious surface	Use not recommended	Use not recommended	TR-55 or Two-Step Technique
Groundwater recharge areas	Reduce effective size of recharge area[2]	Reduce effective size of recharge area[2]	Reduce runoff volume by recharge volume
Time of concentration	Maximum sheet flow length = 150 feet Maximum sheet flow n = 0.40 Include effects of storage and ponding areas		

Notes: Table presents summaries only. See text for complete descriptions for each computation method.
For sites with combination of recharge and non-recharge areas. Methods not recommended where entire area is recharged. See text for details.

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New Jersey Stormwater Best Management Practices Manual

April 2004

CHAPTER 6

Groundwater Recharge

This chapter presents the standards, data, and procedures necessary to meet the groundwater recharge requirements of the NJDEP Stormwater Management Rules at N.J.A.C. 7:8. According to these Rules, a "major development" project, which is one that disturbs at least 1 acre of land or creates at least 0.25 acres of new or additional impervious surface, must include nonstructural and/or structural stormwater management measures that prevent the loss of groundwater recharge at the project site. This requirement is included in the Rules because the loss of groundwater recharge can adversely impact the health of streams and wetlands and the yield of water supply wells. Urban redevelopment and certain linear development projects are exempt from the groundwater recharge requirements, while waivers may obtained under certain conditions for public roadway, railroad, and pedestrian walkway enlargements. Complete details can be found in Subchapter 5 of the Stormwater Management Rules.

Specifically, the Stormwater Management Rules require that a proposed major land development comply with one of the following two groundwater recharge requirements:

Requirement 1: That 100 percent of the site's average annual pre-developed groundwater recharge volume be maintained after development; or

Requirement 2: That 100 percent of the difference between the site's pre- and post-development 2-Year runoff volumes be infiltrated.

The Stormwater Management Rules allow the site designer to select which requirement to follow. The Rules also state that compliance with either of the above alternative requirements must be demonstrated through hydrologic and hydraulic analysis. Regardless of which alternative requirement is selected, such an analysis will generally begin with a computation of the existing (or pre-developed) hydrologic conditions at the proposed development site. In the case of Requirement 1, these conditions will focus on the annual amount of groundwater recharge that occurs at the site under pre-developed conditions while, for Requirement 2, the focus will instead be on the pre-developed volume of 2-Year site runoff.

These computations will then be followed by similar ones for the proposed (or post-developed) conditions at the site. A comparison of the results of either of these pre- and post-development computations will then yield the annual volume of groundwater that must be recharged (Requirement 1) or 2-Year storm runoff volume that must be infiltrated (Requirement 2) through one or more structural recharge or infiltration BMPs. Ideally, the planning and design of the proposed site will have incorporated nonstructural measures to such an extent that the need for structural facilities is reduced to a practical minimum.

Finally, once the analysis of pre- and post-development conditions has established the need for structural recharge (Requirement 1) or infiltration (Requirement 2) BMPs, the hydrologic and hydraulic analysis would next focus on the actual design of such facilities. This process would include answering such questions such as:

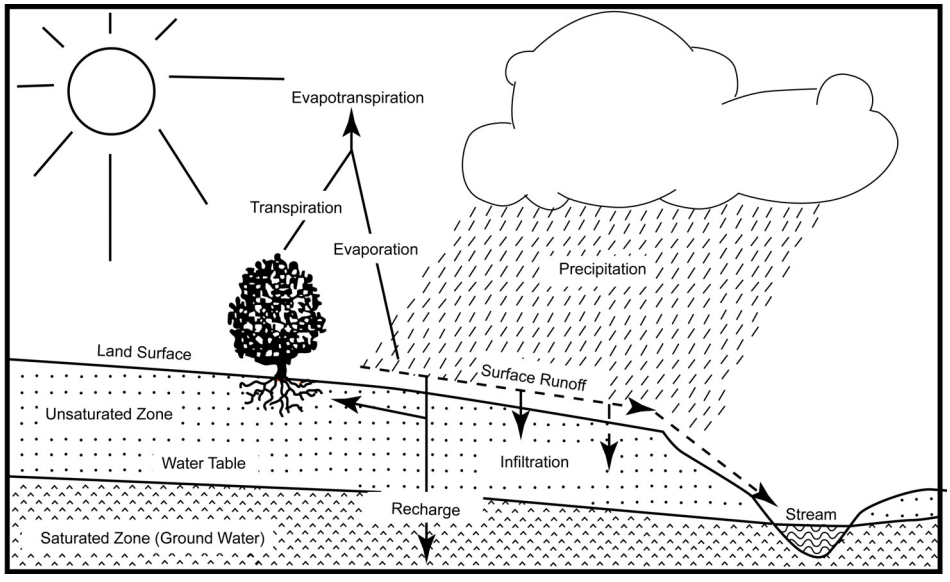
- Should the required recharge or infiltration be achieved at a single facility or several located throughout the development site?
- Should the facilities be located above or below ground?
- Which portions of the development site should be utilized to generate runoff to the facilities?
- What facility dimensions are required?
- Where should the facilities be located on the site relative to buildings, septic systems, property lines, and other sensitive areas?

This chapter presents the groundwater recharge information necessary to perform the hydrologic and hydraulic analysis required for Requirement 1 (maintaining pre-developed annual recharge volumes). Information necessary for the analysis required for Requirement 2 (infiltrating the increased 2-Year runoff volume) is presented in *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. Design information regarding structural recharge and infiltration BMPs can be found in this chapter and *Chapter 9: Structural Stormwater Management Measures*.

Fundamentals

In both the NJDEP Stormwater Management Rules and this manual, groundwater recharge is defined as precipitation that infiltrates into the soil and is not evapotranspired. Instead, the infiltrated precipitation moves downward to a depth below the root zone of the surface vegetation, where it cannot be removed by that vegetation through uptake and evapotranspiration. At such a depth, it is considered available to enter the soil's saturated zone and become groundwater. The role of groundwater recharge in the overall hydrologic cycle is illustrated in Figure 6-1 below.

Figure 6-1: Groundwater Recharge in the Hydrologic Cycle



Source: New Jersey Geological Survey Report GSR-32.

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According to the New Jersey Geological Survey (NJGS):

> *The potential for natural groundwater recharge begins with precipitation (rain, snow, hail, sleet). Some of the precipitation never seeps into the soil, but instead leaves the system as surface runoff. The water that seeps into the soil is infiltration. Part of the water that does infiltrate is returned to the atmosphere through evapotranspiration. Evapotranspiration refers to water that is returned to the atmosphere from vegetated areas by evaporation from the soil and plant surfaces and soil water that is taken up by plant roots and transpired through plant leaves or needles. Infiltrated water that is not returned to the atmosphere by evapotranspiration moves vertically downward and, upon reaching the saturated zone, becomes ground water. This ground water could be in a geologic material that is either an aquifer or nonaquifer, depending on whether it can yield satisfactory quantities to wells.* (NJGS GSR-32)

In addition to supplying water to wells, groundwater can also provide base flow to streams, wetlands, and other water bodies, directly affecting the ecology and geomorphology of these resources.

The potentially adverse impacts of land development on groundwater recharge have long been recognized. From the description presented above, it can be seen that land development activities that either cover permeable soils with impervious surfaces or reduce the soils' permeability through disturbance and compaction will reduce the rate of groundwater recharge that occurs under pre-developed site conditions. As noted above, such reductions in groundwater recharge can adversely impact streams, wetlands, and other water bodies by reducing the volume and rate of base flow to them. Reductions in groundwater recharge to aquifers can also adversely impact the yield of water supply wells. As a result, the New Jersey Stormwater Management Rules require that pre-developed groundwater recharge rates be maintained at land development sites under post-development conditions.

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Computing Groundwater Recharge

Overview

As described above, the groundwater recharge requirements of the NJDEP Stormwater Management Rules can be met by demonstrating that the average volume of precipitation that is annually recharged to the groundwater at a major land development site under pre-developed conditions will be maintained following site development. As described in detail below, this can be achieved through a combination of natural recharge over the developed site's pervious surfaces and artificial recharge through groundwater recharge BMPs constructed at the site. The BMP volume is based on an average annual distribution of runoff-producing precipitation events at the site, the impervious drainage area to the BMP, and the losses that may occur to the infiltrated runoff before it can travel below the root zone of surrounding vegetation and become groundwater.

The data and analytic procedures necessary to meet these requirements have been developed by the New Jersey Department of Environmental Protection (NJDEP) with assistance from the New Jersey Geologic Survey (NJGS), the U.S. Geologic Survey (USGS), and professional consultants, and have been compiled into the New Jersey Groundwater Recharge Spreadsheet (NJGRS), a Microsoft Excel-based computer spreadsheet program. The NJGRS is intended for use by site planners, designers, engineers, and reviewers to determine average annual groundwater recharge amounts under both pre- and post-development site conditions and to design the groundwater recharge BMPs necessary to maintain 100 percent of the pre-developed site's annual groundwater recharge rate. Information regarding the NJGRS, including a detailed User's Guide, an example problem, and instructions on how to download the NJGRS from the NJDEP stormwater management website, is presented below. Details of the program's theoretical basis, equations, and supporting databases are also summarized.

In general, the analytic procedures utilized by the NJGRS to achieve compliance with the groundwater recharge requirements of the Stormwater Management Rules (described as Requirement 1 above) can be summarized by the following computational steps:

1. Compute the average amount of annual groundwater recharge occurring over the land development site under pre-developed site conditions.
2. Compute the average amount of annual groundwater recharge occurring over the land development site under post-developed conditions. Such site conditions should reflect the use, to the maximum extent practicable, of nonstructural stormwater management measures at the post-developed site in accordance with the Stormwater Management Rules. Details of such nonstructural measures are presented in *Chapter 2: Low Impact Development Techniques*.
3. Compute any resulting annual groundwater recharge deficit by subtracting the post-developed annual recharge amount in Step 2 from the pre-developed annual amount in Step 1. This deficit represents the average annual amount of groundwater recharge that must be achieved at the development site through structural groundwater recharge BMPs.
4. Determine the storage volume and related dimensions of the structural groundwater recharge BMP that will be required to satisfy the average annual groundwater recharge deficit computed in Step 3 above. In doing so, the BMP volume must be based on the average annual distribution of runoff-producing precipitation events at the development site, the size of the drainage area over which these events will occur (and from which runoff will be collected or captured for recharge), and the infiltration, evapotranspiration, and other losses that may occur to the recharged runoff in the BMP before it can actually enter the groundwater.

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Theoretical Basis of Computations

Computation of the average annual groundwater recharge at a land development site under either pre- or post-developed conditions (as described above in Steps 1 and 2) can be performed with the New Jersey Groundwater Recharge Spreadsheet (NJGRS). This Microsoft Excel-based spreadsheet is based on the data and computational procedures contained in the 1993 *Geological Survey Report GSR-32: A Method for Evaluating Ground Water Recharge Areas in New Jersey* developed by the NJGS. As described in the report, GSR-32 utilizes precipitation, soil, land cover, and climate data, and rainfall-runoff and mass balance computations to estimate average annual groundwater recharge amounts at sites within any New Jersey municipality under a variety of surface and development conditions. All pertinent GSR-32 databases and computational algorithms have been incorporated into the NJGRS. As such, use of the NJGRS is governed, in part, by the assumptions and limitations of GSR-32.

Design of the required recharge BMP (as described in Step 4 above) to compensate for the developed site's groundwater recharge deficit (as described in Step 3 above) can also be performed with the NJGRS. The design computations in the NJGRS are based on a number of analytic techniques and databases. Conceptually, a groundwater recharge BMP will recharge the runoff it receives from its drainage area for all storms up to a particular precipitation depth, which can be referred to as the BMP's groundwater recharge design storm. While the recharge BMP will also receive runoff from larger storms, it will only recharge that portion of the runoff that equals the Recharge Design Storm runoff. The remaining runoff from these larger storms will overflow or otherwise bypass the BMP. It is important to note that the range of precipitation depths typically involved in the design of a groundwater recharge BMP are relatively small when compared to depths associated with runoff quality or quantity control. As a result, the NJGRS requires that the entire drainage area to a recharge BMP be impervious, since pervious surfaces would typically not be able to produce a sufficient amount of rechargeable runoff from such small precipitation depths.

Assuming that all of the precipitation falling in a recharge BMP's impervious drainage area can be collected and recharged (i.e., no runoff, infiltration, or recharge losses), computation of the BMP's Recharge Design Storm depth can be conceptually illustrated with the following conversion equation:

$$\begin{array}{c}\text{Total Average}\\ \text{Annual Recharge}\\ \text{Deficit}\end{array} = \begin{array}{c}\text{Annual Sum of}\\ \text{Recharge Design and}\\ \text{Smaller Storm}\\ \text{Depths}\end{array} + \left[\begin{array}{c}\text{Recharge Design}\\ \text{Storm Depth}\end{array} \times \begin{array}{c}\text{Number of}\\ \text{Larger}\\ \text{Storms}\end{array}\right]$$

The above equation shows that, with appropriate precipitation data and ignoring all losses, the total annual recharge deficit at a land development site can be converted to the sum of two precipitation amounts, both of which are based on a single groundwater recharge design storm. The first amount is the sum of all storm depths up to and including the Recharge Design Storm that would occur at the site in an average year. The second amount is the product of the Recharge Design Storm depth times the number of larger storms that would also occur at the site in that same average year.

Unfortunately, most of the ease and simplicity of the conversion equation shown above is gained through its two assumptions: that appropriate precipitation data is available, and that all of the precipitation falling on the BMP's impervious drainage area can be recharged without loss. In reality, compiling such precipitation data for a specific land development site requires considerable effort and resources and must be repeated for each new development site. In addition, precipitation losses will occur and must be taken into consideration in the design of a recharge BMP. As noted above, these losses, which will vary with the total precipitation depth, include those occurring in the conversion of precipitation to runoff, including surface storage, evaporation, and infiltration through cracks, joints, and seams in the drainage area's impervious surface. Further losses will occur once the runoff is delivered to the recharge BMP, primarily in

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the form of evapotranspiration by the vegetation above, beneath, and/or adjacent to the BMP. Further complications arise when one attempts to estimate these variable losses. While equations exist to predict such losses for individual storm events, there are none readily available that can do so for an annual precipitation depth.

The NJGRS addresses these problems in several ways. Regarding the need for appropriate precipitation data for all possible development site locations in New Jersey, the NJGRS developers compiled and analyzed 52 years of daily precipitation data collected at 92 precipitation stations throughout New Jersey between 1948 and 1999. To ensure a proper database, only precipitation depths greater than 0.04 inches were considered, since this depth was considered the minimum amount necessary to produce runoff from impervious surfaces. All daily values at each station were sorted for each year and then averaged over the 52 year period of record. Next, all values with the same rank were averaged across all 92 stations to produce an average annual series of 79 precipitation events for the state. Finally, this series was normalized by dividing each event value by 46.32 inches, which was the average annual precipitation for the 92 stations. This produced an average annual series of 79 precipitation events, expressed as a percentage of total annual precipitation, that are analyzed individually by the NJGRS to compute the runoff, infiltration, and recharge losses and the resulting annual groundwater recharge achieved by a recharge BMP at a land development site in any New Jersey municipality.

This average annual series of precipitation events for New Jersey is shown below in Figures 6-2 and 6-3. Figure 6-2 depicts the precipitation depth, expressed as a percentage of total average annual rainfall, of each event in the series in ascending order, while Figure 6-3 depicts, also in ascending order, the events' cumulative percentage of the average annual rainfall. More detailed information about each specific event in the average annual series is contained in the NJGRS' databases. The average annual precipitation series shown in Figure 6-2 is used by NJGRS to produce a site-specific, year-long series of design storms by multiplying each event value in the series by the average annual precipitation in the municipality where the recharge BMP is located. Since the NJGRS also contains average annual precipitation values for each New Jersey municipality, the NJGRS user can generate this site-specific average annual design series simply by specifying the municipality and county in which the development site is located.

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Figure 6-2: Average Annual Precipitation Series in NJGRS

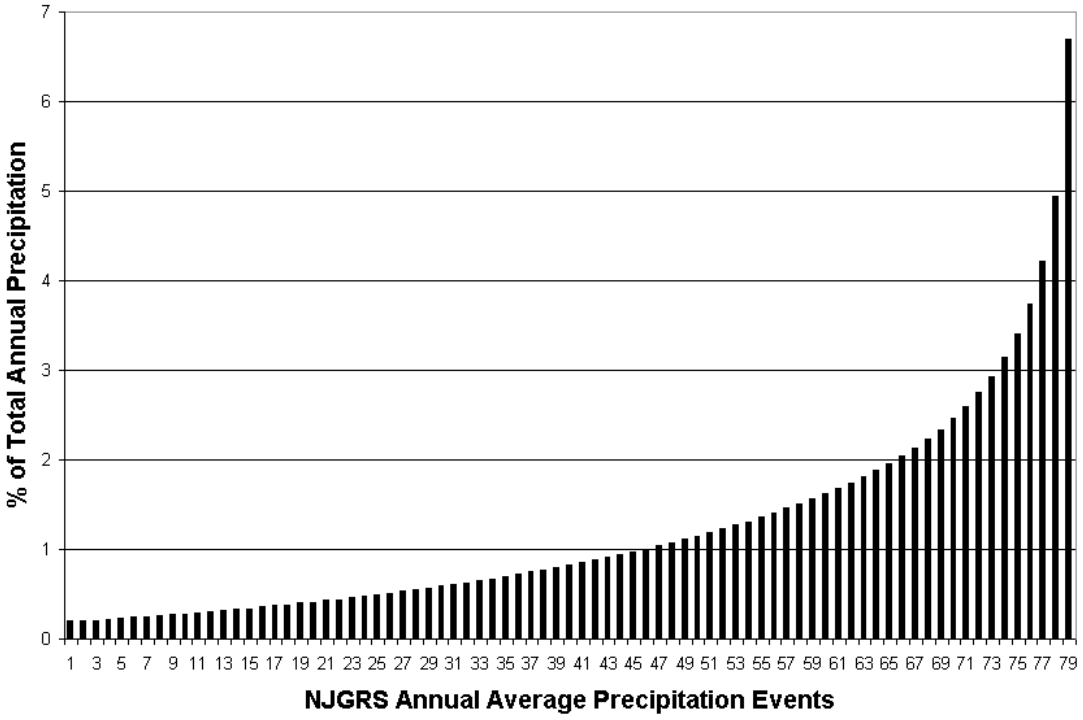
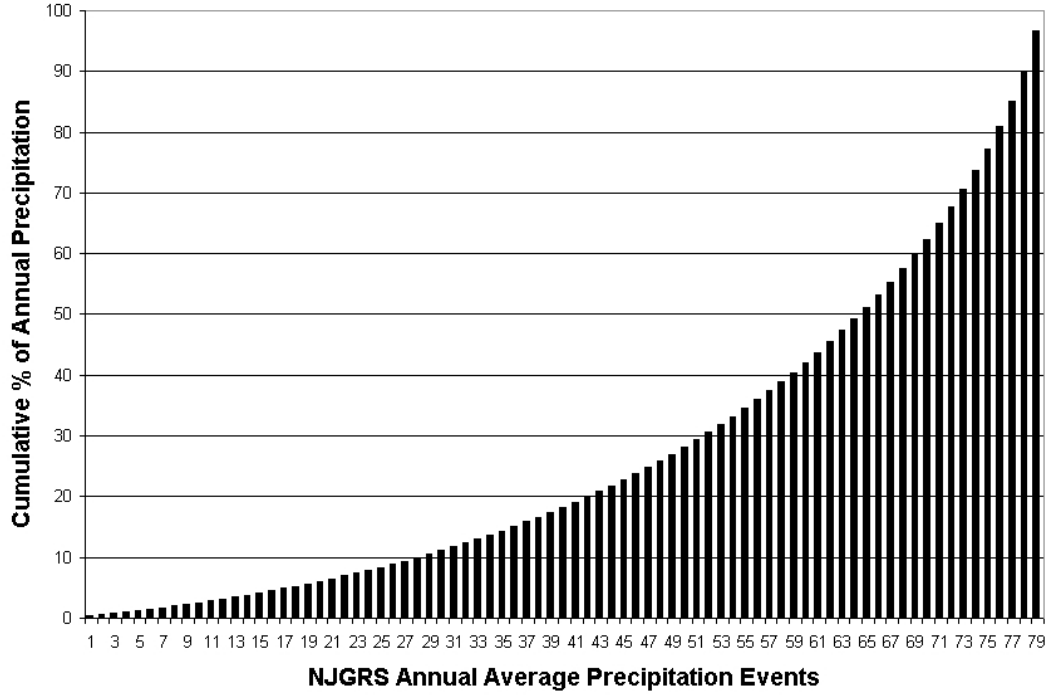


Figure 6-3: Cumulative Total of Average Annual Precipitation Series in NJGRS



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Once an average annual design series is computed for the specific recharge BMP site, the NJGRS next addresses the problem of precipitation losses. As noted above, all of the possible losses that will occur, from the time the precipitation falls on the BMP's impervious drainage area to when the recharged water moves below the root zone of the vegetation in or adjacent to the BMP, must be accounted for in order to accurately compute the actual volume that will be recharged. Such losses can include infiltration and surface storage losses on the drainage area surface as the precipitation is converted into runoff, as well as evapotranspiration and infiltration losses as the runoff is converted to recharge within the BMP itself. To compute runoff losses, the NJGRS uses one of three equations depending upon the total depth of the event. These equations are applied to each event in the average annual design series to compute the resultant runoff for each one. This resultant runoff is then used in additional equations that estimate the losses that will occur for each design event once the runoff enters the recharge BMP.

When computing runoff losses for design event depths less than 0.0408 inches, the NJGRS assumes that the entire precipitation depth is consumed by surface storage, infiltration, and other losses and no runoff is produced.

For design event depths between 0.04 and 1.25 inches, the NJGRS uses the following equation to compute runoff:

$$Q = 0.95\ (P - 0.0408)\ 0.90$$

where:

Q = Runoff Depth in Inches
P = Precipitation Depth in Inches

For design event depths greater than 1.25 inches, the NJGRS uses the NRCS Runoff Equation with a Runoff Curve Number (CN) of 98:

$$Q = \frac{(P - 0.04)^2}{(P + 0.16)}$$

where:

Q = Runoff Depth in Inches
P = Precipitation Depth in Inches

As noted above, the resultant runoff depth for each design event is then applied to specialized equations developed specifically for the NJGRS to estimate the losses that will occur to the runoff after it is stored in the recharge BMP. These losses will depend upon a number of factors, including the climate at the development site, the specific vegetation and soil conditions at the recharge BMP location, and the depth of the BMP relative to the vegetation's root zone. A complete description of the loss equations used in the NJGRS is presented in the program's User's Guide. By subtracting these losses from the stored runoff, the amount of runoff that is actually recharged for each design event is computed. The NJGRS then adds up the recharge amounts from each design event to obtain a total annual recharge amount, which is then compared with the average annual recharge deficit created by the development to determine whether the recharge BMP's performance is adequate. Similar to the computation of the average annual design series described above, the NJGRS' loss computations are performed automatically each time the user provides new development site or recharge BMP data and then requests a BMP design update. The NJGRS will then either evaluate the performance of the proposed recharge BMP or, if requested, compute the effective BMP storage depth or surface area necessary to offset the development's annual recharge deficit.

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New Jersey Groundwater Recharge Spreadsheet (NJGRS)

General Instructions

As described above, the New Jersey Groundwater Recharge Spreadsheet (NJGRS) is a Microsoft Excel-based computer spreadsheet program. It is typically used in a two step procedure, utilizing first the Annual Recharge worksheet and then the BMP Calculations worksheet in the program. During the first step, the average annual groundwater recharge amounts at the site under pre- and post-developed conditions are estimated based upon site data provided by the user. From these estimates, the program computes the average annual groundwater recharge deficit caused by the site development that must be offset by a groundwater recharge BMP. During the second step, this recharge BMP is sized based upon user-specified information regarding both the BMP and its location at the development site. General information regarding each step is provided below. Specific information about the program's use and computation methods are provided in the NJGRS User's Guide, which is presented at the end of this chapter.

It should be noted that, as a spreadsheet, certain cells of the program are reserved for user input while others provide intermediate and final results. All user input cells are shaded with a tan color while spreadsheet output cells are shaded with gray. Only the tan, user-input cells should be changed. In addition, the spreadsheet contains several combinations of commands known as macros. While these macros are essential to the spreadsheet's operations, they are unsigned and, as such, their presence may conflict with the Excel program's security settings in the user's computer. These conflicts would be identified to the user through an error or warning message immediately after opening the NJGRS. If such conflicts are encountered, they can usually be addressed by setting the Excel macro security level to Medium. *The user should determine whether this level of security is acceptable for their own system.* The user would then be prompted to enable the NJGRS macros each time the spreadsheet is opened.

Finally, upon completing use of the NJGRS for a specific project, the user will be asked whether the changes made during use should be saved. While such decisions are at the discretion of each user, it may be helpful for training purposes to retain the spreadsheet original settings, which match those in the NJGRS User's Guide. In this case, a copy of the revised NJGRS with project specific data entered can be saved with a project-specific name using the *Save As* command under *File* on the Excel command line.

Annual Recharge Worksheet

Annual groundwater recharge at a land development site under both pre- and post-developed (or existing and proposed) site conditions can be estimated using the Annual Recharge worksheet in the NJGRS. As discussed above, these estimates are based on the methodology contained in *Geological Survey Report GSR-32: A Method for Evaluating Ground Water Recharge Areas in New Jersey* (GSR-32) developed by the New Jersey Geological Survey. In general, use of this worksheet requires the following user input:

1. Name of municipality and county in which the project site is located (Cell C3). Upon input of this data through use of a drop-down list, the NJGRS will immediately display the average annual precipitation and climate factor for the site's municipality from the GSR-32 databases in the NJGRS. The user can also specify a project name, description, and date in the lines provided (Cells K1, K2, and K3).
2. Land use and land cover (LULC) data for the site under both pre- and post-developed conditions. This data will consist of the area (in acres), LULC characteristics, and soil series name for up to 15 land segments of the pre- and post-developed site. The NJGRS will issue a warning message if the total area specified under pre-developed conditions is different than post-developed. The LULC data and soil series names are listed in a drop-down list next to the respective input cells. It is

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important to note that the LULC categories in the drop-down list are based on those contained in Table 2-2 of the NRCS *Technical Release 55 – Urban Hydrology for Small Watersheds*. For a correlation between these LULC categories and those in GSR-32, upon which the NJGRS is based, see Table 6-1 below.

Table 6-1: NJGRS/TR-55 and GSR-32 LULC Descriptions

NJGRS/TR-55 LULC Descriptions	GSR-32 LULC Descriptions
Brush	Brush
Gravel, Dirt	Unvegetated
Impervious Areas	Unlandscaped Developed
Meadow, Pasture, Grassland or Range	Agricultural – Pasture
Open Space	Landscape Open Space
Residential 1 to 2 Acre	1 - 2 Acre Lots
Residential 1/2 to 1 Acre	1/2 - 1 Acre Lots
Residential 1/3 to 1/4 Acre	1/8 - 1/2 Acre Lots
Residential 1/8 Acre or Less	1/8 Acre Lots
Row Crop	Agricultural – General
Small Grain or Legumes	Agricultural – Cropland, Legume
Urban Districts	Landscaped Developed
Woods	Woods
Woods – Grass Combination	Wooded – General

As noted in the NJGRS User's Guide, it is important to specify a site's LULC characteristics as accurately as possible. Therefore, while a 1/4 acre residential site could be specified in the NJGRS by the "Residential 1/3 to 1/4 Acre" LULC description in Table 6-1, it is generally more accurate to divide the site into impervious and pervious areas and specify each as a separate land segment in the NJGRS. For example, at a 1/4 acre residential site with a total area of 10 acres consisting of 40 percent connected impervious and 60 percent grassed surfaces and a single soil series, it would be more appropriate to specify the site's LULC characteristics in the program as a separate 4 acre impervious area land segment and a 6 acre open space land segment. This separation of connected impervious and pervious areas is similar to the technique for computing runoff volume using the NRCS methodology in Chapter 5. It should be noted that the total impervious area for post-developed conditions displayed in Cell M23 of the Annual Recharge worksheet will be based only on those post-developed land segments specified as impervious.

When using the above technique, it should be noted that if any impervious areas at a development site are unconnected (see Chapters 2 and 5 for complete details and requirements), the area used in the impervious surface designations described above for these unconnected areas should be one half of the actual area. For example, if a site has 3 acres of directly connected impervious surface, but 2 acres of unconnected impervious area, the total impervious area specified in the NJGRS can be 3 + (0.5)(2) or 4

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acres. This 50 percent reduction in the size of unconnected impervious areas accounts for the runoff re-infiltration that can occur downstream of such areas and is consistent with the runoff computations for such areas contained in TR-55. To keep the total site area correct, the user should remember to specify the "remainder" of the unconnected impervious area as a pervious one with the appropriate soil series and LULC based upon the actual pervious area downstream of the unconnected impervious area.

It should also be noted that if a proposed recharge BMP will have a specific location within a land development site with similarly specific LULC and soil characteristics, that portion of the site should be specified as a separate land segment on the Annual Recharge worksheet. This is true even if that segment will be covered with an impervious surface. Doing this will allow the NJGRS to more accurately compute the losses and resultant recharge at the BMP. More details are presented below in the NJGRS User's Guide, including the need to specify this segment on the BMP Calculation worksheet.

From the above, it can be seen that the more generalized Residential and Urban District LULC descriptions in Table 6-1 above should be used only for general planning studies of groundwater recharge requirements, particularly at sites with multiple lots of similar size and impervious coverage where each lot will have a separate groundwater recharge BMP. Since the soil series in which each BMP will be located may vary from lot to lot, the general LULC descriptions can be used to compute typical or general groundwater recharge requirements and BMP dimensions for the entire site. These general values can then be refined on a lot by lot basis during later, more detailed project phases with specific lot and BMP information.

Finally, in accordance with NJGS Report GSR-32, which is the basis of the NJGRS, zero recharge volume will be computed for any land segment specified for either pre- or post-development conditions that contain soils that are hydric. See Report GSR-32 for more details.

BMP Calculations Worksheet

The dimensions of a groundwater recharge BMP can be either determined or tested using the BMP Calculations worksheet in the NJGRS. This worksheet can be used to calculate the effective depth required at a recharge BMP if the impervious drainage area and BMP area are specified. Conversely, the worksheet can also be used to calculate the required area of the BMP if the drainage area and effective BMP depth are specified. Finally, the BMP Calculations worksheet can be used to analyze a specific recharge BMP with a certain area and effective depth to see what amount of annual groundwater recharge it can provide.

As explained in the NJGRS User's Guide, it is critical that the surface area of a recharge BMP (variable ABMP) be specified in the program as accurately as possible. This is because the program uses the ratio of the BMP's drainage area and surface area to determine the resultant depth of runoff in the BMP for each storm event analyzed. In addition, a recharge BMP's effective depth (variable dBMP) represents the maximum equivalent water depth that can be achieved in the BMP before overflow begins. Therefore, if the proposed recharge BMP will consist, for example, of a subsurface, vertical-walled chamber, dBMP will simply be the maximum achievable depth before the chamber is full and overflow occurs. However, if the proposed BMP will be filled with broken stone or other suitable material, dBMP will be the product of the BMP's actual or physical depth and the void ratio of the fill material.

For recharge BMPs that consist of a combination of filled and open areas (e.g., a perforated pipe within a stone filled trench) or for irregular-shaped BMPs with nonvertical sides, dBMP can be computed by dividing the BMP's total storage volume by its surface area (ABMP). For BMPs with varying surface areas (e.g., a trapezoidal infiltration basin with sloping sides or a perforated elliptical pipe), the user should exercise discretion in selecting the correct surface area to use. In most cases, the average surface area would be appropriate. In all cases, the user should always verify that the product of the specified surface area (ABMP) and effective depth (dBMP) equals the BMP's total storage volume (variable VBMP in Cell G12). More information and recommendations can be found in the NJGRS User's Guide.

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In addition to the above, it is important to note that the BMP Calculations Worksheet assumes that all runoff stored in the recharge BMP at depths at or below dBMP (i.e., the maximum storage depth in the BMP) will be infiltrated into the soils below the BMP and that any greater runoff amounts will overflow the BMP. As such, the BMP Calculations Worksheet cannot directly model a recharge BMP that will infiltrate some of its runoff while it is simultaneously discharging some through an overflow or other outlet. Examples of such a recharge BMP would include an extended detention basin where stored runoff is simultaneously infiltrated through the basin bottom and out its outlet structure. For such BMPs, alternative BMP calculation techniques will be required.

With regards to BMP location, if a recharge BMP will be located within a particular post-developed land segment specified on the Annual Recharge worksheet, it should be specified in Cell C9 (variable C9) of the BMP Calculations worksheet. As described earlier, doing so will allow the NJGRS to more accurately compute the losses and resultant recharge at the BMP. If this land segment is not specified on the BMP Calculations worksheet, the NJGRS will, by default, use average soil and loss factors based on all of the post-developed land segments specified on the Annual Groundwater Recharge worksheet.

The BMP Calculations worksheet can analyze a recharge BMP located either on grade or constructed below grade through excavation. An excavated BMP can be either a surface or subsurface BMP. The specific type of BMP is described in the BMP Calculations worksheet through its effective depth (dBMP) and two additional vertical distances. The first is the vertical distance from the vegetated ground surface to the maximum water surface level in the BMP (variable dBMPu in Cell C7). This value is positive if the maximum level is below the vegetated ground surface and negative if above the vegetated ground surface. The second is the vertical distance from the vegetated ground surface to the bottom of the BMP (variable dEXC in Cell C8). For example, if the top of a 36-inch deep stone-filled infiltration trench is located 24 inches below ground level, dBMPu would be 24 inches and dEXC would be 60 inches (i.e., dBMPu plus the 36-inch actual depth of the trench). It should be noted, however, that since the trench is filled with gravel with a certain void ratio, the BMP's effective depth (dBMP) would be 36 inches times that void ratio. Using the dBMPu and dEXC variables, virtually all types of recharge BMPs can be specified, including "above the surface," "semi-buried," and "completely buried" BMPs. See Figure 6-4 below and the NJGRS User's Guide for more information.

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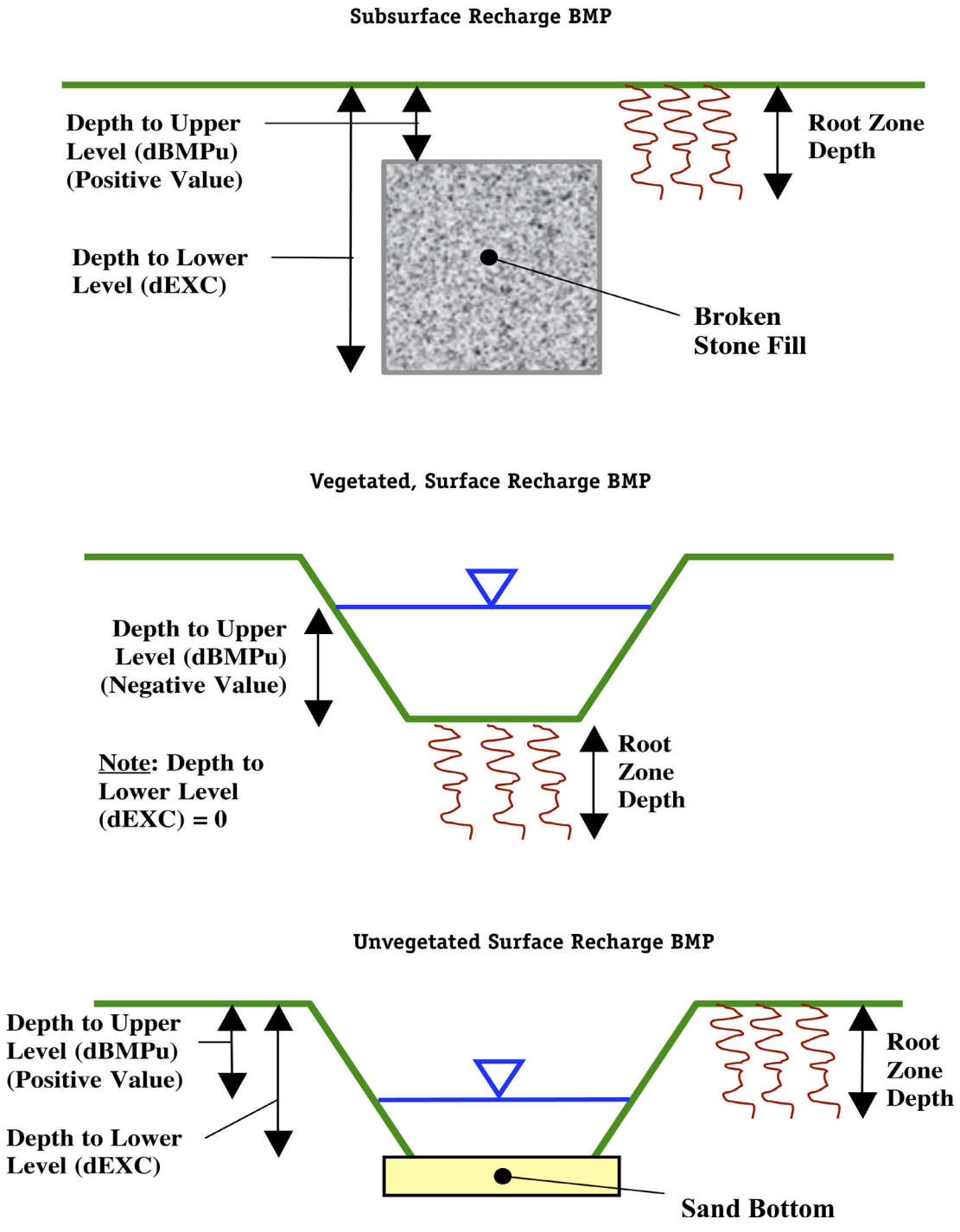
Figure 6-4: Examples of Depths to Upper (dBMPu) and Lower (dEXC) Levels of Recharge BMP



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In using the BMP Calculations worksheet, it is important to note that, by default, the NJGRS takes the values from the Annual Recharge worksheet for the Post-Development Recharge Deficit Volume (Cell K24) and the Total Impervious Area (Cell M23) and specifies them as initial values on the BMP Calculations worksheet for the Post-Development Deficit Recharge (variable Vdef in Cell C14) and Post-Development Impervious Area (variable Aimp in Cell C15). This allows solution of the site's total recharge deficit by a single groundwater recharge BMP that will receive runoff from a developed site's entire impervious area (if specified as impervious land segments). However, in many instances, the single groundwater recharge BMP will receive runoff from only a portion of the site's impervious area (e.g., only roof runoff). In such cases, the user must specify the exact size of Aimp (impervious area to the BMP) in Cell C15. Failure to do this for such BMPs will result in an overestimation of the amount of runoff captured by the BMP and erroneous BMP dimensions and/or recharge amounts.

At other sites, it may be necessary or desirable to utilize more than one groundwater recharge BMP to meet the site's recharge requirements. In such cases, each BMP will not only receive runoff from a portion of the site's impervious surface, but each will also seek to provide only a portion of the site's total recharge deficit. In such cases, the user must specify both the exact Aimp and Vdef (Post-Development Deficit) for each BMP in Cells C14 and 15 of the BMP Calculations worksheet. *In such cases, the user must also use a separate NJGRS spreadsheet for each BMP. Using multiple copies of the BMP Calculations worksheet within a single spreadsheet can yield erroneous results.*

In addition, computational problems can occur if, in designing a recharge BMP, the user selects either an initial BMP surface area (ABMP) or effective depth (dBMP) that is drastically different than the actual value needed to meet the required recharge deficit. If this occurs, the NJGRS may not be able to compute the correct value and will, instead, display excessive large answers or divide by zero messages. If this occurs, the user should adjust the initial value to one that more closely approximates the final answer and rerun the worksheet.

The BMP Calculations worksheet will also present various characteristics of the recharge BMP, including its effectiveness in converting runoff to infiltrated water and then recharged groundwater. See the NJGRS User's Guide presented at the end of this chapter for more information.

BMP Calculation Messages

The BMP Calculations worksheet provides three important messages to check the validity of the computed results. The Volume Balance message (Cell J11) is a check of the Annual BMP Recharge Volume in Cell G14 against the Post-Development Deficit Recharge (variable Vdef in Cell C14). If these values are equal, the problem is solved successfully and the message in this section will read "OK." However, if the BMP's annual recharge volume does not equal Vdef, the message instructs the user to continue to solve the problem. This may also occur if the user changes any of the BMP design parameters and forgets to solve the problem by clicking on any of the two solve buttons.

The dBMP Check message (Cell J12) checks the validity of the value inputted for the dBMP, the BMP's effective depth in Cell C6. If this value is greater than the difference between the depths to the BMP's upper and lower surfaces (variables dBMPu and dEXC in Cells C7 and C8, a warning message is issued telling the user to adjust dBMP. dEXC Check (Cell J13) is the third message. It checks the validity of dEXC to ensure it is larger than dBMPu. If it is not, a message will appear instructing the user to make dEXC larger than dBMPu.

Below these messages is a report on the location of the BMP as specified by the user in Cell C9 (variable segBMP). If the user has entered a valid segment number for segBMP, the message will read "OK." If the user enters a zero for segBMP, the message will read "Location is selected as distributed or undetermined." However, if the user enters a land segment number that was not previously defined in the Annual Recharge

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worksheet under Post-Developed Conditions, the message will say: "Land Segment Number Selected for BMP is not Defined." The user should then make appropriate corrections to segBMP.

See the NJGRS User's Guide for more information regarding calculation check messages and warnings.

Additional Information

In addition to the above, the following important features and characteristics of the NJGRS should be noted:

1. The NJGRS gives the user the opportunity to specify what percentage of a development site's annual groundwater recharge deficit must be retained (Cell K23 of the Annual Recharge worksheet). However, it should be noted that the program's default value is 100 percent which, as noted above, is the amount required by the NJDEP Stormwater Management Rules.
2. The pre- and post-development average annual recharge at a development site is a function, in part, of the municipality in which the site is located. Therefore, changing the name of the municipality in Cell C3 of the Annual Recharge worksheet will change both the pre- and post-development recharge volumes. Similarly, if the user wishes to analyze a site in a different municipality, the new municipality's name must be entered through the drop-down list in Cell C3 in order to accurately compute pre-and post-development recharge amounts.
3. In Cell K6 of the BMP Calculations worksheet, the NJGRS will display the "Inches of Rainfall to Capture." This value is also displayed graphically in Chart 1 of the NJGRS along with other pertinent BMP performance information. This value specifies the minimum depth of rainfall over the BMP's impervious drainage area that must be collected to meet the development site's average annual recharge deficit. It is also the maximum event rainfall that the BMP can store without overflowing and, as such, it is equal to the BMP's Recharge Design Storm depth described previously in "Theoretical Basis of Calculations." This design storm depth is important, as it can be used to estimate the resultant groundwater recharge design storm runoff from a development site with groundwater recharge BMPs. See Examples 4, 5 and 6 in Chapter 5 for more details on this procedure.
4. At the time of the NJGRS' development, all soil series mapped in New Jersey were included in its databases. Nevertheless, instances may arise where a soil series identified at a land development site has not been included. In such instances, the user should select a similar soil series from the program's database. In doing so, the following criteria should be utilized, generally in the order presented:
    - Select a NJGRS soil series within the same Hydrologic Soil Group (HSG) as the site soil.
    - Within the same HSG, select an NJGRS soil series with similar textural characteristics and classification as the soil.
    - If the site soil includes a fragipan, bedrock, or other restrictive layer below its surface, select an NJGRS soil series with a similar restrictive depth.
    - If more than one choice of NJGRS soil series appears reasonable, the user may then analyze and compare the annual groundwater recharge amounts for each using the NJGRS program to help make a final selection.

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Recharge BMP Design Guidelines

In general, the design of a groundwater recharge BMP to offset a development site's groundwater recharge deficit should follow the standards and guidelines for dry wells, infiltration basins, and pervious paving systems with storage beds presented in Chapter 9. This includes utilizing soil permeability data obtained from tests such as those contained in Standards for Individual Subsurface Sewage Disposal Systems at N.J.A.C. 7:9A at the site of the proposed recharge BMP. In addition, the recharge BMP design must be based on the following guidelines:

1. Computation of the pre- and post-development annual groundwater recharge rate and the annual recharge deficit should be based upon the New Jersey Geological Survey Report GSR-32 A Method For Evaluating Ground-Water-Recharge Areas in New Jersey, which is incorporated into the NJGRS.
2. Only the directly connected impervious portions of a recharge BMP's drainage area can be used to compute runoff to the BMP. In the NJGRS, the input parameter Aimp, which is the size of the recharge BMP's drainage area, must represent only directly connected impervious surfaces. This is particularly relevant for infiltration basins and pervious paving systems used for groundwater recharge that may also have pervious and unconnected impervious areas draining to them.
3. Runoff collected from roofs and other above-grade surfaces can be directly conveyed to a recharge BMP. However, roof gutter guards and/or sumps or traps equipped with clean-outs should be included upstream of the recharge BMP wherever possible to minimize the amount of sediment or other solids that can enter the BMP.
4. Runoff collected from parking lots, driveway, roads, and other on-grade impervious surfaces and conveyed to a subsurface recharge BMP must be pretreated to remove 80 percent of TSS in order to prevent the loss of storage volume and/or recharge capacity due to sedimentation and clogging. Exceptions may be possible for patios, tennis courts, and similar on-grade impervious surfaces with minimal TSS loadings on case-by-case basis. Such treatment can also be used to meet the site's overall TSS removal requirements. In addition, all on-grade drainage areas to a subsurface recharge BMP should consist only of impervious surfaces. Exceptions to this requirement may include roadway right-of-ways, vegetated parking lot medians, planting and landscape beds, and other pervious surfaces provided that they comprise only a small percentage of the total drainage area and will not generate an excessive amount of TSS or other material that might adversely impact the subsurface recharge BMP. As noted above, if such areas are part of the actual drainage area, they must not be included in the drainage area size (variable Aimp) used in the NJGRS' BMP Calculations worksheet to design the recharge BMP.

   In addition, it should be noted that, since the BMP Calculations Worksheet assumes that all runoff from a recharge BMP's impervious drainage area will be delivered to the BMP, it cannot directly account for runoff losses incurred at a pretreatment measure located between the drainage area and the recharge BMP. If such losses will occur due to the selected pretreatment measure, appropriate compensating adjustments may be attempted in the BMP Calculations Worksheet input data or alternative BMP calculation techniques utilized.
5. In general, County Soil Surveys prepared by the U.S. Department of Agriculture and the State Soil Conservation Committee can be used to obtain the soil series data required for the determination of annual land development site recharge rates and deficits and the dimensions of recharge BMPs using the NJGRS program. However, site soil tests will be required at the actual location of a proposed recharge BMP in order to confirm the BMP's ability to function properly without failure. Such tests should include a determination of the textural classification and permeability of the soil

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at the bottom of the proposed recharge BMP. As noted above, permeability testing can be conducted in accordance with Standards for Individual Subsurface Sewage Disposal Systems at N.J.A.C. 7:9A.

Depending upon the type, location, use, and maximum design storm of the selected recharge BMP, minimum design soil permeability rates will vary from 0.2 to 0.5 inches per hour and that a factor of safety of 2 must be applied when converting a tested permeability rate to a design rate. In addition, the soil permeability rate must allow the recharge BMP to fully drain its maximum design storm runoff volume within 72 hours. Recharge BMP locations that fail to meet these two requirements should be rejected and alternative onsite locations selected. A groundwater recharge waiver may be sought from the applicable reviewing agencies if suitable permeability rates cannot be found at any recharge BMP locations on the development site.

See Chapter 9 for details on structural best management practices that can be used as recharge BMPs, including minimum design permeability rates. Such BMPs include dry wells (Chapter 9.3), infiltration basins (Chapter 9.5), and certain types of pervious paving systems (Chapter 9.7).

6. The results of the BMP site soil testing should be compared with the County Soil Survey data used in the NJGRS' annual recharge and BMP design computations to ensure reasonable data consistency. If significant differences exist between the BMP site soil test results and the County Soil Survey data, additional development site soil tests are recommended to determine and evaluate the extent of the data inconsistency and the need for revised annual recharge and BMP design computations based upon the site soil test results. All significant inconsistencies should be discussed with the local Soil Conservation District prior to proceeding with such redesign to help ensure that the site soil data is accurate. It should also be noted that significant inconsistencies between development site soil tests and the County Soil Survey may warrant revisions to the site's stormwater quality and quantity storm computations.
7. The development site areas that extensive site soil testing determine to have permeability rates less than 0.2 inches per hour may be considered to belong to Hydrologic Soil Group D in the NJGRS program. For such areas, the user may use any HSG D soil in the NJGRS soil series database to define such site areas in the NJGRS' Annual Recharge worksheet. In accordance with the assumptions of both the NJGRS program and N.J. Geological Survey's Geological Survey Report GSR-32: A Method for Evaluating Ground Water Recharge Areas in New Jersey, such areas will not produce any groundwater recharge. Once again, the assignment of HSG D to any development site areas should be discussed with the local Soil Conservation District prior to proceeding to help ensure that the site soil data is accurate.

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The New Jersey Groundwater Recharge Spreadsheet (NJGRS)

User's Guide

Version 2.0 – November 2003

There are two computational worksheets in the NJGRS spreadsheet:

- **Annual Recharge:** This worksheet, which resides on the first page of the spreadsheet, is used to estimate the annual groundwater recharge volumes that occur naturally under the Pre-Developed and Post-Developed Conditions. Based on the value of *"percent of Pre-Developed Annual Recharge to Preserve"* that the user provides (NJDEP currently requires 100 percent for this parameter), the worksheet calculates the *"Post-Development Annual Recharge Deficit"* in cubic feet. This is the annual recharge volume that must be provided by one or more groundwater recharge BMPs.
- **BMP Calculations:** This worksheet, which resides on the second page of the spreadsheet, is used to design the required size and configuration of one or more groundwater recharge BMPs to satisfy the *"Post-Development Annual Recharge Deficit"* calculated in the Annual Recharge worksheet.

NOTE: Only the above worksheets in the NJ Groundwater Recharge Spreadsheet are for user input. Charts 1 through 3 can be viewed for visual inspection of the results. Other worksheets in the spreadsheet are either for internal calculations or contain the databases used by calculations. The user should refrain from changing anything in these worksheets.

Part 1: Using the Annual Recharge Worksheet

Figure 1: Screen Capture Showing the Annual Recharge Worksheet

New Jersey Groundwater Recharge Spreadsheet Version 2.0 November 2003

Annual Groundwater Recharge Analysis (based on GSR-32)

Select Township ↓	Average Annual P (in)	Climatic Factor
MIDDLESEX CO., PERTH AMBOY CITY	47.8	1.53

Project Name: Sample Project
Description: This is a test application
Analysis Date: 09/01/03

Pre-Developed Conditions

Land Segment	Area (acres)	TR-55 Land Cover	Soil	Annual Recharge (in)	Annual Recharge (cu.ft)
1	1.4	Open space	Woodstown	12.9	65,498
2	0.3	Gravel, dirt	Woodstown	6.9	7,536
3	3.5	Woods-grass combination	Woodstown	13.5	171,255
4	1.4	Open space	Keyport	13.4	68,146
5	0.5	Gravel, dirt	Keyport	7.5	13,657
6	3.3	Woods-grass combination	Keyport	13.9	165,963
7	0				
8	0				
9	0				
10	0				
11	0				
12	0				
13	0				
14	0				
15	0				
Total =	10.4			Total Annual Recharge (in) 13.0	Total Annual Recharge (cu-ft) 492,054

Post-Developed Conditions

Land Segment	Area (acres)	TR-55 Land Cover	Soil	Annual Recharge (in)	Annual Recharge (cu.ft)
1	1.5	Impervious areas	Keyport	0.0	-
2	1.6	Gravel, dirt	Woodstown	6.9	40,191
3	3.65	Open space	Keyport	13.4	177,667
4	3.65	Open space	Woodstown	12.9	170,762
5	0				
6	0				
7	0				
8	0				
9	0				
10	0				
11	0				
12	0				
13	0				
14	0				
15	0				
Total =	10.4			Total Annual Recharge (in) 10.3	Total Annual Recharge (cu.ft) 388,620

Annual Recharge Requirements Calculation ↓

% of Pre-Developed Annual Recharge to Preserve = 100%

Post-Development Annual Recharge Deficit= 103,435 (cubic feet)

Total Impervious Area (sq.ft) 65,340

Recharge Efficiency Parameters Calculations (area averages)

RWC= 3.94 (in) DRWC= 3.94 (in)

ERWC = 0.93 (in) EDRWC= 0.93 (in)

Procedure to fill the Pre-Development and Post-Development Conditions Tables

For each land segment, first enter the area, then select TR-55 Land Cover, then select Soil. Start from the top of the table and proceed downward. Don't leave blank rows (with A=0) in between your segment entries. Rows with A=0 will not be displayed or used in calculations. For impervious areas outside of standard lots select "Impervious Areas" as the Land Cover. Soil type for impervious areas are only required if an infiltration facility will be built within these areas.

- Figure 1 is a screen capture from an example application of the Annual Recharge Worksheet. All user-input cells are tan colored. All gray colored cells are used to show calculation results or internal validity checks and must *not* be changed by the user. The three cells at the upper right corner of the sheet are where the user can input project information. These inputs are optional, but they can help in identifying the project and the alternative being analyzed.
- As the first step, the user must select the project's municipality. Click once on the municipality cell (Cell C3) and select the project's county and municipality from the drop-down list of all New Jersey municipalities, which is arranged by county in alphabetical order. Once the user has selected a municipality, the values of average annual precipitation and the climate factor are set for that municipality in the two cells to the immediate right of the municipality's name (Cells D3 and E3).
- The next step is to provide information about pre-developed site conditions. The first column is the land segment number (Cells A6 to A20). Up to 15 different land segments can be inputted in this table.

  NOTE: If you have more than 15 different land segments, try to combine similar segments together or subdivide your area into smaller areas not consisting of more than 15 land segments.

- For each land segment, first enter the area in acres. Then select an appropriate TR-55 land cover description from the drop-down list of standard NRCS land cover descriptions. Finally, select the segments soil series from the drop-down list. Note that, as soon as the area for a segment is entered, the entries for other columns become visible and selectable. Start from the top of table and proceed downward. Do not leave blank rows (with zero area) between land segment entries; rows with zero areas will not be displayed or used in calculations.

  NOTE: Once you click on any of these cells a pop-up help message will appear to briefly tell you about the required input for that cell.

- As can be seen from the list of available TR-55 land cover descriptions in the drop-down list, there may be more than one way to describe the pre-developed land cover at a project site, particularly when that cover is a mixture of pervious and impervious surfaces such as a single family residential development. For assistance, see the guidelines in the New Jersey Groundwater Recharge Spreadsheet (NJGRS) section of Chapter 6 for selecting segment limits and land cover descriptions. Finally, it should be noted that, under the Pre-Developed Conditions section, it is not necessary to specify the soil series for site segments with impervious land cover, since the natural recharge in these segments is set at zero.

  NOTE: If the soil you select for a land segment is hydric, recharge will be set to zero for that segment.

- Once the user has completed inputting all land covers in the table for the Pre-Developed Conditions, check the total area in acres (Cell B21) to ensure that the total project area is correct. The last two columns of this table show the naturally occurring average annual recharge amount as a depth (in inches over the segment area) and a volume (in cubic feet) for each land segment. At the bottom of these columns (Cells E22 and F22), the average recharge depth (in inches) and the total annual recharge volume (in cubic feet) over the total area under Pre-Developed Conditions is given. This number is later used in the calculation of any post-development recharge deficit.
- The above procedure can also be used to enter the required data for the post-developed site conditions. In doing so, please note the following additional requirements:

  1. To correctly compute the performance and/or required size of a proposed groundwater recharge BMP, the area in which the BMP will be located must be entered as a separate site

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segment with its associated soil series. The number of this segment must also be specified on the BMP Calculations spreadsheet (see below).

2. As noted above, it is normally not necessary to specify the soil series within an impervious site segment. However, the soil series of the impervious segment must be specified if a proposed groundwater recharge BMP will be located within or below it (e.g., a stone-filled infiltration trench below a parking lot). As noted in 1 above, the soil series is necessary in order to accurately compute the performance and/or required size of the proposed BMP.

- Finally, as noted above, see the guidelines in the New Jersey Groundwater Recharge Spreadsheet (NJGRS) section of Chapter 6 for further assistance in selecting appropriate segment limits and TR-55 land cover descriptions for post-developed site conditions.

NOTE: Soil series selected for the impervious areas in the Post-Developed Conditions table are automatically displayed in orange, signifying that they have no effect on the site's natural annual recharge calculation (i.e., recharge set to zero for all land segments classified as "Impervious areas" regardless of the soil type), but that they can affect the artificial annual recharge volume of any groundwater recharge BMP set below them.

- Once the user has completed inputting all land segment information in the table for the Post-Developed Conditions, once again check the total project area (Cell I21) to ensure that the total post-development project area is correct.

NOTE: If the total area in the Post-Developed Conditions is different from the total area in the Pre-Developed Conditions, a warning message will appear to the right of the total Post-Developed project area (Cell J21).

- As an additional check, the total impervious area (in square feet) under Post-Developed conditions will be shown at the bottom right of this table (Cell M23). Please note that this value reflects only those impervious areas specified as separate project segments and does not include any impervious areas within those segments specified by the standard TR-55 residential or urban land descriptions. The last two columns of this table show the naturally occurring average annual recharge depth (in inches) and volume (in cubic feet) for each land segment. At the bottom of these columns (Cells L22 and M22), the average recharge depth (in inches) and the total annual recharge volume (in cubic feet) over the total area under Post-Developed Conditions is given. This number is also used later in the calculation of any Post-Development recharge deficit.
- Immediately below the Post-Developed Conditions table is the Annual Recharge Requirements Calculation section. The user needs to input the "percent of Pre-Developed Annual Recharge to Preserve" (Cell K23) to set the percentage of the recharge under Pre-Developed Conditions that must be maintained under the Post-Developed Conditions. The NJDEP Stormwater Management Rules at N.J.A.C. 7:8 currently requires this value to be 100 percent, which is the spreadsheet's default value. The spreadsheet then computes the difference between the total annual recharge volumes for Pre- and Post-Developed Conditions and multiplies it by the "percent of Pre-Developed Annual Recharge to Preserve." The resulting value is shown as the "Post-Development Annual Recharge Deficit" in the worksheet (Cell K24). This amount is 103,435 cubic feet in the case of the example in Figure 1. This is the volume of groundwater recharge that must be artificially recharged under Post-Developed Conditions annually through groundwater recharge BMPs.
- The "Recharge Efficiency Parameter Calculations" table shown below the "Post-Development Annual Recharge Deficit" show the parameters calculated by this worksheet that are later used in the BMP Calculations worksheet.

NOTE: The Appendix to this guide provides the basic equations and defines the variables used in Recharge Efficiency Parameter Calculations.

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Part 2: Using the BMP Calculations Worksheet

This worksheet allows the proper sizing of groundwater recharge BMPs to provide the desired or required volume of annual groundwater recharge. Alternatively, it can be used to evaluate the performance of a user-specified recharge BMP. As described in Chapter 2, groundwater recharge BMPs can also be referred to as Low Impact Development BMPs (or LID-BMPs), depending on their size and location in the project site.

Figure 2: Screen Capture from the BMP Calculations Worksheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Project Name**		**Description**			**Analysis Date**		**BMP or LID Type**						
2	**Sample Project**		**This is a test application**			**09/01/03**								
3	**Infiltration BMP Input Parameters**				**Root Zone Water capacity Calculated Parameters**				**Recharge Design Parameters**					
4	**Parameter**	**Symbol**	**Value**	**Unit**	**Parameter**	**Symbol**	**Value**	**Unit**	**Parameter**	**Symbol**	**Value**	**Unit**		
5	BMP Area	ABMP	**6656.0**	sq.ft	Empty Portion of RWC under Post-D Natural Recharge	ERWC	**0.93**	in	Inches of Runoff to capture	Qdesign	**0.54**	in		
6	BMP Effective Depth, this is the design variable	dBMP	**5.2**	in	ERWC Modified to consider dEXC	EDRWC	**0.93**	in	Inches of Rainfall to capture	Pdesign	**0.67**	in		
7	Upper level of the BMP surface (negative if above ground)	dBMPu	**-5.2**	in	Empty Portion of RWC under Infilt. BMP	RERWC	**0.74**	in	Recharge Provided Avg. over Imp. Area		**19.0**	in		
8	Depth of lower surface of BMP, must be>=dBMPu	dEXC	**0.0**	in					Runoff Captured Avg. over imp. Area		**24.8**	in		
9	Post-development Land Segment Location of BMP , Input Zero if Location is distributed or undetermined	SegBMP	**0**	unitless										
10	Solve for ABMP to provide Vdef	Solve for dBMP to provide Vdef	Default Vdef & Aimp		**BMP Calculated Size Parameters**				**CALCULATION CHECK MESSAGES**					
11					ABMP/Aimp	Aratio	**0.10**	unitless	Volume Balance->	**OK**				
12					BMP Volume	VBMP	**2,873**	cu.ft	dBMP Check--->	**OK**				
13	**Parameters from Annual Recharge Worksheet**				**System Performance Calculated Parameters**				dEXC Check--->	**OK**				
14	Post-D Deficit Recharge (or desired recharge volume)	Vdef	**103,435**	cu.ft	Annual BMP Recharge Volume		**103,435**	cu.ft	BMP Location--->	**Location is selected as distributed or undetermined**				
15	Post-D Impervious Area (or target Impervious Area)	Aimp	**65,340**	sq.ft	Avg BMP Recharge Efficiency		**76.7%**	Represents % Infiltration Recharged	**OTHER NOTES**					
16	Root Zone Water Capacity	RWC	**3.94**	in	%Rainfall became Runoff		**78.3%**	%	Pdesign is accurate only after BMP dimensions are updated to make rech volume= deficit volume. The portion					
17	RWC Modified to consider dEXC	DRWC	**3.94**	in	%Runoff Infiltrated		**66.2%**	%	of BMP infiltration prior to filling and the area occupied by BMP are ignored in these calculations. Results are					
18	Climatic Factor	C-factor	**1.53**	no units	%Runoff Recharged		**50.8%**	%	sensetive to dBMP, make sure dBMP selected is small enough for BMP to empty in less than 3 days. For land					
19	Average Annual P	Pavg	**47.8**	in	%Rainfall Recharged		**39.7%**	%	Segment Location of BMP if you select "impervious areas" RWC will be minimal but not zero as determined by					
20	Recharge Requirement over Imp. Area	dr	**19.0**	in					the soil type and a shallow root zone for this Land Cover allowing consideration of lateral flow and other losses.					
21	**How to solve for different recharge volumes:** By default the spreadsheet assigns the values of total deficit recharge volume "Vdef" and total proposed impervious area "Aimp" from the "Annual Recharge" sheet to "Vdef" and "Aimp" on this page. This allows solution for a single BMP to handle the entire recharge requirement assuming the runoff from entire impervious area is available to the BMP. To solve for a smaller BMP or a LID-IMP to recharge only part of the recharge requirement, set Vdef to your target value and Aimp to impervious area directly connected to your infiltration facility and then solve for ABMP or dBMP. To go back to the default configuration clik the "Default Vdef & Aimp" button.														

- Figure 2 is a screen capture from a portion of the BMP Calculations worksheet. While most of the calculations in this worksheet are performed in a separate worksheet, the portion shown in Figure 2 can be studied to understand the worksheet usage. There are several sections and solve buttons in this part of the worksheet, as explained below.

  NOTE: The three entries for Project Name, Description and Analysis Date are automatically copied from the Annual Recharge Sheet to the top of this sheet. The user can optionally input information regarding Groundwater Recharge BMP type.

Recharge BMP Input Parameters

- The user may start by inputting an initial value for the BMP surface area in square feet (variable ABMP) in Cell C5. In the NJGRS program, the variable ABMP is used in conjunction with the size of the recharge BMP's drainage area to determine the depth of stored runoff in the BMP resulting from a specific rain event. If a specific recharge BMP is being analyzed, ABMP will be based on the

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actual area of the BMP. If the spreadsheet is being used to determine the required recharge BMP dimensions, this value should be an initial estimate of the required surface area to satisfy the Post-Developed Recharge Deficit volume. This deficit volume (variable Vdef) is shown in Cell C14 and is either user-specified or, by default, taken from the Post-Development Annual Recharge Defici computed on the Annual Recharge worksheet (Cell K24).

- Next, a value for the recharge BMP's effective storage depth (variable dBMP) must be specified in inches in Cell C6. In the NJGRS program, dBMP represents the maximum equivalent water depth that can be achieved in the BMP before overflow begins. Therefore, if the proposed recharge BMP will, for example, be a subsurface, vertical-walled chamber, dBMP will simply be the maximum achievable depth before the chamber is full and overflow occurs. However, if the proposed BMP will be filled with broken stone or other suitable material, dBMP will be the product of the BMP's actual or physical depth and the void ratio of the fill. For recharge BMPs that consist of a combination of filled and open areas (e.g., a perforated pipe within a stone filled trench) or for irregular, nonrectangular BMP shapes (e.g., a perforated elliptical pipe or an infiltration basin with sloping sides), dBMP can be computed by dividing the BMP's total storage volume by its surface area.
- Just like the BMP surface area variable ABMP, the dBMP value entered for effective storage depth can be either a given value for a specific recharge BMP or an initial guess for a BMP to be sized by the spreadsheet. If this second option is selected, the user should remember that the resultant dBMP computed by the program may or may not be its actual or physical depth, depending on whether the BMP uses broken stone or other media in which to store runoff.
- In addition to dBMP, the user must also provide two additional recharge BMP depths. In Cell C7, the variable dBMPu is the vertical distance from the vegetated ground surface to the maximum water level of the BMP. This value should be positive if the maximum level is below the ground surface and negative if above the vegetated ground surface. In Cell C8, the variable dEXC is the vertical distance from the vegetated ground surface to the bottom of the BMP. For example, if the top of a 36-inch deep stone-filled infiltration trench (void ratio = 0.33) is located 24 inches below ground level, dBMPu would be 24 inches and dEXC would be 60 inches (i.e., dBMPu plus the 36-inch actual or physical depth of the trench). Remember, however, that since the trench is filled with gravel, the effective BMP depth (dBMP) would be 12 inches (i.e., 36 inches times 0.33). Using the dBMPu and dEXC variables, virtually all types of recharge BMPs can be specified, including "above the surface," "semi-buried," and "completely buried" BMPs. See Figure 6-4 for additional examples of dBMPu and dEXC.
- The next input cell on the BMP Calculations worksheet is the variable segBMP (Cell C9). This variable represents the post-developed site segment (as specified on the Annual Recharge worksheet) in which the proposed recharge BMP will be located. For example, if the recharge BMP is proposed to be built in Land Segment 3 in the Post-Developed Conditions table shown in Figure 1, then enter 3 for segBMP on the BMP Calculations worksheet.

  NOTE: Input zero for segBMP if the location of the BMP is still undetermined or a series of identical BMPs will be distributed over multiple site segments.

- The last input cell on the BMP Calculations worksheet is the variable Aimp (Cell C15). Similar to the variable Vdef in Cell C14, Aimp is either user-specified or, by default, taken from the Total Impervious Area computed on the Annual Recharge worksheet (Cell M23).

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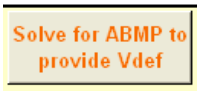
- Once values and/or initial guesses are entered in the input cells, either of two solve buttons can be used to solve the design problem. These buttons are described below.



NOTE: Click this button to automatically evaluate the value of ABMP that provides Vdef given all other input values.



NOTE: Click this button to automatically evaluate the value of dBMP that provides Vdef given all other input values.

If the initial guess values you enter for ABMP or dBMP are drastically off from what is needed to satisfy Vdef (i.e., too small or too big, too shallow or too deep), the program may not be able to find the right answer. You can tell the answers are not acceptable because negative values or division by zero signs will show up. If this happens just change your ABMP and/or dBMP values to more realistic numbers and solve the problem again.

- It is important to remember that, by default, the spreadsheet takes the values computed on the Annual Recharge worksheet for the Post-Development Recharge Deficit Volume (Cell K24) and the Total Impervious Area (Cell M23) and specifies them as initial values on the BMP Calculations worksheet for the Post-Development Deficit Recharge (variable Vdef in Cell C14) and Post-Development Impervious Area (variable Aimp in Cell C15). This allows solution of the site's total recharge deficit by a single groundwater recharge BMP that will receive runoff from the site's entire impervious area. However, in many instances, the single groundwater recharge BMP will receive runoff from only a portion of the site's impervious area (e.g., only roof runoff). In such cases, the user must specify the exact size of Aimp (impervious area to the BMP) in Cell C15. Failure to do this for such BMPs will result in an overestimation of the amount of runoff captured by the BMP and erroneous BMP dimensions and/or recharge amounts.
- At other sites, it may be necessary or desirable to utilize more than one groundwater recharge BMP to meet the site's recharge requirements. In such cases, each BMP will not only receive runoff from a portion of the site's impervious surface, but each will also seek to provide only a portion of the site's total recharge deficit. In such cases, the user must specify both the exact Aimp and Vdef (Post-Development Deficit) for each BMP in Cells C14 and 15 of the BMP Calculations worksheet. *IMPORTANT: In such cases, the user* must *also use a separate NJGRS spreadsheet for each BMP. Using multiple copies of the BMP Calculations worksheet within a single spreadsheet can yield erroneous results.*

NOTE: These procedures area also summarized in a note at the bottom of the BMP Calculations worksheet.



NOTE: Click this button to retrieve the initial, default values of Vdef and Aimp from the Annual Recharge worksheet.

- Similar to the Annual Recharge worksheet, the user-input cells in the BMP Calculations worksheet are tan colored. This includes the cells for Vdef and Aimp so that they can be altered from their default values by the user. As described above, these cells are initially assigned default values from the Annual Recharge worksheet so the user does not have to input values for certain sites and BMPs. All gray colored cells are used to show calculation results or internal validity checks and must *not* be changed by the user.

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NOTE: Remember that the default configuration assumes that the runoff from the site's entire impervious area (set by specifying one or more land segments to "Impervious Areas" on the Annual Recharge worksheet) will drain to the BMP. If only a portion of this impervious area will do so, the correct impervious area must be specified for Aimp (Cell C15) on the BMP Recharge worksheet.

- The values shown in Figure 2 above are the final results obtained by solving for ABMP (with a constant dBMP of 5.2 inches) to satisfy the entire annual recharge deficit of 103,435 cubic feet (which is the default Vdef value from the Annual Recharge worksheet). The user can tell the results are correct by comparing the calculated Annual BMP Recharge Volume amount in Cell G14 (under the "System Performance Calculated Parameters" heading) with the Vdef amount in Cell C14. In addition, the user can see that the volume balance is shown to be "OK" (Cell J11) in the "Calculation Check Messages" section.

Parameters from Annual Recharge Worksheet

- This section of the BMP Calculations worksheet contains various parameters initially computed in and then transferred from the Annual Recharge worksheet. As noted above, the initial values for Vdef (Cell C14) and Aimp (Cell C15) are taken from the Post-Development Recharge Deficit Volume (Cell K24) and the Total Impervious Area (Cell M23) on the Annual Recharge worksheet. A complete description of when the user must specify other values for these parameters is presented above. The values for Root Zone Water Capacity (variable RWM in Cell C16) and RWC Modified to Consider dEXC (variable DRWC in Cell C17) are automatically adjusted to reflect the user's choice for the excavation depth (variable dEXC) of the BMP. The values for Climatic Factor (variable C-Factor in Cell C18) and Average Annual P (variable Pavg in Cell C19) are constant values for the municipality selected in Cell C3 of the Annual Recharge worksheet. It is important to note that if the user wishes to analyze a site in a different municipality, the user must go back to the Annual Recharge worksheet and change the municipality's name in order to obtain the correct C-Factor and Pavg values on the BMP Calculations worksheet.

  WARNING: By changing the municipality, you also change the site's annual recharge deficit.

- The final value shown in this section of the BMP Calculations worksheet is the Recharge Requirement over Impervious Area (variable dr in Cell C20). This value is the average depth of annual recharge in inches over the impervious area (Aimp) specified (either by default or the user) in Cell C15. The value of dr is calculated by dividing Vdef by Aimp.

Root Zone Water Capacity Calculated Parameters

- This section of the BMP Calculations worksheet contains the calculated results for three root zone water capacity parameters. These values are needed for estimating the recharge efficiency of the groundwater recharge BMP under consideration. These parameters enable the NJGRS spreadsheet to estimate what portion of the infiltrated water from the BMP will travel downward below the root zone of the surrounding vegetation. As described above, this degree of water movement is the technical definition of groundwater recharge. The values of these three root zone water capacity parameters are automatically adjusted for the municipality and LULC segment in which the BMP is to be located. If the variable segBMP (Cell C9) is set to zero, weighted averages of these three parameters are utilized based on all the land segments specified on the Annual Recharge worksheet.

  NOTE: See the Appendix to this guide for more information about these three root zone water capacity parameters.

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BMP Calculated Size Parameters

- This section of the BMP Calculations worksheet contains values for two recharge BMP design parameters. The parameter Aratio (Cell G11) is computed by dividing the area (ABMP) of the BMP by the impervious area (Aimp) draining to it. The parameter VBMP (Cell G12) is the maximum storage volume in the BMP. It is computed by multiplying the BMP area (ABMP) by its effective depth (dBMP). These values can be checked by the user to help ensure that the ABMP, Aimp, and dBMP values have been inputted and used correctly by the NJGRS spreadsheet.

System Performance Calculated Parameters

- This section of the BMP Calculations worksheet contains various calculated BMP performance values. Of these, the Annual BMP Recharge Volume value (Cell G14) is the most important, since it must match the Post-Development Deficit Recharge value (variable Vdef in Cell C14) for the BMP to completely satisfy the site's annual recharge deficit or target recharge volume (as described above).
- The next parameter, Average BMP Recharge Efficiency (Cell G15), specifies the percentage of infiltrated water that is recharged (i.e., travels below the root zone) over an average year. This efficiency depends on many factors, including the project location, land cover, soil types, BMP dimensions, and depth of BMP. For the example shown in Figure 2 above, the recharge efficiency of the selected BMP is 76.7 percent.
- The remaining performance values in this section (Cells G16 to G19) are self-explanatory.

Recharge Design Parameters

- Inches of Runoff to Capture (variable Qdesign in Cell K5) is the first value in this section of the BMP Calculations worksheet. This value is the minimum depth of runoff over the BMP's tributary impervious area that must be captured and directed to the BMP to allow it to meet the site's groundwater recharge deficit. Similarly, Inches of Rainfall to Capture (variable Pdesign in Cell K6) specifies the minimum depth of rainfall over the BMP's impervious area that must be similarly controlled by the BMP to meet the site's recharge deficit. This value is also the maximum event rainfall the BMP can store without overflowing and, therefore, is the design rainfall for the BMP as described above.
- The next parameter in this section, Recharge Provided Average over Impervious Area (Cell K7) is the total annual depth of groundwater recharge provided by the BMP. For a site's recharge deficit to be met, this value must equal the Recharge Requirement over Impervious Area (variable dr in Cell C20). Runoff Captured Average over Impervious Area (Cell K8) is the last parameter in this section. It is the total annual depth of runoff over the impervious area tributary to the BMP that infiltrates into the ground. As such, it does not contain that part of the impervious area runoff to the BMP that overflows from the BMP during rainfall events greater than the BMP's design rainfall (Pdesign).

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Calculation Check Messages

- This section the BMP Calculations worksheet provides three important messages to check the validity of the computed results. The Volume Balance message (Cell J11) is a check of the Annual BMP Recharge Volume in Cell G14 against the Post-Development Deficit Recharge (variable Vdef in Cell C14). If these values are equal, the problem is solved successfully and the message in this section should read "OK." However, if the BMP's annual recharge volume does not equal Vdef, the message instructs the user to continue to solve the problem. This may also occur if the user changes any of the BMP design parameters and forgets to solve the problem by clicking on any of the two solve buttons described above.
- The dBMP Check message (Cell J12) checks the validity of the value inputted for the dBMP, the BMP's effective depth in Cell C6. If this value is greater than the difference between the depths to the BMP's upper and lower surfaces (variables dBMPu and dEXC in Cells C7 and C8, a warning message is issued telling the user to adjust dBMP. dEXC Check (Cell J13) is the third message. It checks the validity of dEXC to make sure it is larger than dBMPu. If it is not, a message will appear instructing the user to make dEXC larger than dBMPu.
- Below these messages is a report on the location of the BMP as specified by the user in Cell C9 (variable segBMP). If the user has entered a valid segment number for segBMP, the message will read "OK." If the user enters a zero for segBMP, the message will read "Location is selected as distributed or undetermined." However, if the user enters a land segment number that was not previously defined in the Annual Recharge worksheet under Post-Developed Conditions, the message will say "Land Segment Number Selected for BMP is not Defined." The user should then make appropriate corrections to segBMP.

Other Notes

- This section of the BMP Calculations worksheet contains notes regarding the assumptions and limitations of the calculations in this worksheet. In the current version of the spreadsheet, these notes refer to the following aspects of spreadsheet use:
    1. The variable Pdesign (Cell K6) is accurate only after the BMP's annual recharge volume (Cell G14) is equal to the site's recharge deficit (variable Vdef in Cell C14). In addition, Pdesign is computed from the results of the BMP's performance. It is not used to compute that performance.
    2. A recharge BMP results are sensitive to its effective depth (dBMP in Cell C6). The user must ensure that the selected dBMP is small enough for the BMP to empty in less than 72 hours.
    3. If a BMP is located within an impervious Post-Development land segment, the Root Zone Water Capacity (variable RWC in Cell C16) at the BMP will be minimal, but not zero. This allows consideration for lateral flow and other losses at the BMP.

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A P P E N D I X

Basic Equations and Variables Used in Recharge Efficiency Parameters Calculations

Basic Equations for Soil Water Capacity

A. Equation from GSR-32:

RWC = Root Depth x AWC (1)

RWC: Root Zone Water Capacity, (inch)

AWC: Available Water Capacity, (inch/ft)

B. New Equation:

ERWC = (1-0.5 x C-Factor) x RWC (2)

ERWC: Empty Root Zone Water Capacity under natural recharge, (inch)

C-Factor: Climate Factor = Ratio of precipitation to potential ET, (unitless)

Range of Values in NJ: RWC: (0.3, 14.35), C-Factor: (1.18-1.83)

ERWC: (0.02, 5.88)

Infiltration and Artificial Recharge under BMP or LID-IMP

$$\text{Average Annual Total Infiltration Depth} = \sum_{i=1}^{n} \text{Minimum } (Qi/Aratio, dBMP) \quad (3)$$

n = total number of runoff producing precipitation events in an average year

Aratio = Ratio of surface area of BMP (ABMP) to the impervious surface area served by the BMP (Aimp), unitless.

Find Average Empty RWC under Infiltration Facility

A. Modification to account for the buried depth of the facility

We know that dBMPb = dEXC- Max(0,dBMPu);

We can define the following relationship:

DRWC = Max {0, Root Depth- 0.5 dBMPb - (dEXC- dBMPb)} AWC

which can be simplified to:

DRWC = Max (0, Root Depth- dEXC+ 0.5 dBMPb) AWC (4)

DRWC = Root zone water capacity under BMP modified for the buried portion of the BMP and calculated over all land segments, (inch)

B. Define the empty portion of EDRWC

EDRWC = (1- 0.5 x C-Factor) x DRWC (5)

EDRWC = Empty Portion of DRWC, (inch)

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C. Account for the effect of moisture supplied by infiltration facility in reduction of empty portion of root zone

$$REavg = (1/n) \sum_{i=1}^{n} \text{Maximum } (EDRWC - infi) \quad (6)$$

REavg = DRWC modified to account for infiltration under BMP, (inch)

infi = Infiltration depth in BMP during "i"th event (inch)

$$RERWC = (n/365) \times REavg + [(365-n)/n] \times EDRWC \quad (7)$$

RERWC = Average empty root zone water capacity under BMP operation calculated for the average RWC of all land segments (inch)

$$RBMP = \sum_{i=1}^{n} \text{Maximum } (infi - RERWC, 0) \quad (8)$$

RBMP = Total infiltration depth under BMP during an average year, (inch)

$$\text{BMP Recharge Efficiency} = \frac{RBMP}{\sum_{i=1}^{n} infi} \quad (9)$$

In equations (8) and (9), results are very sensitive to C-Factor. As C-Factor increases, natural recharge increases and recharge deficit due to development increases. The NJGRS equations imply that if a development is constructed in an area of high natural recharge, the recharge efficiency of a BMP at the site would also be high. Therefore, the size of required recharge BMP should not be unduly large in areas with a large C-Factor.

The above parameters are calculated in the spreadsheet for each land segment as well as for the entire area (area weighted average) under Post-Developed Conditions. If the user specifies the location of the recharge BMP, the relevant parameters of the same land segment will be used. If the user does not specify the location, the average soil and loss factors based on all of the post-developed land segments specified on the Annual Groundwater recharge worksheet will be used.

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New Jersey Stormwater Best Management Practices Manual

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CHAPTER 7

Landscaping

Landscaping is critical to improving both the function and appearance of stormwater best management practices (BMPs). This chapter provides landscaping criteria and plant selection guidance for effective stormwater BMPs. Part 1 describes the natural plant communities of New Jersey based on plant hardiness zones and physiographic regions. Plant selection for stormwater BMPs should match as closely as possible the natural plant communities of that region. Part 2 outlines general guidance that should be considered when landscaping any stormwater BMP. Part 3 presents more specific guidance on landscaping criteria and plant selection for individual BMP designs described in Chapter 9. These include:

- constructed stormwater wetlands;
- infiltration basins and sand filter practices;
- bioretention systems;
- open channels;
- vegetative filters and forested buffers;
- wet ponds; and
- extended detention basins.

Part 4 considers plant acquisition and planting guidelines. Part 5 deals with other plant considerations, such as vegetation maintenance, invasive species, plant availability, and costs.[1]

Native Species

This manual encourages the use of native plants in stormwater management facilities. Native plants are defined as species that evolved naturally to live in this region. Practically speaking, this specifically refers to species that lived in New Jersey before Europeans explored and settled in America. Many introduced species were weeds brought in by accident; others were intentionally introduced and cultivated for use as medicinal herbs, spices, dyes, fiber plants, and ornamentals.

[1] Parts of this chapter were adopted directly from the 2000 Maryland Stormwater Design Manual (Schueler and Claytor 2000). The chapter also contains material added and adapted to the physiography, plant life, and growing conditions of New Jersey.

Introduced species often escape cultivation and begin reproducing in the wild. This is significant ecologically because many introduced species out-compete or even replace indigenous species in the wild. Some introduced or aggressive species are invasive, have few predators, and can take over naturally occurring species at an alarming rate. These include reed canary grass (Phalaris arundinacea), phragmites (Phragmites communis), kudzu (Pueraria spp.), purple loosetrife (Lythrum salicara), Norway maple (Acer platanoides), autumn olive (Elaeagnus umbellata), Japanese honeysuckle (Lonicera japonica), Japanese rose (Rosa muliflora), garlic mustard (Alliaria officinalis), birdsfoot trefoil (Lotus corniculatus), lesser celandine (Ranunculus ficaria), and cattail (Typha latifolia). By planting non-aggressive, native species in stormwater management facilities, we can protect New Jersey's natural heritage, encourage biodiversity, and provide a legacy for future generations.

Note: Although both phragmites and cattails can be invasive, they also provide water quality and some wildlife benefits. These species should not necessarily be recommended and, if they do appear on site, it is questionable whether a considerable amount of effort or money should be spent controlling or eradicating these species.

Native species have distinct genetic advantages over non-native species for planting in New Jersey. Because they have evolved to live here naturally, indigenous plants are best suited for our local climate. This translates into greater survivorship and less replacement maintenance during the life of a stormwater management facility. Both of these attributes provide cost savings for facility owners.

Finally, people often plant exotic species for their ornamental value. While it is important to plant aesthetic stormwater management facilities for public acceptance and maintenance of property value, it is not necessary to introduce foreign species for this purpose. Many native species can be used as ornamentals. The following species are part of New Jersey's natural heritage and provide high aesthetic value throughout the year: rhododendron (Rhododendron maximum), pink azalea (Rhododendron nudiflorum), red maple (Acer rubrum), pin oak (Quercus palustris), sycamore (Platanus occidentalis), flowering and shrub dogwoods (Cornus spp.), mountain laurel (Kalmia latifolia), willow (Salix spp.), white pine (Pinus strobus), Atlantic white cedar (Chamaecyparis thyoides), American holly (Ilex americana), swamp rose (Rosa palustris), sunflowers (Helianthus spp.), lobelias (Lobelia spp), pickerel weed (Pontederia cordata), swamp rose mallow (Hibiscus moscheutos), and yellow pond lily (Nuphar avena).

When selecting ornamentals for stormwater management facilities, planting preference should be given to native ornamentals. Refer to the plant lists in Part 5 for a list of native species available for stormwater management facility planting.

Part 1: Natural Plant Communities of New Jersey

Plant Hardiness Zones

Hardiness zones are based on historical annual minimum temperatures recorded in an area. A BMP's location in relation to plant hardiness zones is important because plants differ in their ability to withstand very cold winters. This does not imply that plants are not affected by summer temperatures; New Jersey summers can be very hot, and heat tolerance should be considered in plant selection as well.

It is best to recommend plants known to thrive in specific hardiness zones. The plant list included at the end of this chapter identifies the hardiness zones for each species listed as a general planting guide. It should be noted, however, that certain site factors can create microclimates or environmental conditions that permit the growth of plants not listed as hardy for that zone. By investigating numerous references and using personal experience, a designer should be able to confidently recommend plants that will survive in microclimates.

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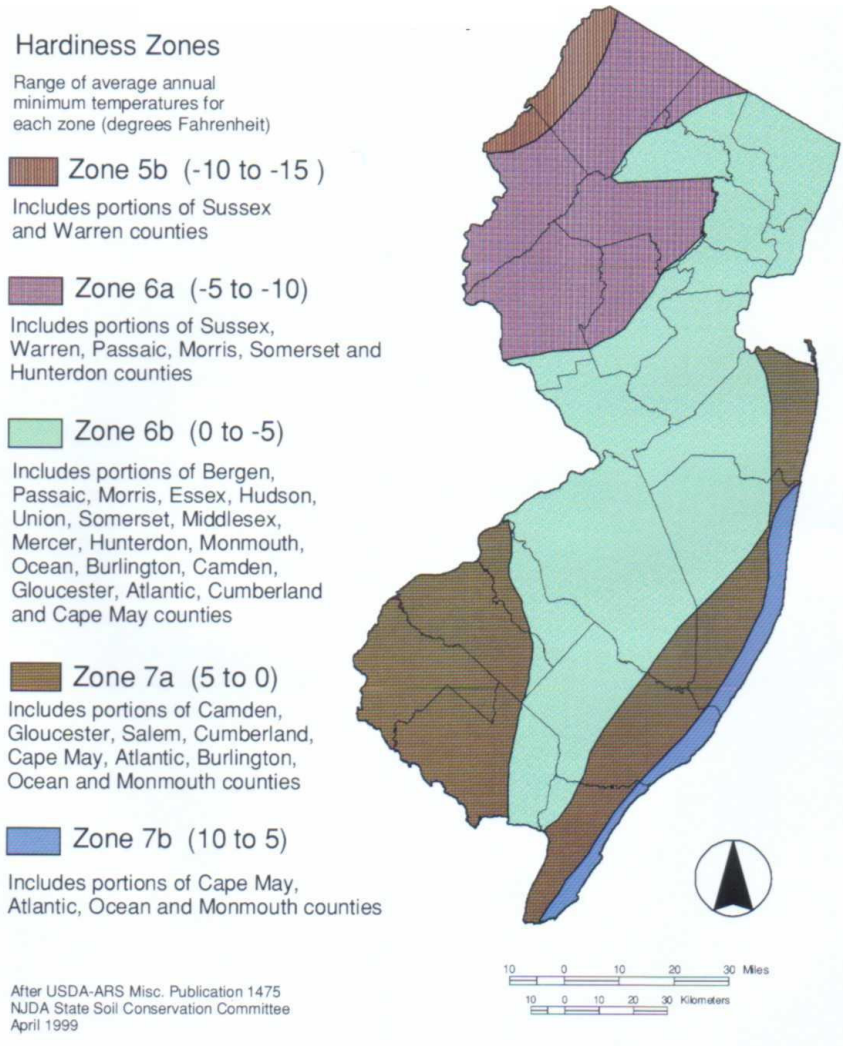
Table 7-1: USDA Hardiness Zones for New Jersey

Zone		USDA Minimum Temperature
Temperate Zone 5	a	-20 to -15
	b	-15 to -10
Temperate Zone 6	a	-10 to -5
	b	-5 to 0
Temperate Zone 7	a	0 to 5
	b	5 to 10

Figure 7-1: USDA Plant Hardiness Zones' Average Annual Minimum Temperature (New Jersey)



This figure can be viewed in color in the PDF version of this chapter available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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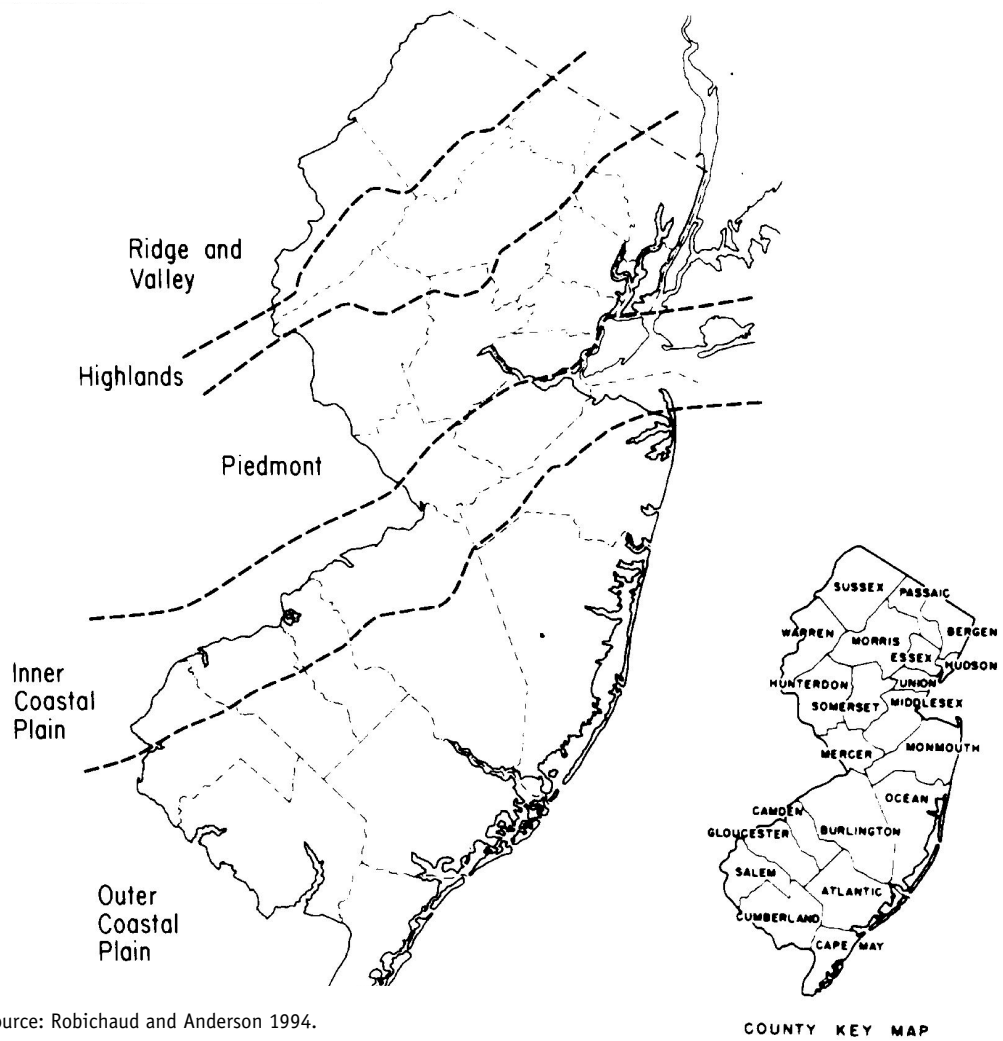
Physiographic Provinces

New Jersey's five physiographic sections describe distinct geographic regions in the state with similar physical and environmental conditions (Figure 7-2). These physiographic provinces include, from west to east, the Ridge and Valley, Highlands, Piedmont, Inner Coastal Plain, and Outer Coastal Plain. Each physiographic region is defined by unique geological strata, soil type, drainage patterns, moisture content, temperature, and degree of slope, which often dictate the predominant vegetation. Because the predominant vegetation has evolved to live in these specific conditions, a successful stormwater management facility planting design can be achieved through mimicking these natural associations.

The five physiographic regions are described below with associated vegetation listed for general planting guidance. [2] For more detailed information and plant listings, please refer to Plant Communities of New Jersey (Robichaud and Anderson 1994).

Figure 7-2: The Five Physiographic Sections of New Jersey



Source: Robichaud and Anderson 1994.

[2] These descriptions were adapted, in part, from Robichaud and Anderson 1994, and Robichaud and Buell 1973.

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Ridge and Valley Section

The Ridge and Valley physiographic province in the northwestern corner of New Jersey covers 635 square miles or about 7 per cent of the total land in New Jersey. It occupies a large part of Warren and Sussex counties. Ridges and valleys occur in this section because parent rock formations underlying the ridges and the valleys differ. Softer rocks such as limestone and shale erode faster than the more resistant sandstone and conglomerates. The lowest valley levels occur wherever limestone underlies the surface; the areas of shale, a slightly more resistant rock, are about 200 to 400 feet higher than the limestone, and ridges occur wherever the bedrock material is more resistant to erosion, such as sandstone or conglomerate rock.

Differences in parent rock material not only account for the variation in relief, but also create contrasts in the kind and amount of soil coverage. In general, the soil covering the Kittatinny and other ridges in this section is poor in quality from the standpoint of vegetation. The soil layer is thin on the ridges, with bedrock exposed in many places. Also, the ridge soil tends to be very acidic and of low fertility and, often, very stony.

In contrast, the soils in the valleys, derived from limestone and shale that were covered by glacial till, are for the most part deeper, more fertile, and well drained. Peat or large muck deposits (thick layers of organic material) may occur where shallow glacial lakes once existed. These were later invaded by vegetation, the dead remains of which accumulated as peat or muck.

Highlands Section

The Highlands physiographic province is located southeast of the Ridge and Valley section and covers about 900 square miles or approximately 12 per cent of New Jersey's land area. As shown in Figure 7-2, this section is broader at the north, where it is about 20 miles wide; at its southern end bordering the Delaware River Valley, it is only 10 miles wide. The Highlands region also has parallel ridges and valleys, but these differ from the Ridge and Valley section in the type of parent rock underlying the surface. Also, the ridges are more massive and generally much broader, while the valleys are narrower and have steeper slopes. Frequent rock outcroppings occur. Glacially formed lakes, such as Lake Hopatcong and Green Pond, contrast with adjacent ridges to make the Highlands a very scenic area of New Jersey.

The geologic formations of the Highlands region are estimated to be approximately 1 billion years old. Elevations in the northern part of the basin in the Highlands average approximately 1,000 feet above mean sea level, while the southern part of the Highlands show valley contours reaching a low of 350 feet. Ridges of the Highlands have resisted erosion due to the very hard rock, sandstone, gneiss, granite, marble, quartzite, igneous, and metamorphic material of which they are made. Highland valleys consist of much softer materials of limestone or shale, making them less resistant to erosion. The soils of the Highlands have been weathered from glacial till deposits and eroding bedrock and are generally shallow and stony, with frequent rock outcrops.

Piedmont Section

The Piedmont physiographic province, which occupies about 21 per cent of New Jersey's land area, is composed mostly of shale, sandstone, and argillite formations that are typically red or brownish-red in color. These formations are less resistant to erosion than the adjacent Highland gneissic rock and so, in comparison to the Highlands, the Piedmont is actually a lowland. The Piedmont section slopes gently southeastward from about 400 feet above sea level at its northwestern margin, to an elevation less than 100 feet at its southern margin bordering the Delaware, and to sea level at Newark Bay. Flat in some areas, the Piedmont contour is slightly rolling with mostly gentle slopes; however, in some areas, rivers have cut rather steep-sided valleys.

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Interestingly, in the Piedmont, several ridge formations tower over the adjacent lowlands – the three Watchung Mountains (850, 650, and 350 feet high), Cushetunk Mountain, the Sourlands, and the Palisades. These ridges are made of intrusive or extrusive lava material known as diabase and basaltic rocks, both of which are much harder than the shale and sandstone of the Piedmont. While the diabase and basalt have resisted erosion, the less resistant shale and sandstone have been worn down, resulting in the lower elevations.

Differences in rock formations, combined with the fact that glacial deposits of varying age covered only part of the Piedmont, have resulted in a variety of soil types within the area. These variations appear to be less important to vegetation than the variation of soil water drainage.

Exposed rock and soil at the surface of the Piedmont is the product of intense weathering of local bedrock and the influence that glacial ice sheets had on the landscape. Continuous cycles of freezing and thawing in the rocks and soils produced landform characteristics consisting of subsurface depressions and uneven ground. Boulder fields, like those found on the Rocky Hill Ridge, were heaved to the surface by the expanding and contracting of the permafrost during glacial periods. During the interglacial periods when the ice sheets retreated, massive loads of sediment were deposited in meltwater streams. Remnants of these outwash sediments formed thin, patchy deposits known as till on the surface of the Piedmont uplands. Riverbeds, stream valleys, and other lowlands were filled with glacial sediments, forming river terraces and wide outwash plains. Silt, clay, and fine sand deposits filled the bottoms of glacially formed lakes and ponds, which have since become swamps and meadows layered with peat and muck. Subsequent weathering and erosion have continued to shape and reshape the surface and produce the modern soil profile of the Piedmont.

Common Species of Ridge and Valley, Highlands, and Piedmont Sections

Tree Species	Understory
• Hickory • Chestnut oak • Scarlet oak • Scrub oak • White oak • Red oak • Black oak • Scrub pine • Pitch pine • Short leaf pine • White pine • Hemlocks • Beech • Black jack oak • Sugar maple	• Sweet fern • Flowering dogwood • Black haw • Chinquapin • Sassafras • Redbud • Mountain laurel • Blueberry • Fringe tree • Pink azalea • Spicebush • Maple-leaved arrowwood

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Inner and Outer Coastal Plain Sections

The Inner and Outer Coastal Plain provinces are recognized by flat or gently rolling topography and elevations rising from sea level to a height of 373 feet. Coastal Plain marshes and swampy tidal flats occur throughout the New Jersey Coastal Zone. Sands, sandy loams, and silt loams resulting from sea deposits make up the soils of the Coastal Plain. The climate is mild and sometimes rainy, similar to that found further south. Because of low topographic relief and proximity to sea level, extensive swamp areas are common to the Coastal Plain province. Most notable are the Atlantic White Cedar swamps found in the Pinelands.

Common Species of the Inner and Outer Coaster Plain Sections

Tree Species	Understory
• Loblolly pine • Virginia pine • Pitch pine • Pond pine • Sweet gum • Willow oak • Water oak • Basket oak • Pin oak • Post oak • Spanish oak • Black cottonwood • Pale hickory • Bitternut hickory • Sweet bay • American holly • Beech • Tulip tree • River birch	• Blueberry • Huckleberry • Greenbrier • Sand blackberry • Beach plum • Beach heather • Bay berry • Sweet pepper bush • Azalea • Maleberry • Stagger bush • Fetter bush • Inkberry • Alder buckhorn

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Floodplain Regions

Floodplains occur across New Jersey's physiographic provinces as low-lying areas adjacent to streams and rivers. Floodplain plant communities are similar across most of the state because of common soil characteristics governed by occasional flooding and high groundwater. Stormwater management facilities are often located in floodplains, and plant associations in these areas can provide valuable information for successful BMP plantings.

Common Species of Floodplain Regions

Tree Species	Understory
• River birch • Willows • Silver maple • Sweet gum • Sycamore • Box elder • Green ash • American elm • Swamp white oak • Basswood • Hackberry	• Shrub willows • Ninebark • Silky and redosier dogwoods • Sweet pepperbush • Buttonbush • Spicebush • Winterberry and inkberry holly • Elderberry • Alders

Three Hydrologic Zones

Before planting within a stormwater management facility, it is necessary to determine which hydrologic zones will be created. Hydrologic zones describe the degree to which an area is inundated by water. Plants have differing tolerances to inundation; as an aid to landscape designers, these tolerance levels have been divided into six zones for which corresponding plant species have been identified.

Part 4 includes a native plant list with appropriate hydrologic zones designated for each species. The hydrologic zones that are bracketed "[ ]" are where the plants tend to occur. There may be other zones listed outside of these brackets. These plants may occur in these zones, but are not typically found in them. On occasion, plants may be found outside of their hardiness and hydrologic zone. Plants tend to grow anywhere they can compete and survive. Additionally, hydrologic conditions in a stormwater management facility may fluctuate in unpredictable ways; thus, the use of plants capable of tolerating wide varieties of hydrologic conditions greatly increases a successful planting. Conversely, plants suited for specific hydrologic conditions may perish when hydrologic conditions fluctuate, expose the soil, and increase the chance for erosion.

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Part 2: General Landscaping Guidance for all Stormwater BMPs

- Plant trees and shrubs at least 15 feet from a dam's toe of slope.
- Do not plant trees or shrubs known to have long taproots within the vicinity of earth dams or subsurface drainage facilities.
- Plant trees and shrubs at least 15 feet from perforated pipes.
- Plant trees and shrubs at least 25 feet from a riser structure.
- Provide 15-foot clearance from a non-clogging, low flow orifice.
- Herbaceous embankment plantings should be limited to 10 inches in height to ensure visibility for inspectors looking for burrowing rodents that may compromise the integrity of the embankment.
- Provide additional stabilization methods for slopes steeper than 2:1, such as turf reinforcement mats or erosion control blankets. Use seed mixes with quick germination rates in this area. Augment temporary seeding measures with container crowns or root mats of more permanent plant material.
- Use erosion control blankets and fabrics in channels that are subject to frequent wash-outs.
- Stabilize all emergency spillways with plant material that can withstand strong flows.
- Root material should be fibrous and substantial, but lack a taproot.
- Place sod in channels that are not stabilized by erosion control blankets.
- Divert flows temporarily from seeded areas until plants are stabilized.
- Check water tolerances of existing plant materials prior to inundating the area.
- Stabilize aquatic and safety benches with emergent wetland plants and wet seed mixes.
- Do not block maintenance access to structures with trees or shrubs.
- To reduce thermal warming, shade inflow and outflow channels as well as the southern exposure of ponds, when possible.
- Avoid plantings that will require routine or intensive chemical applications, i.e., turf areas.
- Have soil tested to determine whether amendments are needed.
- Indigenous plant species should be specified over exotic or foreign species because they are well adapted to local on-site soil conditions and require few or no additional amendments.
- Decrease the areas where turf is used. Use low-maintenance ground cover to absorb run-off.
- Plant riparian buffers with trees, shrubs, and native grasses, where possible, to stabilize banks and provide shade.
- Maintain and frame desirable views. Be careful not to block views at entrances, exits, or difficult road curves. Screen unattractive views into the site. Aesthetics and visual characteristics should be a prime consideration.
- Use plants to prohibit pedestrian access to pools or slopes that may be unsafe.
- Carefully consider the long-term vegetation management strategy for the BMP, keeping in mind the maintenance legacy for future owners. Keep maintenance areas and access free of vegetation to allow vehicle clearance. Provide a planting surface that can withstand compaction from vehicles using maintenance access roads. Make sure the facility maintenance agreement includes requirements that ensure vegetation cover in perpetuity.
- If a BMP is likely to receive excessive amounts of de-icing salt, salt tolerant plants should be used.
- Provide signage for stormwater management areas to help educate the public, and for wildflower areas, when possible, to designate limits of mowing.
- Avoid the overuse of any plant materials, e.g., maples.
- Preserve existing natural vegetation when possible.

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Soil Preparation

It is necessary to test the soil in which you are about to plant in order to determine pH, whether acid, neutral, or alkaline; major soil nutrients, nitrogen, phosphorus, and potassium; and minerals such as chelated iron and lime.

Have soil samples analyzed by experienced and qualified individuals such as those at the Rutgers Cooperative Extension, who will explain the results in writing and recommend which soil amendments would be required. Certain soil conditions, such as marine clays (glauconite), can present serious constraints to the growth of plant materials and may require the guidance of qualified professionals. When poor soils cannot be amended, seed mixes and plant material must be selected to establish ground cover as quickly as possible.

Areas recently involved in construction can become compacted so that plant roots cannot penetrate the soil. Seeds will lie on the surface of compacted soils and are often washed away or eaten by birds. For planting success, soils should be loosened to a 4-inch depth. Hard soils may require discing to a deeper depth. The soil should be loosened regardless of the ground cover to improve seed contact with the soil, increase germination rates, and allow the roots to penetrate the soil. For areas to be sodded, discing is necessary so that roots can penetrate the soil. Good growing conditions can prevent poor vegetative cover, which saves money because vegetation will not need to be replanted.

Whenever possible, topsoil should be spread to a depth of 4 to 6 inches over the entire area to be planted. This provides organic matter and important nutrients for the plant material. The use of topsoil allows vegetation to become established faster and roots to penetrate deeper. This ensures quicker and more complete stabilization, making it less likely that the plants will wash out during a heavy storm.

If topsoil has been stockpiled in deep mounds for a long period of time, it is necessary to test the soil for pH as well as microbial activity. If the microbial activity has been destroyed, inoculate the soil after application.

Because newly installed plant material requires water to recover from the shock of being transplanted, be sure that a source of water is provided, especially during dry periods. This will reduce plant loss and provide the new plant materials a chance to establish root growth.

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Part 3: Specific Landscaping Criteria for BMPs

It is important to recognize that plants typically found in wetlands may be cultivated in non-wetland conditions; hence the importance of obtaining plants cultivated in similar hydrologic and soil conditions as those present in the stormwater management facility. A plant typically found in wetlands, but cultivated in non-wetland conditions, may not survive if installed in wetland conditions.

Ponds and Constructed Wetlands

Before planting within a stormwater management facility, determine which hydrologic zones will be created. Hydrologic zones describe the degree to which an area is inundated by water. Plants have differing tolerances to inundation; the six zones described in this section will dictate which plants will survive where. Every facility does not necessarily exhibit all of these zones.

Table 7-2: Hydrologic Zones

Zone	Zone Description	Hydrologic Conditions
Zone 1	Deep water pool	1-6 feet deep permanent pool
Zone 2	Shallow water bench	6 inches to 1 foot deep
Zone 3	Shoreline fringe	Regularly inundated
Zone 4	Riparian fringe	Periodically inundated
Zone 5	Floodplain terrace	Infrequently inundated
Zone 6	Upland slopes	Seldom or never inundated

Zone 1: Deep Water Pool (1 to 6 feet)

Ponds and wetlands both have deep pool areas that comprise Zone 1. These pools range from 1 to 6 feet in depth and are best colonized by submergent plants, if at all. This pondscaping zone has not been routinely planted for several reasons: first, the availability of plant materials that can survive and grow in this zone is limited; and second, it is feared that plants could clog the stormwater facility outlet structure. In many cases, these plants will gradually become established through natural recolonization, i.e., transport of plant fragments from other ponds via the feet and legs of waterfowl. If submerged plant material becomes more commercially available and clogging concerns are addressed, this area can be planted. The function of the planting is to reduce resedimentation and improve oxidation while creating a greater aquatic habitat.

Select plants that can:

- withstand constant inundation of water of 1 foot or greater in depth;
- withstand being submerged partially or entirely;
- enhance pollutant uptake; and
- provide food and cover for waterfowl, desirable insects, and other aquatic life.

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Suggested emergent or submergent species include, but are not limited to: spatterdock (Nuphar luteum), water lily (Nymphaea odorata), duckweed (Lemna spp.), duck potato (Saggitaria latifolia), wild celery (Vallisneria americana), sago pondweed (Potamogeton pectinatus), and redhead grass (Potamogeton perfoliatus).

Zone 2: Shallow Water Bench (6 inches to 1 foot)

Zone 2 includes all areas that are inundated below the normal pool to a depth of 1 foot; it is the primary area where emergent plants will grow in stormwater wetlands. Zone 2 also coincides with the aquatic bench found in stormwater ponds. This zone offers ideal conditions for the growth of many emergent wetland species. These areas may be located at the edge of the pond or on low mounds of earth below the surface of the water within the pond. When planted, Zone 2 can be an important habitat for many aquatic and non-aquatic animals, creating a diverse food chain that includes predators that provide natural regulation of mosquito populations, thereby reducing the need for insecticide applications.

Select plants that can:

- withstand constant inundation of water to depths between six inches and 1 foot deep;
- be partially submerged;
- enhance pollutant uptake; and
- provide food and cover for waterfowl, desirable insects, and other aquatic life.

Plants will stabilize the bottom and edge of the pond, absorbing wave impacts and reducing erosion when the water level fluctuates. In addition to slowing water velocities and increasing sediment deposition rates, plants can reduce re-suspension of sediments caused by the wind. Plants can also soften the engineered contours of the pond and conceal drawdowns during dry weather.

Appropriate herbaceous species include: water plantain (Alisma plantago-aquatica), three-sided sedge (Dulchium arundinaceum), managrasses (Glyceria spp.), soft rush (Juncus effusus), arrow arum (Peltandra virginica), smartweeds (Polygonum spp.), pickerelweed (Pontederia cordata), lizard tail (Saururus cernuus), many bulrushes (Scirpus spp.), and giant bur-reed (Sparganium eurycarpum).

Zone 3: Shoreline Fringe (regularly inundated)

Zone 3 encompasses the shoreline of a pond or wetland and extends vertically about 1 foot from the normal pool. This zone may be periodically inundated if storm events are subject to extended detention. This zone occurs in a wet pond or shallow marsh and can be the most difficult to establish since plants must be able to withstand inundation of water during storms, when wind might blow water into the area, or the occasional drought during the summer. To stabilize the soil in this zone, Zone 3 must have a vigorous cover.

Select plants that can:

- stabilize the shoreline to minimize erosion caused by wave and wind action or water fluctuation;
- withstand occasional inundation of water, as plants will be partially submerged at times;
- shade the shoreline, whenever possible, especially the southern exposure, to help reduce water temperature;
- enhance pollutant uptake;
- provide food and cover for waterfowl, songbirds, and wildlife (large plants can be selected and located to control overpopulation of waterfowl);
- be located to reduce human access to potential hazards without blocking maintenance access;
- have very low maintenance requirements because they may be difficult or impossible to reach;

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- be resistant to disease and other problems that require chemical applications, since chemical application is not advised in stormwater ponds; and
- be native plants, when possible, because they are low-maintenance and disease-resistant.

Many of the emergent wetlands plants outlined in Table 7-3 also thrive in Zone 3. Some other herbaceous species that do well include: cardinal flower (Lobelia cardinalis), blue flag iris (Iris versicolor), sweet flag (Acorus calamus), Marsh marigold (Caltha palustris), swamp milkweed (Asclepsis incarnata), bentgrass/redtop (Agrostis spp.), switchgrass (Panicum virgatum), Canada bluejoint (Calamagrostis canadensis), many bulrushes (Scirpus spp.), and spike rushes (Eleocharis spp.).

If shading is needed along the shoreline, the following woody species are suggested: river birch (Betula nigra), green ash (Fraxinus pennsylvanica), white ash (Fraxinus americana), pussy willow (Salix discolor), swamp rose (Rosa palustris), buttonbush (Cephalanthus occidentalis), highbush blueberry (Vaccinium spp.), red osier/silky dogwood (Cornus stolonifera/amomum), grey dogwood (Cornus racemosa), arrowood (Viburnum dentatum), spicebush (Lindera Benzoin), sweetbells (Leucothoe racemosa), sweet pepperbush (Clethra alnifolia), winterberry (Ilex verticillata), inkberry holly (Ilex glabra), serviceberry (Amelanchier spp.), black willow (Salix nigra), red maple (Acer rubrum), willow oak (Quercus phellos), swamp white oak (Quercus bicolor), pin oak (Quercus palustris), sweetgum (Liquidambar styraciflua), black gum (Nyssa sylvatica), sweet bay magnolia (Magnolia virginiana), and American sycamore (Platanus occidentalis).

Zone 4: Riparian Fringe (periodically inundated)

Zone 4 extends from 1 to 4 feet above the normal pool. Plants in this zone are subject to periodic inundation after storms and may experience saturated or partly saturated soil. Nearly all of the temporary extended detention area is included within this zone.

Select plants that can:

- withstand periodic inundation of water after storms, as well as occasional drought during the warm summer months;
- stabilize the ground from erosion caused by run-off;
- shade the low-flow channel to reduce pool warming whenever possible;
- enhance pollutant uptake;
- be very low maintenance, as they may be difficult or impossible to access;
- provide food and cover for waterfowl, songbirds, and wildlife (plants may also be selected and located to control overpopulation of waterfowl); and
- be located to reduce pedestrian access to the deeper pools.

Native plants are preferred because they are low-maintenance and disease-resistant. Frequently used plant species in Zone 4 include: many asters (Aster spp.) and goldenrods (Solidago spp.), beebalm (Monarda didyma), bergamont (Monarda fistulosa), lobelias (lobelia spp.), coneflower(Rudbeckia spp.), violets (Viola spp.), lilies (Lilium spp.), primrose (Oenothera spp.), milkwort (Polygala spp.), flatsedge (Cyperus spp.), hollies (Ilex spp.), steeplebush (Spirea tomentosa), serviceberry (Amelanchier arborea), nannyberry (Viburnurn lentago), sweet pepperbush (Clethra alnifolia), bayberry (Morella pensylvanica), elderberry (Sambucus canadensis), sweetbay magnolia (Magnolia virginiana), hawthorn (Crategus), shrub dogwoods (Cornus spp.), green ash (Fraxinus pennsylvanica), river birch (Betula nigra), sweetgum (Liquidambar styraciflua), American hornbeam (Carpinus caroliniana), persimmon (Diospyros virginiana), and red maple (Acer rubrum).

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Zone 5: Floodplain Terrace (infrequently inundated)

Zone 5 is periodically inundated by floodwaters that quickly recede in a day or less. Operationally, Zone 5 extends from the maximum two-year or Cpv water surface elevation up to the 10 or 100-year maximum water surface elevation. Key landscaping objectives for Zone 5 are to stabilize the steep slopes characteristic of this zone and establish low maintenance natural vegetation.

Select plants that can:

- withstand occasional but brief inundation during storms and, between storms, typical moisture conditions that may be moist, slightly wet, or even swinging entirely to drought conditions during the dry weather period;
- stabilize the basin slopes from erosion;
- be very low maintenance as ground cover since they may be difficult to access on steep slopes or mowing frequency may be limited (a dense tree cover may help reduce maintenance and discourage resident geese); and
- provide food and cover for waterfowl, songbirds, and wildlife.

Placement of plant material in Zone 5 is often critical. Some commonly planted species in Zone 5 include: phlox (Phlox spp.), solomon's seal (Polygonatum biflorum), many fescues (Festuca spp.), many viburnums (Viburnum spp.), Virginia rose (Rosa virginiana), American hornbeam (Carpinus caroliniana), cherries (Prunus spp.), willow oak (Quercus phellos), hickories (Carya spp.), and witch-hazel (Hamamelis virginiana).

Zone 6: Upland Slopes (seldom or never inundated)

This zone extends above the maximum 100-year water surface elevation and often includes the outer buffer of a pond or wetland. Unlike other zones, this upland area may have sidewalks, bike paths, retaining walls, and maintenance access roads. Care should be taken to locate plants so they will not overgrow these routes or create hiding places that might make the area unsafe. Plant selections should be made based on soil condition, light, and function within the landscape because little or no water inundation will occur. Ground covers should require infrequent mowing to reduce the cost of maintaining this landscape.

Placement of plants in Zone 6 is important since they are often used to create a visual focal point, frame a desirable view, screen undesirable views, serve as a buffer, or provide shade to allow a greater variety of plant materials. Particular attention should be paid to seasonal color and texture of these plantings.

Some frequently used plant species in Zone 6 include: fine fescues (Festuca spp.), basswood (Tilia americana), Flowering dogwood (Cornus florida), Sassafras (Sassafras albidum), American beech (Fagus grandifolia), white ash (Fraxinus americana), scarlet oak (Quercus coccinea), white oak (Quercus alba), Black oak (Quercus velutina), and pine species (Pinus spp.).

Infiltration and Filter Systems

Infiltration and filter systems either take advantage of existing permeable soils or create a permeable medium such as sand for groundwater recharge and stormwater quality control. In some instances where permeability is great, these facilities are used for quantity control as well. The most common systems include infiltration trenches, infiltration basins, sand filters, and organic filters.

When properly planted, vegetation will thrive and enhance the functioning of these systems. For example, pre-treatment buffers will trap sediments that often are binded with phosphorous and metals. Vegetation planted in the facility will aid in nutrient uptake and water storage. Additionally, plant roots will provide arteries for stormwater to permeate soil for groundwater recharge. Successful plantings provide aesthetic value and wildlife habitat, making these facilities more desirable to the public.

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Figure 7-3: Plan View of Hydrologic Zones Around Stormwater Basin

PONDSCAPING ZONE 3

New England Aster, Marsh Aster, Marsh Marigold, Tussock Sedge, Spotted Joe Pye Weed, Forget Me Nots, Inkberry, Willow species, Shrub Dogwood, Pin Oak, River Birch, Sycamore, Swamp White Oak.

PONDSCAPING ZONE 4

Purple Cone Flower, Birds Foot Trefoil, Slender Rush, Deer Tongue Grass, Switch Grass, Serviceberry, Gray Birch, Hackberry, Sweet Pepper Bush (Coastal Plain), Gray Stem Dogwood, Redosier Dogwood, Green Ash, Black Gum.

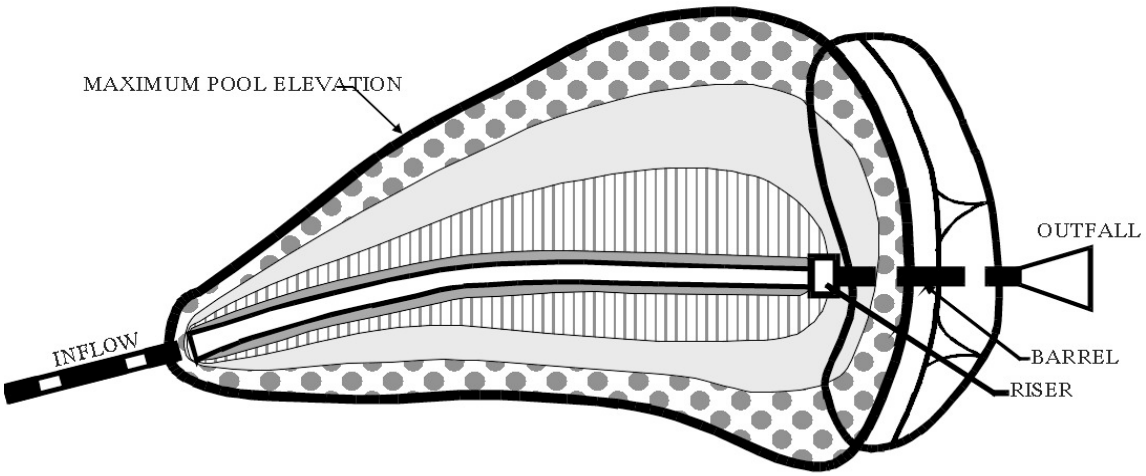
PONDSCAPING ZONE 5

Many wildflowers and native grasses. American Holly, Witch Hazel, Ninebark, Red Oak, American Elderberry, Lowbush Blueberry, Maple Leaf Viburnum, Nannyberry, Blackhaw Viburnum.

PONDSCAPING ZONE 6

(Floodplain) Mostly native ornamentals as long as soils drain well. Many natives. All species must be able to tolerate flood plain conditions. Hackberry, Pitch Pine, Sheep Fescue, Wildflowers, many native grasses.

Note: Tree and shrub setback requirements from the dam embankment, riser, and pipes should be strictly followed.



PLAN VIEW

Source: Adapted from Schueler and Claytor 2000.

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Figure 7-4: Plan View of a Shallow Marsh Planting

PONDSCAPING ZONE 1
12"-36" depth: Water Lily, Deep Water Duck Potato, Sago Pond Plant

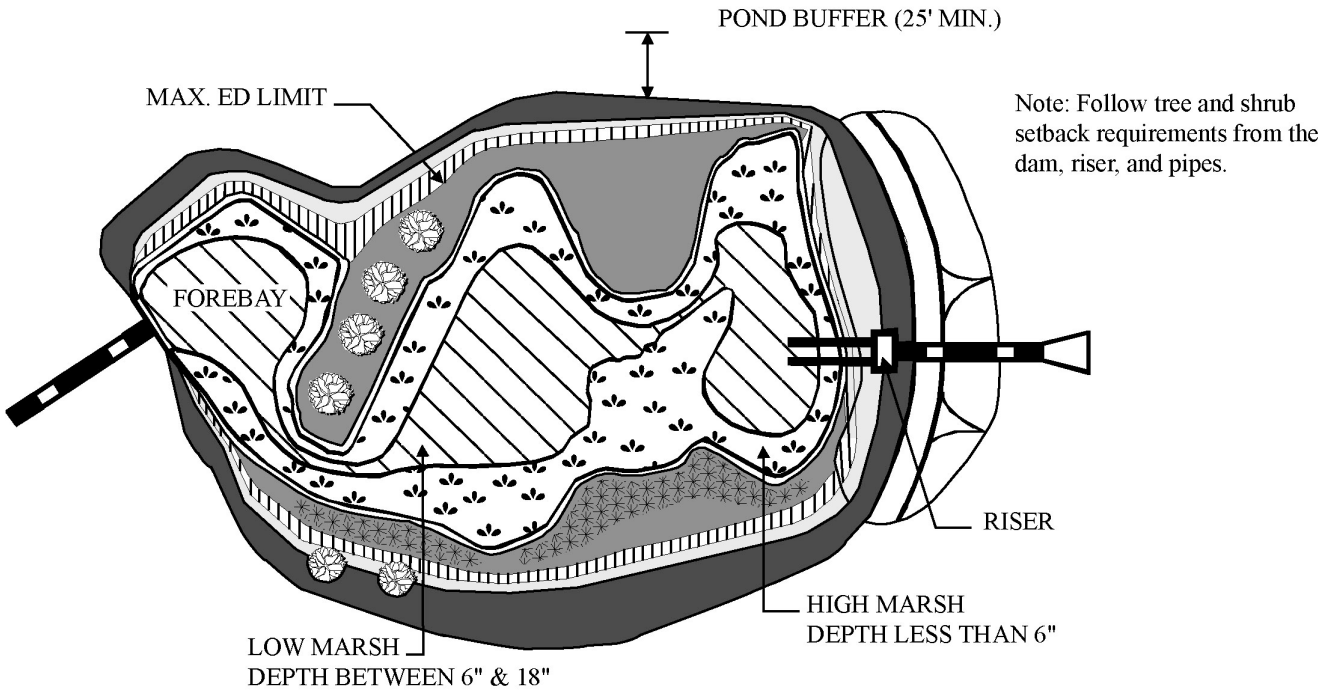
PONDSCAPING ZONE 2
0"-12" depth: Blue Flag Iris, Duck Potato, Flowering Bulrush, Softrush, Sedges

PONDSCAPING ZONE 3
New England Aster, Marsh Aster, Tussock Sedge, Spotted Joe Pye Weed, Inkberry, Shrub willow and Dogwood species, Pin Oak, River Birch, Sycamore, Swamp White Oak

PONDSCAPING ZONE 4
Slender Rush, Deer Tongue Grass, Switch Grass, Service Berry, Gray Birch, Hackberry, Sweet Pepper Bush, Gray Stem Dogwood, Red Osier Dogwood, Green Ash, Black Gum

PONDSCAPING ZONE 5
(Many Wildflowers & Native Grasses), American Holly, Witch Hazel, Ninebark, Red Oak, American Elderberry, American Hemlock, Lowbush Blueberry, Nannyberry, Blackhaw Viburnum

PONDSCAPING ZONE 6
(Floodplain) Mostly ornamentals as long as soil drains well, many natives. All species must be able to tolerate floodplain conditions. Hackberry, Pitch Pine, Sheep Fescue, Wildflowers, Grasses



Source: Adapted from Schueler and Claytor 2000.

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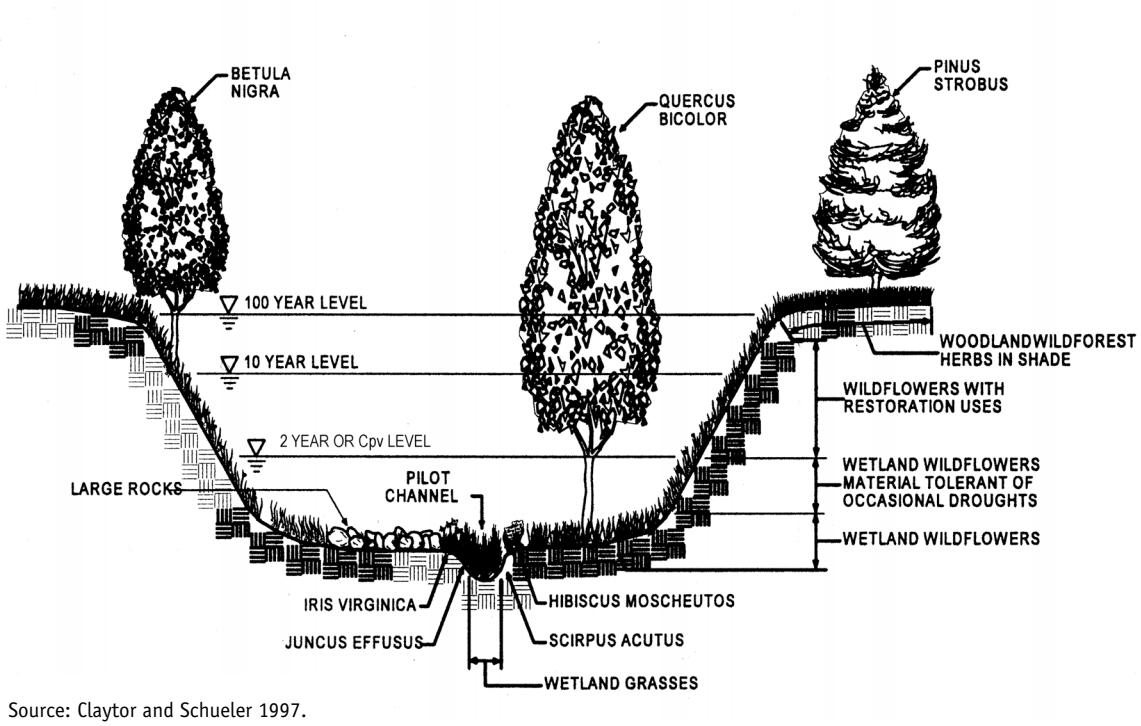
Figure 7-5: Section of a Typical Stormwater Management Detention Pond



Source: Claytor and Schueler 1997.

Design Constraints

- Planting buffer strips of at least 20 feet will cause sediments to settle out before reaching the facility, thereby reducing the possibility of clogging.
- Determine areas that will be saturated with water as well as water table depth so that appropriate plants may be selected (hydrology will be similar to bioretention facilities, see Figure 7-7 and Table 7-4 for planting material guidance).
- Plants known to send down deep taproots should be avoided in systems where filter fabric is used as part of the facility design.
- Test soil conditions to determine whether soil amendments are necessary.
- Plants should be located to allow access for structure maintenance.
- Stabilize heavy flow areas with erosion control mats or sod.
- Temporarily divert flows from seeded areas until vegetation is established.

See Figure 7-6 for additional design considerations.

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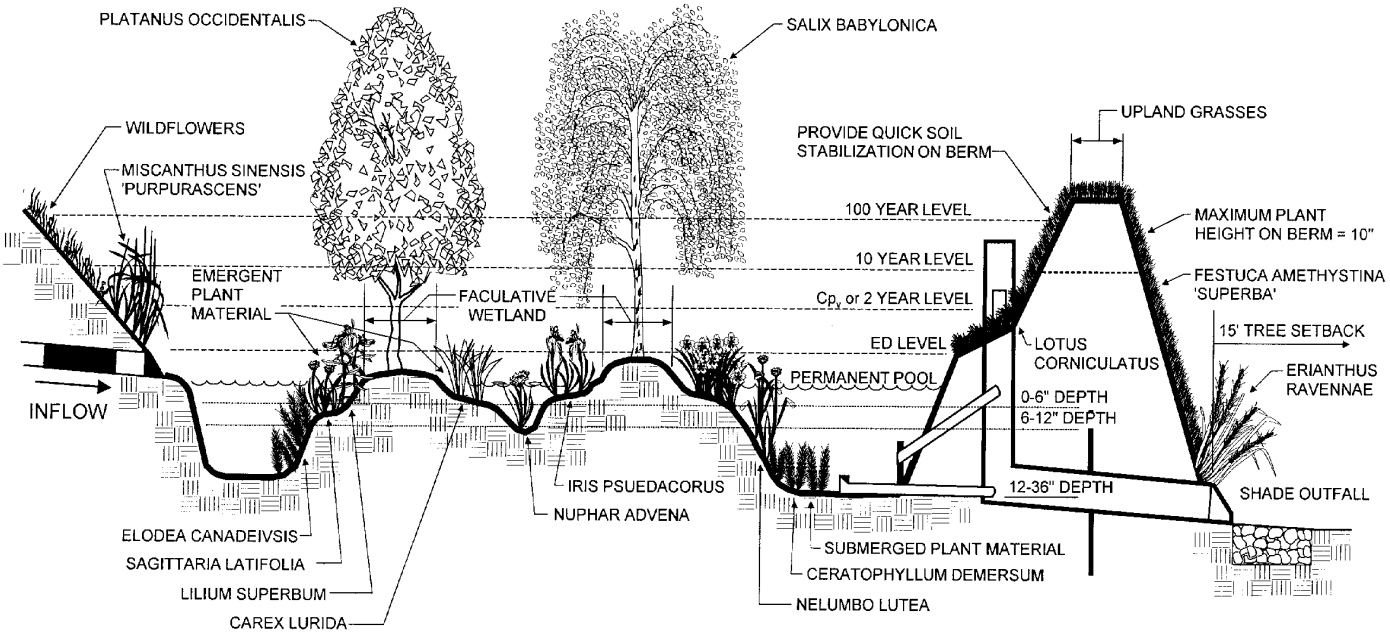
Figure 7-6: Section of Typical Shallow Extended Detention Marsh System



Source: Claytor and Schueler 1997.

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Part 4: Bioretention

Soil Bed Characteristics

The characteristics of the soil for the bioretention facility are perhaps as important as the facility location, size, and treatment volume. The soil must be permeable enough to allow runoff to filter through the media, while having characteristics suitable to promote and sustain a robust vegetative cover crop. In addition, much of the nutrient pollutant uptake (nitrogen and phosphorus) is accomplished through absorption and microbial activity within the soil profile. Therefore, the soils must balance soil chemistry and physical properties to support biotic communities above and below ground.

Table 7-3: Common Emergent Wetland Plant Species Used for Stormwater Wetlands and on Aquatic Benches of Stormwater Ponds

Common Name	Scientific Name	Inundation Tolerance
Arrow arum	Peltandra virginica	up to 12″
Arrowhead/Duck potato	Saggitaria latifolia	up to 12″
Pickerelweed	Pontederia cordata	up to 12″
Blunt spike rush	Eleocharis obtusa	up to 3″
Bushy beardgrass	Andropogon glomeratus	up to 3″
Common three-square	Scirpus pungens	up to 6″
Iris (blue flag)	Iris versicolor	up to 6″
Marsh hibiscus	Hibiscus moscheutos	up to 3″
Spatterdock	Nuphar luteum	up to 36″
Sedges	Carex spp.	up to 6″
Soft rush	Juncus effusus	up to 6″
Switchgrass	Panicum virgatum	up to 3″

Note 1: Inundation tolerance is maximum inches below the normal pool; most plants prefer shallower depths than the maximum indicated.

Note 2: For additional plant options, consult the stormwater planting list in Section 5. Other good sources include the NJDA Standards for Soil Erosion and Sediment Control in New Jersey, Design of Stormwater Wetland Systems (Schueler 1992), and Wetland Planting Guide for the Northeastern United States (Thunhorst 1993).

Details of the planting soil are discussed in *Chapter 9.1 Standard for Bioretention Systems*. The soil should be free of stones, stumps, roots, or other woody material over 1 inch in diameter. Brush or seeds from noxious weeds, such as Johnson grass, Mugwort, Nutsedge, Purple loosestrife, and Canadian thistle should not be present in the soils. Placement of the planting soil should be in lifts of 12 to 18 inches, loosely compacted (tamped lightly with a dozer or backhoe bucket). Specific soil characteristics are presented in Table 7-4.

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Mulch Layer

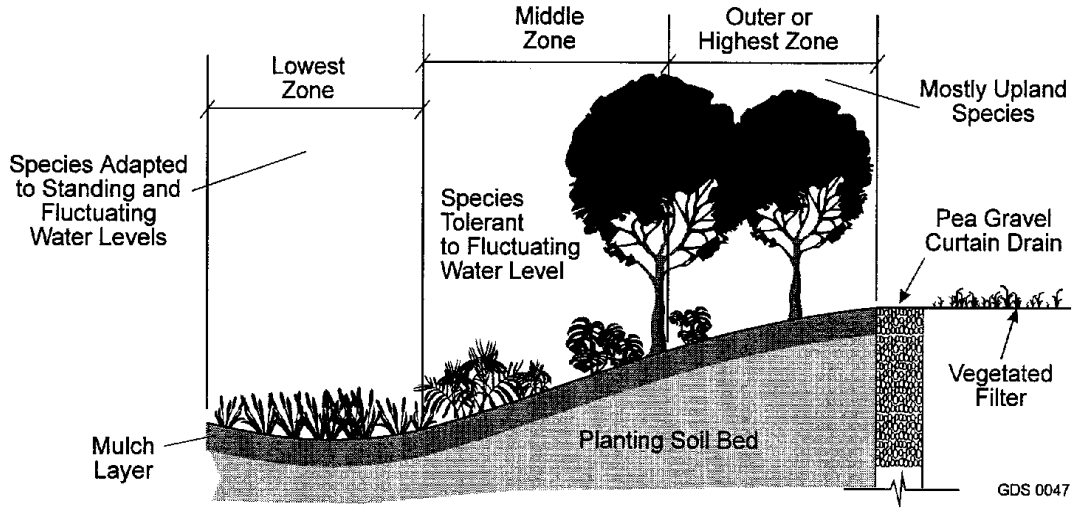
The mulch layer plays an important role in the performance of the bioretention system by helping to maintain soil moisture and avoiding surface sealing that reduces permeability. Mulch helps prevent erosion and provides a microenvironment suitable for soil biota at the mulch/soil interface. It also serves as a pre-treatment layer, trapping the finer sediments that remain suspended after the primary pretreatment.

The mulch layer should be standard landscape style, single or double, shredded hardwood mulch or chips. The mulch layer should be well aged (stockpiled or stored for at least 12 months), uniform in color, and free of other materials such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of 3 inches. Grass clippings should not be used as a mulch material.

Table 7-4: Planting Soil Characteristics

Parameter	Value
pH range	5.2 to 7.00
Organic matter	1.5 to 4.0%
Magnesium	35 lbs. per acre, minimum
Phosphorus (P205)	75 lbs. per acre, minimum
Potassium (K20)	85 lbs. per acre, minimum
Soluble salts	< = 500 ppm
Clay	10 to 25%
Silt	30 to 55%
Sand	35 to 60%
Source: Adapted from Schueler and Claytor 2000.	

Figure 7-7: Planting Zones for a Bioretention Facility



Source: Claytor and Schueler 1997.

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Plant Material Guidance

Plant materials should conform to the American Nursery and Landscape Association publication American Standard Nursery Stock and be selected from certified, reputable nurseries. A landscape architect or other qualified designer should specify a sequence of construction, a description of the contractor's responsibilities, planting schedule and installation specifications, initial maintenance, and a warranty period stipulating expectations of plant survival. *Planting Guidance* below presents some typical issues for planting specifications.

Open Channels

Consult Table 7-7 for grass species that perform well in the stressful environment of an open channel. For more detailed information, consult the Standards for Soil Erosion and Sediment Control in New Jersey. If a BMP is likely to receive excessive amounts of de-icing salt, salt tolerant plants should be used.

Planting Guidance

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an upland-species ecosystem. The community should be dominated by trees, but have a distinct community of understory trees, shrubs, and herbaceous materials. By creating a diverse, dense plant cover, a bioretention facility will be able to treat stormwater runoff and withstand urban stresses from insects, disease, drought, temperature, wind, and exposure.

Planting Plan Design Considerations

- Native plant species should be specified, not exotic or foreign species.
- Appropriate vegetation should be selected based on the zone of hydric tolerance (see Table 7-2).
- Species layout should generally be random and natural.
- A canopy should be established with an understory of shrubs and herbaceous materials.
- Woody vegetation should not be specified in the vicinity of inflow locations.
- Trees should be planted primarily along the perimeter of the bioretention area.
- Exotic (non-native) vegetation should not be specified.
- Urban stressors (e.g., wind, sun, exposure, insect and disease infestation, and drought) should be considered when laying out the planting plan.
- Aesthetics and visual characteristics should be a prime consideration.
- Traffic and safety issues must be considered.
- Existing and proposed utilities must be identified and considered.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention facility (Figure 7-7). The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports plants that prefer drier soil conditions but can tolerate occasional inundation by water. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions. A sample of appropriate plant materials for bioretention facilities is included in Table 7-5. The layout of plant material should be flexible, but should follow the general principals described in Table 7-6. The objective is to have a system that resembles a random and natural plant layout while maintaining optimal conditions for plant establishment and growth. For a more extensive bioretention plan, consult the Design Manual for Use of Bioretention in Stormwater Management (ETA&B 1993) or Design of Stormwater Filtering Systems (Claytor and Schueler1997).

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Table 7-5: Commonly Used Species for Bioretention Areas

Trees	Shrubs	Herbaceous Species
Acer rubrum Red maple	*Clethra alnifolia* Sweet pepperbush	*Andropogon glomeratus* Lowland broomsedge
Betula nigra River birch	*Ilex verticillata* Winterberry	*Eupatorium purpureum* Sweet-scented Joe Pye weed
Juniperus virginiata Eastern red cedar	*Cephalathus occidentalis* Buttonbush	*Scripus pungens* Three square bulrush
Chionanthus virginicus Fringe-tree	*Hamemelis virginiana* Witch hazel	*Iris versicolor* Blue flag
Nyssa sylvatica Black gum	*Vaccinium corymbosum* Highbush blueberry	*Lobelia cardinalis* Cardinal flower
Diospyros virginiana Persimmon	*Ilex glabra* Inkberry	*Panicum virgatum* Switchgrass
Platanus occidentalis Sycamore	*Ilex verticillata* Winterberry	*Dichanthelium clandestinium* Deertongue
Quercus palustris Pin oak	*Viburnum dentatum* Arrowwood	*Rudbeckia laciniata* Cutleaf coneflower
Quercus phellos Willow oak	*Lindera benzoin* Spicebush	*Scirpus cyperinus* Woolgrass
Salix nigra Black willow	*Morella pennsylvanica* Bayberry	*Vernonia noveboracensis* New York ironweed
Note: For more plant section options for bioretention, consult Design Manual for Use of Bioretention in Stormwater Management (ETA&B 1993) or Design of Stormwater Filtering Systems (Claytor and Schueler 1997).		

Table 7-6: Planting Specification Issues for Bioretention Areas

Specification Element	Elements
Sequence of construction	Describe site preparation activities, soil amendments, etc.; address erosion and sediment control procedures; specify step-by-step procedure for plant installation through site clean up.
Contractor's responsibilities	Specify the contractor's responsibilities, such as watering, care of plant material during transport, timeliness of installation, repairs due to vandalism, etc.
Planting schedule and specifications	Specify the plants to be installed, the type of materials (e.g., B&B, bare root, containerized); time of year of installations, sequence of installation of types of plants; fertilization, stabilization seeding, if required; watering and general care.
Maintenance	Specify inspection periods; mulching frequency (annual mulching is most common); removal and replacement of dead and diseased vegetation; treatment of diseased trees; watering schedule after initial installation (once per day for 14 days is common); repair and replacement of staking and wires.
Warranty	Specify the warranty period, the required survival rate, and the expected condition of plant species at the end of the warranty period.

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Table 7-7: Common Grass Species for Open Channels

Common Name	Scientific Name	Notes
Alkali saltgrass	Puccinellia distans	Cool, good for wet, saline swales
Fowl bluegrass	Poa palustris	Cool, good for wet swales
Canada bluejoint	Calamagrostis canadensis	Cool, good for wet swales
Creeping bentgrass	Agrostis palustris	Cool, good for wet swales, salt tolerant
Red fescue	Festuca rubra	Cool, not for wet swales
Redtop	Agrostis gigantea	Cool, good for wet swales
Rough bluegrass	Poa trivialis	Cool, good for wet, shady swales
Switchgrass	Panicum virgatum	Warm, good for wet swales, some salt tolerance
Wildrye	Elymus virginicus/riparius	Cool, good for shady, wet swales

Notes: These grasses are sod forming and can withstand frequent inundation, and are ideal for the swale or grass channel environment. A few are also salt-tolerant. Cool refers to cool season grasses that grow during the cooler temperatures of spring and fall. Warm refers to warm season grasses that grow most vigorously during the hot, mid-summer months.

Where possible, one or more of these grasses should be in the seed mixes. For a more thorough listing of seed mixes see Table 7-8 in Part 5 or consult the Standards for Soil Erosion and Sediment Control in New Jersey.

Vegetative Filters and Stream Buffers

For design and plant selection of vegetative filter strips and stream buffers, consult the USDA Natural Resources Conservation Service, New Jersey Conservation Practice Standards No. 342 "Critical Area Planting," No. 393 "Filter Strip," or No. 391 "Riparian Stream Buffers," available on the web at www.nj.nrcs.usda.gov through the Electronic Field Office Technical Guide (eFOTG).

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Part 5: Obtaining and Planting Native Wetland Plant Propagules

There are many ways to obtain plant materials for wetland revegetation, not all of which are appropriate for every project. The process of choosing which plants will be used, in what form, and how they will be obtained should be thought out as far ahead of time as possible. Several criteria will help you make these decisions:

- Have a clear idea of the project goals and objectives (as basic as whether restoration includes woody or herbaceous vegetation or both, and what wetland functions are desired – wildlife food and habitat, water quality improvement, or soil stabilization).
- Know the hydrology on site. Some plants will tolerate only certain water levels, and some plant materials can be established only under particular hydrologic regimes. For example, it makes no sense to select seeds of a shallow water emergent for an area with standing water over 3 feet deep. The seeds will not germinate, and even if they did, the plant would not tolerate those conditions.
- Determine other unique site factors. What are the soils like? Are there micro-topographies that can be exploited? Are geese or deer a problem? Is the site shaded or in full sun?

Once you have decided on the list of potential species for the site, you need to choose the appropriate plant form. Often, this decision is based on project budget, material cost, and the acceptable level of failure. Seeds are usually less expensive than container plants, but generally do not yield great successes and take longer to establish.

Part of the choice of appropriate plant forms depends on what is available. See Tables 7-9 and 7-10 for a complete listing of plant species and available plant forms. Into this mix comes the issue of ecotypes. An ecotype is a population of plants that has become genetically differentiated in response to the conditions of a particular habitat, and it has a distinctive limit of tolerance to environmental factors. For example, wetland plants growing around a pond in Maine are likely to have later flowering times and be more cold hardy than plants of the same species growing around a pond in Florida. When restoring wetland vegetation, consider using local ecotypes as much as possible. Using plants that are already adapted to your conditions can contribute greatly to the success of a revegetation project.

Herbaceous Plants

Herbaceous (non-woody) plants such as grasses, sedges, rushes, and wildflowers are available in many forms, some of which you can readily assemble for a project.

Seed

Using seed to revegetate a wetland is often a low-cost technique, especially if you plan to collect seed yourself. Purchasing seed is more expensive than collecting, but a collection made by a professional ensures that you have good quality seed and allows you to use some species with which you may be unfamiliar. Seeding a wetland can be tricky, since water levels must be carefully controlled. Seed needs to remain close to the soil surface to receive the three elements necessary for germination: moisture (not inundation), heat, and light. Most herbaceous wetland seed requires some pre-germination treatment, either stratification, a period of exposure to cold, moist conditions, and/or scarification (abrasion of the seedcoat) before they will germinate. If seeds are planted in the fall right after cleaning, winter freeze-thaw and bacterial activity may take care of these requirements. For a spring seeding, it is important to know whether the seed has been treated. Generally, there is a greater chance for failure when using seeds rather than plants for revegetation, and little information is available for direct seeding many species. However, seeding can be used in conjunction with other planting methods to enhance restoration.

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Dormant Propagules

Dormant propagules are overwintering, underground plant parts such as rhizomes, bulbs, corms, and tubers. These parts are fairly easy to work with; they can be purchased from vendors and transplanted into project sites. Revegetating a wetland with these materials is recommended over seeding because plant material is more likely to survive. Some important points to keep in mind:

- Store collected propagules in a cool, moist (not wet) location until needed. These materials have a much shorter shelf-life than seeds, so collect as close to planting time as possible.
- Dormant propagules are best purchased from local wetland plant vendors. This helps ensure that local ecotypes are used. Locally purchased plants are usually of high quality since long distance shipping is eliminated. When the plant materials shipment arrives, inspect the plants; propagules should be firm, not mushy. If they appear to be decomposing or smell bad, do not accept them.
- In temperate regions, wetland plant materials require a cold treatment to break dormancy. Planting propagules during fall, winter, or early spring will ensure that they receive the cold period necessary to develop normally.

Bare Root Plants and Plugs

Herbaceous plants are commonly grown in greenhouse flats, producing plants with a 2-inch root ball or "plug." Some, however, may be sold as bare-root clumps. Bare-root plants are best planted in the early spring, whereas plants grown in a potting mix can generally be planted through mid-summer. Some nurseries grow deeper rooting species such as warm-season grasses in cone shaped containers referred to as Cone-tainers™ or Deep '38s™ (referring to the number of plants in a flat).

Container Plants

Using container plants (quart size or larger) to restore vegetation on a site can be costly, but healthy plants with intact root balls have an advantage over other plant materials in that they do not need to expend energy on re-growing fine roots (as is the case with bareroot materials), germinating, and growing roots and shoots (as is the case with seeds and dormant vegetative propagules). Container materials can be planted at any time of the year, as long as the ground is not frozen and there is adequate moisture. Some nurseries only contract-grow container material since this size plant requires more time to grow.

Handling Herbaceous Plants

While you will most likely not be propagating and growing your own container plants, you may find, especially if a project is delayed, that you will have to pot up and store bareroot plants, dormant propagules, donor plugs, or even seeds that have limited longevity. Wetland plants are not particularly fussy, so they do not require special soil. Clean topsoil is fine for most species. Be careful not to use soil with a lot of weed seeds, or you may end up transporting problem plants into the wetland. If clean topsoil is not available, you can use bagged topsoil. A 1:1 mix of sand and peat is also useful, especially for germinating small seeds of herbaceous species. While many wetland plants can grow under normal watering regimes, you can cut down on watering and acclimate them to the intended site by letting containers sit in tubs partially filled with water.

In the normal scheme of things, you will be buying your container plants from a wetland plant vendor. As with the other materials discussed, try to find as local a supplier as possible to minimize any difficulties the plants will have adapting to local climate conditions. Inspect container plants for overall health and appearance – plant leaves should not appear pale or have yellowing or brown tips, and stems should be

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firm, not spindly. Look for evidence of pests or diseases – holes, wilting, or actual bug sightings should be cause to question the quality of materials. Pull plants from containers to look for strong root systems, with lots of white roots. If you specify particular sizes for materials, be sure that plants' roots fill the containers. Herbaceous materials can be sold in various sizes, but are most commonly available as plugs, quarts, or gallon sized containers. They are grown from seed, cuttings, vegetative propagules, or division. Containers may be made of plastic or biodegradable material such as peat, paper, or fiber.

Woody Plants

Woody plants for wetland revegetation are available in many of the same forms as herbaceous species; however, working with woody plants can take a bit more planning since they grow more slowly than herbaceous plants and it can take several growing seasons for materials to be ready for transplanting.

Seed

The advantages and disadvantages to working with woody plant seed are similar to those for herbaceous seed, that is, using seed is generally inexpensive, but can be tricky, particularly with species whose seed is preferred animal food (e.g., acorns).

Woody plant seed vendors can provide seeds for your project, but these suppliers are rare and, depending on your area, it may be difficult to obtain seed of local origin unless you collect it yourself. Try to get viability or germination information for any seeds you purchase.

Hardwood Cuttings

Stem cuttings from woody plants made during the dormant season are known as hardwood cuttings. These types of plant materials are particularly useful for revegetation on wetland edges and banks, just above the water line within the saturated soil zone. Cuttings are available to a limited extent from nurseries. Disadvantages to using hardwood cuttings include that they can dry out quickly, and that they may have high mortality rates, depending on site conditions.

The best candidates for hardwood cuttings are species of willow, poplar, and shrub dogwoods; these root readily without special treatment. Generally, cuttings are made from one to three-year-old stems, at least 18 inches long and .5 to 1.25 inches in diameter for best results; older materials do not root as readily.

Hardwood cuttings should be stored cold and moist until spring planting. To prime cuttings to form roots quickly after planting, soak cuttings in water for at least 24 hours prior to planting. This process swells the tissue that will expand from the cuttings to form roots.

Bareroot Plants

Bareroot trees and shrubs are commonly grown by native plant nurseries, and are fairly low-cost materials to work with. They are easy to store, transport, and plant, but survival is not as good as with materials that have intact roots.

When purchasing bareroot plants, look for good quality seedlings with a height of at least 18 inches and a root collar of 3/8 inches. Plants should have a substantial root mass left – about equal to the top. Do not accept materials that appear to have too much top growth to the amount of root. Plants should be firm and the growing layer underneath the bark should be green when a small area of the bark is scratched off.

Store bareroot plants in a cool, damp, dark location. Moist sawdust or soil can be packed loosely around the plants to prevent the roots from drying out. Bareroot plants can be stored successfully for several months prior to planting, as long as their roots do not dry out or freeze, and they do not leaf out.

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Container Plants and Balled and Burlapped Material

The most expensive and cumbersome restoration materials, but also the most successful in terms of survival, are container plants. Balled and burlapped (B&B) plants are expensive, but can have lower survival rates because of the loss of roots when dug from nursery beds (similar to bareroot materials). Both types can be planted at any time of the year, so long as hydrologic conditions are favorable and the ground is not frozen.

There are probably few instances when you would actually go through the process of ordering container materials for a project, and it is therefore useful to know what to expect when you purchase trees and shrubs from commercial growers. Order early – as soon as you know what you need for a project, start shopping. It can take two growing seasons or longer to propagate woody plants, especially seedlings. Be sure to specify plant size: if you ask only for specific container sizes, you may end up with tiny plants.

Before you accept delivery of container or B&B stock, look at the quality of the materials, particularly the roots. With container plants, remove several plants from the pots and check roots to be sure they fill the pots and are large enough to support the top growth without being pot-bound. Large, thick roots circling inside the pots or girdling other roots are indicative of plants that have outgrown their containers and were not transplanted to larger pots in time. B&B plants should have solid root balls with enough of the root systems present to support the top growth of the plants.

Overall quality is important. Plants for revegetation sites need not be perfect landscape specimens, but they should be vigorous and healthy, with no leaf damage, wilting, or pest insects. Healthy plant material is most able to tolerate less than ideal conditions and survive on a restoration site.

Direct Seeding of Wetland Plants

Many wetland plants are very difficult to seed in the wild. Wetland plant seeds usually require three things to germinate: heat, water, and light. The need for light means that wetland plant seeds must be seeded on the surface and cannot be covered with soil. Planting the seed with a drill will cover the seed, especially if packer wheels or drag chains are used.

Many species have a very hard seed coat that takes up to a year or longer to break down enough for the embryo to germinate. Many species require special stratification treatments to prepare the seed for planting. These treatments include everything from acid wash to mechanical scarification, from pre-chilling to extremely high temperature soil conditions. Occasionally, dormant seeding (seeding during the late fall or winter after the plants have gone dormant) can be successful, but it depends on the species.

Not having absolute control of the water going into the wetland or riparian area is the most common mistake that occurs when seeding wetland plants. Without good water control, when water enters the system the newly planted seeds will float to the water surface and move to the water's edge, where wave action will deposit the seed in a very narrow zone. The seed will germinate here and the stand will generally be quite successful so long as the hydrologic conditions are maintained for the various species deposited there. With good water control, the seeds, for the most part, will stay in place, and the stand will cover the wetland bottom instead of just around the fringe.

Some species, when seeded in a greenhouse setting, require a cold-hot stratification environment for successful germination. This means that the seeds are placed in cold storage at 32-36º F for 30 to 60 days and are then planted in moist soil containers at about 100º F. Heat is one of the essential requirements for germination and growth.

Based on these difficulties, using direct seeding of herbaceous plants as the primary means of revegetating a site will require more attention to planning and control of site hydrology during the establishment period. It also means you will need to know the specific germination/stratification requirements (if any) the targeted species require. Typically, direct seeding of herbaceous species is not used as the primary means of active revegetation, but as a method to increase the overall species diversity in a wetland, especially around the perimeter, and to establish populations of specific target species. The use of wetland herbaceous plugs is recommended over the use of wetland seed. However, the grass seeding mixtures in Table 7-8 may be used to quickly vegetate newly prepared wetland or fringe areas. Seeding alone may also be used if natural regeneration of indigenous species is desired.

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Table 7-8: Grass Mixtures for Quickly Vegetating Wetland Sites

Species	Common Name	Remarks
Agrostis gigantea	Redtop	SP,I,CG
Agrostis palustris	Creeping bentgrass	P,I,CG
Calamagrostis candensis	Canada bluejoint	P,N,CG
Cinna arundinacea	Wood reedgrass	P,N,CG
Dicanthelium clandestinum	Deertongue	P,N,WG
Elymus virginicus VA./riparius	Riparian wildrye	P,N,CG
Lolium multiflorum	Annual ryegrass	A,I,CG
Panicum virgatum	Switchgrass	P,N,WG
Poa trivialis	Rough bluegrass	P,I,CG
Poa palustris	Fowl bluegrass	P,N,CG
Puccinellia distans	Alkali saltgrass	P,N,CG
Tripsacum dactyloides	Eastern gamagrass	P,N,WG

Legend:

P = perennial	CG = cool-season grass
A = annual	WG = warm-season grass
I = introduced	CL = cool-season legume
N = native	SP = short-lived perennial

Note: Warm-season grass seeding rates are based on Pure Live Seed (PLS).

Suitable Seed Mixtures

SEED MIX 1: Warm-season mixture suitable for highly acid soils. Provides excellent wildlife value.

Blackwell switchgrass	3 lbs./ac. PLS
Tioga deertongue	5 lbs./ac. PLS
Annual ryegrass (nurse)	5 lbs./ac. PLS

SEED MIX 2: Cool-season mixture suitable for highly erosive areas. Provides fair wildlife value.

Canada bluejoint	2 lbs./ac.
Redtop	1 lbs./ac.

SEED MIX 3: All native mixture suitable for somewhat acid soils. Provides good to excellent wildlife value.

Blackwell switchgrass	3 lbs./ac. PLS
Tioga deertongue	5 lbs./ac. PLS
Wild rye	5 lbs./ac.

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SEED MIX 4: Turfgrass mixture suitable for moist, shady areas.

Rough bluegrass	25 lbs./ac.
Creeping bentgrass	10 lbs./ac.

SEED MIX 5: Native grass mixture for shady sites/forested floodplains.

Wood reedgrass	2 lbs./ac.
VA or Riparian wildrye	5 lbs./ac.

SEED MIX 6: Mixture for providing quick, temporary cover in areas where planting may be delayed due to seasonal restrictions, e.g, seed in late fall, plant permanent vegetation the following spring. Excellent wildlife value.

Redtop	1 lbs./ac.
Annual ryegrass	8 lbs./ac.

SEED MIX 7: This mixture is suitable for wet, saline areas, i.e., along roadsides, adjacent to tidal areas.

Creeping bentgrass	10 lbs./ac.
Alkali saltgrass	5 lbs./ac.

SEED MIX 8: Permanent cover mix providing quick perennial cover for saturated areas that will not be planted with other species.

Eastern gamagrass	5 lbs./ac. PLS
Redtop or creeping bentgrass	2 lbs./ac.
Fowl bluegrass	5 lbs./ac.
Wild rye	8 lbs./ac.
Switchgrass	5 lbs./ac. PLS

If aesthetics are desired, the following wildflowers are tolerant of saturated conditions and any or all may be added to the above mixtures at the rates specified:

Asclepias incarnata (Swamp milkweed)	2 lbs./ac.
Aster novae-angliae (New England aster)	0.5 lb./ac.
Aster novi-belgii (New York aster)	0.5 lb./ac.
Bidens frondosa (Beggar's tick sunflower)	1 lb./ac.
Caltha palustris (Marsh marigold)	0.5 lb./ac.
Chelone glabra (Turtlehead)	1 lb./ac.
Eupatorium fistulosum (Joe-pye weed)	1 lb./ac.
Helenium autumnale (Sneezeweed)	1 lb./ac.
Lobelia cardinalis (Cardinal flower)	0.5 lb./ac.
Lobelia siphilitica (Blue lobelia)	0.5 lb./ac.
Mimulus ringens (Monkey flower)	1 lb./ac.
Rudbeckia laciniata (Green-headed coneflower)	1 lb./ac.
Solidago rugosa (Wrinkle-leaf goldenrod)	0.5 lb./ac.
Solidago patula (Rough goldenrod)	0.5 lb./ac.
Verbena hastata (Blue vervain)	1 lb./ac.
Vernonia noveboracensis (New York ironweed)	2 lbs./ac.

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Wetland Transplanting with Plugs

Natural wetland systems normally have high species diversity. When selecting plant species for the project wetland, try to copy a nearby natural wetland using these techniques:

- Identify the particular hydrology in areas where the individual plant species are growing.
- Make note of how deep the water is.
- Try to imagine how long the plants will be inundated.
- Determine whether the plants are in flowing or relatively stagnant water.

Rarely will a natural wetland be totally stagnant through time. Generally, there is water flowing into the wetland from somewhere, either above ground or from groundwater. Spring and fall overturn, as well as wind mixing, helps to circulate the water.

Next, prepare the planting area. The easiest way to plant wetland species plugs is by flooding your planting site. Standing water is much easier to plant than dry soil (this also ensures that the watering system, whatever it may be, works before you plant). Make sure the soil is saturated enough so that you can dig a hole with your hand. This is more successful with fine soils than with coarse soils. Take the plug trays and place them in a Styrofoam cooler (you will not need the lid). Try to cover most of the roots with water while in transit. At the planting site, drain off most of the water so the cooler will float. Use the cooler to move the plugs around the wetland as you plant. Select a spot in your wetland to put a plug, reach into the water with your hand and dig out a hole deep enough for the plug to fit all the way in. Push the plug into the hole and pack around it with your hand. Make sure all of the roots are covered with soil. Be careful to not dislodge the plug and expose the roots when moving around. Start at one end of the planting site and work toward the opposite end.

Spacing of the plugs is a common concern. Research has indicated that many wetland plants will typically spread about 9 to 12 inches in a full growing season. Typically, wetland species are planted on 18 inch centers. Even though it takes fewer plants to plant an area at a wider spacing, plantings at wider spacing have less overall success than planting at a closer spacing. The exact reason for this is unknown, but it could be a sympathetic response to plants of the same species. If the project budget does not allow for the purchase of enough plants to cover the wetland bottom, plant the plugs on 18 inch centers, but plant them in copses or patches that are about 10 feet square or in diameter. Space the copses about 10 feet apart. The copses can be planted to different species according to the hydrology. For hydrologic Zone 2, Scheuler (1996) recommends planting at least five to seven species of emergent plants, three of which should be arrowhead (Sagittaria latifolia), three square (Scirpus pungens), and soft-stem bulrush (Scirpus tabernaemontanii). Based on experience, these three species will establish readily and spread quickly without being too aggressive. Over time, the plants will spread out into the unplanted areas. The additional species selected for the wetland system can be chosen to mimic natural wetlands in the area and/or enhance water quality, wildlife value, or aesthetics. Generally, it is best to keep water levels as shallow as possible to promote greater species diversity and assimilate a higher concentration of pollutants. High nutrient inflows and greatly fluctuating water levels tend to promote the more aggressive species such as reed canarygrass, cattails, and phragmites.

The optimum planting window for wetland plants is from March through late July. Planting plugs in the fall and winter has resulted in frost heaving of the plugs so that only about one-third of the plug remained in the ground. The availability of water is critical – wetland plants like it hot and wet. They tend to spread faster with warmer temperatures. If you plant in the spring, it will take the plants a while to get going, but they will have a longer establishment period. Fall planting will generally result in lower establishment success because of the shorter growing season and frost heaving damage.

The plants can be successfully established in a wide variety of soil textures. Successful wetland plantings have occurred in areas that are clay with no organic matter to gravelly textures. The biggest problem is

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digging the holes. The soil texture will often limit the equipment available to dig the holes. In clay bottoms, a small bulldozer or tractor with a ripper tooth can be used to dig lines across the bottom about 8 inches deep.

In general, fertilizer is not necessary, but its use depends on the site and the soils. If during construction the bottoms have been cut down to the subsoil and all of the naturally present nutrients have been removed, fertilization will probably be necessary unless the water coming into the wetland has a high nutrient load.

After planting, release the water into the site slowly. The young plants have not fully developed the aerenchymous material necessary for them to survive in anaerobic soils and standing water. After the initial planting, be careful not to raise the water level to more than about 1 inch above the substrate. Too much water at this time may stress the new plants. Maintain the water at about 1 inch for about one week, to inhibit the germination and growth of any terrestrial species that may be present in the restored wetland. The water level can then be lowered to the substrate surface for 15 to 20 days. This will expose the mud surface, stimulating any wetland seeds that were brought in with your transplants to germinate as well as increase the rate of spread of the transplants. You can then raise the water level 1 to 2 inches for another week. Then lower the water to the substrate surface for another 15 to 20 days. After this period, slowly raise the water level to 4 to 6 inches for three to five days. Continue to gradually increase the water depth to 6 to 8 inches. The aerenchymous tissues in the plant shoots are what supply the roots with oxygen, so be careful not to raise the water over the tops of the emergent vegetation. If the plants are not showing any stress, continue to carefully raise the water level to 12 to 20 inches, if possible. These suggested water level depths must be modified based on the species used. Some species will not tolerate inundation at these suggested depths or durations. When in doubt, defer to the hydrology conditions on natural reference sites where the species occurs. The goal here is to inundate the transition zone between wetland and upland as much as possible to control any invading terrestrial species. After about 20 days lower the water level to about 2 to 3 inches (Hammer 1992). For the rest of the growing season, adjust the water level to maximize the desired community type. The key to determining the appropriate water level is to monitor the emergent wetland plant community. Raise the water level if weed problems surface. Lower the water level to encourage emergent wetland plant growth and spread. The key is to fluctuate the water level. Natural wetlands rarely have a constant water level. Many species cannot tolerate a constant water level and will begin to die out; species more tolerant to standing water will increase, and the plant diversity that was so carefully planned for will be lost.

Management during the establishment year is important to ensure that the plants do not get too much water or too little. Weed control is important especially during the establishment year because of the low water levels and exposed, unvegetated areas. A good weed control plan needs to be in place before planting. Monitoring the planting for three to five years after the establishment year will help maintain the planting and provide useful information for future plantings.

Recommendations

- Always match the plant species to the hydrology associated with that species. In general, purchase the largest plugs you can. Planting technique will often determine the size of the plugs and the ease of planting.
- Plant the plugs on 18 to 24 inch centers. Plant in patches rather than wider spacing.
- Fertilizer is generally not necessary unless the water coming into the site is relatively clean or construction has cut into the subsoil.
- Plants will spread faster under saturated soil conditions than in standing water. However, terrestrial weeds will move in to saturated soils much faster than flooded soils. Fluctuating the water level helps the plants spread and decreases terrestrial weed establishment.

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- Water control is extremely important during the establishment year.
- Weed control must be planned and budgeted at the beginning of the project.
- Monitoring is essential for the success of the project. Monitoring requires time and money allocated in the budget, and a specific person identified to carry it out.
- Successful wetland plantings take significant planning and a good understanding of the hydrology at each site.

Upland Seeding

There are three main factors to consider when planning the upland seeding phase o stormwater basin: season of seeding, seeding rates, and method of application. Season of seeding is important because some seed may require stratification before germination. Other seed, such as legume species, should probably not be seeded until spring. Seeding rate concerns both economics and plant competition. Too much seed on a site puts unnecessary cost into the total process and, at the same time, a thinner stand will emerge because of plant competition for nutrients traditionally in short supply on disturbed soils. Ideally, the site should have been prepared the previous fall if a spring seeding is desired. Usually, spring seedings are conducted between periods of wet and dry weather (commonly in March to the first of May). There may be a problem getting heavy equipment onto the site to prepare a seedbed in the early spring following a wet winter that has saturated the soil profile. (Refer to the USDA-NRCS Conservation Practice Standard-342 "Critical Area Planting" or the Standards for Soil Erosion and Sediment Control in New Jersey for seed mixtures and mulching information.)

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Part 6: Other Considerations in Stormwater BMP Landscaping

Use or Function

In selecting plants, consider their desired function in the landscape. Is the plant needed as ground cover, soil stabilizer, or a source of shade? Will the plant be placed to frame a view, create focus, or provide an accent? Does the location require that you provide seasonal interest to neighboring properties? Does the adjacent use provide conflicts or potential problems and require a barrier, screen, or buffer? Nearly every plant and plant location should be provided to serve some function in addition to any aesthetic appeal.

Plant Characteristics

Certain plant characteristics, such as size and shape, are so obvious they may actually be overlooked in the plant selection. For example, tree limbs, after several years, can grow into power lines. A wide growing shrub may block an important line of sight to oncoming vehicular traffic. A small tree, when full grown, could block the view from a second story window. Consider how these characteristics can work for you or against you, today and in the future.

Other plant characteristics must be considered to determine how plants provide seasonal interest and whether plants will fit with the landscape today and through the seasons and years to come. Some of these characteristics are: color, texture, growth rate, and seasonal interest, i.e., flowers, fruit, leaves, and stems/bark.

Growth Rate

If shade is required in large amounts, quickly, a sycamore might be chosen over an oak. In urban or suburban settings, a plant's seasonal interest may be of greater importance. Residents living next to a stormwater system may desire that the facility be appealing or interesting to look at throughout the year. For example, willows are usually the first trees to grow leaves signaling the coming of spring. Pink and white dogwoods bloom in mid-spring to early summer, while witch hazel has a yellow bloom every fall, which can be contrasted with the red fall foliage of a sugar maple. Careful attention to the design and planting of a facility can result in greater public acceptance and increased property value.

Availability and Cost

Often overlooked in plant selection is the availability from wholesalers and the cost of the plant material. Many plants listed in landscape books are not readily available from local nurseries. Without knowledge of what is available, time spent researching and finding the one plant that meets all needs will be wasted. That plant may require shipping, making it more costly than the budget may allow. Some planting requirements may require a special effort to find the specific plant that fulfills the needs of the site and the functions of the plant in the landscape. In some cases, it may be cost effective to investigate nursery suppliers for the availability of wetland seed mixtures. Specifications of the seed mix should include wetland seed types and the relative proportion of each species. Some suppliers provide seed mixtures suitable for specific wetland, upland, or riparian habitat conditions. This option may best be employed in small stormwater facilities, such as pocket wetlands and open swales, or to complement woody vegetation plantings in larger facilities. A complete listing of wetland plant suppliers is available on the USDA-NRCS Plant Materials Program website (www.Plant-Materials.nrcs.usda.gov).

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Vegetation Maintenance

To ensure grass vigor, maintain the copse as an upland meadow, which includes cutting no shorter than 6 to 8 inches high. If a more manicured lawn setting is desired, more mowing and special attention to turf health will be needed. Some communities consider the tall wetlands-type vegetation (typically, cattails or rushes) that may grow in dry ponds to be unaesthetic. Some of this vegetation is actually beneficial as it provides water quality benefits and wildlife habitat. Some vegetative needs include:

- pH adjustment (as required);
- pruning;
- pest control;
- reseeding;
- thatch removal; and
- weed removal.

Sediment Filtration

Vegetative cover outside of an embankment filters sediment from runoff as it flows into a pond. It also prevents erosion of the pond banks. A minimum vegetated filter strip BMP is ideal around wet ponds.

Surrounding Vegetation Fertilization (not recommended, except in special cases)

It is important not to over-fertilize the surrounding vegetation. Doing so could result in excess nutrients being washed into the pond, which can contribute to excessive algae growth. As a general rule, the nutrient needs of the surrounding vegetation should be evaluated by testing the pH and nutrient content of the soil prior to fertilization. The adjustment of pH may be necessary to maintain vegetation. Fertilization of all turf areas should occur in the fall.

Purple Loosestrife

If your wetland and/or stormwater management area becomes invaded with purple loosestrife, there are methods to reduce its presence. It is important to catch its presence early, which is evident by the long purple flowering head or inflorescence. To manually rid the wetland and/or stormwater management area of purple loosestrife, it is important to ensure that the rhizomes (large tuberous root systems) are removed as well as the plant (above ground portion) prior to flowering (June through September). Plant parts, immediately upon removal, should be placed in a bag to prevent further spread of the species. If it is not possible to do this, regularly remove the flower heads before the seeds are dispersed. This will help keep this plant at bay. Digging is not recommended as it creates disturbance, which may favor the spread of the species. Herbicides are generally not effective for purple loosestrife as its seeds are long-lived and this solution is therefore short-term. If herbicide applications are used, they will need to be repeated for several years. As a caution, purple loosestrife may be available at local nurseries. Do not introduce this plant into pond areas.

Cattails and Common Reeds (phragmites)

It is important to determine which plants were originally planted when the pond or stormwater wetland was constructed. Cattails planted in these areas are one of the most beneficial plants in improving water quality. It must be noted that ponds and stormwater wetlands were originally designed with the intent of retaining

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stormwater and/or treating stormwater. The concept of wildlife habitat was an ancillary benefit at best and not generally the goal prior to the mid-1990s.

Shallow water (less than 2 feet) will often be taken over by water loving plants. Dense, tall emergent vegetation, most commonly cattails and phragmites, may limit waterfowl use of a pond. Cattails provide good wildlife habitat, but can take over a shallow pond. Phragmites is much more invasive, taller, and generally does not provide for a scenic view. Once established, phragmites is very difficult to completely eradicate.

Dense stands of cattails and phragmites can reduce populations of invertebrates, amphibians, and reptiles, and may possibly increase mosquito populations. It is important to keep some areas of open water. Eradication of these species generally requires assistance from a natural resource professional. A natural resource professional is a person who has been trained in ecology and/or environmental assessment, including soils, plants, animals, air quality, human involvement, and water quantity and quality.

With respect to diversity, research has shown that lower pollutant inputs generally yield greater plant diversity. Conversely, higher pollutant inputs yield lower plant diversity. Hence, if your pond becomes populated with phragmites, cattails or both, it may indicate a high pollutant load. These species, among others, are two of the best plants for improving water quality.

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Stormwater Plant Lists

The following pages present lists of herbaceous and woody vegetation native to New Jersey and suitable for planting in stormwater management facilities. The lists are intended as a guide for general planting purposes and planning considerations. Knowledgeable landscape designers and nursery suppliers may provide additional information for considering specific conditions for successful plant establishment and accounting for the variable nature of stormwater hydrology.

The planting lists are in alphabetical order according to the common name, with the scientific name also provided. Life forms indicate whether a plant species is an annual, perennial, grass, grass-like, fern, tree, or shrub.

Each plant species has a corresponding hydrology zone to indicate the most suitable planting location for successful establishment. While the most common zones for planting are listed in parenthesis, the listing of additional zones indicates that a plant may survive over a broad range of hydrological conditions.

The wetland indicator status has been included to show "the estimated probability of a species occurring in wetlands versus nonwetlands." The indicator categories are defined as follows:

- Obligate wetland (OBL): Plants that nearly always (more than 99 per cent of the time) occur in wetlands under natural conditions.
- Facultative Wetland (FACW): Plants that usually occur in wetlands (from 67 to 99 per cent of the time), but are occasionally found in nonwetlands.
- Facultative (FAC): Plants that are equally likely to occur in wetlands and nonwetlands and are found in wetlands from 34 to 66 per cent of the time.
- Facultative Upland (FACU): Plants that usually occur in nonwetlands (from 67 to 99 per cent of the time), but are occasionally found in wetlands (from 1 to 33 per cent of the time).
- Upland (UPL): Plants that almost always (more than 99 per cent of the time), under natural conditions, occur in nonwetlands.

A given indicator status shown with a "+" or a "-" means that the species is more (+) or less (-) often found in wetlands than other plants with the same indicator status without the "+" or "-" designation.

Since the wetland indicator status alone does not provide an indication of the depth or duration of flooding that a plant will tolerate, the "Inundation Tolerance" section is designed to provide further guidance. Where a plant species is capable of surviving in standing water, a "Yes" is designated in this column. Additional information is provided for depth of inundation for aquatic vegetation and tolerance for seasonal inundation, saturated soil conditions, or tolerance to salt. Because individual plants often have unique life requirements difficult to convey in a general listing, it will be necessary to research specific information on the plant species proposed in order to ensure successful plant establishment.

Commercial availability indicates whether the plant is available as seed, plant form (bare-root, plug, or container), or both. The plant form listed first is the most common form supplied by nurseries. The availability of some species varies from one year to the next. It is best to determine the quantity needed and the plant form desired for each individual species well ahead of time (at least six months).

Table 7-9, a list of herbaceous stormwater plants, begins on the next page, followed by Table 7-10, a list of woody vegetation.

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Table 7-9: Stormwater Plant List – Herbaceous Vegetation

Common Name	Scientific Name	Plant Type	Hydrologic Zone	Wetland Indicator	Inundation Tolerance	Commercial Availability
Arrow arum	Peltandra virginica	Grass-like	[1,2],3	OBL	Yes	Plants, Seed
Arrowhead, bull-tongue	Sagittaria lancifolia	Perennial	[1,2],3	OBL	Yes	Plants
Arrowhead, duck potato	Sagittaria latifolia	Perennial	[1,2],3	OBL	0-2'	Plants, Bare-root, Seed
Arrowhead, grass-leaf	Sagittaria graminea	Perennial	[1,2],3	OBL	0-1'	Plants
Aster, calico	Aster lateriflorus	Perennial	[2,3,4]	FACW-	Seasonal	Seed, Plants
Aster, New England	Aster novae-angliae	Perennial	[2,3],4	FACW	Yes	Seed, Plants
Aster, New York	Aster novibelgil	Perennial	[2,3],4	FACW+	Yes	Seed, Plants
Aster, panicled	Aster simplex (lanceolatus)	Perennial	[2,3],4	FACW	Yes	Seed, Plants
Aster, white heath	Aster ericoides	Perennial	3,[4,5,6]	FACU	No	Seed
Aster, white wood	Aster divercatus	Perennial	4,[5,6]	NI	No	Plants
Beachgrass, American	Ammophila breviligulata	Grass	4[5,6]	FACU-	No	Dormant culms Plants
Beardtongue	Penstemon digitalis	Perennial	3,4,5	FAC	No	Plants, Seed
Beebalm	Monarda didyma	Perennial	3,[4,5]	FAC+	Saturated	Plants, Seed
Beggars-tick	Bidens connata	Annual	[2,3],4	FACW+	Yes	Seed
Beggars-tick	Bidens frondosa	Annual	2,[3,4]	FACW	Yes	Seed
Bentgrass, creeping	Agrostis palustris	Grass	[2,3],4	FACW	Yes	Seed
Bergamot, wild	Monarda fistulosa	Perennial	[4,5,6]	UPL	No	Plants, Seed
Black-eyed susan	Rudbeckia hirta	Perennial	4,[5,6]	FACU-	No	Plugs, Seed
Bladderwort, common	Utricularia macrorhiza	Perennial	[1,2],3	OBL	Yes	Plants
Blue lobelia	Lobelia siphilitica	Perennial	1,[2,3],4	FACW+	Yes	Plants, Seed
Bluebells, Virginia	Mertensia virginica	Perennial	[2,31,4	FACW	Yes	Plants, Seed
Bluegrass, fowl	Poa palustris	Grass	[2,3],4	FACW	Yes	Seed
Bluegrass, rough	Poa trivialis	Grass	2,[3,4],5	FACW	Seasonal	Seed
Bluestem, big	Andropogon gerardii	Grass	[4,5],6	FAC	No	Seed, Plants
Bluestem, little	Schizachyrium scoparium	Grass	6	FACU	No	Seed, Plants
Boneset	Eupatorium perfoliatum	Perennial	[2,3],4	FACW+	Yes	Plants, Seed
Broomsedge	Andropogon virginicus	Grass	[4,5],6	FACU	No	Seed
Broomsedge, lowland	Andropogon glomeratus	Grass	[2,3],4	FACW+	Yes	Plants
Bulrush, alkali	Scirpus robustus	Grass-like	1,[2],3	OBL	Salt, edge	Plants
Bulrush, chairmakers	Scirpus americanus	Grass-like	[1,2],3	OBL	0-6"	Plants, Seed
Bulrush, green	Scirpus atrovirens	Grass-like	[1,2,],3	OBL	Yes	Plants, Seed
Bulrush, hardstemmed	Scirpus acutus	Grass-like	[1,2],3	OBL	0-3'	Plants, Seed

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Common Name	Scientific Name	Plant Type	Hydrologic Zone	Wetland Indicator	Inundation Tolerance	Commercial Availability
Bulrush, river	Scirpus fluviatilis	Grass-like	[1,2],3	OBL	0-1′	Seed
Bulrush, softstem	Scirpus tabermontanii	Grass-like	[1,2],3	OBL	0-1′	Plants, Seed
Bulrush, three-square	Scirpus pungens	Grass-like	[2,3],4	FACW+	0-6″	Plants, Seed
Burnet, Canada	Sanguisorba canadensis	Perennial	4,[5,6]	FACW+	Yes	Plants
Burreed, American	Sparganium americanum	Emergent Perennial	[1,2],3	OBL	0-1′	Plants, Seed
Burreed, giant	Sparganium eurycarpum	Emergent Perennial	[1,2],3	OBL	Yes	Plants, Seed
Bushclover, roundheaded	Lespedeza capitata	Legume	4,5,6	FACU	No	Seed, Plants
Butter-cup, yellow water	Ranunculus flabellaris	Perennial	[2,3,4]	FACW	Yes	Plants
Butterflyweed	Asclepias tuberosa	Perennial	[5,6]	NI	No	Plants, Seed
Cardinal flower	Lobelia cardinalis	Perennial	1,[2,3],4	FACW+	Yes	Plants, Seed
Celery, wild	Vallisneria americana	Perennial	[1,2],3	OBL	Yes	Plants, Seed
Club, golden	Orontium aquaticum	Perennial	[1,2],3	OBL	Yes	Plants
Columbine, wild	Aquilegia canadensis	Perennial	[3,4],5	FAC	No	Plants, Seed
Coneflower, brown-eyed	Rudbeckia triloba	Perennial	4,[5,6]	FACU	No	Plants, Seed
Coneflower, cut-leaf	Rudbeckia laciniata	Perennial	[2,3],4	FACW	Yes	Seed, Plants
Coneflower, orange	Rudbeckia fulgida	Perennial	[3,4],5	FAC	No	Seed
Cordgrass, big	Spartina cynosuroides	Grass	[1,2],3	OBL	Tidal-fresh	Plugs
Cordgrass, prairie	Spartina pectinata	Grass	[1,2],3	OBL	Tidal-fresh	Plants, Seed
Cordgrass, saltmarsh	Spartina alterniflora	Grass	[1,2],3	OBL	Salt, edge	Plants, Seed
Cordgrass, saltmeadow	Spartina patens	Grass	1,[2,3],4	FACW+	Salt, edge	Plants
Coreopsis, dwarf plains	Coreopsis tinctoria	Annual	3,[4,5],6	FAC-	No	Seed, Plants
Coreopsis, lance-leaved	Coreopsis lanceolata	Perennial	5,6	FACU	No	Seed, Plants
Coreopsis, pink	Coreopsis rosea	Perennial	2,[3,4]	FACW	Yes	Seed, Plants
Coreopsis, tall	Coreopsis tripteris	Perennial	[2,3],4	FAC	Yes	Plants, Seed
Cutgrass, rice	Leersia oryzoides	Grass	[1,2],3	OBL	0-6″	Plants, Seed
Dragon-head, false (obedient plant)	Physostegia virginiana	Perennial	2,[3,4],5	FAC+	Saturated	Plants, Seed
False-hellebore, American	Veratrum viride	Perennial	[2,3,4]	FACW+	Yes	Plants, Seed
False-solomon's-seal	Smilacina racemosa	Perennial	[4,5],6	FACU-	No	Seed
Fern, cinnamon	Osmunda cinnamomea	Fern	[2,3],4	FACW	Saturated	Plants
Fern, New York	Thelypteris noveboracensis	Fern	[3,4],5	FAC	Saturated	Plants, Seed
Fern, royal	Osmunda regalis	Fern	[1,2],3	OBL	Saturated	Plugs
Fern, sensitive	Onoclea sensibilis	Fern	[2,3],4	FACW	Saturated	Plants, Seed
Fescue, hard	Festuca duriuscula	Grass	[3,4,5,6]	NI	No	Seed
Fescue, red	Festuca rubra	Grass	[4,5]	FACU	No	Seed
Fescue, sheeps	Festuca ovina	Grass	[4,5],6	NI	No	Seed
Gamagrass, eastern	Tripsacum dactyloides	Grass	2,[3,4],5	FACW	Yes	Seed

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Common Name	Scientific Name	Plant Type	Hydrologic Zone	Wetland Indicator	Inundation Tolerance	Commercial Availability
Goldenrod, roughleaf	Solidago patula	Perennial	1,[2,3,]	OBL	Yes	Seed
Goldenrod, seaside	Solidago sempervirens	Perennial	[2,3],4	FACW	Yes	Plants, Seed
Goldenrod, silverrod	Solidago bicolor	Perennial	5,6	NI	No	Plants, Seed
Goldenrod, stiff	Solidago rigida	Perennial	5,6	UPL	No	Plants, Seed
Goldenrod, wrinkleleaf	Solidago rugosa	Perennial	3,[4,5]	FAC	No	Plants, Seed
Grass, alkali	Puccinellia distans	Grass	[1,2],3	OBL	Yes	Seed
Grass, deertongue	Dichanthelium clandestinium	Grass	[2,3],4	FAC+	Seasonal	Seed
Grass, Japanese millet	Echinochloa frumentcea	Annual Grass	[2,3],4	NI	Yes	Seed
Grass, redtop	Agrostis gigantea	Grass	[2,3,],4	FACW	Yes	Seed
Hornwort, common	Ceratopliyilurn dernersurn	Perennial	[1,21,3	OBL	1-5	Plants
Horsetail, rough	Equisetum hyemale	Fern-like	[2,3],4	FACW	Yes	Plants
Indiangrass	Sorghastrum nutans	Grass	5,6	UPL	No	Seed, Plants
Iris, blue flag	Iris versicolor	Perennial	[1,2],3	OBL	0-6”	Plants, Seed
Iris, yellow flag	Iris pseudacorus	Perennial	[3,4],5	FAC	No	Plants, Seed
Ironweed, New York	Vernonia noveboracensis	Perennial	[2,3],4	FACW+	Yes	Plants, Seed
Jack-in-the-pulpit, swamp	Arisaerna triphyllurn	Perennial	[2,3],4	FACW	Seasonal	Plants
Jacob’s ladder	Polemonium reptans	Perennial	[4,5],6	FACU	No	Seed
Jacob’s-ladder, bog	Polernoniurn van-bruntlae	Perennial	[3,4],5	FAC+	Saturated	Plants
Joe-pye, purple	Eupatoriadelphus purpureus	Perennial	3,[4,5]	FAC	Yes	Plants, Seed
Joe-pye, spotted	Eupatorium maculatus	Perennial	2,[3,4]	FACW	Yes	Plants, Seed
Lily, turk’s-cap	Lilium superbum	Perennial	[2,3,4]	FACW+	Yes	Plants, Seed
Lizards tail	Saururus cernuus	Perennial	2,3,4	OBL	0-1’	Plants
Lotus, American	Nelumbo lutea	Perennial	[1,2],3	OBL	1-5’	Plants, Seed
Lovegrass, purple/tumble	Eragrostis spectabilis	Grass	[5,6]	NI	No	Plants, Seed
Mallow, swamp rose	Hibiscus moscheutos	Perennial	2,3	OBL	0-3”	Plants
Mallow, Virginia seashore	Kosteletzkya virginica	Perennial	[1,2],3	OBL	Yes, saltedge	Plants
Managrass, American	Glyceria grandis	Grass	[1,2],3	OBL	Yes	Plants, Seed
Managrass, Atlantic	Glyceria obtusa	Grass	[1,2],3	OBL	0-1’	Plants, Seed
Managrass, fowl	Glyceria striata	Grass	[1,2],3	OBL	Seasonal	Plants, Seed
Managrass, rattlesnake	Glyceria canadensis	Grass	[1,2],3	OBL	0-1’	Plants, Seed
Marsh marigold	Caltha palustris	Perennial	3,4	OBL	6”, saturated	Plants, Seed
Marsh-mallow, common	Althaea officinalis	Perennial	[1,2,3]	FACW+	Yes	Plants, Seed
Meadow-rue, tall	Thalictrum pubescens	Perennial	[2,3,4]	FACW+	Yes	Seed, Plants
Milkweed, swamp	Asclepias incarnata	Perennial	2,3	OBL	Saturated	Plants, Seed
Monkey-flower	Mimulus ringens	Perennial	[1,2],3	OBL	Yes	Plants, Seed

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Common Name	Scientific Name	Plant Type	Hydrologic Zone	Wetland Indicator	Inundation Tolerance	Commercial Availability
Mountain-mint, slender	Pycnantheinum tenuifolium	Perennial	[2,3,4]	FACW	Yes	Plants, Seed
Nutsedge/ chufa	Cyperus esculentus	Grass-like	[2,3],4	FACW	Yes	Seed, Plants
Panicgrass, coastal	Panicum amarulum	Grass	3,4,[5,6]	FACU-	Yes	Seed, Plants
Partridge-berry	Mitchella repens	Groundcover	[4,5],6	FACU	No	Plants
Pennsylvania smartweed	Polygonum pensylvanicum	Annual	[2,3]	FACW	0-6"	Plants, Seed
Phlox, meadow	Phlox maculata	Perennial	[2,3,4]	FACW	Yes	Plants
Phlox, thick-leaf	Phlox carolina	Perennial	4,[5,6]	FACU	No	Plants
Pickerelweed	Pontederia cordata	Perennial	2,3	OBL	0-1'	Plants, Seed
Pondweed, long-leaf	Potamogeton nodosus	Perennial	[1,2]	OBL	1' min-6'	Plants
Pondweed, sago	Potamogeton pectinatus	Perennial	[1,2]	OBL	1' min-24'	Plants
Primrose, evening	Oenothera biennis	Perennial	4,[5,6]	FACU-	No	Seed
Reedgrass, bluejoint	Calamagrostis canadensis	Grass	1,[2,3]	FACW+	6", saturated	Seed, Plants
Reedgrass, wood	Cinna arundinacea	Perennial	2,[3,4]	FACW+	Yes	Plants, Seed
Rush, baltic	Juncus balticus	Grass	[2,3],4	FACW	Yes	Plants, Seed
Rush, bayonet	Juncus militaris	Grass-like	[2,3],4	OBL	Yes	Plants, Seed
Rush, blackgrass	Juncus gerardili	Grass-like	[2,3],4	FACW+	Yes, saltedge	Plants, Seed
Rush, Canada	Juncus canadensis	Grass-like	[1,2],3	OBL	Yes	Plants, Seed
Rush, needlegrass	Juncus roemerianus	Grass-like	[1,2],3	OBL	Yes, saltedge	Plants, Seed
Rush, soft	Juncus effusus	Grass-like	[2,3],4	FACW+	0-1	Plants, Seed
Saltgrass, seashore	Distichlis spicata	Grass	[2,3,],4	FACW+	Salt, edge	Plants
Sedge, awl	Carex stipata	Grass-like	[4,5],6	NI	No	Plants, Seed
Sedge, bearded	Carex comosa	Grass-like	[1,2],3	OBL	6" , saturated	Plants, Seed
Sedge, bladder	Carex intumescens	Grass-like	1,[2,3]	FACW+	Yes	Plants, Seed
Sedge, broom	Carex scoparia	Grass-like	[3,4],5	FACW	Yes	Plants, Seed
Sedge, fox	Carex vulpinoidea	Grass-like	[1,2],3	OBL	Sat. 0-6"	Plants, Seed
Sedge, fringed	Carex crinita	Grass-like	[1,2],3	OBL	Yes	Plants, Seed
Sedge, hop	Carex lupulina	Grass-like	[1,2],3	OBL	Yes	Seed
Sedge, lakebank	Carex lacustris	Grass-like	[1,2],3	OBL	Sat. 0-2	Plants, Seed
Sedge, pennsylvania	Carex pennsylvanica	Grass-like	[5,6]	NI	No	Plants
Sedge, shallow	Carex lurida	Grass-like	[1,2],3	OBL	Yes	Plants, Seed
Sedge, short's	Carex shortiana	Grass-like	3,[4,5]	FAC	Yes	Plants
Sedge, three-sided	Dulichium arundinaceum	Grass-like	1,[2,3]	OBL	Yes	Plants, Seed
Sedge, tussock	Carex stricta	Grass-like	[1,2],3	OBL	Sat, 0-6"	Plants, Seed
Sedge, yellow-fruit	Carex annectens	Grass-like	[2,3]4	FACW+	Yes	Plants, Seed
Seedbox	Ludwigia x lacustris	Annual	[1,2],3	OBL	Yes	Plants, Seed
Senna, Maryland	Cassia marilandica	Legume	3,[4,5]	FAC	Saturated	Seed

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Common Name	Scientific Name	Plant Type	Hydrologic Zone	Wetland Indicator	Inundation Tolerance	Commercial Availability
Sneezeweed, common	Helenium autumnale	Perennial	[2,3],4	FACW+	Yes	Seed
Solomon's-seal, small	Polygonatum biflorum	Perennial	[4,5],6	FACU	No	Plants
Spikerush, blunt	Eleocharis obtusa	Grass-like	[1,2],3	OBL	0-6"	Plants
Spikerush, creeping	Eleocharis palustris	Grass-like	[1,2],3	OBL	Seasonal	Plants,Seed
Spikerush, square-stem	Eleocharis quadrangulata	Grass-like	[1,2],3	OBL	0-1'	Plants
St. John'swort, marsh	Triadenum virginicum	Perennial	[1,2],3	OBL	Yes	Seed
Swamp-loosestrife, hairy	Decodon verticillatus	Perennial	[1,2],3	OBL	Yes	Plants
Sweetflag	Acorus americanus	Perennial	1,[2,3]	OBL	Yes	Plants, Seed
Switchgrass	Panicum virgatum	Grass	2,[3,4],5	FAC	Seasonal	Seed & Plants
Turtlehead, red	Chelone obliqua	Perennial	[1,2],3	OBL	Yes	Plants
Turtlehead, white	Chelone glabra	Perennial	[1,2],3	OBL	Yes	Plants, Seed
Vervain, blue	Verbena hastata	Perennial	[2,3]4	FACW+	Yes	Plants, Seed
Virginia/riparian wild rye	Elymus virginicus/riparius	Grass	2,[3,4]	FACW-	Yes	Seed & Plants
Water-lily, white	Nymphaea odorata	Perennial	[1,2],3	OBL	1-3'	Plants
Water-lily, yellow (spatterdock)	Nuphars luteum	Perennial	[1,2],3	OBL	1-3'	Plants
Water-plantain	Alisma plantago-aquatica	Perennial	[2,3],4	OBL	Yes	Plants, Seed
Woolgrass	Scirpus cyperinus	Grass-like	[2,3],4	FACW	Yes	Plants, Seed

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Table 7-10: Stormwater Plant List – Woody Vegetation

Common Name	Scientific Name	Form	Zone	Indicator	Inundation	Commercial Availability
Alder, brook-side	Alnus serrulata	Tree	[1,2],3	OBL	0-3″	Yes
Alder, speckled	Alnus rugosa	Tree	[2,3]	FACW+	Yes	Yes
Arrow-wood, southern	Viburnum dentatum	Shrub	[3,4],5	FAC	Seasonal	Yes
Ash, black	Fraxinus nigra	Tree	[2,3],4	FACW	Saturated	Yes
Ash, green	Fraxinus pennsylvanica	Tree	[2,3],4	FACW	Seasonal	Yes
Ash, white	Fraxinus americana	Tree	[4,5],6	FACU	No	Yes
Aspen, big-tooth	Populus grandidentata	Tree	[4,5,6]	FACU	No	Yes, limited
Aspen, quaking	Populus tremuloides	Tree	[4,5],6	FACU	Yes	Yes, limited
Azalea, dwarf	Rhododendron atlanticum	Shrub	[2,3,4],5	FAC	Yes	No
Azalea, smooth	Rhododendron arborescens	Shrub	[3,4],5	FAC	Yes	Yes
Azalea, swamp	Rhododendron viscosum	Shrub	[1,2,3],4	OBL	Seasonal	Yes
Basswood, American	Tilia americana	Tree	3,[4,5],6	FACU	No	Yes
Bayberry, northern	Myrica pennsylvanica	Shrub	[3,4],5	FAC	Seasonal	Yes
Bayberry, southern	Myrica cerifera	Shrub	2,[3,4],5	FAC	Reg.inunda	Yes
Beech, American	Fagus grandifolia	Tree	[4,5],6	FACU	No	Yes
Birch, gray	Betula populifolia	Tree	[3,4],5	FAC	Seasonal	Yes
Birch, river	Betula nigra	Tree	[2,3],4	FACW	Seasonal	Yes
Birch, yellow	Betula lutea	Tree	[3,4],5	FAC	Yes	No
Black gum, swamp tupelo	Nyssa sylvatica	Tree	1,[2,3]	FACW+	Seasonal	Yes
Black-haw	Viburnum prunifolium	Shrub	[3,4,5],6	FACU	Yes	Yes
Blueberry, bog	Vaccinium uliginosum	Shrub	2,3,4,5,6	FACU+	Yes	No
Blueberry, highbush	Vaccinium corymbosum	Shrub	[2,3]	FACW-	Seasonal	Yes
Blueberry, lowbush	Vaccinium angustifolium	Shrub	3,[4,5,6]	FACU-	No	Yes
Box-elder	Acer negundo	Tree	2,[3,4]	FAC+	Seasonal	Yes
Butternut	Juglans cinerea	Tree	[3,4,5,6]	FACU+	Yes	Yes
Buttonbush, common	Cephalanthus occidentalis	Shrub	[1,2],3	OBL	0-3′	Yes
Cedar, atlantic white	Chamaecyparis thyoides	Tree	[1,2],3	OBL	Saturated	Yes
Cedar, eastern red	Juniperus virginiana	Shrub	4,5,6	FACU	No	Yes
Cedar, northern wh1te	Thuja occidentalis	Tree	[2,3],4	FACW	Seasonal	Yes
Cherry, black	Prunus serotina	Tree	[4,5],6	FACU	No	Yes
Cherry, choke	Prunus virginiana	Tree	4,5,6	FACU	Yes	Yes
Cotton-wood, eastern	Populus deltoides	Tree	[3,4],5	FAC	Seasonal	Yes
Dangle-berry	Gaylussacia frondosa	Shrub	2,[3,4],5	FAC	Yes	Yes, limited

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Common Name	Scientific Name	Form	Zone	Indicator	Inundation	Commercial Availability
Dog-hobble, coastal	Leucothoe axillaris	Shrub	[2,3,4],5	FACW+	Yes	Yes, limited
Dogwood, flowering	Cornus florida	Shrub-Tree	4,5,6	FACU-	No	Yes
Dogwood, gray	Cornus racemosa	Shrub	[3,4],5	UPL	Seasonal	Yes
Dogwood, redtwig	Cornus serecia	Shrub	1,2[3,4],5	FACW+	Yes	Yes
Dogwood, silky	Cornus amomum	Shrub	[2,3],4	FACW	Seasonal	Yes
Elm, slippery	Ulmus rubra	Tree	[3,4],5	FAC	Yes	Yes
Fetterbush	Leucothoe racemosa	Shrub	3,[4,5],6	FACW	Yes	Yes, limited
Fetter-bush	Lyonia lucida	Shrub	[2,3,4],5	FACW	Yes	Yes, limited
Germander, American	Teucrium canadense	Shrub	[2,3,4],5	FACW	Yes	No
Groundsel tree	Baccheris halimifolia	Shrub	[2,3],4	FACW	0-6″	Yes
Gum, sweet	Liquidambar styraciflua	Tree	[3,4],5	FAC	Yes	Yes
Hackberry, common	Celtis occidentalis	Shrub-Tree	4,5,6	FACU	Seasonal	Yes
Hawthorn, cockspur	Crataegus crus-galli	Tree	2,[3,4,5],6	FACU	Yes	No
Hawthorn, downy	Crataegus mollis	Tree	1,2,[3,4,5]	FACU	Yes	Yes, limited
Hawthorn, parsley	Crataegus marshallii	Tree	[1,2,3,4],5,	FACU+	Yes	Yes, limited
Hazel-nut, American	Corylus americana	Shrub	3,[4,5,6]	FACU-	No	Yes
Hazel-nut, beaked	Corylus cornuta	Shrub	3,[4,5,6]	FACU-	No	No
Hemlock, eastern	Tsuga canadensis	Tree	4,5,6	FACU	No	Yes
Hickory, big shellbark	Carya laciniosa	Tree	[3,4],5	FAC	Yes	Yes
Hickory, bitter-nut	Carya cordiformis	Tree	4,[5,6]	FACU+	No	Yes
Hickory, pecan	Carya illinoensis	Tree	[4,5],6	FACU	Yes	Yes
Hickory, red	Carya ovalis	Tree	4,[5,6]	FACU-	No	No
Hickory, shag-bark	Carya ovata	Tree	4,[5,6]	FACU-	Yes	Yes
Hickory, sweet pignut	Carya glabra	Tree	[4,5],6	FACU-	No	No
Holly, American	Ilex opaca	Shrub	4,5,6	FACU	Limited	Yes
Holly, deciduous	Ilex decidua	Shrub	1,[2,3,4,5]	FACW-, FACW	Seasonal	Yes
Hop-hornbeam, eastern	Ostrya virginiana	Shrub-Tree	[3,4,5,6]	FACU-	Seasonal	Yes
Hornbeam, American	Carpinus caroliniana	Tree	[3,4],5	FAC	Some	Yes
Huckleberry, black	Gaylussacia baccata	Shrub	3,[4,5],6	FACU	No	No
Huckleberry, dwarf	Gaylussacia dumosa	Shrub	2,[3,4],5	FAC	Yes	No
Hydrangea, wild	Hydrangea arborescens	Shrub	3,[4,5,6]	UPL, FACU	No	No
Inkberry	Ilex glabra	Shrub	[2,3],4	FACW-	Seasonal	Yes
Laurel, mountain	Kairnia latifolia	Shrub	4,5,6	FACU	No	Yes
Locust, black	Robinia pseudoacacia	Tree	4,[5,6]	FACU	Yes	Yes
Magnolia, sweet bay	Magnolia virginiana	Tree	[3,4],5	FAC	Yes	Yes
Maleberry	Lyonia ligustrina	Shrub	[2,3,4],5	FACW	Yes	Yes, limited
Maple, mountain	Acer spicaturn	Tree	4,5,6	FACU	No	No
Maple, red	Acer rubrurn	Tree	[3,4],5	FAC	Seasonal	Yes
Maple, silver	Acer saccharinum	Tree	[2,3],4	FACW	Seasonal	Yes

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Common Name	Scientific Name	Form	Zone	Indicator	Inundation	Commercial Availability
Maple, striped	Acer pensylvanicum	Shrub-Tree	3,[4,5,6]	FACU	No	No
Marsh elder	Iva frutescens	Shrub	1,[2,3]	FACW+		Yes
Meadow-sweet, broad-leaf	Spiraea latifolia	Shrub	[2,3,4]	FACW+	Yes	Yes
Meadow-sweet, narrow-leaf	Spiraea alba	Shrub	[1,2,3,4],5	FACW+	Yes	No
Nannyberry	Vi burn urn lentago	Shrub	[3,4],5	FAC	Seasonal	Yes
Ninebark, eastern	Physocarpus opulifolius	Shrub	[2,3],4	FACW-	Yes	Yes
Oak, bur	Quercus rnacrocarpa	Tree	3,[4,5],6	FAC-	Yes	Yes
Oak, chestnut	Quercus prinus	Tree	4,5,6	FACU	No	Yes
Oak, chinkapin	Quercus rnuhlenbergii	Tree	[3,4],5	FAC	Yes	Yes
Oak, overcup	Quercus lyrata	Tree	[1,2],3	OBL	Yes	Yes
Oak, pin	Quercus palustris	Tree	[2,3],4	FACW	Seasonal	Yes
Oak, post	Quercus stellata	Tree	3,[4,5,6]	NI	No	Yes, limited
Oak, red	Quercus rubra	Tree	6	FACU-	No	Yes
Oak, scarlet	Quercus coccinea	Tree	6		No	Yes
Oak, shumard	Quercus shumardii	Tree	2,[3,4]	FAC+	Yes	Yes
Oak, swamp chestnut	Quercus michauxii	Tree	1,[2,3,4,5]	FACW	Yes	Yes
Oak, swamp white	Quercus bicolor	Tree	1,[2,3]	FACW+	Seasonal	Yes
Oak, water	Quercus nigra	Tree	[3,4],5	FAC	Seasonal	Yes
Oak, white	Quercus alba	Tree	[4,5,6]	FACU	Yes	Yes
Oak, willow	Quercus phellos	Tree	2,[3,4]	FAC+	Seasonal	Yes
Pepper-bush, sweet	Clethra alnifolia	Shrub	2[3,4]	FAC+	Seasonal	Yes
Pine, eastern white	Pinus strobus	Tree	4,5,6	FACU	No	Yes
Pine, loblolly	Pinus taeda	Tree	3,[4,5],6	FAC-	Seasonal	Yes
Pine, pitch	Pinus rigida	Tree	4,5,6	FACU	Seasonal	Yes
Pine, pond	Pinus serotina	Tree	[1,2],3	OBL	Yes	No
Pine, virginia	Pinus viginiana	Tree	6		No	Yes
Redbud, eastern	Cercis canadensis	Shrub-Tree	3[4,5,6]	UPL, FACU	No	Yes
Rh000dendron, rosebay	Rhododendron maximum	Shrub	[3,4],5	FAC	Yes	No
Rhododendron	Rhododendron canadense	Shrub	1,[2,3,4],5	FACW	Yes	Yes, limited
Rose, pasture	Rosa carolina	Shrub	[5,6]	NI	No	Yes
Rose, swamp	Rosa palustris	Shrub	[2,3]4	OBL	Yes	Yes
Rose, virginia	Rosa virginiana	Shrub	[3,4]5	FAC	Seasonal	Yes
Rosemary, bog	Andromeda polifolia	Shrub	[1,2],3	OBL	Yes	No
Sand-myrtle	Leiophyllum buxifolium	Shrub	3,4[5,6]	FACU-	No	No
Sassafras	Sassafras albidum	Tree	3,[4,5,6]	FACU-	No	Yes
Service-berry, downy	Amelanchier arborea	Shrub-Tree	2,[3,4,5]	FAC-	Yes	Yes
Sheep-laurel	Kalmia angustifolia	Shrub	3,[4,5],6	FAC	Yes	Yes

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Common Name	Scientific Name	Form	Zone	Indicator	Inundation	Commercial Availability
Silver-berry, American	Elaeagnus commutata	Shrub	[6]	NI	No	No
Stagger-bush, piedmont	Lyonia mariana	Shrub	[3,4],5,6	FAC-	Yes	Yes, limited
Steeple-bush	Spiraea tomentosa	Shrub	1,[2,3,4],5	FACW	Yes	Yes
Strawberry-bush, American	Euonymus americanus	Shrub	1,[2,3,4,5]	FAC	Yes	Yes
Sugar-berry	Celtis laevigata	Shrub	1,[2,3,4,5],6	FACW	Yes	Yes
Sycamore, amer1can	Platanus occidentalis	Tree	[2,3],4	FACW-	Saturated	Yes
Teaberry	Gaultheria procumbens	Shrub	3,[4,5],6	FACU	No	Yes
Tree, tulip	Liriodendron tulipifera	Tree	[4,5],6	FACU	Yes	Yes
Viburnum, maple-leaf	Viburnum acerifolium	Shrub	3,[4,5,6]	NI	No	Yes
Viburnum, possum-haw	Viburnum nudum	Shrub	[1,2],3	OBL	Yes	Yes
Willow, black	Salix nigra	Tree	[2,3]	FACWI-	Seasonal	Yes
Willow, pussy	Salix discolor	Shrub	[2,3],4	FACW	Yes	Yes
Willow, silky	Salix sericea	Shrub	[1,2],3	OBL	Yes	Yes
Willow, tall prairie	Salix humilis	Shrub	3,[4,5],6	FACU	No	No
Willow, virginia	Itea virginica	Shrub	[1,2],3	OBL	0-6~	Yes
Winterberry, common	Ilex verticillata	Shrub	1,[2,3]	FACW+	Seasonal	Yes
Witch-alder, dwarf	Fothergilla gardenii	Shrub	1,[2,3,4],5	FACW	Yes	Yes
Witch-hazel, American	Hamamelis virginiana	Shrub-Tree	3,[4,5],6	FAC-	No	Yes
Withe-rod	Viburnum cassinoides	Shrub	1,[2,3,4],5	FACW	Yes	Yes
Yew, American	Taxus canadensis	Shrub	[3,4,5],6	FAC	Yes	Yes

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Best Management Practices Manual

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CHAPTER 8

Maintenance and Retrofit of Stormwater Management Measures

Maintenance of Stormwater Management Measures

Research and experience have demonstrated that regular and thorough maintenance is necessary for stormwater management measures to perform effectively and reliably. They have also demonstrated that failure to perform such maintenance can lead to diminished performance, deterioration, and failure, in addition to a range of health and safety problems including mosquito breeding, vermin, and the potential for drowning. The potential for such problems to develop is accentuated by many of the very features and characteristics that allow stormwater management measures to do their job, including standing or slowing moving water, dense vegetation, forebays, trash racks, dams, and the need to continually function in all types of weather. As implied by their name, stormwater management measures are also expected to become the repositories for sediment, nutrients, trash, debris, and other pollutants targeted by the NJDEP Stormwater Management Rules. For this reason, stormwater management measures share maintenance requirements with more mundane items as vacuum cleaner bags, car motor filters, and floor mats, all of which require regular inspection and cleaning, sediment and debris removal, and periodic replacement.

In recognition of these needs and potential problems, the NJDEP Stormwater Management Rules require that a maintenance plan be developed for all stormwater management measures incorporated into the design of a major development. This maintenance plan must contain specific preventative and corrective maintenance tasks, schedules, cost estimates, and the name, address, and telephone number of the person or persons responsible for the measures' maintenance.

In accordance with the Rules, this section of Chapter 8 has been developed to provide guidelines for the development of such maintenance plans. Specific maintenance guidance for structural stormwater management measures is presented in *Chapter 9: Structural Stormwater Management Measures*. Additional maintenance information is also provided in the NJDEP Stormwater Management Facility Maintenance Manual, including maintenance tasks and equipment, inspection procedures and schedules, ownership responsibilities, and design recommendations to minimize and facilitate inspection and maintenance tasks.

Finally, it should be noted that a stormwater management measure that includes a dam as defined in the NJDEP Dam Safety Standards at N.J.A.C. 7:20 must also have an operations and maintenance manual for the dam as described at 7:20-1.11.

Maintenance Plan Contents

According to the NJDEP Stormwater Management Rules, all maintenance plans for stormwater management measures must include the following:

1. The name, address, and telephone number of the person or persons responsible for the preventative and corrective maintenance of the stormwater management measure. If the plan identifies a party other than the owner or developer as having responsibility for maintenance, i.e., a public entity or homeowners' association, the plan must include a copy of the other party's written agreement to assume this responsibility. This agreement must include a copy of any ordinance or regulation that requires the owner or developer to dedicate the stormwater management measure and/or its maintenance to the other party.
2. Specific preventative and corrective maintenance tasks such as removal of sediment, trash, and debris; mowing, pruning, and restoration of vegetation; restoration of eroded areas; elimination of mosquito breeding habitats; control of aquatic vegetation; and repair or replacement of damaged or deteriorated components. Detailed maintenance information for specific structural stormwater management measures is presented in Chapter 9. Maintenance needs of nonstructural measures are discussed in *Chapter 2: Low Impact Development Techniques*.
3. A schedule of regular inspections and tasks. Detailed inspection tasks and schedules for specific structural stormwater management measures are presented in Chapter 9.
4. Cost estimates of maintenance tasks, including sediment, trash, and debris removal.
5. Detailed logs of all preventative and corrective maintenance performed at the stormwater management measure, including all maintenance-related work orders.

In addition, as described in the NJDEP Stormwater Management Facility Maintenance Manual, the following items should also be included in the maintenance plan:

1. Maintenance equipment, tools, and supplies necessary to perform the various preventative and corrective maintenance tasks specified in the plan. Sources of specialized, proprietary, and nonstandard equipment, tools, and supplies should also be provided.
2. Recommended corrective responses to various emergency conditions that may be encountered at the stormwater management measure. It should be noted that, if the stormwater management measure includes a Class I or II dam as defined in the NJDEP Dam Safety Standards at N.J.A.C. 7:20, an emergency action plan for the dam is also required. See N.J.A.C. 7:20-1.7(f) for more information.
3. Maintenance, repair, and replacement instructions for specialized, proprietary, and nonstandard measure components, including manufacturers' product instructions and user manuals.
4. Procedures and equipment required to protect the safety of inspection and maintenance personnel.
5. Approved disposal and recycling sites and procedures for sediment, trash, debris, and other material removed from the measure during maintenance operations.
6. Originals or copies of manufacturers' warranties on pertinent measure components.
7. As-built construction plans of the stormwater management measure and copies of pertinent construction documents such as laboratory test results, permits, and completion certificates.

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Maintenance Plan Considerations

In addition to the plan contents described above, a maintenance plan should address the following important aspects of stormwater management measure maintenance.

Access

All stormwater management measures' components must be readily accessible for inspection and maintenance. Therefore, trees, shrubs, and underbrush must be pruned or trimmed as necessary to maintain access to the stormwater management measure via roadways, paths, and ramps. This includes paths through perimeter vegetation to permanent pools, aquatic benches, and safety ledges to allow for the inspection and control of mosquito breeding. In addition, the exact limits of inspection and maintenance easements and rights-of-way should be specified on stormwater management measure plans and included in the maintenance plan.

Training of Maintenance Personnel

Maintenance training begins with a basic description of the purpose and function of the overall stormwater management measure and its major components. Such understanding will enable maintenance personnel to provide more effective component maintenance and more readily detect maintenance-related problems. Depending on the size, character, location, and components of a stormwater management measure, maintenance personnel may also require training in specialized inspection and maintenance tasks and/or the operation and care of specialized maintenance equipment. Training should also be provided in the need for and use of all required safety equipment and procedures.

Aesthetics

The impacts of the aesthetics of the stormwater management measures on the surrounding community should be included in the consideration for the design and selection of the stormwater management measure.

Required Maintenance Plan Procedures

Once the maintenance plan is completed, the NJDEP Stormwater Management Rules require that the following procedures be followed:

1. Copies of the maintenance plan must be provided to the owner and operator of the stormwater management measure. Copies must also be submitted to all reviewing agencies as part of each agency's approval process. In addition, a copy should be provided to the local mosquito control or extermination commission upon request.
2. The title and date of the maintenance plan and the name, address, and telephone number of the person with stormwater management measure maintenance responsibility as specified in the plan must be recorded on the deed of the property on which the measure is located. Any change in this information due, for example to a change in property ownership, must also be recorded on the deed.
3. The person with maintenance responsibility must evaluate the maintenance plan for effectiveness at least annually and revise as necessary.
4. A detailed, written log of all preventative and corrective maintenance performed at the stormwater management measure must be kept, including a record of all inspections and copies of maintenance-related work orders.
5. The person with maintenance responsibility must retain and, upon request, make available the maintenance plan and associated logs and other records for review by a public entity with administrative, health, environmental, or safety authority over the site.

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Retrofit of Existing Stormwater Management Measures

Retrofitting can be defined as expanding, modifying, or otherwise upgrading existing stormwater management measures. As such, retrofitting stormwater management measures can reduce some of the adverse groundwater recharge and stormwater quantity and quality impacts caused by existing land developments. In many instances, existing stormwater management measures can be dramatically improved, and downstream water bodies protected, through effective retrofitting.

Beginning in the 1970s, many new developments were constructed with stormwater detention facilities. Many of these facilities were built to control the stormwater quantity impacts of 10-year, 25-year, and/or 100-year storms. However, smaller storm events that are typically responsible for the majority of stormwater quality and streambank erosion problems may not have been addressed. Therefore, retrofitting such facilities to also control these smaller storm events can begin to address these problems.

Another important benefit of retrofitting stormwater management facilities is the opportunity to correct site nuisances, maintenance problems, and aesthetic concerns. Retrofitting also allows a community to keep pace with new stormwater management regulations or objectives. It can help a community address a particular stormwater quantity or quality problem that has developed as a result of deficiencies in its existing or past stormwater regulations or a problem that has been identified through a regional plan or TMDL. Addressing such problems through the construction of new stormwater management measures at future land developments may be impractical or even impossible, leaving retrofitting as the only effective technique.

In addition to such basic considerations as need and cost, three important factors must be considered when evaluating retrofit possibilities: health and safety, effectiveness, and maintenance. All three should be thoroughly reviewed before undertaking a stormwater management measure retrofit to help justify the cost and effort and ensure the retrofitted measure's long-term success.

Health and Safety

A retrofit must not increase health and safety risks in any way. For example, the storage volume in an existing detention basin presently used for stormwater quantity control must not be reduced to provide new stormwater quality enhancement without ensuring that the lost quantity storage will not adversely increase peak basin outflows and cause downstream flooding or erosion. Similarly, an existing, well-functioning wet pond must not be converted to a constructed stormwater wetland for enhanced stormwater quality control if the potential for mosquito breeding will increase significantly without adequate additional control measures.

Effectiveness

In many retrofit situations, it may not be possible to upgrade the stormwater management measure to meet all current groundwater recharge and stormwater quality and quantity standards. This means that relative performance improvements for a range of retrofits must be evaluated to determine which one represents the optimum combination of effectiveness, viability, and cost. As a result, the final retrofit selected for an existing stormwater measure will have to be based on its relative rather than absolute effectiveness. In such relative determinations, both the costs and benefits of the evaluated retrofits become more influential factors than when an absolute performance standard is used.

Maintenance

It should be expected that if a retrofit will increase a stormwater management measure's pollutant removal capability, it will also increase the rate and total volume of sediment, trash, debris, and other stormwater pollution that will accumulate in the measure. In addition, the chemical or biological composition of this sediment may be of significantly lower quality, and potentially either hazardous or toxic,

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than the sediment previously captured. Finally, the retrofit may increase the number and/or complexity of components in an existing stormwater management measure. All of these factors can cause increases in the level, frequency, complexity, and/or cost of the present inspection and maintenance efforts performed at the stormwater management measure. Increased staffing, improved equipment, and more specialized training may be required to properly maintain the new, retrofitted measure. Therefore, the extent and impacts of any increased inspection and/or maintenance requirements should be determined and thoroughly evaluated.

Once a retrofit has been determined to be safe, effective, and manageable, two basic approaches can be followed: modify an existing stormwater management measure or construct a new or additional one. Basins designed primarily for flood control may be retrofitted to enhance stormwater quality and groundwater recharge benefits. For example, the pollutant removal rates of an existing detention basin can be improved by creating an extended detention wetland. However, as noted above, the retrofit must maintain the basin's existing flood and erosion control capabilities. As a result, the basin's total storage volume may need to be increased. In addition, new measures such as infiltration systems, permeable paving, and bioretention systems can be introduced at sites where the soil permeability and depth to the seasonal high water table are suitable. Areas for such new measures include parking lot islands, vacant land, and roadside swales.

In addition to structural measures, nonstructural stormwater management measures can be used to enhance the stormwater management of an existing development site. Roofs are one of the largest sources of concentrated runoff from commercial developments. Clean roof runoff can be directed by downspouts to a dry well, disconnecting a portion of the runoff from the storm sewer system and both reducing runoff volume and restoring groundwater recharge. Flat roofs can be retrofitted with vegetation, which can reduce the stormwater impacts of the building. Overflow parking areas and fire lanes can utilize pervious paving systems, which can also reduce runoff and enhance recharge. Vegetative filters can be incorporated into existing developments where runoff from paved or intensely managed turf areas can be discharged across the filters. This may require the removal or slotting of existing curbs along the edge of parking lots or roads. Parking lots with vegetated aisle dividers may be particularly amendable to this type of filter strip application.

In addition, catch basins and drain inlets that are part of a traditional curb and gutter stormwater collection system can be retrofitted with one of several different manufactured treatment devices that catch sediments, trash, organic matter, and other particulates. These proprietary devices are particularly useful in areas with limited space. Several varieties of manufactured treatment devices are available for installation at strategic locations near a discharge point or as a pre-treatment to an existing basin. Additional information regarding manufactured treatment devices is provided in *Chapter 9: Structural Stormwater Management Measures*.

Finally, education should be considered as a retrofit component. Control of household waste, fertilizers, and pesticides can dramatically reduce concentrations or problem pollutants that adversely affect downstream water quality. Prevention is most often the best method for eliminating pollutants from stormwater runoff. *Chapter 2: Low Impact Development Techniques* provides important information regarding stormwater pollution prevention.

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CHAPTER 9.0

Structural Stormwater Management Measures

This chapter presents specific planning, design, construction, and maintenance information about a range of structural stormwater management measures that may be used to address the groundwater recharge and stormwater quality and quantity requirements of the NJDEP Stormwater Management Rules at N.J.A.C. 7:8. The specific structural measures, also known as structural Best Management Practices (BMPs), included in this chapter are:

9.1 – Bioretention Systems

9.2 – Constructed Stormwater Wetlands

9.3 – Dry Wells

9.4 – Extended Detention Basins

9.5 – Infiltration Basins

9.6 – Manufactured Treatment Devices

9.7 – Pervious Paving Systems

9.8 – Rooftop Vegetated Cover (Reserved)

9.9 – Sand Filters

9.10 – Vegetative Filters

9.11 – Wet Ponds

Information regarding each BMP is presented in a separate subchapter, which consists of the following sections.

Definition – Most if not all BMPs are actually rather complex stormwater management systems that have multiple components and utilize several physical, chemical, and biological processes. In addition, many of these components and processes are shared by multiple BMPs. This can often cause confusion over where in the manual users can find information regarding a specific BMP. To prevent this confusion, the

Definition section provides a definitive description of the BMP, including its major components and processes. It also presents the BMP's adopted TSS removal rate.

Purpose – This section describes the uses for which the BMP is particularly suited. This includes groundwater recharge and runoff quality and quantity control as well as ancillary uses such as recreation, wildlife habitat, and open space preservation. This information is intended to help manual users decide whether a particular BMP is capable of meeting their project needs.

Conditions Where Practice Applies – In addition to sharing many components and processes, all BMPs also have unique features and requirements. These must be recognized and met during a BMP's planning, design, and review phases if the BMP is to provide effective, efficient, and enduring service. This section concisely presents these BMP features and requirements so that manual users can decide whether a particular BMP is appropriate for their project

Design Criteria – This section presents specific BMP design criteria that must be met for a particular BMP to achieve the TSS removal rates adopted in the Stormwater Management Rules at N.J.A.C. 7:8. The design criteria also provides the information necessary to address groundwater recharge and stormwater quantity performance standards. The criteria presented in this section vary with each BMP and can range from required runoff storage volumes to maximum drainage area size to minimum soil permeabilities.

Maintenance – Effective BMP performance requires regular and effective maintenance. In addition, the NJDEP Stormwater Management Rules require that all structural BMPs have a specific maintenance plan that must be followed by those responsible for its operation and maintenance. This section provides specific maintenance information which, in combination with *Chapter 8: Maintenance and Retrofit of Stormwater Management Measures,* can be used to develop such a plan and to help ensure the effective, efficient, and enduring service envisioned by the BMP designer.

Considerations – This section presents valuable information that should be considered during a particular BMP's planning, design, review and/or construction phases. While not mandatory, this information is intended to promote BMPs that comprehensively meet the expectations of their designers, reviewers, owners, and maintenance personnel.

Recommendations – As noted above, all BMPs have unique features, requirements, ancillary functions, and maintenance needs. This section identifies various factors that, while not necessarily a mandatory design criteria, should nevertheless be included in the development of a BMP's design whenever possible.

References – This section identifies the major published sources of technical information that were used by the NJDEP in the development of each BMP's subchapter.

Regarding references, it is important to note that the information presented in each BMP subchapter was developed not only from published sources, but also through detailed technical discussions held at numerous BMP Manual Technical and Advisory Committee meetings hosted by the NJDEP. The information and conclusions developed at these meetings reflect the technical knowledge of the committee members, which was derived, in part, from numerous published and unpublished sources.

In recognition of the continued growth of our stormwater management knowledge, it should also be noted that compliance with the NJDEP Stormwater Management Rules is not limited to the BMPs presented in this chapter. Other BMPs that possess similar levels of effectiveness, efficiency, and endurance may also be utilized provided that such levels can be similarly demonstrated.

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CHAPTER 9.1

Standard for Bioretention Systems

Definition

A bioretention system consists of a soil bed planted with native vegetation located above an underdrained sand layer. It can be configured as either a bioretention basin or a bioretention swale. Stormwater runoff entering the bioretention system is filtered first through the vegetation and then the sand/soil mixture before being conveyed downstream by the underdrain system. Runoff storage depths above the planting bed surface are typically shallow. The adopted TSS removal rate for bioretention systems is 90 percent.

Purpose

Bioretention systems are used to remove a wide range of pollutants, such as suspended solids, nutrients, metals, hydrocarbons, and bacteria from stormwater runoff. They can also be used to reduce peak runoff rates and increase stormwater infiltration when designed as a multi-stage, multi-function facility.

Conditions Where Practice Applies

Bioretention systems can be used to filter runoff from both residential and nonresidential developments. Runoff inflow should preferably be overland flow to prevent disturbance to the vegetation and soil bed. Concentrated inflow from a drainage pipe or swale must include adequate erosion protection and energy dissipation measures.

Bioretention systems are most effective if they receive runoff as close to its source as possible. They can vary in size and can receive and treat runoff from a variety of drainage areas within a land development site. They can be installed in lawns, median strips, parking lot islands, unused lot areas, and certain easements. They are intended to receive and filter storm runoff from both impervious areas and lawns.

A bioretention system must not be placed into operation until the contributing drainage area is completely stabilized. Therefore, system construction must either be delayed or upstream runoff diverted around the system until such stabilization is achieved. Such diversions must continue until stabilization is achieved. Additional information is provided in the section on Recommendations, Construction Specifications.

The elevation of the Seasonal High Water Table (SHWT) is critical to ensure proper functioning of the bioretention basin, and must be evaluated to ensure that the SHWT is at least 1 foot below the bottom of the bioretention basin's underdrain system during non-drought conditions. Finally, both the SHWT and the permeability of the soil below the system are critical for bioretention systems that utilize infiltration rather than an underdrain system. See *9.5 Infiltration Basins* for more information on the requirements and design of this type of bioretention system.

Finally, a bioretention system must have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

Design Criteria

The basic design parameters for a bioretention system are its storage volume, the thickness, character, and permeability rate of its planting soil bed, and the hydraulic capacity of its underdrain. The system must have sufficient storage volume above the surface of the bed to contain the design runoff volume without overflow. The thickness and character of the bed itself must provide adequate pollutant removal, while the bed's permeability rate must be sufficient to drain the stored runoff within 72 hours. The underdrain must also have sufficient hydraulic capacity. Details of these and other design parameters are presented below. The components of a typical bioretention system are shown in Figure 9.1-1.

A. Storage Volume, Depth, and Duration

Bioretention systems shall be designed to treat the runoff volume generated by the stormwater quality design storm. Techniques to compute this volume are discussed in *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. The maximum water depth during treatment of the stormwater quality design storm shall be 12 inches in a bioretention basin and 18 inches in a bioretention swale. The minimum diameter of any outlet or overflow orifice is 2.5 inches.

The bottom of a bioretention system, including any underdrain piping or gravel layer, must be a minimum of 1 foot above the seasonal high groundwater table. The planting soil bed and underdrain system shall be designed to fully drain the stormwater quality design storm runoff volume within 72 hours.

B. Permeability Rates

The design permeability rate through the planting soil bed must be sufficient to fully drain the stormwater quality design storm runoff volume within 72 hours. This permeability rate must be determined by field or laboratory testing. Since the actual permeability rate may vary from test results and may also decrease over time due to soil bed consolidation or the accumulation of sediments removed from the treated stormwater, a factor of safety of two shall be applied to the tested permeability rate to determine the design permeability rate. Therefore, if the tested permeability rate of the soil bed material is 4 inches/hour, the design rate would be 2 inches/hour (i.e., 4 inches per hour/2). This design rate would then be used to compute the system's stormwater quality design storm drain time.

C. Planting Soil Bed

The planting soil bed provides the environment for water and nutrients to be made available to the vegetation. The soil particles can adsorb some additional pollutants through cation exchange, and voids within the soil particles can store a portion of the stormwater quality design storm runoff volume. The planting soil bed material should consist of 10 to 15 percent clays, a minimum 65 percent sands, with the balance as silts. The material's pH should range from 5.5 to 6.5. The material shall be placed in 12 to 18 inch lifts. The total depth or thickness of the planting soil bed should be a minimum of 3 feet.

As noted above, the design permeability rate of the soil bed material must be sufficient to drain the stormwater quality design storm runoff volume within 72 hours. Filter fabric should be placed along the sides of the planting soil bed to prevent the migration of soil particles from the adjacent soil into the planting soil bed.

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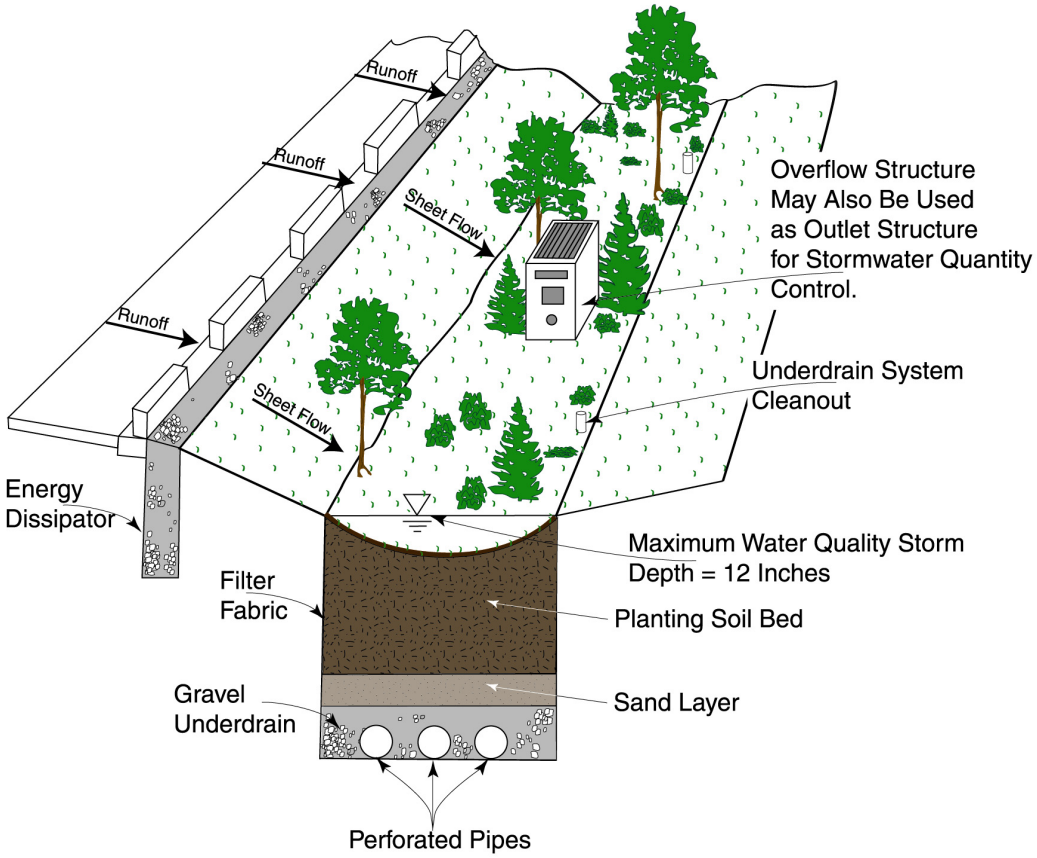
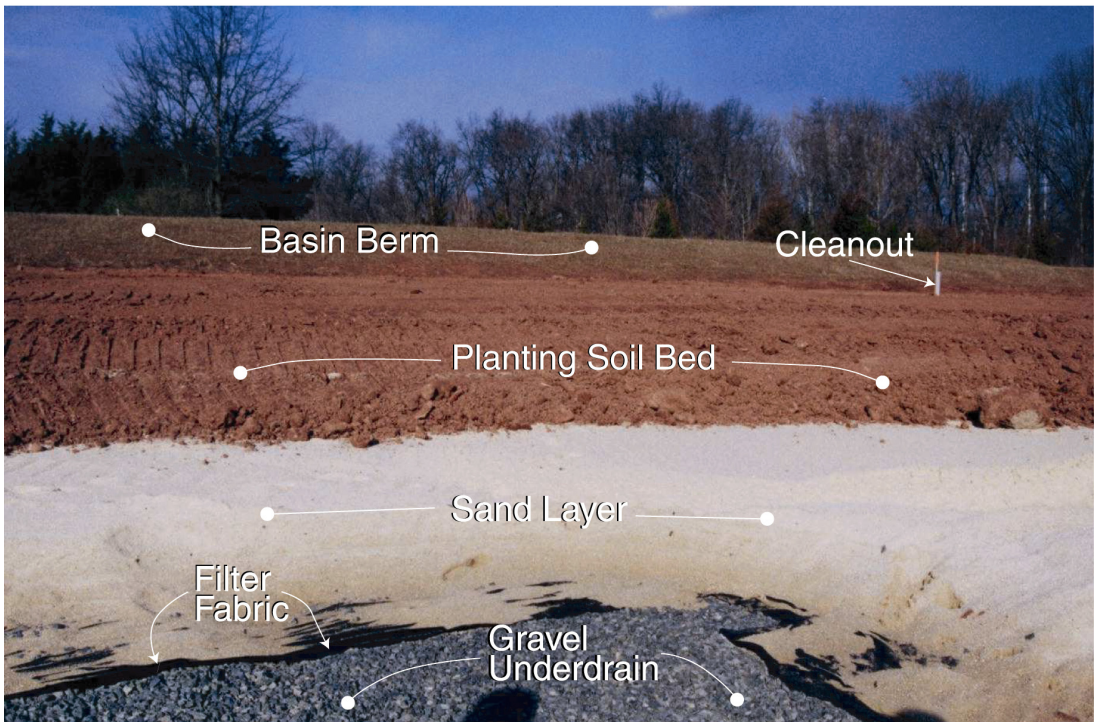
Figure 9.1-1: Bioretention System Components





This figure can be viewed in color in the PDF version of this chapter available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm
Source: Adapted from Claytor and Schueler, 1996.

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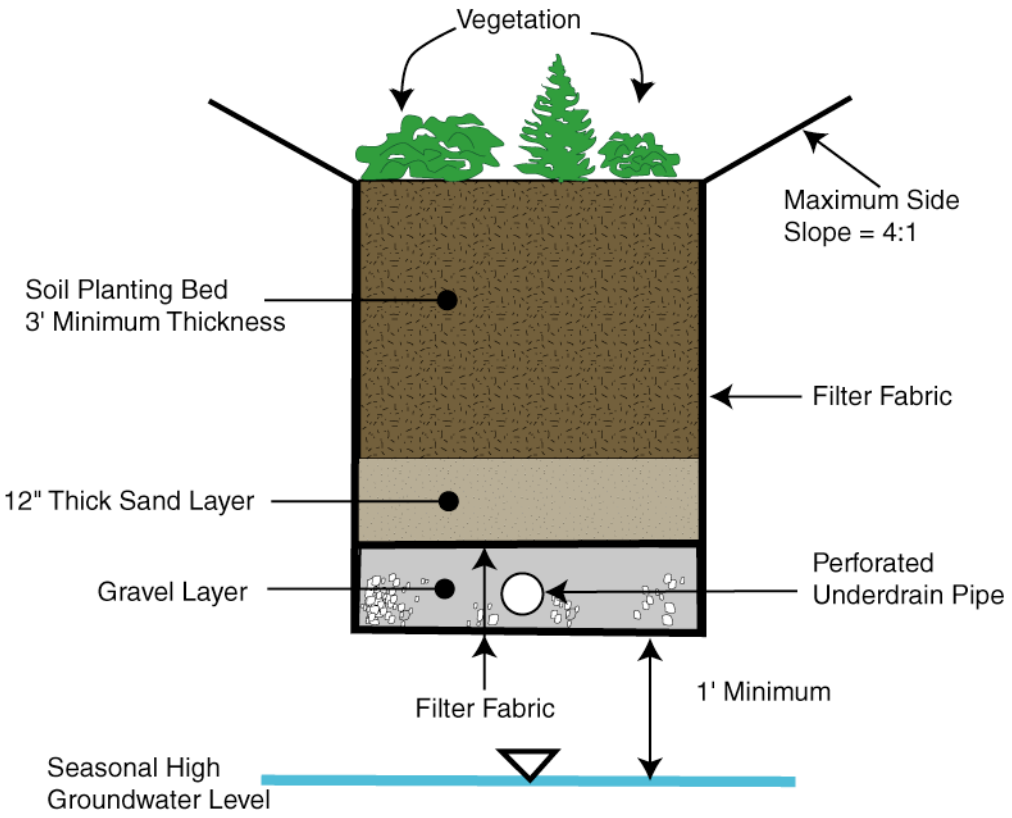
Figure 9.1-2 Bioretention Systems Details



D. Vegetation

The vegetation in a bioretention system removes some of the nutrients and other pollutants in the stormwater inflow. The environment around the root systems breaks down some pollutants and converts others to less harmful compounds. The use of native plant material is recommended for bioretention systems wherever possible. The goal of the planting plan should be to simulate a forest-shrub community of primarily upland type. As there will be various wetness zones within a well-designed and constructed bioretention system, plants must be selected and placed appropriately. In general, trees should dominate the perimeter zone that is subject to less frequent inundation. Shrubs and herbaceous species that are adapted to moister conditions and expected pollutant loads should be selected for the wetter zones. The number of stems per acre should average 1,000, with tree spacing of 12 feet and shrub spacing of 8 feet.

E. Sand Layer

The sand layer serves as a transition between the planting soil bed and the gravel layer and underdrain pipes. It must have a minimum thickness of 12 inches and consist of clean medium aggregate concrete sand (AASSHTO M-6/ASTM C-33). To ensure proper system operation, the sand layer must have a permeability rate at least twice as fast as the design permeability rate of the planting soil bed.

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F. Gravel Layer and Underdrain

The gravel layer serves as bedding material and conveyance medium for the underdrain pipes. It must have sufficient thickness to provide a minimum of 3 inches of gravel above and below the pipes. It should consist of 0.5 to 1.5 inch clean broken stone or pea gravel (AASHTO M-43).

The underdrain piping must be rigid Schedule 40 PVC pipe (AASHTO M-278) laid at a minimum slope of 0.50 percent. The portion of drain piping beneath the planting soil bed and sand layer must be perforated. All remaining underdrain piping, including cleanouts, must be nonperforated. All joints must be secure and watertight. Cleanouts must be located at the upstream and downstream ends of the perforated section of the underdrain and extend to or above the surface of the planting soil bed. Additional cleanouts should be installed as needed, particularly at underdrain pipe bends and connections. Cleanouts can also serve to drain standing water stored above clogged or malfunctioning planting soil beds.

The underdrain piping must connect to a downstream storm sewer manhole, catch basin, channel, swale, or ground surface at a location that is not subject to blockage by debris or sediment and is readily accessible for inspection and maintenance. Blind connections to downstream storm sewers are prohibited. To ensure proper system operation, the gravel layer and perforated underdrain piping must have a conveyance rate at least twice as fast as the design permeability rate of the sand layer.

G. Inflows

To reduce the potential for erosion, scour, and disturbance to vegetation, stormwater inflows to a bioretention system should occur as sheet flow where practical. Stone strips or aprons may be used at the downstream edge of upstream impervious surfaces to further dissipate sheet flow velocities and flow patterns. All points of concentrated inflow to a bioretention system must have adequate erosion protection measures designed in accordance with the Standards for Soil Erosion and Sediment Control in New Jersey.

H. Overflows

All bioretention systems must be able to safely convey system overflows to downstream drainage systems. The capacity of the overflow must be consistent with the remainder of the site's drainage system and sufficient to provide safe, stable discharge of stormwater in the event of an overflow. Bioretention systems classified as dams under the NJDEP Dam Safety Standards at N.J.A.C. 7:20 must also meet the overflow requirements of these Standards. Overflow capacity can be provided by a hydraulic structure such as a drain inlet, weir, or catch basin, or a surface feature such as a swale or open channel as site conditions allow. See *Chapter 9.4: Standard for Extended Detention Basins* for details of outflow and overflow structures in multi-purpose bioretention systems that also provide stormwater quantity control.

I. Tailwater

The hydraulic design of the underdrain and overflow systems, as well as any stormwater quantity control outlets, must consider any significant tailwater effects of downstream waterways or facilities. This includes instances where the lowest invert in the outlet or overflow structure is below the flood hazard area design flood elevation of a receiving stream.

H. On-line and Off-line Systems

Bioretention systems may be constructed on-line or off-line. On-line systems receive upstream runoff from all storms, providing runoff treatment for the stormwater quality design storm and conveying the runoff from larger storms through an overflow. Multi-purpose on-line systems also store and attenuate these larger

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storms to provide runoff quantity control. In such systems, the invert of the lowest stormwater quantity control outlet is set at or above the maximum stormwater quality design storm water surface. In off-line bioretention systems, most or all of the runoff from storms larger than the stormwater quality design storm bypasses the system through an upstream diversion. This not only reduces the size of the required system storage volume, but also reduces the system's long-term pollutant loading and associated maintenance.

Maintenance

Effective bioretention system performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Measures* provides information and requirements for preparing a maintenance plan for stormwater management facilities, including bioretention systems. Specific maintenance requirements for bioretention systems are presented below. These requirements must be included in the system's maintenance plan.

A. General Maintenance

All bioretention system components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times annually as well as after every storm exceeding 1 inch of rainfall. Such components may include bottoms, trash racks, low flow channels, outlet structures, riprap or gabion aprons, and cleanouts.

Sediment removal should take place when the basin is thoroughly dry. Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state, and federal waste regulations.

B. Vegetated Areas

Mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass should be mowed at least once a month during the growing season. Vegetated areas must be inspected at least annually for erosion and scour. Vegetated areas should also be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the planting soil bed and remaining vegetation.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed at least twice annually during both the growing and non-growing seasons. The vegetative cover should be maintained at 85 percent. If vegetation has greater than 50 percent damage, the area should be reestablished in accordance with the original specifications and the inspection requirements presented above.

All use of fertilizers, mechanical treatments, pesticides and other means to assure optimum vegetation health should not compromise the intended purpose of the bioretention system. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

C. Structural Components

All structural components must be inspected for cracking, subsidence, spalling, erosion, and deterioration at least annually.

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D. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take to drain the maximum design storm runoff volume below the ground surface in the bioretention system. This normal drain time should then be used to evaluate the system's actual performance. If significant increases or decreases in the normal drain time are observed or if the 72 hour maximum is exceeded, the system's planting soil bed, underdrain system, and both groundwater and tailwater levels must be evaluated and appropriate measures taken to comply with the maximum drain time requirements and maintain the proper functioning of the system.

The planting soil bed at the bottom of the system should be inspected at least twice annually. The permeability rate of the soil bed material may also be retested. If the water fails to infiltrate 72 hours after the end of the storm, corrective measures must be taken.

Considerations

A. Optional Surface Mulch Layer

The mulch layer on the surface of the planting soil bed provides an environment for plant growth by maintaining moisture, providing microorganisms, and decomposing incoming organic matter. The mulch layer may also act as a filter for finer particles still in suspension and maintain an environment for the microbial community to help break down urban runoff pollutants. The mulch layer should consist of standard 1 to 2 inch shredded hardwood or chips. It should be applied to a depth of 2 to 4 inches and replenished as necessary. However, prior to utilizing a mulch layer, consideration should be given to problems caused by scour and floatation during storm events and the potential for mosquito breeding.

Recommendations

A. Site Considerations

The planning of a bioretention system should consider the topography and geologic and ecological characteristics of both the proposed system site and contiguous areas. Bioretention systems should not be planned in areas where mature trees would have to be removed or where Karst topography is present.

B. Construction

During basin construction, precautions must be taken to prevent planting soil bed compaction by construction equipment and sediment contamination by runoff. Basin excavation and planting soil placement should be performed with equipment placed outside the basin bottom whenever possible. Light earth moving equipment with oversized tires or tracks should be utilized when the basin must be entered.

Bioretention basins are susceptible to clogging and subsequent failure if significant sediment loads are allowed to enter the structure. Therefore, using a bioretention basin site for construction sediment control is discouraged. When unavoidable, excavation for the sediment basin should be a minimum of 2 feet above the final design elevation of the basin bottom. Sediment can then accumulate and be removed during site construction without disturbing the final basin bottom, which should be established only after all other construction within its drainage area is completed and the drainage area stabilized. If basin construction cannot be delayed until then and the basin will not be used for sediment control, diversion berms should be placed around the basin's perimeter during all phases of construction to divert all sediment and runoff

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completely away from the basin. These berms should not be removed until all construction within the basin's drainage area is completed and the area stabilized.

To prevent compaction of the soil below the basin that will reduce its infiltration capacity, bioretention basins designed for infiltration (instead of an underdrain system) should be excavated with light earth moving equipment, preferably with tracks or over-sized tires located outside the basin bottom. Once the basin's final construction phase is reached, the floor of the basin must be deeply tilled with a rotary tiller or disc harrow and smoothed over with a leveling drag or equivalent grading equipment.

Upon stabilization of the bioretention basin and its drainage area, the infiltration rate of the planting soil bed must be retested to ensure that the rate assumed in the computations is provided at the basin. The permeability rate of the subsoil below the basin must also be retested after construction at bioretention basins that utilize infiltration rather than an underdrain system.

C. Pretreatment

As with all other best management practices, pretreatment can extend the functional life and increase the pollutant removal capability of a bioretention system. Pretreatment can reduce incoming velocities and capture coarser sediments, which will extend the life of the system. This is usually accomplished through such means as a vegetative filter, a forebay, or a manufactured treatment device. Information on vegetative filters and manufactured treatment devices is presented in Chapters 9.10 and 9.6, respectively.

Forebays can be included at the inflow points to a bioretention system to capture coarse sediments, trash, and debris, which can simplify and reduce the frequency of system maintenance. A forebay should be sized to hold the sediment volume expected between clean-outs.

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CHAPTER 9.2

Standard for Constructed Stormwater Wetlands

Definition

Constructed stormwater wetlands are wetland systems designed to maximize the removal of pollutants from stormwater runoff through settling and both uptake and filtering by vegetation. Constructed stormwater wetlands temporarily store runoff in relatively shallow pools that support conditions suitable for the growth of wetland plants. The adopted removal rate for constructed stormwater wetlands is 90 percent.

Purpose

Constructed stormwater wetlands are used to remove a wide range of stormwater pollutants from land development sites as well as provide wildlife habitat and aesthetic features. Constructed stormwater wetlands can also be used to reduce peak runoff rates when designed as a multi-stage, multi-function facility.

Conditions Where Practice Applies

Constructed stormwater wetlands require sufficient drainage areas and dry weather base flows to function properly. The minimum drainage area to a constructed stormwater wetland is 10 acres to 25 acres, depending on the type of wetland. See text below for details.

Constructed stormwater wetlands should not be located within natural wetland areas, since they will typically not have the same full range of ecological functions. While providing some habitat and aesthetic values, constructed stormwater wetlands are designed primarily for pollutant removal and erosion and flood control.

It is important to note that a constructed stormwater wetland must be able to maintain its permanent pool level. If the soil at the wetland site is not sufficiently impermeable to prevent excessive seepage, construction of an impermeable liner or other soil modifications will be necessary.

Finally, a constructed stormwater wetland must have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

Design Criteria

The basic design parameters for a constructed stormwater wetland are the storage volumes within its various zones. In general, the total volume within these zones must be equal to the design runoff volume. An exception to this requirement is made for an extended detention wetland. In addition, the character, diversity, and hardiness of the wetland vegetation must be sufficient to provide adequate pollutant removal. Details of these and other design parameters are presented below.

Constructed stormwater wetlands typically consist of three zones: pool, marsh, and semi-wet. Depending upon their relative size and the normal or dry weather depth of standing water, the pool zone may be further characterized as either a pond, micropond, or forebay. Similarly, the marsh zone may be further characterized as either high or low marsh based again upon the normal standing water depth in each.

Depending on the presence and relative storage volume of the pool, marsh, and semi-wet zones, a constructed stormwater wetland may be considered to be one of three types: pond wetland, marsh wetland, or extended detention wetland. As described in detail below, a pond wetland consists primarily of a relatively deep pool with a smaller marsh zone outside it. Conversely, a marsh wetland has a greater area of marsh than pool zone. Finally, an extended detention wetland consists of both pool and marsh zones within an extended detention basin.

Table 9.2-1 below presents pertinent design criteria for each type of constructed stormwater wetland. As shown in the table, each type (i.e., pond, marsh, and extended detention wetland) allocates different percentages of the total stormwater quality design storm runoff volume to its pool, marsh, and semi-wet zones. In a pond wetland, this volume is distributed 70 percent to 30 percent between the pool and marsh zones. Conversely, in a marsh wetland, the total runoff volume is distributed 30 percent to 70 percent between the pool and marsh zones. Both of these zone volumes are based on their normal standing water level.

However, in an extended detention wetland, only 50 percent of the stormwater quality design storm runoff volume is allocated to the pool and wetland zones, with 40 percent of this amount (or 20 percent of the total stormwater quality design storm runoff volume) provided in the pool zone and 60 percent (or 30 percent of the total runoff volume) provided in the marsh zone. The remaining 50 percent of the stormwater quality design storm runoff volume is provided in the wetland's semi-wet zone above the normal standing water level, where it is temporarily stored and slowly released similar to an extended detention basin. As noted in Table 9.2-1, the detention time in the semi-wet zone of an extended detention wetland must meet the same detention time requirements as an extended detention basin. These requirements are presented in *Chapter 9.4: Standard for Extended Detention Basins*. The minimum diameter of any outlet orifice in all wetland types is 2.5 inches.

The components of a typical stormwater wetland are illustrated in Figure 9.2-1. Pertinent design criteria for each component are presented in Table 9.2-1. Additional details of each type of constructed stormwater wetland and the components of each are described below.

A. Pool Zone

Pools generally have standing water depths of 2 to 6 feet and primarily support submerged and floating vegetation. Due to their depths, support for emergent vegetation is normally limited. As noted above, the pool zone may consist of a pond, micropond, and/or forebay, depending on their relative sizes and depths. Descriptions of these pool types are presented below.

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1. Pond

Ponds generally have standing water depths of 4 to 6 feet and, depending on the type, may comprise the largest portion of a constructed stormwater wetland. Ponds provide for the majority of particulate settling in a constructed stormwater wetland.

2. Micropond

In general, a micropond also has a standing water depth of 4 to 6 feet, but is smaller in surface area than a standard pond. A micropond is normally located immediately upstream of the outlet from a constructed stormwater wetland. At that location, it both protects the outlet from clogging by debris and provides some degree of particulate settling. Since a micropond does not provide the same degree of settling as a standard pond, it is normally combined with a larger area of marsh than a standard pond.

3. Forebay

Forebays are located at points of concentrated inflow to constructed stormwater wetlands. As such, they serve as pretreatment measures by removing coarser sediments, trash, and debris. They typically have normal standing water depths of 2 to 4 feet.

B. Marsh Zone

Marshes have shallower standing water depths than ponds, generally ranging from 6 to 18 inches. At such depths, they primarily support emergent wetland vegetation. As noted above, a marsh is classified as either a high or low marsh, depending on the exact depth of standing water.

1. Low Marsh

A low marsh has a standing water depth of 6 to 18 inches. It is suitable for the growth of several emergent wetland plant species.

2. High Marsh

A high marsh has a maximum standing water depth of 6 inches. Due to its shallower depth, it will have a higher standing water surface area to volume ratio than a low marsh. It will normally support a greater density and diversity of emergent wetland species than a low marsh.

C. Semi-Wet Zone

The semi-wet zone in a constructed stormwater wetland is located above the pool and marsh zones and is inundated only during storm events. As a result, it can support both wetland and upland plants.

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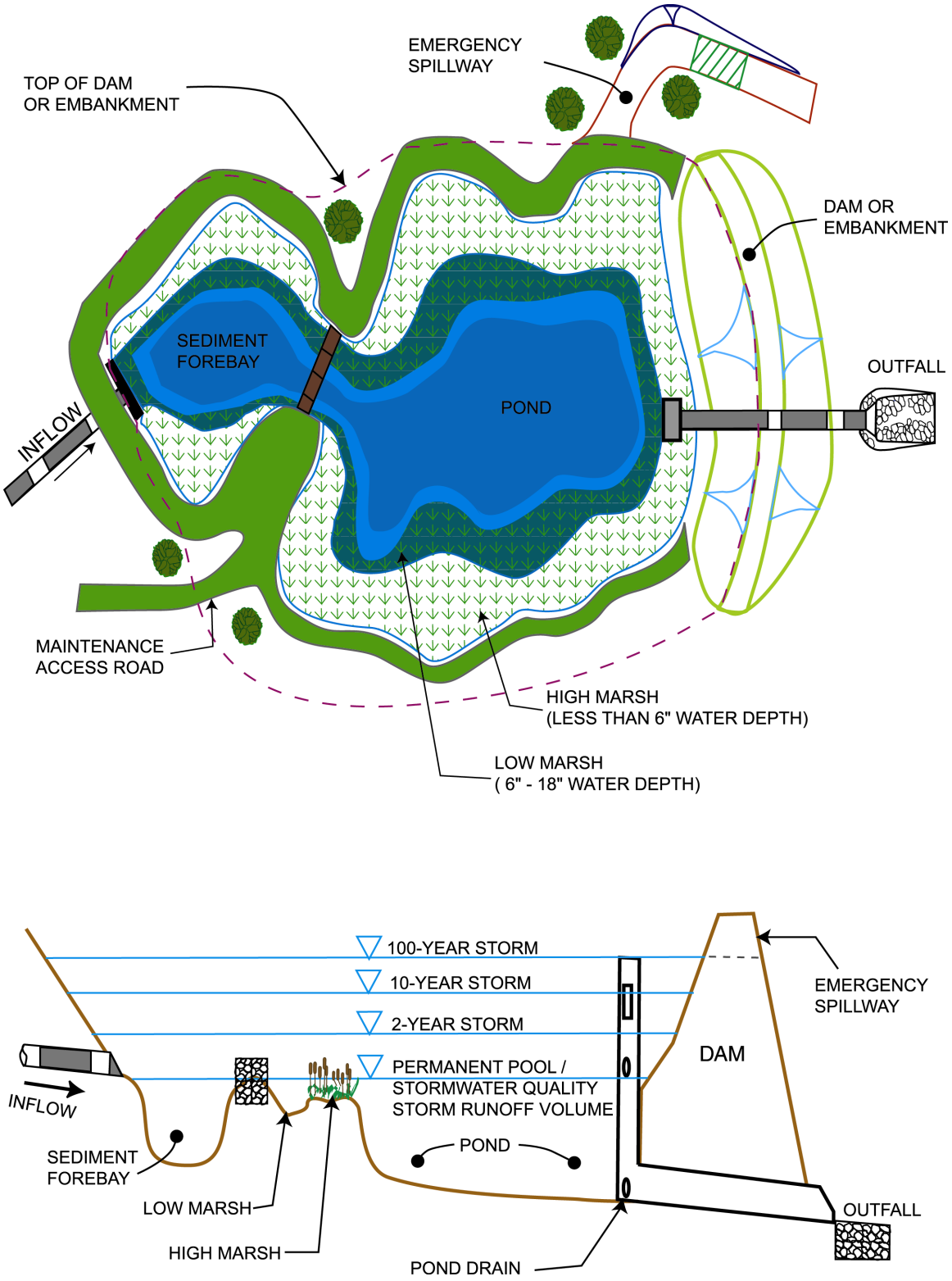
Figure 9.2-1: Constructed Stormwater Wetland Components



Source: Adapted from Schueler and Claytor 2000.

This figure can be viewed in color in the PDF version of this chapter available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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Table 9.2–1: Design Criteria for Constructed Stormwater Wetlands

Wetland Design Feature	Type of Constructed Stormwater Wetland		
	Pond	Marsh	Extended Detention
Minimum Drainage Area (Acres)	25	25	10
Minimum Length to Width Ratio	1:1	1:1	1:1
Allocation of Stormwater Quality Design Storm Runoff Volume (Pool / Marsh / Semi-Wet*)	70 / 30 / 0	30 / 70 / 0	20 / 30 / 50*
Pool Volume (Forebay / Micropond / Pond)	10 / 0 / 60	10 / 20 / 0	10 / 10 / 0
Marsh Volume (Low / High)	20 / 10	45 / 25	20 / 10
Sediment Removal Frequency (Years)	10	2 to 5	2 to 5
Outlet Configuration	Reverse-Slope Pipe or Broad Crested Weir	Reverse-Slope Pipe or Broad Crested Weir	Reverse-Slope Pipe or Broad Crested Weir

* In an Extended Detention Wetland, 50 percent of the stormwater quality design storm runoff volume is temporarily stored in the semi-wet zone. Release of this volume must meet the detention time requirements for extended detention basins (see text above and Chapter 9.4).

D. Types of Constructed Stormwater Wetlands

1. Pond Wetlands

Pond wetlands consist primarily of ponds with standing water depths ranging from 4 to 6 feet in normal or dry weather conditions. Pond wetlands utilize at least one pond component in conjunction with high and low marshes. The pond is typically the component that provides for the majority of particulate pollutant removal. This removal is augmented by a forebay, which also reduces the velocity of the runoff entering the wetland. The marsh zones provide additional treatment of the runoff, particularly for soluble pollutants.

Pond wetlands require less site area than marsh wetlands and generally achieve a higher pollutant removal rate than the other types of constructed stormwater wetland. See Table 9.2-1 for the relative stormwater quality design storm runoff volumes to be provided in each wetland component.

2. Marsh Wetlands

Marsh wetlands consist primarily of marsh zones with standing water depths ranging up to 18 inches during normal or dry weather conditions. These zones are further configured as low and high marsh components as described above. The remainder of the stormwater quality design storm runoff volume storage is provided by a micropond. See Table 9.2-1 for the relative stormwater quality design storm runoff volumes to be provided in each wetland component.

Marsh wetlands should be designed with sinuous pathways to increase retention time and contact area. Marsh wetlands require greater site area than other types of constructed stormwater wetlands. In order to have the base and/or groundwater flow rate necessary to support emergent plants and

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minimize mosquito breeding, marsh wetlands may also require greater drainage areas than the other types. This is due to the relatively larger area of a marsh wetland as compared with either a pond or extended detention wetland. This larger area requires greater rates of normal inflow to generate the necessary flow velocities and volume changeover rates.

3. Extended Detention Wetlands

Unlike pond and marsh wetlands, an extended detention wetland temporarily stores a portion of the stormwater quality design storm runoff volume in the semi-wet zone above its normal standing water level. This temporary runoff storage, which must be slowly released in a manner similar to an extended detention basin, allows the use of relatively smaller pool and marsh zones. As a result, extended detention wetlands require less site area than pond or marsh wetlands. See Table 9.2-1 for the relative stormwater quality design storm runoff volumes to be provided in each wetland component. See *Chapter 9.4: Standard for Extended Detention Basins* for the required detention times for the temporary semi-wet zone storage.

Due to the use of the semi-wet zone, water levels in an extended detention wetland will also increase more during storm events than pond or marsh wetlands. Therefore, the area of wetland vegetation in an extended detention wetland can expand beyond the normal standing water limits occupied by the pool and marsh zones. Wetland plants that tolerate intermittent flooding and dry periods should be selected for these areas.

E. Drainage Area

The minimum drainage area to a constructed stormwater wetland generally varies from 10 to 25 acres, depending on the type of constructed stormwater wetland. Smaller drainage areas may be permissible if detailed analysis indicates that sufficient base or groundwater inflow is available. See Table 9.2-1 for details. See also *D. Types of Constructed Stormwater Wetlands* above and *B. Water Budget* in the *Recommendations* section below for discussions of base and groundwater flow needs.

F. Overflows

All constructed stormwater wetlands must be able to convey overflows to downstream drainage systems in a safe and stable manner. Constructed stormwater wetlands classified as dams under the NJDEP Dam Safety Standards at N.J.A.C. 7:20 must also meet the overflow requirements of these Standards.

G. Tailwater

The design of all hydraulic outlets must consider any significant tailwater effects of downstream waterways or facilities. This includes instances where the lowest invert in the outlet or overflow structure is below the flood hazard area design flood elevation of a receiving stream.

H. On-Line and Off-Line Systems

Constructed stormwater wetlands may be constructed on-line or off-line. On-line systems receive upstream runoff from all storms, providing runoff treatment for the stormwater quality design storm and conveying the runoff from larger storms through an outlet or overflow. Multi-purpose on-line systems also store and attenuate these larger storms to provide runoff quantity control. In such systems, the invert of the lowest stormwater quantity control outlet is set at or above the normal permanent pool level. In off-line constructed stormwater wetlands, most or all of the runoff from storms larger than the stormwater quality design storm bypass the basin through an upstream diversion. This not only reduces the size of the required

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basin storage volume, but reduces the basin's long-term pollutant loading and associated maintenance. In selecting an off-line design, the potential effects on wetland vegetation and ecology of diverting higher volume runoff events should be considered.

I. Safety Ledges

Safety ledges must be constructed on the slopes of all constructed stormwater wetlands with a permanent pool of water deeper than 3 feet. Two ledges must be constructed, each 4 to 6 feet in width. The first or upper ledge must be located between 1 and 1.5 feet above the normal standing water level. The second or lower ledge must be located approximately 2.5 feet below the normal standing water level.

Maintenance

Effective constructed stormwater wetland performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Measures* provides information and requirements for preparing a maintenance plan for stormwater management facilities, including constructed stormwater wetlands. Specific maintenance requirements for constructed stormwater wetlands are presented below. These requirements must be included in the wetland's maintenance plan.

A. General Maintenance

All constructed stormwater wetland components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times annually as well as after every storm exceeding 1 inch of rainfall. Such components may include forebays, bottoms, trash racks, outlet structures, and riprap or gabion aprons.

Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state, and federal waste regulations.

B. Vegetated Areas

Mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass should be mowed at least once a month during the growing season. Vegetated areas must be inspected at least annually for erosion and scour. Vegetated areas should also be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the remaining vegetation.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed at least twice annually during both the growing and non-growing seasons. The vegetative cover should be maintained at 85 percent. If vegetation has greater than 50 percent damage, the area should be reestablished in accordance with the original specifications and the inspection requirements presented above.

The types and distribution of the dominant plants must also be assessed during the semi-annual wetland inspections described above. This assessment should be based on the health and relative extent of both the original species remaining and all volunteer species that have subsequently grown in the wetland. Appropriate steps must be taken to achieve and maintain an acceptable balance of original and volunteer species in accordance with the intent of the wetland's original design.

All use of fertilizers, mechanical treatments, pesticides and other means to assure optimum vegetation health should not compromise the intended purpose of the constructed stormwater wetland. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

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C. Structural Components

All structural components must be inspected for cracking, subsidence, spalling, erosion, and deterioration at least annually.

D. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take to drain the maximum design storm runoff and return the various wetland pools to their normal standing water levels. This drain or drawdown time should then be used to evaluate the wetland's actual performance. If significant increases or decreases in the normal drain time are observed, the wetland's outlet structure, forebay, and groundwater and tailwater levels must be evaluated and appropriate measures taken to comply with the maximum drain time requirements and maintain the proper functioning of the wetland.

Considerations

Constructed stormwater wetlands are limited by a number of site constraints, including soil types, depth to groundwater, contributing drainage area, and available land area at the site.

A. Construction

The following minimum setback requirements should apply to stormwater wetland installations:

Distance from a septic system leach field = 50 feet.

Distance from a septic system tank = 25 feet.

Distance from a property line = 10 feet.

Distance from a private well = 50 feet.

A seven-step process is recommended for the preparation of the wetland bed prior to planting (Schueler 1992).

1. Prepare final pondscaping and grading plans for the stormwater wetland. At this time order wetland plant stock from aquatic nurseries.
2. Once the stormwater wetland volume has been excavated, the wetland should be graded to create the major internal features (pool, safety ledge, marshes, etc.).
3. After the mulch or topsoil has been added, the stormwater wetland needs to be graded to its final elevations. All wetland features above the normal pool should be stabilized temporarily.
4. After grading to final elevations, the pond drain should be closed and the pool allowed to fill. Usually nothing should be done to the stormwater wetland for six to nine months or until the next planting season. A good design recommendation is to evaluate the wetland elevations during a standing period of approximately six months. During this time the stormwater wetland can experience storm flows and inundation, so that it can be determined where the pondscaping zones are located and whether the final grade and microtopography will persist overtime.
5. Before planting, the stormwater wetland depths should be measured to the nearest inch to confirm planting depth. The pondscape plan may be modified at this time to reflect altered depths or availability of plant stock.

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6. Erosion controls should be strictly applied during the standing and planting periods. All vegetated areas above the normal pool elevation should be stabilized during the standing period, usually with hydroseeding.
7. The stormwater wetland should be de-watered at least three days before planting since a dry wetland is easier to plant than a wet one.

Topsoil and/or wetland mulch is added to the stormwater wetland excavation. Since deep subsoils often lack the nutrients and organic matter to support vigorous plant growth, the addition of mulch or topsoil is important. If it is available, wetland mulch is preferable to topsoil.

B. Site Constraints

Medium-fine texture soils (such as loams and silt loams) are best to establish vegetation, retain surface water, permit groundwater discharge, and capture pollutants. At sites where infiltration is too rapid to sustain permanent soil saturation, an impermeable liner may be required. Where the potential for groundwater contamination is high, such as runoff from sites with a high potential pollutant load, the use of liners is recommended. At sites where bedrock is close to the surface, high excavation costs may make constructed stormwater wetlands infeasible.

C. Design Approach

A pondscaping plan should be developed for each constructed stormwater wetland. This plan should include hydrological calculations (or water budget), a wetland design and configuration, elevations and grades, a site/soil analysis, and estimated depth zones. The plan should also contain the location, quantity, and propagation methods for the wetland plants. Site preparation requirements, maintenance requirements, and a maintenance schedule are also necessary components of the plan.

The water budget should demonstrate that there will be a continuous supply of water to sustain the constructed stormwater wetland. The water budget should be developed during site selection and checked after preliminary site design. Drying periods of longer than two months have been shown to adversely effect plant community richness, so the water balance should confirm that drying will not exceed two months.

D. Effectiveness

A review of the existing performance data indicates that the removal efficiencies of constructed stormwater wetlands are slightly higher than those of conventional pond systems, e.g. as wet ponds or dry extended detention ponds. Of the three designs described above, the pond/wetland system has shown the most reliable terms of overall performance.

Studies have also indicated that removal efficiencies of constructed stormwater wetlands decline if they are covered by ice or receive snow melt. Performance also declines during the non-growing season and during the fall when the vegetation dies back. Until vegetation is well established, pollutant removal efficiencies may be lower than expected.

E. Regulatory Issues

A constructed stormwater wetlands, once constructed, may be regulated by the Freshwater Wetlands Protection Act, and require additional permits for subsequent maintenance or amendment of the constructed stormwater wetland.

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Recommendations

A. Vegetation

Establishment and maintenance of the wetland vegetation is an important consideration when planning a stormwater wetland. The following is a series of recommendations (Horner et al. 1994) for creating constructed stormwater wetlands.

In selecting plants, consider the prospects for success more than selection of native species. Since diversification will occur naturally, use a minimum of adaptable species. Give priority to perennial species that establish rapidly. Select species adaptable to the broadest ranges of depth, frequency and duration of inundation (hydroperiod). Give priority to species that have already been used successfully in constructed stormwater wetlands and that are commercially available. Match site conditions to the environmental requirements of plant selections. Avoid using only species that are foraged by the wildlife expected on site.

Establishment of woody species should follow herbaceous species. Add vegetation that will achieve other objectives, in addition to pollution control. Monoculture planting should be avoided due to increased risk of loss from pests and disease. When possible field collected plants should be used in lieu of nursery plants. Plants collected from the field have already adapted and are acclimated to the region. These plants generally require less care than greenhouse plants. If nursery plants are used they should be obtained locally, or from an area with similar climatic conditions as the eco-region of the constructed wetland. Alternating plant species with varying root depths have a greater opportunity of pollutant removal.

Stormwater wetland vegetation development can also be enhanced through the natural recruitment of species from nearby wetland sites. However, transplanting wetland vegetation is still the most reliable method of propagating stormwater wetland vegetation, and it provides cover quickly. Plants are commercially available through wetland plant nurseries.

The plant community will develop best when the soils are enriched with plant roots, rhizomes, and seed banks. Use of wetlands mulch enhances the diversity of the plant community and speeds establishment. Wetlands mulch is hydric soil that contains vegetative plant material. The upper 6 inches of donor soil should be obtained at the end of the growing season, and kept moist until installation. Drawbacks to using constructed stormwater wetlands mulch are its unpredictable content.

During the initial planting precautions should be undertaken to prevent and prohibit animals from grazing until plant communities are well established. Such precautions could be deer fencing, muskrat trapping, planting after seasonal bird migrations, or attracting birds of prey and bats to control nutria populations

B. Water Budget

The water budget should demonstrate that there will be a continuous supply of water to sustain the stormwater wetland. The water budget should demonstrate that the water supply to the stormwater wetland is greater than the expected loss rate. As discussed above, drying periods of longer than two months have been shown to adversely affect plan community richness, so the water balance should confirm that drying will not exceed two months (Schueler 1992).

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C. Wetlands Area

The constructed wetlands should have a minimum surface area in relation to the contributing watershed area. The reliability of pollutant removal tends to increase as the stormwater wetland to watershed ratio increases, although this relationship is not always consistent. Above ground berms or high marsh wedges should be placed at approximately 50 foot intervals, at right angles to the direction of the flow to increase the dry weather flow path within the stormwater wetland.

D. Outlet Configuration

A hooded outlet is recommended with an invert or crest elevation at least 1 foot below the normal pool surface.

A bottom drain pipe with an inverted elbow to prevent sediment clogging should be installed for complete draining of the constructed stormwater wetland for emergency purposes or routine maintenance. Both the outlet pipe and the bottom drain pipe should be fitted with adjustable valves at the outlet ends to regulate flows. Spillways should be designed in conformance with state regulations and criteria for dam safety.

E. Pretreatment

As with all other best management practices, pretreatment can extend the functional life and increase the pollutant removal capability of a constructed stormwater wetland. Pretreatment can reduce incoming velocities and capture coarser sediments, which will extend the life of the system. This is usually accomplished through such means as a vegetative filter and/or a manufactured treatment device. Information on vegetative filters and manufactured treatment devices is presented in Chapters 9.10 and 9.6, respectively.

As shown in Figure 9.2-1, forebays at the inflow points to a constructed stormwater wetland can capture coarse sediments, trash, and debris, which can simplify and reduce the frequency of system maintenance. A forebay should be sized in accordance with Table 9.2-1 to hold the sediment volume expected between clean-outs.

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CHAPTER 9.3

Standard for Dry Wells

Definition

A dry well is a subsurface storage facility that receives and temporarily stores stormwater runoff from roofs of structures. Discharge of this stored runoff from a dry well occurs through infiltration into the surrounding soils. A dry well may be either a structural chamber and/or an excavated pit filled with aggregate. Due to the relatively low level of expected pollutants in roof runoff, a dry well cannot be used to directly comply with the suspended solids and nutrient removal requirements contained in the NJDEP Stormwater Management Rules at N.J.A.C. 7:8. However, due to its storage capacity, a dry well may be used to reduce the total stormwater quality design storm runoff volume that a roof would ordinarily discharge to downstream stormwater management facilities.

Purpose

Dry wells can be used to reduce the increased volume of stormwater runoff caused by roofs of buildings. While generally not a significant source of runoff pollution, roofs are one of the most important sources of new or increased runoff volume from land development sites. Dry wells can also be used to indirectly enhance water quality by reducing the amount of stormwater quality design storm runoff volume to be treated by the other, downstream stormwater management facilities.

Dry wells can also be used to meet the groundwater recharge requirements of the NJDEP Stormwater Management Rules. See *Recharge BMP Design Guidelines* in *Chapter 6: Groundwater Recharge* for a complete discussion of these requirements and the use of dry wells and other groundwater recharge facilities to meet them.

Conditions Where Practice Applies

The use of dry wells is applicable only where their subgrade soils have the required permeability rates. Specific soil permeability requirements are presented below in *Design Criteria*.

Like other BMPs that rely on infiltration, dry wells are not appropriate for areas where high pollutant or sediment loading is anticipated due to the potential for groundwater contamination. Specifically, dry wells must not be used in the following locations:

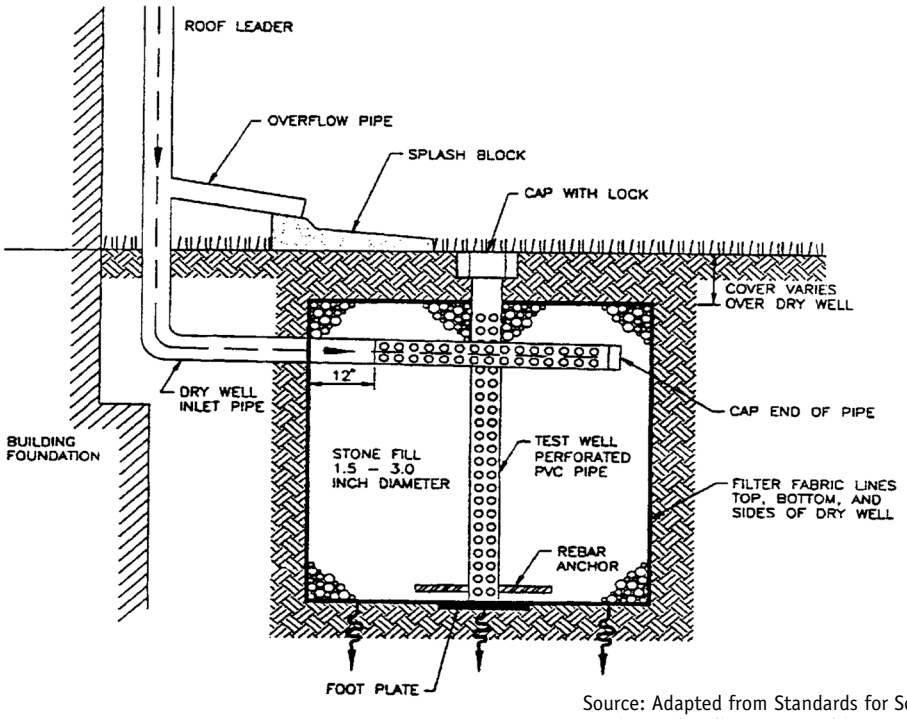
- Industrial and commercial areas where solvents and/or petroleum products are loaded, unloaded, stored, or applied; or pesticides are loaded, unloaded, or stored.

- Areas where hazardous materials are expected to be present in greater than "reportable quantities" as defined by the U.S. Environmental Protection Agency in the Code of Federal Regulations at 40 CFR 302.4.
- Areas where dry well use would be inconsistent with an NJDEP-approved remedial action work plan or landfill closure plan.
- Areas with high risks for spills of toxic materials such as gas stations and vehicle maintenance facilities.
- Areas where industrial stormwater runoff is exposed to "source material." "Source material" means any material(s) or machinery, located at an industrial facility, that is directly or indirectly related to process, manufacturing or other industrial activities, that could be a source of pollutants in any industrial stormwater discharge to groundwater. Source materials include, but are not limited to raw materials, intermediate products, final products, waste materials, by-products, industrial machinery and fuels, and lubricants, solvents, and detergents that are related to process, manufacturing, or other industrial activities that are exposed to stormwater.

In addition, as required by the NJDEP Stormwater Management Rules, dry wells must not be used where their installation would create a significant risk for basement seepage or flooding, cause surficial flooding of groundwater, or interfere with the operation of subsurface sewage disposal systems and other subsurface structures. Such adverse impacts must be assessed and avoided by the design engineer.

Dry wells must be located and configured where their construction will not compact the soils below the dry well. Finally, a dry well must have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

Figure 9.3-1: Dry Well Components



Source: Adapted from Standards for Soil Erosion and Sediment Control in New Jersey

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Design Criteria

The basic design parameters for a dry well are its storage volume and the permeability rate of the subgrade soils. A dry well must have sufficient storage volume to contain the design runoff volume without overflow, while the subgrade soils' permeability rate must be sufficient to drain the stored runoff within 72 hours. Details of these and other design parameters are presented below. The components of a typical dry well are shown above in Figure 9.3-1.

A. Storage Volume, Depth, and Duration

A dry well must be designed to treat the total runoff volume generated by the dry well's maximum design storm. This may either be the groundwater recharge or stormwater quality design storm, depending upon the dry well's proposed use. Techniques to compute these volumes are discussed in *Chapter 6: Groundwater Recharge* and *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. A dry well must also fully drain this runoff volume within 72 hours. Runoff storage for greater times can render the dry well ineffective and may result in anaerobic conditions, odor, and both water quality and mosquito breeding problems. The bottom of the dry well must be at least 2 feet above seasonal high water table or bedrock and be as level as possible to uniformly distribute runoff infiltration over the subgrade soils.

As discussed in *Considerations* below, construction of a dry well must be done without compacting the dry well's subgrade soils. As such, all excavation must be performed by equipment placed outside the dry well whenever possible. This requirement should be considered when designing the dimensions and total storage volume of a dry well.

It is important to note that the use of dry wells is recommended in this manual only for the stormwater quality design storm and smaller storm events. Use of dry wells for larger storm events and the requirements by which such dry wells are to be designed, constructed, and maintained should be reviewed and approved by all applicable reviewing agencies.

B. Permeability Rates

The minimum design permeability rate of the subgrade soils below a dry well will depend upon the dry well's location and maximum design storm. The use of dry wells for stormwater quality or quantity control is feasible only where the soils are sufficiently permeable to allow a reasonable rate of infiltration. Therefore, dry wells designed for storms greater than the groundwater recharge storm can be constructed only in areas with Hydrologic Soil Group A and B soils. Additional permeability requirements are presented below in Table 9.3-1.

Table 9.3-1: Minimum Design Permeability Rates for Dry Wells

Maximum Design Storm	Minimum Design Permeability Rate (Inches/Hour)
Groundwater Recharge*	0.2
Stormwater Quality	0.5
*See text for required diversion of runoff from greater storms.	

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It is important to note that, for dry wells that are used only for groundwater recharge (see Table 9.3-1 above), all runoff from storms greater than the dry well's groundwater recharge storm must be directed around the dry well by a diversion structure or device located upstream of the dry well. If the dry well does receive runoff and associated pollutants from greater storm events, a minimum permeability rate of 0.5 inches/hour must be used. Minor basin inflows from greater storms during normal operation of the diversion are permissible provided they represent a small percentage of the total storm runoff volume. For example, the dry well overflow pipe shown in Figure 9.3-1 can serve as such a diversion if it is located vertically as close to the ground surface as practical. Details of a dry well's groundwater recharge storm are presented in Chapter 6.

In addition to the above, the design permeability rate of the subgrade soils must be sufficient to fully drain the dry well's maximum design storm runoff volume within 72 hours. This design permeability rate must be determined by field or laboratory testing. See *A. Soil Characteristics* in *Considerations* below for more information. Since the actual permeability rate may vary from test results and may also decrease over time due to soil bed consolidation or the accumulation of sediments removed from the treated stormwater, a factor of safety of two must be applied to the tested permeability rate to determine the design permeability rate. Therefore, if the tested permeability rate of the subgrade soils is 4 inches/hour, the design rate would be 2 inches/hour (i.e., 4 inches per hour/2). This design rate would then be used to compute the dry well's maximum design storm drain time.

C. Drainage Area

The maximum drainage area to a dry well is 1 acre.

D. Overflows

All dry wells must be able to safely convey system overflows to downstream drainage systems. The capacity of the overflow must be consistent with the remainder of the site's drainage system and sufficient to provide safe, stable discharge of stormwater in the event of an overflow. The downstream drainage system must have sufficient capacity to convey the overflow from the dry well.

Maintenance

Effective dry well performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Measures* provides information and requirements for preparing a maintenance plan for stormwater management facilities, including dry wells. Specific maintenance requirements for dry wells are presented below. These requirements must be included in the dry well's maintenance plan.

A. General Maintenance

A dry well should be inspected at least four times annually as well as after every storm exceeding 1 inch of rainfall. The water level in the test well should be the primary means of measuring infiltration rates and drain times. Pumping stored runoff from an impaired or failed dry well can also be accomplished through the test well. Therefore, adequate inspection and maintenance access to the test well must be provided.

Disposal of debris, trash, sediment, and other waste material removed from a dry well should be done at suitable disposal/recycling sites and in compliance with local, state, and federal waste regulations.

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B. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take to drain the maximum design storm runoff volume from the dry well. This normal drain time should then be used to evaluate the dry well's actual performance. If significant increases in the normal drain time are observed or if it exceeds the 72 hour maximum, appropriate measures must be taken to comply with the drain time requirements and maintain the proper functioning of the dry well.

Considerations

A. Soil Characteristics

Soils are perhaps the most important consideration for site suitability. In general, County Soil Surveys can be used to obtain necessary soil data for the planning and preliminary design of dry wells. However, for final design and construction, soil tests are required at the exact location of a proposed dry well in order to confirm its ability to function properly without failure or interference.

Such tests should include a determination of the textural classification and permeability of the subgrade soil at and below the bottom of the proposed dry well. The recommended minimum depth for subgrade soil analysis is 5 feet below the bottom of the drywell or to the groundwater table. Soil permeability testing can be conducted in accordance with the Standards for Individual Subsurface Sewage Disposal Systems at N.J.A.C. 7:9A. See *Design Criteria* above for further soil requirements.

In addition, the results of a dry well's soil testing should be compared with the County Soil Survey data used in the computation of development site runoff and the design of specific site BMPs, including the proposed dry well, to ensure reasonable data consistency. If significant differences exist between the dry well's soil test results and the County Soil Survey data, additional development site soil tests are recommended to determine and evaluate the extent of the data inconsistency and the need for revised site runoff and BMP design computations. All significant inconsistencies should be discussed with the local Soil Conservation District prior to proceeding with such redesign to help ensure that the final site soil data is accurate.

B. Construction

For dry wells, protection of the subgrade soils from compaction by construction equipment and contamination and clogging by sediment are vital. Prior to its construction, the area to be used for the dry well should be cordoned off to prevent construction equipment and stockpiled materials from compacting the subgrade soils. During dry well construction, precautions should be taken to prevent both subgrade soil compaction and sediment contamination. All excavation should be performed with the lightest practical excavation equipment. All excavation equipment should be placed outside the limits of the dry well.

To help prevent subgrade soil contamination and clogging by sediment, dry well construction should be delayed until all other construction areas that may temporarily or permanently drain to the dry well are stabilized. This delayed construction emphasizes the need, as described above, to cordon off the dry well area to prevent compaction by construction equipment and material storage during other site construction activities. Similarly, use of the dry well as a sediment basin is strongly discouraged. Where unavoidable, excavation for the sediment basin should be a minimum of 2 feet above the final design elevation of the dry well bottom. Accumulated sediment can then be removed without disturbing the subgrade soils at the dry well bottom, which should be established only after all construction within the dry well's drainage area is completed and the drainage area stabilized.

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If dry well construction cannot be delayed until its drainage area is stabilized, diversion piping or other suitable measures should be installed during all phases of construction to divert all runoff and sediment away from the dry well. These diversion measures should not be removed until all construction within the dry well's drainage area is completed and the drainage area stabilized.

Stone fill aggregate should be placed in lifts and compacted using plate compactors. A maximum loose lift thickness of 12 inches is recommended.

A preconstruction meeting should be held to review the specific construction requirements and restrictions of dry wells with the contractor.

Recommendations

A. Pretreatment

As with all other best management practices, pretreatment can extend the functional life of a dry well. While generally not a significant source of runoff pollution, roofs can nevertheless be the source of particulates and organic matter and, during site construction, sediment and debris. Therefore, roof gutter guards and/or sumps or traps (equipped with clean-outs) in the conduits to a dry well should be included wherever practical to minimize the amount of sediment and other particulates that can enter the dry well.

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CHAPTER 9.4

Standard for Extended Detention Basins

Definition

An extended detention basin is a facility constructed through filling and/or excavation that provides temporary storage of stormwater runoff. It has an outlet structure that detains and attenuates runoff inflows and promotes the settlement of pollutants. An extended detention basin is normally designed as a multi-stage facility that provides runoff storage and attenuation for both stormwater quality and quantity management. The adopted TSS removal rate for extended detention basins is 40 to 60 percent, depending on the duration of detention time provided in the basin.

Purpose

Extended detention basins are used to address both the stormwater runoff quantity and quality impacts of land development. The lower stages of an extended detention basin can detain runoff from the stormwater quality design storm for extended periods of time, thereby promoting pollutant removal through sedimentation. Higher stages in the basin can also attenuate the peak rates of runoff from larger storms for flood and erosion control. Extended detention basins are designed for complete evacuation of runoff and normally remain dry between storm events. However, to enhance soluble pollutant removal, the lower stages of an extended detention basin may also be designed with a permanent pool and partially function as either a wetland or retention basin (see *Chapter 9.2: Standard for Constructed Stormwater Wetlands* and *Chapter 9.11: Standard for Wet Ponds*).

Conditions Where Practice Applies

Extended detention basins may be used at sites where significant increases in runoff are expected from site development. In addition, standard detention basins may be retrofitted or converted to extended detention by increasing the time over which the basin releases the stormwater quality design storm runoff volume, provided that erosion and flood control volumes and outflow rates are not adversely altered.

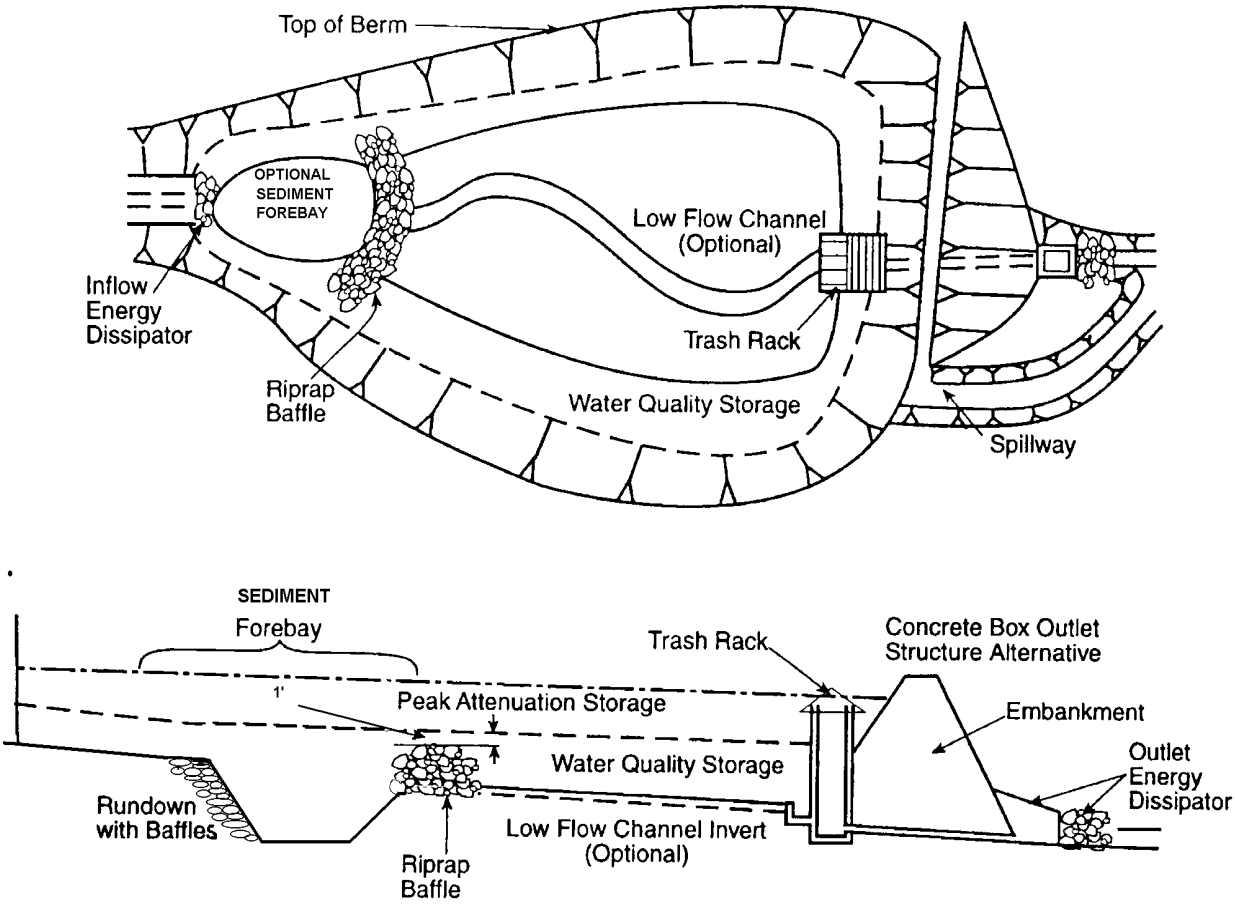
Extended detention basins can be used at residential, commercial, and industrial development sites. However, their limited effectiveness in removing both particulate and soluble pollutants may limit their use for water quality treatment.

Finally, an extended detention basin must have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

Design Criteria

The basic design parameters for an extended detention basin are its storage volume and detention time. An extended detention basin must have the correct combination of storage volume and outflow capacity to contain and slowly discharge the design runoff volume over a prescribed period of time. Details of these and other design parameters are presented below. The components of a typical extended detention basin are shown in Figure 9.4-1.

Figure 9.4-1: Extended Detention Basin Components



Source: Adopted from Pennsylvania Handbook of Best Management Practices for Developing Areas, which adapted the figure from Dam Design and Construction Standards, Fairfax County, Virginia.

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A. Storage Volume, Depth, and Duration

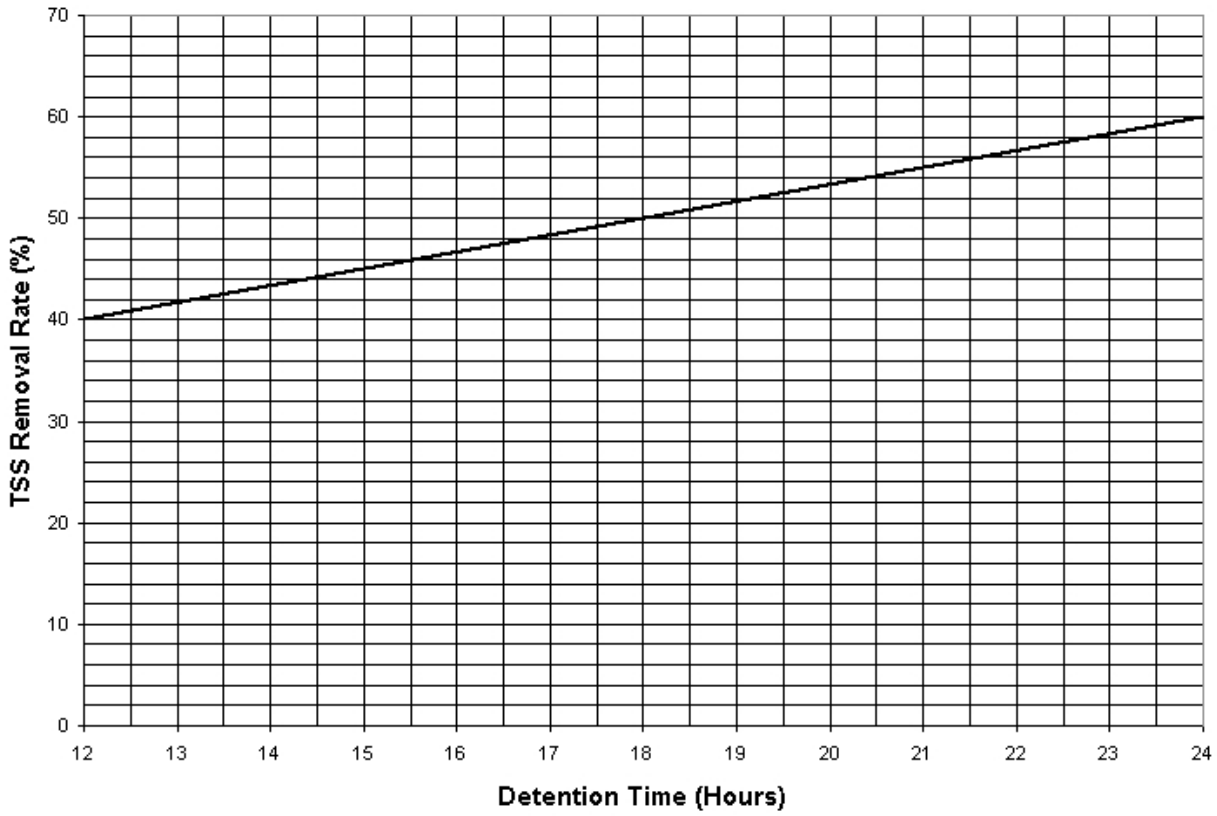
Extended detention basins should be designed to treat the runoff volume generated by the stormwater quality design storm. Techniques to compute this volume are discussed in *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. To achieve a 60 percent TSS removal rate, a minimum of 10 percent of this runoff volume must remain in the basin 24 hours after the peak basin water surface and maximum runoff storage volume is achieved. This applies to all types of land developments.

It should be noted that the time from when the maximum storage volume is achieved until only 10 percent of that volume remains in an extended detention basin is defined as the basin's detention time. As noted above, a 24-hour detention time is required in an extended detention basin in order to achieve a 60 percent TSS removal rate. Figure 9.4-2 below can be used to determine the TSS removal rates at extended detention basins with detention times of 12 to 24 hours. The minimum diameter of any outlet orifice must be 2.5 inches.

The lowest elevation in an extended detention basin, excluding low flow channels, must be at least 1 foot above the seasonal high groundwater table. The lowest elevation in any low flow channel, including any underdrain pipes and bedding material, must be at or above the seasonal high groundwater table.

To enhance safety by minimizing standing water depths, the vertical distance between the basin bottom and the elevation of the first stormwater quantity control outlet (normally set equal to the maximum stormwater quality design storm water surface) should be no greater than 3 feet wherever practical.

Figure 9.4-2: TSS Removal Rate vs. Detention Time



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B. Overflows

All extended detention basins must be able to safely convey system overflows to downstream drainage systems. The capacity of the overflow must be sufficient to provide safe, stable discharge of stormwater in the event of an overflow. Extended detention basins that are classified as dams under the NJDEP Dam Safety Standards at N.J.A.C. 7:20 must also meet the overflow requirements of these Standards.

C. Tailwater

The hydraulic design of the outlet structure, outlet pipe, emergency spillway, and underdrain systems in an extended detention basin must consider any significant tailwater effects of downstream waterways or facilities. This includes instances where the lowest invert in the outlet or overflow structure is below the flood hazard area design flood elevation of a receiving stream.

D. Other Components

Information regarding outlet structures, bottom and side slopes, trash racks, low flow channels, conduit outlet protection, and vegetative cover can be found in both the Soil Erosion and Sediment Control Standards for New Jersey and the NJDEP Stormwater Management Facilities Maintenance Manual.

E. Subsurface Extended Detention Basins

A subsurface detention basin is located entirely below the ground surface. Runoff may be stored in a vault, perforated pipe, and/or stone bed. If a stone bed is utilized for any part of the storage volume, all runoff to the subsurface basin must either be pretreated or the basin's storage volume increased to account for the loss of volume in the stone bed due to sediment accumulation. This loss should be based upon the expected life of the basin. This increase is due to the impracticality of removing this sediment from the stone storage bed. This pretreatment must remove at least 50 percent of the TSS in the runoff from the basin's maximum design storm.

Following pretreatment, additional TSS removal can then be provided by the subsurface extended detention basin as the secondary BMP in a treatment train. Computation of the total TSS removal rate is described in *Chapter 4: Stormwater Pollution Removal Criteria*. See *Recommendations* below for additional information on runoff pretreatment.

Maintenance

Effective extended detention basin performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Measures* provides information and requirements for preparing a maintenance plan for stormwater management facilities, including extended detention basins. Specific maintenance requirements for extended detention basins are presented below. These requirements must be included in the basin's maintenance plan.

A. General Maintenance

All extended detention basin components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times annually as well as after every storm exceeding 1 inch of rainfall. Such components may include bottoms, trash racks, low flow channels, outlet structures, riprap or gabion aprons, and inlets.

Sediment removal should take place when the basin is thoroughly dry. Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state, and federal waste regulations.

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B. Vegetated Areas

Mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass should be mowed at least once a month during the growing season. Vegetated areas must be inspected at least annually for erosion and scour. Vegetated areas should also be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the bottom surface and remaining vegetation.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed at least twice annually during both the growing and non-growing seasons. The vegetative cover should be maintained at 85 percent. If vegetation has greater than 50 percent damage, the area should be reestablished in accordance with the original specifications and the inspection requirements presented above.

All use of fertilizers, mechanical treatments, pesticides, and other means to assure optimum vegetation health must not compromise the intended purpose of the extended detention basin. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

C. Structural Components

All structural components must be inspected for cracking, subsidence, spalling, erosion, and deterioration at least annually.

D. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take to completely drain the maximum design storm runoff volume from the basin. This normal drain time should then be used to evaluate the basin's actual performance. If significant increases or decreases in the normal drain time are observed, the basin's outlet structure, underdrain system, and both groundwater and tailwater levels must be evaluated and appropriate measures taken to comply with the maximum drain time requirements and maintain the proper functioning of the basin.

Considerations

For effective stormwater quality control, the basin must collect as much site runoff as possible, especially from the site's roadways, parking lots, and other impervious areas. The majority of the key pollutants that are removed by extended detention basins originate on these surfaces.

A typical extended detention basin will range from 3 to 12 feet in depth. Depth is often limited by groundwater conditions or the need for positive drainage from excavated basins. At the location of the proposed extended detention basin, the depth to seasonal high groundwater table must be determined. If the basin intercepts the groundwater, it may result in a loss of runoff storage volume, mosquito breeding, and difficulty maintaining the basin bottom.

When designing an extended detention basin, bottom soils should be examined. If soils are relatively impermeable (USDA Hydrologic Soil Group "D"), a dry extended detention basin may exhibit problems with standing water. Conversely, if soils are very permeable (Group "A") the effects on groundwater should be considered. If bedrock lies close to the surface of the soil, excavation for necessary storage volume may be too costly and difficult. In Karst landscapes, other alternatives to detention basins should be examined.

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Recommendations

A. Pretreatment

As with all other best management practices, pretreatment can extend the functional life and increase the pollutant removal capability of an extended detention system. Pretreatment can reduce incoming velocities and capture coarser sediments, which will extend the life of the system. This is usually accomplished through such means as a vegetative filters, a forebay, or a manufactured treatment device. Information on vegetative filters and manufactured treatment devices is presented in Chapters 9.10 and 9.6, respectively.

Forebays can also be included at the inflow points to an extended detention basin to capture coarse sediments, trash, and debris, which can simplify and reduce the frequency of system maintenance. A forebay should be sized to hold the sediment volume expected between clean-outs.

It should be remembered that the runoff to all subsurface extended detention basins that utilize stone beds to store runoff must be pretreated. This pretreatment must provide 50 percent removal of TSS for the maximum design storm runoff to the basin. See *E. Subsurface Extended Detention Basins* in *Design Criteria* above for more information.

B. Sediment Accumulation

A properly designed extended detention basin will accumulate considerable amounts of sediment over time, leading to the loss of the detention volume and, thus, both runoff quality and quantity control effectiveness. Therefore, depending on the clean-out intervals, an increase in an extended detention basin's maximum design storm storage volume should be considered to compensate for this expected loss of storage volume. See *E. Subsurface Extended Detention Basins* in *Design Criteria* above for more information on required volume increases in subsurface basins.

C. Flow Paths

An extended detention basin relies on the process of sedimentation for removal of runoff pollutants. Therefore, the basin should be designed to maximize the degree of sedimentation. Flow path lengths should be maximized and long, narrow basin configurations with length to width ratios from 2:1 to 3:1 should be utilized. Basins that are shallow and have larger surface area to depth ratios will provide better pollutant removal efficiencies than smaller, deeper basins.

D. Wetland Creation

It may be possible to establish a wetland area in the bottom stage of an extended detention basin to increase the pollutant removal rate. See *Chapter 9.2: Standard for Constructed Stormwater Wetlands* for more information.

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New Jersey Stormwater Best Management Practices Manual

February 2004

CHAPTER 9.5

Standard for Infiltration Basins

Definition

An infiltration basin is a facility constructed within highly permeable soils that provides temporary storage of stormwater runoff. An infiltration basin does not normally have a structural outlet to discharge runoff from the stormwater quality design storm. Instead, outflow from an infiltration basin is through the surrounding soil. An infiltration basin may also be combined with an extended detention basin to provide additional runoff storage for both stormwater quality and quantity management. The adopted TSS removal rate for infiltration basins is 80 percent.

It should be noted that a dry well is a specialized infiltration facility intended only for roof runoff. See *Chapter 9.3: Standard for Dry Wells* for further details.

Purpose

Infiltration basins are used to remove pollutants and to infiltrate stormwater back into the ground. Such infiltration also helps to reduce increases in both the peak rate and total volume of runoff caused by land development. Pollutant removal is achieved through filtration of the runoff through the soil as well as biological and chemical activity within the soil.

Infiltration basins may also be used to meet the groundwater recharge requirements of the NJDEP Stormwater Management Rules. See *Recharge BMP Design Guidelines* in *Chapter 6: Groundwater Recharge* for a complete discussion of these requirements and the use of infiltration basins and other groundwater recharge facilities to meet them.

Conditions Where Practice Applies

The use of infiltration basins is applicable only where the soils have the required permeability rates. Specific soil permeability requirements are presented below in *Design Criteria*.

Like other BMPs that rely on infiltration, infiltration basins are not appropriate for areas where high pollutant or sediment loading is anticipated due to the potential for groundwater contamination.

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Specifically, infiltration basins must not be used in the following locations:

- Industrial and commercial areas where solvents and/or petroleum products are loaded, unloaded, stored, or applied or pesticides are loaded, unloaded, or stored.
- Areas where hazardous materials are expected to be present in greater than "reportable quantities" as defined by the U.S. Environmental Protection Agency in the Code of Federal Regulations at 40 CFR 302.4.
- Areas where infiltration basin use would be inconsistent with an NJDEP-approved remedial action work plan or landfill closure plan.
- Areas with high risks for spills of toxic materials such as gas stations and vehicle maintenance facilities.
- Areas where industrial stormwater runoff is exposed to "source material." "Source material" means any material(s) or machinery, located at an industrial facility, that is directly or indirectly related to process, manufacturing, or other industrial activities, that could be a source of pollutants in any industrial stormwater discharge to groundwater. Source materials include, but are not limited to raw materials, intermediate products, final products, waste materials, by-products, industrial machinery and fuels, and lubricants, solvents, and detergents that are related to process, manufacturing, or other industrial activities that are exposed to stormwater.

In addition, as required by the Stormwater Management Rules, infiltration basins must not be used where their installation would create a significant risk for basement seepage or flooding, cause surficial flooding of groundwater, or interfere with the operation of subsurface sewage disposal systems and other subsurface structures. Such adverse impacts must be assessed and avoided by the design engineer.

Infiltration basins must be configured and located where their construction will not compact the soils below the basin. In addition, an infiltration basin must not be placed into operation until the contributing drainage area is completely stabilized. Basin construction must either be delayed until such stabilization is achieved, or upstream runoff must be diverted around the basin. Such diversions must continue until stabilization is achieved.

Finally, an infiltration basin must have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

Design Criteria

The components of a typical infiltration basin are shown in Figure 9.5-1. Additional details of each component are described below.

A. Storage Volume, Depth, and Duration

An infiltration basin must be designed to treat the total runoff volume generated by the basin's maximum design storm. This may either be the groundwater recharge or stormwater quality design storm, depending upon the basin's proposed use. Techniques to compute these volumes are discussed in *Chapter 6: Groundwater Recharge* and *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. An infiltration basin must also fully drain this runoff volume within 72 hours. Runoff storage for greater times can render the basin ineffective and may result in anaerobic conditions, odor, and both water quality and mosquito breeding problems. The bottom of the infiltration basin must be at least 2 feet above seasonal high water table or bedrock. For surface basins, this distance must be measured from the bottom of the sand layer as shown in Figure 9.5-1. The basin bottom must be as level as possible to uniformly distribute runoff infiltration over the subgrade soils.

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To enhance safety by minimizing standing water depths, the vertical distance between the basin bottom and the maximum design storm water surface in surface infiltration basins should be no greater than 2 feet.

As discussed in *Considerations* below, construction of an infiltration basin must be done without compacting the basin's subgrade soils. As such, all excavation must be performed by equipment placed outside the basin whenever possible. This requirement should be considered when designing the dimensions and total storage volume of an infiltration basin.

It is important to note that the use of infiltration basins is recommended in this manual only for the stormwater quality design storm and smaller storm events. Use of infiltration basins for larger storm events and the requirements by which such basins are to be designed, constructed, and maintained should be reviewed and approved by all applicable reviewing agencies.

B. Permeability Rates

The minimum design permeability rate of the soils below an infiltration basin will depend upon the basin's location and maximum design storm. The use of infiltration basins for stormwater quality control is feasible only where soil is sufficiently permeable to allow a reasonable rate of infiltration. Therefore, infiltration basins designed for storms greater than the groundwater recharge storm can be constructed only in areas with Hydrologic Soil Group A and B soils. Additional permeability requirements are presented below in Table 9.5-1.

Table 9.5-1: Minimum Design Permeability Rates for Infiltration Basins

Maximum Design Storm	Basin Location	Minimum Design Permeability Rate (Inches/Hour)
Groundwater Recharge*	Subsurface	0.2
Groundwater Recharge	Surface	0.5
Stormwater Quality	Surface and Subsurface	0.5
*See text for required diversion of runoff from greater storms.		

It is important to note that, for subsurface infiltration basins that are used only for groundwater recharge (see Table 9.5-1 above), all runoff from storms greater than the basin's groundwater recharge storm must be directed around the basin by a diversion structure or device located upstream of the basin. If the basin does receive runoff and associated pollutants from greater storm events, a minimum permeability rate of 0.5 inches/hour must be used. Minor basin inflows from greater storms during normal operation of the diversion are permissible provided they represent a small percentage of the total storm runoff volume. Details of an infiltration basin's groundwater recharge storm are presented in *Chapter 6*. See *E. Online and Offline Systems* below for additional information.

In addition to the above, the design permeability rate of the soil must be sufficient to fully drain the infiltration basin's maximum design storm runoff volume within 72 hours. This design permeability rate must be determined by field or laboratory testing. See *A. Soil Characteristics* in *Considerations* below for more information. Since the actual permeability rate may vary from test results and may also decrease over time due to soil bed consolidation or the accumulation of sediments removed from the treated stormwater, a

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factor of safety of two must be applied to the tested permeability rate to determine the design permeability rate. Therefore, if the tested permeability rate of the soils is 4 inches/hour, the design rate would be 2 inches/hour (i.e., 4 inches per hour/2). This design rate would then be used to compute the basin's maximum design storm drain time.

C. Bottom Sand Layer

To help ensure maintenance of the design permeability rate over time, a 6 inch layer of sand must be placed on the bottom of an infiltration basin (see Figure 9.5-1). This sand layer can intercept silt, sediment, and debris that could otherwise clog the top layer of the soil below the basin. The sand layer will also facilitate silt, sediment, and debris removal from the basin and can be readily restored following removal operations. The sand layer must meet the specifications of a K5 soil. This must be certified by a professional engineer licensed in the State of New Jersey.

D. Overflows

All infiltration basins must be able to convey overflows to downstream drainage systems in a safe and stable manner. Infiltration basins that are classified as dams under the NJDEP Dam Safety Standards at N.J.A.C. 7:20 must also meet the overflow requirements of these Standards.

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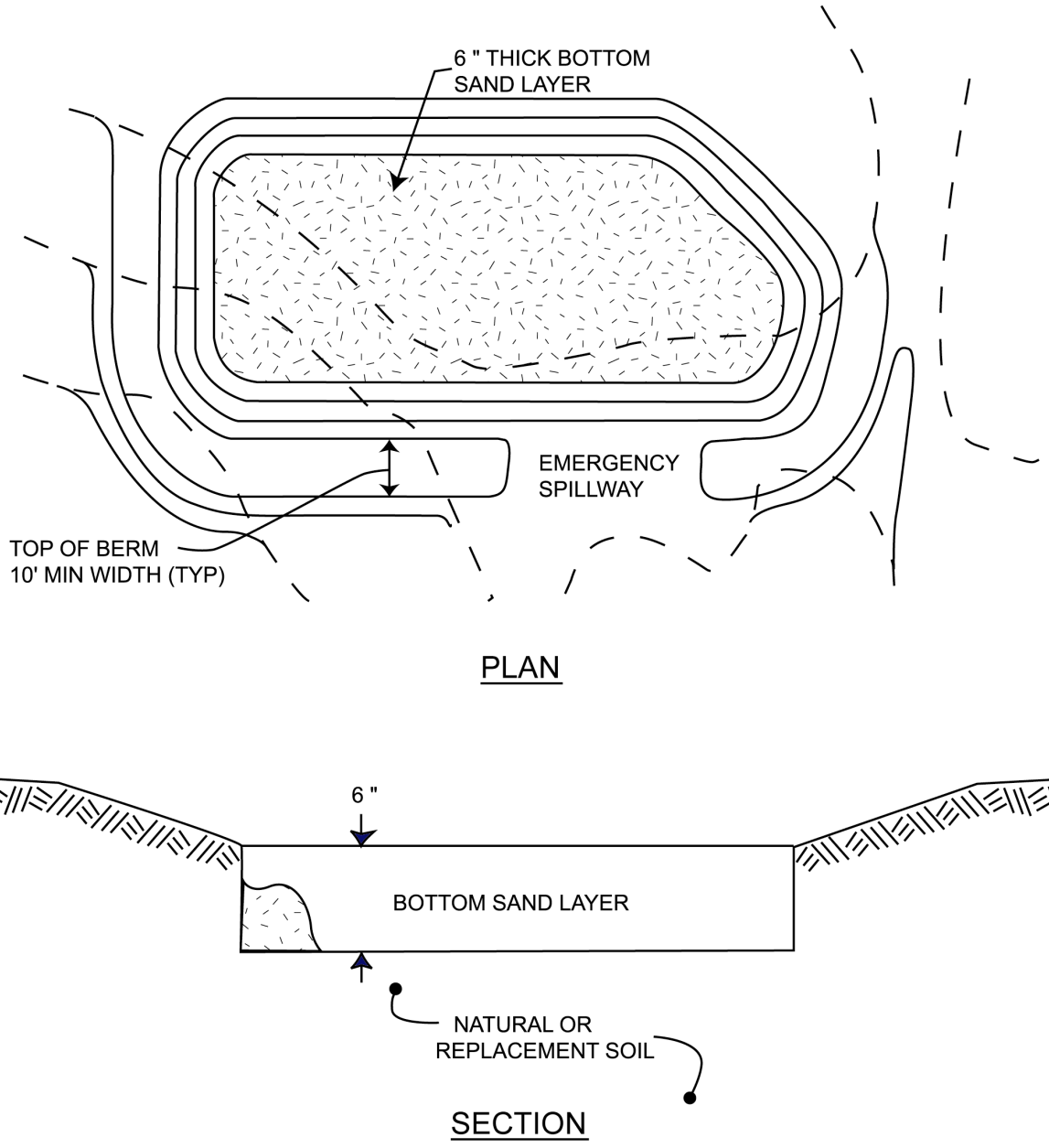
Figure 9.5-1: Infiltration Basin Components



NOTES

1. BOTTOM SAND LAYER MUST CONSIST OF K5 SAND WITH A MAXIMUM OF 15% FINES AND A MINIMUM PERMEABILITY RATE OF 20 INCHES PER HOUR.

2. BASIN CONSTRUCTION MUST NOT COMPACT SOILS BELOW BASIN BOTTOM.

3. SEE TEXT FOR ADDITIONAL REQUIREMENTS.

Source: Adapted from T&M Associates.

E. On-Line and Off-Line Systems

Infiltration basins may be constructed either on-line or off-line. On-line systems receive upstream runoff from all storms, providing runoff treatment for the maximum design storm and conveying the runoff from larger storms through an overflow. With the proper soil and drainage area conditions, an infiltration basin may also be combined with a detention basin to provide runoff quantity control in the detention portion of the basin. In such systems the invert of the lowest stormwater quantity control outlet is set at or above the maximum stormwater quality design storm water surface.

In off-line infiltration basins, most or all of the runoff from storms larger than the maximum design storm bypass the basin through an upstream diversion. This not only reduces the size of the required basin storage volume, but also reduces the basin's long-term pollutant loading and associated maintenance. See *B. Permeability Rates* above for additional information on diversion requirements, particularly for subsurface infiltration basins used only for groundwater recharge.

F. Subsurface Infiltration Basins

A subsurface infiltration basin is located entirely below the ground surface. It may consist of a vault, perforated pipe, and/or stone bed. However, due to the greater difficulty in removing silt, sediment, and debris, all runoff to a subsurface infiltration basin must be pretreated. This pretreatment must remove 80 percent of the TSS in the runoff from the basin's maximum design storm.

Following pretreatment, additional TSS removal can then be provided by the subsurface infiltration basin as the secondary BMP in a treatment train. Computation of the total TSS removal rate is described in *Chapter 4: Stormwater Pollution Removal Criteria*. See *A. Pretreatment* in *Recommendations* below for information on runoff pretreatment.

G. Basis of Design

The design of an infiltration basin is based upon Darcy's Law:

$$Q = KIA$$

where:

Q = the rate of infiltration in cubic feet per second (cfs)
K = the hydraulic conductivity of the soil in feet per second (fps)
I = the hydraulic gradient
A = the area of infiltration in square feet (sf)

From the variables shown in Figure 9.5-2 below:

Average Hydraulic Gradient = D_{avg}/d
Minimum Hydraulic Gradient = D_1/d
Maximum Hydraulic Gradient = D_2/d

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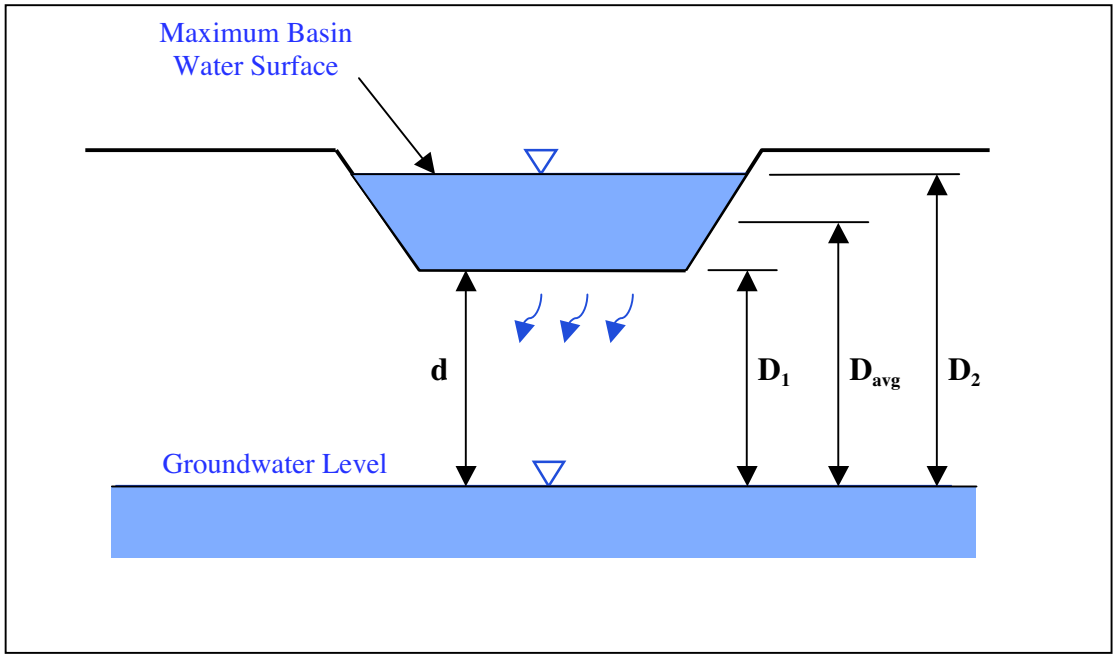
Figure 9.5-2: Schematic of Darcy's Law



The hydraulic conductivity is either field measured or laboratory measured for the soil on site. A number of percolation tests should be done to obtain a reliable measurement of permeability of the underlying soil.

Maintenance

Effective infiltration basin performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Measures* contains information and requirements for preparing a maintenance plan for stormwater management facilities, including infiltration basins. Specific maintenance requirements for infiltration basins are presented below. These requirements must be included in the basin's maintenance plan.

A. General Maintenance

All infiltration basin components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times annually as well as after every storm exceeding 1 inch of rainfall. Such components may include bottoms, riprap or gabion aprons, and inflow points. This applies to both surface and subsurface infiltration basins.

Sediment removal should take place when the basin is thoroughly dry. Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state, and federal waste regulations.

Studies have shown that readily visible stormwater management facilities like infiltration basins receive more frequent and thorough maintenance than those in less visible, more remote locations. Readily visible facilities can also be inspected faster and more easily by maintenance and mosquito control personnel.

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B. Vegetated Areas

Mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass should be mowed at least once a month during the growing season. Vegetated areas must also be inspected at least annually for erosion and scour. The structure must be inspected for unwanted tree growth at least once a year.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed at least twice annually during both the growing and non-growing season. If vegetation has greater than 50 percent damage, the area should be reestablished in accordance with the original specifications and the inspection requirements presented above.

All use of fertilizers, mechanical treatments, pesticides, and other means to assure optimum vegetation health must not compromise the intended purpose of the infiltration basin. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

All vegetated areas should be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the remaining vegetation and basin subsoil.

C. Structural Components

All structural components must be inspected for cracking, subsidence, spalling, erosion, and deterioration at least annually.

D. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take to drain the maximum design storm runoff volume below the bottom of the basin. This normal drain or drawdown time should then be used to evaluate the basin's actual performance. If significant increases or decreases in the normal drain time are observed, the basin's bottom surface, subsoil, and both groundwater and tailwater levels must be evaluated and appropriate measures taken to comply with the maximum drain time requirements and maintain the proper functioning of the basin. This applies to both surface and subsurface infiltration basins.

The bottom sand layer in a surface infiltration basin should be inspected at least monthly as well as after every storm exceeding 1 inch of rainfall. The permeability rate of the soil below the basin may also be retested periodically. If the water fails to infiltrate 72 hours after the end of the storm, corrective measures must be taken. Annual tilling by light equipment can assist in maintaining infiltration capacity and break up clogged surfaces.

Considerations

Infiltration basins can present some practical design problems. When planning for an infiltration basin that provides stormwater quality treatment, consideration should be given to soil characteristics, depth to the groundwater table, sensitivity of the region, and runoff water quality. Particular care must be taken when constructing infiltration basins in areas underlain by carbonate rocks known as Karst landscapes. See Appendix A10 of the Standards for Soil Erosion and Sediment Control in New Jersey for further guidance in Karst landscape areas.

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A. Soil Characteristics

Soils are perhaps the most important consideration for site suitability. In general, County Soil Surveys can be used to obtain necessary soil data for the planning and preliminary design of infiltration basins. However, for final design and construction, soil tests are required at the exact location of a proposed basin in order to confirm its ability to function properly without failure.

Such tests should include a determination of the textural classification and permeability of the subgrade soil at and below the bottom of the proposed infiltration basin. The recommended minimum depth for subgrade soil analysis is 5 feet below the bottom of the basin or to the groundwater table. Soil permeability testing can be conducted in accordance with the Standards for Individual Subsurface Sewage Disposal Systems at N.J.A.C. 7:9A. See *Design Criteria* above for further subgrade soil requirements.

In addition, the results of a basin's soil testing should be compared with the County Soil Survey data used in the computation of development site runoff and the design of specific site BMPs, including the proposed infiltration basin, to ensure reasonable data consistency. If significant differences exist between the basin's soil test results and the County Soil Survey data, additional development site soil tests are recommended to determine and evaluate the extent of the data inconsistency and the need for revised site runoff and BMP design computations. All significant inconsistencies should be discussed with the local Soil Conservation District prior to proceeding with such redesign to help ensure that the final site soil data is accurate.

B. Construction

For infiltration basins, protection of the subgrade soils from compaction by construction equipment and contamination and clogging by sediment are vital. Prior to its construction, the area to be used for the infiltration basin should be cordoned off to prevent construction equipment and stockpiled materials from compacting the subgrade soils. During basin construction, precautions should be taken to prevent both subgrade soil compaction and sediment contamination. All excavation should be performed with the lightest practical excavation equipment. All excavation equipment should be placed outside the limits of the basin.

To help prevent subgrade soil contamination and clogging by sediment, basin construction should be delayed until all other construction within in its drainage area is completed and the drainage area stabilized. This delayed construction emphasizes the need, as described above, to cordon off the basin area to prevent compaction by construction equipment and material storage during other site construction activities. Similarly, use of an infiltration basin as a sediment basin is strongly discouraged. Where unavoidable, excavation for the sediment basin should be a minimum of 2 feet above the final design elevation of the basin bottom. Accumulated sediment can then be removed without disturbing the subgrade soils at the basin bottom, which should be established only after all construction within the basin's drainage area is completed and the drainage area stabilized.

Once the final grading phase of a surface infiltration basin is reached, the bottom of the basin should be deeply tilled with a rotary tiller or disc harrow and then smoothed out with a leveling drag or equivalent grading equipment. These procedures should preferably be performed with equipment located outside the basin bottom. If this is not possible, it should be performed with light-weight, rubber-tired equipment.

If basin construction cannot be delayed until its drainage area is stabilized, diversion berms or other suitable measures should be placed around the basin's perimeter during all phases of construction to divert all runoff and sediment away from the basin. These diversion measures should not be removed until all construction within the basin's drainage area is completed and the drainage area stabilized.

Broken stone fill used in subsurface infiltration basins should be placed in lifts and compacted using plate compactors. A maximum loose lift thickness of 12 inches is recommended.

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A preconstruction meeting should be held to review the specific construction requirements and restrictions of infiltration basins with the contractor.

C. Runoff Quality

The quality of runoff entering an infiltration basin is a primary consideration in determining whether infiltration is advisable and, if so, in designing the basin itself. The planning of an infiltration basin must consider which pollutants will be present in the runoff and whether these pollutants will degrade groundwater quality. Certain soils can have a limited capacity for the treatment of bacteria and the soluble forms of nitrogen, phosphorus, and other pollutants like road salts and pesticides. Such pollutants are either attenuated in the soil column or go directly to the water table. Unfortunately, the soils that normally have the highest and, therefore, most suitable permeability rates also have the least ability to treat such pollutants. As a result, pretreatment of soluble pollutants prior to entry into the infiltration basin may be necessary in these soils. Pretreatment measures may include vegetative filters, bioretention systems (where the infiltration basin takes the place of the standard underdrain), and certain sand filters. Alternatively, the existing soil below the infiltration basin bottom may be augmented or replaced by soils with greater soluble pollutant removal rates.

Recommendations

A. Pretreatment

As with all other best management practices, pretreatment can extend the functional life and increase the pollutant removal capability of an infiltration basin. Pretreatment can reduce incoming velocities and capture coarser sediments, which will extend the life of the system. This is usually accomplished through such means as a vegetative filters, a forebay, and/or a manufactured treatment device. Information on vegetative filters and manufactured treatment devices is presented in Subchapters 9.10 and 9.6, respectively.

Forebays can be included at the inflow points to an infiltration basin to capture coarse sediments, trash, and debris, which can simplify and reduce the frequency of system maintenance. A forebay should be sized to hold the sediment volume expected between clean-outs.

As described above, it should be remembered that the runoff to all subsurface infiltration basins must be pretreated. This pretreatment must provide 80 percent removal of TSS for the maximum design storm runoff. See *Recharge BMP Design Guidelines* in *Chapter 6: Groundwater Recharge* for additional pretreatment information for subsurface infiltration basins used for groundwater recharge.

This pretreatment requirement does not apply to roofs and other above-grade surfaces. However, roof gutter guards and/or sumps or traps (equipped with clean-outs) in the conduits to a subsurface infiltration basin should be included wherever practical to minimize the amount of sediment and other particulates that can enter the basin.

B. Sensitivity of the Area

The planning of an infiltration basin site should consider the geologic and ecological sensitivity of the proposed site. Sensitive areas include FW1 streams, areas near drinking water supply wells, and areas of high aquifer recharge. Infiltration basins should be sited at least 100 feet from a drinking water supply well. They should also be sited away from foundations to avoid seepage problems. Measures should be taken in areas of aquifer recharge to ensure good quality water is being infiltrated to protect ground water supplies. Infiltration basins should be located away from septic systems to help prevent septic system failure and other adverse system interference.

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C. Slopes

Topography of the location is an important consideration for basin operation. Ideally, basin construction should not occur where surrounding slopes are greater than 10 percent. The grading of the basin floor should be as level as possible (with the slope approaching zero) to achieve uniform spreading across the breadth and the length of the basin.

Grading and landscaping throughout the infiltration basin and its components must be designed to facilitate mowing, trimming, sediment and debris removal, and other maintenance activities.

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CHAPTER 9.6

Standard for Manufactured Treatment Devices

Definition

A manufactured treatment device is a pre-fabricated stormwater treatment structure utilizing settling, filtration, absorptive/adsorptive materials, vortex separation, vegetative components, and/or other appropriate technology to remove pollutants from stormwater runoff.

The TSS removal rate for manufactured treatment devices is based on the NJDEP certification of the pollutant removal rates on a case-by-case basis. Details are provided below. Other pollutants, such as nutrients, metals, hydrocarbons, and bacteria can be included in the verification/certification process if the data supports their removal efficiencies.

Purpose

Manufactured treatment devices are intended to capture sediments, metals, hydrocarbons, floatables, and/or other pollutants in stormwater runoff before being conveyed to a storm sewer system, additional stormwater quality treatment measure, or waterbody.

Conditions Where Practice Applies

A manufactured treatment device is adequate for small drainage areas that contain a predominance of impervious cover that is likely to contribute high hydrocarbon and sediment loadings, such as small parking lots and gas stations. For larger sites, multiple devices may be necessary. Devices are normally used for pre-treatment of runoff before discharging to other, more effective stormwater quality treatment facilities.

In addition, a manufactured treatment device must have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

Design Criteria

In addition to its certified pollutant removal rate, the basic design parameters for a manufactured treatment device will depend on the techniques it employs to remove particulate and dissolved pollutants from runoff. In general, the design of devices that treat runoff with no significant storage and flow rate attenuation must be based upon the peak design flow rate. However, devices that do provide storage and flow rate attenuation must be based, at a minimum, on the design runoff volume and, in some instances, on a routing of the design runoff hydrograph. Details of these and other design parameters are presented below.

A. Pollutant Removal Rates

The NJDEP Division of Science, Research & Technology (DSRT) is responsible for certifying final pollutant removal rates for all manufactured treatment devices. This final certification process must be based upon one of the following:

1. Verification of the device's pollutant removal rates by the N.J. Corporation for Advanced Technology (NJCAT) in accordance with the New Jersey Energy and Environmental Technology Verification Program at N.J.S.A. 13:D-134 et seq. This verification must be conducted in accordance with the protocol "Stormwater Best Management Practices Demonstration Tier II Protocol for Interstate Reciprocity" as developed under the Environmental Council of States (ECOS) and Technology Acceptance and Reciprocity Partnership (TARP). This stormwater protocol ensures that technologies are evaluated in a uniform manner assuring minimum standards for quality assurance and quality control (QA/QC). In addition, the protocol establishes an interstate reciprocity pathway for technology and regulatory acceptance.
2. Verification of the device's pollutant removal rates by another TARP state, or another state or government agency that is recognized by New Jersey through a formal reciprocity agreement, provided that such verification is conducted in accordance with the protocol "Stormwater Best Management Practices Demonstration Tier II Protocol for Interstate Reciprocity."
3. Verification of the device's pollutant removal rates by other third party testing organizations (i.e., NSF), provided that such verification is conducted in accordance with the protocol "Stormwater Best Management Practices Demonstration Tier II Protocol for Interstate Reciprocity." Other testing protocols may be considered if it is determined by the NJDEP to be equivalent to the Tier II Protocol.

It should be noted that the pollutant removal rates for a manufactured treatment device may be granted interim conditional certification by the NJDEP provided that the manufacturer submits an interim verification report through NJCAT and further agrees to apply for and complete the final certification process described above. All interim certifications are effective for a limited time period, as determined on a case-by-case basis by the NJDEP.

B. Flow Rates and Storage Volumes

To achieve its assigned TSS removal rate, a manufactured treatment device must be designed to treat the runoff generated by the stormwater quality design storm. Techniques to compute the runoff rates and volume from this storm event are discussed in *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. Depending on the device's pollutant removal technique(s), the primary design parameter for a manufactured treatment device will normally be either the peak rate and/or total runoff volume from the stormwater quality design storm. Devices that convey inflow with little or no storage and provide pollutant removal only through such techniques as vortex flow, filtration, and/or absorption must be based on the peak rate of

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stormwater quality design storm runoff. Devices that store and convey runoff more slowly and provide pollutant removal through such techniques as sedimentation and/or filtration must also be based on the total volume of runoff. Hydraulic losses through a device must be considered in the design of all related upstream and downstream drainage system components.

C. Overflows

All manufactured treatment devices must be able to safely overflow or bypass flows in excess of the stormwater quality design storm to downstream drainage systems. The capacity of the overflow or bypass must be consistent with the remainder of the site's drainage system. All such flows must be conveyed in such a manner that trapped material, including floatables, is not resuspended and released. The designer must also check the capacity of the downstream conveyance system to ensure the adequacy of the overflow or bypass. All manufactured treatment devices must also have similar provisions to safely overflow and/or bypass runoff in the event of internal component clogging, blockage, and/or failure.

D. Tailwater

The hydraulic design of all manufactured treatment devices must consider any significant tailwater effects of downstream waterways or facilities. This includes instances where the lowest invert in the outlet or overflow structure is below the flood hazard area design flood elevation of a receiving stream.

E. Subsurface Devices

All subsurface or underground devices must be designed for HS-20 traffic loading at the surface. All joints and connections must be watertight. The manhole cover or other approved permanent marker for the treatment device must clearly indicate that it is a pollutant-trapping device. Sufficient and suitable access must be provided for each chamber in the device for inspection and maintenance activities. This must include adequate clearance from adjacent structures to allow for placement and operation of maintenance equipment. All subsurface devices must also be installed a minimum of 20 feet from a septic tank/drainage field. Any subsurface device within 20 feet of a slope greater than 2:1 requires a geotechnical review.

F. On-line and Off-line Devices

Manufactured treatment devices may be constructed on-line or off-line. On-line systems receive upstream runoff from all storms, providing runoff treatment for the stormwater quality design storm and conveying the runoff from larger storms through an overflow. In off-line devices, most or all of the runoff from storms larger than the stormwater quality design storm bypass the device through an upstream diversion. This not only reduces the size of the required device overflow, but also reduces the device's long-term pollutant loading and associated maintenance, and the threat of resuspension and release of trapped material by larger storm inflows.

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Maintenance

Effective performance of a manufactured treatment device requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Measures* provides information and requirements for preparing a maintenance plan for stormwater management facilities, including manufactured treatment devices. Specific maintenance requirements for these devices are presented below. These requirements must be included in the device's maintenance plan.

A. General Maintenance

All manufactured treatment devices should be inspected and maintained in accordance with the manufacturer's instructions and/or recommendations and any maintenance requirements associated with the device's certification by the NJDEP Office of Innovative Technology. In addition, all device components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times annually as well as after every storm exceeding 1 inch of rainfall. Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state, and federal waste regulations.

B. Vegetation

In those devices utilizing vegetation, trimming of vegetation must be performed on a regular schedule based on specific site conditions. Vegetated areas must be inspected at least annually for erosion and scour as well as unwanted growth, which should be removed with minimum disruption to the planting soil bed and remaining vegetation. All use of fertilizers, mechanical treatments, pesticides, and other means to ensure optimum vegetation health in devices utilizing vegetation should not compromise the intended purpose of the device. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

C. Structural Components

All structural components must be inspected for cracking, subsidence, spalling, erosion, and deterioration at least annually.

D. Other Maintenance Criteria

The maintenance plan must indicate the maximum level of oil, sediment, and debris accumulation allowed before removal is required. These levels should then be monitored during device inspections to help determine the need for removal and other device maintenance.

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C H A P T E R 9 . 7

Standard for Pervious Paving Systems

Definition

Pervious paving systems are paved areas that produce less stormwater runoff than areas paved with conventional paving. This reduction is achieved primarily through the infiltration of a greater portion of the rain falling on the area than would occur with conventional paving. This increased infiltration occurs either through the paving material itself or through void spaces between individual paving blocks known as pavers.

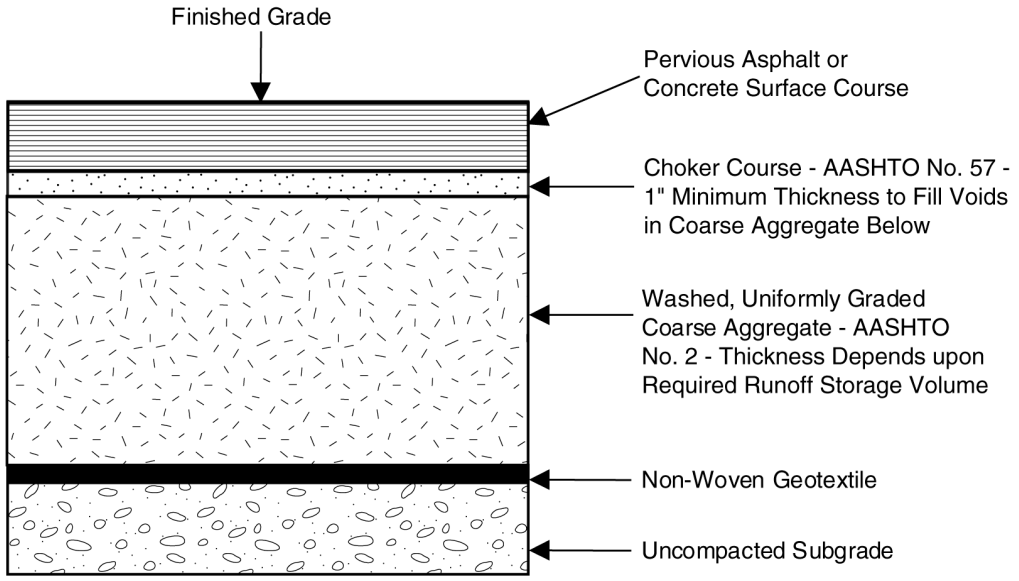
Pervious paving systems are divided into three general types. Each type depends primarily upon the nature of the pervious paving surface course and the presence or absence of a runoff storage bed beneath the surface course. These three types are summarized in Table 9.7-1 and discussed below. Porous paving and permeable paver with storage bed systems treat the stormwater quality design storm runoff through storage and infiltration. Therefore, these systems have adopted TSS removal rates similar to infiltration structures. The adopted TSS removal rate for each type of pervious paving system is presented in Table 9.7-1.

Table 9.7-1: Types of Pervious Paving Systems

Type of Paving System	General Description of Paving System	Adopted TSS Removal Rate
Porous paving	Porous asphalt or concrete paving constructed over runoff storage bed of uniformly graded broken stone	80%
Permeable pavers with storage bed	Impervious concrete pavers with surface voids constructed over runoff storage bed of uniformly graded broken stone	80%
Permeable pavers without storage bed	Impervious concrete pavers with surface voids constructed over structural bed of sand and crushed stone	Volume reduction only

Porous paving systems consist of a porous asphalt or concrete surface course placed over a bed of uniformly graded broken stone. The broken stone bed is placed on an uncompacted earthen subgrade and is used to temporarily store the runoff that moves vertically through the porous asphalt or concrete into the bed. The high rate of infiltration through the porous paving is achieved through the elimination of the finer aggregates that are typically used in conventional paving. The remaining aggregates are bound together with an asphalt or Portland cement binder. The lack of the finer aggregate sizes creates voids in the normally dense paving that allow runoff occurring on the paving to move vertically through the paving and into the void spaces of the broken stone storage bed below. From there, the stored runoff then infiltrates over time into the uncompacted subgrade soils similar to an Infiltration Basin. The depth of the bed, which also provides structural support to the porous surface course, depends upon the volume and rate of rainfall that the porous paving system has been designed to store and infiltrate and the void ratio of the broken stone. A typical detail of a porous paving system is shown in Figure 9.7-1.

Figure 9.7-1: Porous Paving Details



Source: Cahill Associates.

A permeable paver with storage bed system also has a subsurface storage bed and functions in a similar manner to a porous paving system. However, instead of a continuous porous asphalt or concrete surface course, the system's surface consists of impervious concrete blocks known as pavers that either have void spaces cast into their surfaces or interlock in such a way as to create such void spaces. These void spaces allow runoff from the impervious paver surface to collect and move vertically past the individual pavers into the broken stone storage bed below. Similar to a porous paving system, the runoff stored in the broken stone storage bed, which also provides structural support to the pavers, then infiltrates over time into the uncompacted subgrade soils. A typical detail of a permeable paver with storage bed system is shown in Figure 9.7-2.

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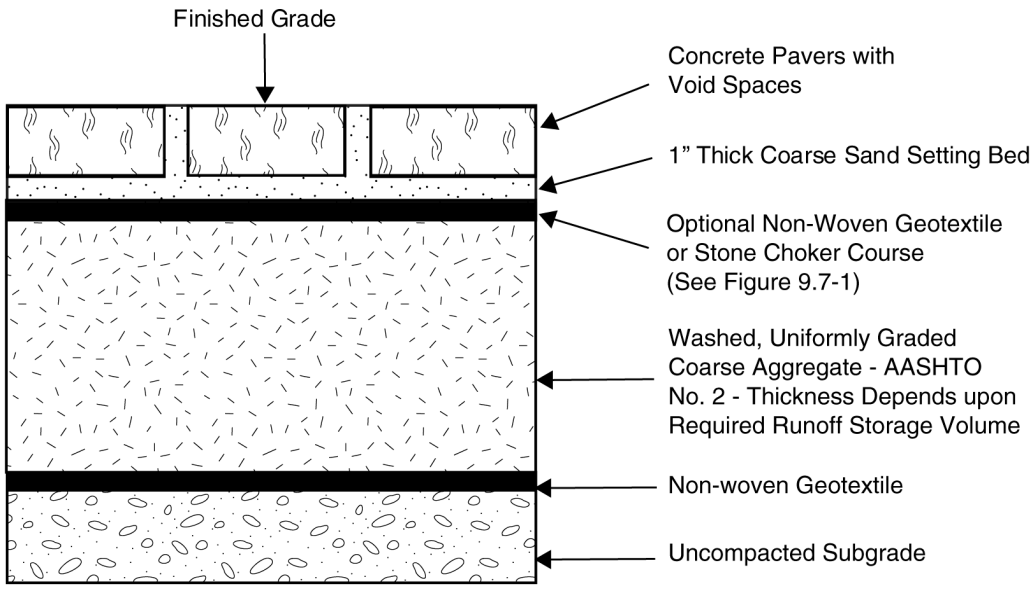
Figure 9.7-2: Permeable Pavers with Storage Base



It is important to note that both a porous paving system and a permeable paver with storage bed system function in the same manner as any other infiltration-based BMP such as an infiltration basin or dry well. That is, the fundamental means of runoff quantity control is into and through the subgrade soils below the BMP. Therefore, in terms of runoff quantity control, the porous paving or permeable paver surface course acts solely as a conveyance measure that delivers the surface course runoff to the subgrade soils. In addition, the broken stone storage bed serves only to temporarily store the runoff transmitted through the surface course. For these reasons, the design and use of porous paving and permeable paver with storage bed systems are generally subject to the same design, operation, and maintenance requirements of all other infiltration-based BMPs. Details of these requirements are presented in *Design Criteria* below.

In addition to runoff volume control, porous paving and permeable paver with storage bed systems also provide stormwater quality control through the infiltration process when designed to store and infiltrate the stormwater quality design storm runoff volume. This is again similar to other infiltration-based BMPs such as infiltration basins. In addition, the porous or permeable paver surface course in such systems can be considered to provide pretreatment of the runoff to their respective subsurface storage beds.

Permeable pavers without a storage bed is the third type of pervious paving system. As described by its name, this type of system does not have a broken stone runoff storage bed beneath it. Instead, the permeable pavers are placed on a generally thinner bed of sand and crushed stone that provides only structural support to the paver surface course and has no significant runoff storage volume. This lack of storage volume prevents the system from storing and infiltrating the relatively larger volumes of runoff typically achieved by a porous paving or permeable paver with storage bed system. However, because of the void spaces in the paver surface, a portion of the runoff from the pavers, albeit smaller than the storage bed systems, can still collect in the surface voids spaces and infiltrate through the sand and crushed stone bed and into the subgrade soils. A typical detail of a permeable paver without storage bed system is shown in Figure 9.7-3.

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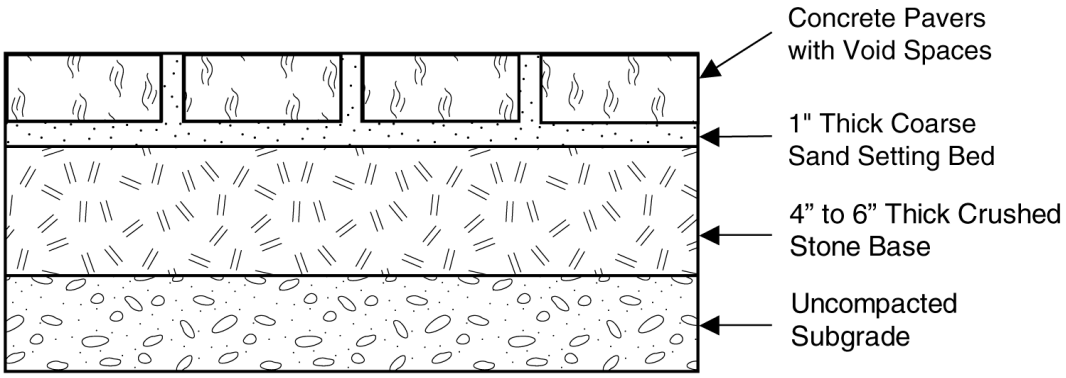
Figure 9.7-3: Permeable Paver without Storage Base



Purpose

In general, pervious paving systems are used to reduce runoff rates and volumes from paved, on-grade surfaces such as patios, walkways, driveways, fire lanes, and parking spaces. Pervious paving systems with runoff storage beds below them achieve these reductions through the delivery and storage of runoff and eventual infiltration into the subgrade soils. Through this infiltration process, these types of pervious paving systems also achieve stormwater quality treatment.

Porous paving and permeable paver with storage bed systems may also be used to meet the groundwater recharge requirements of the NJDEP Stormwater Management Rules. See *Recharge BMP Design Guidelines* in *Chapter 6: Groundwater Recharge* for a complete discussion of these requirements and the use of pervious paving and other groundwater recharge facilities to meet them.

Permeable pavers without storage bed systems also achieve reductions in runoff rates and volumes, primarily by generating less surface runoff than conventional paving. However, due to the lack of a runoff storage bed and significant runoff infiltration, these types of pervious paving systems achieve less runoff reductions than systems with storage beds. For similar reasons, they also do not provide any significant stormwater quality treatment. However, the reduction in runoff rates and volumes they do achieve may reduce the volume of stormwater quality design storm runoff to be treated by other, downstream stormwater management facilities.

Conditions Where Practice Applies

As noted above, porous paving and permeable pavers with storage bed systems function as infiltration facilities. As such, the use of such pervious paving systems is applicable only where their subgrade soils have the required permeability rates. Specific soil permeability requirements are presented below in *Design Criteria*.

Like other BMPs that rely on infiltration, porous paving and permeable pavers with storage bed systems are not appropriate for areas where high pollutant or sediment loading is anticipated due to the potential for groundwater contamination. Specifically, such systems must not be used in the following locations:

- Industrial and commercial areas where solvents and/or petroleum products are loaded, unloaded, stored, or applied or pesticides are loaded, unloaded, or stored.

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- Areas where hazardous materials are expected to be present in greater than "reportable quantities" as defined by the U.S. Environmental Protection Agency in the Code of Federal Regulations at 40 CFR 302.4.
- Areas where system use would be inconsistent with an NJDEP-approved remedial action work plan or landfill closure plan.
- Areas with high risks for spills of toxic materials such as gas stations and vehicle maintenance facilities.
- Areas where industrial stormwater runoff is exposed to "source material." "Source material" means any material(s) or machinery, located at an industrial facility, that is directly or indirectly related to process, manufacturing, or other industrial activities, that could be a source of pollutants in any industrial stormwater discharge to groundwater. Source materials include, but are not limited to raw materials, intermediate products, final products, waste materials, by-products, industrial machinery and fuels, and lubricants, solvents, and detergents that are related to process, manufacturing, or other industrial activities that are exposed to stormwater.

In addition, as required by the Stormwater Management Rules, porous paving and permeable pavers with storage bed systems must not be used where their installation would create a significant risk for basement seepage or flooding, cause surficial flooding of groundwater, or interfere with the operation of subsurface sewage disposal systems and other subsurface structures. Such adverse impacts must be assessed and avoided by the design engineer.

Porous paving and permeable pavers with storage bed systems must be configured and located where their construction will not compact the soils below the system. In addition, such systems must not be placed into operation until the contributing drainage area is completely stabilized. System construction must either be delayed until such stabilization is achieved, or upstream runoff must be diverted around the system. Such diversions must continue until stabilization is achieved.

Due to the reduced shear strength of the surface course, all pervious paving systems are limited to areas of relatively infrequent use by light vehicles. This includes parking lot spaces and secondary aisles, single family residential driveways, sidewalks and walkways, golf cart paths, fire and emergency access lanes, and overflow parking areas. In general, they should not be used in high traffic areas such as roadways, multiple family and nonresidential driveways, and primary parking lot aisles or in any area subject to use by heavy vehicles and other equipment.

One pervious paving use strategy is to alternate areas with impervious and pervious paving. In these instances, conventional paving would be reserved for the heavily trafficked corridors. A wide variety of concrete and brick permeable paving systems are available. These can be combined with conventional and porous paving systems to achieve functional and aesthetically pleasing designs.

Finally, all three types of pervious paving systems must have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

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Design Criteria

The design criteria for pervious paving systems will depend upon the type of system to be used. Details of each system type are presented in Figures 9.7-1, 9.7-2, and 9.7-3 above. Design criteria for each type are presented below.

A. Storage Volume, Depth, and Duration

Porous paving and permeable paver with storage bed systems must be designed to treat the total runoff volume generated by the system's maximum design storm. This may be either the groundwater recharge or stormwater quality design storm depending upon the system's proposed use. Techniques to compute these volumes are discussed in *Chapter 6: Groundwater Recharge* and *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. Such systems must also all fully drain this runoff volume within 72 hours. Runoff storage for greater times can render the systems ineffective and may result in anaerobic conditions and water quality problems. The bottom of these types of pervious paving systems must be at least 2 feet above seasonal high water table or bedrock. This distance must be measured from the bottom of the storage bed as shown in Figures 9.7-1 and 9.7-2. The system bottom must be as level as possible to uniformly distribute runoff infiltration over the subgrade soils.

As discussed in *Considerations* below, construction of all pervious paving systems must be done without compacting the system's subgrade soils. As such, all excavation must be performed by equipment placed outside the system's limits whenever possible. This requirement should be considered when designing the dimensions and total volume of a system's broken stone storage bed or crushed stone base.

It is important to note that the use of both porous paving and permeable pavers with storage bed systems is recommended in this manual only for the stormwater quality design storm and smaller storm events. Use of such systems for larger storm events and the requirements by which such systems are to be designed, constructed, and maintained should be reviewed and approved by all applicable reviewing agencies.

Since permeable paver without storage bed systems do not rely on significant runoff infiltration, they may be used for all frequency storm events.

B. Permeability Rates

The minimum design permeability rate of the soils below porous and permeable paving systems with storage beds will depend upon the pervious paving system's location and maximum design storm. The use of storage beds for stormwater quality control is feasible only where the soil is sufficiently permeable to allow a reasonable rate of infiltration. Therefore, porous paving and permeable paver with storage bed systems can be constructed only in areas with Hydrologic Soil Group A and B soils.

For porous paving and permeable paver with storage bed systems, the minimum design permeability rate of the subgrade soils below a system's runoff storage bed is 0.5 inches per hour. In addition, the design permeability rate of the soils must be sufficient to fully drain the system's maximum design storm runoff volume within 72 hours. This design permeability rate must be determined by field or laboratory testing. See *A. Soil Characteristics* in *Considerations* below for more information. Since the actual permeability rate may vary from test results and may also decrease over time due to soil bed consolidation or the accumulation of sediments removed from the treated stormwater, a factor of safety of two must be applied to the tested permeability rate to determine the design permeability rate. Therefore, if the tested permeability rate of the soils is 4 inches/hour, the design rate would be 2 inches/hour (i.e., 4 inches per hour/2). This design rate would then be used to compute the system's maximum design storm drain time.

Due to its role as a runoff conveyance measure to the storage bed below, the porous surface course of a porous paving system must have a minimum permeability rate at least twice the maximum intensity of the

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system's design storm. In the case of systems designed for the stormwater quality design storm, this permeability rate would be 6.4 inches per hour (i.e., 2 X 3.2 inches per hour, which is the stormwater quality design storm's maximum intensity). Similarly, the minimum permeability of the material used to fill the void spaces of a permeable paver with storage bed system must also meet this requirement. However, since the void spaces in a permeable paver system comprise only a portion of the entire system surface, this minimum rate must be multiplied by the ratio of the entire system surface area to the area of the void spaces. Therefore, the void space material in a permeable paver with storage bed system comprised of 20 percent void space must have a minimum permeability of 2 X (1.0/0.2) or 10 times the maximum design storm intensity. For such systems designed for the stormwater quality design storm, this rate would be 3.2 X 10 or 32 inches per hour.

Since a permeable paver without storage bed system does not rely on significant runoff infiltration, its use does not require a minimum subgrade soil or void space material permeability rate. However, as described below, its ability to reduce runoff rates and volumes below those produced by conventional paving will depend upon both of these system characteristics.

To allow pervious paving surface courses to achieve their design permeability rates, the maximum surface course slope of all pervious paving systems is 5 percent.

C. Pretreatment

As with all other best management practices, pretreatment can extend the functional life and increase the pollutant removal capability of a pervious paving system that receives runoff from areas other than its own surface course. Pretreatment can reduce incoming velocities and capture coarser sediments, which will extend the life and reduce the required maintenance of the system. This is usually accomplished through the use of a vegetative filter immediately upstream of the pervious paving system. Steps can also be taken during the system's design to limit the amount of runoff from upstream areas that will flow to the system.

Runoff collected from parking lots, driveway, roads, and other on-grade surfaces that is conveyed directly to a porous paving or permeable paver storage bed without passing through the system's surface course must be pretreated in order to prevent the loss of storage volume and/or recharge capacity due to sedimentation and clogging. Such pretreatment must provide 80 percent removal of TSS for the system's maximum design storm runoff. This treatment can also be used to meet the site's overall TSS removal requirements.

This pretreatment requirement does not apply to roofs and other above-grade surfaces. However, roof gutter guards and/or sumps or traps (equipped with clean-outs) in the conduits to the system's storage bed should be included wherever practical to minimize the amount of sediment and other particulates that can enter the storage bed.

D. Computing Runoff Rates

In general, runoff to downstream areas from porous paving and permeable paver with storage bed systems will need to be computed under two circumstances. The first occurs when the capacity of the runoff storage bed is exceeded and the water level in the bed rises to the system's surface course. The second circumstance occurs when the intensity of precipitation exceeds the minimum permeability of the system's surface course. See *B. Permeability Rates* above for a discussion of these rates for each type of storage bed system. Once either or both of these circumstances occurs, the resultant system runoff rate to downstream areas for the remainder of the storm can be determined by subtracting the minimum system permeability rate from the rainfall rate. In the case of variable rate storm events such as the stormwater quality design storm or the NRCS Type III Storm, this must be done in a series of appropriate-length time increments over the remaining storm duration.

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Runoff from permeable paver without storage bed systems must be computed for all storm events and can be performed by two methods. The first method is based upon a weighted average runoff coefficient (C) for the Rational or Modified Rational Methods or a weighted average Curve Number (CN) for the NRCS methodology. These values should be based upon the relative areas of the impervious pavers and pervious void spaces in the system's surface. The C or CN value for the paver area should be based upon an impervious surface, while the C or CN value for the void space should be based upon the type of material or surface cover in the void space and the Hydrologic Soil Group of the subgrade soil. In selecting this void space coefficient, all void spaces with vegetated covers should be assumed to be in poor hydrologic condition and all void spaces with bare soil or gravel fill should be based upon soil or gravel roadways.

The second method of computing runoff from permeable paver without storage bed systems considers the pavers to be unconnected impervious areas that drain onto the pervious void spaces. The resultant runoff from the system can then be based upon the unconnected impervious surface methods described in *Chapter 5*. In doing so, the criteria for selecting the appropriate CN for the void space must be based upon the criteria described in the preceding paragraph. In addition, it should be noted that the TR-55 method for unconnected impervious areas as described in *Chapter 5* cannot be used if the void space area is less than 70 percent of the total system area (i.e., the impervious portion of the entire system area exceeds 30 percent).

E. Overflows

All porous paving and permeable paver with storage bed systems must be able to safely convey system overflows to downstream drainage systems. The capacity of the overflow must be consistent with the remainder of the site's drainage system and sufficient to provide safe, stable discharge of stormwater in the event of an overflow. The downstream drainage system must have sufficient capacity to convey the overflow from the pervious paving system.

F. Emergency Inflows

All porous paving and permeable paver with storage bed systems must have measures that will allow runoff from the maximum design storm to enter the runoff storage bed in the event that the porous or permeable paver surface course becomes clogged or otherwise incapable of conveying the maximum design storm runoff to the bed. This may be accomplished in different ways, including surface drain inlets connected to a series of perforated pipes laid throughout the storage bed or by extending the storage bed beyond the edge of the surface course and connecting it to the surface as shown in Figure 9.7-4.

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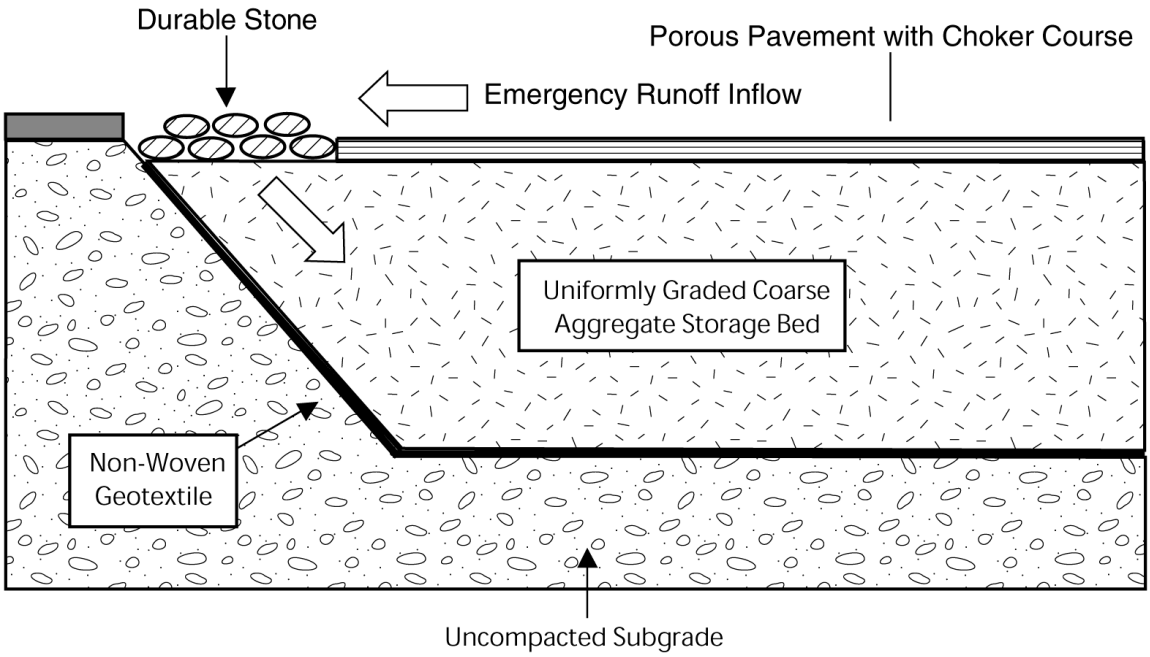
Figure 9.7-4: Example of Porous Paving Emergency Inflow



Note: Emergency inflow may also be provided by surface drain inlets and perforated pipes in the storage bed. See text for details.

Source: Cahill Associates.

G. System Components

The typical components of each type of pervious paving system are shown in Figures 9.7-1, 9.7-2 and 9.7-3. While variations are permissible based upon specific site conditions, the typical system components shown in these figures should be included in all system designs. This includes the sand and crushed stone base below a permeable paver without storage bed system shown in Figure 9.7-3. All such systems constructed without these components must be treated as conventional paved surfaces for the purpose of all runoff and pollutant load computations.

The recommended aggregate for porous asphalt and concrete paving systems are shown in Table 9.7-2. For porous asphalt systems, the recommended amount of asphalt binder is 5.75 to 6.00 percent by weight. Lower amounts of binder have resulted in inadequate surface course shear strength and durability. As shown in Figures 9.7-1 and 9.7-2, the runoff storage beds in both porous paving and permeable paver with storage bed systems should be clean washed, uniformly graded AASHTO No. 2 broken stone. It is particularly important that this stone be washed to keep stone dust and other fine particles that can clog the surface of the subgrade soils from entering the storage bed. The interface between the porous or permeable paver surface course and the storage bed stone should be leveled with a choker course of AASHTO No. 57 broken stone with a minimum thickness of 1 inch. Finally, as shown in Figures 9.7-1 and 9.7-2, the interface between the storage bed stone and the subgrade soil should be lined with a non-woven geotextile. Additional system details are shown in the figures.

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Table 9.7-2 – Porous Asphalt Paving Mix

U.S. Standard Sieve Size	Percent Passing
1/2 inch	100%
3/8 inch	95%
#4	35%
#8	15%
#16	10%
#30	2%

Source: Cahill Associates

Maintenance

Effective pervious paving system performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Measures* contains information and requirements for preparing a maintenance plan for stormwater management facilities, including pervious paving systems. Specific maintenance requirements for all system types are presented below. These requirements must be included in the system's maintenance plan.

General Maintenance

The surface course of all pervious paving systems must be inspected for cracking, subsidence, spalling, deterioration, erosion, and the growth of unwanted vegetation at least once a year. Remedial measures must be taken as soon as practical.

Care must be taken when removing snow from the pervious paving surface courses. Pervious paving surface courses can be damaged by snow plows or loader buckets that are set too low to the ground. This is particularly true at permeable paver systems where differential settlement of pavers has occurred. Sand, grit, or cinders should not be used on pervious paving surface courses for snow or ice control.

If mud or sediment is tracked onto the surface course of a pervious paving system, it must be removed as soon as possible. Removal should take place when the surface course is thoroughly dry. Disposal of debris, trash, sediment, and other waste matter removed from pervious paving surface courses should be done at suitable disposal/recycling sites and in compliance with local, state, and federal waste regulations.

B. Porous Paving Systems

The surface course of a porous paving system must be vacuum swept at least four times a year. This should be following by a high pressure hosing. All dislodged sediment and other particulate matter must be removed and properly disposed.

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C. Permeable Paver Systems

Maintenance of permeable pavers should be consistent with the manufacturer's recommendations.

D. Vegetation

Mowing and/or trimming of turf grass used with permeable pavers must be performed on a regular schedule based on specific site conditions. Grass should be mowed at least once a month during the growing season. All vegetated areas must be inspected at least annually for erosion and scour. Vegetated areas should also be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the paver and remaining vegetation.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed at least twice annually during both the growing and non-growing seasons. The vegetative cover should be maintained at 85 percent. If vegetation has greater than 50 percent damage, the area should be reestablished in accordance with the original specifications and the inspection requirements presented above.

All use of fertilizers, pesticides and other means to assure optimum vegetation health should not compromise the intended purpose of a pervious paving system. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

E. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take to drain the maximum design storm runoff volume below the pervious paving system's surface course. This normal drain time should then be used to evaluate the system's actual performance. If significant increases or decreases in the normal drain time are observed or if the 72 hour maximum is exceeded, the various system components and groundwater levels must be evaluated and appropriate measures taken to comply with the maximum drain time requirements and maintain the proper functioning of the system.

Considerations

Pervious paving systems can present some practical design problems, particularly those with subsurface runoff storage beds that rely on infiltration to discharge the stored runoff. When planning such systems, consideration should be given to soil characteristics, depth to the seasonal high groundwater table, sensitivity of the region, and runoff quality. Particular care must be taken when constructing all pervious paving systems in areas underlain by carbonate rocks known as Karst landscapes. See Appendix A10 of the Standards for Soil Erosion and Sediment Control in New Jersey for further guidance in Karst areas. Further considerations are presented below.

A. Soil Characteristics

Soils are perhaps the most important consideration for site suitability. In general, County Soil Surveys can be used to obtain necessary soil data for system planning purposes, the preliminary design of all pervious paving systems, and the final design of permeable paver without storage bed systems. However, for the final design and construction of porous paving and permeable paver with storage bed systems, soil tests are required at the exact location of a proposed system in order to confirm its ability to function properly without failure.

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Such tests should include a determination of the textural classification and permeability of the subgrade soil at and below the bottom of the proposed system's storage bed. The recommended minimum depth for subgrade soil analysis is 5 feet below the bottom of the storage bed or to the groundwater table. Soil permeability testing can be conducted in accordance with the Standards for Individual Subsurface Sewage Disposal Systems at N.J.A.C. 7:9A. See *Design Criteria* above for further subgrade soil requirements.

In addition, the results of a system's soil testing should be compared with the County Soil Survey data used in the computation of development site runoff and the design of specific site BMPs, including the proposed pervious paving system, to ensure reasonable data consistency. If significant differences exist between the system's soil test results and the County Soil Survey data, additional development site soil tests are recommended to determine and evaluate the extent of the data inconsistency and the need for revised site runoff and BMP design computations. All significant inconsistencies should be discussed with the local Soil Conservation District prior to proceeding with such redesign to help ensure that the final site soil data is accurate.

B. Construction

Similar to other infiltration facilities, the construction of all pervious paver systems must follow certain procedures and sequences. Additional construction requirements are also required for specific systems due to their particular nature and components. Details are provided below.

1. All Pervious Paving Systems

For all pervious paving systems, protection of the subgrade soils from compaction by construction equipment and contamination and clogging by sediment are vital. Prior to its construction, the area to be used for the pervious paving system should be cordoned off to prevent construction equipment and stockpiled materials from compacting the subgrade soils. During system construction, precautions should be taken to prevent both subgrade soil compaction and sediment contamination. All excavation should be performed with the lightest practical excavation equipment. All excavation equipment should be placed outside the limits of the system's storage bed or base.

To help prevent subgrade soil contamination and clogging by sediment, system construction should be delayed until all other construction within in its drainage area is completed and the drainage area stabilized. This delayed construction emphasizes the need, as described above, to cordon off the system area to prevent compaction by construction equipment and material storage during other site construction activities. Similarly, use of a pervious paving system area as a sediment basin is strongly discouraged. Where unavoidable, excavation for the sediment basin should be a minimum of 2 feet above the final design elevation of the system's storage bed or base. Accumulated sediment can then be removed without disturbing the subgrade soils at the system's bottom, which should be established only after all construction within the system's drainage area is completed and the drainage area stabilized.

If system construction cannot be delayed until its drainage area is stabilized, diversion berms or other suitable measures should be placed around the system's perimeter during all phases of construction to divert all runoff and sediment away from the system. These diversion measures should not be removed until all construction within the system's drainage area is completed and the drainage area stabilized.

A preconstruction meeting should be held to review the specific construction requirements and restrictions of all pervious paving systems with the contractor.

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2. Porous Paving Systems

Broken stone in runoff storage beds should be placed in lifts and compacted using plate compactors. A maximum loose lift thickness of 12 inches is recommended. In addition, the following construction requirements for porous asphalt paving systems are recommended by the USEPA:

- Paving temperature = 240° to 260° F.
- Minimum air temperature for paving = 50° F.
- Compact paving with one to two passes with 10-ton roller.
- No vehicular use for a minimum of two days after paving completed.

3. Permeable Paver Systems

Broken stone in runoff storage beds should be placed in lifts and compacted using plate compactors. A maximum loose lift thickness of 12 inches is recommended. In order to provide the runoff quantity and quality benefits described above in *Definition*, the subgrade soils below all permeable paver systems cannot be stabilized through compaction or with cement or other stabilizing agents that reduce the soils' permeability. All permeable paver systems constructed with such stabilization must be treated as conventional paved surfaces for the purpose of all runoff and pollutant load computations.

C. Runoff Quality

The quality of the runoff entering a porous paving or permeable paver with storage bed system is a primary consideration in determining whether such systems are advisable and, if so, in designing the systems themselves. The planning of such systems must consider which pollutants will be present in the runoff and whether these pollutants will degrade groundwater quality. Certain soils can have a limited capacity for the treatment of bacteria and the soluble forms of nitrogen, phosphorus, and other pollutants like road salts and pesticides. Such pollutants are either attenuated in the soil column or go directly to the water table. Unfortunately, the soils that normally have the highest and, therefore, most suitable permeability rates also have the least ability to treat such pollutants. As a result, pretreatment of soluble pollutants prior to entry into a pervious paving system's storage bed may be necessary in these soils. Pretreatment measures may include vegetated filter strips, bioretention systems (where the infiltration basin takes the place of the standard underdrain), and certain sand filters. Alternatively, the existing soil below the infiltration basin bottom may be augmented or replaced by soils with greater soluble pollutant removal rates.

Recommendations

A. Sensitivity of the Area

Since they rely on runoff infiltration, the planning of porous paving or permeable paver with storage bed systems should consider the geologic and ecological sensitivity of the proposed site. Sensitive areas include FW1 streams, areas near drinking water supply wells, and areas of high aquifer recharge. Such pervious paving systems should be sited at least 100 feet from a drinking water supply well. They should also be sited away from foundations to avoid seepage problems. Measures should be taken in areas of aquifer recharge to ensure good quality water is being infiltrated to protect groundwater supplies. Porous paving and permeable paver with storage bed systems should also be located away from septic systems to help prevent septic system failure and other adverse system interference.

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New Jersey Stormwater Best Management Practices Manual

February 2004

CHAPTER 9.9

Standard for Sand Filters

Definition

A sand filter consists of a forebay and underdrained sand bed. It can be configured as either a surface or subsurface facility. Runoff entering the sand filter is conveyed first through the forebay, which removes trash, debris, and coarse sediment, and then through the sand bed to an outlet pipe. Sand filters use solids settling, filtering, and adsorption processes to reduce pollutant concentrations in stormwater. The adopted TSS removal rate for sand filters is 80 percent.

Purpose

Sand filters are normally used to remove relatively large amounts of sediments, metals, hydrocarbons, and floatables from stormwater runoff.

Conditions Where Practice Applies

Sand filters are normally used in highly impervious areas with relatively high TSS, heavy metal, and hydrocarbon loadings such as roads, driveways, drive-up lanes, parking lots, and urban areas. However, due to their relatively high sediment removal capabilities, sand filters are not generally recommended in pervious drainage areas where high coarse sediment loads and organic material such as leaves can quickly clog the sand bed. Where such loadings cannot be avoided, pretreatment is recommended. Since sand filters can be located underground, they can also be used in areas with limited surface space.

A sand filter must have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

Design Criteria

In general, all sand filters consist of four basic components or zones: 1) Forebay Zone, 2) Sand Bed Zone, 3) Sand Bed Underdrain, and 4) Overflow. These and other typical sand filter components are shown in Figures 9.9-1, 2, and 3. These figures depict, respectively, a surface, subsurface, and perimeter sand filter, which are the three sand filter types discussed in this manual.

The basic design parameters for all three of these sand filter types are the surface areas and the temporary storage volumes in their forebay and sand bed zones and the thickness and infiltration rate of their sand beds. There must be sufficient total temporary storage volume within the forebay and sand bed zones (including the sand bed itself) to contain the design runoff volume and direct it thought the sand bed without overflow. The thickness of the sand bed must provide adequate pollutant removal, while the bed's permeability or infiltration rate must be sufficient to drain the stored runoff within 72 hours. In addition, the capacity of the sand bed underdrain must allow the sand bed to drain freely, while the overflow must safely convey the runoff from storms greater than the design storm. Details of these and other design parameters are presented below.

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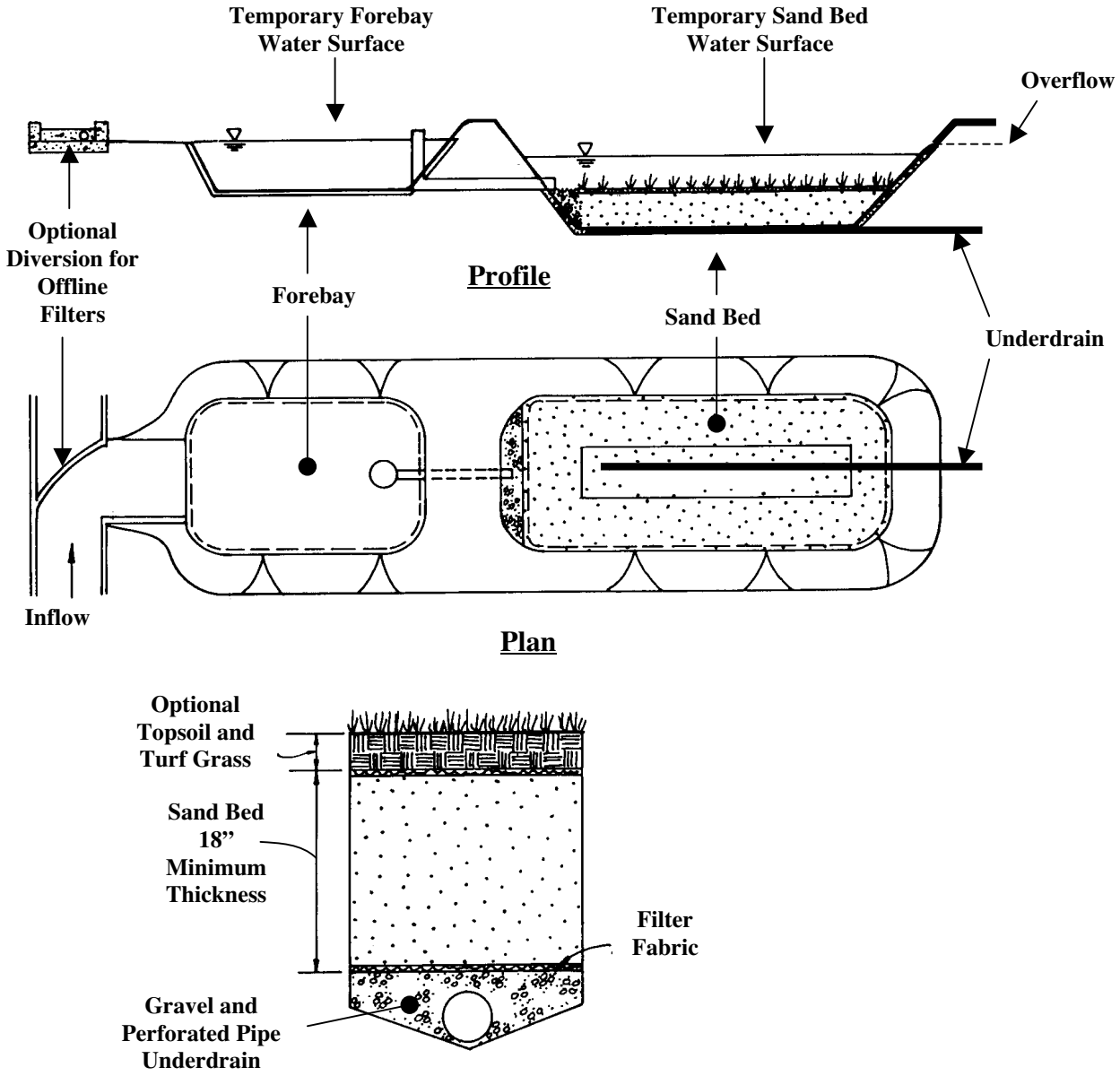
Figure 9.9-1: Typical Surface Sand Filter Components



Source: Adapted from Claytor and Schueler, 1996.

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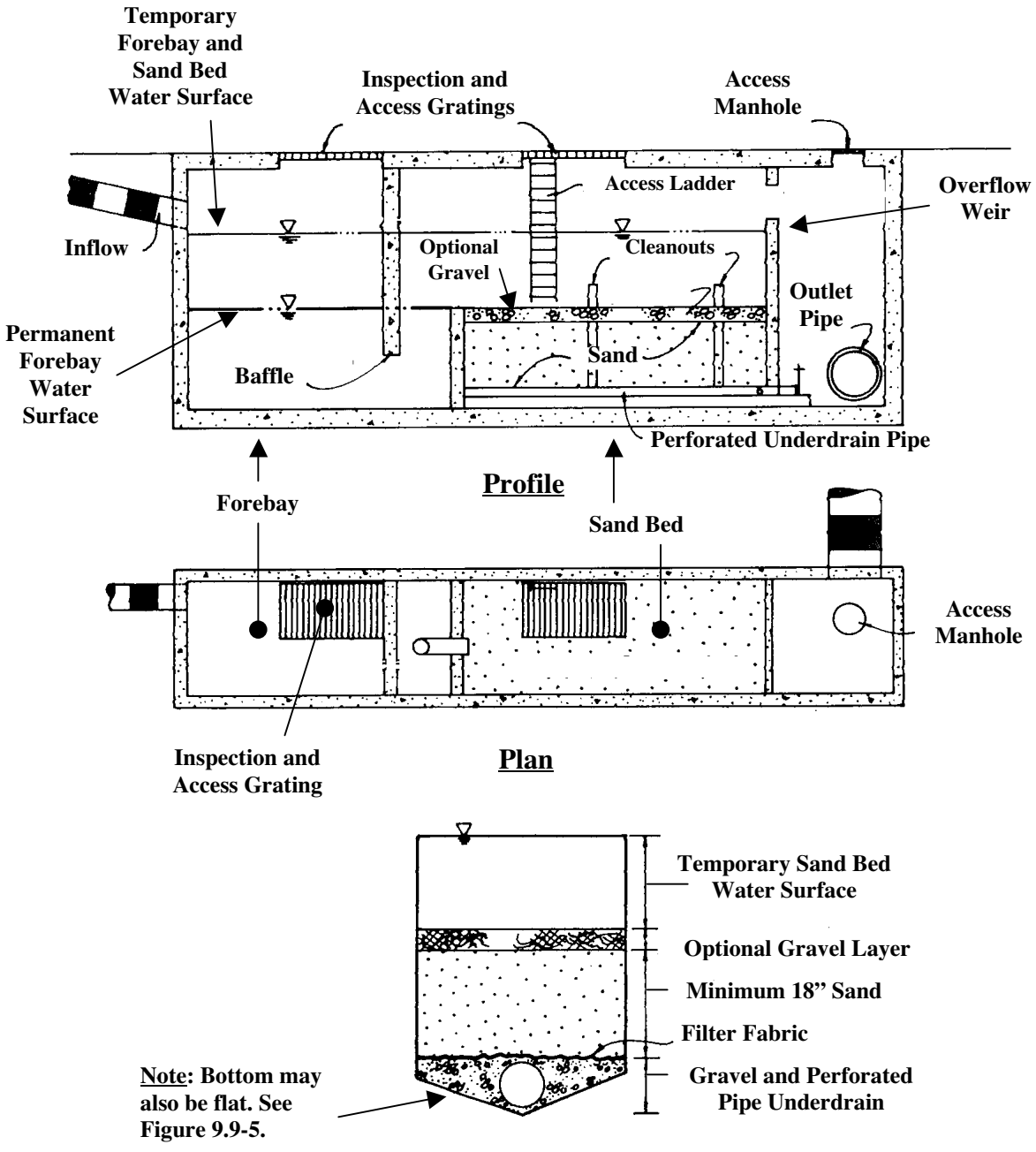
Figure 9.9-2: Typical Subsurface Sand Filter Components



Typical Sand Bed Section

Source: Adapted from Claytor and Schueler, 1996.

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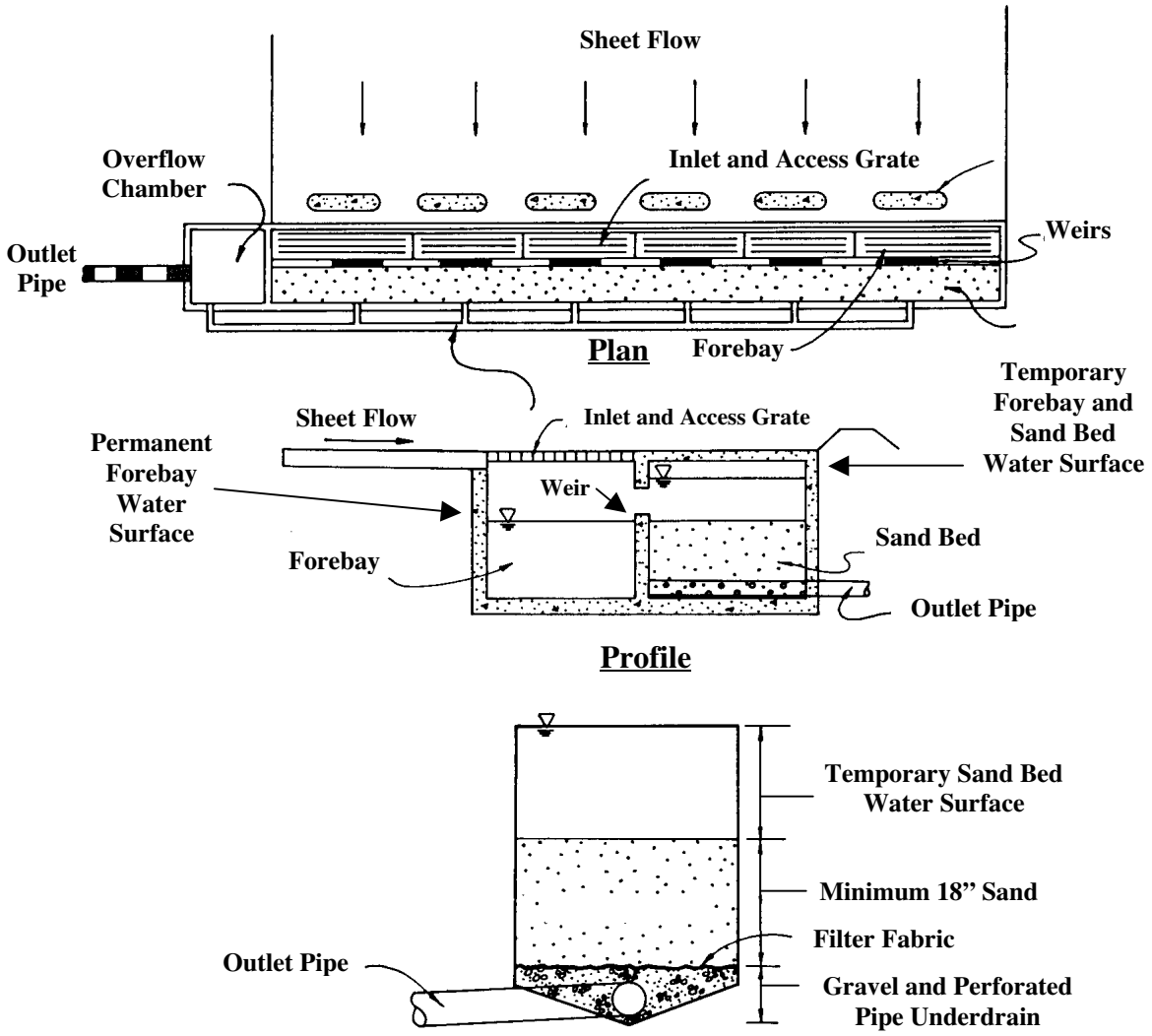
Figure 9.9-3: Typical Perimeter Sand Filter Components



Typical Sand Bed Section

Note: Bottom may also be flat.
See Figure 9.9-5.

Source: Adapted from Claytor and Schueler, 1996.

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A. Storage Volume and Duration

Sand filters must be designed to treat the runoff volume generated by the stormwater quality design storm. Techniques to compute this volume are discussed in *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. The maximum time required to fully drain the stormwater quality design storm runoff volume is 72 hours. As shown in Table 9.9-1, a design drain time of 36 hours must be used when designing the sand bed.

B. Component Dimensions, Areas, and Volumes

The required volumes, areas, and dimensions of the various sand filter components are shown in Table 9.9-1. Several of these parameters are depicted in Figure 9.9-4.

Table 9.9-1: Typical Sand Filter Design Parameters

#	Parameter Description	Parameter	Parameter Value		
			Surface Filter	Subsurface Filter	Perimeter Filter
1	Total Temporary Volume in Forebay and Sand Bed Zones[1]	V_{QS}	Stormwater Quality Design Storm Runoff Volume	Stormwater Quality Design Storm Runoff Volume	Stormwater Quality Design Storm Runoff Volume
2	Approximate Temporary Sand Bed Volume[2]	V_{ST}	$(0.5)(V_{QS})$	$(0.5)(V_{QS})$	$(0.5)(V_{QS})$
3	Minimum Sand Bed Thickness	TH_S	18 Inches	18 Inches	18 Inches
4	Sand Bed Design Porosity	n	0.3	0.3	0.3
5	Sand Bed Design Permeability	k	4 Feet per Day	4 Feet per Day	4 Feet per Day
6	Sand Bed Design Drain Time	T_D	1.5 Days	1.5 Days	1.5 Days
7	Minimum Sand Bed Surface Area	A_S	See Equation 9.9-1	See Equation 9.9-1	See Equation 9.9-1
8	Approximate Temporary Forebay Volume[3]	V_{FT}	$(0.5)(V_{QS})$	$(0.5)(V_{QS})$	$(0.5)(V_{QS})$
9	Minimum Forebay Surface Area	A_F	$(0.05)(V_{QS})$	$(0.05)(V_{QS})$	$(0.05)(V_{QS})$
10	Minimum Temporary Forebay Depth	D_{FT}	2 Feet	N/A	N/A
11	Minimum Permanent Forebay Depth	D_{FP}	N/A[4]	2 Feet	2 Feet
12	Overall Minimum Length to Width Ratio	L/W	2	2	N/A

Notes:

1. Includes temporary storage volume in sand, but excludes storage volume in forebay permanent pool.
2. Includes temporary storage volume in sand.
3. Excludes storage volume in forebay permanent pool.
4. Forebay in surface sand filter typically does not have permanent pool.

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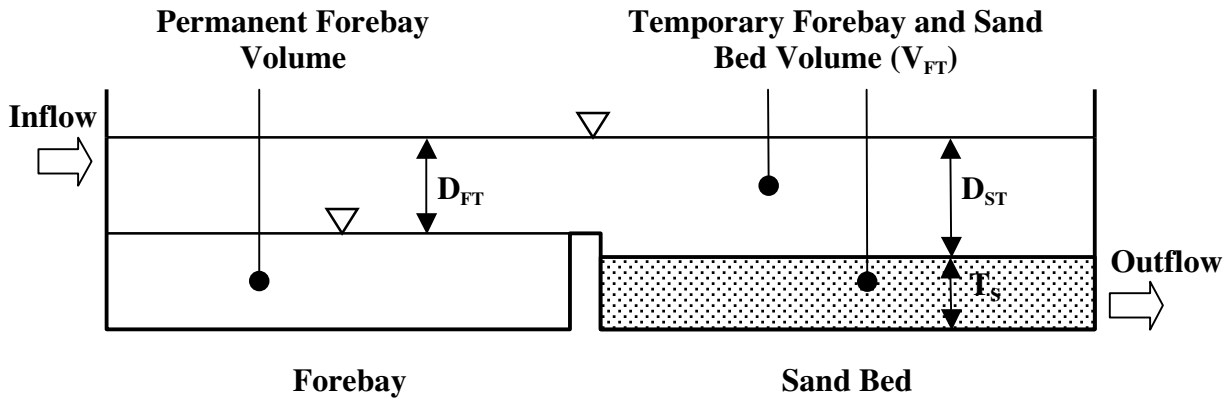
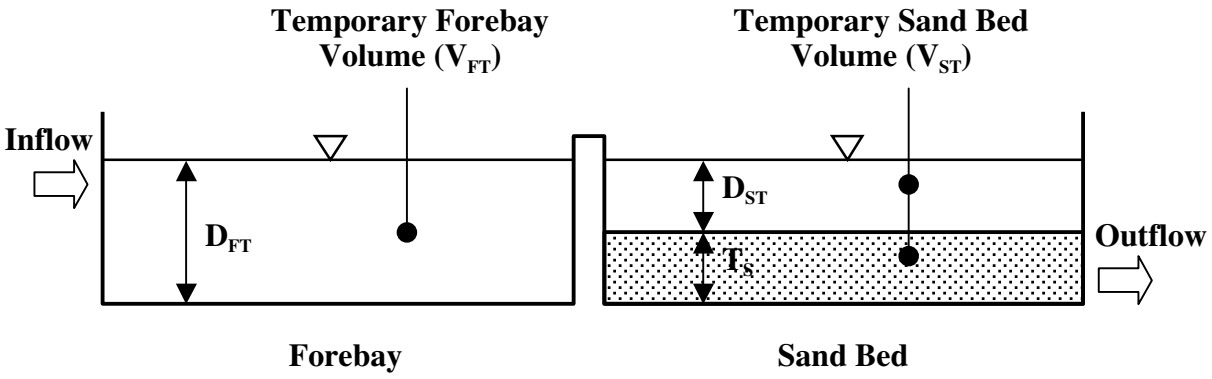
Figure 9.9-4: Sand Filter Schematics



Schematic for Subsurface and Perimeter Sand Filters



Schematic for Surface Sand Filters

Source: Adapted from Claytor and Schueler, 1996.

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C. General Design Procedure

Due to the number of design parameters, the design of a sand filter is generally a trial and error process to some degree. Utilizing the design parameters in Table 9.9-1 and the sand filter schematics shown in Figure 9.9-4, the general design procedure for sand filters is as follows:

1. Determine the runoff volume (V_{QS}) and peak discharge rate (Q_{QDS}) to the sand filter for the stormwater quality design storm. From Line 1 in Table 9.9-1, the total temporary storage volume in the sand filter's forebay and sand bed zones (including the storage volume within the sand bed, but excluding any permanent forebay storage volume) must equal V_{QS}.
2. Determine the approximate required volumes of the sand filter's forebay and sand bed zones. As shown on Lines 2 and 8 in Table 9.9-1, these volumes should each be approximately equal to one half of the stormwater quality design storm runoff volume (V_{QS}).
3. Estimate the maximum temporary depths in the sand bed (D_{ST}) and forebay (D_{FT}) zones for the stormwater quality design storm. This estimate should be based on an analysis of site conditions, including the difference between the invert elevation of the downstream conveyance system and the maximum ground elevation at the filter site. Analysis of this elevation difference should include consideration for the minimum sand bed thickness (T_{HS}) on Line 3 and either the minimum temporary forebay depth (D_{FT}) for surface filters on Line 10 or the permanent forebay depth (D_{FP}) for subsurface and perimeter filters on Line 11 of Table 9.9-1. As shown in Figure 9.9-4, the maximum temporary depth in the sand bed zone (D_{ST}) is measured from the top of the sand bed, while the maximum temporary forebay depth (D_{FT}) is measured from any permanent forebay water surface.
4. Compute the minimum forebay surface area (A_F). As shown on Line 9 of Table 9.9-1, this minimum area is $(0.05)(V_{QS})$. It should be noted that the 0.05 multiplier in the equation has the units of area per volume or L^2/L^3. As such, the equation yields square feet of forebay area from cubic feet of stormwater quality design storm runoff volume.
5. From the maximum temporary depth in the forebay (D_{FT}) from Step 3 and the minimum forebay area (A_F) from Step 4, compute the total temporary storage volume in the forebay (V_{FT}). Compare this volume with the approximate required forebay volume computed in Step 2. Adjust the maximum temporary forebay depth (D_{FT}) and/or forebay area (A_F) as necessary to achieve a total temporary forebay storage volume (V_{FT}) as close as practical to the required forebay volume from Step 2. While adjusting the forebay surface area (A_F) by varying its length and width, remember that the forebay will be located immediately adjacent to the sand bed zone and that the recommended minimum overall length to width ratio of these combined zones in surface and subsurface filters is two to one.
6. As shown on Line 7 of Table 9.9-1, compute the minimum sand bed surface area (A_S) using the following equation:

$$A_S = (V_{QS})(TH_S) / [(k)(D_{ST}/2 + TH_S)(T_D)] \qquad \text{(Equation 9.9-1)}$$

Where:

A_S = Minimum Sand Bed Surface Area (in square feet)
V_{QS} = Runoff Volume from the Stormwater Quality Design Storm (in cubic feet)
TH_S = Thickness of Sand in Sand Bed (in feet)
k = Sand Bed Design Permeability (in feet per day)
D_{ST} = Maximum Temporary Sand Bed Depth (in feet)
T_D = Sand Bed Drain Time (in days)

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As shown in Table 9.9-1, the following parameter design values for Equation 9.9-1 are recommended:

Minimum Sand Thickness in Sand Bed (TH_S) = 18 inches
Sand Bed Design Permeability (k) = 4 feet per day
Sand Bed Design Drain Time = 1.5 days

7. Compute the total temporary storage volume in the sand bed zone (V_{ST}) from the following equation:

$$V_{ST} = (A_S)(D_{ST}) + (A_S)(TH_S)(n) \quad \text{(Equation 9.9-2)}$$

Where:

V_{ST} = Temporary Sand Bed Storage Volume (in cubic feet)
A_S = Sand Bed Surface Area (in square feet)
D_{ST} = Maximum Temporary Sand Bed Depth (in feet)
TH_S = Thickness of Sand in Sand Bed (in feet)
n = Sand Bed Design Porosity

As shown in Table 9.9-1, the following parameter design values for Equation 9.9-2 are recommended:

Minimum Sand Thickness in Sand Bed (TH_S) = 18 inches
Sand Bed Design Porosity (n) = 0.3

8. Compare the total temporary sand bed storage volume (V_{ST}) with the approximate required sand bed zone volume computed in Step 2. As shown on Line 2 of Table 9.9-1, this temporary sand bed storage volume should be approximately one half of the stormwater quality design storm runoff volume (V_{QS}). In addition, add the total temporary sand bed volume (V_{ST}) to the total temporary forebay storage volume (V_{FT}) to determine the total temporary storage volume in the sand filter. As shown on Line 1 of Table 9.9-1, this total temporary storage volume must equal the stormwater quality design storm runoff volume (V_{QS}). Adjust the maximum temporary sand bed depth (D_{ST}) and/or sand bed area (A_S) as necessary to achieve a total temporary sand bed storage volume (V_{ST}) as close as practical to the required sand bed volume from Step 2 and a total filter volume equal to V_{QS}. Once again, while adjusting the sand bed surface area (A_S) by varying its length and width, remember that the sand bed will be located immediately adjacent to the forebay and that the recommended minimum overall length to width ratio of these combined zones in surface and subsurface filters is two to one.

D. Filter Bed Sand

The sand used in the sand bed must meet the specifications for clean medium aggregate concrete sand in accordance with AASHTO M-6 or ASTM C-33. This must be certified by a professional engineer licensed in the State of New Jersey.

E. Gravel Layer and Underdrain

The gravel layer serves as bedding material for the underdrain pipes. It must have sufficient thickness to provide a minimum of 2 inches of gravel above and below the pipes. It should consist of 0.5" to 1.5" clean broken stone or pea gravel (AASHTO M-43).

The underdrain piping must be rigid Schedule 40 PVC pipe in accordance with AASHTO M278. Perforated underdrain piping should have a minimum of 3/8-inch diameter perforations at 6-inch centers

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with four perforations per annular row. The portion of drain piping beneath the sand bed must be perforated. All remaining underdrain piping, including cleanouts, must be nonperforated. All joints must be secure and watertight. Cleanouts must be located at the upstream and downstream ends of the perforated section of the underdrain and extend to or above the surface of the sand bed. Additional cleanouts should be installed as needed.

The underdrain piping must connect to a downstream storm sewer manhole, catch basin, channel, swale, or ground surface at a location that is not subject to blockage by debris or sediment and is readily accessible for inspection and maintenance. Blind connections to downstream storm sewers are prohibited. To ensure proper system operation, the gravel layer and perforated underdrain piping must have infiltration rates at least twice as fast as the design infiltration rate of the sand bed.

Additional details of typical sand filter underdrains are shown in Figure 9.9-5.

F. Overflows

All sand filters must be able to safely convey overflows to downstream drainage systems. The capacity of the overflow must be consistent with the remainder of the site's drainage system and sufficient to provide safe, stable discharge of stormwater in the event of an overflow. Sand filters that are classified as dams under the NJDEP Dam Safety Standards at N.J.A.C. 7:20 must also meet the overflow requirements of these Standards. Overflow capacity can be provided by a hydraulic structure such as a weir or orifice, or a surface feature such as a swale or open channel, as filter location and site conditions allow.

G. Tailwater

The hydraulic design of the underdrain and overflow systems, as well as any stormwater quantity control outlets, must consider any significant tailwater effects of downstream waterways or facilities. This includes instances where the lowest invert in the outlet or overflow structure is below the flood hazard area design flood elevation of a receiving stream.

H. On-line and Off-line Systems

In general, most sand filters are constructed off-line. In off-line sand filters, most or all of the runoff from storms larger than the stormwater quality design storm bypass the filter through an upstream diversion. This not only reduces the size of the required filter overflow, but also reduces the filter's long-term pollutant loading and associated maintenance and the threat of erosion and scour caused by larger storm inflows. However, sand filters may also be constructed on-line. On-line filters receive upstream runoff from all storms, providing runoff treatment for the stormwater quality design storm and conveying the runoff from larger storms through an overflow. Multi-purpose on-line filters also store and attenuate these larger storms to provide runoff quantity control. In such filters, the invert of the lowest stormwater quantity control outlet is set at or above the maximum stormwater quality design storm water surface.

Maintenance

Effective sand filter performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Practices* provides information and requirements for preparing a maintenance plan for stormwater management facilities, including sand filters. Specific maintenance requirements for sand filters are presented below. These requirements must be included in the filter's maintenance plan.

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A. General Maintenance

All sand filter components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times annually as well as after every storm exceeding 1 inch of rainfall. Such components may include inlets and diversion structures, forebays, sand beds, and overflows.

Sediment removal should take place when all runoff has drained from the sand bed and the sand is reasonably dry. In addition, runoff should be drained or pumped from forebays with permanent pools before removing sediment. Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state, and federal waste regulations.

B. Vegetated Areas

In surface sand filters with turf grass bottom surfaces, mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass should be mowed at least once a month during the growing season. Vegetated areas must also be inspected at least annually for erosion and scour. The filter bottom must be inspected for unwanted underbrush and tree growth at least once a year.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed during both the growing and non-growing season at least twice annually. If vegetation has greater than 50 percent damage, the area should be reestablished in accordance with the original specifications and the inspection requirements presented above.

All use of fertilizers, mechanical treatments, pesticides and other means to assure optimum vegetation health must not compromise the intended purpose of the sand filter. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

C. Structural Components

All structural components must be inspected for cracking, subsidence, spalling, erosion, and deterioration at least annually.

D. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take to drain the maximum design storm runoff volume below the top of the filter's sand bed. This normal drain or drawdown time should then be used to evaluate the filter's actual performance. If significant increases or decreases in the normal drain time are observed, the filter's sand bed, underdrain system, and tailwater levels must be evaluated and appropriate measures taken to comply with the maximum drain time requirements and maintain the proper functioning of the filter.

The sand bed should be inspected at least twice annually. The infiltration rate of the sand bed material may also be retested. If the water fails to infiltrate 72 hours after the end of the stormwater quality design storm, corrective measures must be taken.

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Considerations

A. Forebay and Sand Bed Drains

Wherever possible in subsurface and perimeter filters, a drain and valve should be provided in the forebay to permit draining of all standing water and facilitate sediment removal. This drain and valve can be connected to the sand bed underdrain system.

B. Drainage Area Stabilization

No runoff should enter the filter's sand bed until the upstream drainage area is completely stabilized and site construction is completed.

C. Watertight Construction

Underground sand filters should always be constructed completely watertight, especially if treating runoff from "hotspots" or over extremely sensitive groundwater areas.

D. Pretreatment

As with all other best management practices, pretreatment can extend the functional life and increase the pollutant removal capability of a sand filter. Pretreatment can reduce incoming velocities and capture coarser sediments, which will extend the life of the system. This is usually accomplished through such means as a vegetative filters and/or a manufactured treatment device. Information on vegetative filters and manufactured treatment devices is presented in Chapters 9.10 and 9.6, respectively.

As shown in Figures 9.9-1, 9.9-2, and 9.9-3, forebays at the inflow points to sand filters can capture coarse sediments, trash, and debris, which can simplify and reduce the frequency of filter maintenance. A forebay should be sized in accordance with Table 9.9-1 to hold the sediment volume expected between clean-outs.

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C H A P T E R 9 . 1 0

Standard for Vegetative Filters

Definition

A vegetative filter is an area designed to remove suspended solids and other pollutants from stormwater runoff flowing through a length of vegetation called a vegetated filter strip. The vegetation in a filter strip can range from turf and native grasses to herbaceous and woody vegetation, all of which can either be planted or indigenous. It is important to note that all runoff to a vegetated filter strip must both enter and flow through the strip as sheet flow. Failure to do so can severely reduce and even eliminate the filter strip's pollutant removal capabilities.

The total suspended solid (TSS) removal rate for vegetative filters will depend upon the vegetated cover in the filter strip. Table 9.10-1 below presents the adopted TSS removal rates for various vegetated covers.

Table 9.10-1: Adopted TSS Removal Rates for Vegetated Filter Strips

Vegetated Cover	Adopted TSS Removal Rate
Turf grass	60 %
Native Grasses, Meadow, and Planted Woods	70 %
Indigenous woods	80 %

For filter strips with multiple vegetated covers, the final TSS removal rate should be based upon a weighted average of the adopted rates shown above in Table 9.10-1. This weighted average removal rate should be based upon the relative flow lengths through each cover type. For example, a 50-foot long vegetated filter strip (measured in the direction of flow) that has turf grass in the upper 25 feet and native grasses in the lower 25 feet would have a TSS removal rate of (25/50)(60%) + (25/50)(70%) or 65 percent.

Purpose

A vegetative filter is intended to remove pollutants from runoff flowing through it. Vegetated filter strips can be effective in reducing sediment and other solids and particulates, as well as associated pollutants such as hydrocarbons, heavy metals, and nutrients. The pollutant removal mechanisms include sedimentation, filtration, adsorption, infiltration, biological uptake, and microbacterial activity.

Vegetated filter strips with planted or indigenous woods may also create shade along water bodies that lower aquatic temperatures, provide a source of detritus and large woody debris for fish and other aquatic organisms, and provide habitat and corridors for wildlife.

Condition Where Practice Applies

A vegetative filter can be effective only where the runoff entering and flowing through the strip remains as sheet flow and does not concentrate. This sheet flow requirement limits the use of vegetated filter strips in two ways. First, the area used for the filter strip itself must be mildly sloped and uniformly graded to maintain sheet flow or, in the case of indigenous areas, have surface features that retard, pond, and/or disperse runoff generally over the entire filter width. Second, since the runoff to a filter strip must enter the strip as sheet flow, the drainage area to the strip must also be uniformly graded and have a relatively horizontal downstream edge where it meets the upstream end of the filter strip. Such drainage areas may include yards, parking lots, and driveways where runoff flows as sheet flow. As a result, an area with irregular grading and other surface features that cause runoff to concentrate could neither be used as a vegetated filter strip nor have its runoff treated by one. For the same reasons, vegetated filter strips are also not intended to treat concentrated discharges from storm sewers, swales, and channels.

As detailed below in *Design Criteria*, additional factors must be considered. First, the vegetation in all filter strips must be dense and remain healthy and, in the case of planted or indigenous woods, have an effective mulch or duff layer. In addition, a vegetated filter strip must have a maintenance plan and be protected by an easement, deed restriction, or other legal measure that guarantees its existence and effectiveness in the future. Depending upon their TSS removal rate, vegetated filter strips can be used separately or in conjunction with other stormwater quality practices to achieve an overall pollutant removal goal.

Design Criteria

The primary design parameters for a vegetated filter strip are its slope, type of vegetated cover, and the type of soils within its drainage area. These three parameters are then used to determine the standard filter strip length required to achieve the adopted TSS removal rates shown above in Table 9.10-1. In addition, since runoff from the stormwater quality design storm must enter and continue as sheet flow over this length, the peak runoff rate must be sufficiently low and uniformly distributed to ensure such conditions. This peak runoff rate is achieved by limiting the sheet flow length that runoff will flow before entering the filter strip. This length limitation, in turn, limits the size of the drainage area to the filter strip and, consequently, the peak runoff rate. Details of these and other design parameters are presented below. The components of a typical vegetated filter strip are shown in Figure 9.10-1.

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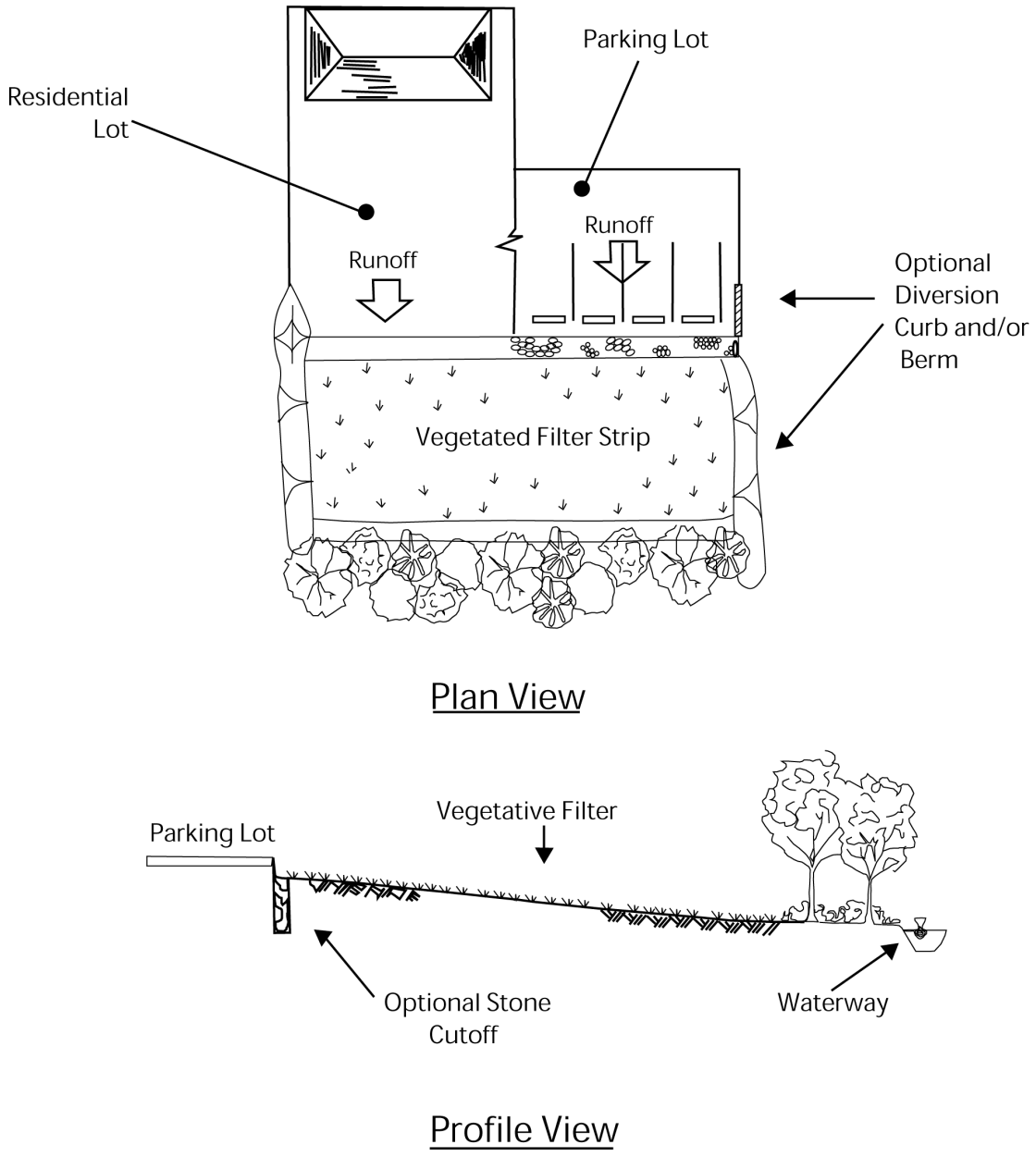
Figure 9.10-1 Vegetative Filter Components



Source: Adapted from Schueler and Claytor 1996.

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A. Drainage Area and Runoff Characteristics

As noted above, runoff from a drainage area may be directed to flow through a filter strip provided it enters the filter strip and continues through it as sheet flow. In addition, the peak rate and maximum depth of runoff entering the filter strip must be low enough to allow the strip's vegetated cover to serve as an effective filter. As such, the maximum drainage area to a vegetated filter strip will be limited to an area 100 feet long for impervious surfaces and 150 feet long for pervious surfaces. These lengths are to be measured in the direction of flow to the upstream edge of the filter strip.

In addition, the interface of the drainage area and the upstream edge of the filter strip must be as horizontal as possible (perpendicular to the flow direction) so that runoff will be evenly distributed along the upstream edge of the strip. As shown in Figure 9.10-1, a stone cutoff trench, recessed curb, or other measure may be used along the filter's upstream edge to help distribute the runoff and dissipate some of its energy as it enters the filter strip.

As noted above, the required strip lengths are based in part upon the type of soils within the filter strip's drainage area. Table 9.10-2 below lists the various types of soils and their associated Hydrologic Soil Groups that will affect the strip's required length. County Soil Surveys and onsite soil investigations can be used to determine these soil types. Where more than one type of soil exists in a drainage area, the soil with the smallest particle size (and, consequently, the longest filter strip length) should be used in the filter strip's design.

B. Filter Strip Cover

As noted above, the vegetation in a filter strip can range from turf and native grasses to herbaceous and woody vegetation, all of which can either be planted or indigenous. The type of vegetation used in the filter strip can be very broad, although the best performance is associated with those with dense growth patterns such as turf-forming grasses and dense forest floor vegetation. All vegetation must be dense and healthy. In addition, planted woods must have a mulch layer with a minimum thickness of 3 inches, while indigenous woods must have at least a 1 inch thick natural duff layer.

Further information and references are presented in *Chapter 7: Landscaping*.

C. Filter Strip Grading

As noted above, the area used for a vegetated filter strip itself must be mildly sloped and uniformly graded to maintain sheet flow or, in the case of indigenous areas, have surface features that retard, pond, and/or disperse runoff generally over the entire filter width. As such, indigenous areas such as meadows and woods under consideration as vegetated filter strips should be surveyed and inspected during runoff events to determine runoff flow patterns. Indigenous areas with surface features that obstruct or retard runoff flow, cause ponding, and/or disperse runoff are acceptable, while those with surface features that cause runoff to concentrate are not. It should be noted that such observations must be made with consideration for the proposed volume and peak rate of runoff that the area would receive as a vegetated filter strip.

D. Maximum Filter Strip Slope

In addition to the soils within a vegetated filter strip's drainage area, the soils within the filter strip itself are also important for determining filter strip's maximum allowable slope. Table 9.10-2 below presents maximum filter strip slopes for various vegetated covers and soil types within the filter strip. County Soil Surveys and onsite soil investigations can be used to determine the soil type within a filter strip.

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Table 9.10-2: Maximum Filter Strip Slope

Filter Strip Soil Type	Hydrologic Soil Group	Maximum Filter Strip Slope (Percent)	
		Turf Grass, Native Grasses, and Meadows	Planted and Indigenous Woods
Sand	A	7	5
Sandy Loam	B	8	7
Loam, Silt Loam	B	8	8
Sandy Clay Loam	C	8	8
Clay Loam, Silty Clay, Clay	D	8	8

E. Required Filter Strip Length

To achieve the adopted TSS removal rates shown above in Table 9.10-1, the required filter strip length can be determined from Figures 9.10-2 to 6 below based upon the filter strip's slope, vegetated cover, and the soil within its drainage area. As shown in the figures, the minimum length for all vegetated filter strips is 25 feet.

Figure 9.10-2: Vegetated Filter Strip Length
Drainage Area Soil: Sand HSG: A

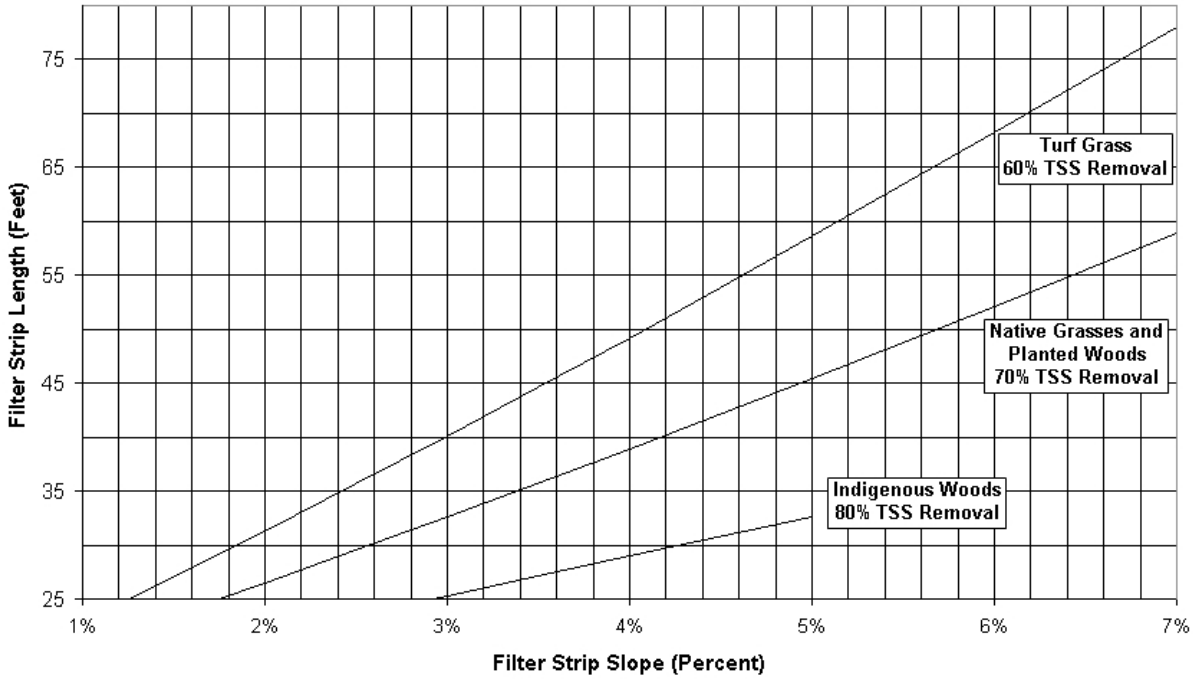

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Figure 9.10-3: Vegetated Filter Strip Length
Drainage Area Soil: Sandy Loam HSG: B

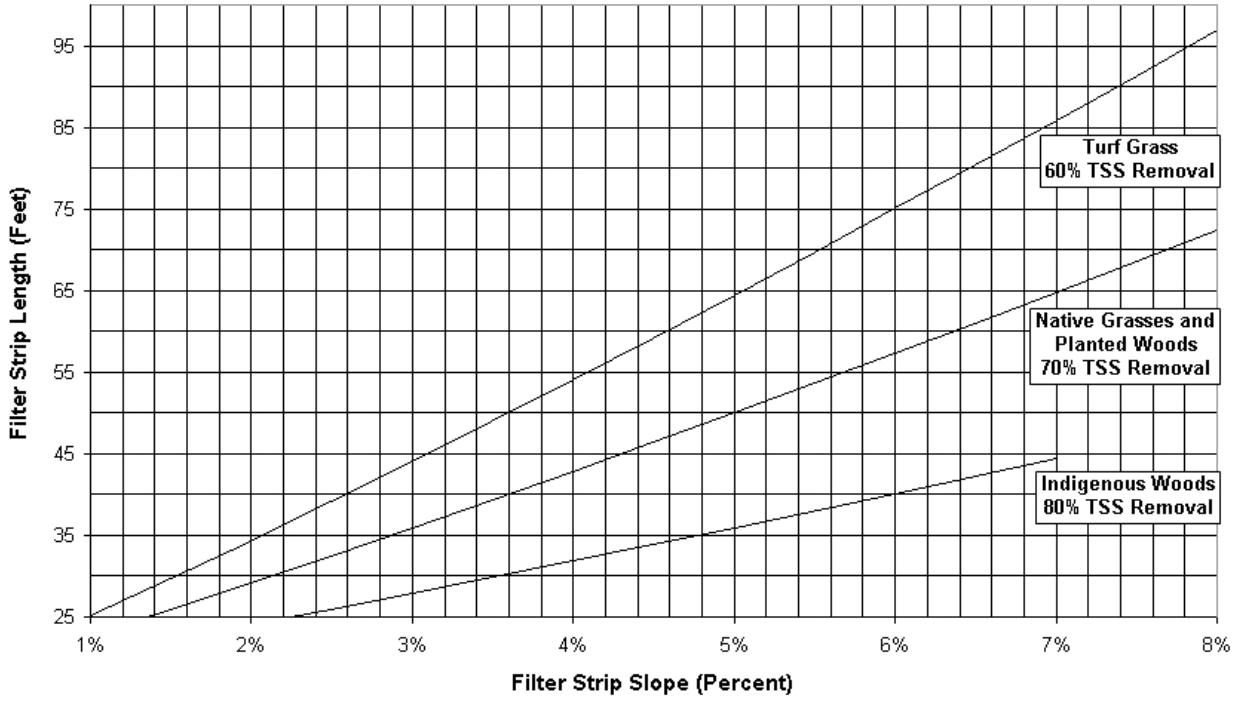

Figure 9.10-4: Vegetated Filter Strip Length
Drainage Area Soil: Loam, Silt Loam HSG: B

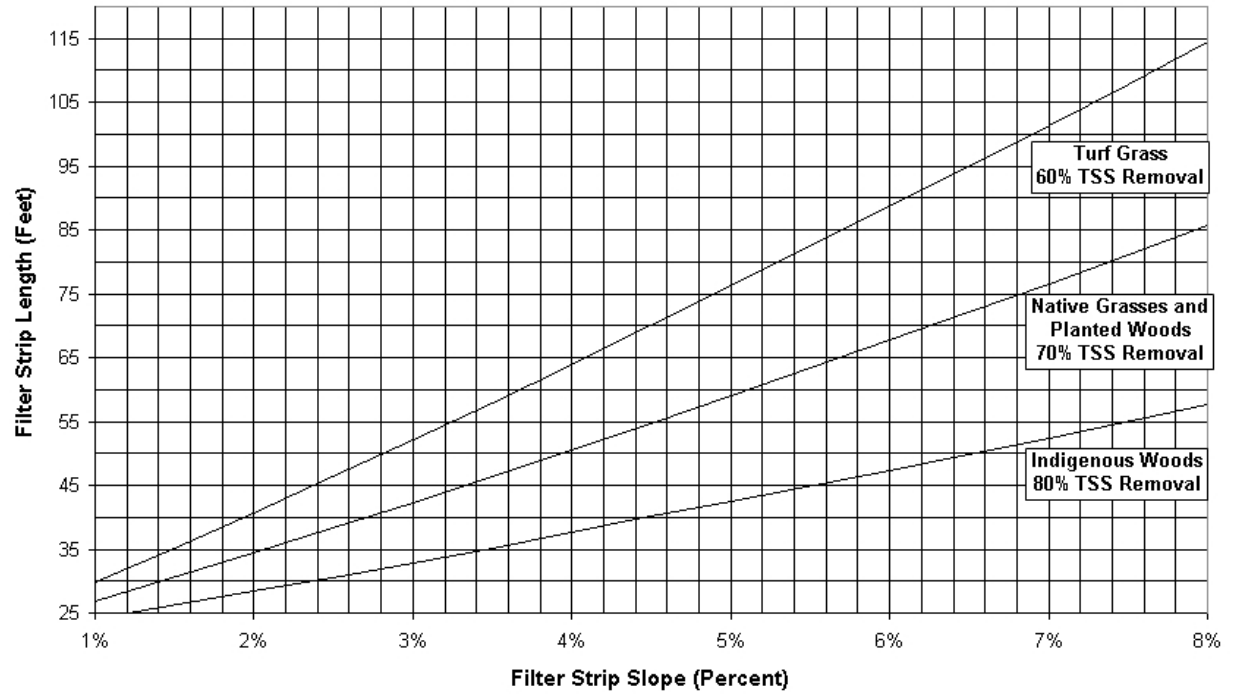

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Figure 9.10-5: Vegetated Filter Strip Length
Drainage Area Soil: Sandy Clay Loam HSG: C

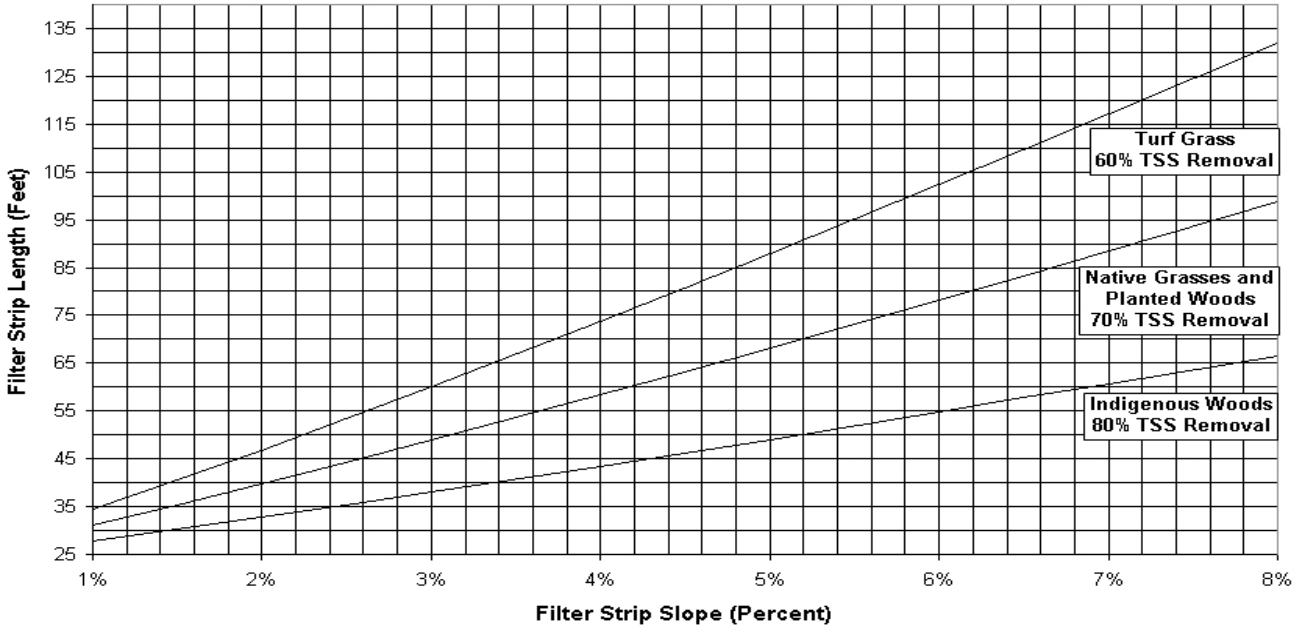
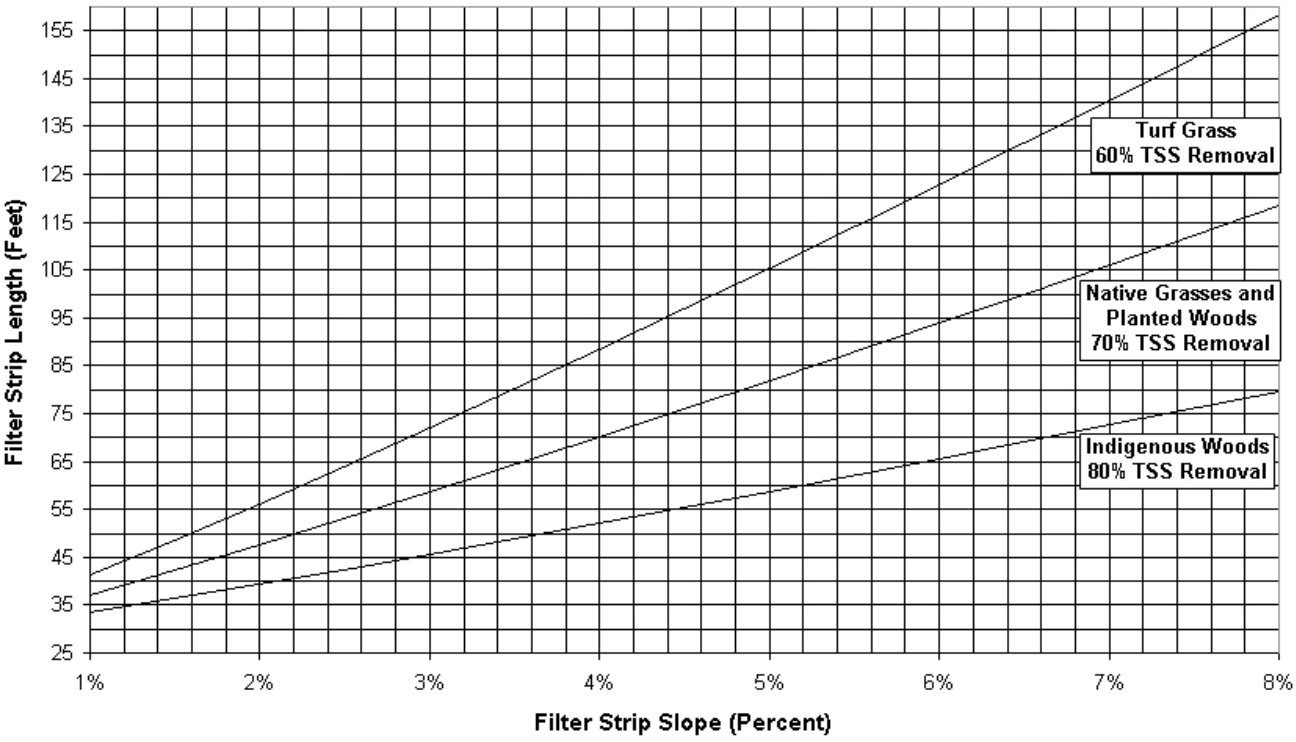


Figure 9.10-6: Vegetated Filter Strip Length
Drainage Area Soil: Clay Loam, Silty Clay, Clay HSG: D



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Example 9.10-1: Computing Required Vegetated Filter Strip Length

A vegetated filter strip is to be installed at a uniform 5 percent slope to treat the runoff from a drainage area consisting of a paved parking lot and turf grass lawn. Runoff from the parking lot and lawn will enter the filter strip as sheet flow. The maximum sheet flow lengths across the parking lot and lawn do not exceed 100 and 150 feet, respectively. The soil in the drainage area is a silt loam. Compute the required filter strip length if the strip is to be vegetated with turf grass.

1. Determine the Hydrologic Soil Group of the drainage area soil. From Table 9.10-2, a silt loam is in Hydrologic Soil Group B.
2. Determine the maximum slope of the filter strip. Also from Table 9.10-2, the maximum slope of a turf grass filter strip with Hydrologic Soil Group B soils is 8 percent, which is greater than the 5 percent slope of the proposed filter strip.
3. Determine the required length of the filter strip. From Figure 9.10-4 for silt loam soils, the required length of a turf grass filter strip with a 5 percent slope is approximately 76 feet. The resultant TSS removal rate for the turf grass filter strip will be 60 percent.

Maintenance

Effective vegetated filter strip performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Practices* provides information and requirements for preparing a maintenance plan for stormwater management facilities, including vegetated filter strips. Specific maintenance requirements for vegetated filter strips are presented below. These requirements must be included in the filter strip's maintenance plan.

A. General Maintenance

All vegetated filter strip components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times annually and after every storm exceeding 1 inch of rainfall. Such components may include vegetated areas and stone cutoffs and, in particular, the upstream edge of the filter strip where coarse sediment and/or debris accumulation could cause inflow to concentrate.

Sediment removal should take place when the filter strip is thoroughly dry. Disposal of debris and trash should be done only at suitable disposal/recycling sites and must comply with all applicable local, state, and federal waste regulations.

B. Vegetated Areas

Mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass should be mowed at least once a month during the growing season. Vegetated areas must be inspected at least annually for erosion and scour. Vegetated areas should also be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the planting soil bed and remaining vegetation.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed during both the growing and non-growing season at least twice annually. The vegetative cover should be maintained at 85 percent. If

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vegetation has greater than 50 percent damage, the area should be reestablished in accordance with the original specifications and the inspection requirements presented above.

All use of fertilizers, mechanical treatments, pesticides and other means to assure optimum vegetation health must not compromise the intended purpose of the vegetative filter. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

All areas of the filter strip should be inspected for excess ponding after significant storm events. Corrective measures should be taken when excessive ponding occurs.

C. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take for the filter strip to drain the maximum design storm runoff volume and begin to dry. This normal drain time should then be used to evaluate the filter's actual performance. If significant increases or decreases in the normal drain time are observed or if the 72 hour maximum is exceeded, the filter strip's planting soil bed, vegetation, and groundwater levels must be evaluated and appropriate measures taken to comply with the maximum drain time requirements and maintain the proper functioning of the filter strip.

Considerations

A number of factors should be considered when utilizing a vegetated filter strip to treat stormwater runoff. Most importantly, an adequate filter area and length of flow must be provided to achieve the desired treatment. Slopes of less than 5 percent are more effective; steeper slopes require a greater area and length of flow to achieve the same effectiveness. Good surface and subsurface drainage is necessary to ensure satisfactory performance. The designer should also be aware of potential ponding factors during the planning stage. Dry period between flows should be achieved in order to reestablish aerobic soil conditions.

Filter strip vegetation must be fully established before incoming stormwater flow is allowed. At least one full growing season should have elapsed prior to strip functioning as part of the stormwater management system. Further information and references on filter strip vegetation are presented in *Chapter 7*. Species must be appropriate for the region, soil, and shade condition. Mulching is required for both seeded and planted filter strips.

Perhaps the most common, naturally occurring filter strips are those upland vegetative stands associated with floodplains or found adjacent to natural watercourses. In some cases, preservation of these upland areas will allow them to continue to function as filter strips. To help ensure the longevity of these natural areas under altered and perhaps increased pollutant loading, a top dressing of fertilizer and supplemental plantings may be necessary.

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CHAPTER 9.11

Standard for Wet Ponds

Definition

A wet pond is a stormwater facility constructed through filling and/or excavation that provides both permanent and temporary storage of stormwater runoff. It has an outlet structure that creates a permanent pool and detains and attenuates runoff inflows and promotes the settlement of pollutants. A wet pond, also known as a retention basin, can also be designed as a multi-stage facility that also provides extended detention for enhanced stormwater quality design storm treatment and runoff storage and attenuation for stormwater quantity management. The adopted TSS removal rate for wet ponds is 50 to 90 percent depending on the permanent pool storage volume in the pond and, where extended detention is also provided, the duration of detention time provided in the pond.

Purpose

Wet ponds are used to address both the stormwater quantity and quality impacts of land development. A wet pond's permanent pool can retain runoff from the stormwater quality design storm, thereby promoting pollutant removal through sedimentation and biological processing. The permanent pool can also protect deposited sediments from resuspension. Higher stages in the basin can also be used to provide additional stormwater quality treatment through extended detention and/or attenuate the peak rates of runoff from larger storms through the use of multi-stage outlets for flood and erosion control. Wet ponds can also provide aesthetic and recreational benefits as well as water supply for fire protection and/or irrigation.

Conditions Where Practice Applies

Wet ponds require sufficient drainage area and, in turn, dry weather or base flow to maintain the volume and environmental quality of the permanent pool. Therefore, the minimum drainage area to a wet pond must be 20 acres.

Wet ponds should not be located within the limits of natural ponds or wetlands, since they will typically not have the full range of ecological functions as these natural facilities. While providing some habitat and aesthetic values, wet ponds are designed primarily for pollutant removal and erosion and flood control.

It is important to note that a wet pond must be able to maintain its permanent pool level. If the soil at the site is not sufficiently impermeable to prevent excessive seepage, construction of an impermeable liner or other soil modifications will be necessary.

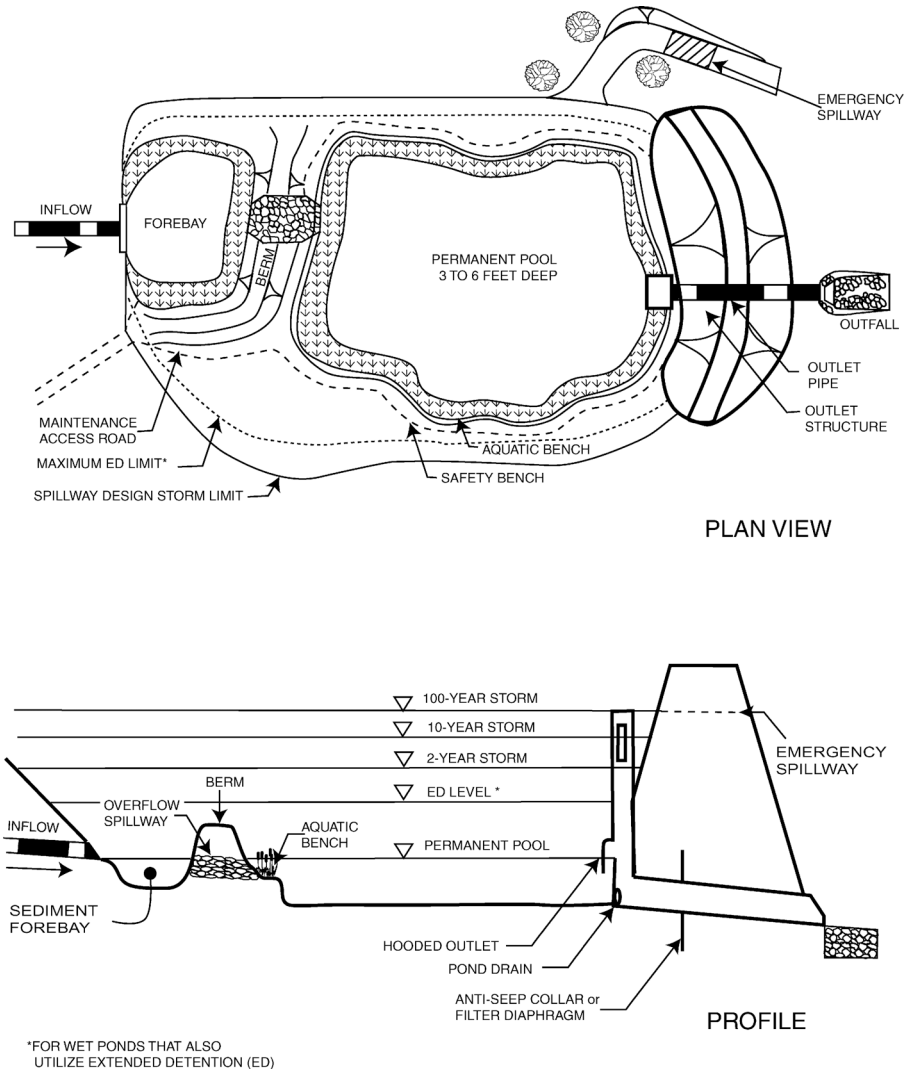
Wet ponds may be limited by the potential for discharge water to be heated in the permanent pool during summer months and should not be used if the receiving waters are ecologically sensitive to temperature change.

Finally, a wet pond must also have a maintenance plan and, if privately owned, should be protected by easement, deed restriction, ordinance, or other legal measures that prevent its neglect, adverse alteration, and removal.

Design Criteria

The basic design parameter for a wet pond is the ratio of its permanent pool volume to the volume of runoff entering the pond. This ratio is used to determine the pond's TSS removal rate. This removal rate can be increased if extended detention storage is also provided above the permanent pool level. Details of these and other design parameters are presented below and summarized in Table 9.11-1. The components of a typical wet pond both with and without extended detention are shown in Figure 9.11-1.

Figure 9.11-1: Wet Pond Components



Source: Adapted from Schueler and Claytor 2000.

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A. Storage Volumes

Wet ponds should be designed to treat the runoff volume generated by the stormwater quality design storm. Techniques to compute this volume are discussed in *Chapter 5: Computing Stormwater Runoff Rates and Volumes*. The resultant TSS removal rate for a wet pond will depend on the ratio of its permanent pool volume to the stormwater quality design storm runoff volume. Figure 9.11-2 presents the range of approved TSS removal rates for various permanent pool to runoff volume ratios. As can be seen in the figure, the minimum required permanent pool volume in a wet pond is equal to the stormwater quality design storm runoff volume to the pond. At this 1:1 volume ratio, a wet pond would have a TSS removal rate of 50 percent. This removal rate increases to 80 percent for wet ponds with permanent pool volumes that are three times the stormwater quality design storm runoff volume (i.e., volume ratio of 3:1).

Also shown in Figure 9.11-2 are TSS removal rates in wet ponds that also provide extended detention above the permanent pool water surface. As shown in Figure 9.2-2, a wet pond with a permanent pool to runoff volume ratio of 3:1 that also provides 24 hours of extended detention would have a TSS removal rate of 90 percent. TSS removal rates for other combinations of permanent pool to runoff volume ratios for extended detention times of 12 and 18 hours are also shown in Figure 9.11-2. Definitions and details of extended detention are presented in Section 9.4: Extended Detention Basins.

B. Permanent Pool Depth

The depth of a wet pond's permanent pool is an important design parameter. The permanent pool should be shallow enough to avoid thermal stratification and deep enough to minimize algal blooms and resuspension of previously deposited materials by subsequent storms and strong winds. Prevention of thermal stratification will minimize short-circuiting and maintain aerobic bottom waters, thus maximizing pollutant uptake and minimizing the potential release of nutrients to the overlying waters. The mean depth of the permanent pool is obtained by dividing the storage volume by the pool surface area. A mean depth of three to six feet is normally sufficient to maintain a healthy environment within the permanent pool. The outlet structure or riser should be located in a relative deep area to facilitate withdrawal of cold bottom water to help mitigate any downstream thermal impacts. If maintained at the recommended three to six foot depth, the permanent pool can better serve as an aquatic habitat.

C. Permanent Pool Surface Area

The surface area of a wet pond's permanent pool is also an important design parameter as it directly affects the settling rate of particulate solids in the runoff to the pond. The surface area of a permanent pool will depend on site topography, minimum and maximum pool depths, and the desired settling rate. The minimum permanent pool surface area is 0.25 acres.

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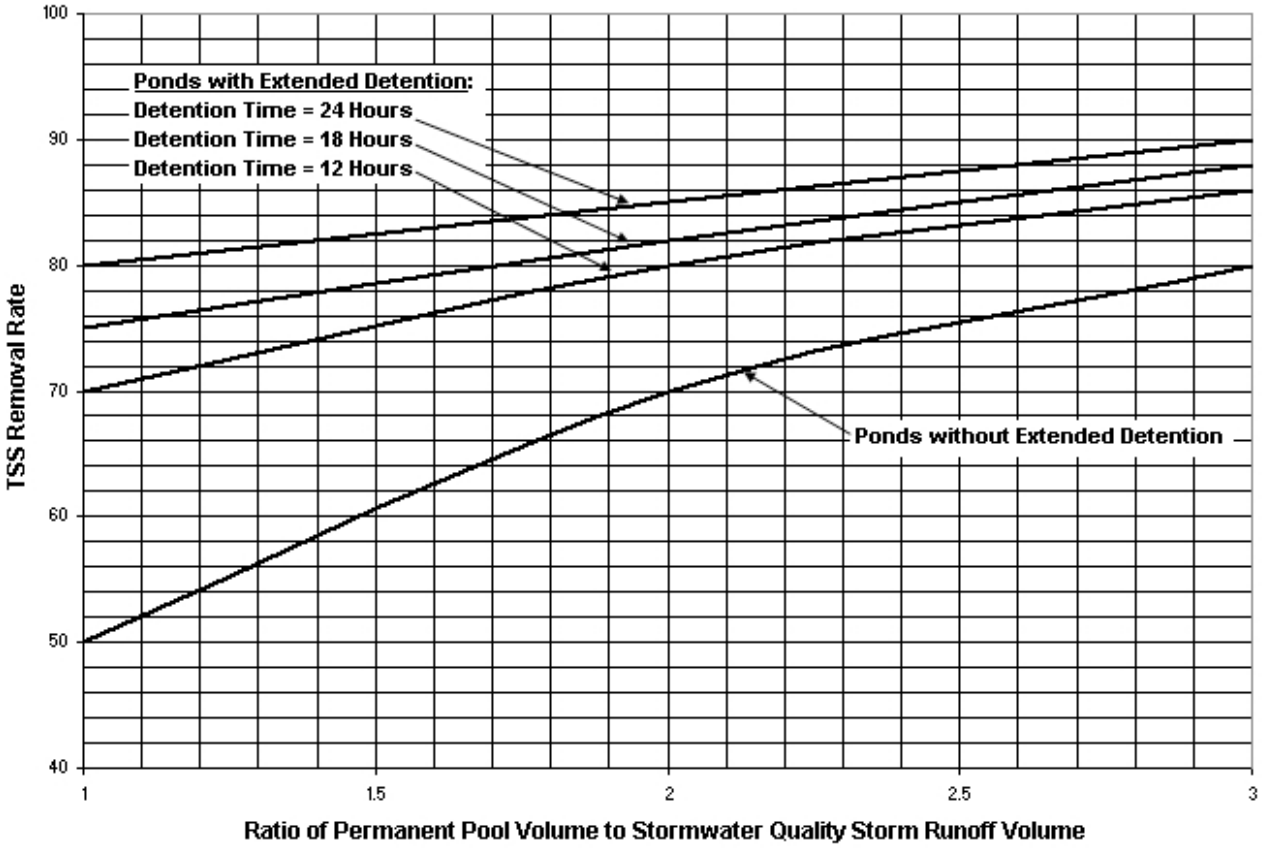
Figure 9.11-2: TSS Removal Rates for Wet Ponds



D. Drainage Area Size

As noted above, wet ponds require sufficient drainage area and dry weather base flow to function properly. A reliable base flow must be available to maintain the volume and quality of the permanent pool. Therefore, the minimum drainage area to a wet pond is 20 acres. Smaller drainage areas may be permissible if detailed analysis indicates that sufficient base or groundwater inflow is available.

E. Pond Configuration

The length to width ratio of a wet pond should as large as possible to simulate conditions found in plug flow reaction kinetics. Under ideal plug flow conditions, a plug or pulse of runoff enters a pond and is treated by chemical reactions as well as the physical processes of dispersion and settlement as the pulse travels the length of the wet pond. Therefore, the pond's length to width should be at least 3:1 to maximize these treatment processes. In cases where it is impractical to construct wet ponds with these lengths, internal baffles or berms may be added within the pond to the increase the travel length and residence time.

F. Safety Ledges

Safety ledges must be constructed on the slopes of all wet ponds with a permanent pool deeper than three feet. Two ledges must be constructed, each 4 to 6 feet in width. The first or upper ledge must be located between 1 and 1.5 feet above the permanent pool level. The second or lower ledge must be located approximately 2.5 feet below the permanent pool level.

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G. Outlet Structure

The riser structure should be equipped with a bottom drain pipe, sized to drain the permanent pool within 40 hours so that sediments may be removed mechanically when necessary. The drain pipe should be controlled by a lockable valve that is readily accessible from the top of the outlet structure. Additional information regarding outlet structures can be found in both the Soil Erosion and Sediment Control Standards for New Jersey and the NJDEP Stormwater Management Facilities Maintenance Manual.

H. Overflows

All wet ponds must be able to safely convey system overflows to downstream drainage systems. The capacity of the overflow must be sufficient to provide safe, stable discharge of stormwater in the event of an overflow. Wet ponds that are classified as dams under the NJDEP Dam Safety Standards at N.J.A.C. 7:20 must also meet the overflow requirements of these Standards, including safe conveyance of the wet pond's spillway design storm.

I. Tailwater

The hydraulic design of the outlet structure, outlet pipe, and emergency spillway in a wet pond must consider any significant tailwater effects of downstream waterways or facilities. This includes instances where the permanent pool level is below the flood hazard area design flood elevation of the receiving stream.

J. Other Components

Information regarding embankments, emergency spillways, bottom and side slopes, trash racks, conduit outlet protection, and vegetative cover can be found in both the Soil Erosion and Sediment Control Standards for New Jersey and the NJDEP Stormwater Management Facilities Maintenance Manual.

Table 9.11-1: Summary of Design Parameters

Design Parameter
Minimum Permanent Pool Volume = Stormwater Quality Design Storm Runoff Volume
Mean Permanent Pool Depth = 3 to 6 Feet
Minimum Permanent Pool Surface Area = 0.25 Acres
Minimum Drainage Area Size = 20 Acres
Maximum Permanent Pool Drain Time = 40 Hours
Recommended Minimum Pool Length to Width Ratio = 3:1

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Maintenance

Effective wet pond performance requires regular and effective maintenance. *Chapter 8: Maintenance and Retrofit of Stormwater Management Practices* provides information and requirements for preparing a maintenance plan for stormwater management facilities, including wet ponds. Specific maintenance requirements for wet ponds are presented below. These requirements must be included in the pond's maintenance plan.

A. General Maintenance

All wet pond components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times annually as well as after every storm exceeding one inch of rainfall. The primary location for debris and particularly sediment accumulation will be within a wet pond's permanent pool. Additional components may include forebays, inflow points, trash racks, outlet structures, and riprap or gabion aprons.

Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state and federal waste regulations.

Studies have shown that readily visible stormwater management facilities like wet ponds receive more frequent and thorough maintenance than those in less visible, more remote locations. Readily visible facilities can also be inspected faster and more easily by maintenance and mosquito control personnel.

B. Vegetated Areas

Mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass should be mowed at least once a month during the growing season. Vegetated areas must also be inspected at least annually for erosion and scour. Vegetated areas should also be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the remaining vegetation.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density and diversity should be performed at least twice annually during both the growing and non-growing season. The vegetative cover should be maintained at 85 percent. If vegetation has greater than 50 percent damage, the area should be reestablished in accordance with the original specifications and the inspection requirements presented above.

All use of fertilizers, mechanical treatments, pesticides and other means to ensure optimum vegetation health must not compromise the intended purpose of the wet pond. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

C. Structural Components

All structural components must be inspected for cracking, subsidence, spalling, erosion and deterioration at least annually. All outlet valves are to be inspected and exercised at least four times annually.

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D. Other Maintenance Criteria

The maintenance plan must indicate the approximate time it would normally take to completely drain the maximum design storm runoff volume and return the pond to its permanent pool level. This normal drain time should then be used to evaluate the pond's actual performance. If significant increases or decreases in the normal drain time are observed, the pond's outlet structure and both groundwater and tailwater levels must be evaluated and appropriate measures taken to comply with the maximum drain time requirements.

Considerations

A. Permanent Pools

The primary component of a wet pond is its permanent pool. To maintain water quality, oxygen levels, control mosquito breeding, and prevent stagnation, an adequate and regular inflow of surface and/or ground water is necessary. Where sufficient oxygen levels and mixing will be difficult to achieve, a fountain or aerator may be included. However, such conditions may be indicative of larger site suitability problems that must be thoroughly investigated before a wet pond is selected for use at a land development site. The potential effects of sediment loading on the permanent pool must also be considered when determining whether a site is suitable for a wet pond. The use of existing lakes and ponds as wet ponds for treatment of stormwater is prohibited.

A well-designed wet pond will accumulate considerable quantities of sediment. The cleanout cycle for a wet pond in a stabilized watershed can vary, with an average cycle of approximately 10 years. Sediment removal at each cycle may cost as much as 20 to 40 percent of the initial construction cost. It should be noted that the exact cleanout cycle and cost will depend on the specific character of the wet pond and its watershed. Therefore, periodic inspections of sediment accumulation in a wet pond are vital to determining how often and how much sediment must be removed. See *Maintenance* above for more information.

In cases where relatively permeable soils are encountered, the risk of seepage losses may be minimized by installing a clay or synthetic liner along the bottom of the pond.

B. Thermal Effects

Thermal effects of the wet pond must be considered since the permanent pool can act as a heat sink between storm events during hot weather. When the water is displaced from the pool, it may be as much as 10 degrees Fahrenheit warmer than the naturally occurring baseflow in the downstream waterway. Runoff to wet ponds from large impervious surfaces can also significantly raise the temperature of runoff during hot weather. The net result of elevated pool temperatures may have an adverse impact on downstream coldwater uses such as trout production.

Therefore, wet pond designers should pay special attention to the potential of thermal effects on downstream water bodies supporting cold water fisheries. Thermal impacts of wet ponds in such areas may be mitigated by:

- Using a deep permanent pool and positioning the outlet pipe to discharge the relatively colder water from near the bottom;
- Planting shade trees on the periphery of the pool to reduce solar warming; and
- Employing a series of pools in sequence rather than a single one.

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C. Vegetation

Aquatic vegetation plays an important role in the pollutant removal dynamics of a wet pond. Soluble pollutants, especially nutrients, are removed through biological assimilation by both phytoplankton and macrophytes. Wetland plants can help keep algal proliferation in check by limiting the amount of nutrients available to the phytoplankton. In addition, an organically enriched wetland substrate will provide an ideal environment for bacterial populations to metabolize organic matter and nutrients. Aquatic vegetation may also aid in the regulation of pond water temperature.

Marsh vegetation can also enhance the appearance of the wet pond, stabilize the side-slopes, serve as wildlife habitat, and temporarily conceal unsightly trash and debris. As such, a wet pond may be designed to promote dense growth of appropriate wetland plant species along the banks. A 10 to 15 foot wide wetland vegetation bench starting one foot below the pool surface may be established along the perimeter of the pond. Water tolerant species of vegetative cover for wet pond surfaces should be used. To promote lasting growth, grasses and other vegetative covers should be compatible with prevailing weather and soil conditions and tolerant of periodic inundation and runoff pollutants. An adequate depth of topsoil should be provided below all vegetative covers in uplands. A minimum thickness of six inches is recommended.

D. Designing for Pollutant Removal

Two alternative approaches may be used to design wet pond pollutant removal. The first approach is based on solids settling and assumes that all pollutant removal within the pond occurs due to sedimentation. The Design Criteria section above is based primarily on this approach. The second approach treats the wet pond as a lake with controlled levels of eutrophication to account for the biological and physical/chemical processes that are principal mechanisms for pollutant removal. Both approaches relate the pollutant removal efficiencies to hydraulic residence time.

Design approach should be selected based on the target pollutants as well as site and economic constraints. The controlled eutrophication approach requires longer residence times and larger storage volumes comparable to those of the solids settling approach. However, where the chief concern is to control nutrient levels in waters such as lakes and reservoirs, it is advantageous to use the controlled eutrophication approach. If the major goal is the removal of a broad spectrum of pollutants, especially those adsorbed onto suspended matter (as discussed in *Chapter 4: Stormwater Pollutant Removal Criteria*), it is generally preferable to base the design on the sedimentation approach.

E. Pretreatment

As with all other best management practices, pretreatment can extend the functional life and increase the pollutant removal capability of a wet pond. Pretreatment can reduce incoming velocities and capture coarser sediments, which will extend the life of the system. This is usually accomplished through such means as a vegetative filters and/or a manufactured treatment device. Information on vegetated filter strips and manufactured treatment devices is presented in Chapters 9.10 and 9.6, respectively.

As shown in Figure 9.11-1, forebays at the inflow points to a wet pond can capture coarse sediments, trash and debris, which can simplify and reduce the frequency of pond maintenance. A forebay should be sized to hold the sediment volume expected between clean-outs.

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New Jersey Stormwater Best Management Practices Manual

February 2004

APPENDIX A

Low Impact Development Checklist

A checklist for identifying nonstructural stormwater management strategies incorporated into proposed land development

According to the NJDEP Stormwater Management Rules at N.J.A.C. 7:8, the groundwater recharge, stormwater quality, and stormwater quantity standards established by the Rules for major land development projects must be met by incorporating nine specific nonstructural stormwater management strategies into the project's design to the maximum extent practicable.

To accomplish this, the Rules require an applicant seeking land development approval from a regulatory board or agency to identify those nonstructural strategies that have been incorporated into the project's design. In addition, if an applicant contends that it is not feasible to incorporate any of the specific strategies into the project's design, particularly for engineering, environmental, or safety reasons, the Rules further require that the applicant provide a basis for that contention.

This checklist has been prepared to assist applicants, site designers, and regulatory boards and agencies in ensuring that the nonstructural stormwater management requirements of the Rules are met. It provides an applicant with a means to identify both the nonstructural strategies incorporated into the development's design and the specific low impact development BMPs (LID-BMPs) that have been used to do so. It can also help an applicant explain the engineering, environmental, and/or safety reasons that a specific nonstructural strategy could not be incorporated into the development's design.

The checklist can also assist municipalities and other land development review agencies in the development of specific requirements for both nonstructural strategies and LID-BMPs in zoning and/or land use ordinances and regulations. As such, where requirements consistent with the Rules have been adopted, they may supersede this checklist.

Finally, the checklist can be used during a pre-design meeting between an applicant and pertinent review personnel to discuss local nonstructural strategies and LID-BMPs requirements in order to optimize the development's nonstructural stormwater management design.

Since this checklist is intended to promote the use of nonstructural stormwater management strategies and provide guidance in their incorporation in land development projects, municipalities are permitted to revise it as necessary to meet the goals and objectives of their specific stormwater management program and plan within the limits of N.J.A.C. 7:8.

Low Impact Development Checklist

A checklist for identifying nonstructural stormwater management strategies incorporated into proposed land development

Municipality: _____

County: _____ Date: _____

Review board or agency:_____

Proposed land development name: _____

Lot(s): _____ Block(s): _____

Project or application number: _____

Applicant's name: _____

Applicant's address: _____

_____

Telephone: _____ Fax: _____

Email address: _____

Designer's name: _____

Designer's address: _____

_____

Telephone:_____ Fax:_____

Email address:_____

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Part 1: Description of Nonstructural Approach to Site Design

In narrative form, provide an overall description of the nonstructural stormwater management approach and strategies incorporated into the proposed site's design. Attach additional pages as necessary. Details of each nonstructural strategy are provided in Part 3 below.

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Part 2: Review of Local Stormwater Management Regulations

Title and date of stormwater management regulations used in development design:

_____

Do regulations include nonstructural requirements? Yes: _____ No: _____

If yes, briefly describe: _____

_____

_____

List LID-BMPs prohibited by local regulations: _____

_____

_____

Pre-design meeting held? Yes: _____ Date: _____ No: _____

Meeting held with: _____

_____

_____

Pre-design site walk held? Yes: _____ Date: _____ No: _____

Site walk held with: _____

_____

_____

Other agencies with stormwater review jurisdiction:

Name: _____

Required approval: _____

Name: _____

Required approval: _____

Name: _____

Required approval: _____

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Part 3: Nonstructural Strategies and LID-BMPs in Design

3.1 Vegetation and Landscaping

Effective management of both existing and proposed site vegetation can reduce a development's adverse impacts on groundwater recharges and runoff quality and quantity. This section of the checklist helps identify the vegetation and landscaping strategies and nonstructural LID-BMPs that have been incorporated into the proposed development's design to help maintain existing recharge rates and/or minimize or prevent increases in runoff quantity and pollutant loading.

A. Has an inventory of existing site vegetation been performed? Yes: _____ No: _____

If yes, was this inventory a factor in the site's layout and design? Yes: _____ No: _____

B. Does the site design utilize any of the following nonstructural LID-BMPs?

Preservation of natural areas? Yes: _____ No: _____ If yes, specify % of site: _____

Native ground cover? Yes: _____ No: _____ If yes, specify % of site: _____

Vegetated buffers? Yes: _____ No: _____ If yes, specify % of site: _____

C. Do the land development regulations require these nonstructural LID-BMPs?

Preservation of natural areas? Yes: _____ No: _____ If yes, specify % of site: _____

Native ground cover? Yes: _____ No: _____ If yes, specify % of site: _____

Vegetated buffers? Yes: _____ No: _____ If yes, specify % of site: _____

D. If vegetated filter strips or buffers are utilized, specify their functions:

Reduce runoff volume increases through lower runoff coefficient: Yes: _____ No: _____

Reduce runoff pollutant loads through runoff treatment: Yes: _____ No: _____

Maintain groundwater recharge by preserving natural areas: Yes: _____ No: _____

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3.2 Minimize Land Disturbance

Minimizing land disturbance is a nonstructural LID-BMP that can be applied during both the development's construction and post-construction phases. This section of the checklist helps identify those land disturbance strategies and nonstructural LID-BMPs that have been incorporated into the proposed development's design to minimize land disturbance and the resultant change in the site's hydrologic character.

A. Have inventories of existing site soils and slopes been performed? Yes: _____ No: _____

If yes, were these inventories factors in the site's layout and design? Yes: _____ No: _____

B. Does the development's design utilize any of the following nonstructural LID-BMPs?

Restrict permanent site disturbance by land owners? Yes: _____ No: _____

If yes, how: _____

_____

Restrict temporary site disturbance during construction? Yes: _____ No: _____

If yes, how: _____

_____

Consider soils and slopes in selecting disturbance limits? Yes: _____ No: _____

If yes, how: _____

_____

C. Specify percentage of site to be cleared: _____ Regraded: _____

D. Specify percentage of cleared areas done so for buildings: _____

For driveways and parking: _____ For roadways: _____

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E. What design criteria and/or site changes would be required to reduce the percentages in C and D above?

_____

_____

_____

F. Specify site's hydrologic soil group (HSG) percentages:

HSG A: _____ HSG B: _____ HSG C: _____ HSG D: _____

G. Specify percentage of each HSG that will be permanently disturbed:

HSG A: _____ HSG B: _____ HSG C: _____ HSG D: _____

H. Locating site disturbance within areas with less permeable soils (HSG C and D) and minimizing disturbance within areas with greater permeable soils (HSG A and B) can help maintain groundwater recharge rates and reduce runoff volume increases. In light of the HSG percentages in F and G above, what other practical measures if any can be taken to achieve this?

_____

_____

_____

I. Does the site include Karst topography? Yes: _____ No: _____

If yes, discuss measures taken to limit Karst impacts:

_____

_____

_____

_____

_____

_____

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3.3 Impervious Area Management

New impervious surfaces at a development site can have the greatest adverse effect on groundwater recharge and stormwater quality and quantity. This section of the checklist helps identify those nonstructural strategies and LID-BMPs that have been incorporated into a proposed development's design to comprehensively manage the extent and impacts of new impervious surfaces.

A. Specify impervious cover at site: Existing: _____ Proposed: _____

B. Specify maximum site impervious coverage allowed by regulations: _____

C. Compare proposed street cartway widths with those required by regulations:

Type of Street	Proposed Cartway Width (feet)	Required Cartway Width (feet)
Residential access – low intensity		
Residential access – medium intensity		
Residential access – high intensity with parking		
Residential access – high intensity without parking		
Neighborhood		
Minor collector – low intensity without parking		
Minor collector – with one parking lane		
Minor collector – with two parking lanes		
Minor collector – without parking		
Major collector		

D. Compare proposed parking space dimensions with those required by regulations:

Proposed: _____ Regulations: _____

E. Compare proposed number of parking spaces with those required by regulations:

Proposed: _____ Regulations: _____

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F. Specify percentage of total site impervious cover created by buildings:

By driveways and parking: _____ By roadways: _____

G. What design criteria and/or site changes would be required to reduce the percentages in F above?

_____

_____

_____

_____

H. Specify percentage of total impervious area that will be unconnected:

Total site: _____ Buildings: _____ Driveways and parking: _____ Roads: _____

I. Specify percentage of total impervious area that will be porous:

Total site: _____ Buildings: _____ Driveways and parking: _____ Roads: _____

J. Specify percentage of total building roof area that will be vegetated: _____

K. Specify percentage of total parking area located beneath buildings: _____

L. Specify percentage of total parking located within multi-level parking deck: _____

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3.4 Time of Concentration Modifications

Decreasing a site's time of concentration (Tc) can lead directly to increased site runoff rates which, in turn, can create new and/or aggravate existing erosion and flooding problems downstream. This section of the checklist helps identify those nonstructural strategies and LID-BMPs that have been incorporated into the proposed development's design to effectively minimize such Tc decreases.

When reviewing Tc modification strategies, it is important to remember that a drainage area's Tc should reflect the general conditions throughout the area. As a result, Tc modifications must generally be applied throughout a drainage area, not just along a specific Tc route.

A. Specify percentage of site's total stormwater conveyance system length that will be:

Storm sewer: _____ Vegetated swale: _____ Natural channel: _____

Stormwater management facility: _____ Other: _____

Note: the total length of the stormwater conveyance system should be measured from the site's downstream property line to the downstream limit of sheet flow at the system's headwaters.

B. What design criteria and/or site changes would be required to reduce the storm sewer percentages and increase the vegetated swale and natural channel percentages in A above?

_____

_____

_____

C. In conveyance system subareas that have overland or sheet flow over impervious surfaces or turf grass, what practical and effective site changes can be made to:

Decrease overland flow slope: _____

_____

_____

Increase overland flow roughness: _____

_____

_____

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3.5 Preventative Source Controls

The most effective way to address water quality concerns is by pollution prevention. This section of the checklist helps identify those nonstructural strategies and LID-BMPs that have been incorporated into the proposed development's design to reduce the exposure of pollutants to prevent their release into the stormwater runoff.

A. Trash Receptacles

Specify the number of trash receptacles provided: _____

Specify the spacing between the trash receptacles: _____

Compare trash receptacles proposed with those required by regulations:

Proposed: _____ Regulations: _____

B. Pet Waste Stations

Specify the number of pet waste stations provided: _____

Specify the spacing between the pet waste stations: _____

Compare pet waste stations proposed with those required by regulations:

Proposed: _____ Regulations: _____

C. Inlets, Trash Racks, and Other Devices that Prevent Discharge of Large Trash and Debris

Specify percentage of total inlets that comply with the NJPDES storm drain inlet criteria: _____

D. Maintenance

Specify the frequency of the following maintenance activities:

Street sweeping: Proposed: _____ Regulations: _____

Litter collection: Proposed: _____ Regulations: _____

Identify other stormwater management measures on the site that prevent discharge of large trash and debris:

_____

_____

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E. Prevention and Containment of Spills

Identify locations where pollutants are located on the site, and the features that prevent these pollutants from being exposed to stormwater runoff:

Pollutant: _____ Location: _____

Feature utilized to prevent pollutant exposure, harmful accumulation, or contain spills:

Pollutant: _____ Location: _____

Feature utilized to prevent pollutant exposure, harmful accumulation, or contain spills:

Pollutant: _____ Location: _____

Feature utilized to prevent pollutant exposure, harmful accumulation, or contain spills:

Pollutant: _____ Location: _____

Feature utilized to prevent pollutant exposure, harmful accumulation, or contain spills:

Pollutant: _____ Location: _____

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Part 4: Compliance with Nonstructural Requirements of NJDEP Stormwater Management Rules

1. Based upon the checklist responses above, indicate which nonstructural strategies have been incorporated into the proposed development's design in accordance with N.J.A.C. 7:8-5.3(b):

No.	Nonstructural Strategy	Yes	No
1.	Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss.		
2.	Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces.		
3.	Maximize the protection of natural drainage features and vegetation.		
4.	Minimize the decrease in the pre-construction time of concentration.		
5.	Minimize land disturbance including clearing and grading.		
6.	Minimize soil compaction.		
7.	Provide low maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers, and pesticides.		
8.	Provide vegetated open-channel conveyance systems discharge into and through stable vegetated areas.		
9.	Provide preventative source controls.		

2. For those strategies that have not been incorporated into the proposed development's design, provide engineering, environmental, and/or safety reasons. Attached additional pages as necessary.

_____

_____

_____

_____

_____

_____

_____

_____

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APPENDIX B

Municipal Regulations Checklist

A checklist for incorporating nonstructural stormwater management strategies into local regulations

As part of the requirements for municipal stormwater management plans in the Stormwater Management Rules at N.J.A.C. 7:8-4, municipalities are required to evaluate the municipal master plan, and land use and zoning ordinances to determine what adjustments need to be made to allow the implementation of nonstructural stormwater management techniques, also called low impact development techniques, which are presented in *Chapter 2: Low Impact Development Techniques*. *Chapter 3: Regional and Municipal Stormwater Management Plans* provides information on the development of municipal stormwater management plans, including the evaluation of the master plan, and land use and zoning ordinances. This checklist was prepared to assist municipalities in identifying the specific ordinances that should be evaluated, and the types of changes to be incorporated to address the requirements of the Stormwater Management Rules.

Part 1: Vegetation and Landscaping

Effective management of both existing and proposed site vegetation can reduce a development's adverse impacts on groundwater recharge and stormwater runoff quality and quantity.

A. Preservation of Natural Areas

Municipal regulations should include requirements to preserve existing vegetated areas, minimize turf grass lawn areas, and use native vegetation.

❑ Yes ❑ No Are applicants required to provide a layout of the existing vegetated areas, and a description of the conditions in those areas?

❑ Yes ❑ No Does the municipality have maximum as well as minimum yard sizing ordinances?

❑ Yes ❑ No Are residents restricted from enlarging existing turf lawn areas?

❑ Yes ❑ No Do the ordinances provide incentives for the use of vegetation as filters for stormwater runoff?

❑ Yes ❑ No Do the ordinances require a specific percentage of permanently preserved open space as part of the evaluation of cluster development?

B. Tree Protection Ordinances

Municipalities often have a tree ordinance to minimize the removal of trees and to replace trees that are removed. However, while tree ordinances protect the number of trees, they do not typically address the associated leaf litter or smaller vegetation that provides additional water quality and quantity benefits. Municipalities should consider enhancing tree ordinances to a forest ordinance that would also maintain the benefits of a forested area.

❑ Yes ❑ No Does the municipality have a tree protection ordinance?

❑ Yes ❑ No Can the municipality include a forest protection ordinance?

❑ Yes ❑ No If forested areas are present at development sites, is there a required percentage of the stand to be preserved?

C. Landscaping Island and Screening Ordinances

Municipalities often have ordinances that require landscaping islands for parking areas. The landscaping islands can provide ideal opportunities for the filtration and disconnection of runoff, or the placement of small LID-BMPs. Screening ordinances limit the view of adjoining properties, parking areas, or loading areas. Low maintenance vegetation can be required in islands and areas used for screening to provide stormwater quality, groundwater recharge, or stormwater quantity benefits.

❑ Yes ❑ No Do the ordinances require landscaping islands in parking lots, or between the roadway and the sidewalk? Can the ordinance be adjusted to require vegetation that is more beneficial for stormwater quality, groundwater recharge, or stormwater quantity, but that does not interfere with driver vision at the intersections?

❑ Yes ❑ No Is the use of bioretention islands and other stormwater practices within landscaped areas or setbacks allowed?

❑ Yes ❑ No Do the ordinances require screening from adjoining properties? Can the screening criteria require the use of vegetation to the maximum extent practicable before the use of walls or berms?

D. Riparian Buffers

Municipalities may have existing buffer and/or floodplain ordinances that require the protection of vegetation adjacent to streams. Municipalities should consult existing regulations adopted by the Department to ensure that riparian buffer or floodplain ordinances reflect the requirements of the Department within these areas. The municipality should consider conservation restrictions and allowable maintenance to ensure the preservation of these areas.

❑ Yes ❑ No Is there a stream buffer or floodplain ordinance in the community?

❑ Yes ❑ No Is the ordinance consistent with existing state regulatory requirements?

❑ Yes ❑ No Does the ordinance require a conservation easement, or other permanent restrictions on buffer areas?

❑ Yes ❑ No Does the ordinance identify or limit when stormwater outfall structures can cross the buffer?

❑ Yes ❑ No Does the ordinance give detailed information on the type of maintenance and/or activities that is allowed in the buffer?

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Part 2: Minimizing Land Disturbance

The minimization of disturbance can be used at different phases of a development project. The goal is to limit clearing, grading, and other disturbance associated with development to protect existing features that provide stormwater benefits. Zoning ordinances typically limit the amount of impervious surfaces on building lots, but do not limit the amount of area that can be disturbed during construction. This strategy helps preserve the site's existing hydrologic character, as well as limiting the occurrence of soil compaction.

A. Limits of Disturbance

Designing with the terrain, or site fingerprinting, requires an assessment of the characteristics of the site and the selection of areas for development that would minimize the impact. This can be incorporated into the requirements for existing site conditions and the environmental impact statement. Limits of disturbance should be incorporated into construction plans reviewed and approved by the municipality. Setbacks should be evaluated to determine whether they can be reduced. The following maximum setbacks are recommended for low impact development designs:

- front yard – 20 feet;
- rear yard – 25 feet; and
- side yard – 8 feet.

❑ Yes ❑ No As part of the depiction of existing conditions, are environmentally critical and environmentally constrained areas identified? (Environmentally critical areas are areas or features with significant environmental value, such as steep slopes, stream corridors, natural heritage priority sites, and habitats of threatened and endangered species. Environmentally constrained areas are those with development restrictions, such as wetlands, floodplains, and sites of endangered species.)

❑ Yes ❑ No Can any of the existing setbacks be reduced?

❑ Yes ❑ No Are there maximum turf grass or impervious cover limits in any of the setbacks?

❑ Yes ❑ No Do the ordinances inhibit or prohibit the clearcutting of the project site as part of the construction?

❑ Yes ❑ No Is the traffic of heavy construction vehicles limited to specific areas, such as areas of proposed roadway? Are these areas required to be identified on the plans and marked in the field?

❑ Yes ❑ No Do the ordinances require the identification of specific areas that provide significant hydrologic functions, such as existing surface storage areas, forested areas, riparian corridors, and areas with high groundwater recharge capabilities?

❑ Yes ❑ No Does the municipality require an as-built inspection before issuing a certificate of occupancy? If so, does the inspection include identification of compacted areas, if they exist within the site?

❑ Yes ❑ No Does the municipality require the restoration to compacted areas in accordance with the Soil Erosion and Sediment Control Standards?

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B. Open Space and Cluster Development

Open space areas are restricted land that may be set aside for conservation, recreation, or agricultural use, and are often associated with cluster development requirements. Since open space can have a variety of uses, the municipality should evaluate its open space ordinances to determine whether amendments are necessary to provide improved stormwater benefits.

❑ Yes ❑ No Are open space or cluster development designs allowed in the municipality?

❑ Yes ❑ No Are flexible site design incentives available for developers that utilize open space or cluster design options?

❑ Yes ❑ No Are there limitations on the allowable disturbance of existing vegetated areas in open space?

❑ Yes ❑ No Are the requirements to re-establish vegetation in disturbed areas dedicated for open space?

❑ Yes ❑ No Is there a maximum allowable impervious cover in open space areas?

Part 3: Impervious Area Management

The amount of impervious area, and its relationship to adjacent vegetated areas, can significantly change the amount of runoff that needs to be addressed by BMPs. Most of a site's impervious surfaces are typically located in the streets, sidewalks, driveway, and parking areas. These areas are further hampered by requirements for continuous curbing that prevent discharge from impervious surfaces into adjacent vegetated areas.

A. Streets and Driveways

Street widths of 18 to 22 feet are recommended for low impact development designs in low density residential developments. Minimum driveway widths of 9 and 18 feet for one lane and two lanes, respectively, are also recommended. The minimum widths of all streets and driveways should be evaluated to demonstrate that the proposed width is the narrowest possible consistent with safety and traffic concerns and requirements. Municipalities should evaluate which traffic calming features, such as circles, rotaries, medians, and islands, can be vegetated or landscaped. Cul-de-sacs can also be evaluated to reduce the radius area, or to provide a landscape island in the center.

❑ Yes ❑ No Are the street widths the minimum necessary for traffic density, emergency vehicle movement, and roadside parking?

❑ Yes ❑ No Are street features, such as circles, rotaries, or landscaped islands allowed to or required to receive runoff?

❑ Yes ❑ No Are curb cuts or flush curbs with curb stops an allowable alternative to raised curbs?

❑ Yes ❑ No Can the minimum cul-de-sac radius be reduced or is a landscaped island required in the center of the cul-de-sac?

❑ Yes ❑ No Are alternative turn-arounds such as "hammerheads" allowed on short streets in low density residential developments?

❑ Yes ❑ No Can the minimum driveway width be reduced?

❑ Yes ❑ No Are shared driveways permitted in residential developments?

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B. Parking Areas and Sidewalks

A mix of uses at a development site can allow for shared parking areas, reducing the total parking area. Municipalities require minimum parking areas, but seldom limit the total number of parking spaces. Table 1 shows recommendations for minimum parking space ratios for low impact design:

Table 1: Low Impact Development Parking Space Ratios

Use	Parking Ratio per 1000 sq. ft. of Gross Floor Area
Professional office building	Less than 3.0
Shopping centers	Less than 4.5

❑ Yes ❑ No Can the parking ratios be reduced?

❑ Yes ❑ No Are the parking requirements set as maximum or median rather than minimum requirements?

❑ Yes ❑ No Is the use of shared parking arrangements allowed to reduce the parking area?

❑ Yes ❑ No Are model shared parking agreements provided?

❑ Yes ❑ No Does the presence of mass transit allow for reduced parking ratios?

❑ Yes ❑ No Is a minimum stall width of 9 feet allowed?

❑ Yes ❑ No Is a minimum stall length of 18 feet allowed?

❑ Yes ❑ No Can the stall lengths be reduced to allow vehicle overhang into a vegetated area?

❑ Yes ❑ No Do ordinances allow for permeable material to be used in overflow parking areas?

❑ Yes ❑ No Do ordinances allow for multi-level parking?

❑ Yes ❑ No Are there incentives to provide parking that reduces impervious cover, rather than providing only surface parking lots?

Sidewalks can be made of pervious material or disconnected from the drainage system to allow runoff to re-infiltrate into the adjacent pervious areas.

❑ Yes ❑ No Do ordinances allow for sidewalks constructed with pervious material?

❑ Yes ❑ No Can alternate pedestrian networks be substituted for sidewalks (e.g., trails through common areas)?

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C. Unconnected Impervious Areas

Disconnection of impervious areas can occur in both low density development and high density commercial development, provided sufficient vegetated area is available to accept dispersed stormwater flows. Areas for disconnection include parking lot or cul-de-sac islands, lawn areas, and other vegetated areas.

❑ Yes ❑ No Are developers required to disconnect impervious surfaces to promote pollutant removal and groundwater recharge?

❑ Yes ❑ No Do ordinances allow the reduction of the runoff volume when runoff from impervious areas are re-infiltrated into vegetated areas?

❑ Yes ❑ No Do ordinances allow flush curb and/or curb cuts to allow for runoff to discharge into adjacent vegetated areas as sheet flow?

Part 4: Vegetated Open Channels

The use of vegetated channels, rather than the standard concrete curb and gutter configuration, can decrease flow velocity, and allow for stormwater filtration and re-infiltration. One design option is for vegetated channels that convey smaller storm events, such as the water quality design storm, and provide an overflow into a storm sewer system for larger storm events.

❑ Yes ❑ No Do ordinances allow or require vegetated open channel conveyance instead of the standard curb and gutter designs?

❑ Yes ❑ No Are there established design criteria for vegetated channels?

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New Jersey Stormwater Best Management Practices Manual

February 2004

A P P E N D I X C

Sample Municipal Stormwater Management Plan

This is a sample of a municipal stormwater management plan. It was prepared to assist municipalities in developing the municipal stormwater management plans required by the new Stormwater Phase II Permitting Regulations and the Stormwater Management Rules. The plan has all of the required elements outlined in the Stormwater Management Rules at N.J.A.C. 7:8-4.2. The plan also includes additional recommended elements to enable municipalities to better manage the impact of stormwater on the receiving waters of the state from new and existing development. *Throughout the document, italicized text is provided to assist municipalities in the preparation of their own plan.*

Please note that portions of this plan are fictional and intended only as a model to assist municipalities in the development of the stormwater management plan. It is anticipated that municipalities will provide more detail and information than what is presented in this plan.

Note: Figures can be viewed in color in the PDF version of this appendix available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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Introduction

Every plan should include an introduction to identify why the plan is being prepared and a summary of the contents of the plan. Here is sample language.

This Municipal Stormwater Management Plan (MSWMP) documents the strategy for the ABC Township ("the Township") to address stormwater-related impacts. The creation of this plan is required by N.J.A.C. 7:14A-25 Municipal Stormwater Regulations. This plan contains all of the required elements described in N.J.A.C. 7:8 Stormwater Management Rules. The plan addresses groundwater recharge, stormwater quantity, and stormwater quality impacts by incorporating stormwater design and performance standards for new major development, defined as projects that disturb one or more acre of land. These standards are intended to minimize the adverse impact of stormwater runoff on water quality and water quantity and the loss of groundwater recharge that provides baseflow in receiving water bodies. The plan describes long-term operation and maintenance measures for existing and future stormwater facilities.

A "build-out" analysis has been included in this plan based upon existing zoning and land available for development. The plan also addresses the review and update of existing ordinances, the Township Master Plan, and other planning documents to allow for project designs that include low impact development techniques. The final component of this plan is a mitigation strategy for when a variance or exemption of the design and performance standards is sought. As part of the mitigation section of the stormwater plan, specific stormwater management measures are identified to lessen the impact of existing development.

Goals

Although each municipal plan may have different or more specific goals, listed below are the minimum set of goals that should be included in all municipal stormwater management plans.

The goals of this MSWMP are to:

- reduce flood damage, including damage to life and property;
- minimize, to the extent practical, any increase in stormwater runoff from any new development;
- reduce soil erosion from any development or construction project;
- assure the adequacy of existing and proposed culverts and bridges, and other in-stream structures;
- maintain groundwater recharge;
- prevent, to the greatest extent feasible, an increase in nonpoint pollution;
- maintain the integrity of stream channels for their biological functions, as well as for drainage;
- minimize pollutants in stormwater runoff from new and existing development to restore, enhance, and maintain the chemical, physical, and biological integrity of the waters of the state, to protect public health, to safeguard fish and aquatic life and scenic and ecological values, and to enhance the domestic, municipal, recreational, industrial, and other uses of water; and
- protect public safety through the proper design and operation of stormwater basins.

To achieve these goals, this plan outlines specific stormwater design and performance standards for new development. Additionally, the plan proposes stormwater management controls to address impacts from existing development. Preventative and corrective maintenance strategies are included in the plan to ensure long-term effectiveness of stormwater management facilities. The plan also outlines safety standards for stormwater infrastructure to be implemented to protect public safety.

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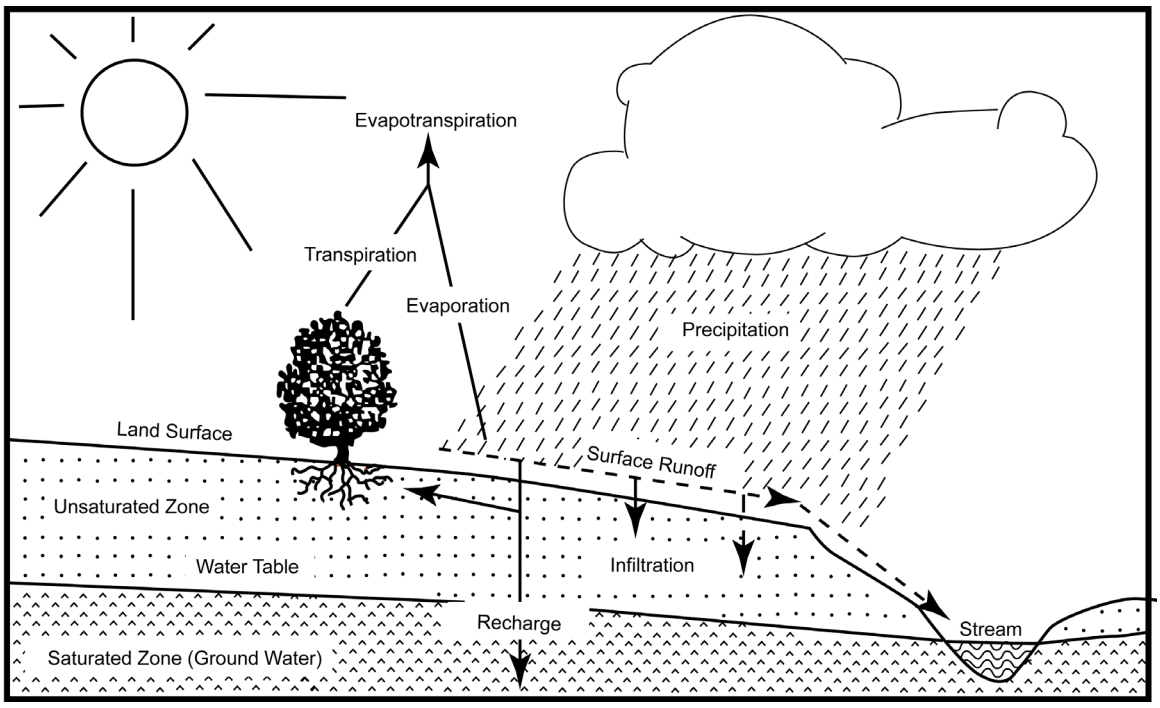
Stormwater Discussion

Some of the readers of the plan may have limited knowledge of stormwater related issues. A brief description of the hydrologic cycle and how development affects the cycle may be useful to the reader. Sample language is provided below.

Land development can dramatically alter the hydrologic cycle (See Figure C-1) of a site and, ultimately, an entire watershed. Prior to development, native vegetation can either directly intercept precipitation or draw that portion that has infiltrated into the ground and return it to the atmosphere through evapotranspiration. Development can remove this beneficial vegetation and replace it with lawn or impervious cover, reducing the site's evapotranspiration and infiltration rates. Clearing and grading a site can remove depressions that store rainfall. Construction activities may also compact the soil and diminish its infiltration ability, resulting in increased volumes and rates of stormwater runoff from the site. Impervious areas that are connected to each other through gutters, channels, and storm sewers can transport runoff more quickly than natural areas. This shortening of the transport or travel time quickens the rainfall-runoff response of the drainage area, causing flow in downstream waterways to peak faster and higher than natural conditions. These increases can create new and aggravate existing downstream flooding and erosion problems and increase the quantity of sediment in the channel. Filtration of runoff and removal of pollutants by surface and channel vegetation is eliminated by storm sewers that discharge runoff directly into a stream. Increases in impervious area can also decrease opportunities for infiltration which, in turn, reduces stream base flow and groundwater recharge. Reduced base flows and increased peak flows produce greater fluctuations between normal and storm flow rates, which can increase channel erosion. Reduced base flows can also negatively impact the hydrology of adjacent wetlands and the health of biological communities that depend on base flows. Finally, erosion and sedimentation can destroy habitat from which some species cannot adapt.

Figure C-1: Groundwater Recharge in the Hydrologic Cycle



Source: New Jersey Geological Survey Report GSR-32.

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In addition to increases in runoff peaks, volumes, and loss of groundwater recharge, land development often results in the accumulation of pollutants on the land surface that runoff can mobilize and transport to streams. New impervious surfaces and cleared areas created by development can accumulate a variety of pollutants from the atmosphere, fertilizers, animal wastes, and leakage and wear from vehicles. Pollutants can include metals, suspended solids, hydrocarbons, pathogens, and nutrients.

In addition to increased pollutant loading, land development can adversely affect water quality and stream biota in more subtle ways. For example, stormwater falling on impervious surfaces or stored in detention or retention basins can become heated and raise the temperature of the downstream waterway, adversely affecting cold water fish species such as trout. Development can remove trees along stream banks that normally provide shading, stabilization, and leaf litter that falls into streams and becomes food for the aquatic community.

Background

The plan should include background information on the municipality to help the reader understand its characteristics – size in square miles, population, population changes, waterways, and health of these waterways. For example, is the municipality a rural community rapidly becoming developed or is it an older established community where land use is fairly stable? Is the health of the waterways in the municipality impaired? Are there flooding concerns in the municipality? Also, maps should be included to help the reader visualize the municipality and its physical features.

A township was selected for this sample plan so that the mapping and municipal characteristics can be presented along with information as to where to obtain these data. Due to the sample nature of this plan, this section does not present a comprehensive background of the municipality and its stormwater-related issues.

The Township encompasses 55 square mile area in Somerset County, New Jersey. In recent years, the Township has been under significant development pressure. The population of the Township has increased from 19,061 in 1980, to 28,808 in 1990, to 36,634 in 2000. This population increase has resulted in considerable demand for new development; changes in the landscape have most likely increased stormwater runoff volumes and pollutant loads to the waterways of the municipality. Figure C-2 illustrates the waterways in the Township. Figure C-3 depicts the Township boundary on the USGS quadrangle maps.

Each municipality should have population statistics. This information is available from the New Jersey Department of Labor at www.wnjpin.net/OneStopCareerCenter/LaborMarketInformation/lmi25/index.html. Mapping required for a municipal plan is fairly simple, but requires Geographic Information System (GIS) software. Mapping information is available at http://www.nj.gov/dep/gis/lists.html as well as a link to a free version of GIS software, ArcExplorer. Many local watershed associations and environmental commissions have GIS and can help create maps for an MSWMP. Rutgers University Center for Remote Sensing and Spatial Analysis can also assist in preparing these maps. Detailed direction on how to create these maps is provided at http://rwqp.rutgers.edu/univ/nj/.

The New Jersey Department of Environmental Protection (NJDEP) has established an Ambient Biomonitoring Network (AMNET) to document the health of the state's waterways. There are over 800 AMNET sites throughout the state of New Jersey. These sites are sampled for benthic macroinvertebrates by NJDEP on a five-year cycle. Streams are classified as non-impaired, moderately impaired, or severely impaired based on the AMNET data. The data is used to generate a New Jersey Impairment Score (NJIS), which is based on a number of biometrics related to benthic macroinvertebrate community dynamics. The two major rivers that border the Township to the north and east, the Raritan River and the Millstone River,

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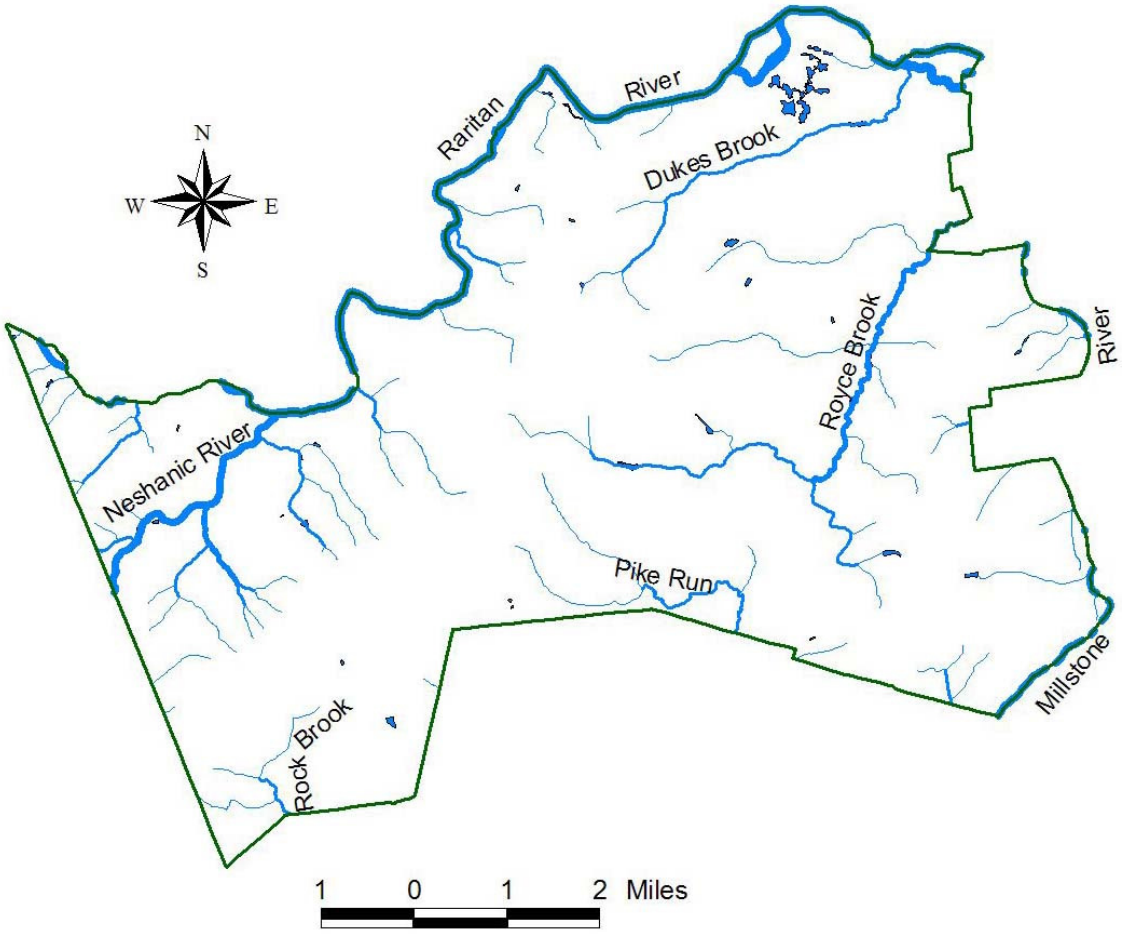
Figure C-2: Township and Its Waterways



This figure can be viewed in color in the PDF version of this appendix available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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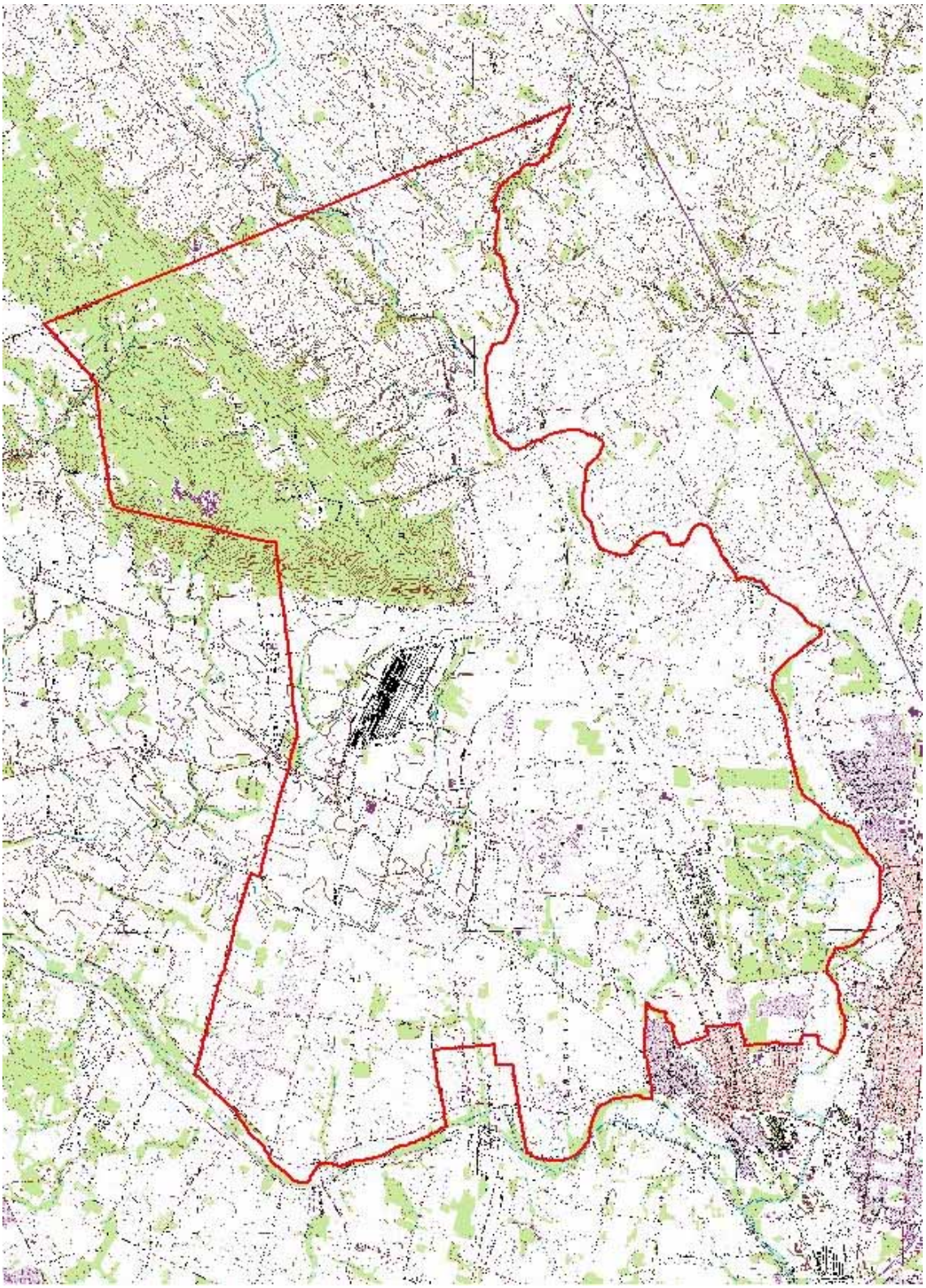
Figure C-3: Township Boundary on USGS Quadrangles



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respectively, are both moderately impaired. The five tributaries that flow through the Township to these major rivers are also moderately impaired based on AMNET data. In addition to the AMNET data, the NJDEP and other regulatory agencies collect water quality chemical data on the streams in the state. These data show that the instream total phosphorus concentrations and fecal coliform concentrations of the Raritan River and Millstone River frequently exceed the state's criteria. This means that these rivers are impaired waterways and the NJDEP is required to develop a Total Maximum Daily Load (TMDL) for these pollutants for each waterway.

A TMDL is the amount of a pollutant that can be accepted by a waterbody without causing an exceedance of water quality standards or interfering with the ability to use a waterbody for one or more of its designated uses. The allowable load is allocated to the various sources of the pollutant, such as stormwater and wastewater discharges, which require an NJPDES permit to discharge, and nonpoint source, which includes stormwater runoff from agricultural areas and residential areas, along with a margin of safety. Provisions may also be made for future sources in the form of reserve capacity. An implementation plan is developed to identify how the various sources will be reduced to the designated allocations. Implementation strategies may include improved stormwater treatment plants, adoption of ordinances, reforestation of stream corridors, retrofitting stormwater systems, and other BMPs.

The New Jersey Integrated Water Quality Monitoring and Assessment Report (305(b) and 303(d)) (Integrated List) is required by the federal Clean Water Act to be prepared biennially and is a valuable source of water quality information. This combined report presents the extent to which New Jersey waters are attaining water quality standards, and identifies waters that are impaired. Sublist 5 of the Integrated List constitutes the list of waters impaired or threatened by pollutants, for which one or more TMDLs are needed.

The integrated list is available from the NJDEP website at www.nj.gov/dep/wmm/sgwqt/wat/index.html. Specific data on biological monitoring (AMNET data) is available from the NJDEP web site at www.state.nj.us/dep/wmm/bfbm. Additional data can be found on the United States Geological Survey (USGS) site at www.water.usgs.gov.

In addition to water quality problems, the Township has exhibited severe water quantity problems including flooding, stream bank erosion, and diminished base flow in its streams. Many of the culverts associated with road crossings in the Township are undersized. During severe storm events, these undersized culverts do not have adequate capacity, thereby causing a backwater effect and flooding upstream.

The municipality should list specific areas that are affected by stormwater quantity problems and the extent. For example, if in a storm event in 2001, considered equivalent to a 20-year design storm, specific areas reached particular elevations, that should be included.

These culverts were designed for much different hydrologic conditions (i.e., less impervious area) than presently exist in the Township. As the imperviousness increased in the Township, the peak and volumes of stream flows also increased. The increased amount of water resulted in stream bank erosion, which resulted in unstable areas at roadway/bridge crossings, and degraded stream habitats. The high imperviousness of the Township has significantly decreased groundwater recharge, decreasing base flows in streams during dry weather periods. Lower base flows can have a negative impact on instream habitat during the summer months. A map of the groundwater recharge areas are shown in Figure C-4. Wellhead protection areas, also required as part of the MSWMP, are shown in Figure C-5.

The Township may want to adopt specific ordinances to protect wellhead protection areas to minimize the infiltration of pollutants into aquifers.

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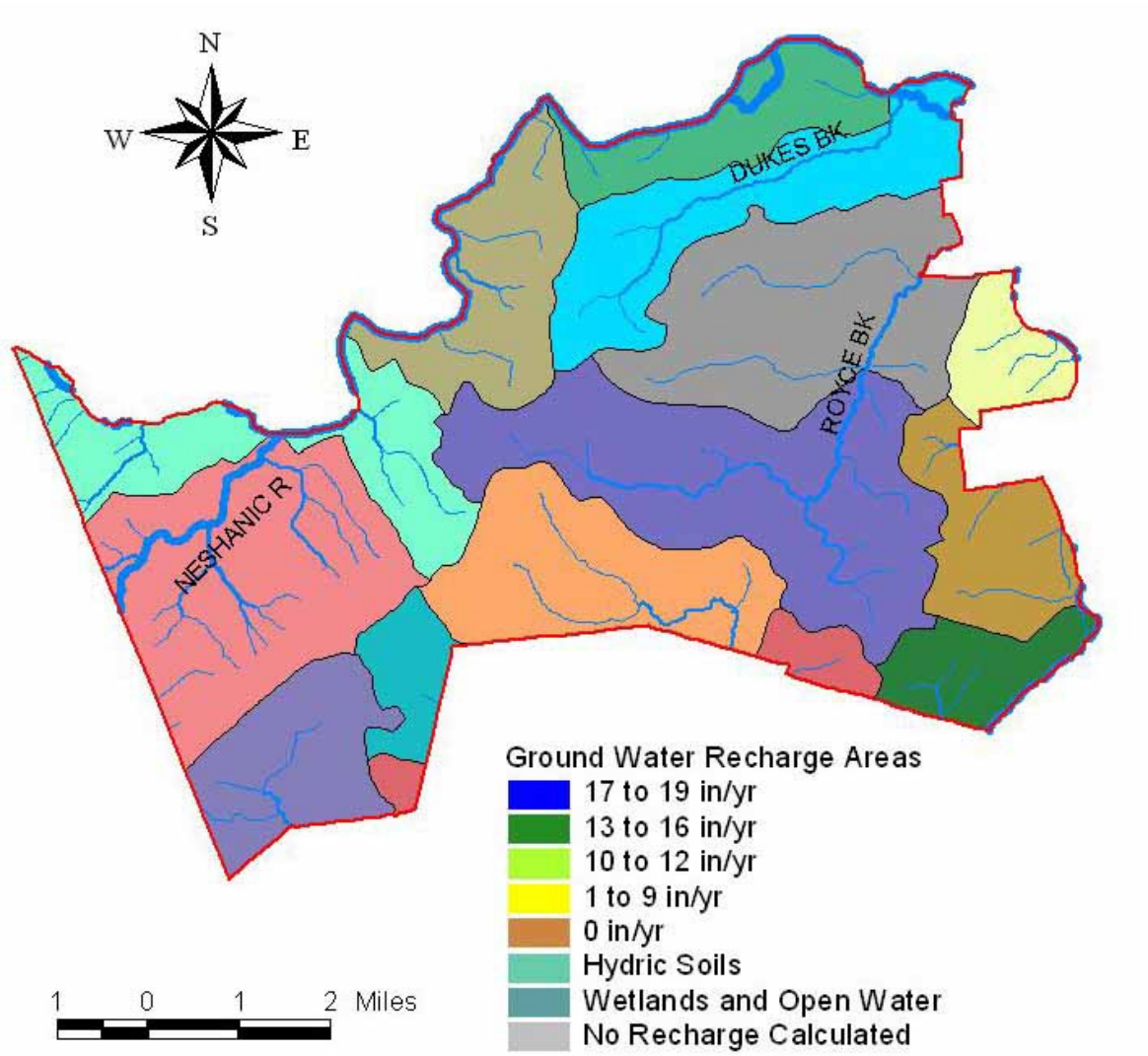
Figure C-4: Groundwater Recharge Areas in the Township



This figure can be viewed in color in the PDF version of this appendix available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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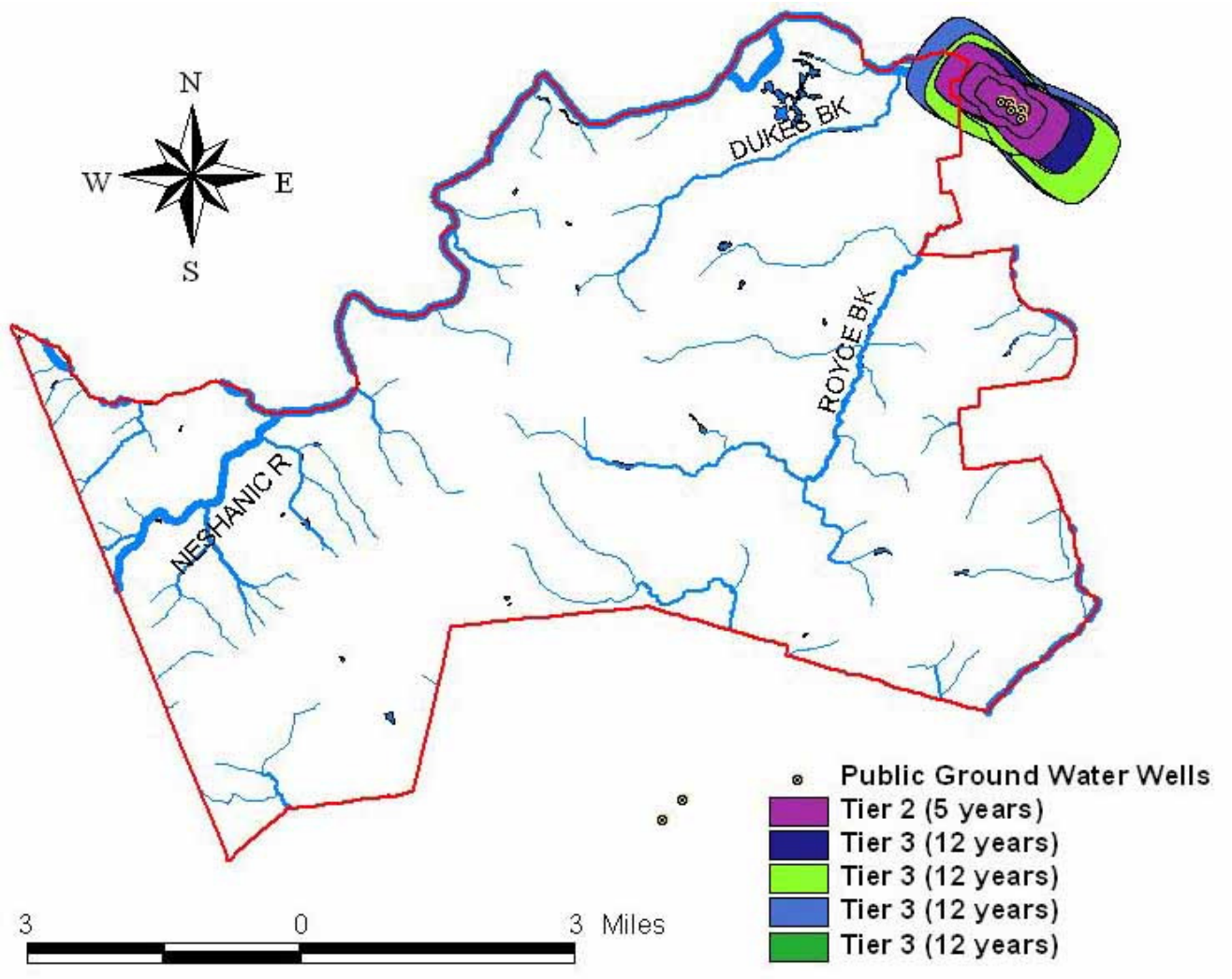
Figure C-5: Wellhead Protection Areas in the Township



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Design and Performance Standards

Municipal stormwater management plans must describe how the plan incorporates the design and performance standards in N.J.A.C. 7:8-5 or alternative design and performance standards that were adopted as a part of a regional stormwater management plan or water quality management plan. The design and performance standards should be incorporated into the municipality's stormwater management ordinance to be consistent with this requirement. A sample ordinance is provided in Appendix D: Model Stormwater Control Ordinance for Municipalities *to assist in the incorporation of these design and performance standards into municipal plans. This section should clearly state that the municipality will adopt ordinances consistent with the design and performance standards at N.J.A.C. 7:8-5, ordinances to address maintenance consistent with N.J.A.C. 7:8-5.8, and ordinances to address safety consistent with N.J.A.C. 7:8-6. It should also indicate steps the municipality will take to ensure compliance with these standards.*

The Township will adopt the design and performance standards for stormwater management measures as presented in N.J.A.C. 7:8-5 to minimize the adverse impact of stormwater runoff on water quality and water quantity and loss of groundwater recharge in receiving water bodies. The design and performance standards include the language for maintenance of stormwater management measures consistent with the stormwater management rules at N.J.A.C. 7:8-5.8 Maintenance Requirements, and language for safety standards consistent with N.J.A.C. 7:8-6 Safety Standards for Stormwater Management Basins. The ordinances will be submitted to the county for review and approval within [24 months of the effective date of the Stormwater Management Rules.]

During construction, Township inspectors will observe the construction of the project to ensure that the stormwater management measures are constructed and function as designed.

The simplest method to address the need to incorporate design and performance standards is to adopt the language in the Stormwater Management Rules and model ordinance. However, the municipality may adjust these standards. For example, certain municipalities have designated entities required to assume maintenance responsibility. In some cases, the municipality may choose to assume this responsibility. The municipality may choose to revise land use and zoning ordinances to prescribe how nonstructural stormwater management measures must be addressed. Additional discussion on the relationship of nonstructural stormwater management measures and ordinances are provided in Chapter 2: Low Impact Development Techniques, Chapter 3: Regional and Municipal Stormwater Management Plans, and Appendix B: Municipal Regulations Checklist.

Plan Consistency

The MSWMP must be coordinated with the appropriate Soil Conservation District and any other stormwater management plan, such as an adopted regional stormwater management plan. A short paragraph as given below is sufficient to comply with this requirement unless there is a TMDL for any of the waterways within the municipality. If a TMDL is in place and requires reductions in nonpoint sources within the municipalities, the TMDL requirements should be incorporated into this municipal stormwater management plan. For example, if a TMDL completed for fecal coliform identified the need for a goose management plan to control the impact from the resident geese at a local park, the goose management plan should be incorporated into this municipal stormwater management plan. Another example is that a TMDL may have identified over-fertilization of residential lawns as a source of nutrients to the impaired waterway and recommended development of a no-phosphorus ordinance for a particular section of the Township unless soil testing indicates a lack of sufficient phosphorus in the soil. This ordinance should be incorporated into this municipal stormwater management plan.

The Township is not within a Regional Stormwater Management Planning Area and no TMDLs have been developed for waters within the Township; therefore this plan does not need to be consistent with any regional stormwater management plans (RSWMPs) nor any TMDLs. If any RSWMPs or TMDLs are developed in the future, this Municipal Stormwater Management Plan will be updated to be consistent.

The Municipal Stormwater Management Plan is consistent with the Residential Site Improvement Standards (RSIS) at N.J.A.C. 5:21. The municipality will utilize the most current update of the RSIS in the

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stormwater management review of residential areas. This Municipal Stormwater Management Plan will be updated to be consistent with any future updates to the RSIS.

The Township's Stormwater Management Ordinance requires all new development and redevelopment plans to comply with New Jersey's Soil Erosion and Sediment Control Standards. During construction, Township inspectors will observe on-site soil erosion and sediment control measures and report any inconsistencies to the local Soil Conservation District.

Nonstructural Stormwater Management Strategies

In addition to the design and performance standards for nonstructural strategies discussed above, the municipal stormwater management plan must be evaluated to determine how the municipal plan and ordinances should be amended to implement the principles of nonstructural stormwater management. Municipalities are required to evaluate the municipal master plan, and land use and zoning ordinances to determine what adjustments need to be made to allow the implementation of nonstructural stormwater management techniques, also called low impact development techniques, which are presented in Chapter 2: Low Impact Development Techniques. Additional discussion on the relationship of nonstructural stormwater management measures and ordinances is provided in Chapter 3: Regional and Municipal Stormwater Management Plans.

To address this requirement, municipal ordinances and plans must be reviewed to determine where changes can be made to incorporate nonstructural stormwater management strategies. Appendix B: Municipal Regulations Checklist has been provided to assist municipalities.

An example of the changes identified in ordinances is given below. (Note: This is not an exhaustive list of every ordinance that should be evaluated, but presents some examples.) Since many municipal codes are similar in much of the state, the recommendations provided here may prove useful in modifying individual municipal codes. When submitting the plan and ordinances to the county for review and a copy to the Department, all revised ordinances, master plans, and maps must be attached, along with an adoption schedule.

The Township has reviewed the master plan and ordinances, and has provided a list of the sections in the Township land use and zoning ordinances that are to be modified to incorporate nonstructural stormwater management strategies. These are the ordinances identified for revision. Once the ordinance texts are completed, they will be submitted to the county review agency for review and approval within [24 months of the effective date of the Stormwater Management Rules]. A copy will be sent to the Department of Environmental Protection at the time of submission.

Chapter 77 of the Township Code, entitled Development Regulations, was reviewed with regard to incorporating nonstructural stormwater management strategies. Several changes were made to Article VI of this Chapter, entitled "Design and Performance Standards" to incorporate these strategies.

Section 77-39: Buffers requires buffer areas along all lot and street lines separating residential uses from arterial and collector streets, separating a nonresidential use from either a residential use or residential zoning district line, and along all street lines where loading and storage areas can be seen from the street. The landscape requirements for these buffer areas in the existing section do not recommend the use of native vegetation. The language of this section was amended to require the use of native vegetation, which requires less fertilization and watering than non-native species. Additionally, language was included to allow buffer areas to be used for stormwater management by disconnecting impervious surfaces and treating runoff from these impervious surfaces. This section currently requires the preservation of natural wood tracts and limits land disturbance for new construction.

Section 77-41: Cluster Development provides for a cluster development option to preserve land for public and agricultural purposes, to prevent development on environmentally sensitive areas, and to aid in reducing the cost of providing streets, utilities and services in residential developments. This cluster

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option is an excellent tool for reducing impervious roads and driveways. The option allows for smaller lots with smaller front and side yard setbacks than traditional development options. It also minimizes the disturbance of large tracts of land, which is a key nonstructural stormwater management strategy. The cluster option is being amended to require that [*insert percentage here*] of the total tract be preserved as common open space for residential area. The cluster option does require that 25 percent of the green or common area be landscaped with trees and/or shrubs. This language was amended to promote the use of native vegetation, which requires less fertilization and watering than non-native ornamental plants. Although the cluster option requires public concrete sidewalks to be installed along all streets, the option requires paths in open space to be mulched or stone to decrease the impervious area.

Section 77-43: Curbs and Gutters requires that concrete curb and gutter, concrete curb, or Belgian block curb be installed along every street within and fronting on a development. This section was amended to allow for curb cuts or flush curbs with curb stops to allow vegetated swales to be used for stormwater conveyance and to allow the disconnection of impervious areas.

Section 77-44: Drainage, Watercourses and Flood Hazard Areas requires that all streets be provided with inlets and pipes where the same are necessary for proper drainage. This section was amended to encourage the used of natural vegetated swales in lieu of inlets and pipes.

Section 77-45: Driveways and Accessways describes the procedure for construction of any new driveway or accessway to any street. This section was amended to allow the use of pervious paving materials to minimize stormwater runoff and promote groundwater recharge.

Section 77-60: Natural Features requires that natural features, such as trees, brooks, swamps, hilltops, and views, be preserved whenever possible, and that care be taken to preserve selected trees to enhance soil stability and landscaped treatment of the area. This section was amended to expand trees to forested areas, to ensure that leaf litter and other beneficial aspects of the forest are maintained in addition to the trees.

Section 77-62: Nonconforming Uses, Structures or Lots requires a variance for existing single family homes proposing additions that exceed the maximum percent impervious. The homeowner must mitigate the impact of the additional impervious surfaces unless the stormwater management plan for the development provided for these increases in impervious surfaces. This mitigation effort must address water quality, flooding, and groundwater recharge as described in Chapter 135. A detailed description of how to develop a mitigation plan is present in the Township Code.

Section 77-63: Off-site and Off-tract Improvements describes essential off-site and off-tract improvements. Language was added to this section to require that any off-site and off-tract stormwater management and drainage improvements must conform to the "Design and Performance Standards" described in this plan and provided in Chapter 135 of the Township Code.

Section 77-64: Off-street Parking and Loading details off-street parking and loading requirements. All parking lots with more than 10 spaces and all loading areas are required to have concrete or Belgian block curbing around the perimeter of the parking and loading areas. This section also requires that concrete or Belgian block curbing be installed around all landscaped areas within the parking lot or loading areas. This section was amended to allow for flush curb with curb stop, or curbing with curb cuts to encourage developers to allow for the discharge of impervious areas into landscaped areas for stormwater management. Also, language was added to allow for use of natural vegetated swales for the

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water quality design storm, with overflow for larger storm events into storm sewers. This section also provides guidance on minimum parking space requirements. These requirements are based on the number of dwelling units and/or gross floor area. The section allows a developer to demonstrate that fewer spaces would be required, provided area is set aside for additional spaces if necessary. This section was amended to allow pervious paving to be used in areas to provide overflow parking, vertical parking structures, smaller parking stalls, and shared parking.

Sections 77-66: Performance Standards provide pollution source control. It prohibits materials or wastes to be deposited upon a lot in such form or manner that they can be transferred off the lot, directly or indirectly, by natural forces such as precipitation, evaporation or wind. It also requires that all materials and wastes that might create a pollutant or a hazard be enclosed in appropriate containers.

Section 77-73: Shade Trees requires a minimum of three shade trees per lot to be planted in the front yard. In addition to Section 77-73, the Township has a Tree Preservation Ordinance (Sections 77-160 to 77-165) that restricts and otherwise controls the removal of mature trees throughout the Township. This ordinance recognizes that the preservation of mature trees and forested areas is a key strategy in the management of environmental resources, particularly watershed management, air quality, and ambient heating and cooling. These sections set out a "critical footprint area" that extends 20 feet beyond the driveway and building footprint where clearing of trees cannot occur. This complies with minimizing land disturbance, which is a nonstructural stormwater management strategy. These sections were amended to require the identification of forested areas, and that [*insert percentage here*] of forested areas be protected from disturbance.

Section 77-74: Sidewalks describe sidewalk requirements for the Township. Although sidewalks are not required along all streets, the Township can require them in areas where the probable volume of pedestrian traffic, the development's location in relation to other populated areas and high vehicular traffic, pedestrian access to bus stops, schools, parks, and other public places, and the general type of improvement intended indicate the advisability of providing a pedestrianway. Sidewalks are to be a minimum of four feet wide and constructed of concrete. Language was added to this section to require developers to design sidewalks to discharge stormwater to neighboring lawns where feasible to disconnect these impervious surfaces, or use permeable paving materials where appropriate.

Section 77-77: Soil Erosion and Sediment Control addresses soil erosion and sediment control by referencing Chapter 128, the Township's Soil Erosion and Sediment Control Ordinance. This ordinance requires developers to comply with the New Jersey Soil Erosion and Sediment Control Standards and outlines some general design principles, including: whenever possible, retain and protect natural vegetation; minimize and retain water runoff to facilitate groundwater recharge; and, install diversions, sediment basins, and similar required structures prior to any on-site grading or disturbance.

Section 77-79 Stormwater Runoff addresses stormwater runoff by referencing Chapter 135, the Township's Surface Water Management Ordinance, which was updated to include all requirements outlined in N.J.A.C. 7:8-5. These changes were presented earlier in this document.

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Section 77-82: Streets describes the requirements for streets in the Township. The Township has several street classifications, ranging from "Arterial," which has a minimum right-of-way of 80 feet, to "Secondary Local," which has a minimum right-of-way of 50 feet. Street paving widths are a function of the number of units served, whether a street is curbed, whether on-street parking is permitted, whether the interior streets serve lots of two acres or larger, and whether on-site topographical constraints allow design flexibility. Depending on these factors, paving width for secondary local streets has a range from 20 to 32 feet. This section was amended to encourage developers to limit on-street parking to allow for narrower paved widths. This section also required that cul-de-sacs have a minimum radius of 50 feet. Language was added to this section to reduce the minimum radius of cul-de-sac designs. Cul-de-sacs with landscaped islands have a minimum radius of [*insert radius here*], cul-de-sacs with flush curbs have a minimum radius of [*insert radius here*], with a [*insert width here*] reinforced shoulder to accommodate larger equipment and emergency vehicles.

Several changes were made to Article VII of the Township Code entitled "Zoning Districts and Standards." The Township has 11 types of residential districts. Each district has a maximum percent impervious surface allocation, ranging from 5 percent for the MZ District, which has a minimum lot size of five acres for detached single-family homes, to 40 percent for the AM and RCA Districts, which have a minimum lot size of 7,000 square feet for cluster single-family homes. The Township has 12 types of non-residential districts. Each of these districts has a maximum percent impervious surface allocation, ranging from 30 percent for the HOO District to 60 percent for the I-1 District. Although each zone has a maximum allowable percent impervious surface, the Township Code was amended to remind developers that satisfying the percent impervious requirements does not relieve them of responsibility for complying with the Design and Performance Standards for Stormwater Management Measures contained in Chapter 135 – Surface Water Runoff. The Township is evaluating the maximum allowable impervious cover for each zone to determine whether a reduction in impervious cover is appropriate. The Township is also evaluating a maximum percent of disturbance for each zone, for those areas identified as natural features in Section 77-60. Also, if a developer is given a variance to exceed the maximum allowable percent imperviousness, the developer must mitigate the impact of the additional impervious surfaces. This mitigation effort must address water quality, flooding, and groundwater recharge as described in Chapter 135. A detailed description of how to develop a mitigation plan is included in this Municipal Stormwater Management Plan.

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Land Use/Build-Out Analysis

If a municipality can document that it has a combined total of less than one square mile of vacant or agricultural lands, the municipality is not required to complete the following build-out analysis. Otherwise, a build-out analysis must be conducted assuming full development under existing zoning for each HUC14 drainage area in the municipality. To satisfy the minimum requirements, the result of the build-out analysis is acreage of impervious surfaces by HUC14 and associated nonpoint loadings attributed to the build-out of the municipality. Although not required by the regulations, a quantitative analysis of the impact of build-out can be calculated, including population and number of school-age children, housing units and housing density, traffic, tax revenues, demands on schools, water supply, sewage, electrical production, and police force. Additional information on the build-out is provided in Chapter 3.

There are four steps to preparing a build-out analysis that satisfies the requirements for the municipal stormwater management plan:

1. *Determine the total land area within each of the HUC14s of the municipality.*
2. *Determine the area of constrained lands within each HUC14 of the municipality.*
3. *Determine the land available for development by simply subtracting the constrained lands from the total land area for each HUC14. In essence, the land available for development is the agricultural, forest and/or barren lands available within each HUC14. Existing residential, commercial, and industrial areas are also eligible for redevelopment and should be considered as land available for development.*
4. *For each HUC14, complete a build-out analysis by using the municipal zoning map and applicable ordinances to determine the acreage of new development. Once the build-out acreage of each land use is determined for each HUC14, nonpoint source loadings can be determined for the build-out scenario. Shown below are examples of build-out analyses for two HUC14s located in the municipality.*

A detailed land use analysis for the Township was conducted. Figure C-6 illustrates the existing land use in the Township based on 1995/97 GIS information from NJDEP. Figure C-7 illustrates the HUC14s within the Township. The Township zoning map is shown in Figure C-8. Figure C-9 illustrates the constrained lands within the Township. *(Note: For this sample plan, every constrained land was not mapped.)* The build-out calculations for impervious cover are shown in Table C-1. As expected when developing agricultural and forest lands, the build-out of these two HUC14s will result in a significant increase in impervious surfaces.

Table C-2 presents the pollutant loading coefficients by land cover. The pollutant loads at full build-out are presented in Table C-3.

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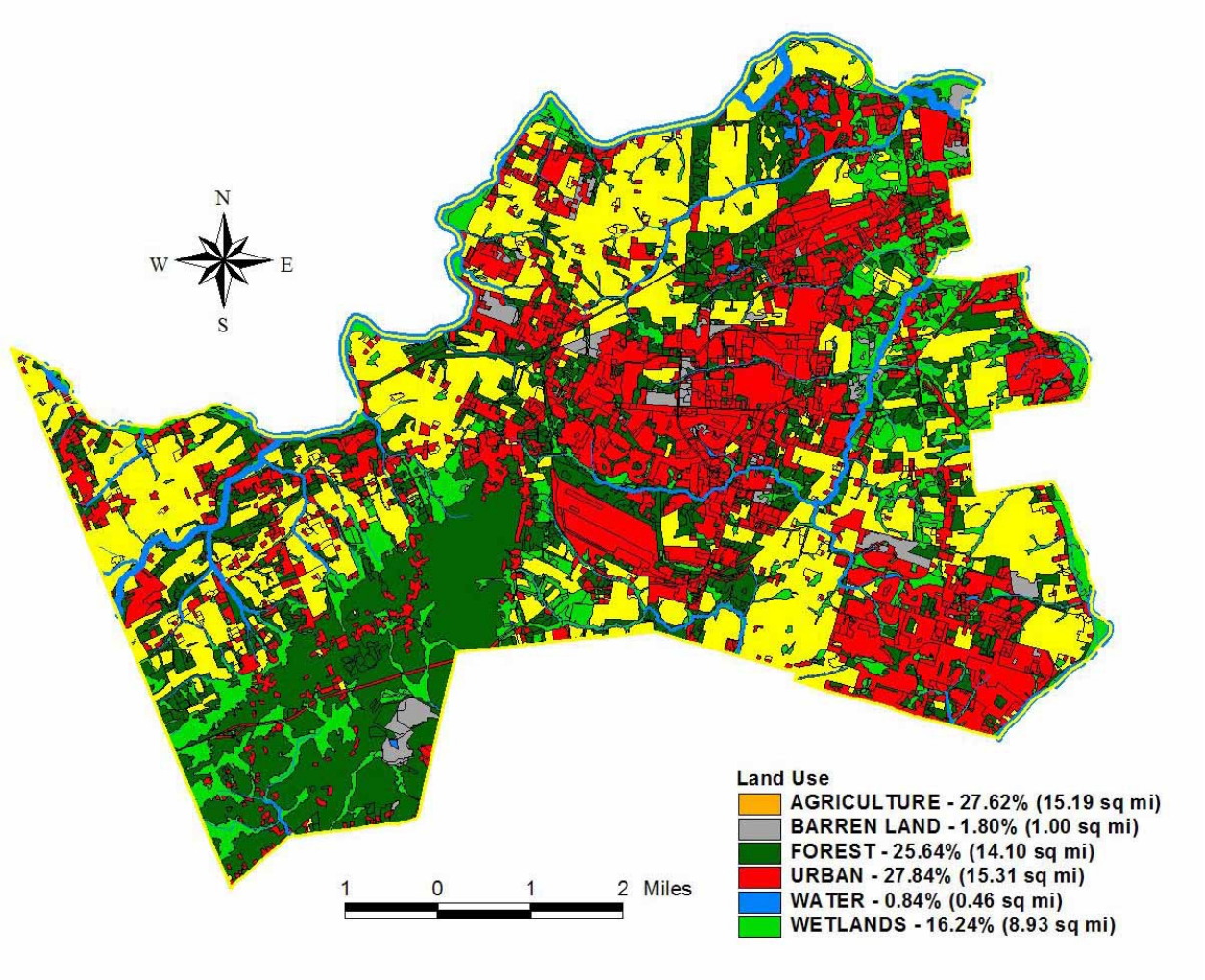
Figure C-6: Township's Existing Land Use



This figure can be viewed in color in the PDF version of this appendix available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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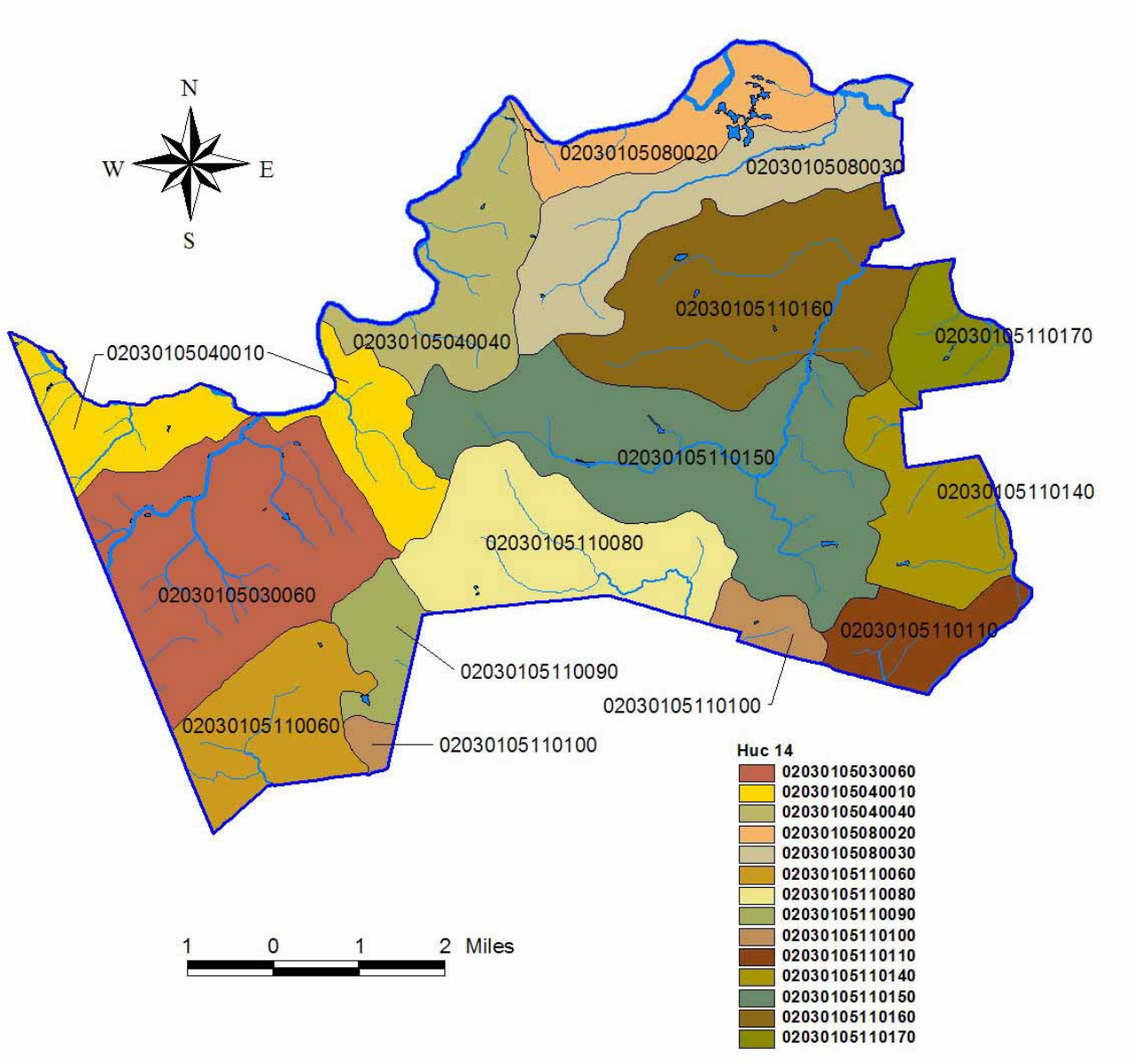
Figure C-7: Hydrologic Units (HUC14s) Within the Township



This figure can be viewed in color in the PDF version of this appendix available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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It is important to note that, although the pollutant loads for agricultural lands are higher than those for low density residential for the parameters in Table C-2, converting agricultural lands to residential typically results in an increase in pollutant loads for metals and petroleum hydrocarbons. It is recommended that each municipality calculate build-out pollutant loads for each. Also, total suspended solids loads due to stormwater runoff may decrease due to the conversion of agricultural lands to low density residential, but the percentage of impervious surfaces increases dramatically. If, due to the increase of impervious surfaces, increases in stormwater runoff flows are not managed properly, these high flows will increase streambank erosion, thereby increasing sediment loads to the receiving waters.

There are a number of resources available for assistance with preparing the build-out analysis, including the Association of New Jersey Environmental Commissions (ANJEC), the Stony Brook-Millstone Watershed Association, Rutgers University's Center for Remote Sensing and Spatial Analysis, the Nonpoint Education of Municipal Officials (NEMO), and USEPA (Green Communities: How to do a Build-Out Analysis at www.epa.gov/greenkit/build-out.htm). The mapping and querying ability of GIS software such as ESRI's ArcView is essential for preparing a build-out analysis in a cost-effective manner.

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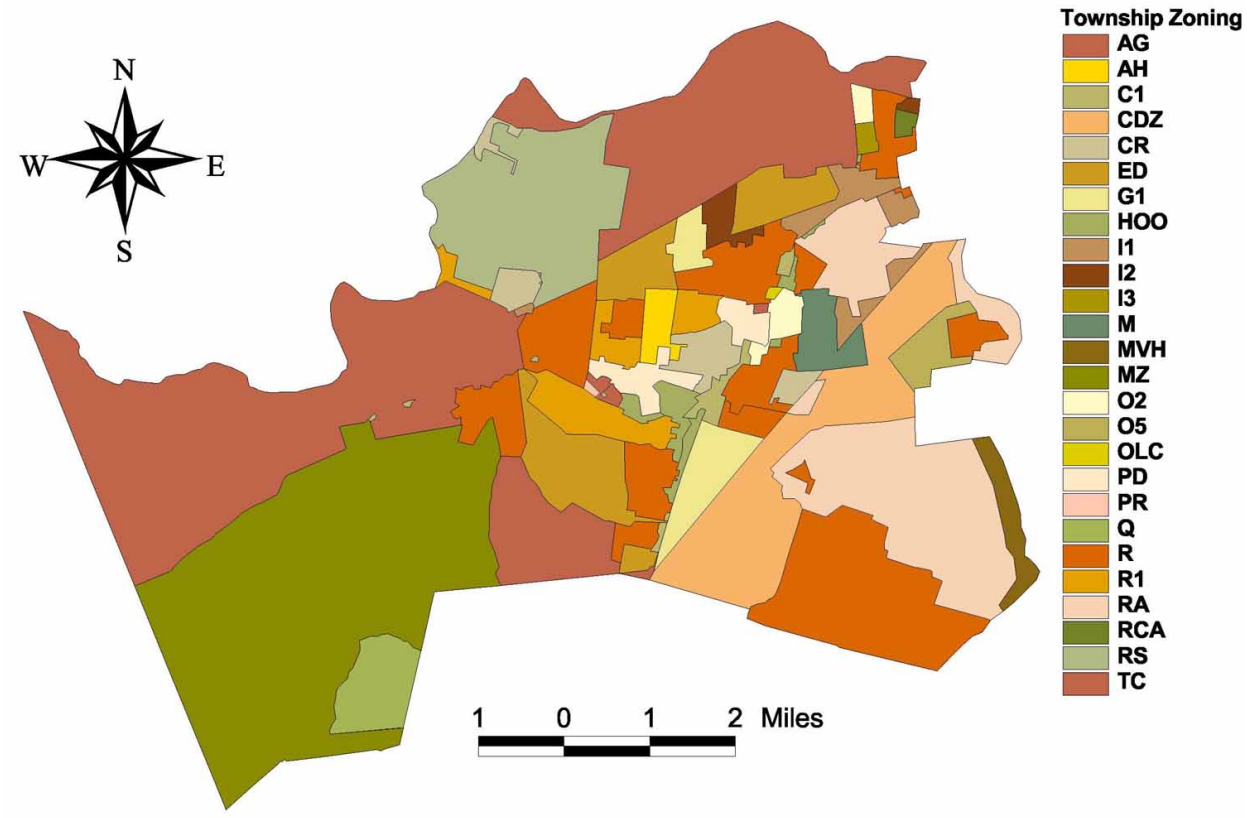
Figure C-8: Zoning Districts Within the Township



This figure can be viewed in color in the PDF version of this appendix available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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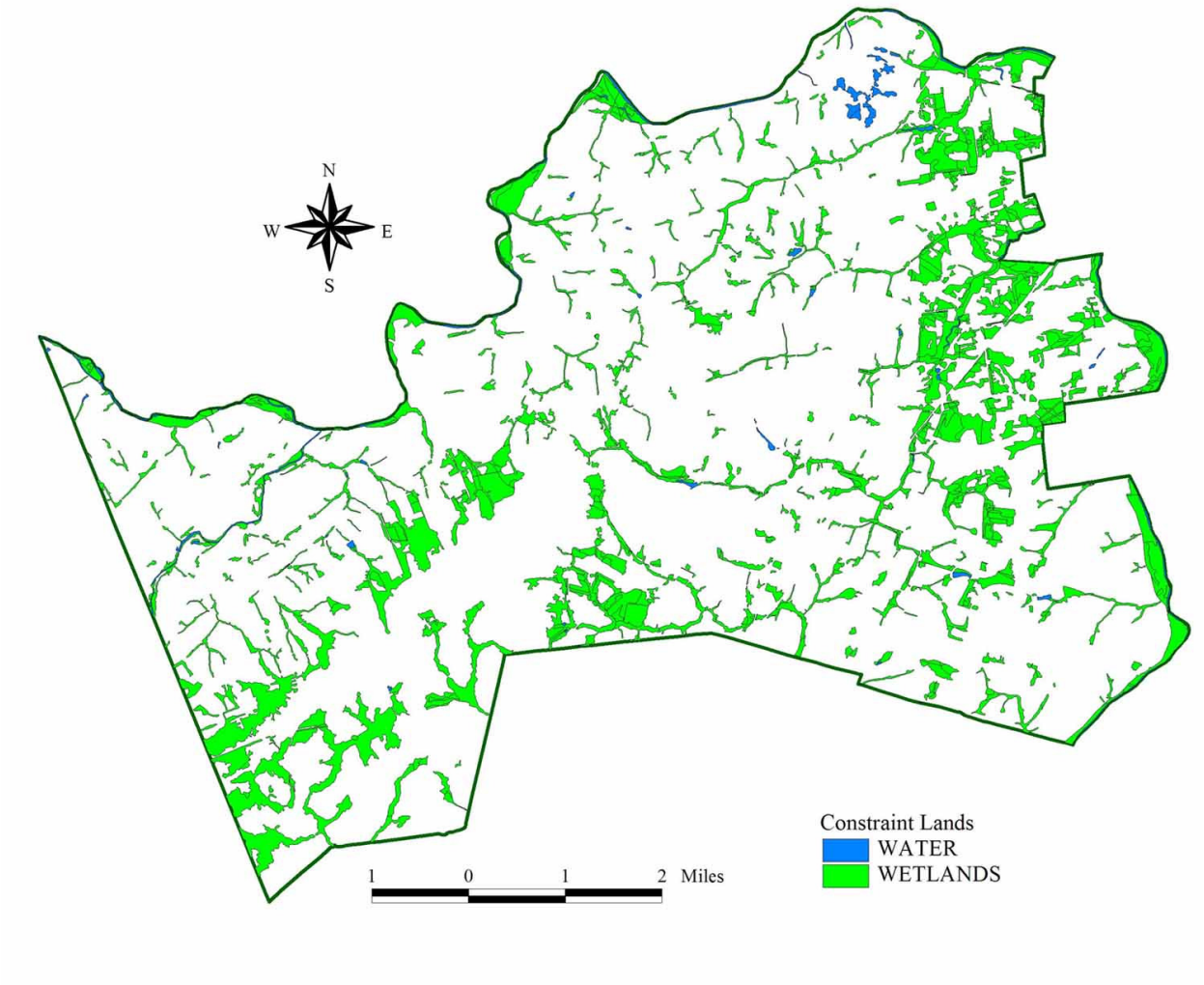
Figure C-9: Wetlands and Water Land Uses Within the Township – Constrained Land



This figure can be viewed in color in the PDF version of this appendix available at http://www.state.nj.us/dep/watershedmgt/bmpmanualfeb2004.htm

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Table C-1: Sample Build-Out Calculations for Two HUC14s

HUC14 and Zone	Total Area (acres)	Existing Impervious (%)	Existing Impervious (acres)	Wetlands/ Water Area (acres)	Developable Area (acres)	Allowable Impervious (%)	Build-Out Impervious (acres)
02030105110060							
Mountain (MZ)	2,009.84	1.08%	21.68	485.84	1,524.00	5%	76.20
Quarry (Q)	765.52	0.02%	0.18	32.46	733.06	5%	36.65
TOTALS	2,775.36	0.8%	21.86	518.30	2,257.06	5%	112.85
020301050040010							
Agriculture (AG)	2,206.32	2.94%	64.92	327.38	1,878.94	5%	93.95
Neighborhood Shopping Center District (C1)	402.70	1.85%	7.47	7.05	395.65	65%	257.17
Mountain (MZ)	663.23	2.88%	19.12	134.88	528.35	5%	26.42
TOTALS	3,272.25	2.8%	91.51	469.31	2,802.94	13%	377.54

Note: The Mountain, Quarry, and Agricultural Zoning District allow for rural residential development on five acre lots with a maximum percent impervious of 5 percent.

Table C-2: Pollutant Loads by Land Cover

Land Cover	Total Phosphorus Load (lbs/acre/year)	Total Nitrogen Load (lbs/acre/year)	Total Suspended Solids Load (lbs/acre/yr)
High, Medium Density Residential	1.4	15	140
Low Density, Rural Residential	0.6	5	100
Commercial	2.1	22	200
Industrial	1.5	16	200
Urban, Mixed Urban, Other Urban	1.0	10	120
Agricultural	1.3	10	300
Forest, Water, Wetlands	0.1	3	40
Barrenland/Transitional Area	0.5	5	60

Source: NJDEP Stormwater BMP Manual 2004.

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Table C-3: Nonpoint Source Loads at Build-Out for Two Example HUC14s

HUC14 and Zone	Build-Out Zoning	Developable Area (acres)	TP (lbs/acre/yr)	TP (lbs/yr)	TN (lbs/acre/yr)	TN (lbs/yr)	TSS (lbs/acre/yr)	TSS (lbs/yr)
02030105110060								
Mountain (MZ)	Rural Residential	1,524	0.60	963	5	7,685	100	153,267
Quarry (Q)	Rural Residential	733	0.60	443	5	3,666	100	73,313
TOTALS		2,257		1,406		11,351		226,580
020301050040010								
Agriculture (AG)	Rural Residential	1,879	0.60	1,160	5	9,589	100	190,491
Neighborhood Shopping Center District (C1)	Commercial	396	2.10	832	22	8,727	200	79,429
Mountain (MZ)	Rural Residential	528	0.60	331	5	2,699	100	53,600
TOTALS		2,803		2,323		21,015		323,520

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Mitigation Plans

A mitigation plan is required to grant a variance or exemption from the design and performance standards of a municipal stormwater management plan. The mitigation requirements should offer a hierarchy of options that clearly offset the effect on groundwater recharge, stormwater quantity control, and/or stormwater quality control that was created by granting the variance or exemption. The following fictional example is one of the means a municipality can select for a mitigation plan.

This mitigation plan is provided for a proposed development that is granted a variance or exemption from the stormwater management design and performance standards. Presented is a hierarchy of options.

Mitigation Project Criteria

1. The mitigation project must be implemented in the same drainage area as the proposed development. The project must provide additional groundwater recharge benefits, or protection from stormwater runoff quality and quantity from previously developed property that does not currently meet the design and performance standards outlined in the Municipal Stormwater Management Plan. The developer must ensure the long-term maintenance of the project, including the maintenance requirements under Chapters 8 and 9 of the NJDEP Stormwater BMP Manual.

a. The applicant can select one of the following projects listed to compensate for the deficit from the performance standards resulting from the proposed project. More detailed information on the projects can be obtained from the Township Engineer. Listed below are specific projects that can be used to address the mitigation requirement.

Groundwater Recharge

- Retrofit the L.B. Middle School site and detention basin to provide an additional 300,000 cf of average annual groundwater recharge.
- Replace the existing deteriorated 20,000 sf overflow impervious parking lot at Children's Memorial Soccer Complex with permeable paving to provide 150,000 cf of additional average annual groundwater recharge.

Water Quality

- Retrofit the existing stormwater management facility at Matisse Elementary School to provide the removal of 80 percent of total suspended solids from the parking lot runoff.
- Retrofit the existing parking area at the West Side Municipal Complex to provide the removal of 80 percent of total suspended solids. Due to site constraints, the retrofit BMP must be installed underground and cannot reduce the existing number of parking spaces.

Water Quantity

- Install stormwater management measures in the open space in the Woodlot Development to reduce the peak flow from the upstream development on the receiving stream by 20 cfs, 35 cfs, and 100 cfs for the 2, 10, and 100-year storms respectively.

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2. If a suitable site cannot be located in the same drainage area as the proposed development, as discussed in Option 1, the mitigation project may provide mitigation that is not equivalent to the impacts for which the variance or exemption is sought, but that addresses the same issue. For example, if a variance is given because the 80 percent TSS requirement is not met, the selected project may address water quality impacts due to a fecal impairment. Listed below are specific projects that can be used to address the mitigation option.

Water Quality

- Re-establish a vegetative buffer (minimum 50 foot wide) along 1,500 linear feet of the shoreline at Sunshine Pond as a goose control measure and to filter stormwater runoff from the high goose traffic areas.
- Provide goose management measures, including public education at Central Park.

Options 1 and 2 would be available only if the MSWMP includes a list of environmental enhancement projects that provide groundwater recharge, control flooding, or control nonpoint source pollution. These are fictitious projects for the purposes of providing examples for this plan. Although only a brief description of each project is presented here, it is important for the municipality to have sufficient information on each project, including size of the project, permit requirements, land ownership, and estimated project costs (i.e., permitting fees, engineering costs, construction costs, and maintenance costs).

The municipality may allow a developer to provide funding or partial funding to the municipality for an environmental enhancement project that has been identified in a Municipal Stormwater Management Plan, or towards the development of a Regional Stormwater Management Plan. The funding must be equal to or greater than the cost to implement the mitigation outlined above, including costs associated with purchasing the property or easement for mitigation, and the cost associated with the long-term maintenance requirements of the mitigation measure.

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New Jersey Stormwater Best Management Practices Manual

April 2004

A P P E N D I X D

Model Stormwater Control Ordinance for Municipalities

Important note: *This sample ordinance is provided to assist municipalities in the development of municipal stormwater control ordinances and the incorporation of design and performance standards into municipal stormwater management plans. It is provided for information purposes only. It is important that current regulations are carefully reviewed before any portion of this draft ordinance is adopted.*
This model ordinance does not include a section on fees. The Department expects that the review of development applications under this ordinance would be an integral part of the municipal review of subdivisions and site plans. As a result, the costs to municipalities of reviewing development applications under this ordinance can be defrayed by fees charged for review of subdivisions and site plans under N.J.S.A. 40:55D-8.b.

Notes are provided in italics throughout this model stormwater control ordinance, and are not intended to be adopted as part of the ordinance.

An editable Word version of this model ordinance is available at: *http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_D.doc.*

Section 1: Scope and Purpose

A. Policy Statement

Flood control, groundwater recharge, and pollutant reduction through nonstructural or low impact techniques shall be explored before relying on structural BMPs. Structural BMPs should be integrated with nonstructural stormwater management strategies and proper maintenance plans. Nonstructural strategies include both environmentally sensitive site design and source controls that prevent pollutants from being placed on the site or from being exposed to stormwater. Source control plans should be developed based upon physical site conditions and the origin, nature, and the anticipated quantity or amount of potential pollutants. Multiple stormwater management BMPs may be necessary to achieve the established performance standards for water quality, quantity, and groundwater recharge.

Note: Municipalities are encouraged to participate in the development of regional stormwater management plans, and to adopt and implement ordinances for specific drainage area performance standards that address local stormwater management and environmental characteristics.

B. Purpose

It is the purpose of this ordinance to establish minimum stormwater management requirements and controls for "major development," as defined in Section 2.

C. Applicability

1. This ordinance shall be applicable to all site plans and subdivisions for the following major developments that require preliminary or final site plan or subdivision review:

   a. Non-residential major developments; and

   b. Aspects of residential major developments that are not pre-empted by the Residential Site Improvement Standards at N.J.A.C. 5:21.

2. This ordinance shall also be applicable to all major developments undertaken by [*insert name of municipality*].

D. Compatibility with Other Permit and Ordinance Requirements

Development approvals issued for subdivisions and site plans pursuant to this ordinance are to be considered an integral part of development approvals under the subdivision and site plan review process and do not relieve the applicant of the responsibility to secure required permits or approvals for activities regulated by any other applicable code, rule, act, or ordinance. In their interpretation and application, the provisions of this ordinance shall be held to be the minimum requirements for the promotion of the public health, safety, and general welfare. This ordinance is not intended to interfere with, abrogate, or annul any other ordinances, rule or regulation, statute, or other provision of law except that, where any provision of this ordinance imposes restrictions different from those imposed by any other ordinance, rule or regulation, or other provision of law, the more restrictive provisions or higher standards shall control.

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Section 2: Definitions

Unless specifically defined below, words or phrases used in this ordinance shall be interpreted so as to give them the meaning they have in common usage and to give this ordinance its most reasonable application. The definitions below are the same as or based on the corresponding definitions in the Stormwater Management Rules at N.J.A.C. 7:8-1.2.

"CAFRA Planning Map" means the geographic depiction of the boundaries for Coastal Planning Areas, CAFRA Centers, CAFRA Cores and CAFRA Nodes pursuant to N.J.A.C. 7:7E-5B.3.

"CAFRA Centers, Cores or Nodes" means those areas within boundaries accepted by the Department pursuant to N.J.A.C. 7:8E-5B.

"Compaction" means the increase in soil bulk density.

"Core" means a pedestrian-oriented area of commercial and civic uses serving the surrounding municipality, generally including housing and access to public transportation.

"County review agency" means an agency designated by the County Board of Chosen Freeholders to review municipal stormwater management plans and implementing ordinance(s). The county review agency may either be:

A county planning agency; or

A county water resource association created under N.J.S.A 58:16A-55.5, if the ordinance or resolution delegates authority to approve, conditionally approve, or disapprove municipal stormwater management plans and implementing ordinances.

"Department" means the New Jersey Department of Environmental Protection.

"Designated Center" means a State Development and Redevelopment Plan Center as designated by the State Planning Commission such as urban, regional, town, village, or hamlet.

"Design engineer" means a person professionally qualified and duly licensed in New Jersey to perform engineering services that may include, but not necessarily be limited to, development of project requirements, creation and development of project design and preparation of drawings and specifications.

"Development" means the division of a parcel of land into two or more parcels, the construction, reconstruction, conversion, structural alteration, relocation or enlargement of any building or structure, any mining excavation or landfill, and any use or change in the use of any building or other structure, or land or extension of use of land, by any person, for which permission is required under the Municipal Land Use Law , N.J.S.A. 40:55D-1 et seq. In the case of development of agricultural lands, development means: any activity that requires a State permit; any activity reviewed by the County Agricultural Board (CAB) and the State Agricultural Development Committee (SADC), and municipal review of any activity not exempted by the Right to Farm Act , N.J.S.A 4:1C-1 et seq.

"Drainage area" means a geographic area within which stormwater, sediments, or dissolved materials drain to a particular receiving waterbody or to a particular point along a receiving waterbody.

"Environmentally critical areas" means an area or feature which is of significant environmental value, including but not limited to: stream corridors; natural heritage priority sites; habitat of endangered or threatened species; large areas of contiguous open space or upland forest; steep slopes; and well head protection and groundwater recharge areas. Habitats of endangered or threatened species are identified

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using the Department's Landscape Project as approved by the Department's Endangered and Nongame Species Program.

"Empowerment Neighborhood" means a neighborhood designated by the Urban Coordinating Council "in consultation and conjunction with" the New Jersey Redevelopment Authority pursuant to N.J.S.A 55:19-69.

"Erosion" means the detachment and movement of soil or rock fragments by water, wind, ice or gravity.

"Impervious surface" means a surface that has been covered with a layer of material so that it is highly resistant to infiltration by water.

"Infiltration" is the process by which water seeps into the soil from precipitation.

"Major development" means any "development" that provides for ultimately disturbing one or more acres of land. Disturbance for the purpose of this rule is the placement of impervious surface or exposure and/or movement of soil or bedrock or clearing, cutting, or removing of vegetation.

"Municipality" means any city, borough, town, township, or village.

"Node" means an area designated by the State Planning Commission concentrating facilities and activities which are not organized in a compact form.

"Nutrient" means a chemical element or compound, such as nitrogen or phosphorus, which is essential to and promotes the development of organisms.

"Person" means any individual, corporation, company, partnership, firm, association, [*insert name of municipality*], or political subdivision of this State subject to municipal jurisdiction pursuant to the Municipal Land Use Law , N.J.S.A. 40:55D-1 et seq.

"Pollutant" means any dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, refuse, oil, grease, sewage sludge, munitions, chemical wastes, biological materials, medical wastes, radioactive substance (except those regulated under the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.), thermal waste, wrecked or discarded equipment, rock, sand, cellar dirt, industrial, municipal, agricultural, and construction waste or runoff, or other residue discharged directly or indirectly to the land, ground waters or surface waters of the State, or to a domestic treatment works. "Pollutant" includes both hazardous and nonhazardous pollutants.

"Recharge" means the amount of water from precipitation that infiltrates into the ground and is not evapotranspired.

"Sediment" means solid material, mineral or organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water or gravity as a product of erosion.

"Site" means the lot or lots upon which a major development is to occur or has occurred.

"Soil" means all unconsolidated mineral and organic material of any origin.

"State Development and Redevelopment Plan Metropolitan Planning Area (PA1)" means an area delineated on the State Plan Policy Map and adopted by the State Planning Commission that is intended to be the focus for much of the state's future redevelopment and revitalization efforts.

"State Plan Policy Map" is defined as the geographic application of the State Development and Redevelopment Plan's goals and statewide policies, and the official map of these goals and policies.

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"Stormwater" means water resulting from precipitation (including rain and snow) that runs off the land's surface, is transmitted to the subsurface, or is captured by separate storm sewers or other sewage or drainage facilities, or conveyed by snow removal equipment.

"Stormwater runoff" means water flow on the surface of the ground or in storm sewers, resulting from precipitation.

"Stormwater management basin" means an excavation or embankment and related areas designed to retain stormwater runoff. A stormwater management basin may either be normally dry (that is, a detention basin or infiltration basin), retain water in a permanent pool (a retention basin), or be planted mainly with wetland vegetation (most constructed stormwater wetlands).

"Stormwater management measure" means any structural or nonstructural strategy, practice, technology, process, program, or other method intended to control or reduce stormwater runoff and associated pollutants, or to induce or control the infiltration or groundwater recharge of stormwater or to eliminate illicit or illegal non-stormwater discharges into stormwater conveyances.

"Tidal Flood Hazard Area" means a flood hazard area, which may be influenced by stormwater runoff from inland areas, but which is primarily caused by the Atlantic Ocean.

"Urban Coordinating Council Empowerment Neighborhood" means a neighborhood given priority access to State resources through the New Jersey Redevelopment Authority.

"Urban Enterprise Zones" means a zone designated by the New Jersey Enterprise Zone Authority pursuant to the New Jersey Urban Enterprise Zones Act, N.J.S.A. 52:27H-60 et. seq.

"Urban Redevelopment Area" is defined as previously developed portions of areas:

(1) Delineated on the State Plan Policy Map (SPPM) as the Metropolitan Planning Area (PA1), Designated Centers, Cores or Nodes;

(2) Designated as CAFRA Centers, Cores or Nodes;

(3) Designated as Urban Enterprise Zones; and

(4) Designated as Urban Coordinating Council Empowerment Neighborhoods.

"Waters of the State" means the ocean and its estuaries, all springs, streams, wetlands, and bodies of surface or ground water, whether natural or artificial, within the boundaries of the State of New Jersey or subject to its jurisdiction.

"Wetlands" or "wetland" means an area that is inundated or saturated by surface water or ground water at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions, commonly known as hydrophytic vegetation.

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Section 3: General Standards

A. Design and Performance Standards for Stormwater Management Measures

1. Stormwater management measures for major development shall be developed to meet the erosion control, groundwater recharge, stormwater runoff quantity, and stormwater runoff quality standards in Section 4. To the maximum extent practicable, these standards shall be met by incorporating nonstructural stormwater management strategies into the design. If these strategies alone are not sufficient to meet these standards, structural stormwater management measures necessary to meet these standards shall be incorporated into the design.

2. The standards in this ordinance apply only to new major development and are intended to minimize the impact of stormwater runoff on water quality and water quantity in receiving water bodies and maintain groundwater recharge. The standards do not apply to new major development to the extent that alternative design and performance standards are applicable under a regional stormwater management plan or Water Quality Management Plan adopted in accordance with Department rules.

   Note: Alternative standards shall provide at least as much protection from stormwater-related loss of groundwater recharge, stormwater quantity and water quality impacts of major development projects as would be provided under the standards in N.J.A.C. 7:8-5.

Section 4: Stormwater Management Requirements for Major Development

A. The development shall incorporate a maintenance plan for the stormwater management measures incorporated into the design of a major development in accordance with Section 10.

B. Stormwater management measures shall avoid adverse impacts of concentrated flow on habitat for threatened and endangered species as documented in the Department' Landscape Project or Natural Heritage Database established under N.J.S.A. 13:1B-15.147 through 15.150, particularly *Helonias bullata* (swamp pink) and/or *Clemmys muhlnebergi* (bog turtle).

C. The following linear development projects are exempt from the groundwater recharge, stormwater runoff quantity, and stormwater runoff quality requirements of Sections 4.F and 4.G:

1. The construction of an underground utility line provided that the disturbed areas are revegetated upon completion;

2. The construction of an aboveground utility line provided that the existing conditions are maintained to the maximum extent practicable; and

3. The construction of a public pedestrian access, such as a sidewalk or trail with a maximum width of 14 feet, provided that the access is made of permeable material.

D. A waiver from strict compliance from the groundwater recharge, stormwater runoff quantity, and stormwater runoff quality requirements of Sections 4.F and 4.G may be obtained for the enlargement of an existing public roadway or railroad; or the construction or enlargement of a public pedestrian access, provided that the following conditions are met:

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1. The applicant demonstrates that there is a public need for the project that cannot be accomplished by any other means;

2. The applicant demonstrates through an alternatives analysis, that through the use of nonstructural and structural stormwater management strategies and measures, the option selected complies with the requirements of Sections 4.F and 4.G to the maximum extent practicable;

3. The applicant demonstrates that, in order to meet the requirements of Sections 4.F and 4.G, existing structures currently in use, such as homes and buildings, would need to be condemned; and

4. The applicant demonstrates that it does not own or have other rights to areas, including the potential to obtain through condemnation lands not falling under D.3 above within the upstream drainage area of the receiving stream, that would provide additional opportunities to mitigate the requirements of Sections 4.F and 4.G that were not achievable on-site.

E. Nonstructural Stormwater Management Strategies

1. To the maximum extent practicable, the standards in Sections 4.F and 4.G shall be met by incorporating nonstructural stormwater management strategies set forth at Section 4.E into the design. The applicant shall identify the nonstructural measures incorporated into the design of the project. If the applicant contends that it is not feasible for engineering, environmental, or safety reasons to incorporate any nonstructural stormwater management measures identified in Paragraph 2 below into the design of a particular project, the applicant shall identify the strategy considered and provide a basis for the contention.

2. Nonstructural stormwater management strategies incorporated into site design shall:

   a. Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss;

   b. Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces;

   c. Maximize the protection of natural drainage features and vegetation;

   d. Minimize the decrease in the "time of concentration" from pre-construction to post construction. "Time of concentration" is defined as the time it takes for runoff to travel from the hydraulically most distant point of the watershed to the point of interest within a watershed;

   e. Minimize land disturbance including clearing and grading;

   f. Minimize soil compaction;

   g. Provide low-maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers and pesticides;

   h. Provide vegetated open-channel conveyance systems discharging into and through stable vegetated areas;

   i. Provide other source controls to prevent or minimize the use or exposure of pollutants at the site, in order to prevent or minimize the release of those pollutants into stormwater runoff. Such source controls include, but are not limited to:

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(1) Site design features that help to prevent accumulation of trash and debris in drainage systems, including features that satisfy Section 4.E.3. below;

(2) Site design features that help to prevent discharge of trash and debris from drainage systems;

(3) Site design features that help to prevent and/or contain spills or other harmful accumulations of pollutants at industrial or commercial developments; and

(4) When establishing vegetation after land disturbance, applying fertilizer in accordance with the requirements established under the Soil Erosion and Sediment Control Act, N.J.S.A. 4:24-39 et seq., and implementing rules.

3. Site design features identified under Section 4.E.2.i.(2) above shall comply with the following standard to control passage of solid and floatable materials through storm drain inlets. For purposes of this paragraph, "solid and floatable materials" means sediment, debris, trash, and other floating, suspended, or settleable solids. For exemptions to this standard see Section 4.E.3.c below.

a. Design engineers shall use either of the following grates whenever they use a grate in pavement or another ground surface to collect stormwater from that surface into a storm drain or surface water body under that grate:

(1) The New Jersey Department of Transportation (NJDOT) bicycle safe grate, which is described in Chapter 2.4 of the NJDOT Bicycle Compatible Roadways and Bikeways Planning and Design Guidelines (April 1996); or

(2) A different grate, if each individual clear space in that grate has an area of no more than seven (7.0) square inches, or is no greater than 0.5 inches across the smallest dimension.

Examples of grates subject to this standard include grates in grate inlets, the grate portion (non-curb-opening portion) of combination inlets, grates on storm sewer manholes, ditch grates, trench grates, and grates of spacer bars in slotted drains. Examples of ground surfaces include surfaces of roads (including bridges), driveways, parking areas, bikeways, plazas, sidewalks, lawns, fields, open channels, and stormwater basin floors.

b. Whenever design engineers use a curb-opening inlet, the clear space in that curb opening (or each individual clear space, if the curb opening has two or more clear spaces) shall have an area of no more than seven (7.0) square inches, or be no greater than two (2.0) inches across the smallest dimension.

c. This standard does not apply:

(1) Where the review agency determines that this standard would cause inadequate hydraulic performance that could not practicably be overcome by using additional or larger storm drain inlets that meet these standards;

(2) Where flows from the water quality design storm as specified in Section 4.G.1 are conveyed through any device (e.g., end of pipe netting facility, manufactured treatment device, or a catch basin hood) that is designed, at a minimum, to prevent delivery of all solid and floatable materials that could not pass through one of the following:

(a) A rectangular space four and five-eighths inches long and one and one-half inches wide (this option does not apply for outfall netting facilities); or

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(b) A bar screen having a bar spacing of 0.5 inches.

(3) Where flows are conveyed through a trash rack that has parallel bars with one-inch (1") spacing between the bars, to the elevation of the water quality design storm as specified in Section 4.G.1; or

(4) Where the New Jersey Department of Environmental Protection determines, pursuant to the New Jersey Register of Historic Places Rules at N.J.A.C. 7:4-7.2(c), that action to meet this standard is an undertaking that constitutes an encroachment or will damage or destroy the New Jersey Register listed historic property.

4. Any land area used as a nonstructural stormwater management measure to meet the performance standards in Sections 4.F and 4.G shall be dedicated to a government agency, subjected to a conservation restriction filed with the appropriate County Clerk's office, or subject to an approved equivalent restriction that ensures that measure or an equivalent stormwater management measure approved by the reviewing agency is maintained in perpetuity.

5. Guidance for nonstructural stormwater management strategies is available in the New Jersey Stormwater Best Management Practices Manual. The BMP Manual may be obtained from the address identified in Section 7, or found on the Department's website at www.njstormwater.org.

F. Erosion Control, Groundwater Recharge and Runoff Quantity Standards

1. This subsection contains minimum design and performance standards to control erosion, encourage and control infiltration and groundwater recharge, and control stormwater runoff quantity impacts of major development.

a. The minimum design and performance standards for erosion control are those established under the Soil Erosion and Sediment Control Act, N.J.S.A. 4:24-39 et seq. and implementing rules.

b. The minimum design and performance standards for groundwater recharge are as follows:

(1) The design engineer shall, using the assumptions and factors for stormwater runoff and groundwater recharge calculations at Section 5, either:

(a) Demonstrate through hydrologic and hydraulic analysis that the site and its stormwater management measures maintain 100 percent of the average annual pre-construction groundwater recharge volume for the site; or

(b) Demonstrate through hydrologic and hydraulic analysis that the increase of stormwater runoff volume from pre-construction to post-construction for the 2-year storm is infiltrated.

(2) This groundwater recharge requirement does not apply to projects within the "urban redevelopment area," or to projects subject to (3) below.

(3) The following types of stormwater shall not be recharged:

(a) Stormwater from areas of high pollutant loading. High pollutant loading areas are areas in industrial and commercial developments where solvents and/or petroleum products are loaded/unloaded, stored, or applied, areas where pesticides are loaded/unloaded or stored; areas where hazardous materials are expected to be present in greater than "reportable quantities" as defined by the United States Environmental Protection Agency (EPA) at 40

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CFR 302.4; areas where recharge would be inconsistent with Department approved remedial action work plan or landfill closure plan and areas with high risks for spills of toxic materials, such as gas stations and vehicle maintenance facilities; and

(b) Industrial stormwater exposed to "source material." "Source material" means any material(s) or machinery, located at an industrial facility, that is directly or indirectly related to process, manufacturing or other industrial activities, which could be a source of pollutants in any industrial stormwater discharge to groundwater. Source materials include, but are not limited to, raw materials; intermediate products; final products; waste materials; by-products; industrial machinery and fuels, and lubricants, solvents, and detergents that are related to process, manufacturing, or other industrial activities that are exposed to stormwater.

(4) The design engineer shall assess the hydraulic impact on the groundwater table and design the site so as to avoid adverse hydraulic impacts. Potential adverse hydraulic impacts include, but are not limited to, exacerbating a naturally or seasonally high water table so as to cause surficial ponding, flooding of basements, or interference with the proper operation of subsurface sewage disposal systems and other subsurface structures in the vicinity or downgradient of the groundwater recharge area.

c. In order to control stormwater runoff quantity impacts, the design engineer shall, using the assumptions and factors for stormwater runoff calculations at Section 5, complete one of the following:

(1) Demonstrate through hydrologic and hydraulic analysis that for stormwater leaving the site, post-construction runoff hydrographs for the two, 10, and 100-year storm events do not exceed, at any point in time, the pre-construction runoff hydrographs for the same storm events;

(2) Demonstrate through hydrologic and hydraulic analysis that there is no increase, as compared to the pre-construction condition, in the peak runoff rates of stormwater leaving the site for the two, 10, and 100-year storm events and that the increased volume or change in timing of stormwater runoff will not increase flood damage at or downstream of the site. This analysis shall include the analysis of impacts of existing land uses and projected land uses assuming full development under existing zoning and land use ordinances in the drainage area;

(3) Design stormwater management measures so that the post-construction peak runoff rates for the 2, 10 and 100 year storm events are 50, 75 and 80 percent, respectively, of the pre-construction peak runoff rates. The percentages apply only to the post-construction stormwater runoff that is attributable to the portion of the site on which the proposed development or project is to be constructed. The percentages shall not be applied to post-construction stormwater runoff into tidal flood hazard areas if the increased volume of stormwater runoff will not increase flood damages below the point of discharge; or

(4) In tidal flood hazard areas, stormwater runoff quantity analysis in accordance with (1), (2) and (3) above shall only be applied if the increased volume of stormwater runoff could increase flood damages below the point of discharge.

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2. Any application for a new agricultural development that meets the definition of major development at Section 2 shall be submitted to the appropriate Soil Conservation District for review and approval in accordance with the requirements of this section and any applicable Soil Conservation District guidelines for stormwater runoff quantity and erosion control. For the purposes of this section, "agricultural development" means land uses normally associated with the production of food, fiber and livestock for sale. Such uses do not include the development of land for the processing or sale of food and the manufacturing of agriculturally related products.

G. Stormwater Runoff Quality Standards

1. Stormwater management measures shall be designed to reduce the post-construction load of total suspended solids (TSS) in stormwater runoff by 80 percent of the anticipated load from the developed site, expressed as an annual average. Stormwater management measures shall only be required for water quality control if an additional 1/4 acre of impervious surface is being proposed on a development site. The requirement to reduce TSS does not apply to any stormwater runoff in a discharge regulated under a numeric effluent limitation for TSS imposed under the New Jersey Pollution Discharge Elimination System (NJPDES) rules, N.J.A.C. 7:14A, or in a discharge specifically exempt under a NJPDES permit from this requirement. The water quality design storm is 1.25 inches of rainfall in two hours. Water quality calculations shall take into account the distribution of rain from the water quality design storm, as reflected in Table 1. The calculation of the volume of runoff may take into account the implementation of non-structural and structural stormwater management measures.

Table 1: Water Quality Design Storm Distribution

Time (Minutes)	Cumulative Rainfall (Inches)	Time (Minutes)	Cumulative Rainfall (Inches)
0	0.0000	65	0.8917
5	0.0083	70	0.9917
10	0.0166	75	1.0500
15	0.0250	80	1.0840
20	0.0500	85	1.1170
25	0.0750	90	1.1500
30	0.1000	95	1.1750
35	0.1330	100	1.2000
40	0.1660	105	1.2250
45	0.2000	110	1.2334
50	0.2583	115	1.2417
55	0.3583	120	1.2500
60	0.6250		

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2. For purposes of TSS reduction calculations, Table 2 below presents the presumed removal rates for certain BMPs designed in accordance with the New Jersey Stormwater Best Management Practices Manual. The BMP Manual may be obtained from the address identified in Section 7, or found on the Department's website at www.njstormwater.org. The BMP Manual and other sources of technical guidance are listed in Section 7. TSS reduction shall be calculated based on the removal rates for the BMPs in Table 2 below. Alternative removal rates and methods of calculating removal rates may be used if the design engineer provides documentation demonstrating the capability of these alternative rates and methods to the review agency. A copy of any approved alternative rate or method of calculating the removal rate shall be provided to the Department at the following address: Division of Watershed Management, New Jersey Department of Environmental Protection, PO Box 418 Trenton, New Jersey, 08625-0418.

3. If more than one BMP in series is necessary to achieve the required 80 percent TSS reduction for a site, the applicant shall utilize the following formula to calculate TSS reduction:

   $R = A + B - (AXB)/100$

   Where

   R = total TSS percent load removal from application of both BMPs, and

   A = the TSS percent removal rate applicable to the first BMP

   B = the TSS percent removal rate applicable to the second BMP

Table 2: TSS Removal Rates for BMPs

Best Management Practice	TSS Percent Removal Rate
Bioretention Systems	90
Constructed Stormwater Wetland	90
Extended Detention Basin	40-60
Infiltration Structure	80
Manufactured Treatment Device	See Section 6.C
Sand Filter	80
Vegetative Filter Strip	60-80
Wet Pond	50-90

4. If there is more than one onsite drainage area, the 80 percent TSS removal rate shall apply to each drainage area, unless the runoff from the subareas converge on site in which case the removal rate can be demonstrated through a calculation using a weighted average.

5. Stormwater management measures shall also be designed to reduce, to the maximum extent feasible, the post-construction nutrient load of the anticipated load from the developed site in stormwater runoff generated from the water quality design storm. In achieving reduction of nutrients to the maximum extent feasible, the design of the site shall include nonstructural strategies and structural

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measures that optimize nutrient removal while still achieving the performance standards in Sections 4.F and 4.G.

6. Additional information and examples are contained in the New Jersey Stormwater Best Management Practices Manual, which may be obtained from the address identified in Section 7.

7. In accordance with the definition of FW1 at N.J.A.C. 7:9B-1.4, stormwater management measures shall be designed to prevent any increase in stormwater runoff to waters classified as FW1.

8. Special water resource protection areas shall be established along all waters designated Category One at N.J.A.C. 7:9B, and perennial or intermittent streams that drain into or upstream of the Category One waters as shown on the USGS Quadrangle Maps or in the County Soil Surveys, within the associated HUC14 drainage area. These areas shall be established for the protection of water quality, aesthetic value, exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, and exceptional fisheries significance of those established Category One waters. These areas shall be designated and protected as follows:

   a. The applicant shall preserve and maintain a special water resource protection area in accordance with one of the following:

      (1) A 300-foot special water resource protection area shall be provided on each side of the waterway, measured perpendicular to the waterway from the top of the bank outwards or from the centerline of the waterway where the bank is not defined, consisting of existing vegetation or vegetation allowed to follow natural succession is provided. (2) Encroachment within the designated special water resource protection area under Subsection (1) above shall only be allowed where previous development or disturbance has occurred (for example, active agricultural use, parking area or maintained lawn area). The encroachment shall only be allowed where applicant demonstrates that the functional value and overall condition of the special water resource protection area will be maintained to the maximum extent practicable. In no case shall the remaining special water resource protection area be reduced to less than 150 feet as measured perpendicular to the top of bank of the waterway or centerline of the waterway where the bank is undefined. All encroachments proposed under this subparagraph shall be subject to review and approval by the Department.

   b. All stormwater shall be discharged outside of and flow through the special water resource protection area and shall comply with the Standard for Off-Site Stability in the "Standards For Soil Erosion and Sediment Control in New Jersey," established under the Soil Erosion and Sediment Control Act , N.J.S.A. 4:24-39 et seq.

   c. If stormwater discharged outside of and flowing through the special water resource protection area cannot comply with the Standard For Off-Site Stability in the "Standards for Soil Erosion and Sediment Control in New Jersey," established under the Soil Erosion and Sediment Control Act , N.J.S.A. 4:24-39 et seq., then the stabilization measures in accordance with the requirements of the above standards may be placed within the special water resource protection area, provided that:

      (1) Stabilization measures shall not be placed within 150 feet of the Category One waterway;

      (2) Stormwater associated with discharges allowed by this section shall achieve a 95 percent TSS post-construction removal rate;

      (3) Temperature shall be addressed to ensure no impact on the receiving waterway;

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(4) The encroachment shall only be allowed where the applicant demonstrates that the functional value and overall condition of the special water resource protection area will be maintained to the maximum extent practicable;

(5) A conceptual project design meeting shall be held with the appropriate Department staff and Soil Conservation District staff to identify necessary stabilization measures; and

(6) All encroachments proposed under this section shall be subject to review and approval by the Department.

d. A stream corridor protection plan may be developed by a regional stormwater management planning committee as an element of a regional stormwater management plan, or by a municipality through an adopted municipal stormwater management plan. If a stream corridor protection plan for a waterway subject to Section 4.G(8) has been approved by the Department of Environmental Protection, then the provisions of the plan shall be the applicable special water resource protection area requirements for that waterway. A stream corridor protection plan for a waterway subject to G.8 shall maintain or enhance the current functional value and overall condition of the special water resource protection area as defined in G.8.a.(1) above. In no case shall a stream corridor protection plan allow the reduction of the Special Water Resource Protection Area to less than 150 feet as measured perpendicular to the waterway subject to this subsection.

e. Paragraph G.8 does not apply to the construction of one individual single family dwelling that is not part of a larger development on a lot receiving preliminary or final subdivision approval on or before February 2, 2004 , provided that the construction begins on or before February 2, 2009.

Section 5: Calculation of Stormwater Runoff and Groundwater Recharge

A. Stormwater runoff shall be calculated in accordance with the following:

1. The design engineer shall calculate runoff using one of the following methods:

   a. The USDA Natural Resources Conservation Service (NRCS) methodology, including the NRCS Runoff Equation and Dimensionless Unit Hydrograph, as described in the NRCS National Engineering Handbook Section 4 – Hydrology and Technical Release 55 – Urban Hydrology for Small Watersheds; or

   b. The Rational Method for peak flow and the Modified Rational Method for hydrograph computations.

2. For the purpose of calculating runoff coefficients and groundwater recharge, there is a presumption that the pre-construction condition of a site or portion thereof is a wooded land use with good hydrologic condition. The term "runoff coefficient" applies to both the NRCS methodology at Section 5.A.1.a and the Rational and Modified Rational Methods at Section 5.A.1.b. A runoff coefficient or a groundwater recharge land cover for an existing condition may be used on all or a portion of the site if the design engineer verifies that the hydrologic condition has existed on the site or portion of the site for at least five years without interruption prior to the time of application. If more than one land cover have existed on the site during the five years immediately prior to the time of application, the land cover with the lowest runoff potential shall be used for the computations. In addition, there is the presumption that the site is in good hydrologic condition (if the land use type is pasture, lawn, or park), with good cover (if the land use type is woods), or with good hydrologic condition and conservation treatment (if the land use type is cultivation).

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3. In computing pre-construction stormwater runoff, the design engineer shall account for all significant land features and structures, such as ponds, wetlands, depressions, hedgerows, or culverts, that may reduce pre-construction stormwater runoff rates and volumes.

4. In computing stormwater runoff from all design storms, the design engineer shall consider the relative stormwater runoff rates and/or volumes of pervious and impervious surfaces separately to accurately compute the rates and volume of stormwater runoff from the site. To calculate runoff from unconnected impervious cover, urban impervious area modifications as described in the NRCS Technical Release 55 – Urban Hydrology for Small Watersheds and other methods may be employed.

5. If the invert of the outlet structure of a stormwater management measure is below the flood hazard design flood elevation as defined at N.J.A.C. 7:13, the design engineer shall take into account the effects of tailwater in the design of structural stormwater management measures.

B. Groundwater recharge may be calculated in accordance with the following:

1. The New Jersey Geological Survey Report GSR-32 A Method for Evaluating Ground-Water Recharge Areas in New Jersey, incorporated herein by reference as amended and supplemented. Information regarding the methodology is available from the New Jersey Stormwater Best Management Practices Manual; at http://www.state.nj.us/dep/njgs/; or at New Jersey Geological Survey, 29 Arctic Parkway, P.O. Box 427 Trenton, New Jersey 08625-0427; (609) 984-6587.

Section 6: Standards for Structural Stormwater Management Measures

A. Standards for structural stormwater management measures are as follows:

1. Structural stormwater management measures shall be designed to take into account the existing site conditions, including, for example, environmentally critical areas, wetlands; flood-prone areas; slopes; depth to seasonal high water table; soil type, permeability and texture; drainage area and drainage patterns; and the presence of solution-prone carbonate rocks (limestone).

2. Structural stormwater management measures shall be designed to minimize maintenance, facilitate maintenance and repairs, and ensure proper functioning. Trash racks shall be installed at the intake to the outlet structure as appropriate, and shall have parallel bars with one-inch (1") spacing between the bars to the elevation of the water quality design storm. For elevations higher than the water quality design storm, the parallel bars at the outlet structure shall be spaced no greater than one-third (1/3) the width of the diameter of the orifice or one-third (1/3) the width of the weir, with a minimum spacing between bars of one-inch and a maximum spacing between bars of six inches. In addition, the design of trash racks must comply with the requirements of Section 8.D.

3. Structural stormwater management measures shall be designed, constructed, and installed to be strong, durable, and corrosion resistant. Measures that are consistent with the relevant portions of the Residential Site Improvement Standards at N.J.A.C. 5:21-7.3, 7.4, and 7.5 shall be deemed to meet this requirement.

4. At the intake to the outlet from the stormwater management basin, the orifice size shall be a minimum of two and one-half inches in diameter.

5. Stormwater management basins shall be designed to meet the minimum safety standards for stormwater management basins at Section 8.

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B. Stormwater management measure guidelines are available in the New Jersey Stormwater Best Management Practices Manual. Other stormwater management measures may be utilized provided the design engineer demonstrates that the proposed measure and its design will accomplish the required water quantity, groundwater recharge and water quality design and performance standards established by Section 4 of this ordinance.

C. Manufactured treatment devices may be used to meet the requirements of Section 4 this ordinance, provided the pollutant removal rates are verified by the New Jersey Corporation for Advanced Technology and certified by the Department.

Section 7: Sources for Technical Guidance

A. Technical guidance for stormwater management measures can be found in the documents listed at 1 and 2 below, which are available from Maps and Publications, New Jersey Department of Environmental Protection, 428 East State Street, P.O. Box 420, Trenton, New Jersey, 08625; telephone (609) 777-1038.

1. Guidelines for stormwater management measures are contained in the New Jersey Stormwater Best Management Practices Manual, as amended. Information is provided on stormwater management measures such as: bioretention systems, constructed stormwater wetlands, dry wells, extended detention basins, infiltration structures, manufactured treatment devices, pervious paving, sand filters, vegetative filter strips, and wet ponds.

2. The New Jersey Department of Environmental Protection Stormwater Management Facilities Maintenance Manual, as amended.

B. Additional technical guidance for stormwater management measures can be obtained from the following:

1. The "Standards for Soil Erosion and Sediment Control in New Jersey" promulgated by the State Soil Conservation Committee and incorporated into N.J.A.C. 2:90. Copies of these standards may be obtained by contacting the State Soil Conservation Committee or any of the Soil Conservation Districts listed in N.J.A.C. 2:90-1.3(a)4. The location, address, and telephone number of each Soil Conservation District may be obtained from the State Soil Conservation Committee, P.O. Box 330, Trenton, New Jersey 08625; (609) 292-5540;

2. The Rutgers Cooperative Extension Service, 732-932-9306; and

3. The Soil Conservation Districts listed in N.J.A.C. 2:90-1.3(a)4. The location, address, and telephone number of each Soil Conservation District may be obtained from the State Soil Conservation Committee, P.O. Box 330, Trenton, New Jersey, 08625, (609) 292-5540.

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Section 8: Safety Standards for Stormwater Management Basins

A. This section sets forth requirements to protect public safety through the proper design and operation of stormwater management basins. This section applies to any new stormwater management basin.

Note: The provisions of this section are not intended to preempt more stringent municipal or county safety requirements for new or existing stormwater management basins. Municipal and county stormwater management plans and ordinances may, pursuant to their authority, require existing stormwater management basins to be retrofitted to meet one or more of the safety standards in Sections 8.B.1, 8.B.2, and 8.B.3 for trash racks, overflow grates, and escape provisions at outlet structures.

B. Requirements for Trash Racks, Overflow Grates and Escape Provisions

1. A trash rack is a device designed to catch trash and debris and prevent the clogging of outlet structures. Trash racks shall be installed at the intake to the outlet from the stormwater management basin to ensure proper functioning of the basin outlets in accordance with the following:

   a. The trash rack shall have parallel bars, with no greater than six inch spacing between the bars.

   b. The trash rack shall be designed so as not to adversely affect the hydraulic performance of the outlet pipe or structure.

   c. The average velocity of flow through a clean trash rack is not to exceed 2.5 feet per second under the full range of stage and discharge. Velocity is to be computed on the basis of the net area of opening through the rack.

   d. The trash rack shall be constructed and installed to be rigid, durable, and corrosion resistant, and shall be designed to withstand a perpendicular live loading of 300 lbs/ft sq.

2. An overflow grate is designed to prevent obstruction of the overflow structure. If an outlet structure has an overflow grate, such grate shall meet the following requirements:

   a. The overflow grate shall be secured to the outlet structure but removable for emergencies and maintenance.

   b. The overflow grate spacing shall be no less than two inches across the smallest dimension.

   c. The overflow grate shall be constructed and installed to be rigid, durable, and corrosion resistant, and shall be designed to withstand a perpendicular live loading of 300 lbs./ft sq.

3. For purposes of this paragraph 3, escape provisions means the permanent installation of ladders, steps, rungs, or other features that provide easily accessible means of egress from stormwater management basins. Stormwater management basins shall include escape provisions as follows:

   a. If a stormwater management basin has an outlet structure, escape provisions shall be incorporated in or on the structure. With the prior approval of the reviewing agency identified in Section 8.C a free-standing outlet structure may be exempted from this requirement.

   b. Safety ledges shall be constructed on the slopes of all new stormwater management basins having a permanent pool of water deeper than two and one-half feet. Such safety ledges shall be comprised of two steps. Each step shall be four to six feet in width. One step shall be located approximately two and one-half feet below the permanent water surface, and the second step shall be located one to

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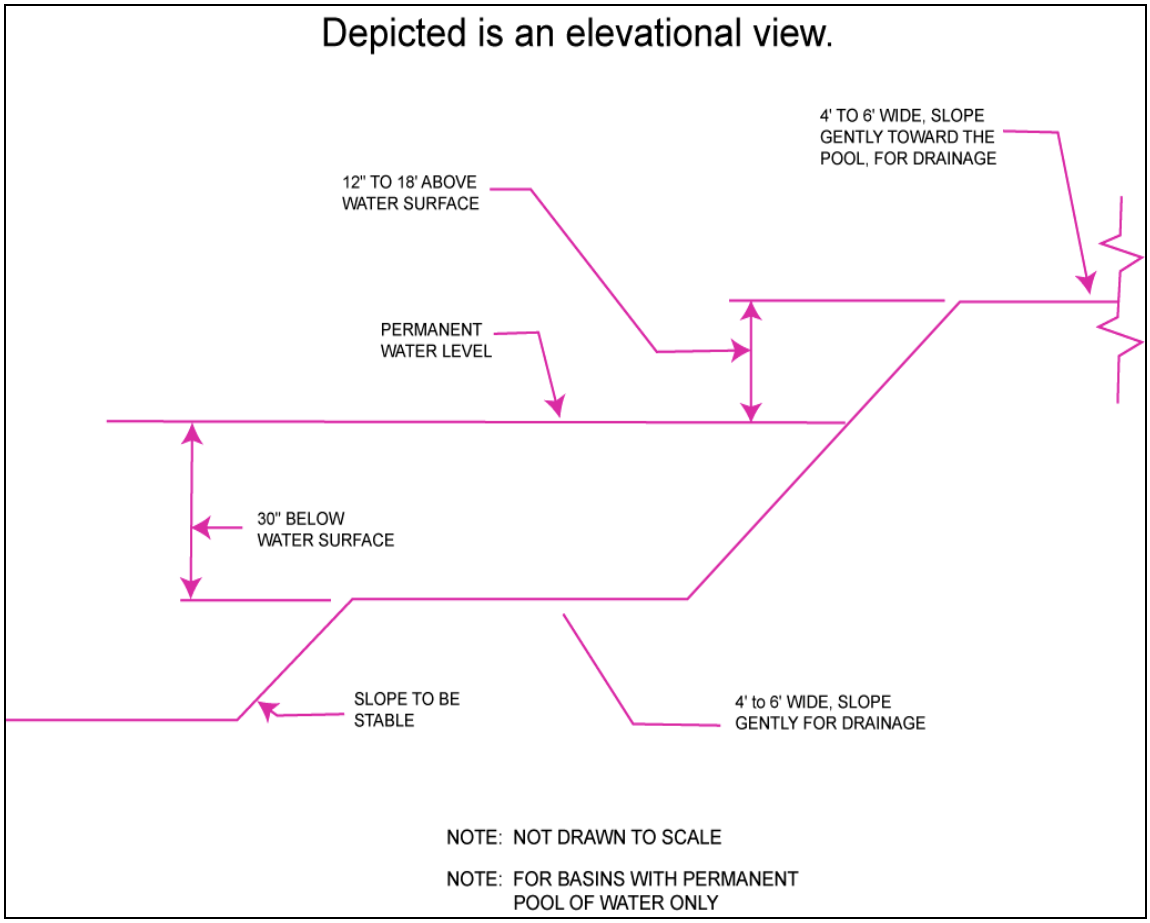
one and one-half feet above the permanent water surface. See Section 8.D for an illustration of safety ledges in a stormwater management basin.

c. In new stormwater management basins, the maximum interior slope for an earthen dam, embankment, or berm shall not be steeper than 3 horizontal to 1 vertical.

C. Variance or Exemption from Safety Standards

1. A variance or exemption from the safety standards for stormwater management basins may be granted only upon a written finding by the appropriate reviewing agency (municipality, county or Department) that the variance or exemption will not constitute a threat to public safety.

D. Illustration of Safety Ledges in a New Stormwater Management Basin



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Section 9: Requirements for a Site Development Stormwater Plan

A. Submission of Site Development Stormwater Plan

1. Whenever an applicant seeks municipal approval of a development subject to this ordinance, the applicant shall submit all of the required components of the Checklist for the Site Development Stormwater Plan at Section 9.C below as part of the submission of the applicant's application for subdivision or site plan approval.

2. The applicant shall demonstrate that the project meets the standards set forth in this ordinance.

3. The applicant shall submit [*specify number*] copies of the materials listed in the checklist for site development stormwater plans in accordance with Section 9.C of this ordinance.

B. Site Development Stormwater Plan Approval

The applicant's Site Development project shall be reviewed as a part of the subdivision or site plan review process by the municipal board or official from which municipal approval is sought. That municipal board or official shall consult the engineer retained by the Planning and/or Zoning Board (as appropriate) to determine if all of the checklist requirements have been satisfied and to determine if the project meets the standards set forth in this ordinance.

C. Checklist Requirements

The following information shall be required:

1. Topographic Base Map

The reviewing engineer may require upstream tributary drainage system information as necessary. It is recommended that the topographic base map of the site be submitted which extends a minimum of 200 feet beyond the limits of the proposed development, at a scale of 1"=200' or greater, showing 2-foot contour intervals. The map as appropriate may indicate the following: existing surface water drainage, shorelines, steep slopes, soils, erodible soils, perennial or intermittent streams that drain into or upstream of the Category One waters, wetlands and flood plains along with their appropriate buffer strips, marshlands and other wetlands, pervious or vegetative surfaces, existing man-made structures, roads, bearing and distances of property lines, and significant natural and manmade features not otherwise shown.

2. Environmental Site Analysis

A written and graphic description of the natural and man-made features of the site and its environs. This description should include a discussion of soil conditions, slopes, wetlands, waterways and vegetation on the site. Particular attention should be given to unique, unusual, or environmentally sensitive features and to those that provide particular opportunities or constraints for development.

3. Project Description and Site Plan(s)

A map (or maps) at the scale of the topographical base map indicating the location of existing and proposed buildings, roads, parking areas, utilities, structural facilities for stormwater management and sediment control, and other permanent structures. The map(s) shall also clearly show areas where alterations occur in the natural terrain and cover, including lawns and other landscaping, and seasonal

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high ground water elevations. A written description of the site plan and justification of proposed changes in natural conditions may also be provided.

4. Land Use Planning and Source Control Plan

This plan shall provide a demonstration of how the goals and standards of Sections 3 through 6 are being met. The focus of this plan shall be to describe how the site is being developed to meet the objective of controlling groundwater recharge, stormwater quality and stormwater quantity problems at the source by land management and source controls whenever possible.

5. Stormwater Management Facilities Map

The following information, illustrated on a map of the same scale as the topographic base map, shall be included:

a. Total area to be paved or built upon, proposed surface contours, land area to be occupied by the stormwater management facilities and the type of vegetation thereon, and details of the proposed plan to control and dispose of stormwater.

b. Details of all stormwater management facility designs, during and after construction, including discharge provisions, discharge capacity for each outlet at different levels of detention and emergency spillway provisions with maximum discharge capacity of each spillway.

6. Calculations

a. Comprehensive hydrologic and hydraulic design calculations for the pre-development and post-development conditions for the design storms specified in Section 4 of this ordinance.

b. When the proposed stormwater management control measures (e.g., infiltration basins) depends on the hydrologic properties of soils, then a soils report shall be submitted. The soils report shall be based on onsite boring logs or soil pit profiles. The number and location of required soil borings or soil pits shall be determined based on what is needed to determine the suitability and distribution of soils present at the location of the control measure.

7. Maintenance and Repair Plan

The design and planning of the stormwater management facility shall meet the maintenance requirements of Section 10.

8. Waiver from Submission Requirements

The municipal official or board reviewing an application under this ordinance may, in consultation with the municipal engineer, waive submission of any of the requirements in Sections 9.C.1 through 9.C.6 of this ordinance when it can be demonstrated that the information requested is impossible to obtain or it would create a hardship on the applicant to obtain and its absence will not materially affect the review process.

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Section 10: Maintenance and Repair

A. Applicability

1. Projects subject to review as in Section 1.C of this ordinance shall comply with the requirements of Sections 10.B and 10.C.

B. General Maintenance

1. The design engineer shall prepare a maintenance plan for the stormwater management measures incorporated into the design of a major development.

2. The maintenance plan shall contain specific preventative maintenance tasks and schedules; cost estimates, including estimated cost of sediment, debris, or trash removal; and the name, address, and telephone number of the person or persons responsible for preventative and corrective maintenance (including replacement). Maintenance guidelines for stormwater management measures are available in the New Jersey Stormwater Best Management Practices Manual. If the maintenance plan identifies a person other than the developer (for example, a public agency or homeowners' association) as having the responsibility for maintenance, the plan shall include documentation of such person's agreement to assume this responsibility, or of the developer's obligation to dedicate a stormwater management facility to such person under an applicable ordinance or regulation.

3. Responsibility for maintenance shall not be assigned or transferred to the owner or tenant of an individual property in a residential development or project, unless such owner or tenant owns or leases the entire residential development or project.

4. If the person responsible for maintenance identified under Section 10.B.2 above is not a public agency, the maintenance plan and any future revisions based on Section 10.B.7 below shall be recorded upon the deed of record for each property on which the maintenance described in the maintenance plan must be undertaken.

5. Preventative and corrective maintenance shall be performed to maintain the function of the stormwater management measure, including repairs or replacement to the structure; removal of sediment, debris, or trash; restoration of eroded areas; snow and ice removal; fence repair or replacement; restoration of vegetation; and repair or replacement of nonvegetated linings.

6. The person responsible for maintenance identified under Section 10.B.2 above shall maintain a detailed log of all preventative and corrective maintenance for the structural stormwater management measures incorporated into the design of the development, including a record of all inspections and copies of all maintenance-related work orders.

7. The person responsible for maintenance identified under Section 10.B.2 above shall evaluate the effectiveness of the maintenance plan at least once per year and adjust the plan and the deed as needed.

8. The person responsible for maintenance identified under Section 10.B.2 above shall retain and make available, upon request by any public entity with administrative, health, environmental, or safety authority over the site, the maintenance plan and the documentation required by Sections 10.B.6 and 10.B.7 above.

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9. The requirements of Sections 10.B.3 and 10.B.4 do not apply to stormwater management facilities that are dedicated to and accepted by the municipality or another governmental agency.

   (Note: It may be appropriate to delete requirements in the maintenance and repair plan that are not applicable if the ordinance requires the facility to be dedicated to the municipality. If the municipality does not want to take this responsibility, the ordinance should require the posting of a two year maintenance guarantee in accordance with N.J.S.A. 40:55D-53. Guidelines for developing a maintenance and inspection program are provided in the New Jersey Stormwater Best Management Practices Manual and the NJDEP Ocean County Demonstration Study, Stormwater Management Facilities Maintenance Manual, dated June 1989 available from the NJDEP, Watershed Management Program.)

10. In the event that the stormwater management facility becomes a danger to public safety or public health, or if it is in need of maintenance or repair, the municipality shall so notify the responsible person in writing. Upon receipt of that notice, the responsible person shall have fourteen (14) days to effect maintenance and repair of the facility in a manner that is approved by the municipal engineer or his designee. The municipality, in its discretion, may extend the time allowed for effecting maintenance and repair for good cause. If the responsible person fails or refuses to perform such maintenance and repair, the municipality or County may immediately proceed to do so and shall bill the cost thereof to the responsible person.

B. Nothing in this section shall preclude the municipality in which the major development is located from requiring the posting of a performance or maintenance guarantee in accordance with N.J.S.A. 40:55D-53.

Section 11: Penalties

Any person who erects, constructs, alters, repairs, converts, maintains, or uses any building, structure or land in violation of this ordinance shall be subject to the following penalties: [*Municipality to specify*].

Section 12: Effective Date

This ordinance shall take effect immediately upon the approval by the county review agency, or sixty (60) days from the receipt of the ordinance by the county review agency if the county review agency should fail to act.

Section 13: Severability

If the provisions of any section, subsection, paragraph, subdivision, or clause of this ordinance shall be judged invalid by a court of competent jurisdiction, such order of judgment shall not affect or invalidate the remainder of any section, subsection, paragraph, subdivision, or clause of this ordinance.

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Guidance for the Development of Municipal Mitigation Plans – February 2006

Purpose

The Stormwater Management rules, N.J.A.C. 7:8, establish design and performance standards for management of stormwater that address water quality, water quantity and recharge. These standards are to be met on the site of the proposed development and, to the maximum extent practicable, using nonstructural stormwater management strategies. The Department recognizes that situations may arise in which the design and performance standards may be impossible to meet on the site of a proposed project because of site constraints such as soils or slope. Therefore, at N.J.A.C. 7:8-4, the Stormwater Management rules allow a municipality to develop a mitigation plan to accommodate these special cases.

A municipal mitigation plan is an optional element of a Municipal Stormwater Management Plan, but is required for a municipality to grant a variance or exemption to the design and performance standards for stormwater runoff quality, stormwater runoff quantity, and ground water recharge, established under the Stormwater Management rules at N.J.A.C. 7:8-5. A municipal mitigation plan must identify the measures necessary to offset the deficit created with respect to the design and performance standard(s) that would result from the grant of a variance or exemption at a project site. The plan must ensure that the mitigation is completed in the drainage area and for the performance standard(s) for which the variance or exemption was granted for a project. In order to be in effect, a municipal mitigation plan must be adopted into the municipal stormwater control ordinance and approved by the county review agency.

The existence of a mitigation plan does not supersede the requirements that an applicant meet the design and performance standards for ground water recharge, stormwater quantity, and stormwater quality on site to the maximum extent practicable and that the standards be met using nonstructural techniques to the maximum extent practicable. Instead, it allows municipalities, in limited circumstances, to waive strict compliance with one or more of the performance standards, where full compliance cannot reasonably be accommodated on site, provided there is mitigation of the effect of the deficient compliance provided in accordance with an approved mitigation plan. The test of reasonable accommodation includes reducing the size, scale or layout of the proposed project in order to meet the design and performance standards on site and thereby avoid the need to seek a variance or exemption. A waiver cannot be granted if the project requesting a waiver/exemption would result in a localized adverse impact or create a compliance deficit that can not be compensated for by off site mitigation.

It should be noted that the standards for the Special Water Resource Protection Area (SWRPA) established under the Stormwater Management rules at N.J.A.C. 7:8-5.5(h) cannot be waived through the municipal mitigation plan. A municipality is authorized to

develop a Stream Corridor Protection Plan, in accordance with N.J.A.C. 7:8-4.2(c)13, which can adjust the spatial extent within which the SWRPA requirements apply. All Stream Corridor Protection Plans must be approved by both the county review agency and the New Jersey Department of Environmental Protection, Division of Watershed Management prior to implementation.

Subject to the caveats for applicability and consistent with the provisions of an approved mitigation plan, a municipality may waive one or more of the design and performance standards for projects reviewed under the Municipal Land Use Law, or for projects undertaken by the municipality that are not subject to MLUL. Waivers for linear development projects must be evaluated using the requirements under N.J.A.C. 7:8-5.2(e), which includes the requirement to address mitigation for the performance standard for which strict compliance was not obtained. Where the Department issues a permit that includes a stormwater management review and an associated waiver under the provisions of the specific permit, the municipality is not required to further consider the project under the provisions of the municipal mitigation plan. However, the municipality may choose to require mitigation for projects receiving a waiver from the Department.

Beyond the specific regulatory purpose described, a mitigation plan can also be used to identify existing problems resulting from current stormwater management practices and the means to address them proactively. In addition, where current stormwater management practices contribute to water quality problems or designated use impairments, TMDL implementation plans can target problem areas and prioritize funding available for watershed restoration. Further, measures to address existing stormwater management problems can become a regulatory requirement when they are identified as "additional measures" in a municipal stormwater permit. "Additional measures" become a permit requirement when they are identified in an adopted TMDL or water quality management plan amendment.

Mitigation Plan Requirements

There are two basic approaches that can be used to identify mitigation projects through a municipal mitigation plan. Municipalities may identify a pool of specific mitigation projects that could be selected by an applicant to offset the effect of a requested waiver/exemption or to address an existing stormwater problem, or choose to provide a process through which an applicant has the flexibility and responsibility to identify an appropriate mitigation project and a location to implement the mitigation project to offset the deficit that would be created by the grant of a waiver/exemption or to address a stormwater based impairment. Ideally, municipalities will offer both options.

In order to select an appropriate mitigation project to respond to a requested waiver/exemption requires, an assessment of the impact that would result from the requested deviation from full compliance with the standard(s) in the drainage area affected by the proposed project is required. For example, a waiver for stormwater quantity requirements must focus on the impacts of increased runoff on flooding,

considering both quantity and location. Stormwater quality mitigation must aim to prevent an increase in pollutant load to the waterbodies that would be affected by the waiver/exemption. Ground water recharge mitigation must seek to maintain the baseflow and aquifer recharge in the area that would be affected by the waiver/exemption. For the purpose of this discussion, the term "sensitive receptor" is used to refer to a specific area or feature that would be sensitive to the impact assessed above.

Selection of an appropriate mitigation project for a requested waiver/exemption must adhere to the following requirements:

1. The project must be within the same area that would contribute to the receptor impacted by the project. *Note that depending on the specific performance standard waived, the sensitive receptor and/or the contributory area to that receptor may be different.* If there are no specific sensitive receptors that would be impacted as the result of the grant of the waiver/exemption, then the location of the mitigation project can be located anywhere within the municipality, and should be selected to provide the most benefit relative to an existing stormwater problem in the same category (quality, quantity or recharge).

2. Legal authorization must be obtained to construct the project at the location selected. This includes the maintenance and any access needs for the project in the future.

3. The project should be close to the location of the original project, and if possible, be located upstream at a similar distance from the identified sensitive receptor. This distance should not be based on actual location, but on a similar hydraulic distance to the sensitive receptor. For example, if the project for which a waiver is obtained discharges to a tributary, but the closest location discharges to the main branch, it may be more beneficial to identify a location discharging to the same tributary.

4. For ease of administration, if sensitive receptors are addressed, it is preferable to have one location that addresses any and all of the performance standards waived, rather than one location for each performance standard.

5. It must be demonstrated that implementation of the mitigation project will result in no adverse impacts to other properties.

6. Mitigation projects that address stormwater runoff quantity can provide storage for proposed increases in runoff volume, as opposed to a direct peak flow reduction.

Stormwater Quantity Considerations

Increased stormwater runoff volume from new development can cause damages to property and habitat due to increased flood elevations and/or flood velocities. Mitigation project areas can include locations that will provide for additional storage and slower release of excess stormwater. Mitigation of stormwater quantity can be accomplished by increasing flood storage areas along the waterway, creating new best management practices (BMPs) to control previously uncontrolled runoff or by retrofitting existing stormwater structures to decrease the volume and peak of runoff.

In areas adjacent to the stream, a hydrologic and hydraulic analysis can be performed to determine if increasing storage capacity would offset the additional volume of runoff and associated peak increase from sites upstream of the storage area. Increases in the storage capacity of an existing structure, such as upstream of a bridge or culvert, can also be considered provided that it is demonstrated that such an increase does not exacerbate flooding at other areas.

Note that work in regulated areas, such as floodplains and wetlands must be performed in accordance with applicable regulations such as the Flood Hazard Area Control Act Rules and the Freshwater Wetland Act Rules. Also, many areas of open space in New Jersey have received funding by the Department's Green Acres Program and many of those encumbered lands have restrictions placed on them as a result of that funding. Any and all restrictions placed on these lands must be investigated by the municipality before these areas can be utilized for mitigation to ensure that there are no conflicts.

Some examples of areas or features sensitive to changes with regard to flooding include:

Culverts and bridges—these features may constrict flow and cause flooding or may provide storage that, if lost, would cause downstream flooding problems
Property subject to flooding—areas of concern include those where there is historical evidence of recurrent problems, particularly if exacerbated over time because of increasing impervious surface in the contributing watershed
Eroding/widening stream banks or channels—particularly if due to changes in hydrology due to effects of development
Category One waters—flooding affects could alter habitat that was the basis for the designation
Wetlands—changes in hydrology can affect viability of wetlands, either by increasing or decreasing volumes and velocities of water discharging to the wetlands

Stormwater Quality Considerations

Stormwater quality is regulated for the purpose of minimizing/preventing nonpoint source pollution from reaching the waterway. Mitigation for stormwater quality can be achieved either by directing the runoff from the water quality design storm into a natural area where it can be filtered and/or infiltrated into the ground, by constructing a new BMP to intercept previously untreated runoff or by retrofitting existing stormwater systems that previously did not provide sufficiently for water quality.

Existing forested and other vegetated non-wetland areas can also be used as a water quality mitigation area if runoff is discharged as sheet flow through the area in a non-erosive manner, and the vegetated area is restricted from future development. A discussion of the appropriate widths for these vegetative filters is provided in Chapter 9 of the New Jersey Stormwater Best Management Practices Manual (BMP Manual).

If a mitigation project cannot be identified that would compensate for a waiver related to water quality, and provided the project requiring a waiver would not result in a measurable change in water quality relative to TSS and nutrients, the mitigation project could be designed to address another parameter of concern in the watershed (as indicated by an impairment listing and/or an adopted TMDL) for which stormwater is a source, such as fecal coliform.

Some examples of areas or features sensitive to water quality changes include:

Trout associated waters—chemical pollutants and temperature effects can diminish viability of populations
Lakes, ponds or other impoundments—these waterways are sensitive to addition of nutrients
Threatened and endangered species or their habitats—sensitive to both quality and quantity changes
Drinking water supplies—adverse affects on quality can increase the cost of treatment or threaten the use
Category One waters—an issue where quality was the basis of the designation
Waterways with a water quality or use impairment—deterioration of quality in an impaired waterway will increase the cost and challenge of restoration

Ground Water Recharge Considerations

Recharge is regulated to maintain the availability of ground water as a water supply source as well as to provide a stable source of baseflow in streams.

There are two requirements associated with the recharge standard. The first is that 100 percent of the site's average annual pre-developed ground water recharge volume be maintained after development and the second is that 100 percent of the difference between the site's pre- and post-development 2-year runoff volumes be infiltrated. To mitigate for groundwater recharge design requirements, either computational method can be utilized to determine the volume lost that needs to be provided by the mitigation project.

One method to accomplish ground water recharge mitigation is to discharge runoff as sheet flow across a vegetated area to allow for the infiltration of runoff. It should be noted that, if this measure is used, calculating compliance with the recharge standard is limited to the 2-year storm standard, given existing methods.

Some examples of areas or features sensitive to ground water recharge changes include:

Springs, seeps, wetlands, white cedar swamps—sensitive to changes in ground water level/hydrology
Threatened and endangered species or their habitats—some are sensitive to changes in ambient ground water levels
Streams with low base flow or passing flow requirements—would be particularly sensitive to changes in hydrology
Aquifer recharge zones—loss of recharge in these areas can adversely affect ground water supply
Category One waters—loss of base flow can affect many of the bases for designation

Identification of Specific Mitigation Projects

As discussed above, mitigation projects should be selected after examining existing problems related to stormwater quality, quantity, and recharge in the affected drainage area. Municipal mitigation plans can be a very effective means to address existing problems resulting from stormwater management while ensuring that existing problems are not made worse and new problems are avoided.

Where a list of mitigation projects is identified, the plan must also identify the type of design and performance standard the individual projects may mitigate. Wherever possible, quantification of the mitigation provided by each project relative to the applicable standard should also be included.

Initially, some municipalities may wish to allow developers to fund analyses to identify potential mitigation projects that could be used to address deficits in complying with each of the performance standards. However, the funding option shall only be allowed where the project requesting the waiver will have no measurable impact with respect to flooding, erosion, water quality degradation, etc. The funding option may also be appropriate in situations where the size of an individual project requesting a waiver/exemption is small, or the degree of deficit in complying with the design and performance standard(s) is small. Or, where the project requiring mitigation is for one individual single family home, given authority constraints, a financial contribution may be a preferred option. In these situations, it may not be practical to implement a commensurate mitigation project and may be preferable to accumulate funds to implement a larger mitigation project. In such cases, the receipt of the financial contribution shall satisfy the mitigation obligation for the project. However, the municipality becomes responsible to ensure that the mitigation occurs in a timely fashion and must provide a detailed discussion of the status of the mitigation fund and funded projects in the annual report required under the NJPDES municipal stormwater permit.

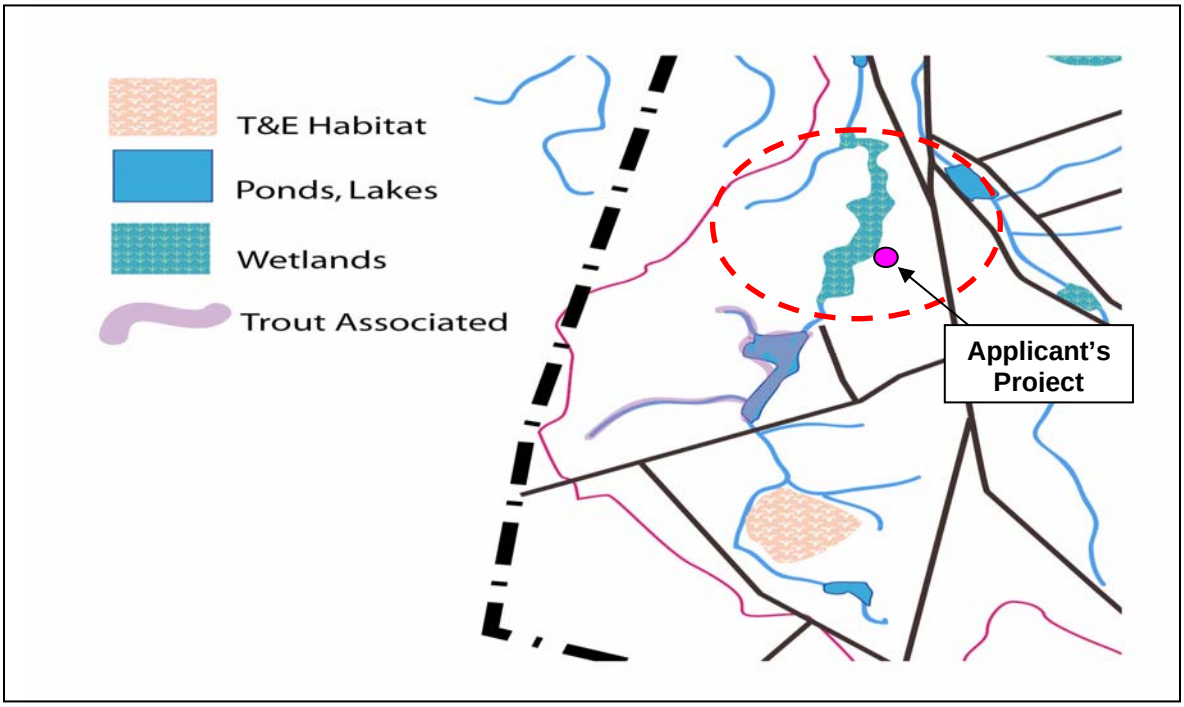
The identification of sensitive receptor areas for stormwater quantity, stormwater quality and stormwater recharge will require collecting and organizing, preferably in a Geographic Information System (GIS) format, both existing and new monitoring data, flooding information and unique local knowledge about conditions in the municipality. This identification process may be done by the municipality to establish a menu of

specific mitigation projects or project locations, or by an individual developer as part of the mitigation process established in the mitigation plan.

Preliminary screening information to identify sensitive receptors is available in GIS format from the Department's GIS website at http://www.nj.gov/dep/gis/. However, information from existing GIS coverages must be supplemented by local information about locally flood prone areas, including specific stream segments and drainage areas that have inadequate bridges or culverts, areas with stormwater induced stream bank or channel erosion, waterways that have been listed as impaired for water quality or designated uses, etc.

For each of sensitive receptor or groups of receptors, the pertinent drainage area must be identified. The pertinent drainage area is that which encompasses the area that would affect the sensitive receptor(s). Typically, the pertinent drainage area would be the contributory drainage area to the receptor. However, depending on the receptor, only portions of the contributory drainage area may be appropriate to consider locating a mitigation project that would adequately address the impact of a waiver/exemption on a particular sensitive receptor.

In the example below sensitive receptors for water quality are depicted in a drainage area. In order to mitigate for the performance standard waived, the mitigation project must take place in an area that contributes to the same sensitive receptor.



For example, the wetlands area circled is a sensitive receptor relative to water quality. The applicant has a project upstream of the wetland that is unable to comply with the water quality performance standards. Therefore, the mitigation project may be located in the drainage area to the same wetlands complex. However, there is a pond upstream of

the wetlands that may reduce the effectiveness of a mitigation project relative to the wetlands if placed upstream of the impoundment. Therefore, the mitigation project should be located downstream of the impoundment, even though the contributory drainage area to this wetlands complex includes the impoundment and areas upstream.

Administrative Requirements

Each municipality that received a Tier A or Tier B NJPDES Municipal Stormwater General Permit is required to file an annual report to demonstrate continuing compliance with the permit requirements. The municipality must indicate in the annual report form whether any variances or exemptions from stormwater management standards have been given. When submitting the annual report as required by the NJPDES permit, the municipality must provide an annual submission of its variances, exemptions, and related mitigation projects to the NJDEP Division of Watershed Management (DWM). This annual report to DWM must includes both projects reviewed by the municipality under the Municipal Land Use Law, as well as the municipality's own projects unable to fully comply with the design and performance standards. The following information is required for each waiver granted from the performance standard(s).

- **Impact from noncompliance.** Provide a table quantifying what would be required for the project to achieve the standards, the extent to which this value will be achieved on site and the extent to which the value must be mitigated off site.

- **Narrative and supporting information regarding the need for the waiver including:**
  - The waiver cannot be due to a condition created by the applicant. If the applicant can comply with the Stormwater Management rules through a reduction in the scope of the project, the applicant has created the condition and a waiver **cannot** be issued. Demonstrate that the need for a waiver is not created by the applicant.

  - Provide a discussion and supporting documentation of the site conditions peculiar to the subject property that prevent the construction of a stormwater management facility that would achieve full compliance with the design and performance standards. Site conditions may include soil type, the presence of karst geology, acid soils, a high groundwater table, unique conditions that would create an unsafe design, as well as conditions that may provide a detrimental impact to public health, welfare, and safety.

  - Demonstration that the grant of the requested waiver/exemption would not result in an adverse impact that would not be compensated for by off site mitigation.

- **Sensitive Receptor:** Identify the sensitive receptor(s) related to the performance standard from which a waiver is sought. Demonstrate that the mitigation site contributes to the same sensitive receptor.

- **Design of the Mitigation Project:** Provide the design details of the mitigation project. This includes, but is not limited to, drawings, calculations, and other information needed to evaluate the mitigation project.

- **Responsible Party**: List the party or parties responsible for the construction and the maintenance of the mitigation project. Documentation must be provided to demonstrate that the responsible party is aware of, has authority to, and accepts the responsibility for construction and maintenance. Under no circumstance shall the responsible party be an individual single-family homeowner. Selection of a project location that is under municipal authority avoids the need to obtain authority from a third party for the construction and future maintenance of the project.

- **Maintenance:** Include a maintenance plan that addresses the maintenance criteria at N.J.A.C. 7:8-5.8. In addition, if the maintenance responsibility is being transferred to the municipality or another entity, the entity responsible for the cost of the maintenance must be identified. The municipality may provide the option for the applicant to convey the mitigation project to the municipality, if the applicant provides for the cost of maintenance in perpetuity.

- **Permits**: Obtain any and all necessary local, State or other applicable permits for the mitigation measure or project must be obtained prior to the municipal approval of the project for which mitigation is being provided.

- **Construction**: Demonstrate that the construction of the mitigation project coincides with the construction of the proposed project. A certificate of occupancy or final approval by the municipality for the project requiring mitigation cannot be issued until the mitigation project or measure receives final approval. Any mitigation projects proposed by the municipality to offset the stormwater impacts of that municipality's own projects must be completed within 6 months of the completion of the municipal project, in order to remain in compliance with their NJPDES General Permit.

CURVE NUMBER AND GROUNDWATER RECHARGE CREDITS FOR LID FACILITIES IN NEW JERSEY

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ABSTRACT

A credit system for implementation of innovative stormwater management practices such as LID facilities will encourage the use of such practices. Such credit system should be based on the expected role of the facilities in meeting the local stormwater management requirements. A series of simplified tools were developed to quantify the impact of various LID facilities in controlling the runoff volume and providing groundwater recharge in New Jersey. Simple equations and charts were developed to evaluate credit in terms of Curve Number (CN) reduction for the LID facilities that directly receive runoff from an impervious area or are located within a development lot. Also, a chart was developed to provide estimates of the annual groundwater recharge volume provided by buried exfiltration facilities. This paper presents these LID impact quantification equations and charts and discusses the implementation of these tools in New Jersey and elsewhere. Also, example applications are provided to demonstrate the use of these tools and to put the relative role of LID facilities in CN reduction and groundwater recharge enhancement in perspective.

Key Words: *LID, Stormwater Management Credit, Groundwater Recharge, Curve Number Reduction.*

INTRODUCTION

The State of New Jersey has been working to find ways to encourage implementation of innovative stormwater management techniques such as Low Impact Development (LID). At the same time, the State is requiring that the post-development groundwater recharge volumes must match those of the pre-development natural conditions. Logically, the developers expect some sort of credit for utilizing LID practices, perhaps in form of a size reduction for the traditional stormwater facilities serving the same development. They also need computational tools to estimate the pre- and post-development groundwater recharge volumes and to quantify the amount of annual recharge volume expected from a given facility at a given location. Dewberry worked with New Jersey Department of Environmental Protection and Department of Agriculture to develop

computational tools to facilitate implementation of LID and groundwater recharge preservation for area undergoing development in various locations in the State.

A general theoretical investigation using common hydrological tools was conducted to get a sense of the impact of LID implementation in runoff control from a development area. Preliminary conclusions of the study show that LID practices would be generally ineffective in controlling the design peak flow rates. However, they may be effective in controlling the runoff volume and quality and in providing groundwater recharge. This study focused on potential runoff volume control (Curve Number reduction) and groundwater recharge benefits provided by LID.

CURVE NUMBER REDUCTION METHODS

Since the NRCS Curve Number (CN) procedure for estimating runoff volume is commonly in use it was decided to develop an LID credit calculation procedure in terms of CN reduction. The NRCS runoff equations were manipulated to consider the additional runoff reduction due to the storage provided by the LID facility. The additional hydrological loss provided by the LID facility would result in an effective CN that would be potentially smaller than the original CN. It must be noted here that the CN reduction discussed here is only relevant to calculation of the design runoff volume (e.g. water quality control volume) and not to the design peak flow rates. Two cases were considered for CN reduction estimation.

The first case involves diversion of runoff from an impervious area to a LID facility resulting into a possible reduction of the effective CN of the impervious area. The effectiveness of this method in reducing runoff volume is directly related to the volume of the storage provided by the facility as well as the area of the impervious surface. Since most LID facilities are small in terms of their footprint area, the facility would have to be relatively deep to provide any considerable storage volume. Also, the facility would have to have good infiltration potential to allow dissipation of the water after it is filled during a storm. LID Integrated Management Practices (IMP) that have considerable depth and infiltration rates best represent the type of practices for which CN reduction calculations can be applied. Such facilities are labeled here as deep Infiltration LID-IMPs. Examples of these IMPs include rooftop runoff connected to a dry well and parking lot runoff diverted to a vegetated buffer strip. The assumption here is that the runoff from the entire impervious area of the interest is diverted to the infiltration facility. This does not mean that the facility would have to have enough capacity to contain all of the runoff from the impervious area.

Table 1 presents the equations and an example application of the CN reduction by deep infiltration LID-IMPs. In the example given in Table 1 connecting the rooftop runoff to a dry well reduces the CN of the rooftop area from 98 to 94. The nomograph presented here as Figure 1 was developed to facilitate the use of these equations. As seen in Figure 1 the original CN of the impervious area is 98 but depending on the ratio of the facility area to the impervious area and the effective depth of the facility this CN is effectively

reduced to a lower value. Figure 1 also contains an explanation of how to use this nomograph.

In New Jersey, the Water Quality Design Storm is 1.25 inches. Since the water quality storm is the most commonly used design storm in runoff volume calculations, the author developed a separate simplified chart for this storm (not shown here for brevity).

The second case involves a small LID such as a bioretention facility within a lot potentially decreasing the effective CN of the lot. In this case, the reduction of the CN not only depends on the relative size of the facility but also on the original CN of the drainage area and the design rainfall depth. Table 2 shows the equations and two example applications of the CN reduction by a small LID facility in a drainage area. In the first example, two bioretention ponds used in a 1-acre lot under a design rainfall of 4.5 inches reduce the lot CN from 85 to 84. In the second example, the same two bioretention ponds are used in a ½ acre lot under a design rainfall of 3" and reduce the lot CN from 75 to 73. These examples indicate the fact that small LID facilities will have limited impact in reduction of the lot CN even for calculation of runoff volumes. To enforce a meaningful impact several LID facilities would have to be implemented in a given lot.

A nomograph was also prepared to allow quick estimation of the CN reduction credit for this case. However, this nomograph is more complex than Figure 1 and is not presented here.

GROUNDWATER RECHARGE CREDIT METHOD

The New Jersey stormwater management regulations require the post-development annual groundwater recharge volumes match those of the pre-development conditions. To comply with this regulation one has to be able to estimate the pre- and post-development recharge volumes and calculate the annual recharge volume provided by infiltration LID or BMPs designed for compensatory recharge under post-development conditions.

To allow these estimations the author developed a comprehensive method and implemented it in the format of the New Jersey Groundwater Recharge Spreadsheet. This spreadsheet is currently available through the New Jersey Department of Environmental Protection Web Site as part of The New Jersey Stormwater Best Management Practices Manual (see NJDEP, 2004). Chapter Six of this reference contains an explanation of the theoretical developments of the spreadsheet as well as a user manual for it. Additional developments by the author to the New Jersey Groundwater Recharge Spreadsheet also allow evaluation of the annual groundwater recharge provided by discharging surface runoff over forested buffer zones in New Jersey (Zomorodi, 2003).

For detailed evaluation of the groundwater recharge volume and the recharge credit for any infiltration facility in any township of New Jersey one would use the spreadsheet as described above. However, for a preliminary overall estimate of the performance of an infiltration facility a simpler tool may be in order. Based on the New Jersey Groundwater

Recharge Spreadsheet, the author developed a simplified nomograph that can be used for any location in New Jersey or possibly for neighboring areas with similar rainfall regimes. Figure 2 shows this chart which can be used to quickly estimate the recharge credit of an infiltration facility operating at near 100% recharge efficiency. In order for a facility to have 100% recharge efficiency (meaning that virtually all of the water in the facility actually infiltrates deeper than the prevailing root zone in the area) it must be a deep LID-IMP as discussed in the previous section.

Figure 2 also presents an explanation of how to use the nomograph. For example consider the case of a dry well 3-ft in diameter and 5-ft deep. The Effective Depth of the well considering the void ratio of the fill material is 2-ft or 48-inches. If this dry well is connected to a rooftop area of 1000 sq-ft, the ratio of the LID-IMP Surface Area to Impervious Area would be approximately 0.007. Entering the chart with this value on the X-axis and moving vertically up to the 48" curve a value of 225 cu.ft/sq.ft is read from the Y-axis. This value is the Annual Recharge Volume per Unit Area of the LID-IMP Surface Area. Considering the surface area of the dry well (7.07 sq-ft) the annual recharge volume is found by multiplying 225 by 7.07 which gives an annual recharge volume of 1590 cu.ft This volume can be used as recharge credit towards satisfying the annual groundwater recharge volume deficiency expected due to development.

Sample calculations showed that recharge volumes provided by small LID facilities are typically only a small fraction of the recharge deficit caused by representative developments. Therefore, normally several LID facilities per lot would be needed to compensate the recharge lost to development.

CONCLUSIONS

The computational tools discussed in this paper help in quantifying the LID impacts. They can be used in assigning CN reduction and annual groundwater recharge credits resulting from implementation of LID techniques.

Sample calculations showed that under typical development scenarios several LID facilities per lot would be needed to have a considerable impact in reduction of runoff volumes and providing groundwater recharge.

The groundwater recharge tools discussed here were specifically developed for the New Jersey conditions and data. However, the CN reduction tools may be used anywhere the NRCS CN method is acceptable for runoff volume estimations.

Table 1. Curve Number Credit Equations for Deep Infiltration LID-IMPs

Notation:

P: Design Precipitation Depth (in),
$\mathbf{A_{LID}}$: The Surface Area of the LID-IMP (sq.ft),
$\mathbf{A_{IMP}}$: The Area of the Impervious Surface Connected tot the LID-IMP (sq.ft),
Qr: Revised Runoff Depth (in),
d = Depth of the LID-IMP (in),
VR = Void Ratio of the Fill Material in LID-IMP,
CNr = Revised CN of the Impervious Area Connected to the LID-IMP.

Equations:

$$Q_r = \{ (P-0.0408)^2 / (P+0.1632) \} - (d\ VR\ (A_{LID}/A_{IMP}))$$

$$CN_r = 100 / (0.5\ P + Q_r - (1.25\ P\ Q_r + Q_r^2)^{(0.5)} + 1)$$

Example:

Problem Statement
Find the revised CN for a 1500 sq.ft rooftop connected to a dry well with surface area of 15 sq.ft and depth of 12 ft. The well is filled with gravel with a void ratio of 0.33. The design 24-hr precipitation is 4.5 inches.
The expected infiltration depth in three days of operation (considering seepage from sides of the well) is 6 feet.
Solution
Because the expected infiltration depth (6 ft) is larger than well depth multiplied by void ratio (4 ft) the effective depth is not restricted by 3-day infiltration depth.
Q_r = { (4.5-0.0408)2 / (4.5+0.1632)} - (12 x 12 x 0.33 x (15/1500)) = 3.79 inches
$CN_r = 100 / (.5 \times 4.5 + 4.22 - (1.25 \times 4.5 \times 4.22 + 4.22^2)^{(0.5)} + 1) = 93.76$ use 94.

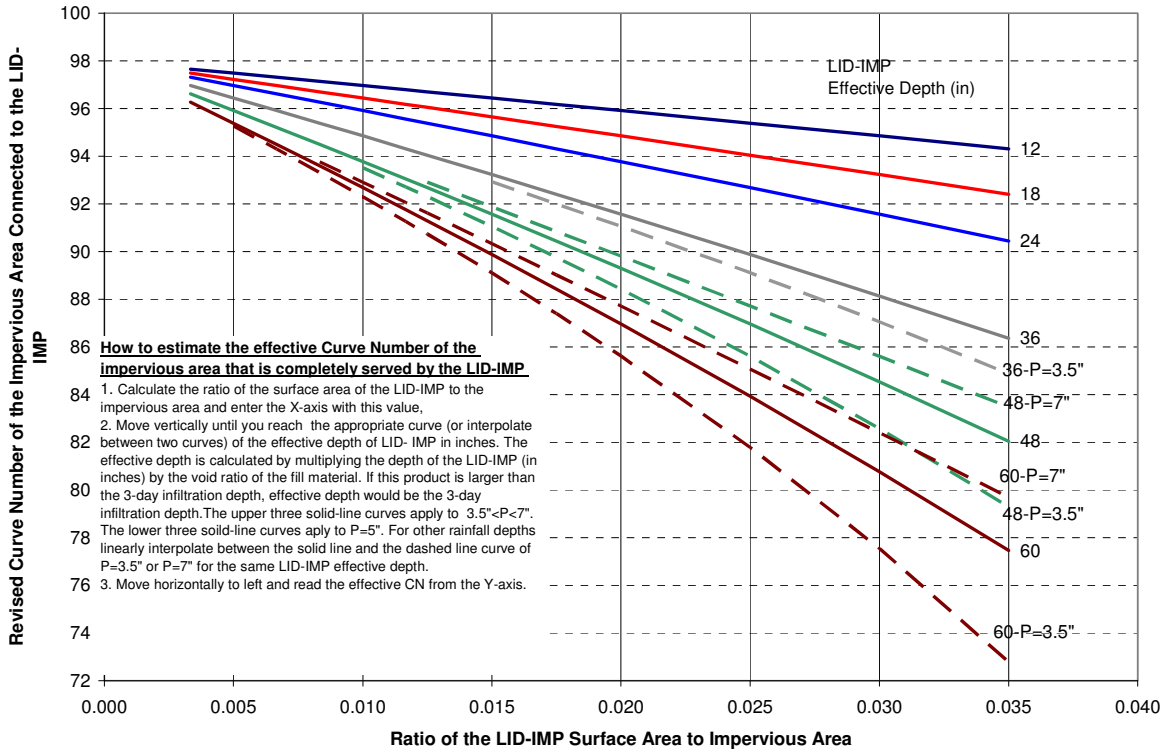

Figure 1. CN Reduction for Deep Infiltration LID-IMPs.

Table 2. Curve Number Credit Equations for Small LID-IMPs

Notation:

P: Design Precipitation Depth (in),
$\mathbf{A_{LID}}$: The Surface Area of the LID-IMP (sq.ft),
A: The Area of the Lot (sq.ft),
Qr: Revised Runoff Depth (in),
d = Depth of the LID-IMP (in),
CN = Post-development CN without the LID-IMP.
CNr = Revised CN of the lthe lot with the LID-IMP.

Equations:

$$Q_r = \{ (P - 0.2 (1000/CN-10))^2 / (P+0.8* (1000/CN-10)) \} - (d (A_{LID}/A_{IMP}))$$

$$CN_r = 100 / (0.5\ P + Q_r - (1.25\ P\ Q_r + Q_r^2)^{(0.5)} + 1)$$

Example Applications

Example A
Find the revised CN for a 1-ac lot with the post development CN of 85 considering the effects of a two 6-inch-deep bioretention ponds with a combined surface area of 300 sq.ft. The design 24-hr precipitation is 4.5 inches.
Solution
Q_r = {{ (4.5- 0.2 (1000/85-10))2 / (4.5+0.8* (1000/85-10)) } - (6 (300/(1.0 x 43560))= 2.83 inches
CN_r = 100 / (.5 x 4.5 + 2.83- (1.25 x 4.5 x 2.83 + $2.83^2)^{(0.5)}$ + 1) = 84.1 use 84.

Example B
What if the same ponds were built in a 1/2-acre lot with a post-development CN of 75 and a design 24-hr rainfall of 3 inches?
Solution
Qr = {{ (3 - 0.2 (1000/75-10))2 / (3+0.8* (1000/75-10)) } - (6 (300/(0.5 x 43560))= 0.88 inches
CNr = 100 / (.5 x 3+ 0.88 - (1.25 x 3 x 0.88+ $0.88^2)^{(0.5)}$ + 1) = 73.4 use 73.

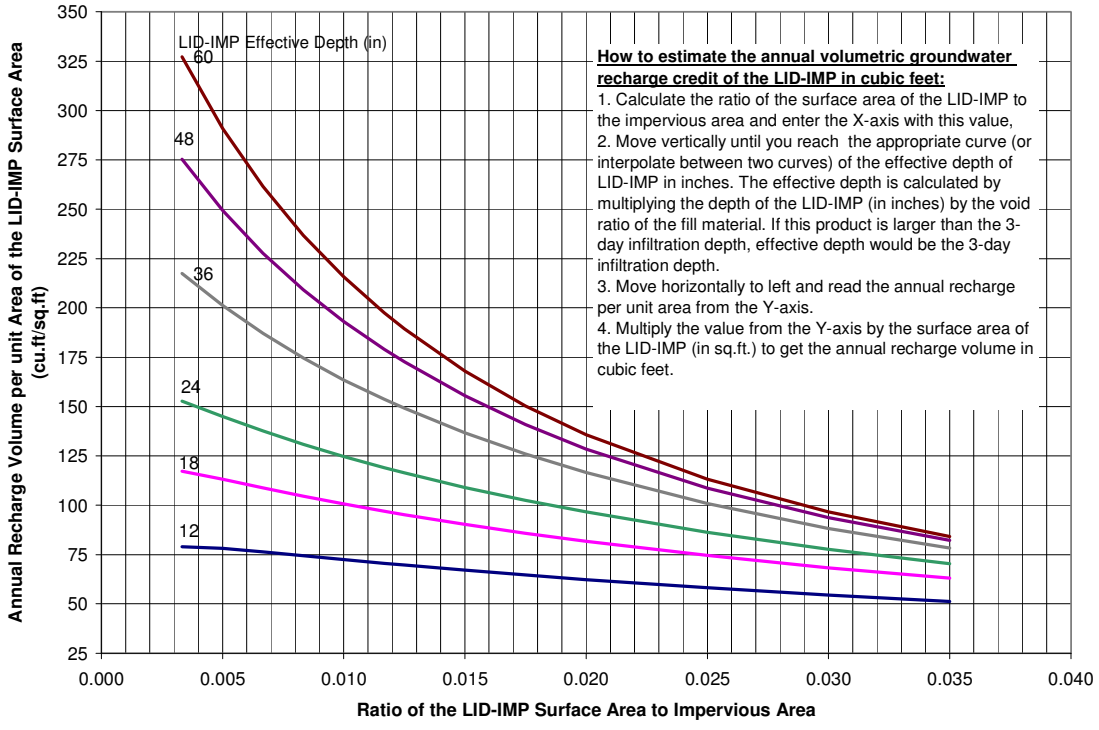

Figure 2. Simplified Groundwater Recharge Credit Chart for Deep LID-IMPs in New Jersey.

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New York State

Stormwater Management Design Manual

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Forward

On November 16, 1990, the initial federal NPDES stormwater regulations were established. These required certain industrial activities to obtain permit authorization in order to discharge site runoff. DEC, as the NPDES permit issuing authority in this State, promulgated two SPDES general permits for stormwater runoff in 1993, GP-93-05 for the more traditional industrial sites and GP-93-06 for construction sites.

GP-93-06 requires that an operator who is covered under the permit implement a stormwater pollution prevention plan (SWPPP) that has been developed for the particular site. The minimum components of the SWPPP include a variety of requirements, including both structural and non-structural practices, inspections, contractor certifications, compliance with narrative water quality standards and other conditions. The attention, concern and efforts being directed at stormwater management practices at construction sites are constantly growing as new technologies emerge and experiences with older ones is gained. Additionally, construction site runoff is gaining wider attention as the federal NPDES stormwater program progresses. There is an ever-growing need to disseminate information concerning practices that are acceptable in New York.

The scope of attention is broadening on a national scale to smaller construction sites as evidenced by the "Phase 2" stormwater regulations. Phase 2 lowers the threshold to one or more acres of disturbance, the runoff from which requires NPDES authorization for discharges to surface waters. Permitting will be required beginning on March 10, 2003. It=s becoming more evident as time passes that there is a greater need for stormwater management practices that are technically effective and viable in New York State. "Spreading the word" to engineers, municipal officials, and the general public is crucial to the success of DEC=s efforts in implementing the federal NPDES stormwater regulations and reducing incidences of water quality impairments.

Accordingly, permits that are issued in the future for construction site runoff will rely heavily on this new manual and the practices that are described therein. When properly designed and maintained, the implementation of these practices will become an important component of New York=s overall stormwater management program. Adherence to the criteria and practices described will better ensure a successful implementation of stormwater controls and compliance with the SPDES general permit(s) issued for construction site runoff and maintaining water quality.

N. G. Kaul, P.E.
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Preface

The New York State Stormwater Design Manual is prepared to provide standards for the design of the Stormwater Management Practices (SMPs) to protect the waters of the State of New York from the adverse impacts of urban stormwater runoff. This manual is intended to establish specifications and uniform criteria for the practices that are part of a Stormwater Pollution Prevention Plan (SWPPP).

This manual is intended primarily for engineers and other professionals who are engaged in the design of stormwater treatment facilities for new developments. Users are assumed to have a background in hydrology, hydraulics, and runoff and pollutant load computation. It is not intended to be a primer on any of these subjects. The manual may also be used by reviewing authorities to assess the adequacy of SWPPPs.

The manual is limited to the design of structures. It does not address the temporary control of sedimentation and erosion from construction activities, nor the development of Stormwater Pollution Prevention Plans. The reader is referred to the documents *"Reducing the Impacts of Runoff from New Development"* and *"New York State Guidelines for Urban Erosion and Sediment Control"* for guidance with these subjects.

Recommended Standards, consisting of proven technology, are intended to serve as a guide in the design and preparation of plans and specifications for Stormwater Management Practices, to suggest limiting values for items upon which an evaluation of such plans and specifications may be made by the reviewing authority, and to establish, as far as practicable, uniformity of practice. As statutory requirements and legal authority pertaining to stormwater management are not uniform across the State, and since conditions and administrative procedures and policies also differ, the use of these Standards must be adjusted to these variations.

The terms "shall" and "must" are used where the practice is sufficiently standardized to permit specific delineation of requirements or where safeguarding of the public health justifies such definite action. Other terms, such as "should," "recommend," and "preferred," indicate desirable procedures or methods, with deviations subject to individual consideration.

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Chapter 1

Introduction

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Chapter 1: Introduction to the Manual

Section 1.1 Purpose of the Manual

The purpose of this manual is threefold:

1. To protect the waters of the State of New York from the adverse impacts of urban stormwater runoff
2. To provide design guidance on the most effective stormwater management practices (SMPs) for new development sites
3. To improve the quality of SMPs constructed in the State, specifically in regard to their performance, longevity, safety, ease of maintenance, community acceptance and environmental benefit

Section 1.2 How to Use the Manual

The *New York State Stormwater Management Design Manual* provides designers a general overview on how to size, design, select and locate SMPs at a development site to comply with State stormwater performance standards. The manual also contains appendices with more detailed information on landscaping, SMP construction specifications, step–by- step SMP design examples and other assorted design tools. The manual is organized as follows:

Chapter 2. Impacts of Stormwater Runoff

This chapter examines the physical, chemical, and biological effects of unmanaged stormwater runoff on the water quality of local streams and waterbodies. This brief overview provides the background for why the stormwater management manual is needed and how the new criteria will help local communities meet water quality standards.

Chapter 3. Permit Requirements

This chapter explains the permitting process for stormwater management facilities, and what permits may be necessary to construct these facilities.

Chapter 4. Sizing Criteria

This chapter explains sizing criteria for water quality, channel protection, overbank flood control, and extreme flood management in the State of New York. The chapter also outlines the basis for design calculations.

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Chapter 5. List of Practices

This chapter briefly outlines the five groups of acceptable structural SMPs that can be used to meet water quality sizing criteria. The following are acceptable SMP groups:

- Stormwater Ponds
- Stormwater Wetlands
- Infiltration Practices
- Filtering Systems
- Open-Channel Practices

The chapter also explains the criteria for addition of a new practice to the list of acceptable SMPs, and provides fact sheets for some practices that are not on the list of practices, but can be used to provide supplemental treatment.

Chapter 6. Performance Criteria

This chapter presents specific performance criteria and guidelines for the design of the five groups of structural SMPs. The performance criteria for each group of SMPs are based on six factors:

- Feasibility
- Conveyance
- Pretreatment
- Treatment
- Landscaping
- Maintenance

In addition, the chapter provides guidance on design adjustments that may be required to ensure proper functioning in cold climates.

Chapter 7. Guide to SMP Selection and Location

This chapter presents guidance on how to select the best SMP or group of practices at a development site, as well as environmental and other factors to consider when actually locating each SMP. The chapter contains five comparative matrices that evaluate SMPs based on the following factors:

- Land Use
- Physical Feasibility
- Watershed /Regional Factors
- Stormwater Management Capability
- Community and Environmental Factors

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Chapter 7 is designed so that the reader can use the matrices in a step-wise fashion to identify the most appropriate SMP or group of practices to use at a site.

Chapter 8. Design Examples

Design examples are provided to help designers and plan reviewers better understand the new criteria in this manual. The step-by-step design examples demonstrate how the new stormwater sizing criteria are applied, and some of the design procedures and performance criteria that should be considered when planning a new stormwater management practice.

Stormwater Design Appendices

The appendices contain the technical information needed to actually design, landscape and construct an SMP. There are a total of thirteen appendices:

Appendix A. The Simple Method to Calculate Urban Stormwater Loads

This appendix describes a fast and effective way to calculate stormwater runoff pollutant loads. Using impervious cover estimates based on land use, the Simple Method calculates annual runoff volume as a product of annual rainfall, and a runoff coefficient (Rv). Annual runoff can then be combined with readily available stormwater pollutant concentrations to provide a quick estimate of annual pollutant loads. The appendix also discusses the limitations of the Simple Method.

Appendix B. Design Tools

The accurate calculation of stormwater flows may require modifications to some methods to account for small storm hydrology. This appendix provides methodologies to calculate the storage requirements for the channel protection flow event, and a methodology to calculate the peak flow from the small water quality storm.

Appendix C. SMP Construction Specifications

Good designs only work if careful attention is paid to proper construction techniques and materials. Appendix C contains detailed specifications for constructing ponds, infiltration practices, filters, bioretention areas and open channels.

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Appendix D. Infiltration Testing

This appendix describes methodologies to test soil infiltration rates, in order to determine if infiltration is an acceptable option on site.

Appendices E-G. Checklists

These three appendices provide example checklists that can be used to assist in the plan review, construction, and operation and maintenance of an SMP.

Appendix H. Landscaping Guidance

Good landscaping can often be an important factor in the performance and community acceptance of stormwater SMPs. Appendix H also includes tips on how to establish more functional landscapes within stormwater SMPs, and contains an extensive list of trees, shrubs, ground covers, and wetland plants that can be used to develop an effective and diverse planting plan.

Appendix I. Cold Climate Sizing Example

This appendix supplies guidance on sizing SMPs to account for cold climate conditions that might hamper performance. Example sizing designs that illustrate how to incorporate cold climate criteria into SMP design are also included.

Appendix J. Geomorphic Assessment

This appendix provides a description of the Distributed Runoff Control (DRC) methodology to size stormwater practices based on downstream geomorphic characteristics.

Appendix K. Miscellaneous Details

The designs of various structures previously discussed in the manual are presented in Appendix K. These structures help enhance the performance of stormwater management practices, especially in cold climates. Schematics of structures such as weirs, trash racks, and observation wells are included.

Appendix L. Critical Erosive Velocities

This appendix provides data on critical erosive velocities for soil and grasses.

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Section 1.3 Symbols and Acronyms

As an aid to the reader, Table 1.1 outlines the symbols and acronyms that are used throughout the text. In addition, a glossary is provided at the end of this volume that defines the terminology used in the text.

Table 1.1 Key Symbols and Acronyms Cited in Manual

Symbol	Definition	Symbol	Definition
A	drainage area	Qf	extreme flood storage volume
A_f	filter bed area	Qi	peak inflow discharge
A_s	surface area, sedimentation basin	Qo	peak outflow discharge
cfs	cubic feet per second	Qp	overbank flood control storage volume
Cp_v	channel protection storage volume	q_p	water quality peak discharge
CMP	corrugated metal pipe	qu	unit peak discharge
CN	curve number	SMP	stormwater management practice
Cp_v-ED	extended detention of the 1 year post-development runoff	R_v	volumetric runoff coefficient
d_f	depth of filter bed	R/W	right of way
du	dwelling units	SD	separation distance
DOT	Department of Transportation	SPDES	State Pollutant Discharge Elimination System
DPW	Department of Public Works	t_c	time of concentration
ED	extended detention	t_t	time to drain filter bed
f_c	soil infiltration rate	TR-20	Technical Release No. 20 Project Formulation-Hydrology, computer program
fps	feet per second	TR-55	Technical Release No. 55 Urban Unit Hydrology for Small Watersheds
h_f	head above filter bed	TSS	total suspended solids
HSG	hydrologic soil group	Vr	volume of runoff
Ia	initial abstraction	Vs	volume of storage
I	percent impervious cover	Vt	total volume
K	coefficient of permeability	Vv	volume of voids
NYSDEC	New York State Department of Environmental Conservation	WQ_v	water quality storage volume
NRCS	Natural Resources Conservation Service	WQ_v-ED	12 or 24 hour extended detention of the water quality volume
P	precipitation depth	WSEL	water surface elevation

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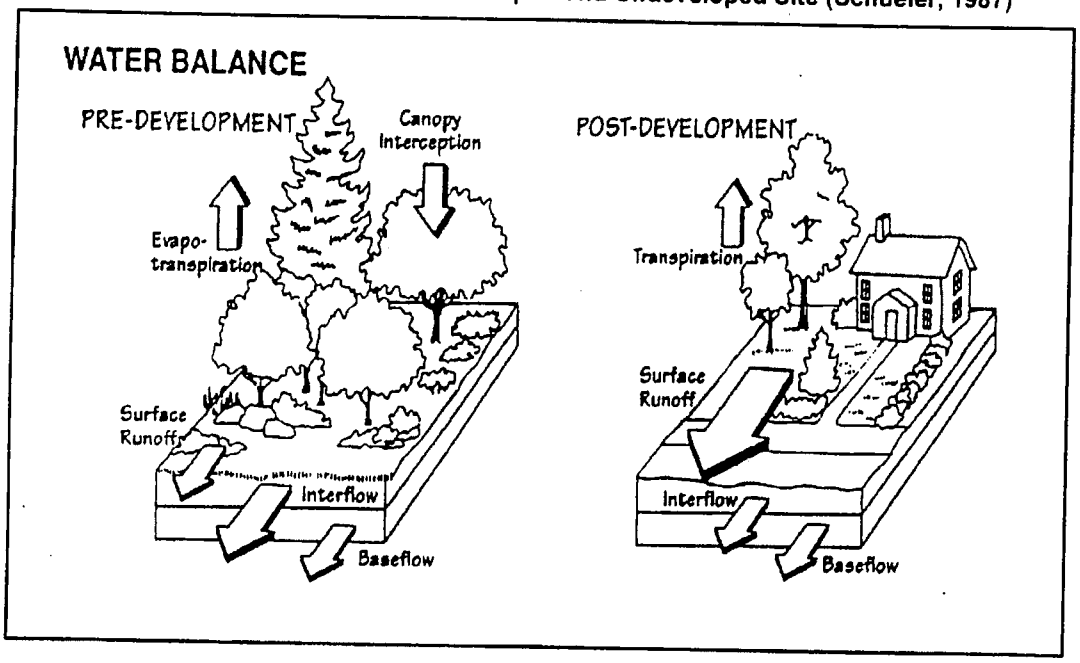
Chapter 2

Impacts of New Development

New York State Stormwater Management Design Manual

Urban development has a profound influence on the quality of New York's waters. To start, development dramatically alters the local hydrologic cycle (see Figure 2.1). The hydrology of a site changes during the initial clearing and grading that occur during construction. Trees that had intercepted rainfall are removed, and natural depressions that had temporarily ponded water are graded to a uniform slope. The spongy humus layer of the forest floor that had absorbed rainfall is scraped off, eroded or severely compacted. Having lost its natural storage capacity, a cleared and graded site can no longer prevent rainfall from being rapidly converted into stormwater runoff.

Figure 2.1 Water Balance at a Developed and Undeveloped Site (Schueler, 1987)



The situation worsens after construction. Rooftops, roads, parking lots, driveways and other impervious surfaces no longer allow rainfall to soak into the ground. Consequently, most rainfall is directly converted into stormwater runoff. This phenomenon is illustrated in Figure 2.2, which shows the increase in the volumetric runoff coefficient (R_v) as a function of site imperviousness. The runoff coefficient expresses the fraction of rainfall volume that is converted into stormwater runoff. As can be seen, the volume of stormwater runoff increases sharply with impervious cover. For example, a one-acre parking lot can produce 16 times more stormwater runoff than a one-acre meadow each year (Schueler, 1994).

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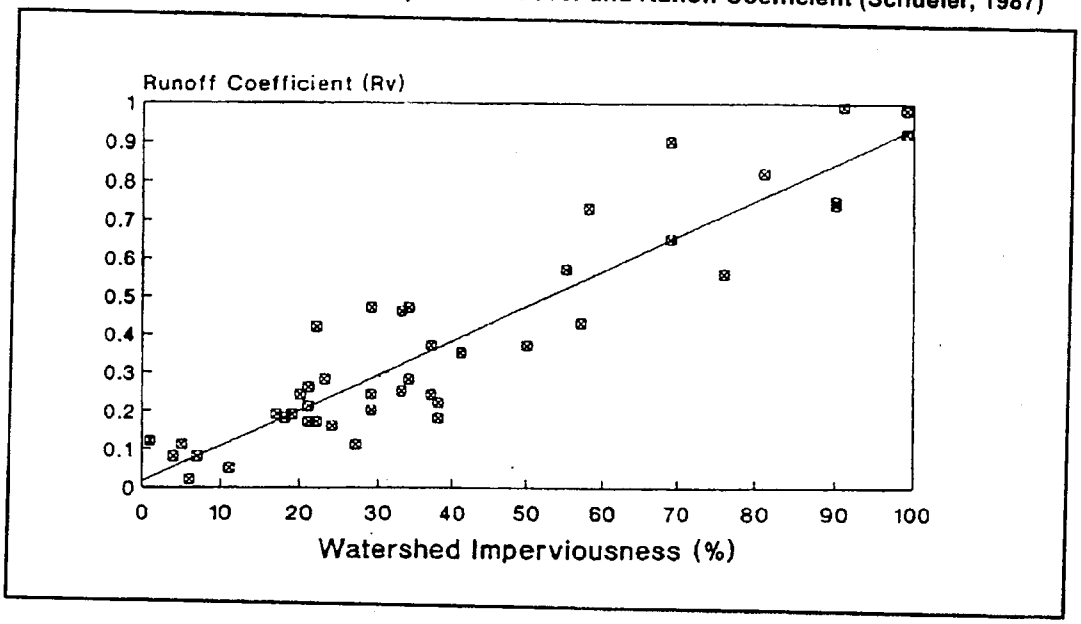
The increase in stormwater runoff can be too much for the existing drainage system to handle. As a result, the drainage system is often "improved" to rapidly collect runoff and quickly convey it away (using curb and gutter, enclosed storm sewers, and lined channels). The stormwater runoff is subsequently discharged to downstream waters, such as streams, reservoirs, lakes or estuaries.

Figure 2.2 Relationship Between Impervious Cover and Runoff Coefficient (Schueler, 1987)



Section 2.1 Declining Water Quality

Impervious surfaces accumulate pollutants deposited from the atmosphere, leaked from vehicles, or windblown in from adjacent areas. During storm events, these pollutants quickly wash off, and are rapidly delivered to downstream waters. Some common pollutants found in urban stormwater runoff are profiled in Table 2.1.

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Table 2.1 National Median Concentrations for Chemical Constituents in Stormwater

Constituent	Units	Concentration
Total Suspended Solids[1]	mg/l	54.5
Total Phosphorus[1]	mg/l	0.26
Soluble Phosphorus[1]	mg/l	0.10
Total Nitrogen[1]	mg/l	2.00
Total Kjeldhal Nitrogen[1]	mg/l	1.47
Nitrite and Nitrate[1]	mg/l	0.53
Copper[1]	ug/l	11.1
Lead[1]	ug/l	50.7
Zinc[1]	ug/l	129
BOD[1]	mg/l	11.5
COD[1]	mg/l	44.7
Organic Carbon[2]	mg/l	11.9
PAH[3]	mg/l	3.5*
Oil and Grease[4]	mg/l	3.0*
Fecal Coliform[5]	col/100 ml	15,000*
Fecal Strep[5]	col/ 100 ml	35,400*
Chloride (snowmelt)[6]	mg/l	116

* Represents a Mean Value

Source:

1: Pooled NURP/USGS (Smullen and Cave, 1998)
2: Derived from the National Pollutant Removal Database (Winer, 2000)
3: Rabanal and Grizzard 1995
4: Crunkilton *et al.* (1996)
5: Schueler (1999)
6: Oberts 1994

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Sediment (Suspended Solids)

Sources of sediment include washoff of particles that are deposited on impervious surfaces and erosion from streambanks and construction sites. Streambank erosion is a particularly important source of sediment, and some studies suggest that streambank erosion accounts for up to 70% of the sediment load in urban watersheds (Trimble, 1997).

Both suspended and deposited sediments can have adverse effects on aquatic life in streams, lakes and estuaries. Turbidity resulting from sediment can reduce light penetration for submerged aquatic vegetation critical to estuary health. In addition, the reflected energy from light reflecting off of suspended sediment can increase water temperatures (Kundell and Rasmussen, 1995). Sediment can physically alter habitat by destroying the riffle-pool structure in stream systems, and smothering benthic organisms such as clams and mussels. Finally, sediment transports many other pollutants to the water resource.

Nutrients

Runoff from developed land has elevated concentrations of both phosphorus and nitrogen, which can enrich streams, lakes, reservoirs and estuaries. This process is known as eutrophication. Significant sources of nitrogen and phosphorus include fertilizer, atmospheric deposition, animal waste, organic matter, and stream bank erosion. Another nitrogen source is fossil fuel combustion from automobiles, power plants and industry. Data from the upper Midwest suggest that lawns are a significant contributor, with concentrations as much as four times higher than other land uses, such as streets, rooftops, or driveways (Steuer *et al.*, 1997; Waschbusch *et al.*, 2000; Bannerman *et al.*, 1993).

Nutrients are of particular concern in lakes and estuaries, and are a source of degradation in many of New York's waters. Nitrogen has contributed to hypoxia in the Long Island Sound, and is a key pollutant of concern in the New York Harbor and the Peconic Estuary. Phosphorus in runoff has impacted the quality of a number of New York natural lakes, including the Finger Lakes and Lake Champlain, which are susceptible to eutrophication from phosphorus loading. Phosphorus has been identified as a key parameter in the New York City Reservoir system. The New York City DEP recently developed water quality guidance values for phosphorus for City drinking water reservoirs (NYC DEP, 1999); a source-water phosphorus guidance value of 15 µg/l has been proposed for seven reservoirs (Kensico, Rondout, Ashokan, West Branch, New Croton, Croton Falls, and Cross River) in order to protect them from use-impairment due to eutrophication, with other reservoirs using the State recommended guidance value of 20 µg/l.

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Organic Carbon

Organic matter, washed from impervious surfaces during storms, can present a problem in slower moving downstream waters. Some sources include organic material blown onto the street surface, and attached to sediment from stream banks, or from bare soil. In addition, organic carbon is formed indirectly from algal growth within systems with high nutrient loads.

As organic matter decomposes, it can deplete dissolved oxygen in lakes and tidal waters. Declining levels of oxygen in the water can have an adverse impact on aquatic life. An additional concern is the formation of trihalomethane (THM), a carcinogenic disinfection by-product, due to the mixing of chlorine with water high in organic carbon. This is of particular importance in unfiltered water supplies, such as the New York City Reservoir System.

Bacteria

Bacteria levels in stormwater runoff routinely exceed public health standards for water contact recreation. Some stormwater sources include pet waste and urban wildlife. Other sources in developed land include sanitary and combined sewer overflows, wastewater, and illicit connections to the storm drain system. Bacteria is a leading contaminant in many of New York's waters, and has lead to shellfish bed closures in the New York Bight Area, on Long Island, and in the Hudson-Raritan Estuary. In addition, Suffolk, Nassau, and Erie Counties issue periodic bathing-beach advisories each time a significant rainfall event occurs (NRDC, 2000).

Hydrocarbons

Vehicles leak oil and grease that contain a wide array of hydrocarbon compounds, some of which can be toxic to aquatic life at low concentrations. Sources are automotive, and some areas that produce runoff with high runoff concentrations include gas stations, commuter parking lots, convenience stores, residential parking areas, and streets (Schueler, 1994).

Trace Metals

Cadmium, copper, lead and zinc are routinely found in stormwater runoff. Many of the sources are automotive. For example, one study suggests that 50% of the copper in Santa Clara, CA comes from brake pads (Woodward-Clyde, 1992). Other sources of metals include paints, road salts, and galvanized pipes.

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These metals can be toxic to aquatic life at certain concentrations, and can also accumulate in the bottom sediments of lakes and estuaries. Specific concerns in aquatic systems include bioaccumulations in fish and macro-invertebrates, and the impact of toxic bottom sediments on bottom-dwelling species.

Pesticides

A modest number of currently used and recently banned insecticides and herbicides have been detected in urban and suburban streamflow at concentrations that approach or exceed toxicity thresholds for aquatic life. Key sources of pesticides include application to urban lawns and highway median and shoulder areas.

Chlorides

Salts that are applied to roads and parking lots in the winter months appear in stormwater runoff and meltwater at much higher concentrations than many freshwater organisms can tolerate. One study of four Adirondack streams found severe impacts to macroinvertebrate species attributed to chlorides (Demers and Sage, 1990). In addition to the direct toxic effects, chlorides can impact lake systems by altering their mixing cycle. In 1986, incomplete mixing in the Irondequoit Bay was attributed to high salt use in the region (MCEMC, 1987). A primary source of chlorides in New York State, particularly in the State's northern regions, is salt applied to road surfaces as a deicer.

Thermal Impacts.

Runoff from impervious surfaces may increase temperature in receiving waters, adversely impacting aquatic organisms that require cold and cool water conditions (e.g., trout). Data suggest that increasing development can increase stream temperatures by between five and twelve degrees Fahrenheit, and that the increase is related to the level of impervious cover in the drainage area (Galli, 1991). Thermal impacts are a serious concern in trout waters, where cold temperatures are critical to species survival.

Trash and Debris

Considerable quantities of trash and debris are washed through the storm drain networks. The trash and debris accumulate in streams and lakes and detract from their natural beauty. Depending on the type of trash, this material may also lead to increased organic matter or toxic contaminants in water bodies.

Snowmelt Concentrations

The snow pack can store hydrocarbons, oil and grease, chlorides, sediment, and nutrients. In cold regions, the pollutant load during snowmelt can be significant, and chemical traits of snowmelt change over the

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course of the melt event. Oberts (1994) studied this phenomenon, and describes four types of snowmelt runoff (Table 2.2). Oberts and others have reported that 90% of the hydrocarbon load from snowmelt occurs during the last 10% of the event. From a practical standpoint, the high hydrocarbon loads experienced toward the end of the season suggest that stormwater management practices should be designed to capture as much of the snowmelt event as possible.

Table 2.2 Runoff and Pollutant Characteristics of Snowmelt Stages (Oberts, 1994)

Snowmelt Stage	Duration/ Frequency	Runoff Volume	Pollutant Characteristics
Pavement Melt	Short, but many times in winter	Low	Acidic, high concentrations of soluble pollutants, Cl, nitrate, lead. Total load is minimal.
Roadside Melt	Moderate	Moderate	Moderate concentrations of both soluble and particulate pollutants.
Pervious Area Melt	Gradual, often most at end of season	High	Dilute concentrations of soluble pollutants, moderate to high concentrations of particulate pollutants, depending on flow.
Rain-on-Snow Melt	Short	Extreme	High concentrations of particulate pollutants, moderate to high concentrations of soluble pollutants. High total load.

Section 2.2 Diminishing Groundwater Recharge and Quality

The slow infiltration of rainfall through the soil layer is essential for replenishing groundwater. Groundwater is a critical water resource across the State. Not only do many residents depend on groundwater for their drinking water, but the health of many aquatic systems is also dependent on its steady discharge. For example, during periods of dry weather, groundwater sustains flows in streams and helps to maintain the hydrology of non-tidal wetlands.

Because development creates impervious surfaces that prevent natural recharge, a net decrease in groundwater recharge rates can be expected in urban watersheds. Thus, during prolonged periods of dry weather, streamflow sharply diminishes. Another source of diminishing baseflow is well drawdowns as populations increase in the watershed. In smaller headwater streams, the decline in stream flow can cause a perennial stream to become seasonally dry. One study in Long Island suggests that the supply of

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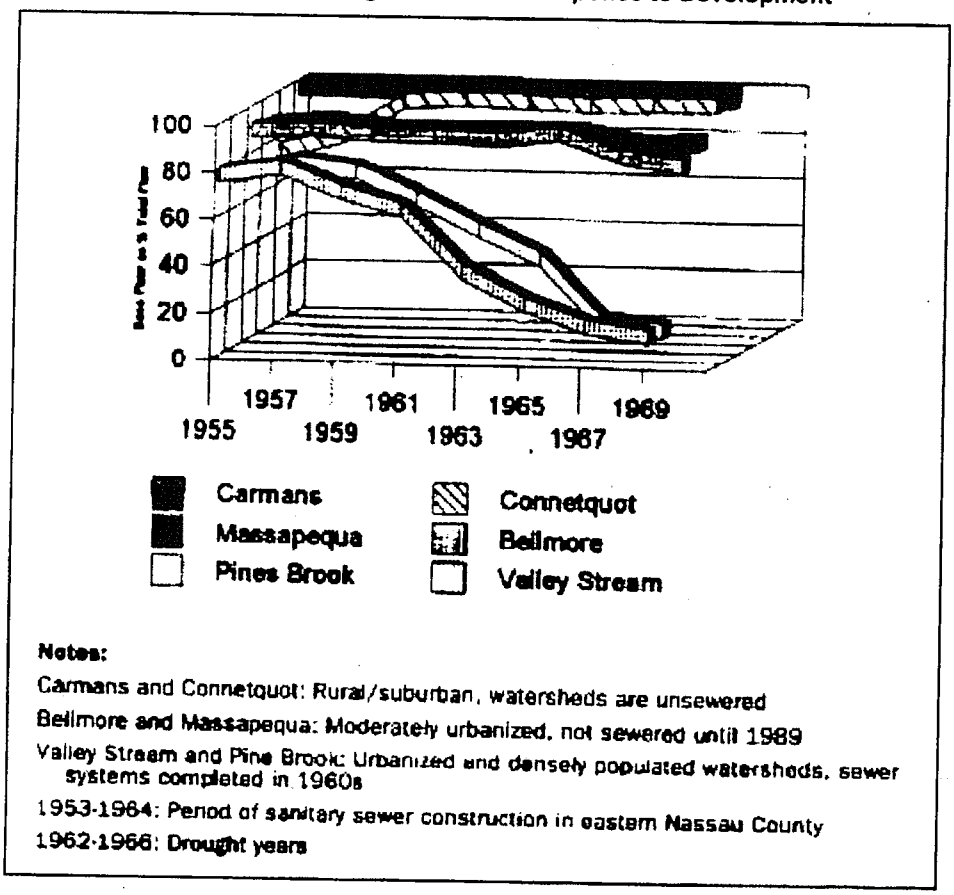
baseflow decreased in some developing watersheds, particularly where the water supply was sewered (Spinello and Simmons, 1992; Figure 2.3).

Urban land uses and activities can also degrade *groundwater quality,* if stormwater runoff is infiltrated without adequate treatment. Certain land uses and activities are known to produce higher loads of metals and toxic chemicals and are designated as *stormwater hotspots*. Soluble pollutants, such as chloride, nitrate, copper, dissolved solids and some polycyclic aromatic hydrocarbons (PAH's) can migrate into groundwater and potentially contaminate wells. Stormwater runoff from designated hotspots should never be infiltrated, unless the runoff receives full pretreatment with another practice.

Figure 2.3 Declining Baseflow in Response to Development



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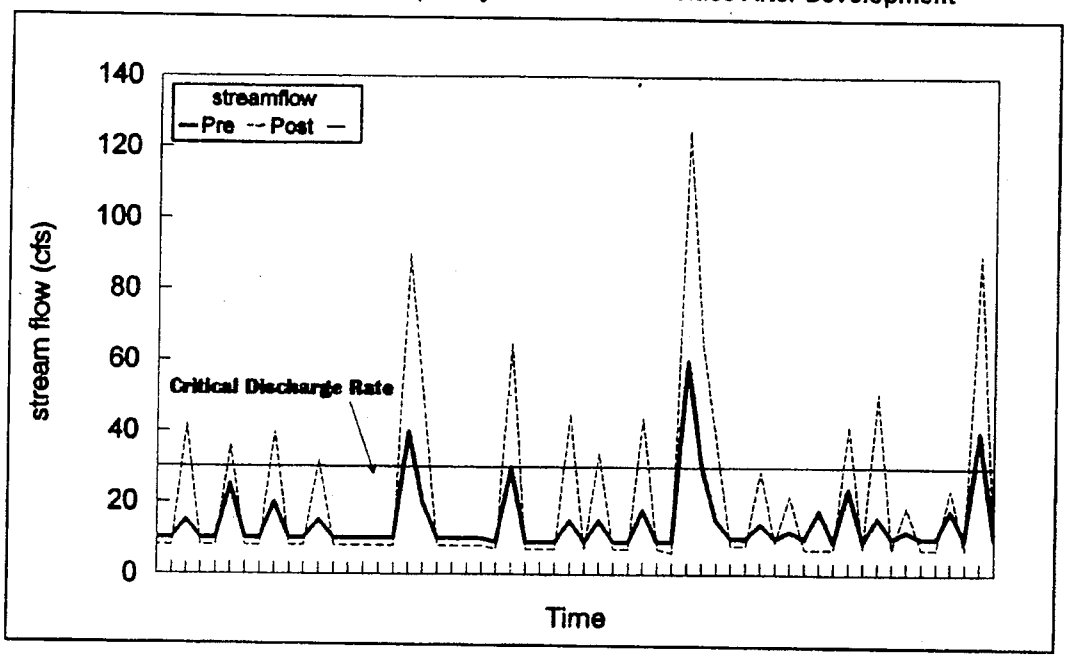
Section 2.3 Impacts to the Stream Channel

As pervious meadows and forests are converted into less pervious urban soils, or pavement, both the frequency and magnitude of storm flows increase dramatically. As a result, the bankfull event occurs two to seven times more frequently after development occurs (Leopold, 1994). In addition, the discharge associated with the original bankfull storm event can increase by up to five times (Hollis, 1975). As Figure 2.4 demonstrates, the total flow beyond the "critical erosive velocity" increases substantially after development occurs. The increased energy resulting from these more frequent bankfull flow events results in erosion and enlargement of the stream channel, and consequent habitat degradation.

Figure 2.4 Increased Frequency of Erosive Velocities After Development



Channel enlargement in response to watershed development has been observed for decades, with research indicating that the stream channel area expands to between two and five times its original size in response to upland development (Hammer, 1972; Morisawa and LaFlure, 1979; Allen and Narramore, 1985; Booth, 1990). One researcher developed a direct relationship between the level of impervious cover and the "ultimate" channel enlargement, the area a stream will eventually reach over time (MacRae, 1996; Figure 2.5).

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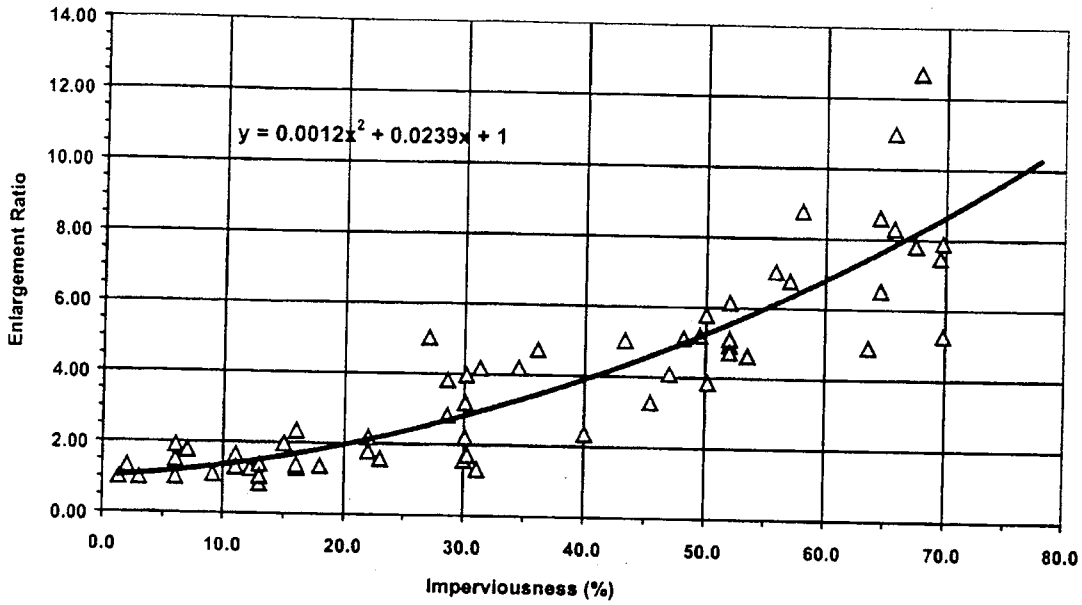
Figure 2.5 Relationship Between Impervious Cover and Channel Enlargement



Historically, New York has used two-year control (i.e., reduction of the peak flow from the two-year storm to predeveloped levels) to prevent channel erosion, as required in the 1993 SPDES General Permit (GP-93-06). Research suggests that this measure does not adequately protect stream channels (McCuen and Moglen, 1988, MacRae, 1996). Although the peak flow is lower, it is also extended over a longer period of time, thus increasing the duration of erosive flows. In addition, the bankfull flow event actually becomes more frequent after development occurs. Consequently, capturing the two-year event may not address the channel-forming event.

This stream channel erosion and expansion, combined with direct impacts to the stream system, act to decrease the habitat quality of the stream. The stream will thus experience the following impacts to habitat (Table 2.3):

- Decline in stream substrate quality (through sediment deposition and embedding of the substrate)
- Loss of pool/riffle structure in the stream channel
- Degradation of stream habitat structure
- Creation of fish barriers by culverts and other stream crossings
- Loss of "large woody debris," which is critical to fish habitat

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Table 2.3 Impacts to Stream Habitat			
Stream Channel Impact	**Key Finding**	**Reference**	**Year**
Habitat Characteristics			
Embeddedness	Interstitial spaces between substrate fill with increasing watershed imperviousness	Horner *et al.*	1996
Large Woody Debris (LWD)	Important for habitat diversity and anadramous fish.	Spence *et al.*	1996
	Decreased LWD with increases in imperviousness	Booth *et al.*	1996
Changes in Stream Features	Altered pool/riffle sequence with urbanization	Richey	1982
	Loss of habitat diversity	Scott *et al.*	1986
Direct Channel Impacts			
Reduction in 1st Order Streams	Replaced by storm drains and pipes increases erosion rate downstream	Dunne and Leopold	1972
Channelization and hardening of stream channels	Increase instream velocities often leading to increased erosion rates downstream	Sauer *et al.*	1983
Fish Blockages	Fish blockages caused by bridges and culverts	MWCOG	1989

Section 2.4 Increased Overbank Flooding

Flow events that exceed the capacity of the stream channel spill out into the adjacent floodplain. These are termed "overbank" floods, and can damage property and downstream structures. While some overbank flooding is inevitable and sometimes desirable, the historical goal of drainage design in New York has been to maintain pre-development peak discharge rates for both the two- and ten-year frequency storm after development, thus keeping the level of overbank flooding the same over time. This management technique prevents costly damage or maintenance for culverts, drainage structures, and swales.

Overbank floods are ranked in terms of their statistical return frequency. For example, a flood that has a 50% chance of occurring in any given year is termed a "two-year" flood. The two-year event is also known as the "bankfull flood," as researchers have demonstrated that most natural stream channels in the State have just enough capacity to handle the two-year flood before spilling out into the floodplain. Although many factors, such as soil moisture, topography, and snowmelt, can influence the magnitude of a particular flood event, designers typically design for the "two-year" storm event. In New York State,

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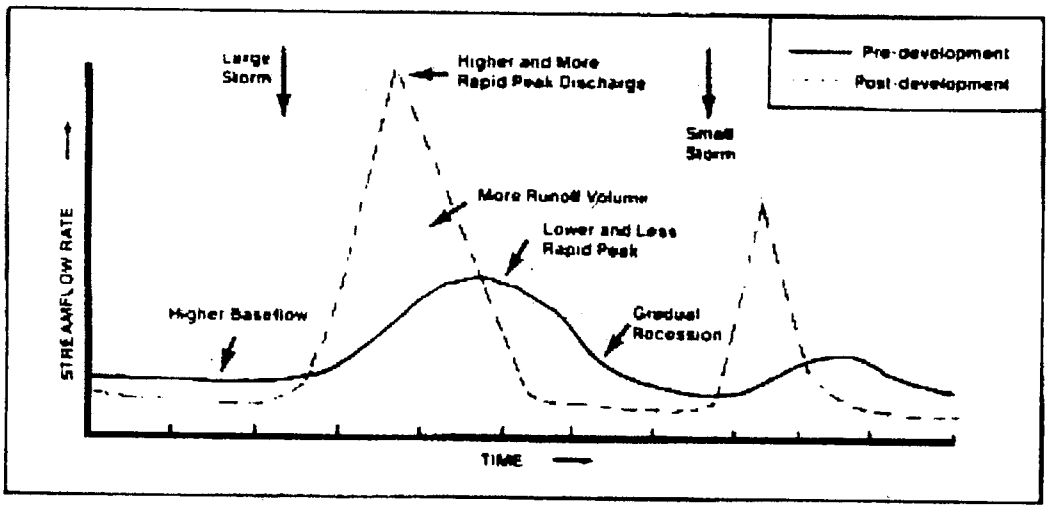
the two-year design storm ranges between about 2.0 to 4.0 inches of rain in a 24-hour period. Similarly, a flood that has a 10% chance of occurring in any given year is termed a "ten-year flood." A ten-year flood occurs when a storm event produces between 3.2 and 6.0 inches of rain in a 24-hour period. Under traditional engineering practice, most channels and storm drains in New York are designed with enough capacity to safely pass the peak discharge from the ten-year design storm.

Urban development increases the peak discharge rate associated with a given design storm, because impervious surfaces generate greater runoff volumes and drainage systems deliver it more rapidly to a stream. The change in post-development peak discharge rates that accompany development is profiled in Figure 2.6. Note that this change in hydrology increases not only the magnitude of the peak event, but the total volume of runoff produced.

Figure 2.6 Hydrographs Before and After Development



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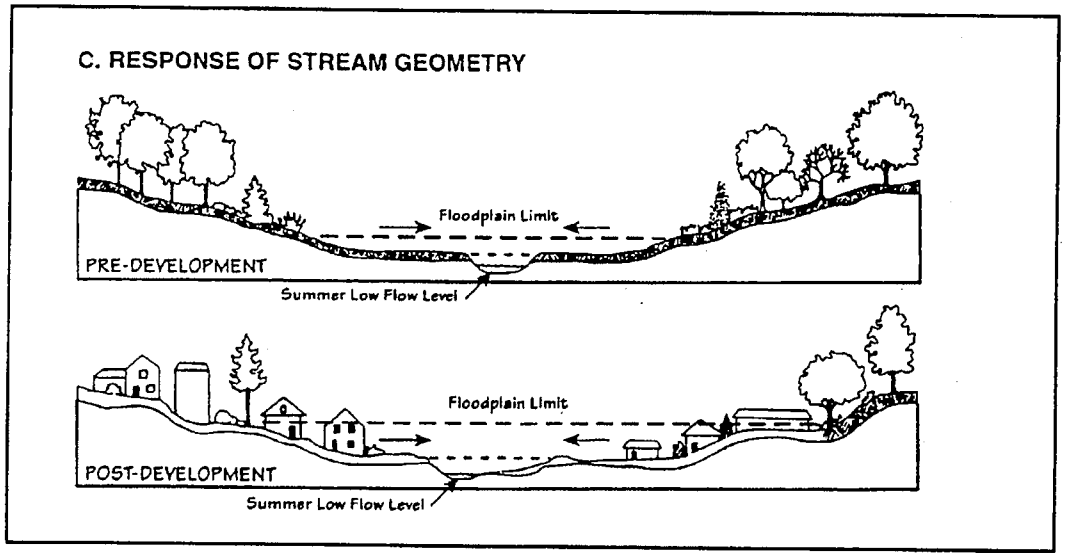
Section 2.5 Floodplain Expansion

The level areas bordering streams and rivers are known as floodplains. Operationally, the floodplain is usually defined as the land area within the limits of the 100-year storm flow water elevation. The 100-year storm has a 1% chance of occurring in any given year. In New York, a 100-year flood occurs after between five and eight inches of rainfall in a 24-hour period (i.e., the 100-year storm). These floods can be very destructive, and can pose a threat to property and human life.

As with overbank floods, development sharply increases the peak discharge rate associated with the 100-year design storm. As a consequence, the elevation of a stream's 100-year floodplain becomes higher and the boundaries of its floodplain expand (see Figure 2.7). In some instances, property and structures that had not previously been subject to flooding are now at risk. Additionally, such a shift in a floodplain's hydrology can degrade wetland and forest habitats.

Figure 2.7 Floodplain Expansion with New Development



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Section 2.6 Impacts to Aquatic Organisms

The decline in the physical habitat of the stream, coupled with lower base flows and higher stormwater pollutant loads, has a severe impact on the aquatic community. Research suggests that new development impacts aquatic insects, fish, and amphibians at fairly low levels of imperviousness, usually around 10% impervious cover (Table 2.4). New development appears to cause declining **richness** (the number of different species in an area or community), **diversity** (number and relative frequency of different species in an area or community), and **abundance** (number of individuals in a species).

Table 2.4 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms

Watershed Indicator	Key Finding	Reference	Year	Location
Aquatic insects and fish	A comparison of three stream types found urban streams had lowest diversity and richness. Urban streams had substantially lower EPT scores (22% vs 5% as number of all taxa, 65% vs 10% as percent abundance) and IBI scores in the poor range.	Crawford & Lenat	1989	North Carolina
Insects, fish, habitat water quality,	Steepest decline of biological functioning after 6% imperviousness. There was a steady decline, with approx 50% of initial biotic integrity at 45% I.	Horner *et al.*	1996	Puget Sound Washington
Fish, Aquatic insects	A study of five urban streams found that as land use shifted from rural to urban, fish and macroinvertebrate diversity decreased.	Masterson & Bannerman	1994	Wisconsin
Insects, fish, habitat, water quality, riparian zone	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as the percentage of total impervious area exceeded the 5-10% range.	May *et al.*	1997	Washington
Aquatic insects and fish	There was significant decline in the diversity of aquatic insects and fish at 10% impervious cover.	MWCOG	1992	Washington, DC
Aquatic insects and fish	Evaluation of the effects of runoff in urban and non-urban areas found that native fish and insect species dominated the non-urban portion of the watershed, but native fish accounted for only 7% of the number of species found in urban areas.	Pitt	1995	California
Wetland plants, amphibians	Mean annual water fluctuation inversely correlated to plant & amphibian density in urban wetlands. Declines noted beyond 10% impervious area.	Taylor	1993	Seattle

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Table 2.4 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms				
Watershed Indicator	**Key Finding**	**Reference**	**Year**	**Location**
Aquatic insects & fish	Residential urban land use in Cuyahoga watersheds created a significant drop in IBI scores at around 8%, primarily due to certain stressors that functioned to lower the non-attainment threshold When watersheds smaller than 100mi^2 were analyzed separately, the level of urban land use for a significant drop in IBI scores occurred at around 15%.	Yoder *et. al.*	1999	Ohio
Aquatic insects & fish	All 40 urban sites sampled had fair to very poor index of biotic integrity (IBI) scores, compared to undeveloped reference sites.	Yoder	1991	Ohio
IBI: Index of Biotic Integrity: A measure of species diversity for fish and macroinvertebrates EPT: A measure of the richnies of three sensitive macro-invertebrates (may flies, caddis flies, and stone flies), used to indicate the ability of a waterbody to support sensitive organisms.				

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Chapter 3

Stormwater Permit Requirements

New York State Stormwater Management Design Manual

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Chapter 3: Department of Environmental Conservation Permits

This chapter provides a summary of the applications that may need to be filed with the Department of Environmental Conservation (DEC) for new development projects. This section identifies general policies and timelines for filing a State Pollutant Discharge Elimination System ("SPDES") General Permit for stormwater discharges from construction activities as well as environmental permits under the Uniform Procedures Act (UPA). More detailed information on the permits and up-to-date regional contact information are available from the DEC web site at the following URLs:

www.dec.state.ny.us/website/dcs/permits_level2.html

www.dec.state.ny.us/website/dcs/upa/upa_permits.html

Section 3.1 Filing for a Stormwater Permit

40 CFR Part 122 prohibits point source discharges of stormwater to waters of the United States without a permit issued under the National Pollutant Discharge Elimination System ("NPDES"). New York State is approved by the EPA to administer its SPDES program in lieu of EPA's NPDES program. The operator of a storm water discharge, which qualifies for coverage under the SPDES General Permit for stormwater, must submit a Notice of Intent (NOI) form to obtain permit coverage. Consult the general permit for any possible restrictions on eligibility of coverage. The permit includes a complete set of instructions for filing an NOI and for filing a Notice of Termination (NOT).

3.1.1 Where to File the NOI Form

Completed NOIs should be sent to:

NYS DEC – Notice of Intent
Bureau of Water Permits
625 Broadway
Albany, NY 12233-3505

3.1.2 Stormwater Pollution Prevention Plan

The applicant must check whether the project will be a small or large one and whether the plan conforms to either NYSDEC or local Municipal Separate Storm Sewer System (MS4) requirements. The flow chart in Figure 3.1 identifies what components of the Stormwater Pollution Prevention Plan need to be prepared depending on the size and complexity of the site.

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If one wishes to seek some variance from either local or NYSDEC requirements, then the information in Section V of the NOI must be filled out. The purpose of this section is to give NYSDEC some preliminary information. Based on the information provided, DEC will determine if other information is required. Only operators who state that their plan will NOT conform to either NYSDEC or local MS4 requirements need to fill out this section.

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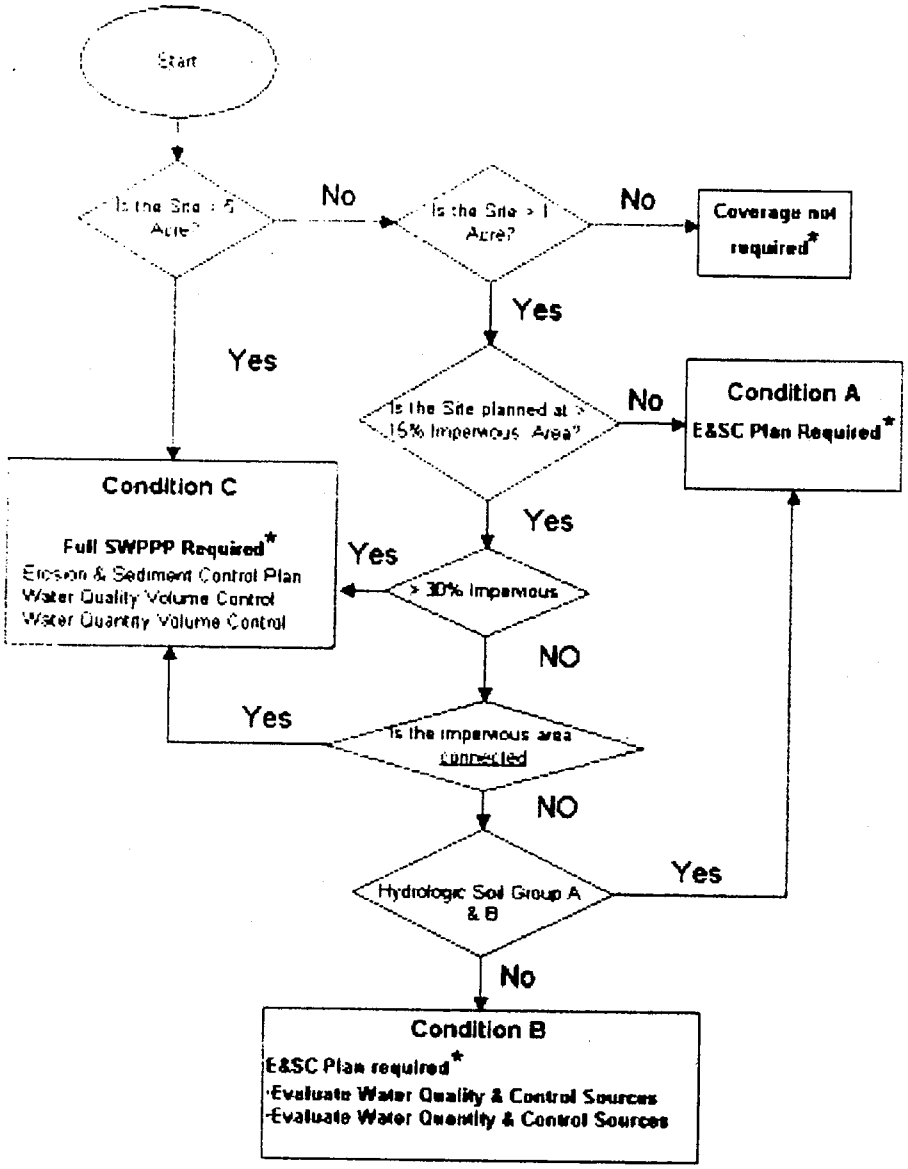
Figure 3.1 Stormwater Pollution Prevention Plan Component Requirements



* Under any of the above conditions other permits may be required

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3.1.3 Review and Approval

Once the Notice of Intent (NOI) has been reviewed by DEC, an acknowledgement letter will be returned to the sender. Filing of an NOI does not supercede or negate the necessity to comply with other local laws and other state or federal requirements, which affect stormwater management. It is the responsibility of the operator to comply with any and all such regulations. Operators are encouraged to have their Stormwater Pollution Prevention Plan reviewed by the local Soil and Water Conservation District.

New York City has enacted various land use controls that affect certain construction projects in areas tributary to their drinking water reservoirs. Similarly, the Lake George Park Commission and the Adirondack Park Agency (APA) have enacted regulations which impact construction activity. The APA has jurisdiction over private lands within the Adirondack Park and requires environmental review for most land development projects. It also administers the State's Wild and Scenic Rivers and Freshwater Wetlands programs on these lands. Development within the APA's jurisdiction is not subject to SEQR. For more information, please contact the APA at 518-891-4050.

Other municipalities and agencies of New York State may have adopted similar legislation. It is the responsibility of the operator to comply with any and all such regulations. Table 3.1 provides a summary table describing the permits issued by DEC that may apply to the new development.

Section 3.2 Filing Other Permit Applications

Most other environmental permits are administered under the UPA, which establishes uniform review procedures for the DEC's major regulatory programs and provides time periods for DEC action on applications for environmental protection permits. Generally permits identified under the UPA need to be filed through the DEC Regional Office. (See Figure 3.2 for regional contact information). If more than one permit is required, the applicant should submit all applications at one time. In addition, the applicant must list permits of other agencies that he or she knows to be applicable, together with a statement of the status of approval of the review under the State Environmental Quality Review (SEQR).

3.2.1 What Other Permits Do I Need to File?

Several permits under the UPA may be applicable to a particular development project. Table 3.1 lists many of permits required under the UPA that may apply to new residential, commercial, and industrial development in New York State, and provides a brief description of each. Please note that the table includes only the permits that are directly applicable to the stormwater and site plan development. Thus

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several UPA permits may be required that are not included on this table, including Long Island Wells, Water Supply, 401 Water Quality Certification, Air Pollution Control, Mined Land Reclamation, Hazardous Waste Management Facilities, and Waste Transporter.

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Table 3.1 Summary of Environmental Permits Issued by DEC That May Apply to New Development			
3.1 Permit Title	**3.2 Implementation Authority**	**3.2.1 Applicability**	**3.2.2 Regulated Activities**
State Pollutant Discharge Elimination System	ECL Article 17 Division of Water	• Construction sites disturbing one acre or more.	*Regulated:* Stormwater discharge associated with industrial activity, including new construction; point source discharges and disposal systems *Exempted:* Agricultural discharge[1], discharge of sewage effluent to groundwater less than 1,000 gallons a day.
Dam Safety	ECL Article 15-0503 see *Guidelines for Design of Dams*	• Applies to on-stream and off-stream structures having height > 6' and storage capacity > 3MG, or height ≥ 15' and storage capacity ≥ 1 MG.	*Regulated:* Construction, reconstruction, repair or removal of dams or impoundment. *Exempted:* Structures for treatment or storage of wastewater, or materials other than water.
Freshwater Wetlands	ECL Article 24 Division of Fish, Wildlife and Marine Resources	• Freshwater wetlands appearing on New York State freshwater wetland maps • Generally limited to 12.4 acres or greater, but stricter requirements in the Adirondack Park	*Regulated:* Construction of buildings, roadways, septic systems, dams, docks; filling, draining, or excavating; vegetation removal *Exempted:* Ordinary maintenance and repair of existing structures; recreational activities
Tidal Wetlands	ECL Article 25 NY DEC, Tidal Wetlands Regulatory Program	• Official DEC tidal wetlands maps. • Anywhere tidal inundation occurs on a daily, monthly, or intermittent basis, including but not exclusively within the salt wedge (salt marshes, vegetated flats, and shorelines)[2] • Adjacent areas extend up to 300 ft. inland from wetland boundary (NYC 150 ft)	*Regulated:* Residences and condos; accessory structures; commercial and industrial buildings; roadways and parking lots; boat ramps; septic systems; drainage structures; erosion control structures (groins, sea walls); docks, piers, etc. Clearing/clear cutting; beach nourishment; dredging, excavation, and grading.
Protection of Waters	Title 5, ECL Article 15 Division of Fish, Wildlife and Marine Resources	Bed or banks of protected streams	*Regulated:* Modification or disturbance of the bed or banks of protected streams, including removal of sand or gravel; filling dredging in navigable waters; construction/modification/ repair of

[1]- Eligible for coverage under Concentrated Animal Feeding Operation (CAFO)

[2] Applicable to Rockland and Westchester Counties, NYC and Long Island.

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Table 3.1 Summary of Environmental Permits Issued by DEC That May Apply to New Development			
			certain dams, docks, and mooring areas. *Exempted:* Ordinary maintenance
Coastal Erosion Hazard Areas	ECL Article 34 Division of Water	• Lands adjacent to Lakes Erie and Ontario; the St. Lawrence, Niagara, Harlem, East, and Hudson Rivers; Kill van Kull; Arthur Kill; Atlantic Ocean; and connective water-bodies. • Natural Protective Features (NPF) nearshore areas; and landward Structural Hazard Areas (SHA)	*Regulated*: Construction/ modification/ restoration of structures, e.g. buildings, docks, piers, walkways; Filling, draining or excavating; Construction/modification/restoration of erosion control structures *Exempted:* Ordinary maintenance and repair of existing structures
Wild, Scenic, & Recreational Rivers	Title 27, ECL Article 15 Division of Fish, Wildlife and Marine Resources	All or portions of DEC-designated waterways: Three levels of classification include recreational rivers, scenic rivers, wild rivers	*Regulated*: Specifics depend on classification, but includes construction of residential, non-residential, accessory structures, and roads; Water quality, wastewater treatment, disposal; Vegetative cutting and agriculture; Recreational uses and development; Commercial and industrial uses. *Exempted*: Continuation of existing land uses; Maintenance and repair--without changes
* UPA permits not included in this table are Long Island Wells, Water Supply, 401 Water Quality Certification, Air Pollution Control; Mined Land Reclamation, Hazardous Waste Management Facilities, Waste Transporter Source URL:(http://www.dec.state.ny.us/website/dcs/upa/upa_permits.html)			

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3.2.2 Schedule for DEC Review

The time for permit approval depends on whether a project is determined to be UPA major or UPA minor. Each of the permits included in the UPA process has specific definitions of what constitutes UPA major and UPA minor projects. DEC first determines if an application is complete, and then begins the review process. For most projects, DEC must determine completeness within 15 days and for federally delegated permits within 60 days. For UPA minor projects, DEC must make a decision on the permit within 45 days of determining the application complete.

For UPA major projects, the length of time for review depends on whether a public hearing is required. If no hearing is required, DEC must make a decision within 90 days of determining the project complete. If a hearing is required, DEC notifies the applicant and the public of a hearing within 60 days of the completeness determination. The hearing must commence within 90 days of the completeness determination. Once the hearing ends, DEC must issue a final decision on the application within 60 days after receiving the final hearing record.

- **Dam Safety**

Constructing, reconstructing, repairing, or modifying dams and water impounding structures that permanently or temporarily impound water as a result of a structure placed across a watercourse or overland drainage way or which receive water from an external source such as drainage diversion or pumping of groundwater require a dam safety permit. Some examples of activities requiring this permit are: siting and constructing a new dam or water impounding structure, reconstruction, modification or maintenance which may affect the structural integrity or functional capability of a dam or impounding structure.

- **Freshwater Wetlands/Tidal Wetlands**

A freshwater or tidal wetlands permit may be required for work in or adjacent to wetlands designated by the State. Official tidal wetlands maps showing the locations of New York's regulated tidal wetlands are on file at DEC regional offices in Regions 1, 2, and 3, and in the County Clerks' Offices of Nassau, Suffolk, Bronx, Kings, New York, Queens, Richmond, Rockland, and Westchester Counties. They are also available at local assessing agencies in these areas. Official freshwater wetlands maps showing the locations of New York's wetlands are on file at DEC regional offices, the Adirondack Park Agency, and local government offices.

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Wetlands permit applications require analysis of alternatives. Even when a development is adjacent to a regulated wetland, the site plan and stormwater management plan need to be modified to adequately protect these resources.

- **Protection of Waters**

This permit applies to the dredging and filling in navigable waters and dams and work on the banks of protected streams. The permit also regulates the construction of dams in both waterways and overland drainage ways. When a site plan includes dam construction as a part of a quantity or quality control requirement, a permit will be required unless the following conditions are met:

- Maximum height is six feet or less (maximum height is measured as the height from the downstream (outside) toe of the dam at its lowest point to the highest point at the top of the dam).
- Maximum impounding capacity is one million gallons or less (maximum impounding capacity is measured as the volume of water impounded when the water level is at the top of the dam).
- Maximum height is between six feet and 15 feet and the maximum impounding capacity is less than three million gallons.

- **Coastal Erosion Hazard Areas**

This permit is required where coastal erosion is a concern, and applies to Natural Protective Features (NPFs), such as sand dunes, and a Shoreline Hazard Area (SHA) defined based on the annual recession rate of the coast. The permit is required for construction of any structures within the SHA, and the permitee must demonstrate that the proposed project does not contribute to coastal erosion.

- **Wild, Scenic, & Recreational Rivers**

This regulation applies strict regulations, which restrict certain uses for development bordering wild, scenic, or recreational rivers in New York State. Furthermore, the applicant must demonstrate that no reasonable alternative exists, and that the proposed activity will not have an undue adverse environmental impact. Listed waterways include:

<u>Scenic Rivers</u>

Carmans River
Peconic River
East Canada Creek
Grasse River
Oswegatchie River
GenesseeRiver

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Recreational Rivers

Carmans River
Connetquot River
Nissequogue River
Peconic River
Ramapo River
Shawangunk Kill
Ausable River
Fall Creek

- **State Environmental Quality Review Act (SEQR)**

Many projects are subject to SEQR. It is important that operators inform local governments about their projects and obtain necessary local approvals before starting work. Projects, for which only a general permit is needed, are not subject to SEQR. If any other permits are required, the applicant must submit applications, which are reviewed in accordance with SEQR.

All agencies involved (state and local), must consider the environmental impacts of construction projects before approving, funding, or directly undertaking an action. Development projects subject to SEQR will require an Environmental Assessment Form. If a project may have a significant environmental impact, an Environmental Impact Statement (EIS) will be required. Projects will require public involvement as a part of this process.

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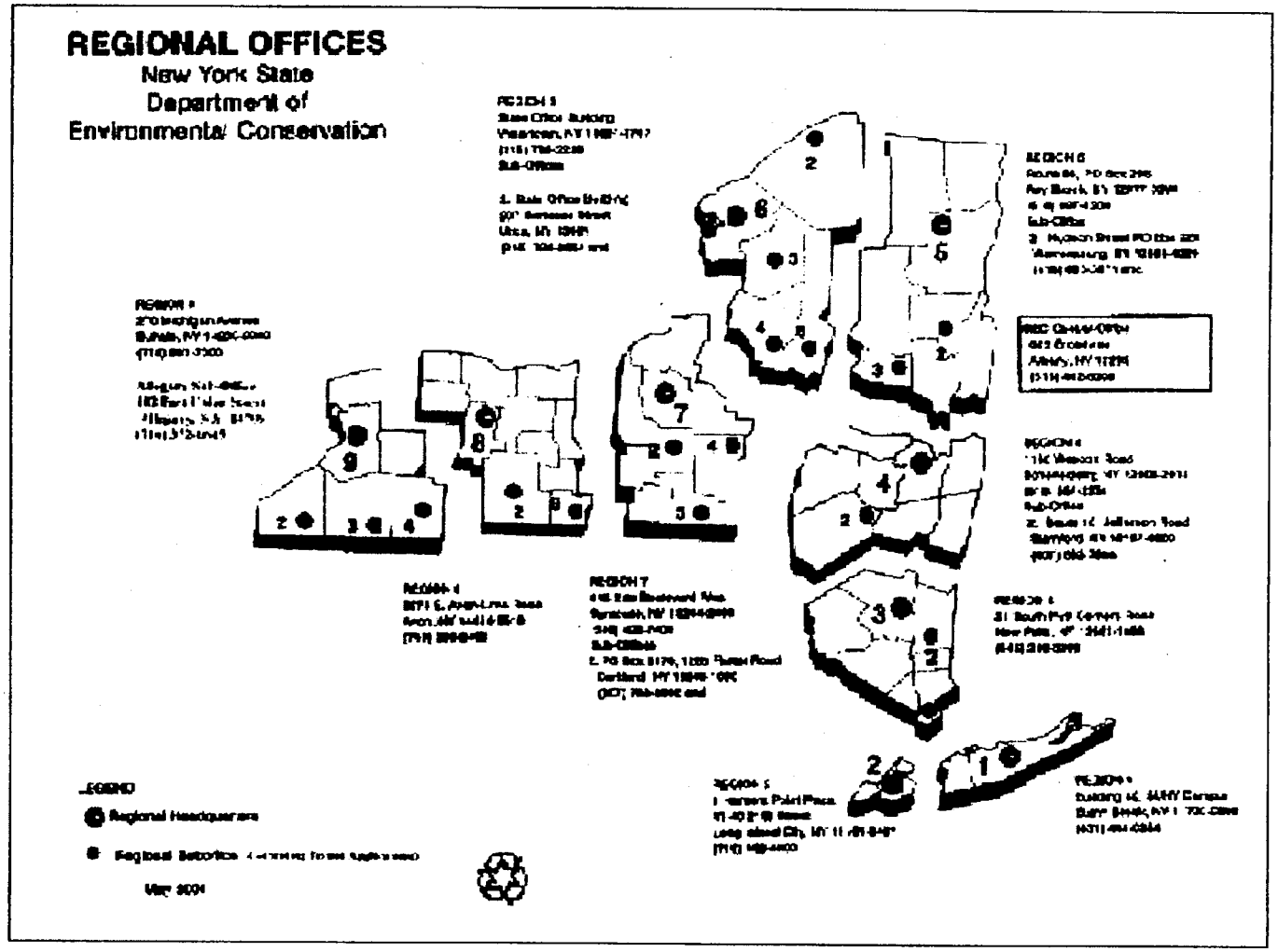
Figure 3.2 New York State Regional Contact Information



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Chapter 4

Unified Stormwater Sizing Criteria

New York State Stormwater Management Design Manual

Chapter 4: Unified Stormwater Sizing Criteria

Section 4.1 Introduction

This chapter presents a unified approach for sizing SMPs in the State of New York to meet pollutant removal goals, reduce channel erosion, prevent overbank flooding, and help control extreme floods. For a summary, please consult Table 4.1 below. The remaining sections describe the four sizing criteria in detail and present guidance on how to properly compute and apply the required storage volumes.

Table 4.1 New York Stormwater Sizing Criteria

Water Quality (WQ_v)	**90% Rule:** $WQ_v = [(P)(R_v)(A)] /12$ $Rv = 0.05+0.009(I)$ I = Impervious Cover (Percent) Minimum Rv = 0.2 P = 90% Rainfall Event Number (See Figure 4.1) A = site area in acres
Channel Protection (Cp_v)	**Default Criterion:** Cp_v = 24 hour extended detention of post-developed 1-year, 24-hour storm event. **Option for Sites Larger than 50 Acres:** Distributed Runoff Control - geomorphic assessment to determine the bankfull channel characteristics and thresholds for channel stability and bedload movement.
Overbank Flood (Q_p)	Control the peak discharge from the 10-year storm to 10-year predevelopment rates.
Extreme Storm (Q_f)	Control the peak discharge from the 100-year storm to 100-year predevelopment rates. Safely pass the 100-year storm event.
Note: The local review authority may waive channel protection, overbank flood, and extreme storm requirements in some instances. Guidance is provided in this chapter.	

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Section 4.2 Water Quality Volume (WQ_v)

The Water Quality Volume (denoted as the WQ_v) is designed to improve water quality sizing to capture and treat 90% of the average annual stormwater runoff volume. The WQ_v is directly related to the amount of impervious cover created at a site. Contour lines of the 90% rainfall event are presented in Figure 4.1.

The following equation can be used to determine the water quality storage volume WQ_v (in acre-feet of storage):

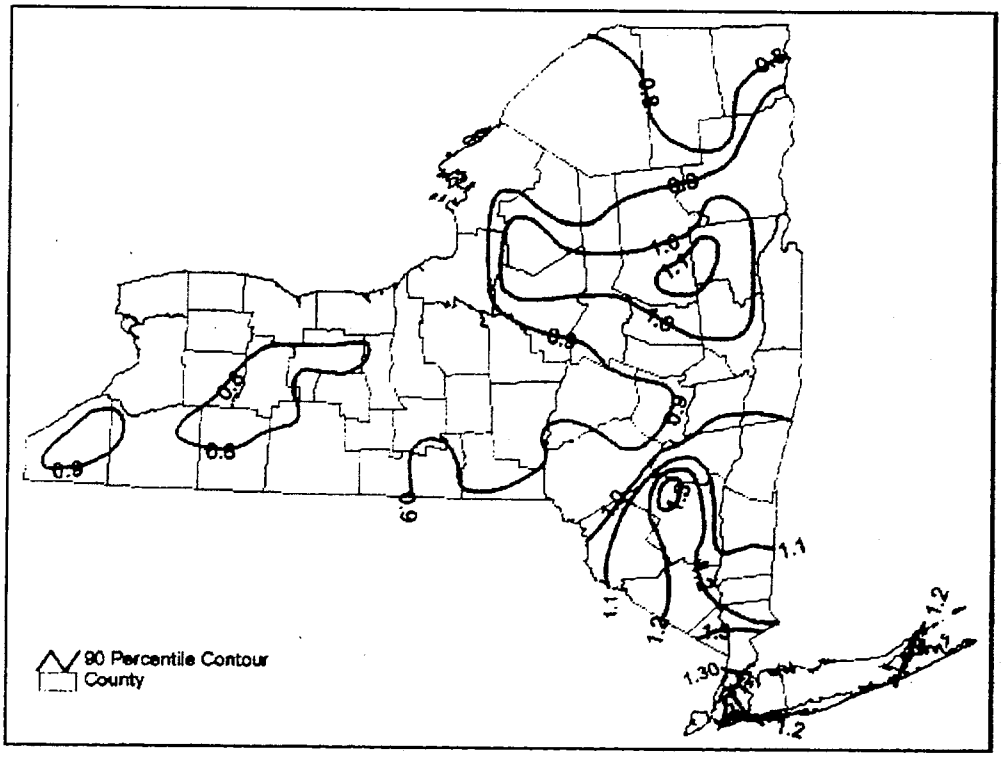
$$WQ_v = \frac{(P)(R_v)(A)}{12}$$

where:

WQ_v = water quality volume (in acre-feet)
P = 90% Rainfall Event Number (see Figure 4.1)
R_v = 0.05 + 0.009(I), where I is percent impervious cover
A = site area in acres

A minimum WQ_v of 0.2 inches per acre shall be met at residential sites that have less than 17% impervious cover.

Figure 4.1 90% Rainfall in New York State



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It is assumed that by meeting the WQ_v requirements through employment of the practices presented in Table 5.1 a project will, by default, meet water quality objectives. In some jurisdictions, on-site load calculations are required to demonstrate removal of specific pollutants. As an aid to communities, Appendix A of this manual includes a discussion of a method for calculating pollutant export loads from development sites. This method, known as the "Simple Method," provides estimates for stormwater runoff pollutant loads for urban areas using a modest amount of information, including the subwatershed drainage area and impervious cover, stormwater runoff pollutant concentrations, and annual precipitation. Please consult Appendix A for a more detailed discussion of the Simple Method and its applications for water quality determinations. Please note that the Simple Method is intended as an analysis tool, and should not be used to guide the design of SMPs.

Basis Of Design for Water Quality

As a basis for design, the following assumptions may be made:

- *Measuring Impervious Cover*: the measured area of a site plan that does not have permanent vegetative or permeable cover shall be considered total impervious cover. Impervious cover is defined as all impermeable surfaces and includes: paved and gravel road surfaces, paved and gravel parking lots, paved driveways, building structures, paved sidewalks, and miscellaneous impermeable structures such as patios, pools, and sheds. Porous or modular block pavement may be considered 50% impervious. Where site size makes direct measurement of impervious cover impractical, the land use/impervious cover relationships presented in Table 4.2 can be used to initially estimate impervious cover.

Table 4.2 Land Use and Impervious Cover (Source: Cappiella and Brown, 2001)

Land Use Category	Mean Impervious Cover
Agriculture	**2**
Open Urban Land*	**9**
2 Acre Lot Residential	**11**
1 Acre Lot Residential	**14**
1/2 Acre Lot Residential	**21**

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Table 4.2 Land Use and Impervious Cover (Source: Cappiella and Brown, 2001)	
Land Use Category	**Mean Impervious Cover**
1/4Acre Lot Residential	**28**
1/8 Acre Lot Residential	**33**
Townhome Residential	**41**
Multifamily Residential	**44**
Institutional**	**28-41%**
Light Industrial	**48-59%**
Commercial	**68-76%**
* Open urban land includes developed park land, recreation areas, golf courses, and cemeteries. ** Institutional is defined as places of worship, schools, hospitals, government offices, and police and fire stations	

- *Aquatic Resources*: More stringent local regulations may be in place or may be required to protect drinking water reservoirs, lakes, or other sensitive aquatic resources. Consult the local authority to determine the full requirements for these resources.

- *SMP Treatment*: The final WQ_v shall be treated by an acceptable practice from the list presented in this manual. Please consult Chapter 5 for a list of acceptable practices.

- *Determining Peak Discharge for WQ_v Storm*: When designing flow splitters for off-line practices, consult the small storm hydrology method provided in Appendix B.

- *Extended Detention for Water Quality Volume*: The water quality requirement can be met by providing 24 hours of the WQ_v (provided a micropool is specified) extended detention. A local jurisdiction may reduce this requirement to as little as 12 hours in trout waters to prevent stream warming.

- *Off-site Areas:* Provide treatment for off-site areas in their current condition. If water quality treatment is provided off-line, the practice must only treat on-site runoff.

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Section 4.3 Stream Channel Protection Volume Requirements (Cp_v)

Stream Channel Protection Volume Requirements (Cp_v) are designed to protect stream channels from erosion. In New York State this goal is accomplished by providing 24-hour extended detention of the one-year, 24-hour storm event. Trout waters may be exempted from the 24-hour ED requirement, with only 12 hours of extended detention required to meet this criterion.

For developments greater than 50 acres, with impervious cover greater than 25%, it is recommended that a detailed geomorphic assessment be performed to determine the appropriate level of control. Appendix J provides guidance on how to conduct this assessment.

The Cp_v requirement does not apply in certain conditions, including the following:

- Recharge of the entire Cp_v volume is achieved at a site.
- The site discharges directly tidal waters or fourth order (fourth downstream) or larger streams. Within New York State, streams are classified using the following:
  New York State Codes Rules and Regulations (NYCRR)
  Volumes B-F, Parts 800-941
  West Publishing, Eagan, MN
- A downstream analysis reveals that channel protection is not required (see section 4.7).

Detention ponds or underground vaults are methods to meet the Cp_v requirement (and subsequent Q_{p10} and Q_f criteria). Schematics of typical designs are shown in Figures 4.2. and 4.3. Note that, although these practices meet water quantity goals, they are unacceptable for water quality because of poor pollutant removal, and need to be coupled with a practice listed in Table 5.1. The Cp_v requirement may also be provided above the water quality (WQ_v) storage in a wet pond or stormwater wetland.

Basis for Determining Channel Protection Storage Volume

The following represent the minimum basis for design:

- TR-55 and TR-20 (or approved equivalent) shall be used to determine peak discharge rates.
- Rainfall depths for the one-year, 24 hour storm event are provided in Figure 4.4.
- Off-site areas should be modeled as "present condition" for the one-year, 24 hour storm event.
- The length of overland flow used in time of concentration (t_c) calculations is limited to no more than 100 feet for post development conditions.
- Cp_v is not required at sites where the resulting diameter of the ED orifice is too small to prevent clogging. (A minimum 3" orifice with a trash rack or 1" if the orifice is protected by a standpipe

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having slots with an area less than the internal orifice are recommended to prevent clogging. See Figure 3 in Appendix K for design details).

- Extended detention storage provided for the channel protection (Cp_v-ED) does not meet the WQ_v requirement. Both water quality and channel protection storage may be provided in the same SMP, however.
- The CP_v detention time for the one-year storm is defined as the time difference between the center of mass of the inflow hydrograph (entering the SMP) and the center of mass of the outflow hydrograph (leaving the SMP). See Appendix B for a methodology for detaining this storm event.

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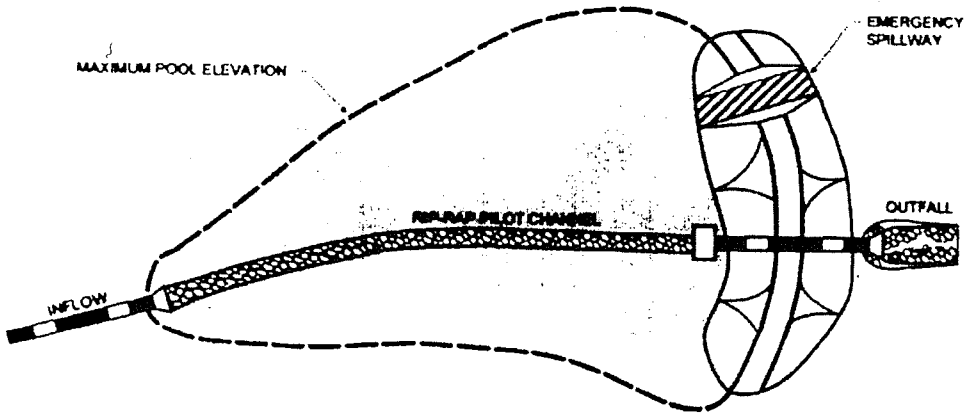
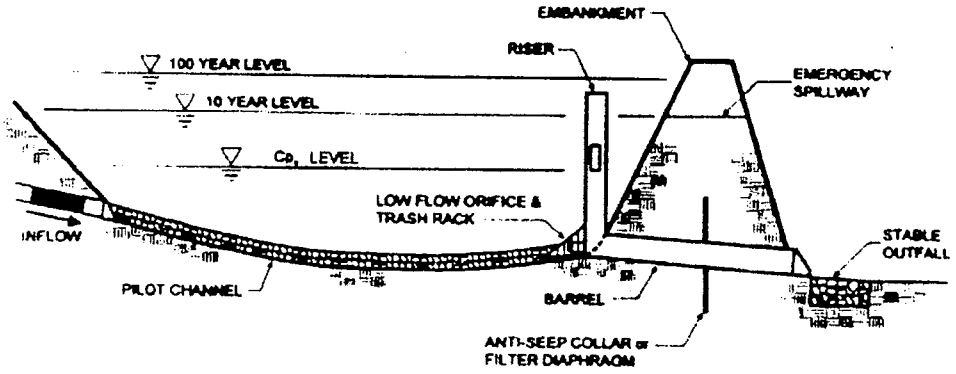
Figure 4.2 Example of a Conventional Stormwater Detention Pond



PLAN VIEW



PROFILE

A typical detention facility provides channel protection control (Cp_v) and overbank control (Q_p) but no water quality control (WQ_v). If this practice is used, WQv must be provided in a separate facility listed in Table 5.1.

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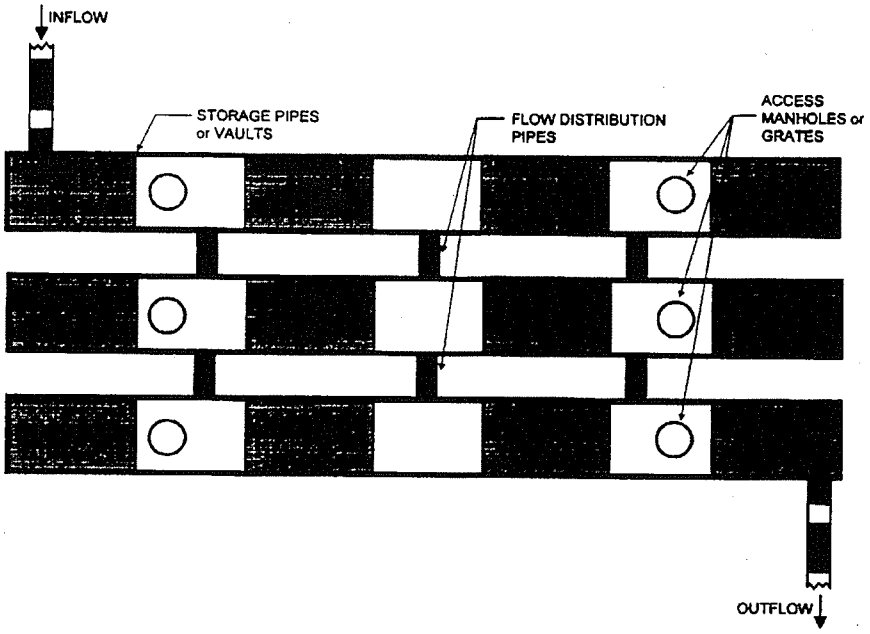
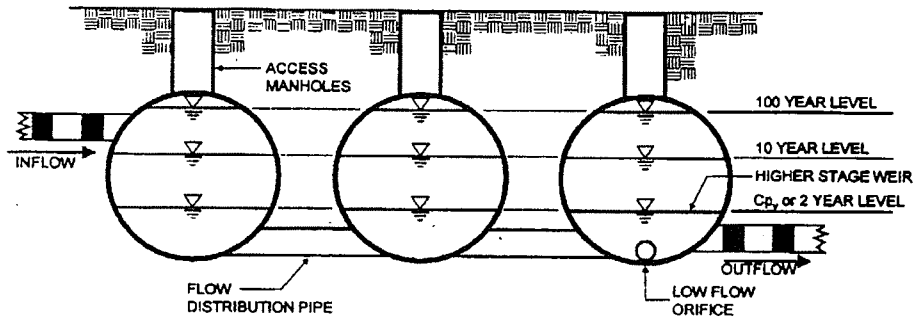
Figure 4.3 Example of Stormwater Detention Provided by an Underground Pipe System



PLAN VIEW



TYPICAL SECTION

An underground pipe system or vaults may be used to provide Cp_v, Q_p and Q_f controls but not WQ_v.

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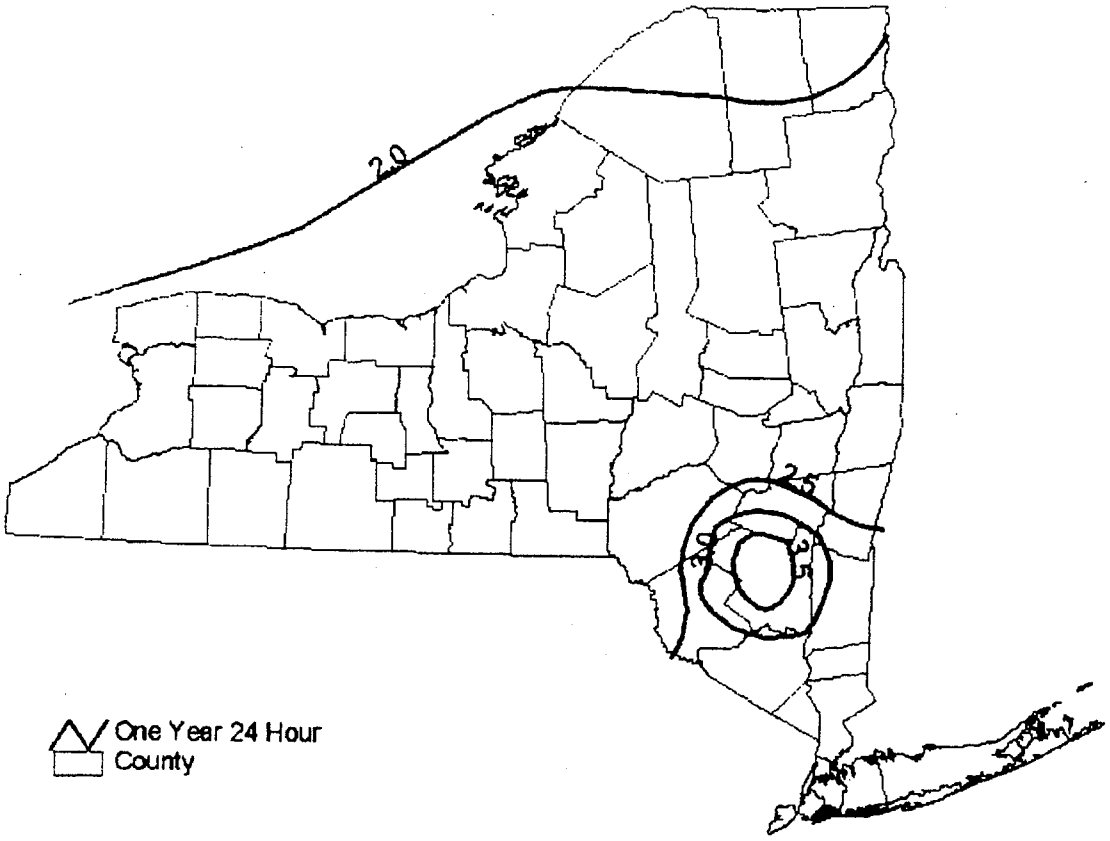
Figure 4.4 One-Year Design Storm



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Section 4.4 Overbank Flood Control Criteria (Q_p)

The primary purpose of the overbank flood control sizing criterion is to prevent an increase in the frequency and magnitude of out-of-bank flooding generated by urban development (i.e., flow events that exceed the bankfull capacity of the channel, and therefore must spill over into the floodplain).

Overbank control requires storage to attenuate the post development 10-year, 24-hour peak discharge rate (Q_p) to predevelopment rates.

The overbank flood control requirement (Q_p) does not apply in certain conditions, including:

- The site discharges directly tidal waters or fourth order (fourth downstream) or larger streams. Within New York State, streams are classified using the following:
  New York State Codes Rules and Regulations (NYCRR)
  Volumes B-F, Parts 800-941
  West Publishing, Eagan, MN
- A downstream analysis reveals that overbank control is not needed (see section 4.7).

Basis for Design of Overbank Flood Control

When addressing the overbank flooding design criteria, the following represent the minimum basis for design:

- TR-55 and TR-20 (or approved equivalent) will be used to determine peak discharge rates.
- When the predevelopment land use is agriculture, the curve number for the pre-developed condition shall be derived from the recommended five-year crop rotation for a region, from the local Soil Conservation Service, or from the historical five-year crop rotation for the site, whichever results in a lower curve number value.
- Off-site areas should be modeled as "present condition" for the 10-year storm event.
- Figure 4.5 indicates the depth of rainfall (24 hour) associated with the 10-year storm event throughout the State of New York.
- The length of overland flow used in t_c calculations is limited to no more than 150 feet for predevelopment conditions and 100 feet for post development conditions. On areas of extremely flat terrain (<1% average slope), this maximum distance is extended to 250 feet for predevelopment conditions and 150 feet for postdevelopment conditions.

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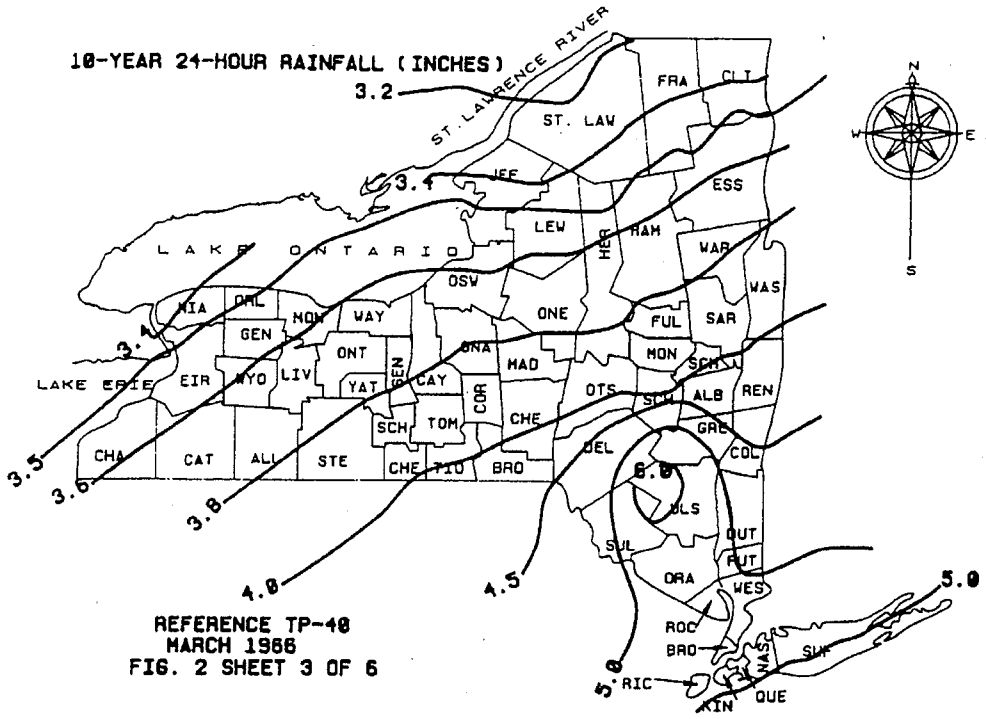
Figure 4.5 10-Year Design Storm



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Section 4.5 Extreme Flood Control Criteria (Q_f)

The intent of the extreme flood criteria is to (a) prevent the increased risk of flood damage from large storm events, (b) maintain the boundaries of the predevelopment 100-year floodplain, and (c) protect the physical integrity of stormwater management practices

100 Year Control requires storage to attenuate the post development 100-year, 24-hour peak discharge rate (Q_f) to predevelopment rates.

The 100-year storm control requirement can be waived if:

- The site discharges directly tidal waters or fourth order (fourth downstream) or larger streams. Within New York State, streams are classified using the following:
  New York State Codes Rules and Regulations (NYCRR)
  Volumes B-F, Parts 800-941
  West Publishing, Eagan, MN
- Development is prohibited within the ultimate 100-year floodplain
- A downstream analysis reveals that 100-year control is not needed (see section 4.7)

Detention structures must provide safe overflow of the 100-year flood, as discussed in the New York State Department of Environmental Conservation publication: "Guidelines for the Design of Dams," available from the Bureau of Flood Protection at 518-402-8151.

Basis for Design for Extreme Flood Criteria

- Consult with the appropriate review authority *including the local municipality's flood protection permit administrator,* to determine the analysis required for the Q_f storm.
- The same hydrologic and hydraulic methods used for overbank flood control shall be used to analyze Q_f.
- Figure 4.6 indicates the depth of rainfall (24 hour) associated with the 100-year storm event throughout New York State.
- When determining the storage required to reduce 100-year flood peaks, model off-site areas under current conditions.
- When determining storage required to safely pass the 100-year flood, model off-site areas under ultimate conditions.

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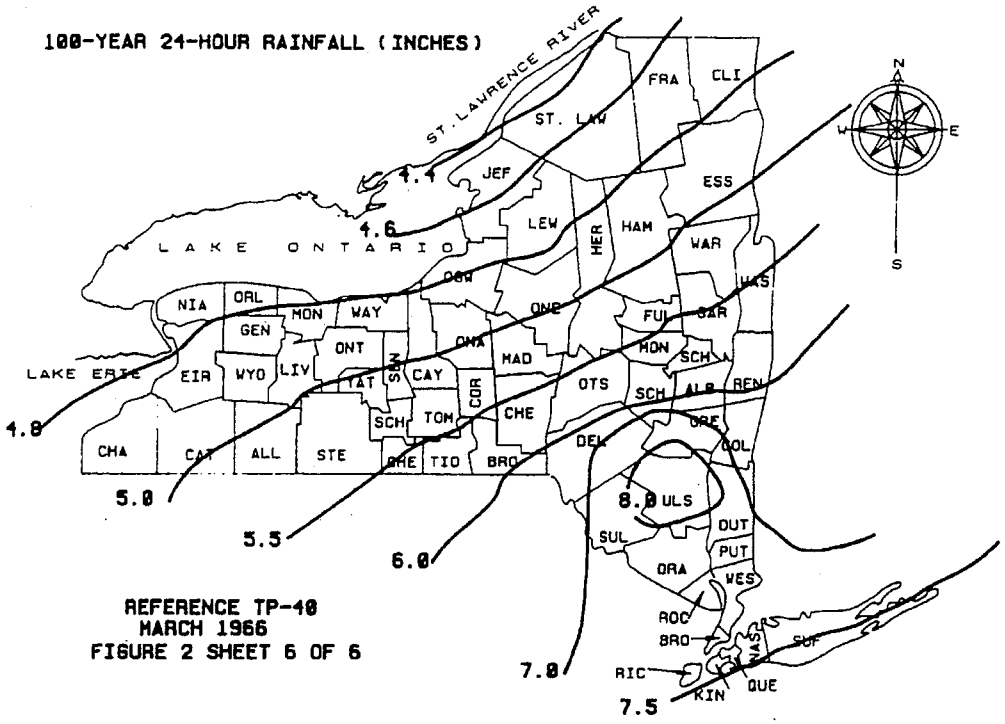
Figure 4.6 100-Year Design Storm



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Section 4.6 Conveyance Criteria

In addition to the stormwater treatment volumes described above, the manual also provides guidance on safe and non-erosive conveyance to, from, and through SMPs. Typically, the targeted storm frequencies for conveyance are the two-year and ten-year events. The two-year event is used to ensure non-erosive flows through roadside swales, overflow channels, pond pilot channels, and over berms within practices. Figure 4.7 presents rainfall depths for the two-year, 24-hour storm event throughout New York State. The 10-year storm is typically used as a target sizing for outfalls, and as a safe conveyance criterion for open channel practices and overflow channels. Note that some agencies or municipalities may use a different design storm for this purpose.

Section 4.7 Downstream Analysis

A community may waive the channel protection, overbank, and extreme flood requirements based on the results of a downstream analysis. In addition, such an analysis is recommended for larger sites (i.e., greater than 50 acres) to size facilities in the context of a larger watershed. The analysis will help ensure that storage provided at a site is appropriate to when combined with upstream and downstream flows. For example, detention at a site may in some instances exacerbate flooding problems within a watershed. This section provides brief guidance for conducting this analysis, including the area of stream to be evaluated and minimum elements to be included in the analysis.

Downstream analysis can be conducted using the 10% rule. That is, the analysis should extend downstream to the point where the site represents 10% of the total drainage area. For example, the analysis point for a 10-acre site would be analyzed to the nearest downstream point with a drainage area of 100 acres.

The analysis should include the following:

- Computation of flows and velocities for channel protection, overbank, and flood control storms at 200-foot intervals, at the point where the 10% rule is met, and at all confluences along the downstream channel with first order or higher streams.
- Hydrologic and hydraulic effects of all culverts and/or obstructions within the downstream channel.
- An assessment of water surface elevations to determine if an increase in water surface elevations will impact existing buildings and other structures.

The design, or waiver, at a site level can be approved if the following criteria are met:

- Flow rates and velocities increase by less than 5% of the pre-developed condition for all flow conditions analyzed.
- No downstream structures or buildings are impacted.
- The site as designed is not expected to exacerbate downstream channel erosion.

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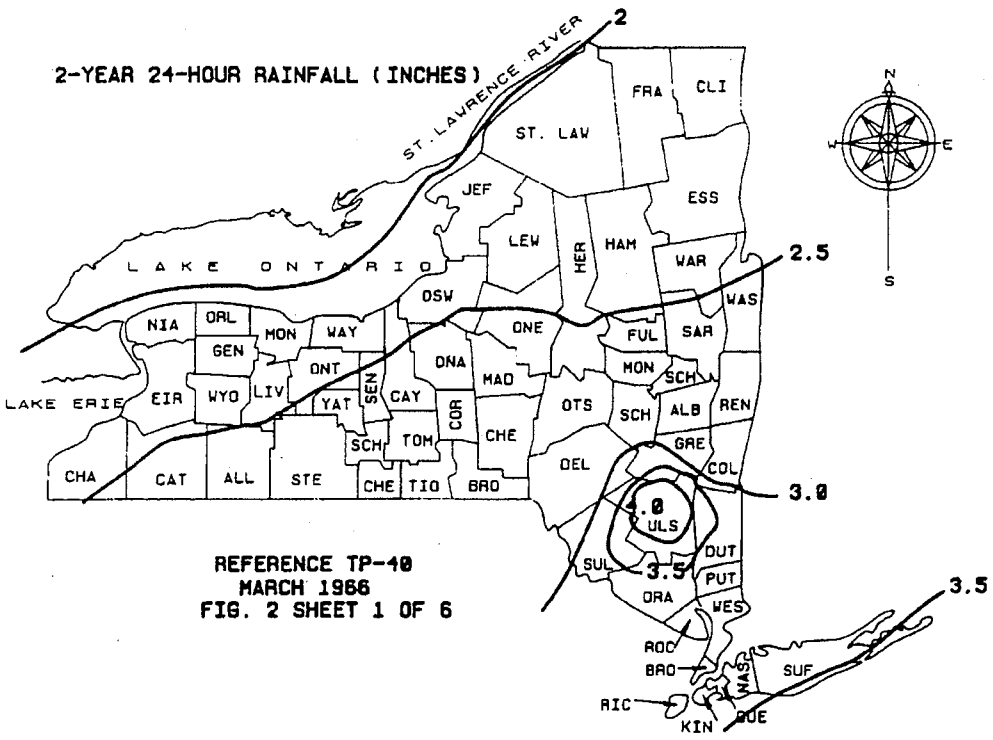
Figure 4.7. Two-Year Design Storm



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Section 4.8 Stormwater Hotspots

A stormwater hotspot is defined as a land use or activity that generates higher concentrations of hydrocarbons, trace metals or toxicants than are found in typical stormwater runoff, based on monitoring studies. If a site is designated as a hotspot, it has important implications for how stormwater is managed. First and foremost, stormwater runoff from hotspots cannot be allowed to infiltrate into groundwater, where it may contaminate water supplies. Second, a greater level of stormwater treatment is needed at hotspot sites to prevent pollutant washoff after construction. This treatment plan typically involves preparing and implementing *a stormwater pollution prevention plan* that involves a series of operational practices at the site that reduce the generation of pollutants from a site or prevent contact of rainfall with the pollutants. Table 4.3 provides a list of designated hotspots for the State of New York

Under EPA's stormwater NPDES program, some industrial sites are required to prepare and implement a stormwater pollution prevention plan. A list of industrial categories that are subject to the pollution prevention requirement can be found in the State of New York SPDES. In addition, New York's requirements for preparing and implementing a stormwater pollution prevention plan are described in the SPDES general discharge permit. The stormwater pollution prevention plan requirement applies to both existing and new industrial sites.

Table 4.3 Classification of Stormwater Hotspots

The following land uses and activities are deemed *stormwater hotspots:*

- Vehicle salvage yards and recycling facilities #
- Vehicle fueling stations
- Vehicle service and maintenance facilities
- Vehicle and equipment cleaning facilities #
- Fleet storage areas (bus, truck, etc.) #
- Industrial sites (based on SIC codes outlined in the SPDES)
- Marinas (service and maintenance) #
- Outdoor liquid container storage
- Outdoor loading/unloading facilities
- Public works storage areas
- Facilities that generate or store hazardous materials #
- Commercial container nursery
- Other land uses and activities as designated by an appropriate review authority

 # indicates that the land use or activity is required to prepare a stormwater pollution prevention plan under the SPDES stormwater program.

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The following land uses and activities are not normally considered hotspots:

- Residential streets and rural highways
- Residential development
- Institutional development
- Office developments
- Non-industrial rooftops
- Pervious areas, except golf courses and nurseries (which may need an Integrated Pest Management (IPM) Plan).

While large highways (average daily traffic volume (ADT) greater than 30,000) are not designated as a stormwater hotspot, it is important to ensure that highway stormwater management plans adequately protect groundwater.

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Chapter 5

List of Acceptable Stormwater Management Practices

New York State Stormwater Management Design Manual

Chapter 5: Acceptable Stormwater Management Practices (SMPs)

This section presents a list of practices that are acceptable for water quality treatment. The practices on this list are selected based on the following criteria:

1. Can capture and treat the full water quality volume (WQ_v)
2. Are capable of 80% TSS removal and 40% TP removal.
3. Have acceptable longevity in the field.
4. Have a pretreatment mechanism.

It also provides data justifying the use of these practices, and minimum criteria for the addition of new practices to the list.

Section 5.1 Practice List

Practices on the following list will be presumed to meet water quality requirements set forth in this manual if designed in accordance with the sizing criteria presented in Chapter 4 and constructed in accordance with the performance criteria in Chapter 6. The practices must also be maintained properly in accordance with the prescribed maintenance criteria also presented in Chapter 6. Acceptable practices are divided into five broad groups, including:

I. **Stormwater Ponds**	Practices that have either a permanent pool of water or a combination of permanent pool and extended detention capable of treating the WQ_v
II. **Stormwater Wetlands**	Practices that include significant shallow marsh areas, and may also incorporate small permanent pools and extended detention storage to achieve the full WQ_v
III. **Infiltration Practices**	Practices that capture and temporarily store the WQ_v before allowing it to infiltrate into the soil.
IV. **Filtering Practices**	Practices that capture and temporarily store the WQ_v and pass it through a filter bed of sand, organic matter, soil, or other acceptable treatment media.
V. **Open Channel Practices**	Practices explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means.

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Within each of these broad categories, select practices are presumed to meet the established water quality goals (see Table 5.1). It is important to note that several practices that are not on the list may be of value as pretreatment, or to meet water quantity requirements (see Section 5.2). Guidance on the performance criteria for each practice type and matrices for selecting practices are provided in Chapters 6 and 7.

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Table 5.1 Stormwater Management Practices Acceptable for Water Quality		
Group	**Practice**	**Description**
Pond	Micropool Extended Detention Pond (P-1)	Pond that treats the majority of the water quality volume through extended detention, and incorporates a micropool at the outlet of the pond to prevent sediment resuspension.
	Wet Pond (P-2)	Pond that provides storage for the entire water quality volume in the permanent pool.
	Wet Extended Detention Pond (P-3)	Pond that treats a portion of the water quality volume by detaining storm flows above a permanent pool for a specified minimum detention time.
	Multiple Pond System (P-4)	A group of ponds that collectively treat the water quality volume.
	Pocket Pond (P-5)	A stormwater wetland design adapted for the treatment of runoff from small drainage areas that has little or no baseflow available to maintain water elevations and relies on ground water to maintain a permanent pool.
Wetland	Shallow Wetland (W-1)	A wetland that provides water quality treatment entirely in a wet shallow marsh.
	Extended Detention Wetland (W-2)	A wetland system that provides some fraction of the water quality volume by detaining storm flows above the marsh surface.
	Pond/ Wetland System (W-3)	A wetland system that provides a portion of the water quality volume in the permanent pool of a wet pond that precedes the marsh for a specified minimum detention time.
	Pocket Wetland (W-4)	A shallow wetland design adapted for the treatment of runoff from small drainage areas that has variable water levels and relies on groundwater for its permanent pool.
Infiltration	Infiltration Trench (I-1)	An infiltration practice that stores the water quality volume in the void spaces of a gravel trench before it is infiltrated into the ground.
	Infiltration Basin (I-2)	An infiltration practice that stores the water quality volume in a shallow depression, before it is infiltrated it into the ground.
	Dry Well (I-3)	An infiltration practice similar in design to the infiltration trench, and best suited for treatment of rooftop runoff.
Filtering Practices	Surface Sand Filter (F-1)	A filtering practice that treats stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a sand matrix.
	Underground Sand Filter (F-2)	A filtering practice that treats stormwater as it flows through underground settling and filtering chambers.
	Perimeter Sand Filter (F-3)	A filter that incorporates a sediment chamber and filer bed as parallel vaults adjacent to a parking lot.
	Organic Filter (F-4)	A filtering practice that uses an organic medium such as compost in the filter, in the place of sand.
	Bioretention (F-5)	A shallow depression that treats stormwater as it flows through a soil matrix, and is returned to the storm drain system.
Open Channels	Dry Swale (O-1)	An open drainage channel or depression explicitly designed to detain and promote the filtration of stormwater runoff into the soil media.
	Wet Swale (O-2)	An open drainage channel or depression designed to retain water or intercept groundwater for water quality treatment.

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Section 5.2 Structural Practices Suitable for Pretreatment or as Supplemental Practices Only

Several practices that are not capable of providing water quality treatment can nonetheless function in a pretreatment role or as a supplemental practice to the recommended practices in Table 5.1. These practices can often be incorporated into SMP design as pretreatment devices, to treat a small portion of a site, or in retrofit or redevelopment applications. Some of these practices, including dry ponds and underground storage vaults, can be used to meet water quantity goals such as channel protection and flood control requirements. In addition, some of these practices may be helpful to reduce the total volume of runoff from a site or to disconnect impervious surfaces, as indicated on the Fact Sheets presented in this chapter. Some practices not currently deemed effective for stand-alone water quality treatment include:

- Catch basin inserts
- Dry ponds
- Underground vaults (designed for flood control)
- Oil/grit separators and hydrodynamic structures
- Filter strips
- Grass channels (includes ditches designed primarily for conveyance as well as modified practices that can achieve some pollutant removal)
- Deep sump catch basins
- On-line storage in the storm drain network
- Porous pavement

Fact sheets for some of these practices (dry ponds, filter strips, porous pavement, and grass channels) have been provided following section 5.3.

Section 5.3 Criteria for Practice Addition

The stormwater field is always evolving, and new technologies constantly emerge. New practices can be included in future revisions to the stormwater design manual, provided they can prove that they meet the water quality goals established in the manual. These goals include the 80% TSS (defined as suspended organic and inorganic material) and 40% TP removal target and a proven record of longevity in the field. For a practice to receive consideration for addition to the manual, the following monitoring criteria must be met by supporting studies:

- Must be monitored in at least two locations.
- At least five storm events must be sampled at each site.
- Concentrations reported in the studies must be flow-weighted.
- The studies must be independent (i.e., may not be conducted by the vendor or designer).
- The studies must be conducted in the field, as opposed to laboratory testing.

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- The practice must have been in the ground for at least one year at the time of monitoring (to assume the practice will be tested after a minimum amount of "in-service" time).
- At least one storm event in each study must be greater than the 90% storm event for the location.

Additional testing for new technologies based on the performance of practices with a similar design may be required before consideration. For example, if a practice has a very similar design to an oil/grit separator, which has consistently poor removal, then additional studies may be required to justify incorporation of that practice into the manual. The long-term performance of a practice based on field applications in New York or other regions with a similar climate or conditions may also determine if that practice will receive consideration for inclusion in the manual. A poor maintenance record is a valid justification for not including a practice in the manual.

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Dry Ponds



Description: Dry extended detention ponds (a.k.a. dry ponds, extended detention basins, detention ponds, extended detention ponds) are basins designed to temporarily detain runoff for some minimum time. Dry detention ponds are used for water quantity control only, and can also be used to provide flood control by including additional flood detention storage.

REASONS FOR LIMITED USE

- Controls stormwater quantity – not intended to provide water quality treatment

KEY CONSIDERATIONS

- Applicable for drainage areas up to 75 acres
- Typically less costly than stormwater (wet) ponds for equivalent flood storage, as less excavation is required
- May provide recreational and open space opportunities between storm runoff events

STORMWATER MANAGEMENT SUITABILITY

- ☐ **Water Quality**
- ☒ **Channel/Flood Protection**

SPECIAL APPLICATIONS

- ☐ **Pretreatment**
- ☐ **High Density/Ultra-Urban**
- ☐ **Runoff Reduction/Impervious Cover Disconnection**

Residential Subdivision Use: *Yes*

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Filter Strip



Description: Grassed filter strips (a.k.a., vegetated filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces and remove pollutants through filtration and infiltration.

REASONS FOR LIMITED USE

- Cannot alone achieve the 80% TSS removal target

KEY CONSIDERATIONS

- Runoff from an adjacent impervious area must be evenly distributed across the filter strip (i.e., sheet flow)
- Can be used as part of the runoff conveyance system to provide pretreatment
- Can provide groundwater recharge
- Reasonably low construction cost
- Large land requirement
- Requires periodic repair, regrading, and sediment removal to prevent channelization
- To size this practice, design a berm at the base of the filter strip. The volume to be treated should be captured behind the berm.

STORMWATER MANAGEMENT SUITABILITY

- [ ] **Water Quality**
- [ ] **Channel/Flood Protection**

SPECIAL APPLICATIONS

- [X] **Pretreatment**
- [ ] **High Density/Ultra-Urban**
- [X] **Runoff Reduction / Impervious Cover Disconnection**
- [X] **Other:** Use in buffer system; treating runoff from pervious areas

Residential Subdivision Use: *Yes*

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Modular Block Porous Pavement



Description: Modular block porous pavement is a permeable pavement surface with an underlying stone reservoir designed to temporarily store surface runoff before it infiltrates into the subsoil. Porous pavement options are primarily intended for low vehicle traffic areas such as spillover parking or simply the parking aisle portion of a parking lot.

REASONS FOR LIMITED USE

- Maintenance record is unclear, and pretreatment cannot be provided.
- Should not be applied on parking lots that are sanded or salted for snow control.

DESIGN CONSIDERATIONS

- Soil permeability between 0.5 and 3.0 inches per hour
- Do not locate on slopes > 15% or within fill soils
- Site at least 3 feet above the seasonally high groundwater table, and at least 100 feet away from drinking water wells
- Direct runoff from pervious or exposed areas away from pavement
- Size the gravel trench using the same equation provided in Section 6.3 for infiltration trenches.
- Provide conveyance for larger storms with raised inlet or perimeter gravel trench
- Sediment-laden runoff must be directed away from the porous pavement
- Maximum depth should not exceed 4 feet
- Ensure that the upland drainage is fully stabilized after construction;.
- Use permanent sign(s) containing a short list of maintenance requirements
- Do not use excavated stone reservoir as a sediment control device
- Avoid compacting subsoils during construction
- Ensure that paving dewaters between storms
- Periodically inspect the surface for deterioration or spalling

STORMWATER MANAGEMENT SUITABILITY

- [ ] **Water Quality**
- [ ] **Channel/Flood Protection**

SPECIAL APPLICATIONS

- [ ] **Pretreatment**
- [X] **High Density/Ultra-Urban**
- [X] **Runoff Reduction / Impervious Cover Disconnection**
- [X] **Other:** Overflow Parking

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Grass Channel



Description: Vegetated channels designed to filter stormwater runoff and meet velocity targets for the water quality design storm and the two-year storm event.

REASONS FOR LIMITED USE

- Cannot alone achieve the 80% TSS removal target

KEY CONSIDERATIONS

- Can be used as part of the runoff conveyance system to provide pretreatment
- Grass channels can act to partially infiltrate runoff from small storm events if underlying soils are pervious
- Less expensive than curb and gutter systems
- Should not be used on slopes greater than 4%; slopes between 1% and 2% recommended
- Design as a parabola, or as a trapezoid with a bottom width of between 2' and 8', with 3:1 or flatter side slopes.
- Provide sufficient length to retain the treatment volume in the system for 10 minutes, to flow at no greater than 1.0 fps, and at a depth of no greater than 4".
- Design to maintain between 4.0 and 5.0 fps for the 2-year storm, and no greater than 7.0 fps for the 10-year storm event.
- Size the channel to safely convey the 10-year storm event.
- Size using Manning's Equation (US DOT, 1990). Us an "n" value of 0.15 for flow depths of 4" or smaller, and linearly increase to 0.03 for a depth of 12".

STORMWATER MANAGEMENT SUITABILITY

- [ ] **Water Quality**
- [ ] **Channel/Flood Protection**

SPECIAL APPLICATIONS

- [X] **Pretreatment**
- [ ] **High Density/Ultra-Urban**
- [X] **Runoff Reduction / Impervious Cover Disconnection**
- [X] **Other:** Curb and gutter replacement

Residential Subdivision Use: *Yes*

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Chapter 6

Performance Criteria

New York State Stormwater Management Design Manual

Chapter 6: Performance Criteria

This chapter outlines performance criteria for five groups of structural stormwater management practices (SMPs) to meet water quality treatment goals. These include ponds, wetlands, infiltration practices, filtering systems and open channels. Each set of SMP performance criteria, in turn, is based on six performance goals:

Feasibility

Identify site considerations that may restrict the use of a practice.

Conveyance

Convey runoff to the practice in a manner that is safe, minimizes erosion and disruption to natural channels, and promotes filtering and infiltration.

Pretreatment

Trap coarse elements before they enter the facility, thus reducing the maintenance burden and ensuring a long-lived practice.

Treatment Geometry

Provide water quality treatment, through design elements that provide the maximum pollutant removal as water flows through the practice.

Environmental/Landscaping

Reduce secondary environmental impacts of facilities through features that minimize disturbance of natural stream systems and comply with environmental regulations. Provide landscaping that enhances the pollutant removal and aesthetic value of the practice.

Maintenance

Maintain the long-term performance of the practice through regular maintenance activities, and through design elements that ease the maintenance burden.

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Cold climate regions of New York State may present special design considerations. Each section includes a summary of possible design modifications that address the primary concerns associated with the use of that SMP in cold climates. A more detailed discussion of cold climate modifications can be found in the publication *Stormwater BMP Design Supplement for Cold Climates* (Caraco & Claytor, 1997). In addition, Appendix I of this manual provides some sizing examples that incorporate cold climate design.

IMPORTANT NOTES:

ANY PRACTICE THAT CREATES A DAM IS REQUIRED TO FOLLOW THE GUIDANCE PRESENTED IN THE *GUIDELINES FOR DESIGN OF DAMS* AND MAY REQUIRE A PERMIT FROM THE NYSDEC. FOR THE MOST RECENT COPY OF THIS DOCUMENT, CONTACT THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, DAM SAFETY DIVISION, AT: 518-402-8151. AN EVALUATION OF HAZARD CLASSIFICATION MUST BE INCLUDED IN THE DESIGN REPORT FOR STORMWATER PONDS OR WETLANDS CREATED BY A DAM.

THIS CHAPTER FOLLOWING TEXT PRESENTS CRITERIA IN TWO PARTS. DESIGN GUIDELINES ARE FEATURES THAT ENHANCE PRACTICE PERFORMANCE, BUT MAY NOT BE NECESSARY FOR ALL APPLICATIONS. REQUIRED ELEMENTS ARE FEATURES THAT SHOULD BE USED IN ALL APPLICATIONS. A FACT SHEET AT THE BACK OF EACH SECTION HIGHLIGHTS THE REQUIRED ELEMENTS.

APPENDICES F AND G PROVIDE EXAMPLE CHECKLISTS FOR THE CONSTRUCTION AND OPERATION&MAINTENANCE OF EACH OF THE PRACTICE TYPES.

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Section 6.1 Stormwater Ponds

Stormwater ponds are practices that have either a permanent pool of water, or a combination of a permanent pool and extended detention, and some elements of a shallow marsh equivalent to the entire WQ_v. Five design variants include:

- P-1 Micropool Extended Detention Pond (Figure 6.1)
- P-2 Wet Pond (Figure 6.2)
- P-3 Wet Extended Detention Pond (Figure 6.3)
- P-4 Multiple Pond System (Figure 6.4)
- P-5 Pocket Pond (Figure 6.5)

Treatment Suitability:

Dry extended detention ponds without a permanent pool are not considered an acceptable option for meeting water quality treatment goals. Each of the five stormwater pond designs can be used to provide channel protection volume as well as overbank and extreme flood attenuation. The term "pocket" refers to a pond or wetland that has such a small contributing drainage area that little or no baseflow is available to sustain water elevations during dry weather. Instead, water elevations are heavily influenced, and in some cases maintained, by a locally high water table.

IMPORTANT NOTES:

ANY PRACTICE THAT CREATES A DAM IS REQUIRED TO FOLLOW THE GUIDANCE PRESENTED IN THE *GUIDELINES FOR DESIGN OF DAMS* AND MAY REQUIRE A PERMIT FROM THE NYSDEC. FOR THE MOST RECENT COPY OF THIS DOCUMENT, CONTACT THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, DAM SAFETY DIVISION, AT: 518-402-8151. AN EVALUATION OF HAZARD CLASSIFICATION MUST BE INCLUDED IN THE DESIGN REPORT FOR STORMWATER PONDS CREATED BY A DAM.

WHILE THE STORMWATER PONDS DESIGNED ACCORDING TO THIS GUIDANCE MAY ACT AS A COMMUNITY AMMENITY, AND MAY PROVIDE SOME HABITAT VALUE, THEY CANNOT BE ANTICIPATED TO FUNCTION AS NATURAL LAKES OR PONDS.

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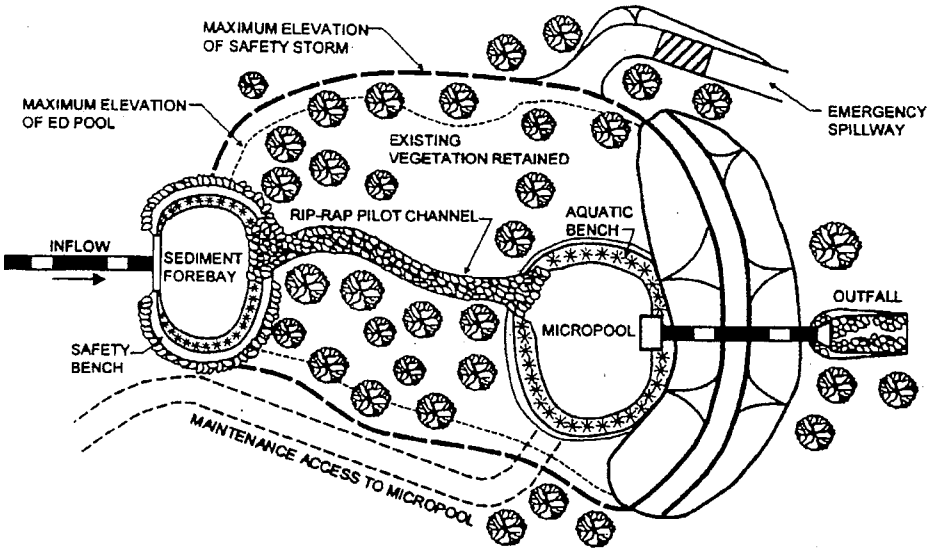
Figure 6.1 Micropool Extended Detention Pond (P-1)



PLAN VIEW

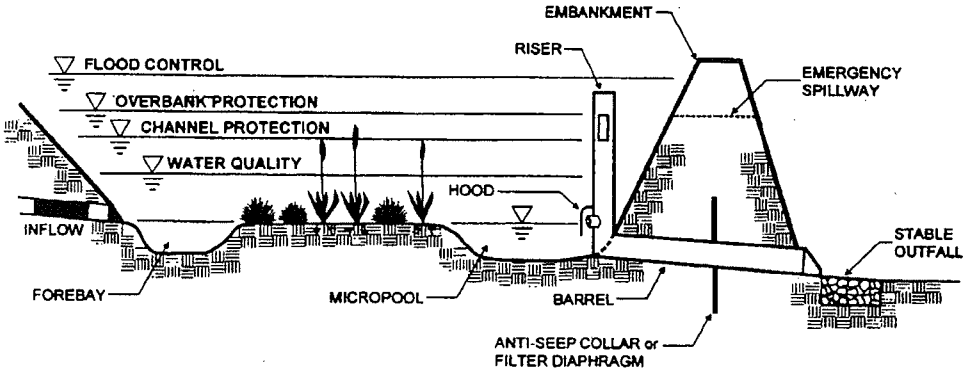


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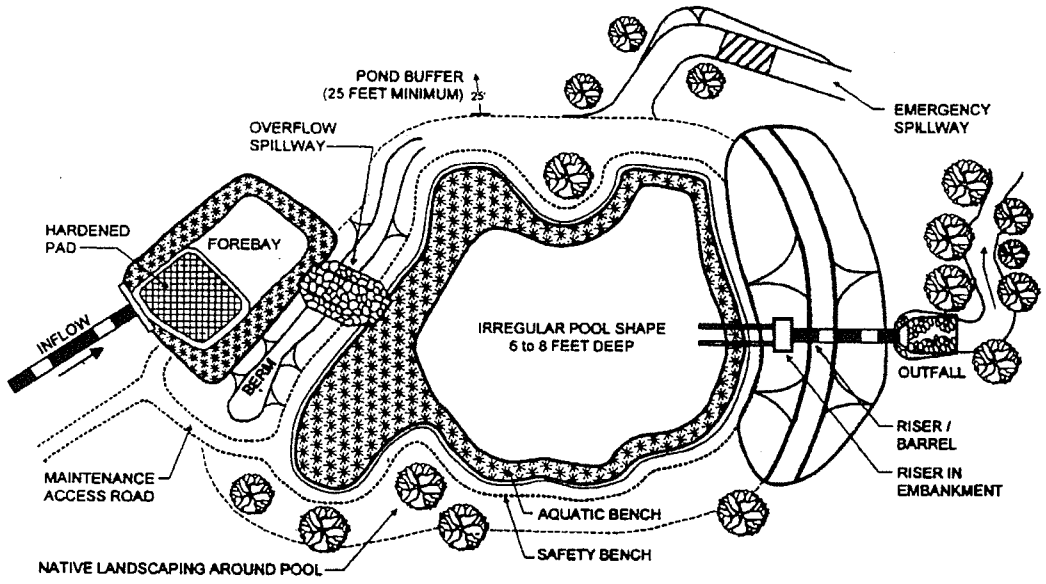
Figure 6.2 Wet Pond (P-2)



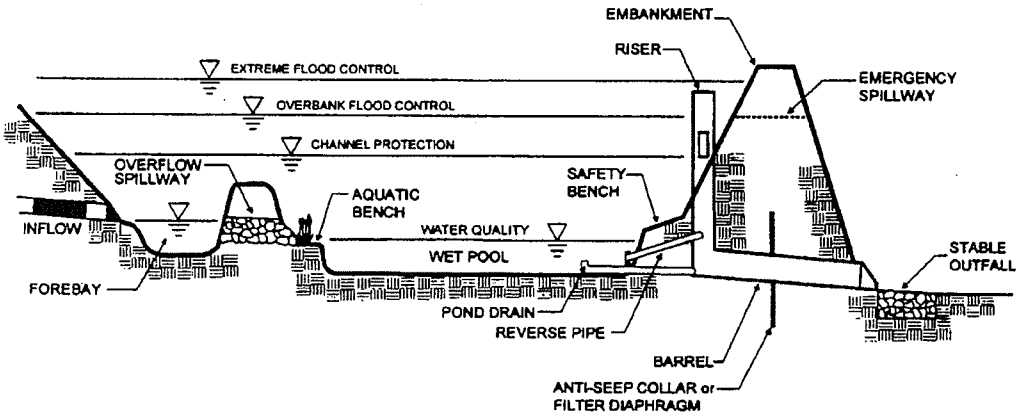


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Figure 6.3 Wet Extended Detention Pond (P-3)

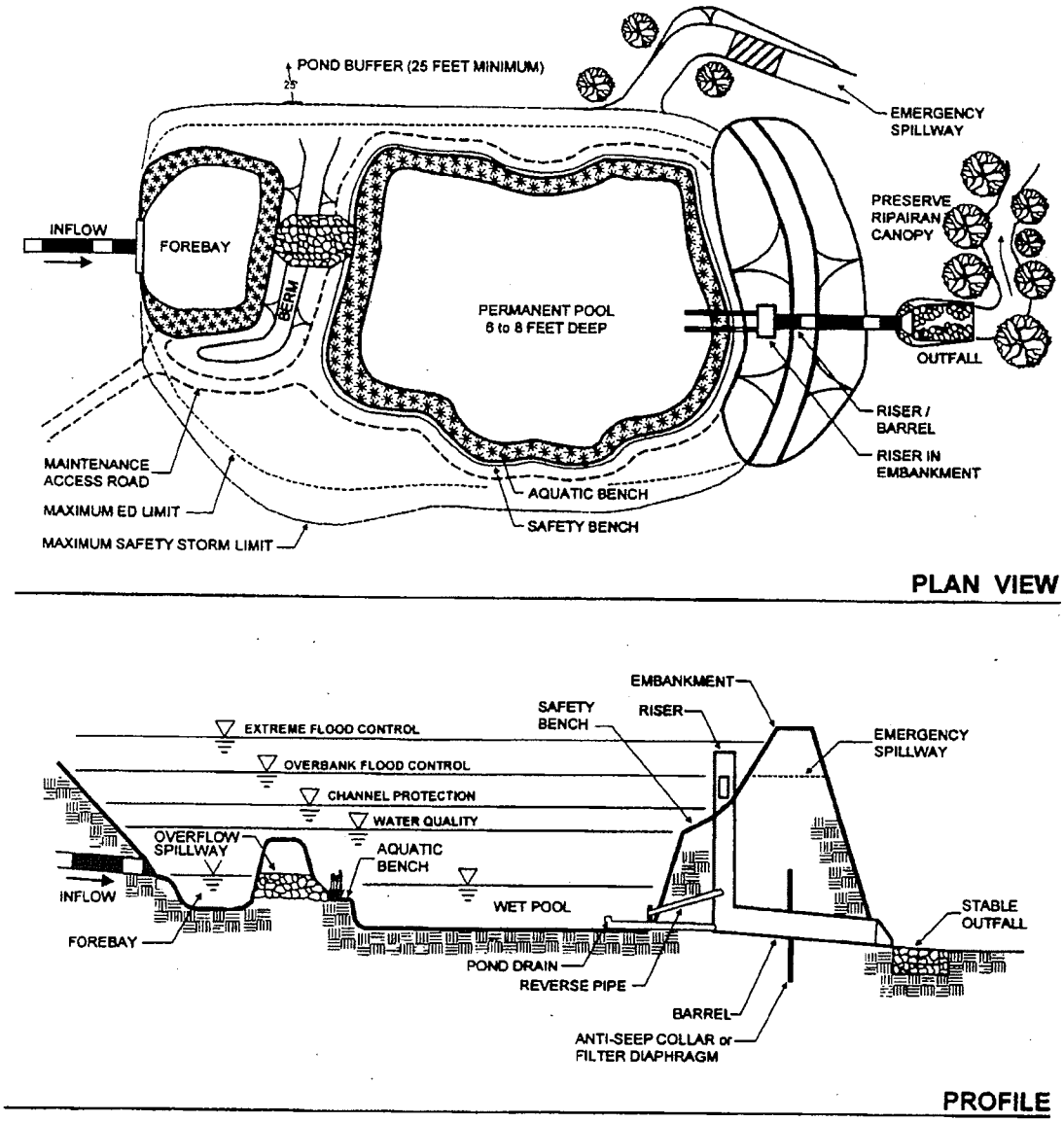

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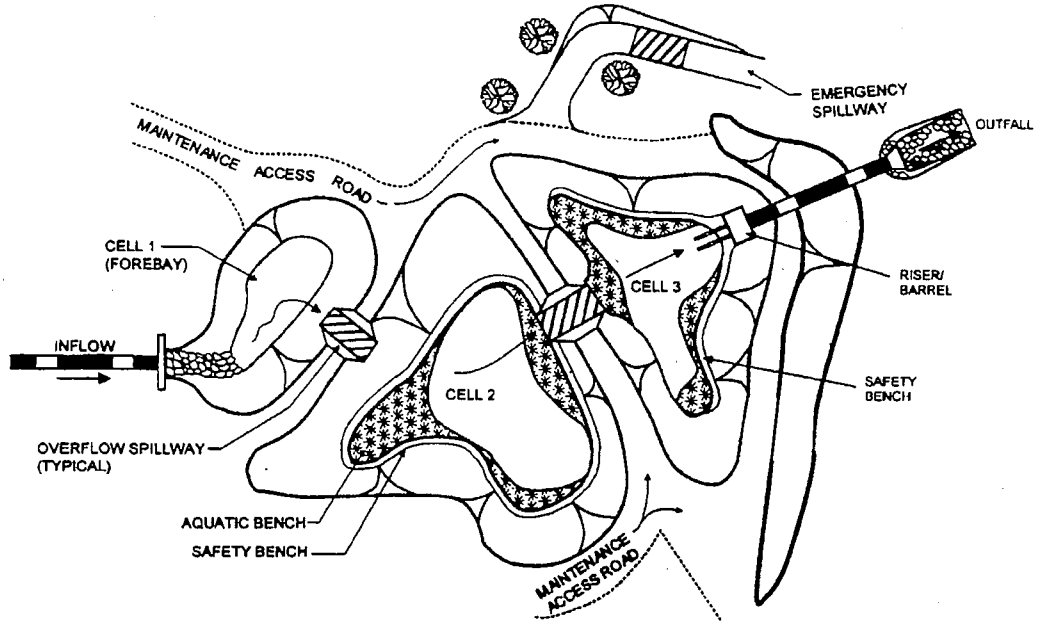
Figure 6.4 Multiple Pond System (P-4)



PLAN VIEW

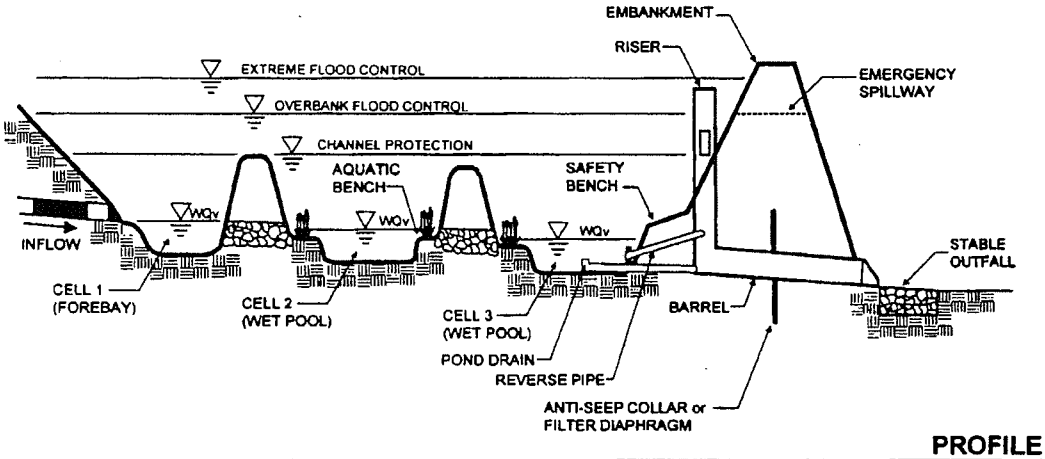


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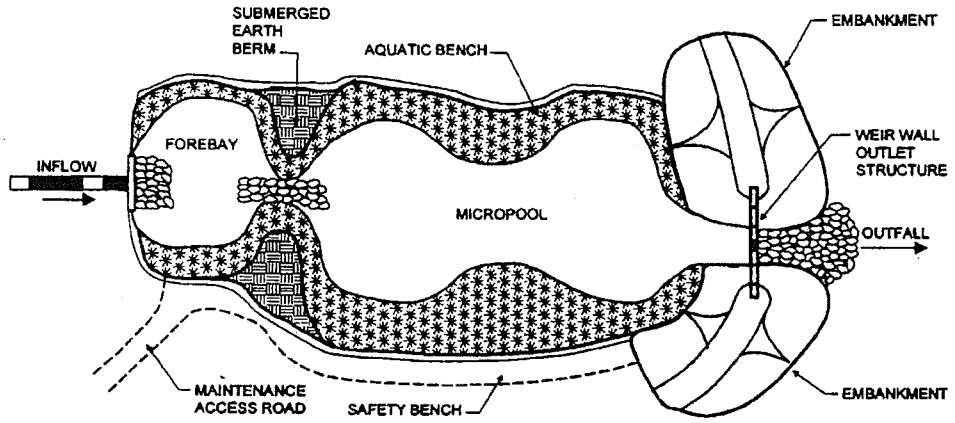
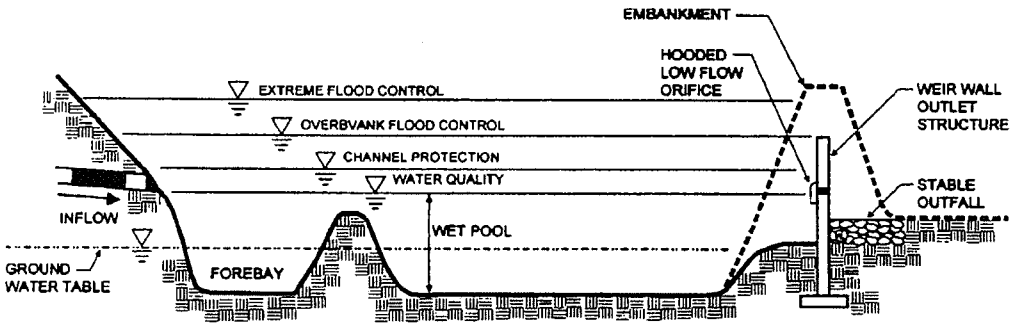
Figure 6.5 Pocket Pond (P-5)



PLAN VIEW



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6.1.1 Feasibility

Required Elements

- Designs P-2, P-3, and P-4 shall have a minimum contributing drainage area of 25 acres. A 10-acre drainage is required for design P-1.
- Stormwater ponds shall not be located within jurisdictional waters, including wetlands.
- Evaluate the site to determine the Hazard Class, and to determine what design elements are required to ensure dam safety (see *Guidelines for Design of Dams)*. For the most recent copy of this document, contact the New York State Department of Environmental Conservation, Dam Safety Division, at: 518-402-8151.
- Avoid direction of hotspot runoff to design P-5.
- Provide a 2' minimum separation between the pond bottom and groundwater in sole source aquifer recharge areas.

Design Guidance

- The use of stormwater ponds (with the exception of design P-1, Micropool Extended Detention Pond) on trout waters is strongly discouraged, as available evidence suggests that these practices can increase stream temperatures.
- Avoid location of pond designs within the stream channel, to prevent habitat degradation caused by these structures.
- A maximum drainage area of five acres is suggested for design P-5.

6.1.2 Conveyance

Inlet Protection

Required Elements

- A forebay shall be provided at each pond inflow point, unless an inflow point provides less than 10% of the total design storm flow to the pond.

Design Guidance

- Inlet areas should be stabilized to ensure that non-erosive conditions exist for at least the 2-year frequency storm event.

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- Except in cold regions of the State, the ideal inlet configuration is a partially submerged (i.e., ½ full) pipe.

Adequate Outfall Protection

Required Elements

- The channel immediately below a pond outfall shall be modified to prevent erosion and conform to natural dimensions in the shortest possible distance, typically by use of appropriately-sized riprap placed over filter cloth. Typical examples include submerged earthen berms, concrete weirs, and gabion baskets.
- A stilling basin or outlet protection shall be used to reduce flow velocities from the principal spillway to non-erosive velocities (3.5 to 5.0 fps). (See Appendix L for a table of erosive velocities for grass and soil).

Design Guidance

- Outfalls should be constructed such that they do not increase erosion or have undue influence on the downstream geomorphology of the stream.
- Flared pipe sections that discharge at or near the stream invert or into a step-pool arrangement should be used at the spillway outlet.
- If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of riprap should be avoided to reduce stream warming.

Pond Liners

Design Guidance

- When a pond is located in gravelly sands or fractured bedrock, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include: (a) six to 12 inches of clay soil (minimum 15% passing the #200 sieve and a minimum permeability of 1 x 10^{-5} cm/sec), (b) a 30 ml poly-liner (c) bentonite, (d) use of chemical additives (*see NRCS Agricultural Handbook No. 386*, dated 1961, or *Engineering Field Manual*) or (e) a design prepared by a Professional Engineer registered in the State of New York.

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6.1.3 Pretreatment

Required Elements

- A sediment forebay is important for maintenance and longevity of a stormwater treatment pond. Each pond shall have a sediment forebay or equivalent upstream pretreatment. The forebay shall consist of a separate cell, formed by an acceptable barrier. Typical examples include earthen berms, concrete weirs, and gabion baskets.
- The forebay shall be sized to contain 10% of the water quality volume (WQ_v), and shall be four to six feet deep. The forebay storage volume counts toward the total WQ_v requirement.
- The forebay shall be designed with non-erosive outlet conditions, given design exit velocities.
- Direct access for appropriate maintenance equipment shall be provided to the forebay.
- In sole source aquifers, 100% of the WQ_v for stormwater runoff from designated hotspots shall be provided in pretreatment.

Design Guidance

- A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time.
- The bottom of the forebay may be hardened to ease sediment removal

6.1.4 Treatment

Minimum Water Quality Volume (WQ_v)

Required Elements

- Provide water quality treatment storage to capture the computed WQ_v from the contributing drainage area through a combination of permanent pool, extended detention (WQ_v-ED) and marsh. The division of storage into permanent pool and extended detention is outlined in Table 6.1.

Table 6.1 Water Quality Volume Distribution in Pond Designs

Design Variation	%WQ_v	
	Permanent Pool	Extended Detention
P-1	20% min.	80% max.
P-2	100%	0%
P-3	50% min.	50% max.
P-4	50% min.	50% max.
P-5	50% min.	50% max.

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- Although both CP_v and WQ_v-ED storage can be provided in the same practice, WQ_v cannot be met by simply providing Cp_v storage for the one-year storm.

Design Guidance

- It is generally desirable to provide water quality treatment off-line when topography, hydraulic head and space permit (i.e., apart from stormwater quantity storage; see Appendix K for a schematic).
- Water quality storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and marsh).

Minimum Pond Geometry

Required Elements

- The minimum length to width ratio for the pond is 1.5:1 (i.e., length relative to width).
- Provide a minimum Surface Area:Drainage Area of 1:100.

Design Guidance

- To the greatest extent possible, maintain a long flow path through the system, and design ponds with irregular shapes.

6.1.5 Landscaping

Pond Benches

Required Elements

- The perimeter of all deep pool areas (four feet or greater in depth) shall be surrounded by two benches:
  - Except when pond side slopes are 4:1 (h:v) or flatter, provide a safety bench that generally extends 15 feet outward (10' to 12' allowable on sites with extreme space limitations) from the normal water edge to the toe of the pond side slope. The maximum slope of the safety bench shall be 6%; *and*

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- Incorporate an aquatic bench that generally extends up to 15 feet inward from the normal shoreline, has an irregular configuration, and a maximum depth of 18 inches below the normal pool water surface elevation.

Landscaping Plan

Required Elements

- A landscaping plan for a stormwater pond and its buffer shall be prepared to indicate how aquatic and terrestrial areas will be vegetatively stabilized and established.

Design Guidance

- Wherever possible, wetland plants should be encouraged in a pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes (ED wetlands) or within shallow areas of the pool itself.
- The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within six inches (plus or minus) of the normal pool.
- The soils of a pond buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration, and therefore, may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites, and backfill these with uncompacted topsoil.
  - As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the rootball (of balled and burlap stock), and five times deeper and wider for container grown stock. This practice should enable the stock to develop unconfined root systems. Avoid species that require full shade, are susceptible to winterkill, or are prone to wind damage. Extra mulching around the base of the tree or shrub is strongly recommended as a means of conserving moisture and suppressing weeds.

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Pond Buffers and Setbacks

Required Elements

- A pond buffer shall be provided that extends 25 feet outward from the maximum water surface elevation of the pond. The pond buffer shall be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers). An additional setback may be provided to permanent structures.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure.

Design Guidance

- Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To help discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers.
- Annual mowing of the pond buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.

6.1.6 Maintenance

Required Elements

- Maintenance responsibility for a pond and its buffer shall be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.
- The principal spillway shall be equipped with a removable trash rack, and generally accessible from dry land.
- Sediment removal in the forebay shall occur every five to six years or after 50% of total forebay capacity has been lost.

Design Guidance

- Sediments excavated from stormwater ponds that do not receive runoff from designated hotspots are generally not considered toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing may be required prior to sediment disposal when a hotspot land use is present (see Section 4.8 for a list of potential hotspots).

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- Sediment removed from stormwater ponds should be disposed of according to an approved comprehensive operation and maintenance plan.

Maintenance Access

Required Elements

- A maintenance right of way or easement shall extend to the pond from a public or private road.

Design Guidance

- Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access should extend to the forebay, safety bench, riser, and outlet and be designed to allow vehicles to turn around.

Non-clogging Low Flow Orifice

Required Elements

- A low flow orifice shall be provided, with the size for the orifice sufficient to ensure that no clogging shall occur. (See Appendix K for details of a low flow orifice and trash rack options).

Design Guidance

- The low flow orifice should be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 3") or by internal orifice protection that may allow for smaller diameters (recommended minimum orifice of 1").
- The preferred method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point one foot below the normal pool elevation.
- Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 12 inches below the normal pool.
- The use of horizontally extended perforated pipe protected by geotextile fabric and gravel is not recommended. Vertical pipes may be used as an alternative if a permanent pool is present.

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Riser in Embankment

Required Elements

- The riser shall be located within the embankment for maintenance access, safety and aesthetics.

Design Guidance

- Access to the riser should be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls. The principal spillway opening should be "fenced" with pipe or rebar at 8-inch intervals (for safety purposes).

Pond Drain

Required Elements

- Except where local slopes prohibit this design, each pond shall have a drain pipe that can completely or partially drain the pond. The drain pipe shall have an elbow or protected intake within the pond to prevent sediment deposition, and a diameter capable of draining the pond within 24 hours.

Design Guidance

- Care should be exercised during pond drawdowns to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The approving jurisdiction should be notified before draining a pond.

Adjustable Gate Valve

Required Elements

- Both the WQ_v-ED pipe and the pond drain shall be equipped with an adjustable gate valve (typically a handwheel activated knife gate valve).
- Valves shall be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner.

Design Guidance

- Both the WQ_v-ED pipe and the pond drain should be sized one pipe size greater than the calculated design diameter.

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- To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step or other fixed object.

Safety Features

Required Elements

- Side slopes to the pond shall not exceed 3:1 (h:v), and shall terminate at a safety bench.
- The principal spillway opening shall not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter shall be fenced to prevent a hazard.

Design Guidance

- Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool.
- Warning signs prohibiting swimming and skating may be posted.
- Pond fencing is generally not encouraged, but may be required by some municipalities. A preferred method is to manage the contours of the pond to eliminate dropoffs or other safety hazards.

6.1.7 Cold Climate Pond Design Considerations

Inlets, outlet structures and outfall protection for pond systems require modifications to function well in cold climates. Among the problems those wishing to use stormwater ponds in cold climates may encounter are:

- Higher runoff volumes and increased pollutant loads during the spring melt
- Pipe freezing and clogging
- Ice formation on the permanent pool
- Road sand build-up

Higher runoff volumes and increased pollutant loads during the spring melt

- Operate the pond based on seasonal inputs by adjusting dual water quality outlets to provide additional storage (see Figure 6.6).
- Adapt sizing based on snowmelt characteristics (see Appendix I).
- Do not drain ponds during the spring season. Due to temperature stratification and high chloride concentrations at the bottom, the water may become highly acidic and anoxic and may cause negative downstream effects.

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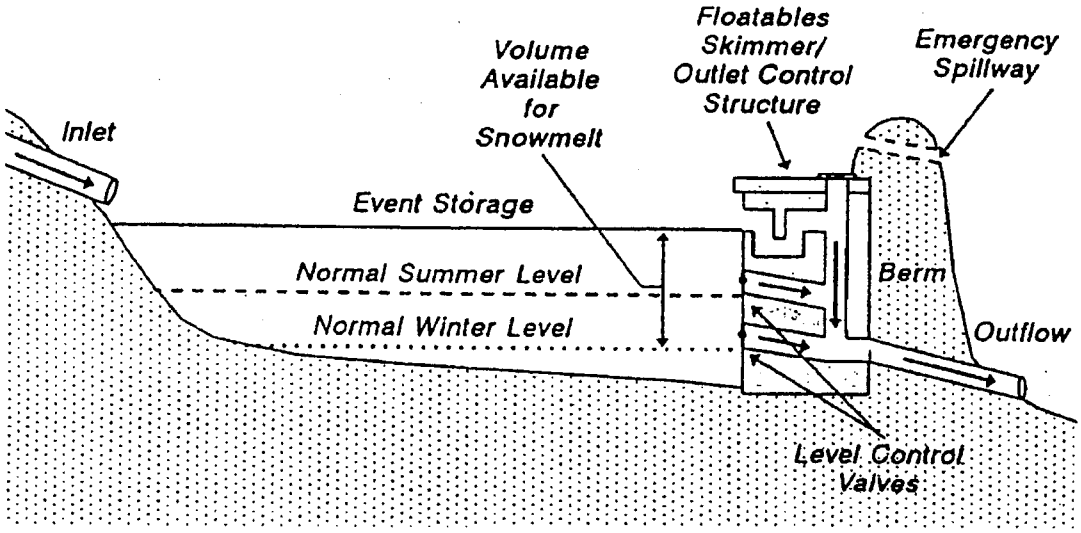
Pipe Freezing and Clogging

- Inlet pipes should not be submerged, since this can result in freezing and upstream damage or flooding.
- Bury all pipes below the frost line to prevent frost heave and pipe freezing. Bury pipes at the point furthest from the pond deeper than the frost line to minimize the length of pipe exposed.
- Increase the slope of inlet pipes to a minimum of 1% to prevent standing water in the pipe, reducing the potential for ice formation. This design may be difficult to achieve at sites with flat local slopes.
- If perforated riser pipes are used, the minimum orifice diameter should be ½". In addition, the pipe should have a minimum 6" diameter.
- When a standard weir is used, the minimum slot width should be 3", especially when the slot is tall.
- Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of baseflow through the system (see Appendix K).
- In cold climates, riser hoods and reverse slope pipes should draw from at least 6" below the typical ice layer. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet.
- Trash racks should be installed at a shallow angle to prevent ice formation (see Appendix K).

Figure 6.6 Seasonal Operation Pond



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Ice Formation on the Permanent Pool

- In cold climates, the treatment volume of a pond system should be adjusted to account for ice build-up on the permanent pool by providing one foot of elevation above the WQ_v. The total depth of the pond, including this additional elevation, should not exceed eight feet.
- Using pumps or bubbling systems can reduce ice build-up and prevent the formation of an anaerobic zone in pond bottoms.
- Provide some storage as extended detention. This recommendation is made for very cold climates to provide detention while the permanent pond is iced over. In effect, it discourages the use of wet ponds (P-2), replacing them with wet extended detention ponds (P-3).
- Multiple pond systems are recommended regardless of climate because they provide redundant treatment options. In cold climates, a berm or simple weir should be used instead of pipes to separate multiple ponds, due to their higher freezing potential.

Road Sand Build-up

- In areas where road sand is used, an inspection of the forebay and pond should be scheduled after the spring melt to determine if dredging is necessary. For forebays, dredging is needed if one half of the capacity of the forebay is full.

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Stormwater Ponds



Description:
Constructed stormwater retention basin that has a permanent pool (or micropool). Runoff from each rain event is detained and treated in the pool through settling and biological uptake mechanisms.

Design Options:
Micropool Extended Detention (P-1), Wet Pond (P-2), Wet Extended Detention (P-3), Multiple Pond (P-4), Pocket Pond (P-5)

KEY CONSIDERATIONS

FEASIBILITY
- Contributing drainage area greater than 10 acres for P-1, 25 acres for P-2 to P-4.
- Follow DEC Guidelines for Design of Dams.
- Provide a minimum 2' separation from the groundwater in sole source aquifers.
- Do not locate ponds in jurisdictional wetlands.
- Avoid directing hotspot runoff to design P-5.

CONVEYANCE
- Forebay at each inlet, unless the inlet contributes less than 10% of the total inflow, 4' to 6' deep.
- Stabilize the channel below the pond to prevent erosion.
- Stilling basin at the outlet to reduce velocities.

PREATREATMENT
- Forebay volume at least 10% of the WQ_v
- Forebay shall be designed with non-erosive outlet conditions.
- Provide direct access to the forebay for maintenance equipment
- In sole source aquifers, provide 100% pretreatment for hotspot runoff.

TREATMENT
- Provide the water quality volume in a combination of permanent pool and extended detention (Table 6.1 in manual provides limitations on storage breakdown)
- Minimum length to width ratio of 1.5:1
- Minimum surface area to drainage area ratio of 1:100

LANDSCAPING
- Provide a minimum 10' and preferably 15' safety bench extending from the high water mark, with a maximum slope of 6%.
- Provide an aquatic bench extending 15 feet outward from the shoreline, and a maximum depth of 18" below normal water elevation.
- Develop a landscaping plan.
- Provide a 25'pond buffer.
- No woody vegetation within 15 feet of the toe of the embankment, or 25 feet from the principal spillway.

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [X] **Channel Protection**
- [X] **Overbank Flood Protection**
- [X] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes*
(2 feet minimum separation distance required to water table)

FEASIBILITY CONSIDERATIONS

- [L] **Cost**
- [L] **Maintenance Burden**

Key: **L**=Low **M**=Moderate **H**=High

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *No*

Soils: *Hydrologic group 'A' soils may require pond liner*

Hydrologic group 'D' soils may have compaction constraints

Other Considerations:
- *Thermal effects*
- *Outlet clogging*
- *Safety bench*

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MAINTENANCE REQUIREMENTS

- Legally binding maintenance agreement
- Sediment removal from forebay every five to six years or when 50% full.
- Provide a maintenance easement and right-of-way.
- Removable trash rack on the principal spillway.
- Non-clogging low flow orifice
- Riser in the embankment.
- Pond drain required, capable of drawing down the pond in 24 hours.
- Notification required for pond drainage.
- Provide an adjustable gate valve on both the WQ_v-ED pipe, and the pond drain.
- Side Slopes less than 3:1, and terminate at a safety bench.
- Principal spillway shall not permit access by small children, and endwalls above pipes greater than 48" in diameter shall be fenced.

POLLUTANT REMOVAL

G	**Phosphorus**
G	**Nitrogen**
G	**Metals** - Cadmium, Copper, Lead, and Zinc removal
G	**Pathogens** Coliform, E.Coli, Streptococci removal

Key: **G**=Good **F**=Fair **P**=Poor

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Section 6.2 Stormwater Wetlands

Stormwater wetlands are practices that create shallow marsh areas to treat urban stormwater and often incorporate small permanent pools and/or extended detention storage to achieve the full WQv. Design variants include:

- W-1 Shallow Wetland (Figure 6.7)
- W-2 ED Shallow Wetland (Figure 6.8)
- W-3 Pond/Wetland System (Figure 6.9)
- W-4 Pocket Wetland (Figure 6.10)

Wetland designs W-1 through W-4 can be used to provide Channel Protection volume as well as Overbank and Extreme Flood attenuation. In these design variations, the permanent pool is stored in a depression excavated into the ground surface. Wetland plants are planted at the wetland bottom, particularly in the shallow regions.

IMPORTANT NOTES

ALL OF THE POND CRITERIA PRESENTED IN PERFORMANCE CRITERIA – PONDS (CHAPTER 6.1) ALSO APPLY TO THE DESIGN OF STORMWATER WETLANDS. ADDITIONAL CRITERIA THAT GOVERN THE GEOMETRY AND ESTABLISHMENT OF CREATED WETLANDS ARE PRESENTED IN THIS SECTION.

ANY PRACTICE THAT CREATES A DAM IS REQUIRED TO FOLLOW THE GUIDANCE PRESENTED IN THE *GUIDELINES FOR DESIGN OF DAMS* AND MAY REQUIRE A PERMIT FROM THE NYSDEC. FOR THE MOST RECENT COPY OF THIS DOCUMENT, CONTACT THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, DAM SAFETY DIVISION, AT: 518-402-8151. AN EVALUATION OF HAZARD CLASSIFICATION MUST BE INCLUDED IN THE DESIGN REPORT FOR STORMWATER WETLANDS CREATED BY A DAM.

WHILE THE STORMWATER WETLANDS DESIGNED ACCORDING TO THIS GUIDANCE MAY ACT AS A COMMUNITY AMMENITY, AND MAY PROVIDE SOME HABITAT VALUE, THEY CANNOT BE ANTICIPATED TO FUNCTION AS NATURAL WETLANDS

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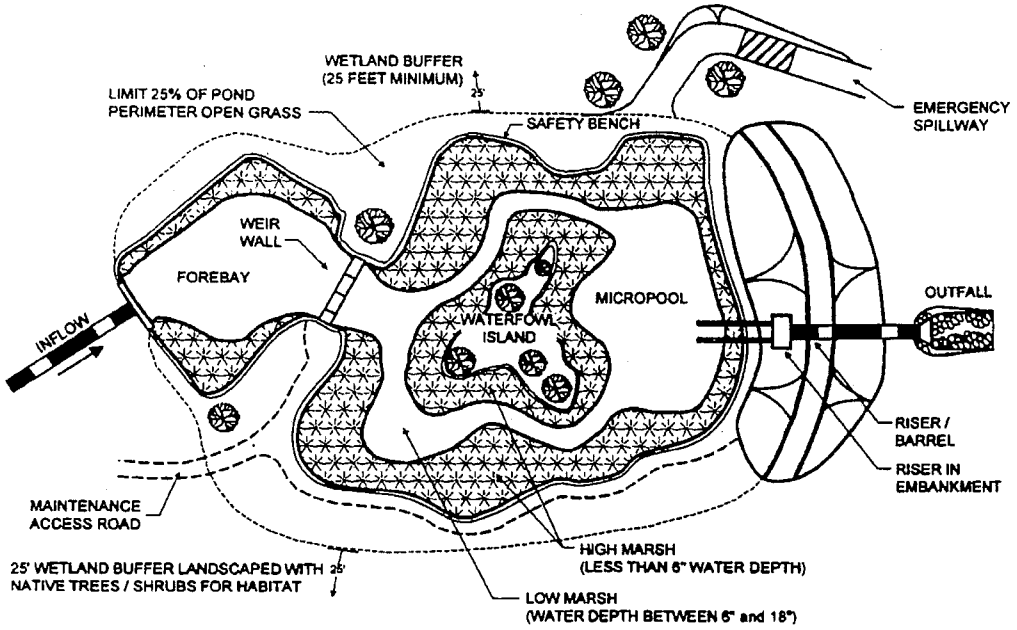
Figure 6.7 Shallow Wetland (W-1)



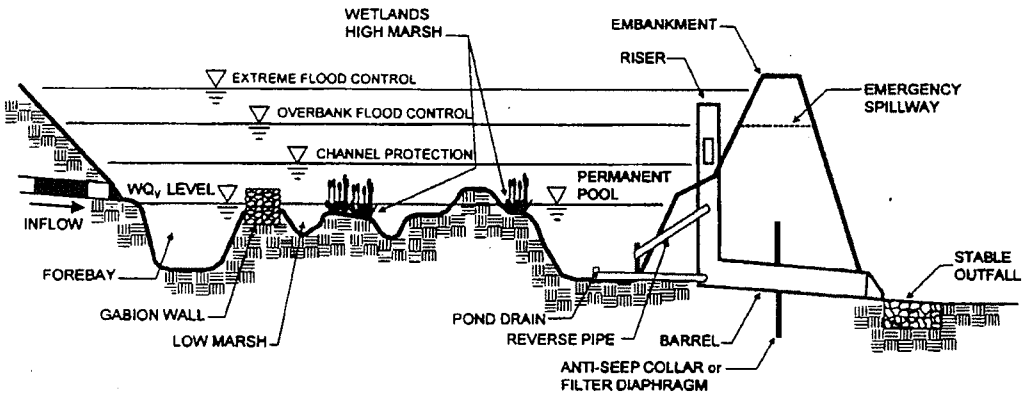


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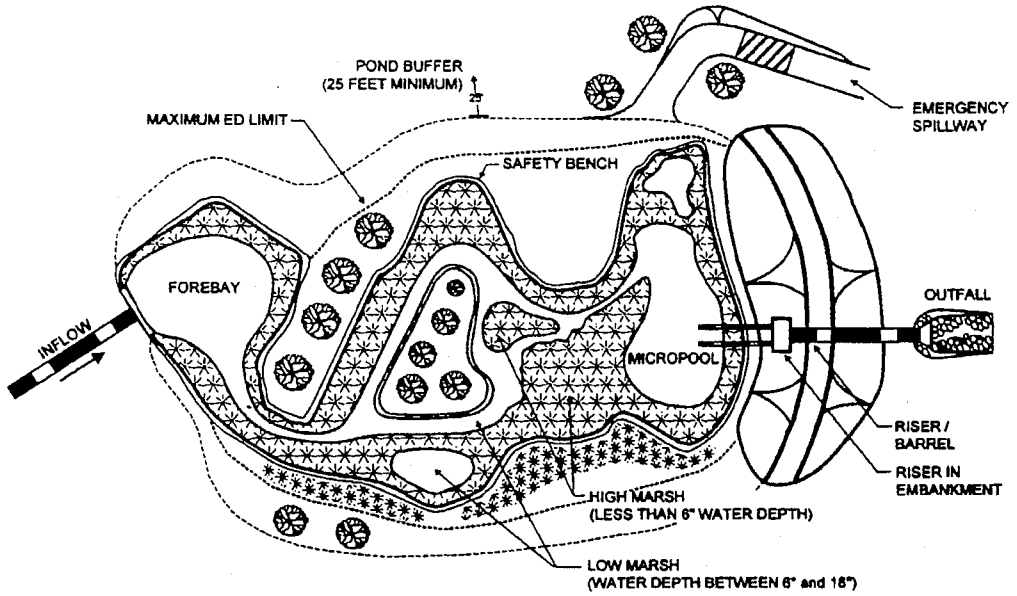
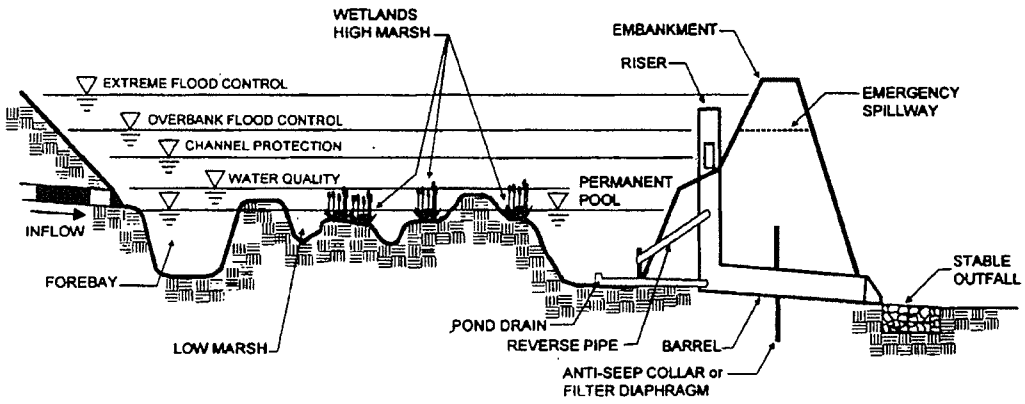
Figure 6.8 Extended Detention Shallow Wetland (W-2)



PLAN VIEW



PROFILE

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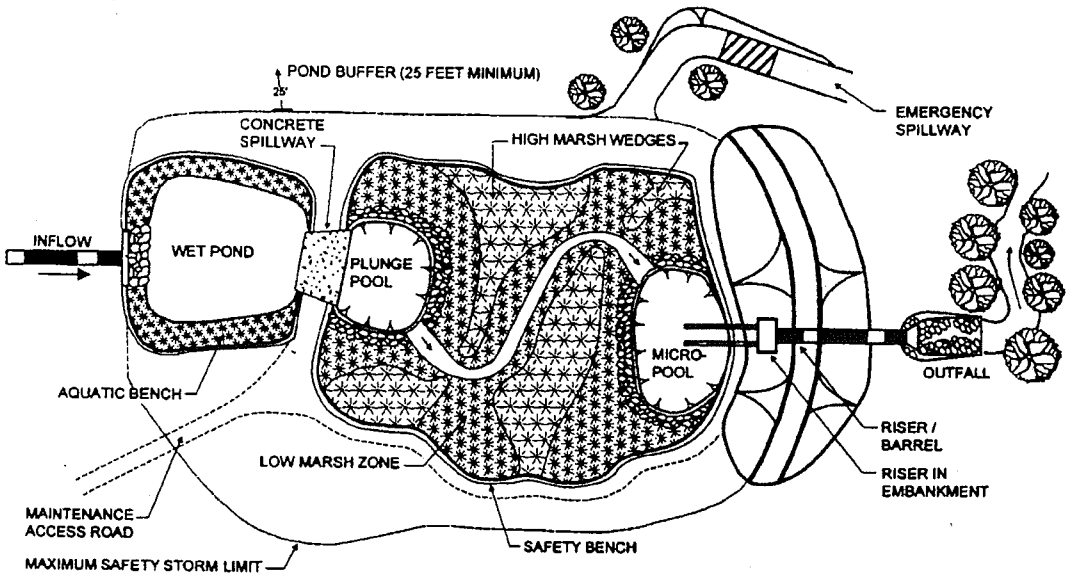
Figure 6.9 Pond/Wetland System (W-3)



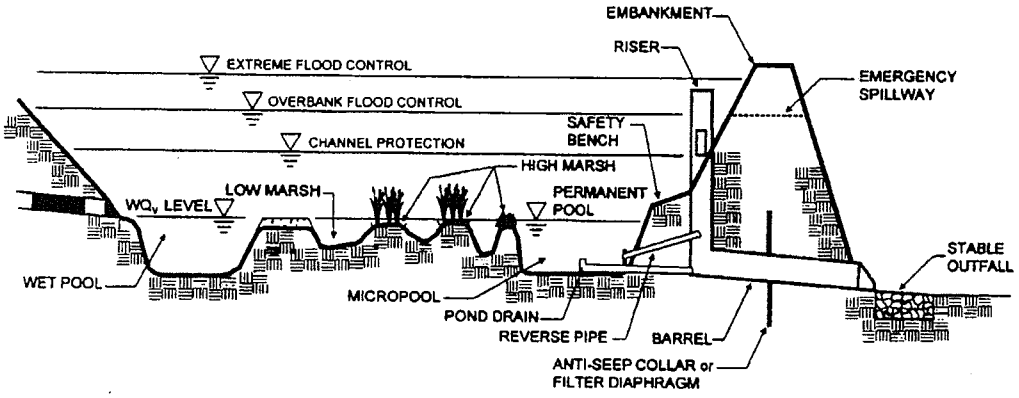


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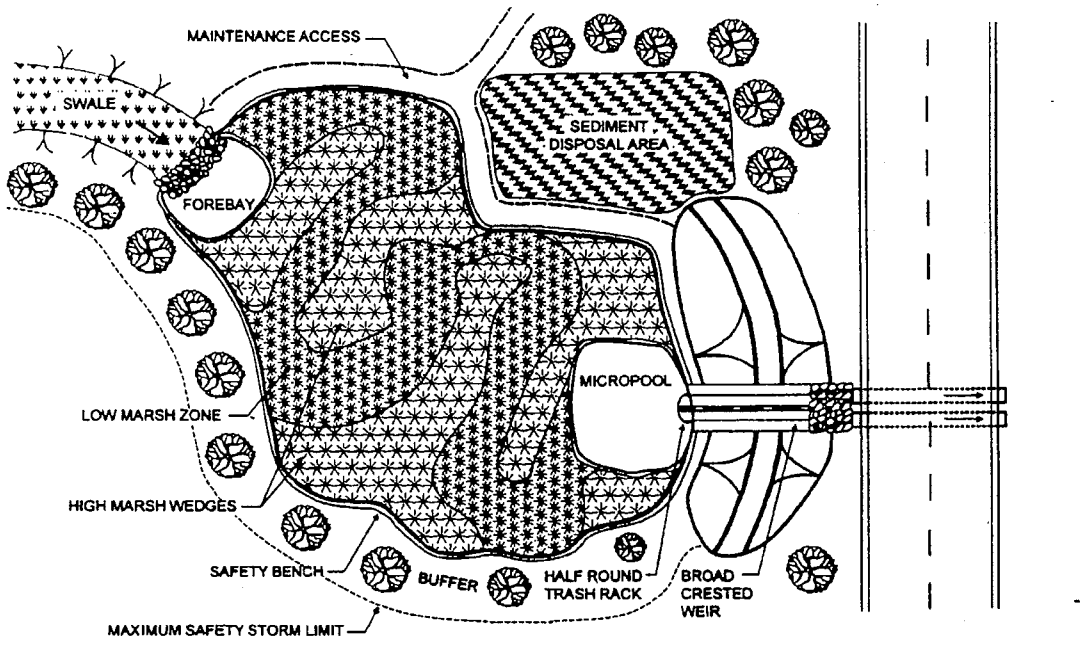
Figure 6.10 Pocket Wetland (W-4)



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6.2.1 *Feasibility*

Design Guidance

- *Stormwater wetlands should not be located within existing jurisdictional wetlands.* In some isolated cases, a permit may be granted to convert an existing degraded wetland in the context of local watershed restoration efforts.
- The use of stormwater wetlands on trout waters is strongly discouraged, as available evidence suggests that these practices can increase stream temperatures.

6.2.2 Conveyance

Required Elements

- Flowpaths from the inflow points to the outflow points of stormwater wetlands shall be maximized.
- A minimum flowpath of 2:1 (length to relative width) shall be provided across the stormwater wetland. This path may be achieved by constructing internal berms (e.g., high marsh wedges or rock filter cells).

Design Guidance

- Microtopography is encouraged to enhance wetland diversity.

6.2.3 Pretreatment

Required Elements

- A forebay shall be located at the inlet, and a four to six foot deep micropool that stores approximately 10% of the WQ_v shall be located at the outlet to protect the low flow pipe from clogging and prevent sediment resuspension.

6.2.4 Treatment

Required Elements

- The surface area of the entire stormwater wetland shall be at least one percent of the contributing drainage area (1.5% for shallow marsh design).
- At least 25% of the WQ_v shall be in deepwater zones with a depth greater than four feet.

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- A minimum of 35% of the total surface of area can have a depth of six inches or less, and at least 65% of the total surface area shall be shallower than 18 inches.
- If extended detention is used in a stormwater wetland, provide a minimum of 50% of the WQ_v in permanent pool; the maximum water surface elevation of WQ_v-ED shall not extend more than three feet above the permanent pool.

Design Guidance

- The bed of stormwater wetlands should be graded to create maximum internal flow path and microtopography.
- To promote greater nitrogen removal, rock beds may be used a medium for growth of wetland plants. The rock should be one to three inches in diameter, placed up to the normal pool elevation, and open to flow-through from either direction.

6.2.5 Landscaping

Required Elements

- A landscaping plan shall be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of pondscaping zones, selection of corresponding plant species, planting plan, sequence for preparing wetland bed (including soil amendments, if needed) and sources of plant material.
- A wetland plant buffer must extend 25 feet outward from the maximum water surface elevation, with an additional 15-foot setback to structures.
- Donor soils for wetland mulch shall not be removed from natural wetlands.

Design Guidance

- Structures such as fascines, coconut rolls, straw bales, or carefully designed stone weirs can be used to create shallow marsh cells in high-energy areas of the stormwater wetland.
- The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers.
- Follow wetland establishment guidelines (see Appendix H).

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6.2.6 Maintenance

Required Elements

- If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, a reinforcement planting is required.

Design Guidance

- Stormwater wetlands that are separated from jurisdictional wetlands and regularly maintained are not typically regulated under State and Federal laws.

6.2.7 Cold Climate Design Considerations

Many of the cold climate concerns for wetlands are very similar to the ones for ponds. Two additional concerns with regards to stormwater wetlands focus on cold climate impacts to wetland plants:

- Short Growing Season
- Chlorides

Short Growing Season

- Planting schedule should reflect the short growing season, perhaps incorporating relatively mature plants, or planting rhizomes during the winter.

Chlorides

- Use in combination with a grassed infiltration area prior to the wetland to provide some infiltration of chlorides to dampen the shock to wetland plants
- Emphasize the pond/wetland design option to dilute chlorides prior to the wetland area. If this option is used, the pond should use the modifications described in Section 6.1.7. The pond system dilutes chlorides before they enter the marsh, protecting wetland plants.
- Consider salt-tolerant plants if wetland treats runoff from roads or parking lots where salt is used as a deicer.

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Stormwater Wetlands



Description: Stormwater wetlands (a.k.a. constructed wetlands) are structural practices that incorporate wetland plants into the design to both store and treat runoff. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake within the practice

Design Options:
Shallow wetland (W-1), Extended Detention Wetland (W-2), Pond/Wetland (W-3), Pocket Wetland (W-4)

KEY CONSIDERATIONS

MUST MEET ALL OF THE REQUIREMENTS OF STORMWATER PONDS.

CONVEYANCE

- Minimum flowpath of 2:1 (length to width)
- Flowpath maximized

PREATREATMENT

- Micropool at outlet, capturing 10% of the WQ_v

TREATMENT

- Minimum drainage area to surface ratio of 1:100
- ED no greater than 50% of entire WQ_v (permanent pool at least 50% of the volume)25% of the WQ_v in deepwater zones.
- 35% of the total surface area in depths six inches or less, and 65% shallower than 18"

LANDSCAPING

- Landscaping plan that indicates methods to establish and maintain wetland coverage. Minimum elements include: delineation of pondscaping zones, selection of species, planting plan, and sequence for bed preparation.
- Wetland buffer 25 feet from maximum surface elevation, with 15 foot additional setback for structures.
- Donor plant material must not be from natural wetlands

MAINTENANCE REQUIREMENTS

- Reinforcement plantings after second season if 50% coverage not achieved

POLLUTANT REMOVAL

G	**Phosphorus**
G	**Nitrogen**
F	**Metals** - Cadmium, Copper, Lead, and Zinc removal
G	**Pathogens** - Coliform, Streptococci, E.Coli removal

Key: G=Good F=Fair P=Poor

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [X] **Channel Protection**
- [X] **Overbank Flood Protection**
- [X] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes*
(2 feet minimum separation distance required to water table)

IMPLEMENTATION CONSIDERATIONS

Capital Cost: M

Maintenance Burden:

M	Shallow Wetland
M	ED Shallow Wetland
H	Pocket Wetland
M	Pond/Wetland

Residential Subdivision Use: Yes
High-Density/Ultra-Urban: *No*

Soils: *Hydrologic group 'A' and 'B' soils may require liner*

Key : L=Low M=Moderate H=High

R0080303

Section 6.3 Stormwater Infiltration

Stormwater infiltration practices capture and temporarily store the WQ_v before allowing it to infiltrate into the soil over a two-day period. Design variants include the following:

- I-1 Infiltration Trench (Figure 6.11)
- I-2 Infiltration Basin (Figure 6.12)
- I-3 Dry Well (Figure 6.13)

Treatment Suitability: Infiltration practices alone typically cannot meet detention (Q_p) and channel protection (Cp_v) requirements, except on sites where the soil infiltration rate is greater than 5.0 in/hr. However, extended detention storage may be provided above an infiltration basin. Extraordinary care should be taken to assure that long-term infiltration rates are achieved through the use of performance bonds, post construction inspection and long-term maintenance.

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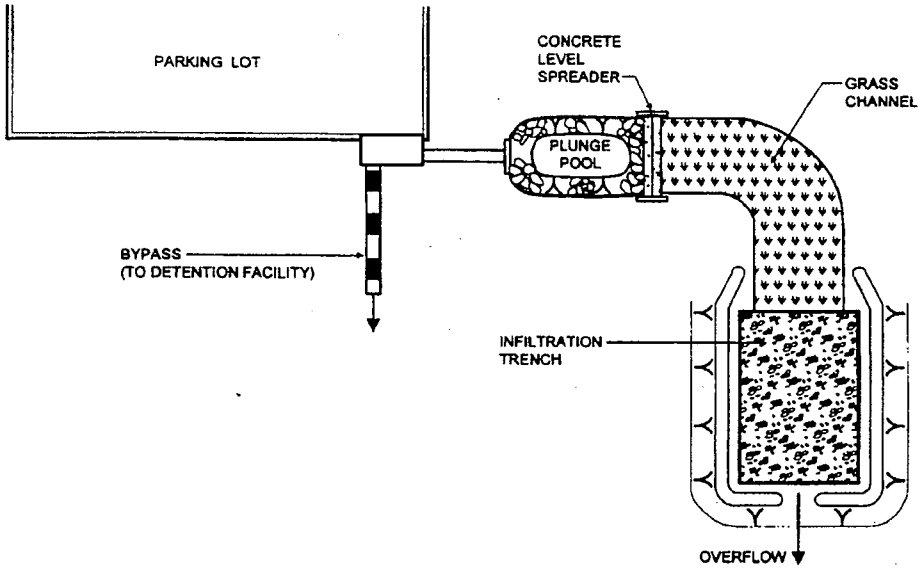
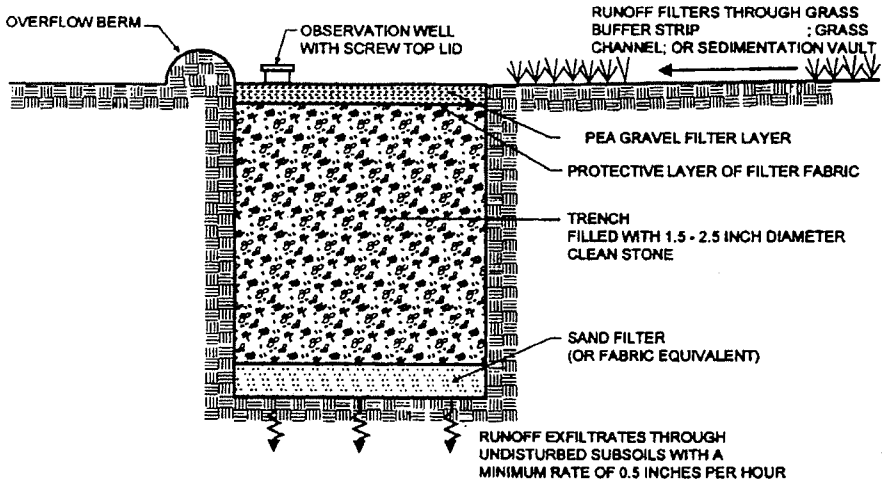
Figure 6.11 Infiltration Trench (I-1)



PLAN VIEW



SECTION

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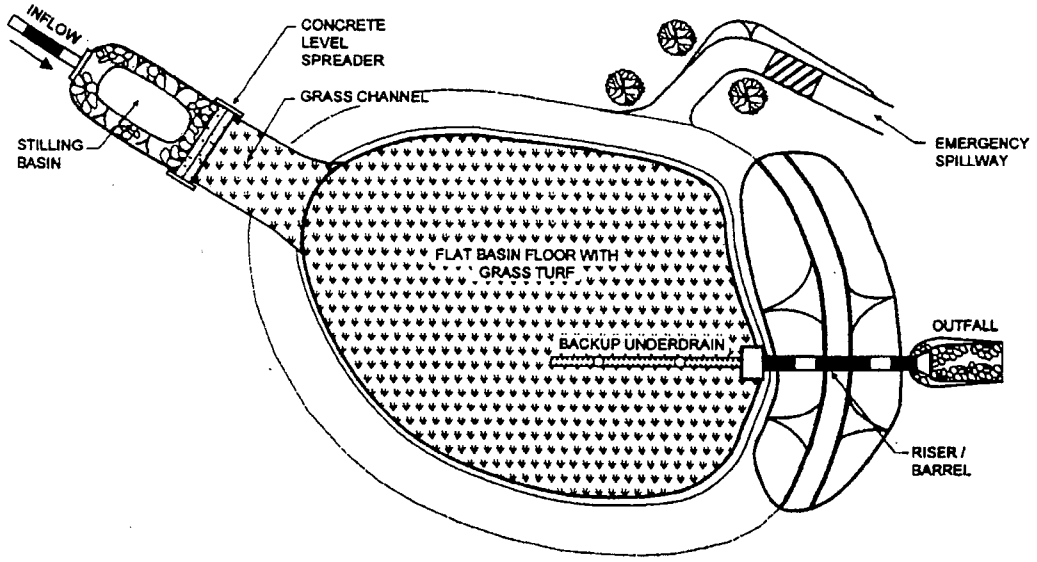
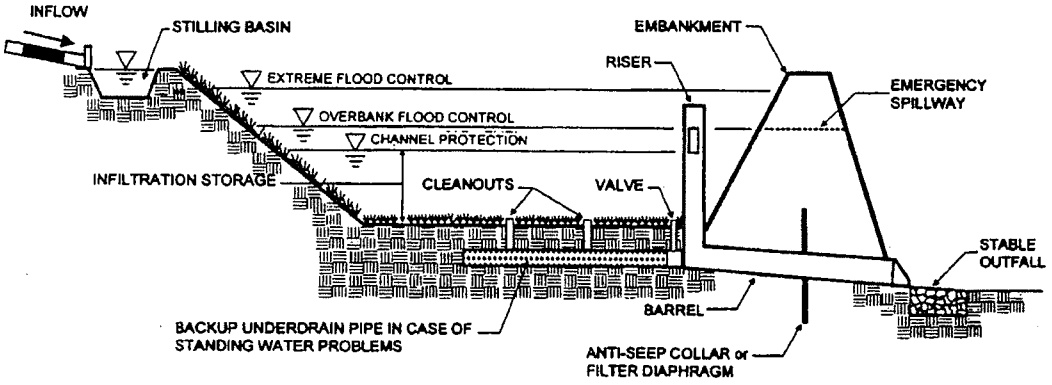
Figure 6.12 Infiltration Basin (I-2)



PLAN VIEW



PROFILE

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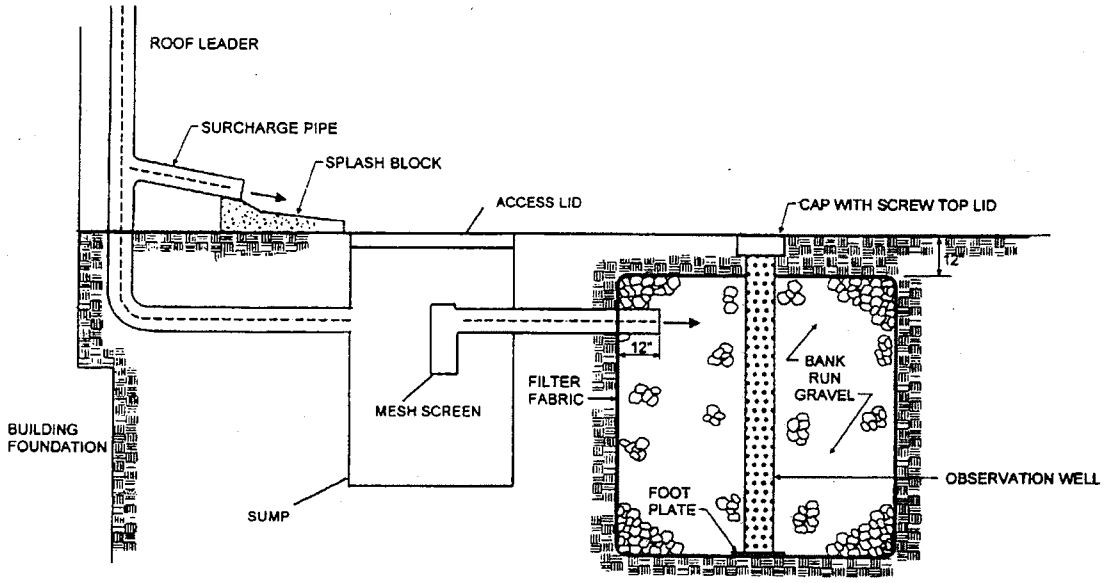
Figure 6.13 Dry Well (I-3)



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6.3.1 Feasibility

Required Elements

- To be suitable for infiltration, underlying soils shall have an infiltration rate (fc) of at least 0.5 inches per hour, as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests (see Appendix D). The minimum geotechnical testing is one test hole per 5000 sf, with a minimum of two borings per facility (taken within the proposed limits of the facility).
- Soils shall also have a clay content of less than 20% and a silt/clay content of less than 40%.
- Infiltration practices cannot be located on areas with natural slopes greater than 15%.
- Infiltration practices cannot be located in fill soils, except the top quarter of an infiltration trench or dry well.
- To protect groundwater from possible contamination, runoff from designated hotspot land uses or activities must not be directed to a formal infiltration facility. In cases where this goal is impossible (e.g., where the storm drain system leads to a large recharge facility designed for flood control), redundant pretreatment must be provided by applying two of the practices listed in Table 5.1 in series, both of which are sized to treat the entire WQ_v.
- The bottom of the infiltration facility shall be separated by at least three feet vertically from the seasonally high water table or bedrock layer, as documented by on-site soil testing. (Four feet in sole source aquifers).
- Infiltration facilities shall be located at least 100 feet horizontally from any water supply well.
- Infiltration practices cannot be placed in locations that cause water problems to downgradient properties. Infiltration trenches and basins shall be setback 25 feet downgradient from structures and septic systems. Dry wells shall be separated a minimum of 10 feet from structures.

Design Guidance

- The maximum contributing area to infiltration basins or trenches should generally be less than five acres. The infiltration basin can theoretically receive runoff from larger areas, provided that the soil is highly permeable (i.e., greater than 5.0 inches per hour). (See Appendix L for erosive velocities of grass and soil).
- The maximum drainage area to dry wells should generally be smaller than one acre, and should include rooftop runoff only.

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6.3.2 Conveyance

Required Elements

- The overland flow path of surface runoff exceeding the capacity of the infiltration system shall be evaluated to preclude erosive concentrated flow during the overbank events. If computed flow velocities exceed erosive velocities (3.5 to 5.0 fps), an overflow channel shall be provided to a stabilized watercourse. (See Appendix L for erosive velocities of grass and soil).
- All infiltration systems shall be designed to fully de-water the entire WQ_v within 48 hours after the storm event.
- If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice must be designed as an off-line practice (see Appendix K for a detail), except when used as a regional flood control practice.

Design Guidance

- For infiltration basins and trenches, adequate stormwater outfalls should be provided for the overflow associated with the 10-year design storm event (non-erosive velocities on the down-slope
- For dry wells, all flows that exceed the capacity of the dry well should be passed through the surcharge pipe.

6.3.3 Pretreatment

Required Elements

- A minimum pretreatment volume of 25% of the WQ_v must be provided prior to entry to an infiltration facility, and can be provided in the form of a sedimentation basin, sump pit, grass channel, plunge pool or other measure.
- If the f_c for the underlying soils is greater than 2.00 inches per hour, a minimum pretreatment volume of 50% of the WQ_v must be provided.
- If the f_c for the underlying soils is greater than 5.00 inches per hour, 100% of the WQ_v shall be pre-treated prior to entry into an infiltration facility.
- Exit velocities from pretreatment chambers shall be non-erosive (3.5 to 5.0 fps) during the two-year design storm). (See Appendix L for erosive velocities of grass and soil).

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Pretreatment Techniques to Prevent Clogging

Infiltration basins or trenches can have redundant methods to ensure the long-term integrity of the infiltration rate. The following techniques are pretreatment options for infiltration practices:

- Grass channel (Maximum velocity of 1 fps for water quality flow. See the Fact Sheet on page 5-10 for more detailed design information.)
- Grass filter strip (minimum 20 feet and only if sheet flow is established and maintained)
- Bottom sand layer (for I-1)
- Upper sand layer (for I-1; 6" minimum with filter fabric at sand/gravel interface)
- Use of washed bank run gravel as aggregate
- Alternatively, a pre-treatment settling chamber may be provided and sized to capture the pretreatment volume. Use the method prescribed in section 6.4.3 (i.e., the Camp-Hazen equation) to size the chamber.
- Plunge Pool
- An underground trap with a permanent pool between the downspout and the dry well (I-3)

Design Guidance

- The sides of infiltration trenches and dry wells should be lined with an acceptable filter fabric that prevents soil piping.
- In infiltration trench designs, incorporate a fine gravel or sand layer above the coarse gravel treatment reservoir to serve as a filter layer.

6.3.4 Treatment

Required Elements

- Infiltration practices shall be designed to exfiltrate the entire WQ_v through the floor of each practice (sides are not considered in sizing).
- The construction sequence and specifications for each infiltration practice shall be precisely followed. Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction
- Calculate the surface area of infiltration trenches as:

$$A_p = V_w / (nd_t)$$

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Where:

A_p = surface area (sf)
V_W = design volume (e.g., WQ_V) (ft^3)
n = porosity (assume 0.4)
d_t = trench depth (maximum of four feet, and separated at least three feet from seasonally high groundwater) (ft)

- Calculate the approximate bottom area of infiltration basins using the following equation:

$$A = V_w/d_b$$

Where:

A = surface area of the basin (ft^2)
d_b = depth of the basin (ft)

Note that in trapezoidal basins, this area should first be used to approximate the area at the bottom of the basin, but can later be modified to account for additional storage provided above side slopes.

Design Guidance

- Infiltration practices are best used in conjunction with other practices, and downstream detention is often needed to meet the Cp_v and Q_p sizing criteria.
- A porosity value (V_v/V_t) of 0.4 can be used to design stone reservoirs for infiltration practices.

The bottom of the stone reservoir should be completely flat so that infiltrated runoff will be able to infiltrate through the entire surface.

6.3.5 Landscaping

Required Elements

- Upstream construction shall be completed and stabilized before connection to a downstream infiltration facility. A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility.
- Infiltration trenches shall not be constructed until all of the contributing drainage area has been completely stabilized.

Design Guidance

- Mow upland and adjacent areas, and seed bare areas.

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6.3.6 Maintenance

Required Elements

- Infiltration practices shall never serve as a sediment control device during site construction phase. In addition, the Erosion and Sediment Control plan for the site shall clearly indicate how sediment will be prevented from entering an infiltration facility. Normally, the use of diversion berms around the perimeter of the infiltration practice, along with immediate vegetative stabilization and/or mulching can achieve this goal.
- An observation well shall be installed in every infiltration trench and dry well, consisting of an anchored six- inch diameter perforated PVC pipe with a lockable cap installed flush with the ground surface.
- Direct access shall be provided to infiltration practices for maintenance and rehabilitation. If a stone reservoir or perforated pipe is used to temporarily store runoff prior to infiltration, the practice shall not be covered by an impermeable surface.

Design Guidance

- OSHA trench safety standards should be consulted if the infiltration trench will be excavated more than five feet.
- Infiltration designs should include dewatering methods in the event of failure. Dewatering can be accomplished with underdrain pipe systems that accommodate drawdown.

6.3.7 Cold Climate Design Considerations

Because of additional challenges in cold climates, infiltration SMPs need design modifications to function properly. These modifications address the following problems:

- Reduced infiltration into frozen soils
- Chlorides

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Reduced Infiltration

- Draining the ground beneath an infiltration system with an underdrain can increase cold weather soil infiltration.
- Another alternative is to divide the treatment volume between an infiltration SMP and another SMP to provide some treatment during the winter months.
- A seasonally operated infiltration/detention facility combines several techniques to improve the performance of infiltration SMPs in cold climates. Two features, the underdrain system and level control valves, are useful in cold climates. The level control and valves are opened at the beginning of the winter season and the soil is allowed to drain. As the snow begins to melt in the spring, the valves are closed, and the snowmelt is infiltrated until the capacity of the soil is reached. After this point, the facility acts as a detention facility, providing storage for particles to settle (Figure 6.14)

Chlorides

- Consider diverting snowmelt runoff past infiltration devices, especially in regions where chloride concentration in groundwater is a concern.
- Incorporate mulch into infiltration basin soil to mitigate problems with soil fertility.
- The selection of upland landscaping materials should include salt-tolerant grasses where appropriate.

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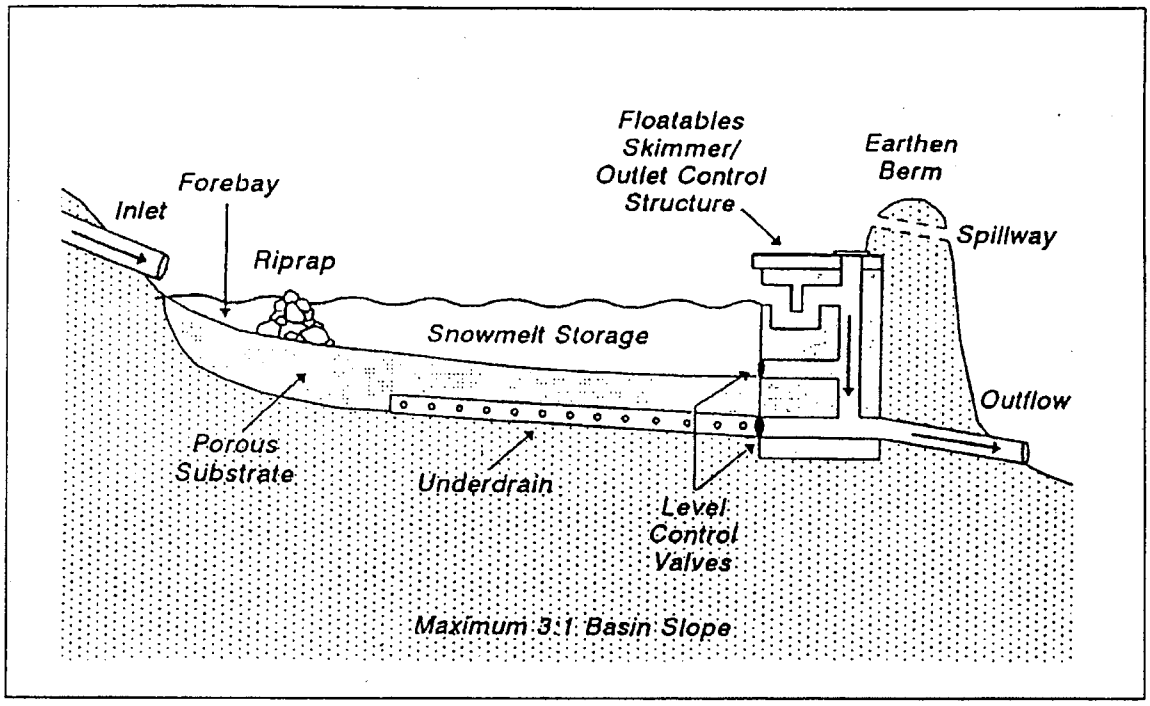
Figure 6.14 Seasonal Operation Infiltration Facility



R0080314

Infiltration Practices



Description: Excavated trench or basin used to capture and allow infiltration of stormwater runoff into the surrounding soils from the bottom and sides of the basin or trench.

Design Options:
Infiltration Trench (I-1), Shallow Infiltration Basin (I-2), Dry Well (I-3)

KEY CONSIDERATIONS

FEASIBILITY

- Minimum soil infiltration rate of 0.5 inches per hour
- Soils less than 20% clay, and 40% silt/clay, and no fill soils.
- Natural slope less than 15%
- Cannot accept hotpot runoff, except under the conditions outlined in Section 6.3.1.
- Separation from groundwater table of at least three feet (four feet in sole source aquifers).
- 25' separation from structures for I-1 and I-2; 10' for I-3.

CONVEYANCE

- Flows exiting the practice must be non-erosive (3.5 to 5.0 fps)
- Maximum dewatering time of 48 hours.
- Design off-line if stormwater is conveyed to the practice by a storm drain pipe.

PRETREATMENT

- Pretreatment of 25% of the WQv at all sites.
- 50% pretreatment if fc >2.0 inches/hour.
- 100% pretreatment in areas with fc >5.0 inches/hour.
- Exit velocities from pretreatment must be non-erosive for the 2-year storm.

TREATMENT

- Water quality volume designed to exfiltrate through the floor of the practice.
- Construction sequence to maximize practice life.
- Trench depth shall be less than four feet (I-2 and I-3).
- Follow the methodologies in Chapter 6 to size practices.

LANDSCAPING

- Upstream area shall be completely stabilized before flow is directed to the practice.

MAINTENANCE REQUIREMENTS

- Never serves as a sediment control device
- Observation well shall be installed in every trench, (6" PVC pipe, with a lockable cap)
- Provide direct maintenance access.

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [ ] **Channel Protection**
- [ ] **Overbank Flood Protection**
- [ ] **Extreme Flood Protection**

Accepts Hotspot Runoff: *No*

IMPLEMENTATION CONSIDERATIONS

- [H] **Capital Cost**
- [H] **Maintenance Burden**

Residential Subdivision Use: Yes

High Density/Ultra-Urban: *Yes*

Drainage Area: *10 acres max.*

Soils: *Pervious soils required (0.5 in/hr or greater)*

Other Considerations:

- *Must not be placed under pavement or concrete*

Key: **L**=Low **M**=Moderate **H**=High

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POLLUTANT REMOVAL	
G **Phosphorus**	
G **Nitrogen**	
G **Metals** - Cadmium, Copper, Lead, and Zinc removal	
G **Pathogens** - Coliform, Streptococci, E.Coli removal	
Key: G=Good F=Fair P=Poor	

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Section 6.4 Stormwater Filtering Systems

Stormwater filtering systems capture and temporarily store the WQ_v and pass it through a filter bed of sand, organic matter, or soil. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially exfiltrate into the soil. Design variants include:

F-1	Surface Sand Filter	(Figure 6.15)
F-2	Underground Sand Filter	(Figure 6.16)
F-3	Perimeter Sand Filter	(Figure 6.17)
F-4	Organic Filter	(Figure 6.18)
F-5	Bioretention	(Figure 6.19)

Treatment Suitability: Filtering systems should not be designed to provide stormwater detention (Q_p) or channel protection (Cp_v) except under extremely unusual conditions. Filtering practices shall generally be combined with a separate facility to provide those controls.

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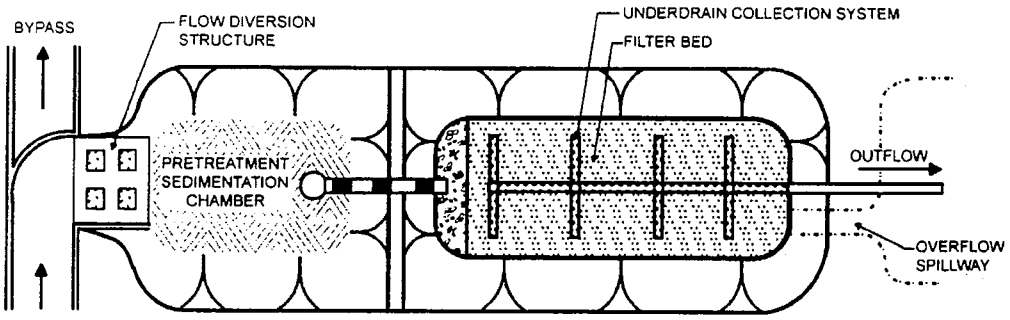
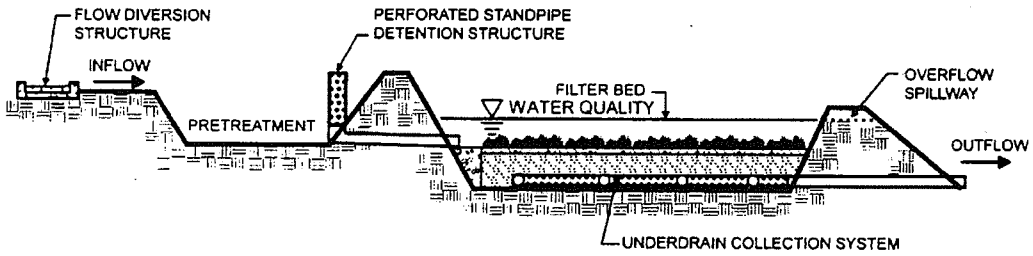
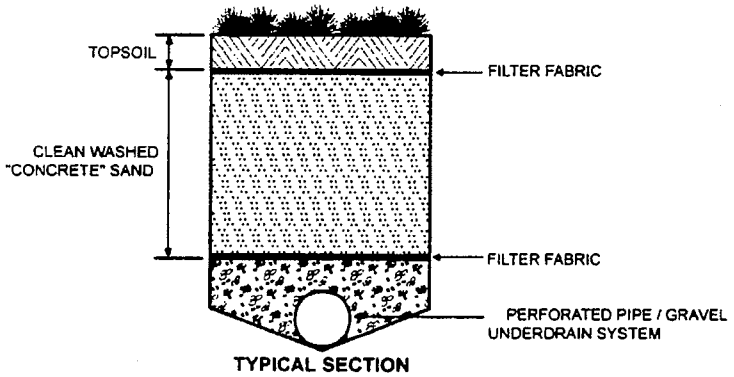
Figure 6.15 Surface Sand Filter (F-1)



PLAN VIEW



PROFILE



TYPICAL SECTION

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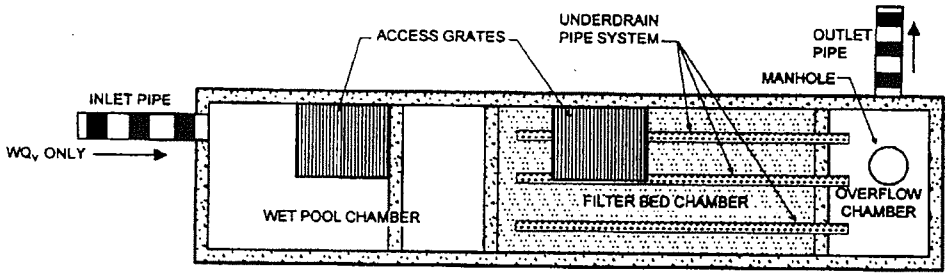
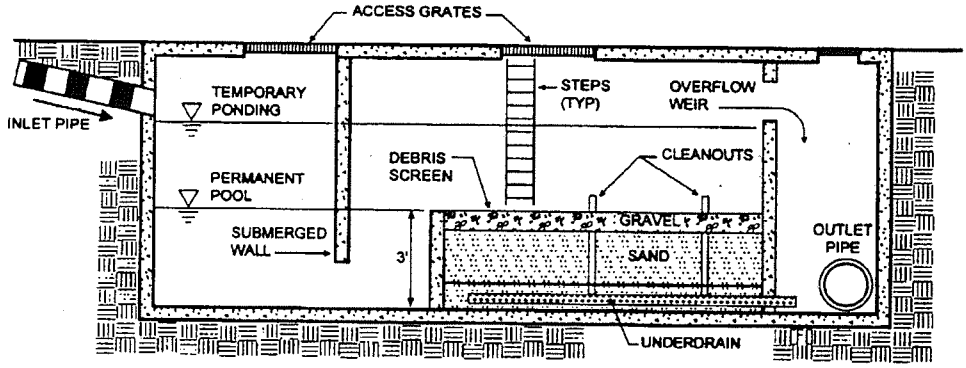
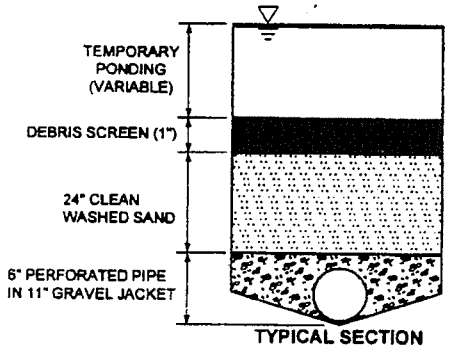
Figure 6.16 Underground Sand Filter (F-2)



PLAN VIEW



PROFILE



TYPICAL SECTION

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Figure 6.17 Perimeter Sand Filter (F-3)

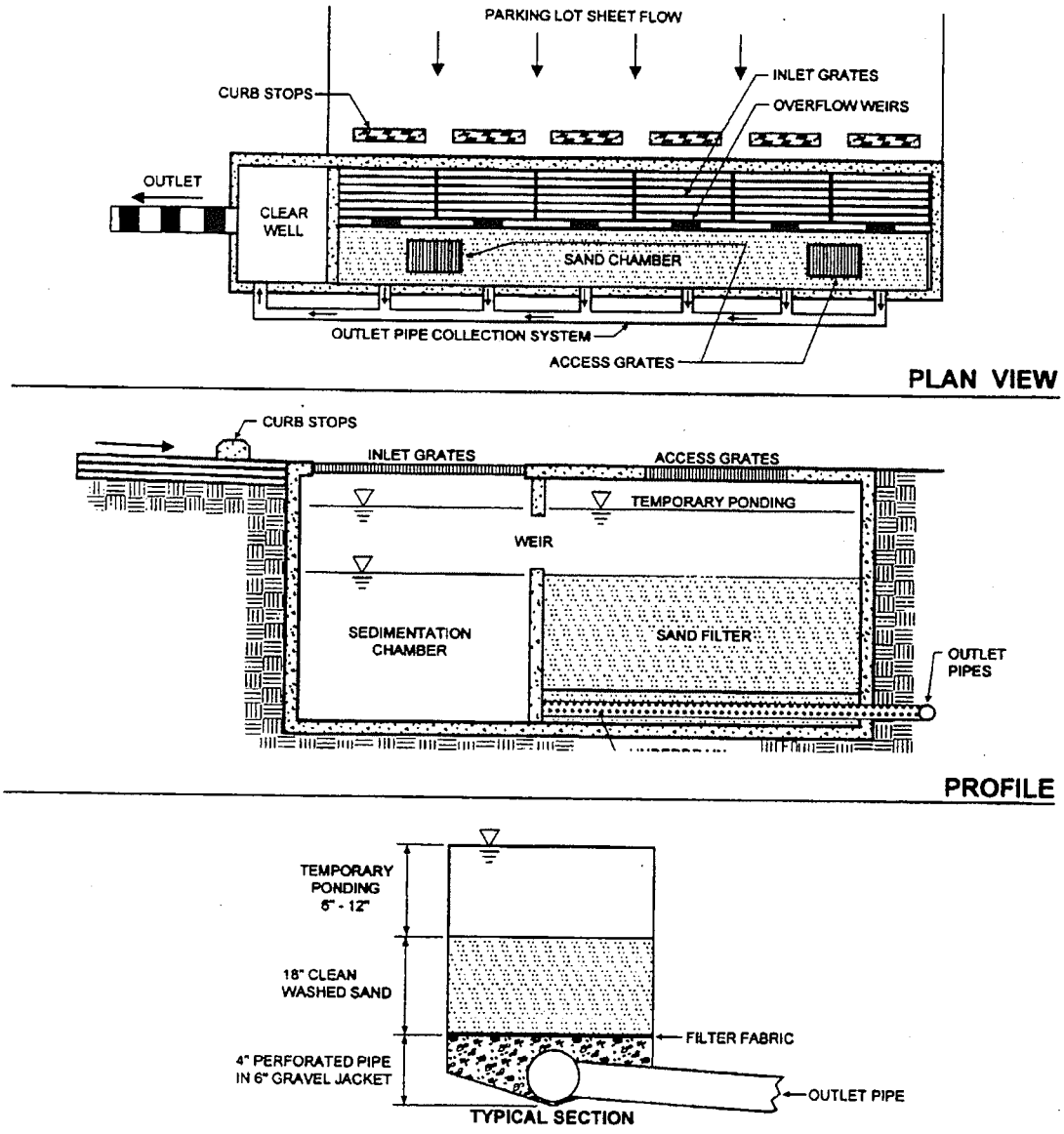

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Figure 6.18 Organic Filter (F- 4)

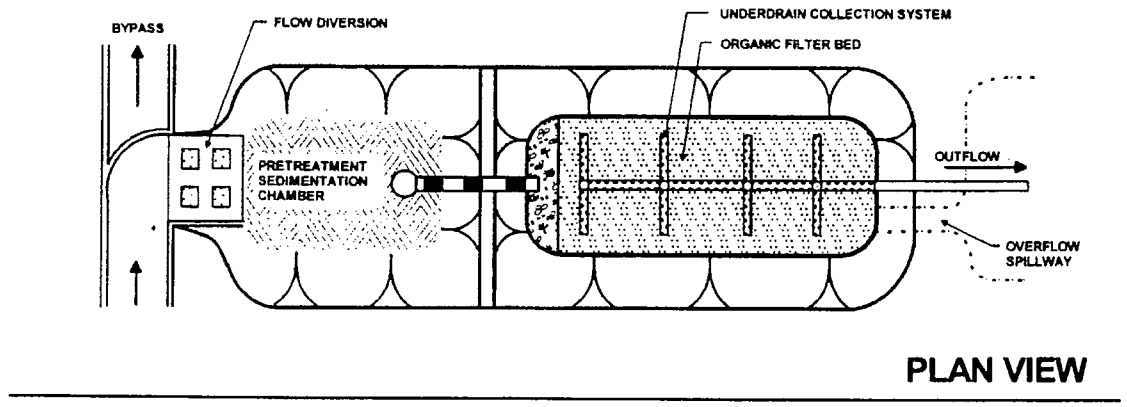

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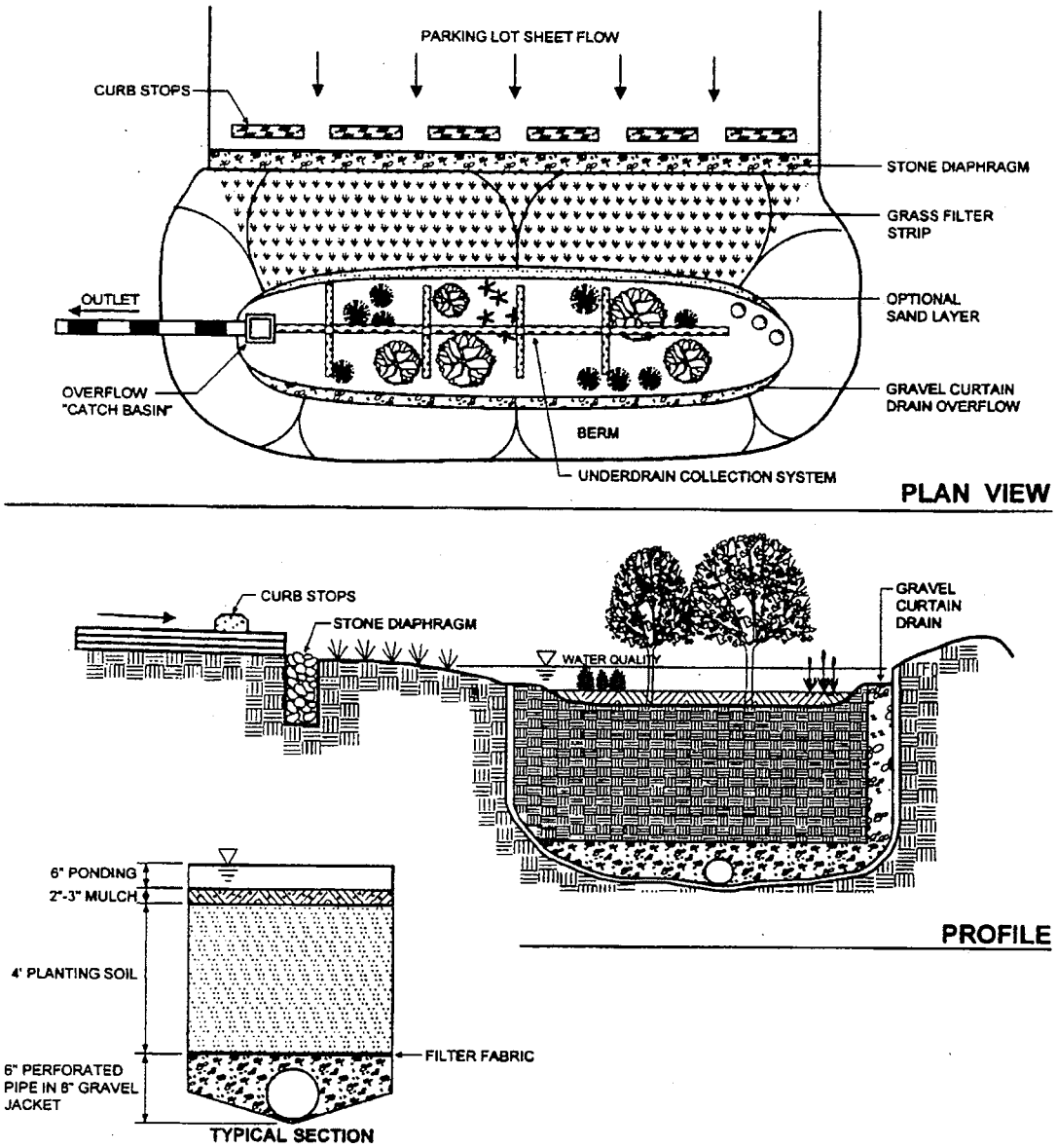
Figure 6.19 Bioretention (F-5)



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6.4.1 Feasibility

Design Guidance

- Most stormwater filters require four to six feet of head, depending on site configuration and land area available. The perimeter sand filter (F-3), however, can be designed to function with as little as 18" to 24" of head.
- The recommended maximum contributing area to an individual stormwater filtering system is usually less than 10 acres. In some situations, larger areas may be acceptable.
- Sand and organic filtering systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with imperviousness less than 75% will require full sedimentation pretreatment techniques.

6.4.2 Conveyance

Required Elements

- If runoff is delivered by a storm drain pipe or is along the main conveyance system, the filtering practice shall be designed off-line (see Appendix K).
- An overflow shall be provided within the practice to pass a percentage of the WQ_v to a stabilized water course. In addition, overflow for the ten-year storm shall be provided to a non-erosive outlet point (i.e., prevent downstream slope erosion).
- A flow regulator (or flow splitter diversion structure) shall be supplied to divert the WQ_v to the filtering practice, and allow larger flows to bypass the practice.
- Stormwater filters shall be equipped with a minimum 4" perforated pipe underdrain (6" is preferred) in a gravel layer. A permeable filter fabric shall be placed between the gravel layer and the filter media.
- Require a minimum 2' separation between the filter bottom and groundwater.

6.4.3 Pretreatment

Required Elements

- Dry or wet pretreatment shall be provided prior to filter media equivalent to at least 25% of the computed WQ_v. The typical method is a sedimentation basin that has a length to width ratio of 1.5:1. The Camp-Hazen equation is used to compute the required surface area for sand and organic filters requiring full sedimentation for pretreatment (WSDE, 1992) as follows:

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- The required sedimentation basin area is computed using the following equation:

$$A_s = -(Qo/W) \cdot Ln\ (1-E)$$

where:

A_s = Sedimentation basin surface area (ft^2)
E = sediment trap efficiency (use 90%)
W = particle settling velocity (ft/sec)
use 0.0004 ft/sec for imperviousness (I) ≤75%
use 0.0033 ft/sec for I > 75%
Qo = Discharge rate from basin = (WQ_v/24 hr)

This equation reduces to:

A_s = (0.066) (WQ_v) ft^2 for I ≤75%
A_s = (0.0081) (WQ_v) ft^2 for I > 75%

Design Guidance

- Adequate pretreatment for bioretention systems should incorporate all of the following: (a) grass filter strip below a level spreader or grass channel, (b) gravel diaphragm and (c) a mulch layer.
- The grass filter strip should be sized using the guidelines in Table 6.2.

Table 6.2 Guidelines for Filter Strip Pretreatment Sizing

Parameter	Impervious Parking Lots				Residential Lawns			
Maximum Inflow Approach Length (ft.)	35		75		75		150	
Filter Strip Slope	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%
Filter Strip Minimum Length	10'	15'	20'	25'	10'	12'	15'	18'

- The grass channel should be sized using the following procedure:
  1- Determine the channel length needed to treat the WQ_v, using sizing techniques described in the Grass Channel Fact Sheet (Chapter 5).
  2- Determine the volume directed to the channel for pretreatment
  3- Determine the channel length by multiplying the length determined in step 1 above by the ratio of the volume in step 2 to the WQ_v.

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6.4.4 Treatment

Required Elements

- The entire treatment system (including pretreatment) shall be sized to temporarily hold at least 75% of the WQ_v prior to filtration.
- The filter media shall consist of a medium sand (meeting ASTM C-33 concrete sand). Media used for organic filters may consist of peat/sand mix or leaf compost. Peat shall be a reed-sedge hemic peat.
- Bioretention systems shall consist of the following treatment components: A four foot deep planting soil bed, a surface mulch layer, and a six inch deep surface ponding area. Soils shall meet the design criteria outlined in Appendix H.

Design Guidance

- The filter bed typically has a minimum depth of 18". The perimeter filter may have a minimum filter bed depth of 12".
- The filter area for sand and organic filters should be sized based on the principles of Darcy's Law. A coefficient of permeability (k) should be used as follows:

Sand:	3.5 ft/day (City of Austin 1988)
Peat:	2.0 ft/day (Galli 1990)
Leaf compost:	8.7 ft/day (Claytor and Schueler, 1996)
Bioretention Soil:	0.5 ft/day (Claytor and Schueler, 1996)

The required filter bed area is computed using the following equation

$$A_f = (WQ_v)\,(d_f) \,/\, [\,(k)\,(h_f + d_f)\,(t_f)]$$

Where:

A_f = Surface area of filter bed (ft^2)
d_f = Filter bed depth (ft)
k = Coefficient of permeability of filter media (ft/day)
h_f = Average height of water above filter bed (ft)
t_f = Design filter bed drain time (days)
(1.67 days or 40 hours is recommended maximum t_f for sand filters, two days for bioretention)

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6.4.5 Landscaping

Required Elements

- A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility.
- Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan must be provided for bioretention areas.

Design Guidance

- Surface filters can have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.

- Planting recommendations for bioretention facilities are as follows:
  - Native plant species should be specified over non-native species.
  - Vegetation should be selected based on a specified zone of hydric tolerance.
  - A selection of trees with an understory of shrubs and herbaceous materials should be provided.
  - Woody vegetation should not be specified at inflow locations.
  - Trees should be planted primarily along the perimeter of the facility.
  - A tree density of approximately one tree per 100 square feet (i.e., 10 feet on-center) is recommended. Shrubs and herbaceous vegetation should generally be planted at higher densities (five feet on-center and 2.5 feet on center, respectively).

6.4.6 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the local review authority to ensure the following:

  - Sediment shall be cleaned out of the sedimentation chamber when it accumulates to a depth of more than six inches. Vegetation within the sedimentation chamber shall be limited to a height of 18 inches. The sediment chamber outlet devices shall be cleaned/repaired when drawdown times exceed 36 hours. Trash and debris shall be removed as necessary.

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- Silt/sediment shall be removed from the filter bed when the accumulation exceeds one inch. When the filtering capacity of the filter diminishes substantially (i.e., when water ponds on the surface of the filter bed for more than 48 hours), the top few inches of discolored material shall be removed and shall be replaced with fresh material. The removed sediments shall be disposed in an acceptable manner (i.e., landfill).

- A stone drop of at least six inches shall be provided at the inlet of bioretention facilities (F-6) (pea gravel diaphragm). Areas devoid of mulch shall be re-mulched on an annual basis. Dead or diseased plant material shall be replaced.

Design Guidance

- Organic filters or surface sand filters that have a grass cover should be mowed a minimum of three times per growing season to maintain maximum grass heights less than 12 inches.

6.4.7 Cold Climate Design Considerations

In cold climates, stormwater filtering systems need to be modified to protect the systems from freezing and frost heaving. The primary cold climate concerns to address with regards to filtering systems are:

- Freezing of the filter bed
- Pipe freezing
- Clogging of filter

NOTE

ALTHOUGH FILTERING SYSTEMS ARE NOT AS EFFECTIVE DURING THE WINTER, THEY ARE OFTEN EFFECTIVE AT TREATING STORM EVENTS IN AREAS WHERE OTHER SMPS ARE NOT PRACTICAL, SUCH AS IN HIGHLY URBANIZED REGIONS. THUS, THEY MAY BE A GOOD DESIGN OPTION, EVEN IF WINTER FLOWS CANNOT BE TREATED. IT IS ALSO IMPORTANT TO REMEMBER THAT THESE SMPS ARE DESIGNED FOR HIGHLY IMPERVIOUS AREAS. IF THE SNOW FROM THEIR CONTRIBUTING AREAS IS TRANSPORTED TO ANOTHER AREA, SUCH AS A PERVIOUS INFILTRATION AREA, A PRACTICE'S PERFORMANCE DURING THE WINTER SEASON MAY BE LESS CRITICAL TO OBTAIN WATER QUALITY GOALS.

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Freezing of the Filter Bed

- Place filter beds for underground filter below the frost line to prevent the filtering medium from freezing during the winter.
- Discourage organic filters using peat and compost media, which are ineffective during the winter in cold climates. These organic filters retain water, and consequently can freeze solid and become completely impervious during the winter.
- Combine treatment with another SMP option that can be used as a backup to the filtering system to provide treatment during the winter when the filter is ineffective

Pipe Freezing

- Use a minimum 8" underdrain diameter in a 1' gravel bed. Increasing the diameter of the underdrain makes freezing less likely, and provides a greater capacity to drain standing water from the filter. The porous gravel bed prevents standing water in the system by promoting drainage. Gravel is also less susceptible to frost heaving than finer grained media.
- Replace standpipes with weirs, which can be "frost free." Although weir structures will not always provide detention, they can provide retention storage (i.e., storage with a permanent pool) in the pretreatment chamber.

Clogging of Filter with Excess Sand from Runoff

- If a filter is used to treat runoff from a parking lot or roadway that is frequently sanded during snow events, there is a high potential for clogging from sand in runoff. In these cases, the size of the pretreatment chamber should be increased to 40% of the treatment volume. For bioretention systems, a grass strip, such as a swale, of at least twenty-five feet in length should convey flow to the system.
- Filters should always be inspected for sand build-up in the filter chamber following the spring melt event.

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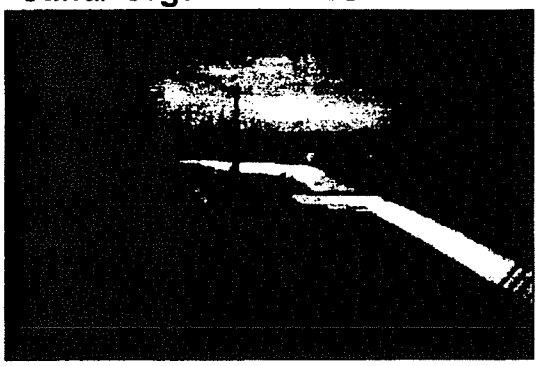
Sand/ Organic Filters



Description: Multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay, a primary filter media and, typically, an underdrain collection system.

Design Variations:
Surface Sand Filter (F-1), Underground Sand Filter (F-2), Perimeter Sand Filter (F-3), Organic Sand Filter (F-4)

KEY CONSIDERATIONS

CONVEYANCE

- If stormwater is delivered by stormdrain, design off-line.
- Overflow shall be provided to pass a fraction of the WQ_v to a stabilized watercourse.
- Overflow for the ten-year storm to a non-erosive point.
- Flow regulator needed to divert WQ_v to the practice, and bypass larger flows.
- Underdrain (4" perforated pipe minimum; 6" preferred)

PRETREATMENT

- Pretreatment volume of 25% of WQ_v.
- Typically a sediment basin with a 1.5:1 L:W ratio, sized with the Camp-Hazen equation (See Section 6.4.3)

TREATMENT

- System must hold 75% of the WQ_v
- Filter media shall be ASTM C-33 sand for sand filters
- Organic filters shall be a peat/sand mix, or leaf compost.
- Peat shall be reed-sedge hemic peat

LANDSCAPING

- Contributing area stabilized before runoff is directed to the facility

MAINTENANCE REQUIREMENTS:

- Legally binding maintenance agreement.
- Sediment cleaned out of sedimentation chamber when it reaches more than 6" in depth.
- Vegetation height limited to 18"
- Sediment chamber cleaned if drawdowns exceed 36 hours.
- Trash and debris removal
- Silt/sediment removed from filter bed after it reaches one inch.
- If water ponds on the filter bed for greater than 48 hours, remove material, and replace.

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [ ] **Channel Protection**
- [ ] **Overbank Flood Protection**
- [ ] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

IMPLEMENTATION CONSIDERATIONS

- [H] **Capital Cost**
- [H] **Maintenance Burden**

Residential Subdivision Use: No

High Density/Ultra-Urban: *Yes*

Drainage Area: *2-10 acres max.*

Soils: *No restrictions*

Other Considerations:

Typically needs to be combined with other controls to provide water quantity control

Key: L=Low M=Moderate H=High

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POLLUTANT REMOVAL	
G **Phosphorus**	
G **Nitrogen**	
G **Metals** - Cadmium, Copper, Lead, and Zinc removal	
F **Pathogens** - Coliform, Streptococci, E.Coli removal	
Key: G=Good **F**=Fair **P**=Poor	

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Bioretention Areas (F-5)



Description: Shallow stormwater basin or landscaped area which utilizes engineered soils and vegetation to capture and treat runoff. The practice is often located in parking lot islands, and can also be used to treat residential areas.

KEY CONSIDERATIONS

CONVEYANCE

- Provide overflow for the 10-year storm to the conveyance system.
- Conveyance to the system is typically overland flow delivered to the surface of the system, typically through curb cuts or over a concrete lip.

PRETREATMENT

- Pretreatment consists of a grass channel or grass filter strip, a gravel diaphragm, and a mulch layer, sized based on the methodologies described in Section 6.4.2.

TREATMENT

- Treatment area should have a four foot deep planting soil bed, a surface mulch layer, and a 6" ponding layer.
- Size the treatment area using equations provided in Chapter 6.

LANDSCAPING

- Detailed landscaping plan required.

MAINTENANCE

- Inspect and repair/replace treatment area components
- Stone drop (at least 6") provided at the inlet
- Remulch annually

POLLUTANT REMOVAL

[G] **Phosphorus**

[G] **Nitrogen**

[G] **Metals** - Cadmium, Copper, Lead, and Zinc removal

[F] **Pathogens** – Coliform, Streptococci, E.Coli removal

Key: **G**=Good **F**=Fair **P**=Poor

STORMWATER MANAGEMENT SUITABILITY

[X] **Water Quality**

[ ] **Channel Protection**

[ ] **Overbank Flood Protection**

[ ] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

IMPLEMENTATION CONSIDERATIONS

[M] **Capital Cost**

[M] **Maintenance Burden**

Residential Subdivision Use: Yes

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max.*

Soils: *Planting soils must meet specified criteria; No restrictions on surrounding soils*

Other Considerations:

- *Use of native plants is recommended*

Key: L=Low **M**=Medium **H**=High

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Section 6.5 Open Channel Systems

Open channel systems are vegetated open channels that are explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means. Design variants include:

- O-1 Dry Swale (Figure 6.20)
- O-2 Wet Swale (Figure 6.21)

Treatment Suitability: Open Channel Systems can meet water quality treatment goals only, and are not appropriate for Cp_v or Q_p.

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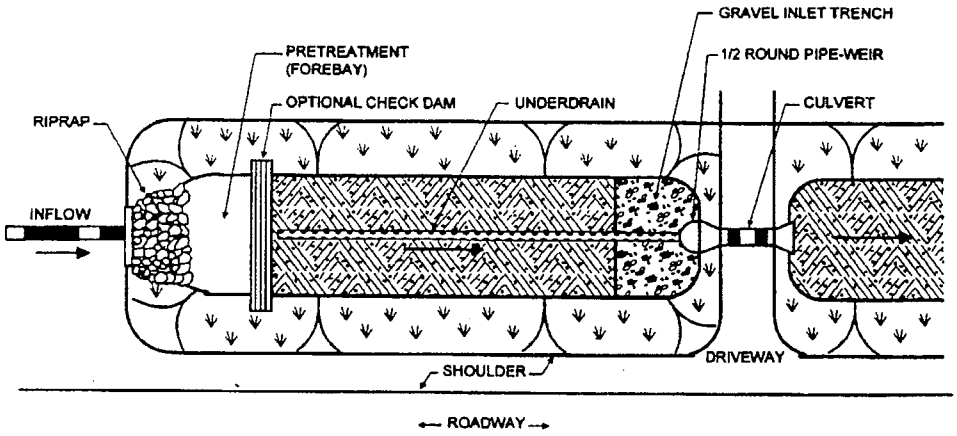
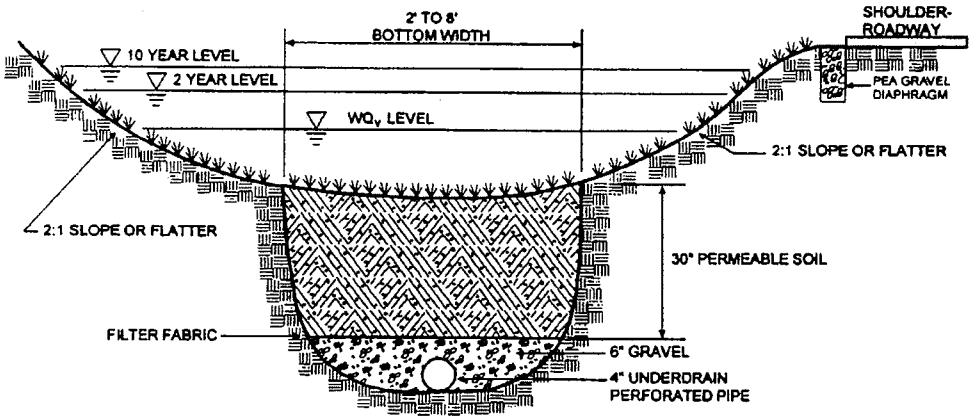
Figure 6.20 Dry Swale (O-1)



PLAN VIEW



SECTION

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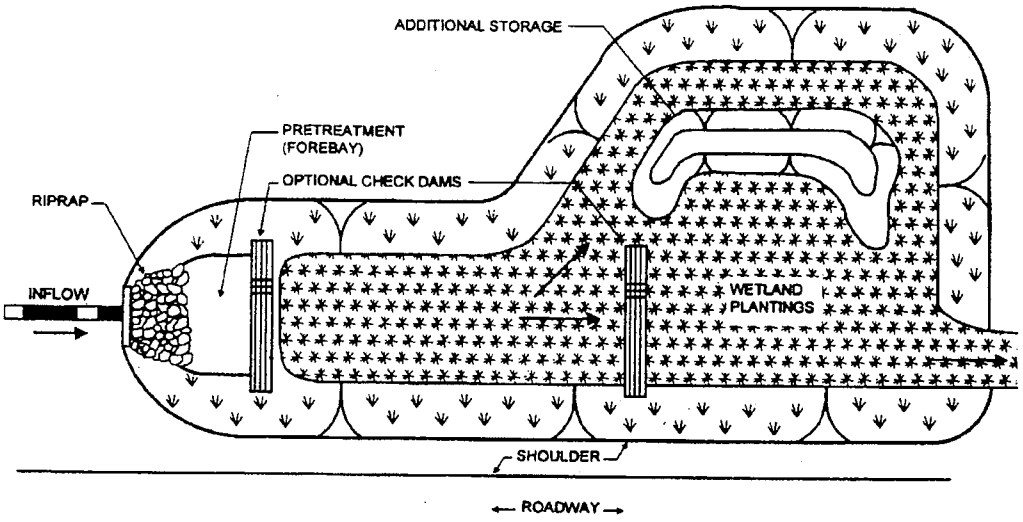
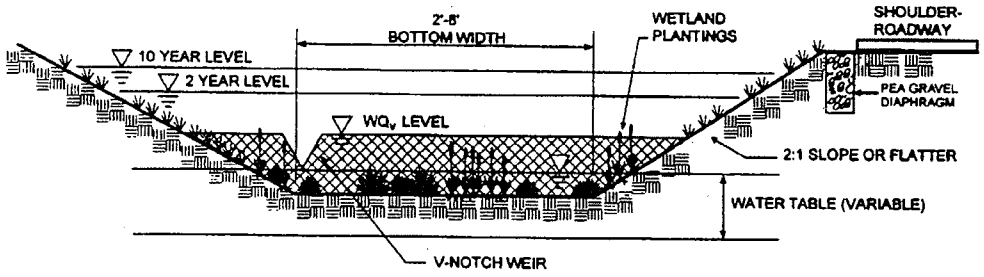
Figure 6.21 Wet Swale (O-2)



PLAN VIEW



PROFILE

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6.5.1 Feasibility

Required Elements

- The system shall have a maximum longitudinal slope of 4.0%

Design Guidance

- Dry Swales (O-1) are primarily applicable for land uses such as roads, highways, residential development, and pervious areas.
- Wet Swales (O-2) should be restricted in residential areas because of the potential for stagnant water and other nuisance ponding.
- Provide a 2' separation distance from groundwater for O-2.

6.5.2 Conveyance

Required Elements

- The peak velocity for the two-year storm must be non-erosive (i.e., 3.5-5.0 fps). (See Appendix L for a table of erosive velocities for grass and soil).
- Open channels shall be designed to safely convey the ten-year storm with a minimum of 6 inches of freeboard. Note that some agencies or local municipalities may design channel to convey a different design storm.
- The maximum allowable temporary ponding time within a channel shall be less than 48 hours. An underdrain system shall be used in the dry swale to ensure this ponding time.
- Channels shall be designed with moderate side slopes (flatter than 3:1) for most conditions. 2:1 is the absolute maximum side slope.

Design Guidance

- Open channel systems which directly receive runoff from impervious surfaces may have a 6 inch (maximum) drop onto a protected shelf (pea gravel diaphragm) to minimize the clogging potential of the inlet.
- The underdrain system should be composed of a 6" gravel bed with a 4" PVC pipe.
- If the site slope is greater than 2%, check dams may be needed to retain the water quality volume within the swale system.

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6.5.3 Pretreatment

Required Elements

- Provide 10% of the WQ_v in pretreatment. This storage is usually obtained by providing checkdams at pipe inlets and/or driveway crossings.

Design Guidance

- Utilize a pea gravel diaphragm and gentle side slopes along the top of channels to provide pretreatment for lateral sheet flows.

6.5.4 Treatment

Required Elements

- Temporarily store the WQ_v within the facility to be released over a minimum 30 minute duration.
- Design with a bottom width no greater than eight feet to avoid potential gullying and channel braiding, but no less than two feet.
- Soil media for the dry swale shall meet the specifications outlined in Appendix H.

Design Guidance

- Open channels should maintain a maximum ponding depth of one foot at the mid-point of the channel, and a maximum depth of 18" at the end point of the channel (for storage of the WQ_v).

6.5.5 Landscaping

Design Guidance

- Landscape design should specify proper grass species and wetland plants based on specific site, soils and hydric conditions present along the channel (see Appendix H for landscaping guidance for New York).

6.5.6 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the local review authority to ensure the following:

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- Sediment build-up within the bottom of the channel or filter strip is removed when 25% of the original WQ_v volume has been exceeded.
- Vegetation in dry swales is mowed as required during the growing season to maintain grass heights in the 4 to 6 inch range.

6.5.7 Cold Climate Design Considerations

For open channel systems, the primary cold climate design challenges that need to be addressed are:

- Snowmelt infiltration on frozen ground
- Culvert freezing
- The impacts of deicers on channel vegetation.

Snowmelt Infiltration on Frozen Ground

- In order to ensure that the filter bed remains dry between storm events, increase the size of the underdrain pipe to a minimum diameter of 6" with a minimum 1' filter bed.
- The soil bed permeability of the dry swale should be NRCS class SM (NRCS, 1984), which is slightly higher than in the base criteria. This increased permeability will encourage snowmelt infiltration.

Culvert Freezing

- Use culvert pipes with a minimum diameter of 18".
- Design culverts with a minimum 1% slope where possible.

The Impacts of De-icers on Channel Vegetation

- Inspect open channel systems after the spring melt. At this time, residual sand should be removed and any damaged vegetation should be replaced.
- If roadside or parking lot runoff is directed to the practice, mulching may be required in the spring to restore soil structure and moisture capacity to reduce the impacts of deicing agents.
- Use salt-tolerant plant species in vegetated swales.

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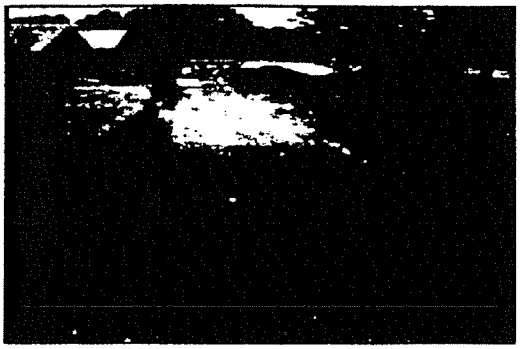
Open Channels



Description: Vegetated channels that are explicitly designed and constructed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other means.

Design Options:
Dry Swale (O-1), Wet Swale (O-2)

KEY CONSIDERATIONS

FEASIBILITY

- Maximum longitudinal slope of 4%

CONVEYANCE

- Non-erosive (3.5 to 5.0 fps) peak velocity for the 2-year storm
- Safe conveyance of the ten-year storm with a minimum of 6 inches of freeboard.
- Side slopes gentler than 2:1 (3:1 preferred).
- The maximum allowable temporary ponding time of 48 hours

PRETREATMENT

- 10% of the WQ_v in pretreatment, usually provided using check dams at culverts or driveway crossings.

TREATMENT

- Temporary storage the WQ_v within the facility to be released over a minimum 30 minute duration.
- Bottom width no greater than 8 feet, but no less than two feet.
- Soil media as detailed in Appendix H.

MAINTENANCE

- Removal of sediment build-up within the bottom of the channel or filter strip when 25% of the original WQ_v volume has been exceeded.
- Maintain a grass height of 4" to 6" in dry swales.

MANAGEMENT CAPABILITY

G	**Phosphorus**
F	**Nitrogen**
G	**Metals** - Cadmium, Copper, Lead, and Zinc removal
P	**Pathogens** - Coliform, Streptococci, E.Coli removal

Key: G=Good F=Fair P=Poor

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [ ] **Channel Protection**
- [ ] **Overbank Flood Protection**
- [ ] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

IMPLEMENTATION CONSIDERATIONS

L	**Capital Cost**
L	**Maintenance Burden**

Residential Subdivision Use: Yes

High Density/Ultra-Urban: *No*

Drainage Area: *5 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Permeable soil layer (dry swale)*
- *Wetland plants (wet swale)*

Key: H=High M=Medium L=Low

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Chapter 7

SMP Selection Matrices

New York State Stormwater Management Design Manual

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Chapter 7: SMP Selection

This chapter presents a series of matrices that can be used as a screening process to select the best SMP or group of SMPs for a development site. It also provides guidance for best locating practices on the site. The matrices presented can be used to screen practices in a step-wise fashion. The screening factors include:

1. Land Use
2. Physical Feasibility
3. Watershed/ Regional Factors
4. Stormwater Management Capability
5. Community and Environmental Factors

The five matrices presented here are not exhaustive. Specific additional criteria may be incorporated depending on local design knowledge and resource protection goals. Furthermore, many communities may wish to eliminate some of the selection factors presented in this section. Caveats for the application of each matrix are included in the detailed description of each.

More detail on the proposed step-wise screening process is provided below:

Step 1 Land Use

Which practices are best suited for the proposed land use at this site? In this step, the designer makes an initial screen to select practices that are best suited to a particular land use.

Step 2 Physical Feasibility Factors

Are there any physical constraints at the project site that may restrict or preclude the use of a particular SMP? In this step, the designer screens the SMP list using Matrix No. 2 to determine if the soils, water table, drainage area, slope or head conditions present at a particular development site might limit the use of a SMP.

Step 3 Watershed Factors

What watershed protection goals need to be met in the resource my site drains to? Matrix No.3 outlines SMP goals and restrictions based on the resource being protected.

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Step 4 Stormwater Management Capability

Can one SMP meet all design criteria, or is a combination of practices needed? In this step, designers can screen the SMP list using Matrix No. 4 to determine if a particular SMP can meet water quality, channel protection, and flood control storage requirements. At the end of this step, the designer can screen the SMP options down to a manageable number and determine if a single SMP or a group of SMPs is needed to meet stormwater sizing criteria at the site.

Step 5 Community and Environmental Factors

Do the remaining SMPs have any important community or environmental benefits or drawbacks that might influence the selection process? In this step, a matrix is used to compare the SMP options with regard to cold climate restrictions, maintenance, habitat, community acceptance, cost and other environmental factors.

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Section 7.1 Land Use

This matrix allows the designer to make an initial screen of practices most appropriate for a given land use (Table 7.1).

Rural. This column identifies SMPs that are best suited to treat runoff in rural or very low density areas (e.g., typically at a density of less than ½ dwelling unit per acre).

Residential. This column identifies the best treatment options in medium to high density residential developments.

Roads and Highways. This column identifies the best practices to treat runoff from major roadways and highway systems.

Commercial Development. This column identifies practices that are suitable for new commercial development

Hotspot Land Uses. This last column examines the capability of an SMP to treat runoff from designated hotspots (see Appendix A). An SMP that receives hotspot runoff may have design restrictions, as noted.

Ultra-Urban Sites. This column identifies SMPs that work well in the ultra-urban environment, where space is limited and original soils have been disturbed. These SMPs are frequently used at redevelopment sites.

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Table 7.1 Land Use Selection Matrix

SMP Group	SMP Design	Rural	Residential	Roads and Highways	Commercial/ High Density	Hotspots	Ultra Urban
Pond	Micropool ED	○	○	○	◗	①	●
	Wet Pond	○	○	○	◗	①	●
	Wet ED Pond	○	○	○	◗	①	●
	Multiple Pond	○	○	◗	◗	①	●
	Pocket Pond	○	◗	○	◗	●	●
Wetland	Shallow Wetland	○	○	◗	◗	①	●
	ED Wetland	○	○	◗	◗	①	●
	Pond/Wetland	○	○	●	◗	①	●
	Pocket Wetland	○	◗	○	◗	●	●
Infiltration	Infiltration Trench	◗	◗	○	○	●	◗
	Shallow I-Basin	◗	◗	◗	◗	●	◗
	Dry Well[1]	◗	○	●	◗	●	◗
Filters	Surface Sand Filter	●	◗	○	○	②	○
	Underground SF	●	●	◗	○	○	○
	Perimeter SF	●	●	◗	○	○	○
	Organic SF	●	◗	○	○	②	○
	Bioretention	◗	◗	○	○	②	○
Open Channels	Dry Swale	○	◗	○	◗	②	◗
	Wet Swale	○	●	○	●	●	●

○: Yes. Good option in most cases.
◗: Depends. Suitable under certain conditions, or may be used to treat a portion of the site.
●: No. Seldom or never suitable.
①: Acceptable option, but may require a pond liner to reduce risk of groundwater contamination.
②: Acceptable option, if not designed as an exfilter.
1: The dry well can only be used to treat rooftop runoff

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Section 7.2 Physical Feasibility Factors

This matrix allows the designer to evaluate possible options based on physical conditions at the site (Table 7.2). More detailed testing protocols are often needed to confirm physical conditions at the site. Five primary factors are:

Soils. The key evaluation factors are based on an initial investigation of the NRCS hydrologic soils groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors. Appendix H describes geotechnical testing requirements for New York State.

Water Table. This column indicates the minimum depth to the seasonally high water table from the bottom elevation, or floor, of an SMP.

Drainage Area. This column indicates the minimum or maximum drainage area that is considered optimal for a practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is warranted where a practice meets other management objectives. Likewise, the minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (baseflow or groundwater), mechanisms employed to prevent clogging, or the ability to assume an increased maintenance burden.

Slope. This column evaluates the effect of slope on the practice. Specifically, the slope guidance refers to how flat the area where the practice is installed must be and/or how steep the contributing drainage area or flow length can be.

Head. This column provides an estimate of the elevation difference needed for a practice (from the inflow to the outflow) to allow for gravity operation.

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Table 7.2 Physical Feasibility Matrix

SMP Group	SMP Design	Soils	Water Table	Drainage Area (acres)	Site Slope	Head (ft)
Pond	Micropool ED	HSG A soils may require pond liner.	2 foot separation if hotspot or aquifer	10 min[1]	No more than 15%	6 to 8 ft
	Wet Pond			25 min[1]		
	Wet ED Pond					
	Multiple Pond					
	Pocket Pond	OK	below WT	5 max[2]		4 ft
Wetland	Shallow Wetland	HSG A soils may require liner	2 foot separation if hotspot or aquifer	25 min	No more than 8%	3 to 5 ft
	ED Wetland					
	Pond/Wetland					
	Pocket Wetland	OK	below WT	5 max		2 to 3 ft
Infiltration	Infiltration Trench	$f_c > 0.5$ inch/hr; additional pretreatment required over 2.0 in/hr (See Section 6.3.3)	3 feet, 4 feet if sole source aquifer.	5 max	No more than 15%	1 ft[6]
	Shallow I-Basin			10 max[3]		3 ft
	Dry Well			1 max[4]		1 ft
Filters	Surface SF	OK	2 feet[5]	10 max[2]	No more than 6%	5 ft
	Underground SF			2 max[2]		5 to 7ft
	Perimeter SF			2 max[2]		2 to 3 ft
	Organic SF			5 max[2]		2 to 4 ft
	Bioretention			5 max[2]		5 ft
	Dry Swale	Made Soil				3 to 5 ft
Open Channels	Wet Swale	Made Soil	2 feet	5 max	No more than 4%	1 ft
	Wet Swale	OK	below WT	5 max		1 ft

Notes:
1: Unless adequate water balance and anti-clogging device installed
2: Drainage area can be larger in some instances
3: May be larger in areas where the soil percolation rate is greater than 5.0 in/hr
4: Designed to treat rooftop runoff only
5: If designed with a permeable bottom, must meet the depth requirements for infiltration practices.
6: Required ponding depth above geotextile layer.

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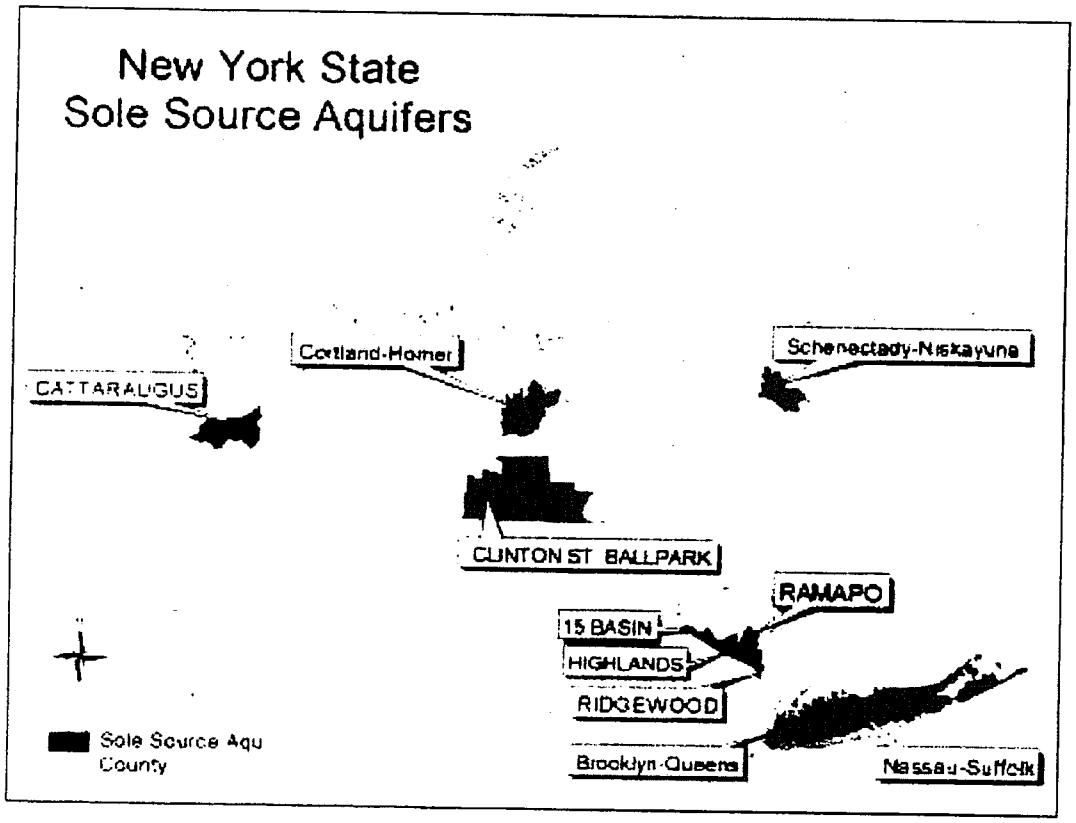
Section 7.3 Watershed/Regional Factors

The choices made by the designer should be influenced to some extent by the resource being protected, and the region of New York State where the site is located. The following matrices (Tables 7.3a and 7.3b) present some design considerations for six watershed or regional factors in New York:

Sensitive Streams. The guidance presented here should apply to all trout waters and Class N waters, and any streams that support high biodiversity and water quality, and have a low density of development.

Aquifers. In sole source aquifers, special care should be taken to select practices and incorporate design considerations that protect the groundwater quality. Figure 7.1 depicts sole source aquifers in the State of New York.

Figure 7.1 Sole Source Aquifers in New York State



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Lakes. Lakes are of particular concern in New York, which has many natural lake systems and borders on two Great Lakes. The information in this matrix focuses on phosphorous removal, which is an important concern in most lake systems. It is important to note, however, that many lakes in New York State have other important issues to address. Some lakes, such as Lake Onondoga, have other specific concerns, such as toxics and metals. Each community should also take these goals into consideration when reviewing site plans.

Table 7.3a Watershed/ Regional Selection Matrix-1

SMP Group	Sensitive Stream	Aquifer	Lakes
Ponds	Emphasize channel protection. Restrict in-stream practices. In trout waters, minimize permanent pool area, and encourage shading.	May require liner if HSG A soils are present. Pretreat 100% of WQ_v from hotspots. Provide a 2' separation distance to water table.	Encourage the use of a large permanent pool to improve phosphorus removal.
Wetlands	Require channel protection. Restrict in-stream practices. Restrict use in trout waters.		
Infiltration	Strongly encourage use for groundwater recharge. Combine with a detention facility to provide channel protection.	Provide 100' horizontal separation distance from wells and 4' vertical distance from the water table.	OK. Provides high phosphorus removal.
Filtering Systems	Combine with a detention facility to provide channel protection.	Excellent pretreatment for infiltration or open channel practices.	OK, but designs with a submerged filter may result in phosphorus release.
Open Channels	Combine with a detention facility to provide channel protection.	OK, but hotspot runoff must be adequately pretreated	OK. Moderate P removal.

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Reservoirs. For drinking water reservoirs, and in particular for unfiltered water supplies such as the New York City Reservoir system, turbidity, phosphorous removal, and bacteria are of particular concern. A particular reservoir may have other specific concerns, which should be identified as part of a Source Water Assessment.

Estuary/Coastal. In New York State, coastal or estuary areas include the South Shore Estuary Reserve, Peconic Estuary, NY/NJ Harbor, and Hudson River Estuary. In these areas, nitrogen is typically a concern due to potential eutrophication. In addition, bacteria control is important to protect shellfish beds.

Cold Climates. Many portions of New York State experience cold or very snowy winters. This matrix summarizes some of the design considerations in these cold climate areas. For more detailed information, consult Chapter 6, which provides cold climate design guidance for each group of SMPs.

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Table 7.3b Watershed/Regional Selection Matrix-2			
SMP Group	**Reservoir**	**Estuary/Coastal**	**Cold Climates**
Ponds	Encourage the use of a large permanent pool to improve sediment and phosphorous removal. Promote long detention times to encourage bacteria removal.	Encourage long detention times to promote bacteria removal. Provides high nitrogen removal. In flat coastal areas, a pond drain may not be feasible.	Incorporate design features to improve winter performance.
Wetlands			Encourage the use of salt-tolerant vegetation.
Infiltration	Provide a separation distance from bedrock and water table Pretreat runoff prior to infiltration practices.	OK, but provide a separation distance to seasonally high groundwater. In the sandy soils typical of coastal areas, additional pretreatment may be required (See Section 6.3.3)	Incorporate features to minimize the risk of frost heave. Discourage infiltration of chlorides.
Filtering Systems	Excellent pretreatment for infiltration or open channel practices. Moderate to high coliform removal	Moderate to high coliform removal Designs with a submerged filter bed appear to have very high nitrogen removal	Incorporate design features to improve winter performance.
Open Channels	Poor coliform removal for wet swales.	Poor coliform removal for grass wet swales.	Encourage the use of salt-tolerant vegetation.

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Section 7.4 Stormwater Management Capability

This matrix examines the capability of each SMP option to meet stormwater management criteria (Table 7.4). It shows whether an SMP can meet requirements for:

Water Quality. The matrix summarizes the relative pollutant removal of each practice for nitrogen, metals, and bacteria. All of the practices approved for water quality achieve at least 80% TSS and 40% TP removal. For more detailed information, consult Appendix A, which describes the application of the Simple Method in New York State. Pollutant removals are based a comprehensive pollutant removal database produced by the Center for Watershed Protection (Winer, 2000).

Channel Protection. The matrix indicates whether the SMP can typically provide channel protection storage. The finding that a particular SMP cannot meet the channel protection requirement does not necessarily imply that the SMP should be eliminated from consideration, but is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream ED pond).

Flood Control The matrix shows whether an SMP can typically meet the overbank flooding criteria for the site. Again, the finding that a particular SMP cannot meet the requirement does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream stormwater detention pond).

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Table 7.4 Stormwater Management Capability Matrix

SMP Group	SMP Design	Water Quality			Channel Protection	Flood Control
		Nitrogen	Metals	Bacteria		
Pond	Micropool ED	○	○	○	○	○
	Wet Pond				○	○
	Wet ED Pond				○	○
	Multiple Pond				○	○
	Pocket Pond				○	○
Wetland	Shallow Wetland	○	◗	○	○	○
	ED Wetland				○	○
	Pond/Wetland				○	○
	Pocket Wetland				○	❶
Infiltration	Infiltration Trench	○	○	○	●	●
	Shallow I-Basin				❷	❷
	Dry Well				●	●
Filters	Surface Sand Filter	○	○	◗	❶	●
	Underground SF				●	●
	Perimeter SF				●	●
	Organic SF				●	●
	Bioretention				❶	●
	Dry Swale				●	●
Open Channels	Wet Swale	◗	○	●	●	●
	Wet Swale				●	●

○: Good option for meeting management goal
Good pollutant removal (>30% TN, >60% Metals, >70% Bacteria)
◗: Fair pollutant removal (15-30% TN, 30-60% Metals, 35-70% Bacteria)
●: Cannot meet management goal.
Poor pollutant removal (<15% TN, <30 Metals, <35% Bacteria)
❶: In most cases, cannot meet this goal, but the design may be adapted to add storage.
❷: Generally cannot meet this goal, except in areas with soil percolation rates greater than 5.0 in/hr

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Section 7.5 Community and Environmental Factors

The last step assesses community and environmental factors involved in SMP selection. This matrix employs a comparative index approach (Table 7.5.). An open circle indicates that the SMP has a high benefit and a dark circle indicates that the particular SMP has a low benefit.

Ease of Maintenance. This column assesses the relative maintenance effort needed for an SMP, in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging) and reported failure rates. It should be noted that **all SMPs** require routine inspection and maintenance.

Community Acceptance. This column assesses community acceptance, as measured by three factors: market and preference surveys, reported nuisance problems, and visual orientation (i.e., is it prominently located or is it in a discrete underground location). It should be noted that a low rank can often be improved by a better landscaping plan.

Affordability. The SMPs are ranked according to their relative construction cost per impervious acre treated.

Safety. A comparative index that expresses the relative safety of an SMP. An open circle indicates a safe SMP, while a darkened circle indicates deep pools may create potential safety risks. The safety factor is included at this stage of the screening process because liability and safety are of paramount concern in many residential settings.

Habitat. SMPs are evaluated on their ability to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, wetland features and vegetative cover of the SMP and its buffer.

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Table 7.5 Community and Environmental Factors Matrix

SMP Group	SMP List	Ease of Maintenance	Community Acceptance	Affordability	Safety	Habitat
Ponds	Micropool ED	◗	◗	○	○	◗
	Wet Pond	○	○	○	●	○
	Wet ED Pond	○	○	○	●	○
	Multiple Pond	○	○	◗	●	○
	Pocket Pond	●	◗	○	◗	●
Wetlands	Shallow Wetland	◗	○	◗	○	○
	ED Wetland	◗	◗	◗	◗	○
	Pond/Wetland	○	○	◗	●	○
	Pocket Wetland	●	●	○	○	◗
Infiltration	Infiltration Trench	●	○	◗	○	●
	Shallow I-Basin	●	●	◗	○	●
	Dry Well	●	◗	◗	○	●
Filters	Surface SF	◗	◗	●	○	●
	Underground SF	●	○	●	◗	●
	Perimeter SF	●	○	●	○	●
	Organic SF	◗	○	●	○	●
	Bioretention	◗	◗	◗	○	◗
Open Channels	Dry Swale	○	○	◗	○	●
	Wet Swale	○	◗	○	○	◗

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Chapter 8

Stormwater Management Design Examples

New York State Stormwater Management Design Manual

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Chapter 8: Stormwater Management Design Examples

This chapter presents design examples for two hypothetical development sites in the State of New York. The first site, "Stone Hill Estates," is a residential development near Ithaca. The second is a commercial site in Albany. The chapter is divided into five sections, each of which focuses on a particular element of stormwater management design.

- Section 8.1 provides an example of detailed hydrology calculations at the residential site.
- Section 8.2 presents a pond design example based on the hydrology calculated in Section 8.1. This design example demonstrates the hydrologic and hydraulic computations to achieve water quality and water quantity control for stormwater management. Other specific dam design criteria such as soil compaction, structural appurtenances, embankment drainage, outlet design, gates, reservoir drawdown requirements, etc. are stated in Guidelines For Design of Dams.
- This design example in Section 8.2 requires an Article 15 Permit from NYS-DEC since the dam is 15 feet high measured from the top of dam to the low elevation at the downstream outlet, and the storage measured behind the structure to the top of the dam is 2.2 MG.
- Sections 8.3 through 8.5 present design examples for three practices on the commercial site: a sand filter, infiltration trench, and bioretention practice.

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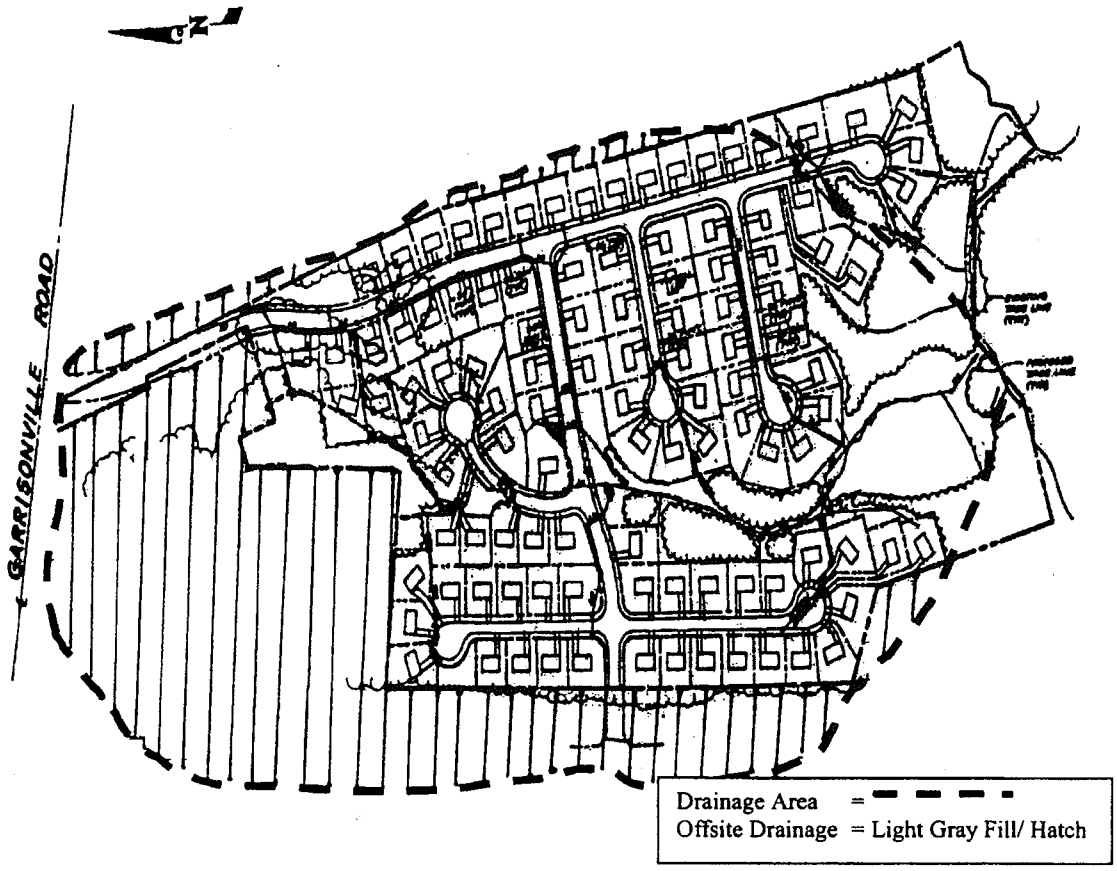
Section 8.1 Sizing Example - Stone Hill Estates

Following is a sizing example for the hypothetical "Stone Hill Estates," a 45-acre residential development in Ithaca, New York (Figure 8.1). The site also drains approximately 20 acres of off-site drainage, which is currently in a meadow condition. The site is on mostly C soils with some D soils.

Figure 8.1 Stone Hill Site Plan



Base Data
Location: Ithaca, NY
Site Area = 45.1 ac; Offsite Area = 20.0 ac (meadow)
Total Drainage Area (A) = 65.1
Measured Impervious Area=12.0 ac;
Site Soils Types: 78% "C", 22% "D"
Offsite Soil Type: 100% "C"
Zoning: Residential (½ acre lots)

Hydrologic Data

	Pre	Post	Ult.
CN	72	78	82
t_c (hr)	.46	.35	.35

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Computation of Preliminary Stormwater Storage Volumes and Peak Discharges

The layout of the Stone Hill subdivision is shown on the previous page.

Water Quality Volume, WQ_v

- Compute Impervious Cover

  Use both on-site and off-site drainage:

  $I = 12.0 \text{ acres}/65.1 \text{ acres}$

  $= 18.4\%$

- Compute Runoff Coefficient, R_v

$$R_v = 0.05 + (I)(0.009)$$
$$= 0.05 + (18.4)(0.009) = 0.22$$

- Compute WQ_v (Includes both on-site and off-site drainage)

Use the 90% capture rule with 0.9" of rainfall. (From Figure 4.1)

$$WQ_v = (0.9")(R_v)(A)$$
$$= (0.9")(0.22)(65.1 \text{ ac})(1\text{ft}/12\text{in})$$
$$= 1.07 \text{ ac-ft}$$

Establish Hydrologic Input Parameters and Develop Site Hydrology (see Figures 8.2, 8.3, and 8.4)

Condition	Area	CN	Tc
	Ac		*hrs*
Pre-developed	65.1	72	0.46
Post-developed	65.1	78	0.35
Ultimate buildout*	65.1	82	0.35

*Zoned land use in the drainage area.

Hydrologic Calculations

Condition	$Q_{1\text{-yr}}$	$Q_{1\text{-yr}}$	$Q_{10\text{-yr}}$	$Q_{100\text{-yr}}$
Runoff	*inches*	*cfs*	*cfs*	*cfs*
Pre-developed	0.4	19	72	141
Post-developed	0.7	38	112	202
Ultimate buildout	NA	NA	NA	227

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PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	PRE DEVELOPMENT			21-Jan-97
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D?	Curve	AREA (In acres)
MEADOW		C	71	20.25 Ac.
MEADOW		D	78	7.95 Ac.
WOOD		C	70	15.09 Ac.
WOOD		D	77	1.81 Ac.
OFF-SITE MEADOW		C	71	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	150 Ft.	3.80% 0.28 Hrs
Shallow Flow	UNPAVED		1300 Ft. 2.65 F.P.S.	2.70% 0.14 Hrs.
Channel Flow Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 17.5 Ft.	1100 Ft. 7.14 F.P.S.	2.70% 0.04 Hrs.

Total Area in Acres =	65.10 Ac.	Total Sheet Flow=	Total Shallow Flow=	Total Channel Flow =
Weighted CN =	72			
Time Of Concentration =	0.46 Hrs.	0.28 Hrs.	0.14 Hrs.	0.04 Hrs.
Pond Factor =	1	RAINFALL TYPE II		

STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.4 In.	18.6 CFS	101,195 Cu. Ft.
2 Year	2.7 In.	0.6 In.	30.2 CFS	150,257 Cu. Ft.
10 Year	3.9 In.	1.4 In.	72 CFS	328,570 Cu. Ft.
100 Year	5.5 In.	2.6 In.	141 CFS	611,958 Cu. Ft.

Figure 8.2 Stone Hill Pre-Development Conditions

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PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	POST DEVELOPMENT			21-Jan-97
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D?	Curve	AREA (In acres)
MEADOW		C	71	0.16 Ac.
MEADOW		D	78	0.14 Ac.
WOOD		C	70	3.09 Ac.
WOOD		D	77	1.81 Ac.
IMPERVIOUS			98	12.00 Ac.
GRASS		C	74	20.09 Ac.
GRASS		D	80	7.81 Ac.
OFFSITE MEADOW		C	71	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	100 Ft.	3.80% 0.20 Hrs
Shallow Flow (a)	UNPAVED		100 Ft. 1.98 F.P.S.	1.50% 0.01 Hrs.
(b)	PAVED		400 Ft. 2.03 F.P.S.	1.00% 0.05 Hrs.
Channel Flow (a) Hydraulic Radius =0.50	1.6 SqFt	'n'=0.013 3.2 Ft.	1550 Ft. 7.22 F.P.S.	1.00% 0.06 Hrs.
(b) Hydraulic Radius =1.42	12.0 SqFt	'n'=0.030 8.5 Ft.	350 Ft. 13.01 F.P.S.	4.30% 0.01 Hrs.
(c) Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 8.5 Ft.	300 Ft. 7.89 F.P.S.	3.30% 0.01 Hrs.
Total Area in Acres =	65.10 Ac.	Total Sheet Flow=	Total Shallow Flow=	Total Channel Flow =
Weighted CN =	78	0.20 Hrs.	0.07 Hrs.	0.08 Hrs.
Time Of Concentration =	0.35 Hrs.			
Pond Factor =	1	RAINFALL TYPE II		

STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.7 In.	37.6 CFS	156,283 Cu. Ft.
2 Year	2.7 In.	0.9 In.	54.0 CFS	217,511 Cu. Ft.
10 Year	3.9 In.	1.8 In.	112 CFS	427,155 Cu. Ft.
100 Year	5.5 In.	3.1 In.	202 CFS	742,265 Cu. Ft.

Figure 8.3 Stone Hill Post-Development Conditions

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PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	ULTIMATE BUILDOUT			21-Jan-97
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D?	Curve	AREA (In acres)
MEADOW		C	71	0.16 Ac.
MEADOW		D	78	0.14 Ac.
WOOD		C	70	3.09 Ac.
WOOD		D	77	1.81 Ac.
IMPERVIOUS			98	12.00 Ac.
GRASS		C	74	20.09 Ac.
GRASS		D	80	7.81 Ac.
OFFSITE ULTIMATE				
SF RES (0.25 AC LOTS)		C	83	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	100 Ft.	3.80% 0.20 Hrs
Shallow Flow (a)	UNPAVED		100 Ft. 1.98 F.P.S.	1.50% 0.01 Hrs.
(b)	PAVED		400 Ft. 2.03 F.P.S.	1.00% 0.05 Hrs.
Channel Flow (a) Hydraulic Radius =0.50	1.6 SqFt	'n'=0.013 3.2 Ft.	1550 Ft. 7.22 F.P.S.	1.00% 0.06 Hrs.
(b) Hydraulic Radius =1.42	12.0 SqFt	'n'=0.030 8.5 Ft.	350 Ft. 13.01 F.P.S.	4.30% 0.01 Hrs.
(c) Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 8.5 Ft.	300 Ft. 7.89 F.P.S.	3.30% 0.01 Hrs.
Total Area in Acres =	65.10 Ac.	Total Sheet Flow=	Total Shallow Flow=	Total Channel Flow =
Weighted CN =	82	0.20 Hrs.	0.07 Hrs.	0.08 Hrs.
Time Of Concentration =	0.35 Hrs.			
Pond Factor =	1	RAINFALL TYPE II		

STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.9 In.	50.9 CFS	201,772 Cu. Ft.
2 Year	2.7 In.	1.1 In.	70.0 CFS	271,097 Cu. Ft.
10 Year	3.9 In.	2.1 In.	135 CFS	500,458 Cu. Ft.
100 Year	5.5 In.	3.5 In.	227 CFS	834,167 Cu. Ft.

Figure 8.4 Stone Hill Ultimate Buildout Conditions

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Compute Stream Channel Protection Volume, (Cp_v) (see Section 4.3 and Appendix B)

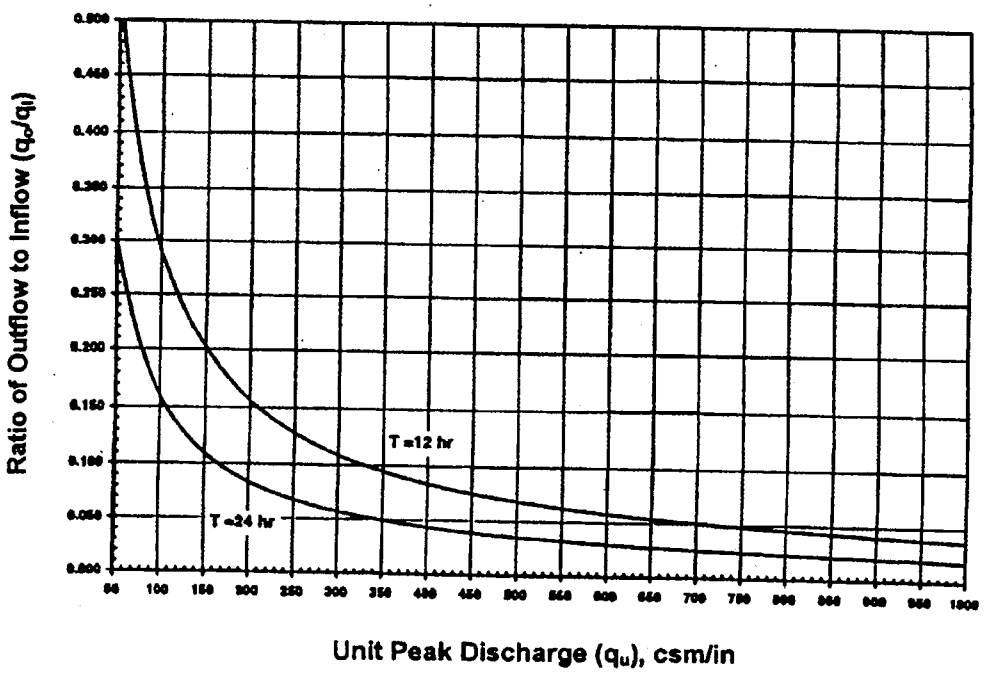
For stream channel protection, provide 24 hours of extended detention (T) for the one-year event.

Compute Channel Protection Storage Volume

First, determine the value of the unit peak discharge (q_u) using TR-55 and Type II Rainfall Distribution

- Initial abstraction (Ia) for CN of 78 is 0.564: [Ia = (200/CN - 2)]
- Ia/P = (0.564)/ 2.3 inches = 0.245
- T_c = 0.35 hours
- Using the above data, q_u = 570 csm/in (cubic feet per second per square mile per year)

Figure 8.5 Detention Time vs. Discharge Ratios (Source: MDE, 2000)



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- Knowing q_u and T = 24 hours, find q_o/q_i using Figure 8.5 (also see methodology in Appendix B)
- Peak outflow discharge/peak inflow discharge $(q_o/q_i) = 0.035$
- $Vs/Vr = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$ (from Appendix B)
  Where Vs equals channel protection storage (Cp_v) and Vr equals the volume of runoff in inches.
- Vs/Vr = 0.63 and, from figure 8.3, Q = 0.7"
- Solving for V_s

  $Vs = Cp_v = 0.63(0.7")(1/12)(65.1\ ac) = 2.4$ ac-ft (104,214 cubic feet)

Define the Average Release Rate

- The above volume, 2.4 ac-ft, is to be released over 24 hours
- $(2.4\ ac\text{-}ft \times 43{,}560\ ft^2/ac) / (24\ hrs \times 3{,}600\ sec/hr) = 1.2$ cfs

Compute Overbank Flood Protection Volume, (Qp_{10}) (see Section 4.4)

For both the overbank flood protection volume and the extreme flood protection volume, size is determined using the TR-55 "Short-Cut Method," which relates the storage volume to the required reduction in peak flow and storm inflow volume (Figure 8.6).

- For a q_i of of 112 cfs (post-developed), and an allowable q_o of 72 cfs (pre-developed), the value of $(q_o)/(q_i)$ is 0.64
- Using figure 8.6, and a post-developed curve number of 78, Vs/Vr = 0.23
- Using a total storm runoff volume of 427,155 cubic feet (9.8 acre-feet), the required storage (Vs) is:

  $V_s = Qp_v = 0.23(427{,}155)/43{,}560 = 2.26$ acre-feet

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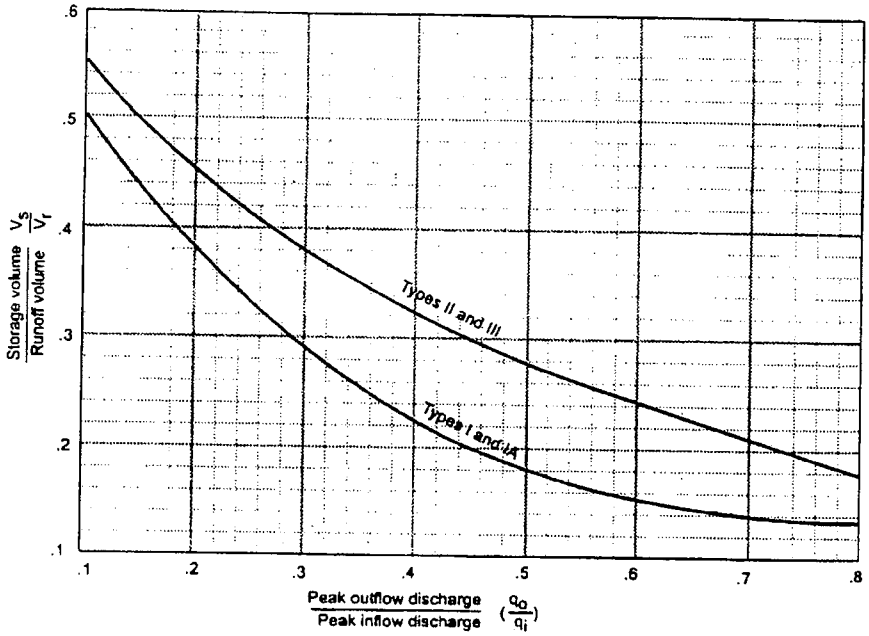
Figure 8.6 Approximate Detention Basin Routing for Rainfall Types I, IA, II, and III
Source: TR-55, 1986



While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided inclusive with the 10-year storm. So, for preliminary sizing purposes, add 15% to the required volume for the 10-year storm. $Q_{p\text{-}10} = 2.23 \times 1.15 = 2.59$ ac-ft.

Compute Extreme Flood Protection Volume, (Q_f)

Extreme flood protection is calculated using the same methodology as overbank protection.

- For a Q_{in} of, and an allowable Q_{out} of, and a runoff volume of the Vs necessary for 100-year control is, under a developed CN of 78. Note that 5.5 inches of rain fall during this event, with approximately 3.1 inches of runoff.
- While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided inclusive with the 100-year storm. So, for preliminary sizing purposes add 15% to the required volume for the 100-year storm. $Q_{f\text{-}100} = 3.53 \times 1.15 = 4.06$ ac-ft.

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Analyze Safe Passage of 100-Year Design Storm (Qf)

If peak discharge control of the 100-year storm is not required, it is still necessary to provide safe passage for the 100-year event under ultimate buildout conditions (Q_{ult} = 227 cfs).

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Section 8.2 Pond Design Example

Following is a step-by-step design example for an extended detention pond (P-3) applied to Stone Hill Estates, which is described in detail in Section 8.1 along with design treatment volumes. This example continues with the design to develop actual design parameters for the constructed facility.

Step 1. Compute preliminary runoff control volumes.

The volume requirements were determined in Section 8.1. Table 8.1 provides a summary of the storage requirements.

Table 8.1. Summary of General Storage Requirements for Stone Hill Estates

Symbol	*Category*	Volume Required (ac- ft)	*Notes*
WQ_v	Water Quality Volume	1.07	
Cp_v	Stream Protection	2.4	Average ED release rate is 1.2 cfs over 24 hours
Q_p	Peak Control	2.6	10-year, in this case
Q_f	Flood Control	4.1	

Step 2. Determine if the development site and conditions are appropriate for the use of a stormwater pond.

The drainage area to the pond is 65.1 acres. Existing ground at the proposed pond outlet is 619 MSL. Soil boring observations reveal that the seasonally high water table is at elevation 618. The underlying soils are SC (sandy clay) and are suitable for earthen embankments and to support a wet pond without a liner. The stream invert at the adjacent stream is at elevation 616.

Step 3. Confirm local design criteria and applicability.

There are no additional requirements for this site.

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Step 4. Determine pretreatment volume.

Size wet forebay to treat 10% of the WQ_v. (10%)(1.07 ac-ft) = **0.1 ac-ft**
(forebay volume is included in WQ_v as part of permanent pool volume)

Step 5. Determine permanent pool volume and ED volume.

Size permanent pool volume to contain 50% of WQ_v:
0.5 × (1.07 ac-ft) = **0.54 ac-ft.** (includes 0.1 ac-ft of forebay volume)

Size ED volume to contain 50% of WQ_v: 0.5 × (1.07 ac-ft) = **0.54 ac-ft**

NOTE

THIS DESIGN APPROACH ASSUMES THAT ALL OF THE ED VOLUME WILL BE IN THE POND AT ONCE. WHILE THIS WILL NOT BE THE CASE, SINCE THERE IS A DISCHARGE DURING THE EARLY STAGES OF STORMS, THIS CONSERVATIVE APPROACH ALLOWS FOR ED CONTROL OVER A WIDER RANGE OF STORMS, NOT JUST THE TARGET RAINFALL.

Step 6. Determine pond location and preliminary geometry. Conduct pond grading and determine storage available for WQv permanent pool and WQv-ED if applicable.

This step involves initially grading the pond (establishing contours) and determining the elevation-storage relationship for the pond. Storage must be provided for the permanent pool (including sediment forebay), extended detention (WQ_v-ED), Cp_v-ED, 10-year storm, 100-year storm, plus sufficient additional storage to pass the ultimate condition 100-year storm with required freeboard. An elevation-storage table and curve is prepared using the average area method for computing volumes. See Figure 8.7 for pond location on site, Figure 8.8 for grading and Figure 8.9 for Elevation-Storage Data.

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Figure 8.7 Pond Location on Site

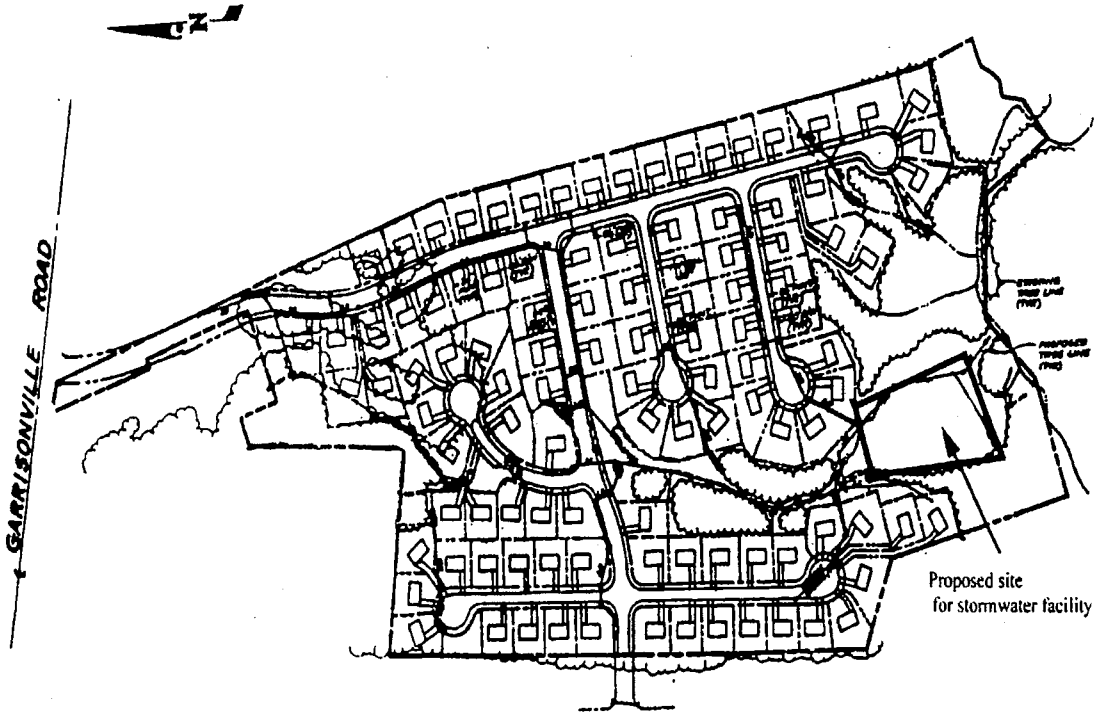

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Figure 8.8 Plan View of Pond Grading (Not to Scale)

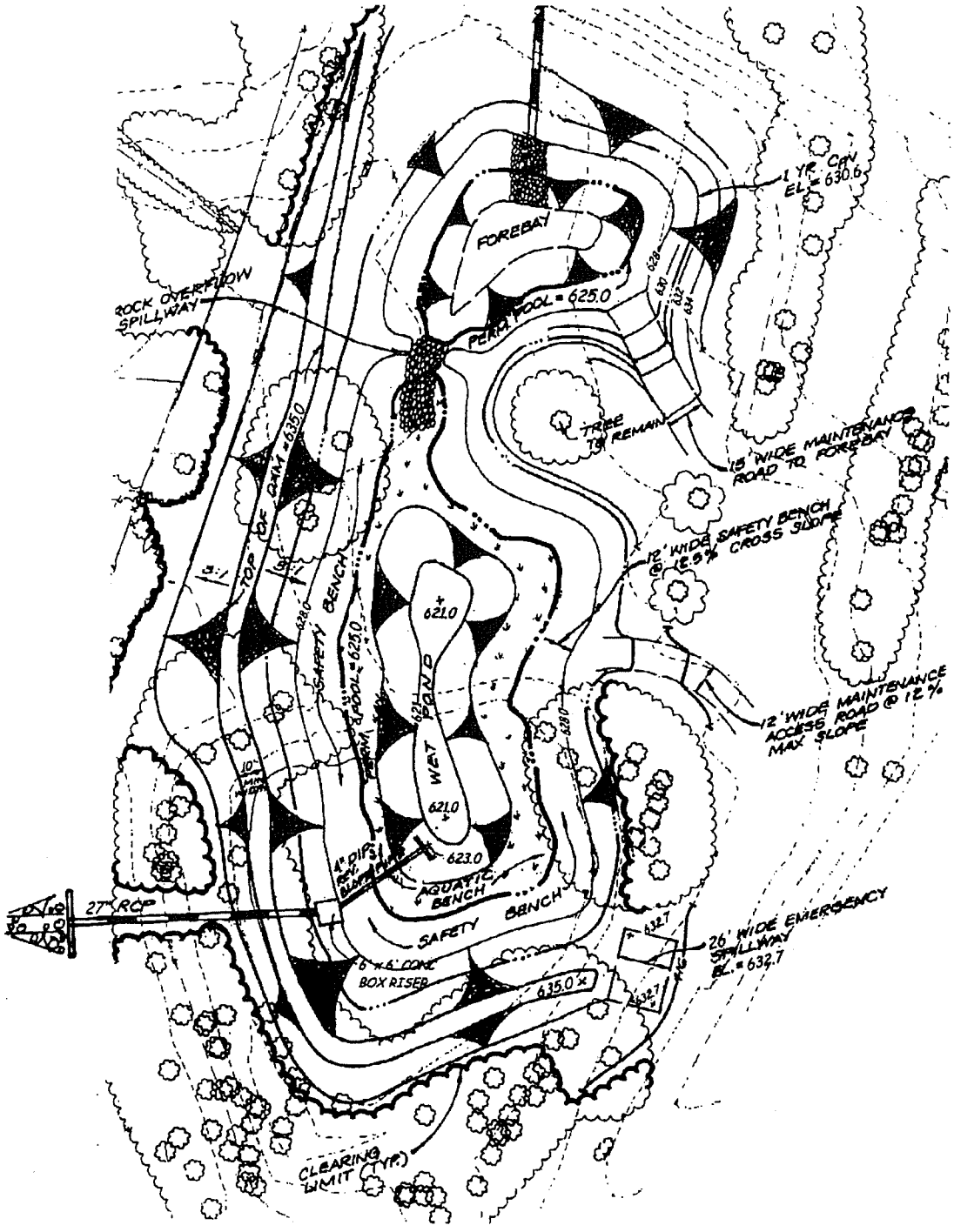

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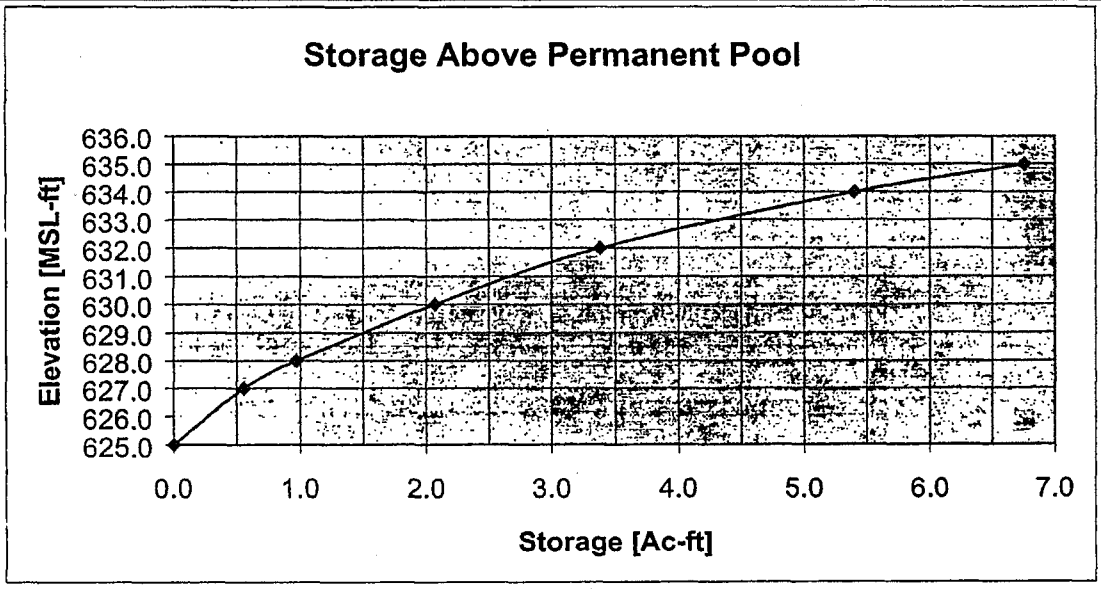
Figure 8.9 Storage-Elevation Table/Curve

Elevation MSL	Area ft^2	Average Area ft^2	Depth ft	Volume ft^3	Cumulative Volume ft^3	Cumulative Volume ac-ft	Volume Above Permanent Pool ac-ft
621.0	3150						
624.0	8325	5738	3	17213	17213	0.40	
625.0	10400	9363	1	9363	26575	0.61	0
627.0	13850	12125	2	24250	50825	1.17	0.56
628.0	21850	17850	1	17850	68675	1.58	0.97
630.0	26350	24100	2	48200	116875	2.68	2.07
632.0	30475	28413	2	56825	173700	3.99	3.38
634.0	57685	44080	2	88160	261860	6.01	5.40
635.0	60125	58905	1	58905	320765	7.36	6.75



Set basic elevations for pond structures

- The pond bottom is set at elevation 621.0
- Provide gravity flow to allow for pond drain, set riser invert at 620.5
- Set barrel outlet elevation at 620.0

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Set water surface and other elevations

- Required permanent pool volume = 50% of WQv = 0.54 ac-ft. From the elevation-storage table, read elevation 625.0 (0.61 ac-ft > 0.54 ac-ft) site can accommodate it and it allows a small safety factor for fine sediment accumulation – OK

Set permanent pool wsel = 625.0

- Forebay volume provided in single pool with volume = 0.1 ac-ft - OK
- Required extended detention volume (WQ_v-ED)= 0.54 ac-ft. From the elevation-storage table (volume above permanent pool), read elevation 627.0 (0.56 ac-ft > 0.54 ac-ft) OK. Set ED wsel = 627.0

Note: Total storage at elevation 627.0 = 1.17 ac-ft (greater than required WQ_v of 1.07 ac-ft)

Compute the required WQ_v-ED orifice diameter to release 0.54 ac-ft over 24 hours

- Avg. ED release rate = (0.54 ac-ft)(43,560 ft^2/ac)/(24 hr)(3600 sec/hr) = 0.27 cfs
- Invert of orifice set at wsel = 625.0
- Average head = (627.0 - 625.0)/ 2 = 1.0'
- Use orifice equation to compute cross-sectional area and diameter

  $Q = CA(2gh)^{0.5}$, for Q=0.27 cfs h = 1.0 ft; C = 0.6 = discharge coefficient. Solve for A

  $A = 0.27 \text{ cfs} / [(0.6)((2)32.2 \text{ ft/s}^2)(1.0 \text{ ft}))^{0.5}]$ $A = 0.057 \text{ ft}^2$, $A = \pi d^2 / 4$;

  dia. = 0.26 ft = 3.2", say 3.0 inches

  Use 4" pipe with 4" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 3.0" dia. WQv orifice

- $Q_{WQv\text{-}ED} = CA(2gh)^{0.5} = (0.6)\ (0.052 \text{ ft}^2)\ [((2)(32.2 \text{ ft/s}^2))^{0.5}]\ (h^{0.5})$,
- $Q_{WQv\text{-}ED} = (0.25)\ h^{0.5}$, where: h = wsel - 625.125

  (Note: Account for one half of orifice diameter when calculating head)

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Step 7. Compute ED orifice size, and compute release rate for Cpv-ED control and establish Cpv elevation.

Set the Cp_v pool elevation

- Required Cp_v storage = 2.4 ac-ft (see Table 1).
- From the elevation-storage table, read elevation 630.6 (this includes the WQ_v).
- Set Cp_v wsel = 630.6

Size Cp_v orifice

- Size to release average of 1.2 cfs.
- Set invert of orifice at wsel = 627.0
- Average WQ_v-ED orifice release rate is 0.41 cfs, based on average head of 2.74' ((630.6 – 625.125)/2)
- Cp_v-ED orifice release = 1.2 -0.41 = 0.79 cfs
- Head = (630.6 - 627.0)/2 = 1.8'

Use orifice equation to compute cross-sectional area and diameter

- $Q = CA(2gh)^{0.5}$, for h = 1.8'
  - $A = 0.79 \text{ cfs} / [(0.6)((2)(32.2'/s^2)(1.8'))^{0.5}]$
  - $A = 0.12 \text{ ft}^2$, $A = \pi d^2 / 4$;
  - dia. = 0.39 ft = 4.7"
  - Use 6" pipe with 6" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 4.7" dia. Cp_v orifice

- $Q_{Cpv\text{-}ED} = CA(2gh)^{0.5} = (0.6)\ (0.12 \text{ ft}^2)\ [((2)\ (32.2'/s^2))^{0.5}]\ (h^{0.5})$,
- $Q_{Cpv\text{-}ED} = (0.58)\ (h^{0.5})$, where: h = wsel – 627.2

(Note: Account for one half of orifice diameter when calculating head)

Step 8. Calculate Qp_{10} (10 year storm) release rate and water surface elevation.

In order to calculate the 10 year release rate and water surface elevation, the designer must set up a stage-storage-discharge relationship for the control structure for each of the low flow release pipes (WQ_v-ED and Cp_v-ED) plus the 10 year storm.

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Develop basic data and information

- The 10 year pre-developed peak discharge = 72 cfs,
- The post developed inflow = 112 cfs, from Table 1,
- From previous estimate Q_{p-10} = 2.26 ac-ft. Adding 15% to account for ED storage yields a preliminary volume of 2.56 ac-ft.
- From elevation-storage table (Figure 8.9), read elevation 631.0.
- Size 10 year slot to release 72 cfs at elevation 631.0.

@ wsel 631.0:

- WQ_v-ED orifice releases 0.61 cfs,
- Cp_v-ED orifice releases 1.13 cfs, therefore;
- Allowable Q_{p-10} = 72 cfs - (.61 + 1.13) = 70.26 cfs, say 70.3 cfs.
- Set weir crest elevation at wsel = 630.6
- Max head = (631.0 – 630.6) = 0.4'

Use weir equation to compute slot length

- $Q = CLh^{3/2}$
- $L = 70.3 \text{ cfs} / (3.1)(0.4^{3/2}) = 89.6$ ft
- This weir length is impractical, so adjust max head (and therefore slot height) to 1.5' and recalculate weir length.
- $L = 70.3 \text{ cfs} / (3.1)(1.5^{3/2}) = 12.3$ ft
- Use three 5ft x 1.5 ft slots for 10-year release (opening should be slightly larger than needed so as to have the barrel control before slot goes from weir flow to orifice flow).
- Maximum $Q = (3.1)(15)(1.5)^{3/2} = 85.4$ cfs

Check orifice equation using cross-sectional area of opening

- $Q = CA(2gh)^{0.5}$, for h = 0.75' (For orifice equation, h is from midpoint of slot)
- $A = 3\ (5.0')\ (1.5') = 22.5 ft^2$
- $Q = 0.6\ (22.5ft^2)\ [(64.4)(0.75)]^{0.5} = 93.8$ cfs > 85.4 cfs, so use weir equation

$$Q_{10} = (3.1)\ (15')\ h^{3/2}\ ,\ \underline{Q_{10} = (46.5)\ h^{3/2},\ \text{where } h = \text{wsel} - 630.6}$$

- Size barrel to release approximately 70.3 cfs at elevation 632.1 (630.6 + 1.5)
- Check inlet condition: (use FHWA culvert charts)

H_w = 632.1-620.5 = 11.6 ft

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- Try 27" diameter RCP, Using FHWA Chart ("Headwater Depth for Concrete Pipe Culverts with Inlet Control") with entrance condition 1
- $H_w / D = 11.6/2.25 = 5.15$, Discharge = 69 cfs
- Check outlet condition (use NRCS pipe flow equation from NEH Section 5 ES-42):
- $Q = a [(2gh)/(1+k_m+k_pL)]^{0.5}$

where:
- Q = discharge in cfs
- a = pipe cross sectional area in ft^2
- g = acceleration of gravity in ft/sec^2
- h = head differential (wsel - downstream centerline of pipe or tailwater elev.)
- k_m = coefficient of minor losses (use 1.0)
- k_p = pipe friction loss coef. (= $5087n^2/d^{4/3}$, d in inches, n is Manning's n)
- L = pipe length in ft

h = 632.1 - (620.0 + 1.125) = 10.98'

for 27" RCP, approximately 70 feet long:

$Q = 4.0 [(64.4) (10.98) / (1+1+(0.0106) (70))]^{0.5} = 64.2$ cfs

64.2 cfs < 69 cfs, so barrel is outlet controlled and use outlet equation

$Q = 19.4 (h)^{0.5}$, where h = wsel – 621.125

Note: pipe will control flow before high stage inlet reaches max head.

Complete stage-storage-discharge summary (Figure 8.10) up to preliminary 10-year wsel (632.1) and route 10 year post-developed condition inflow using computer software (e.g., TR-20). Pond routing computes 10-year wsel at 632.5 with discharge = 65.4 cfs < 72 cfs, OK (see Figure 8.11).

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Figure 8.10 Stage-Storage-Discharge Summary

Elevation MSL	Storage ac-ft	Low Flow WQv-ED 3.0" eq dia		Riser						27" Barrel				Emergency Spillway 26' earthen 3:1		Total Discharge
				Cpv-ED 4.7" eq. dia		High Stage Slot				Inlet		Pipe				
						Orifice		Weir								
		H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	Q cfs
625.0	0.00	0	0													0.00
625.5	0.14	0.4	0.15													0.15
626.0	0.28	0.9	0.23													0.23
626.5	0.42	1.4	0.29													0.29
627.0	0.56	1.9	0.34	0.0	0.00											0.34
627.5	0.77	2.4	0.39	0.3	0.32											0.70
628.0	0.97	2.9	0.42	0.8	0.52											0.94
629.0	1.52	3.9	0.49	1.8	0.78											1.27
629.5	1.80	4.4	0.52	2.3	0.88											1.40
630.0	2.07	4.9	0.55	2.8	0.97											1.52
630.6	2.40	5.5	0.58	3.4	1.07	-	-	0.0	0.0							1.65
631.0	2.73	5.9	0.61	3.8	1.13	-	-	0.4	11.8							13.5
632.1	3.45	7.0	0.66	4.9	1.28	0.75	94	1.5	85.4	11.6	69.0	11.0	64.2			64.2
632.5	3.80	7.4	0.68	5.3	1.34	0.95	106	-	-	12.0	70.0	11.4	65.4			65.4
632.7	4.10	7.6	0.69	5.5	1.36	1.05	111	-	-	12.2	71.0	11.6	66.0	0.0	0.0	66.0
633.3	4.70	-	-	-	-	-	-	-	-	12.8	72.0	12.2	67.6	0.6	26.0	93.6
634.0	5.40	-	-	-	-	-	-	-	-	13.5	73.0	12.9	69.6	1.3	95.0	164.6
635.0	6.75	-	-	-	-	-	-	-	-	14.5	86.0	13.9	72.2	2.3	251.0	323.2

Note: Adequate outfall protection must be provided in the form of a riprap channel, plunge pool, or combination to ensure non-erosive velocities.

Step 9. Calculate Qp_{100} (100-year storm) release rate and water surface elevation, size emergency spillway, calculate 100-year water surface elevation.

In order to calculate the 100-year release rate and water surface elevation, the designer must continue with the stage-storage-discharge relationship (Figure 8.10) for the control riser and emergency spillway.

Develop basic data and information

- The 100 year pre-developed peak discharge = 141 cfs,
- The post developed inflow = 202 cfs, from Table 1,
- From previous estimate $Q_{p\text{-}100}$ = 3.53 ac-ft. Adding 15% to account for ED storage yields a preliminary volume of 4.06 ac-ft.
- From elevation-storage table (Figure 8.10), read elevation 632.8, say 633.0.

The 10-year wsel is at 632.5. Set the emergency spillway at elevation at 632.7 (this allows for some additional storage above the 10-yr wsel) and use design information and criteria for Earth Spillways (not included in this manual).

- Size 100 year spillway to release 141 cfs at elevation 633.0.
- @ wsel 633.0:

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- Outflow from riser structure is controlled by barrel (under outlet control), from Figure 8.11, read Q = 67.6 cfs at wsel = 633.3. Assume Q = 67 cfs at wsel = 633.0.
- Set spillway invert at wsel = 632.7
- Try 26' wide vegetated emergency spillway with 3:1 side slopes.
- Finalize stage-storage-discharge relationships and perform pond routing

Pond routing (TR-20) computes 100-year wsel at 633.76 with discharge = 140.95 cfs < 141 cfs, OK (see Figure 8.11).

Note: this process of sizing the emergency spillway and storage volume determination is usually iterative. This example reflects previous iterations at arriving at an acceptable design solution.

Step 10. Check for safe passage of Qp_{100} under ultimate buildout conditions and set top of embankment elevation.

The safety design of the pond embankment requires that the 100-year discharge, based on ultimate buildout conditions be able to pass safely through the emergency spillway with sufficient freeboard (one foot). This criteria does not mean that the ultimate buildout peak discharge be attenuated to pre-development rates.

From previous hydrologic modeling we know that:

- The 100 year ultimate buildout peak discharge = 227 cfs,
- The ultimate buildout composite curve number is 82.

Using TR-20 or equivalent routing model, determine peak wsel. Pond routing computes 100-year wsel at 634.0 with discharge = 192 cfs (Figure 8.12).

Therefore, with one foot of freeboard, the minimum embankment elevation is 635.0. Table 8.2 provides a summary of the storage, stage, and discharge relationships determined for this design example. See Figure 8.13 for a schematic of the riser.

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Table 8.2 Summary of Controls Provided					
Control Element	**Type/Size of Control**	**Storage Provided**	**Elevation**	**Discharge**	**Remarks**
Units		Acre-feet	MSL	cfs	
Permanent Pool		0.61	625.0	0	part of WQ_v
Forebay	submerged berm	0.1	625.0	0	included in permanent pool vol.
Extended Detention (WQ_v-ED)	4" pipe, sized to 3.0" equivalent diameter	0.56	627.0	0.25	part of WQ_v, vol. above perm. pool, discharge is average release rate over 24 hours
Channel Protection (Cp_v-ED)	6" pipe sized to 4.7" equivalent diameter	2.4	630.6	1.2	volume above perm. pool, discharge is average release rate over 24 hours
Overbank Protection (Q_{p-10})	Three 5' x 1.5' slots on a 6' x 6' riser, 30"barrel.	2.5	632.5	65.4	volume above perm. pool
Extreme Storm (Q_{f-100})	26' wide earth spillway	4.0	633.8	140.9	volume above perm. pool
Extreme Storm Ultimate Buildout	26' wide earth spillway	NA	634	192.0	Set minimum embankment height at 635.0

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Figure 8.11 TR-20 Model Input and Output

```
******************80-80 LIST OF INPUT DATA FOR TR-20 HYDROLOGY*****************

JOB TR-20                          FULLPRINT                        NOPLOTS
TITLE      New York Manual Wet ED Example 1/01                EWB
TITLE      Post Developed Conditions Routing for 1, 10, and 100
 3 STRUCT       1
 8                        625.0        0.0          0.0
 8                        625.5        0.15         0.14
 8                        626.0        0.23         0.28
 8                        626.5        0.29         0.42
 8                        627.0        0.34         0.56
 8                        627.5        0.70         0.77
 8                        628.0        0.94         0.97
 8                        629.0        1.27         1.52
 8                        629.5        1.40         1.80
 8                        630.0        1.52         2.07
 8                        630.6        1.65         2.40
 8                        631.0        13.50        2.73
 8                        632.1        64.20        3.45
 8                        632.7        66.00        4.10
 8                        633.3        93.60        4.70
 8                        634.0        165.0        5.40
 8                        635.0        35230        6.75
 9 ENDTBL
 6 RUNOFF 1       1      2 0.102      78.0         0.35         1 1    0 0 1
 6 RESVOR 2       1 2    3 625.0                                1 1        1
   ENDATA
 7 INCREM 6               0.1
 7 COMPUT 7       1      1 0.0        2.3          1.0          2 2    1  01
   ENDCMP 1
 7 COMPUT 7       1      1 0.0        3.9          1.0          2 2    1  10
   ENDCMP 1
 7 COMPUT 7       1      1 0.0        5.5          1.0          2 2    1  99
   ENDCMP 1
   ENDJOB 2

*********************************END OF 80-80 LIST*********************************
```


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TR20 XEQ 1/22/** New York Manual Wet ED Example 1/01 EWB JOB 1 SUMMARY
REV 09/01/83 Post Developed Conditions Routing for 1, 10, and 100 PAGE 8

SUMMARY TABLE 1 - SELECTED RESULTS OF STANDARD AND EXECUTIVE CONTROL INSTRUCTIONS IN THE ORDER PERFORMED
A STAR(*) AFTER THE PEAK DISCHARGE TIME AND RATE (CFS) VALUES INDICATES A FLAT TOP HYDROGRAPH
A QUESTION MARK(?) INDICATES A HYDROGRAPH WITH PEAK AS LAST POINT.)

SECTION/ STRUCTURE ID	STANDARD CONTROL OPERATION	DRAINAGE AREA (SQ MI)	RAIN TABLE #	ANTEC MOIST COND	MAIN TIME INCREM (HR)	PRECIPITATION BEGIN (HR)	PRECIPITATION AMOUNT (IN)	PRECIPITATION DURATION (HR)	RUNOFF AMOUNT (IN)	PEAK DISCHARGE ELEVATION (FT)	PEAK DISCHARGE TIME (HR)	PEAK DISCHARGE RATE (CFS)	PEAK DISCHARGE RATE CSM)
ALTERNATE 1 STORM 1													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	2.30	24.00	.66	---	12.13	40.62	398.2
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	2.30	24.00	.40	630.31	18.00?	1.59?	15.6
ALTERNATE 1 STORM 10													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	3.90	24.00	1.81	---	12.11	118.47	161.5
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	3.90	24.00	1.49	632.51	12.34	65.43	41.5
ALTERNATE 1 STORM 99													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	5.50	24.00	3.14	---	12.11	206.59	025.4
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	5.50	24.00	2.80	633.76	12.29	140.95	381.9

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Figure 8.12 TR-20 Model Input and Output for Ultimate Buildout Conditions

```
TR20 XEQ  1/22/**          New York Manual Wet ED Example 1/01          EWB          JOB  1  SUMMARY
     REV 09/01/83          Ultimate Buildout Conditions for 100-yr                   PAGE  4

SUMMARY TABLE 1 - SELECTED RESULTS OF STANDARD AND EXECUTIVE CONTROL INSTRUCTIONS IN THE ORDER PERFORMED
                  (A STAR(*) AFTER THE PEAK DISCHARGE TIME AND RATE (CFS) VALUES INDICATES A FLAT TOP HYDROGRAPH
                   A QUESTION MARK(?) INDICATES A HYDROGRAPH WITH PEAK AS LAST POINT.)
```

SECTION/ STRUCTURE ID	STANDARD CONTROL OPERATION	DRAINAGE AREA (SQ MI)	RAIN TABLE #	ANTEC MOIST COND	MAIN TIME INCREM (HR)	PRECIPITATION BEGIN (HR)	PRECIPITATION AMOUNT (IN)	PRECIPITATION DURATION (HR)	RUNOFF AMOUNT (IN)	PEAK DISCHARGE ELEVATION (FT)	PEAK DISCHARGE TIME (HR)	PEAK DISCHARGE RATE (CFS)	PEAK DISCHARGE RATE (CSM)
ALTERNATE 1 STORM 99													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	5.50	24.00	3.53	---	12.10	230.71	2261.9
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	5.50	24.00	3.19	634.00	12.22	191.83	1880.7

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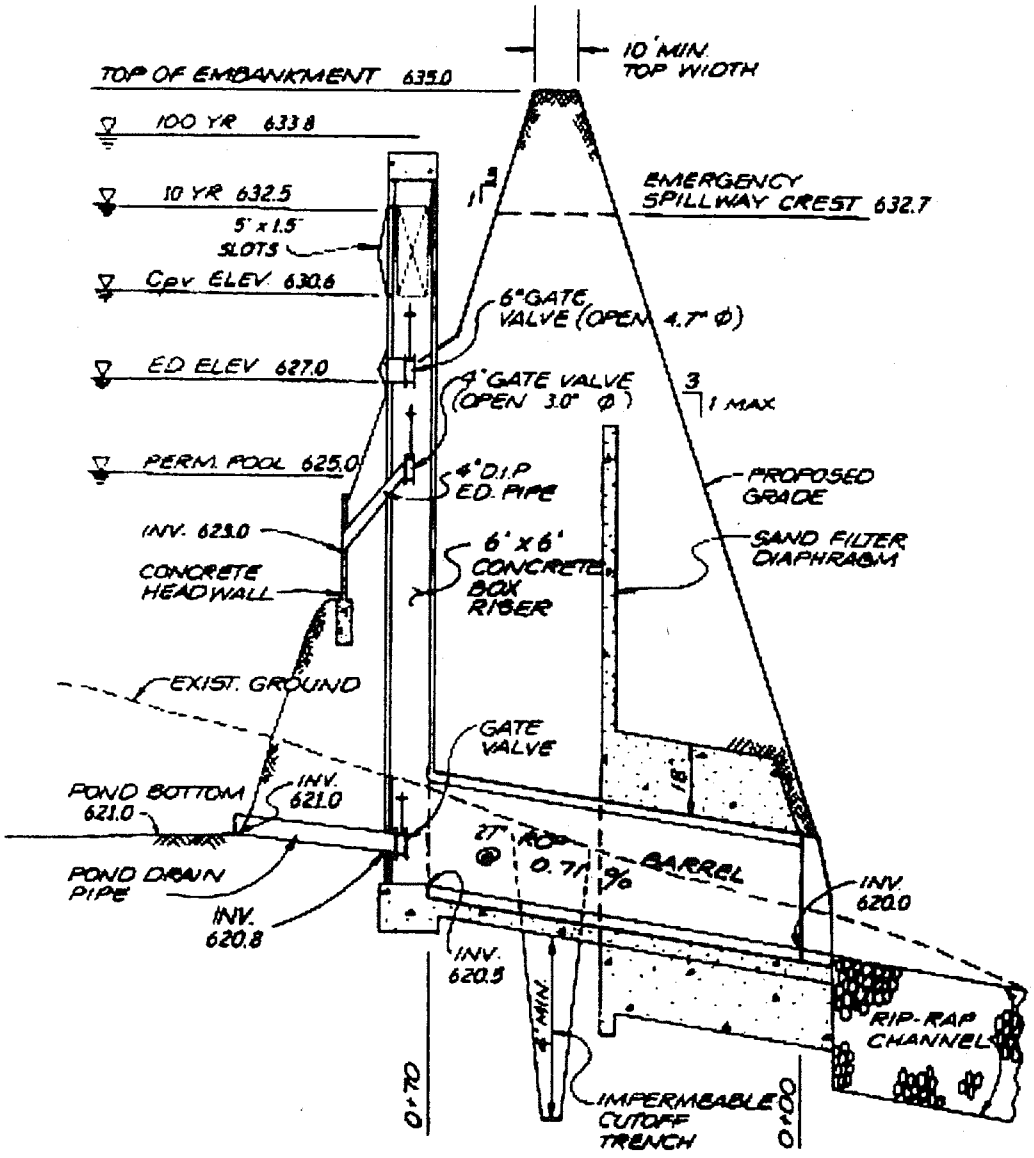
Figure 8.13 Profile of Principle Spillway



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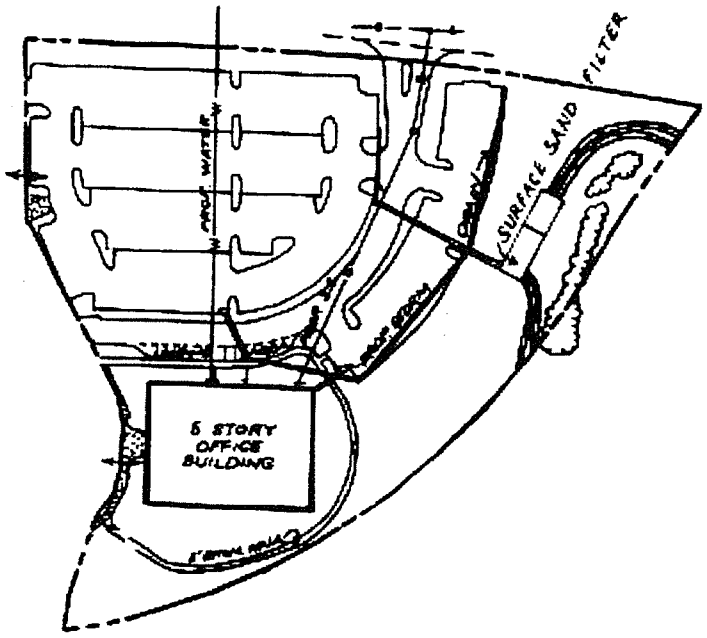
Section 8.3 Sand Filter Design Example

This design example focuses on the design of a sand filter for a 4.5-acre catchment of Lake Center, a hypothetical commercial site located in Albany, NY. A five-story office building and associated parking are proposed within the catchment. The layout is shown in Figure 8.14. The catchment has 3.05 acres of impervious cover, resulting in 68% impervious cover. The pre-developed site is a mixture of forest and meadow. On-site soils are predominantly HSG "B" soils.

Figure 8.14 Lake Center Site Plan



Base Data
Location: Albany, NY
Site Area = Total Drainage Area (A) = 4.50 ac
Impervious Area = 3.05 ac; or I =3.05/4.50 = 68%
Soils Type "B"

Hydrologic Data

	Pre	Post
CN	58	83
t_c (hr)	.44	.10

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This step-by-step example will focus on meeting the water quality requirements. Channel protection control, overbank flood control, and extreme flood control are not addressed in this example. Therefore, a detailed hydrologic analysis is not presented. For an example of detailed sizing calculations, consult section 8.1. In general, the primary function of sand filters is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. For this example, the post-development 10-yr peak discharge is provided to appropriately size the necessary by-pass flow splitter. Where quantity control is required, bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults).

Step 1. Compute design volumes using the Unified Stormwater Sizing Criteria.

Water Quality Volume, WQ_v

Select the Design Storm

Consulting Figure 4.1 of this document, use 1.0" as the 90% rainfall event for Albany.

Compute Runoff Coefficient, R_v

$R_v = 0.05 + (68)\ (0.009) = 0.66$

Compute WQ_v

$WQ_v = (1.0")\ (R_v)\ (A) / 12$

$= (1.0")\ (0.66)\ (4.5\ ac)\ (43{,}560 ft^2/ac)\ (1ft/12in)$

$= \underline{10{,}781}\ ft^3 = \underline{0.25\ ac\text{-}ft}$

Develop Site Hydrologic Input Parameters and Perform Preliminary Hydrologic Calculations (see Table 8.3)

Note: For this design example, the 10-year peak discharge is given and will be used to size the bypass flow splitter. Any hydrologic models using SCS procedures, such as TR-20, HEC-HMS, or HEC-1, can be used to perform preliminary hydrologic calculations.

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SARB_007529

Table 8.3 Site Hydrology					
Condition	**CN**	**Q_1**	**Q_2**	**Q_{10}**	**Q_{100}**
		cfs	*cfs*	*cfs*	*cfs*
Pre-developed	58	0.2	0.4	3	9
Post-Developed	83	7	10	19	36

Step 2. Determine if the development site and conditions are appropriate for the use of a surface sand filter.

Site Specific Data:

Existing ground elevation at practice location is 222.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 211.0 feet. Adjacent drainage channel invert is at 213.0 feet.

Step 3. Compute available head, & peak discharge (Q_{wq}).

- Determine available head (See Figure 8.15)

The low point at the parking lot is 223.5. Subtract 2' to pass the Q_{10} discharge (221.5) and a half foot for the inflow channel to the facility (221.0). The low point at the channel invert is 213.0. Set the outfall underdrain pipe 1.0' above the drainage channel invert and add 0.5' to this value for the drain slope (214.5). Add to this value 8" for the gravel blanket over the underdrains, and 18" for the sand bed (216.67). The total available head is 221.0 - 216.67 or 4.33 feet. Therefore, the available average depth (h_f) = 4.33' / 2 = 2.17'.

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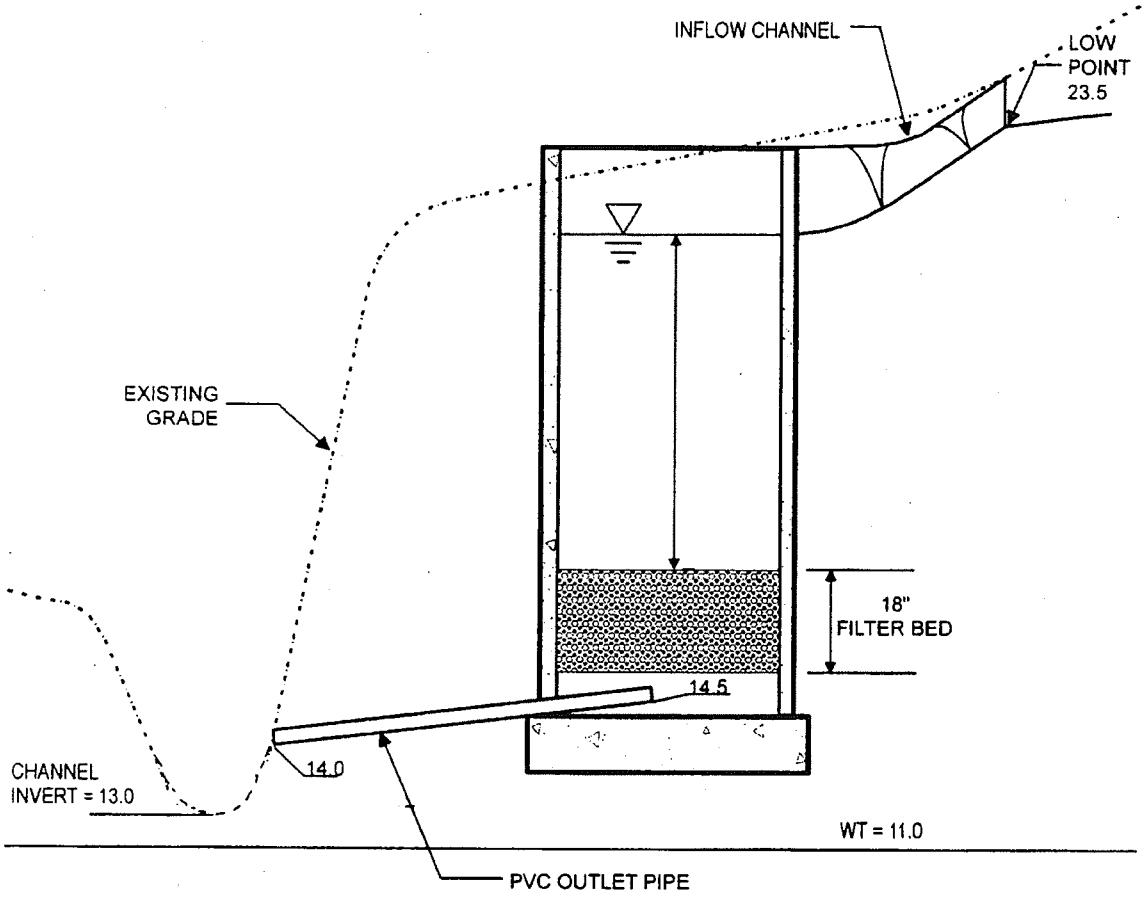
Figure 8.15 Available Head Diagram



- Compute Peak Water Quality Discharge:

The peak rate of discharge for the water quality design storm is needed for the sizing of off-line diversion structures, such as sand filters and grass channels. The Small Storm Hydrology Method presented in Appendix B was followed to calculate a modified curve number and subsequent peak discharge associated with the 1.0-inch rainfall. Calculation steps are provided below.

Compute modified CN for 1.0" rainfall

$P = 1.0"$

$Q_a = WQ_v \div \text{area} = (10{,}781\ ft^3 \div 4.5\ ac \div 43{,}560\ ft^2/ac \times 12\ in/ft) = 0.66"$

$CN = 1000/[10+5P+10Q_a-10(Q_a^2+1.25*Q_a*P)^{½}]$

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$= 1000/[10+5*1.0+10*0.66-10(0.66^2+1.25*0.66*1.0)^{1/2}]$

$= 96.4$

Use CN = 96

For CN = 96 and the t_c = 0.1 hours, compute the Q_{wq} for a 1.0" storm. With the CN = 96, a 1.0" storm will produce 0.6" of runoff. From TR-55 Chapter 2, Hydrology, I_a = 0.083, therefore:

$I_a/P = 0.083/1.0 = 0.083$.

From TR-55 Chapter 4 q_u = 1000 csm/in, and

Q_{wq} = (1000 csm/in) (4.5 ac/640ac/sq mi.) (0.66") = 4.6 cfs.

Step 4. Size the flow diversion structure.

Assume that flows are diverted to a diversion structure (Figure 8.16). First, size a low-flow orifice to pass the water quality storm (Q_p = 4.6 cfs).

$Q = CA(2gh)^{1/2}$; 4.6 cfs = (0.6) (A) $[(2)\ (32.2\ ft/s^2)\ (1.5')]^{1/2}$

A = 0.77 sq ft = $\pi d^2/4$: d = 0.99' or 12"

Size the 10-year overflow as follows:
The 10-year wsel is initially set at 223.0. Use a concrete weir to pass the 10-year flow (19.0 cfs), minus the flow carried by the low flow orifice, into a grassed overflow channel using the Weir equation. Assume 2' of head to pass this event. Overflow channel should be designed to provide sufficient energy dissipation (e.g., riprap, plunge pool, etc.) so that there will be non-erosive velocities.

Determine the flow from the low-flow orifice (Q_{lf}). Assume 3.5' of head (1.5' plus 2' for the 10-year head):

Q_{lf}=(0.6) (A) $[(2)\ (32.2\ ft/s^2)\ (3.5')]^{1/2}$

$A = \pi(1')^2/4$

$= 0.78$ sf

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So,

Q_{tf} = (0.6) (0.78) [(2) (32.2 ft/s^2) (3.5')]$^{1/2}$

= 7.0 cfs

Thus, determine the flow passed to the through the channel as:

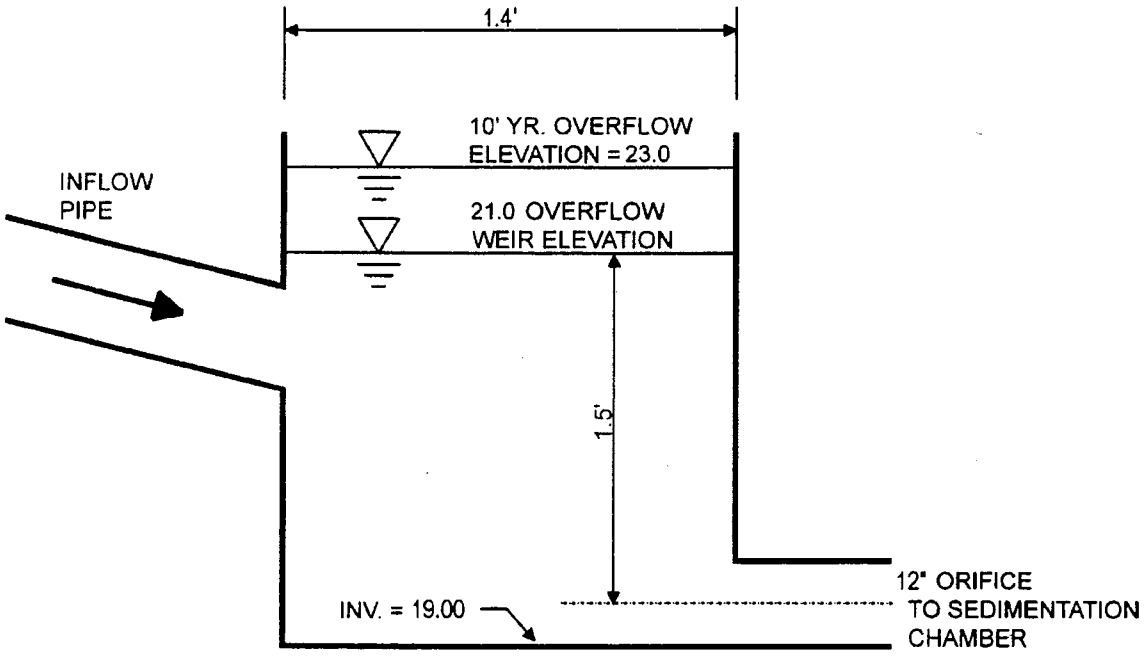
$Q = CLH^{3/2}$

(19-7) = 3.1 (L) (2')$^{1.5}$

L = 1.4' which sets the minimum length of the flow diversion overflow weir.

Weir wall elev. = 21.0. Set low flow invert at 21.0 - [1.5' + (0.5*12"*1ft/12")] = 19.00.

Figure 8.16 Flow Diversion Structure



Step 5. Size filtration bed chamber (see Figure 8.17).

From Darcy's Law: $A_f = WQ_v (d_f) / [k (h_f + d_f) (t_f)]$

where d_f = 18" or 1.5' (Filter thickness)

k = 3.5 ft/day (Flow-through rate)

h_f = 2.17' (Average head on filter)

t_f = 40 hours (Drain time)

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A_f = (10,781 cubic feet) (1.5') / [3.5 (2.17' + 1.5') (40hr/24hr/day)]

A_f = 755 sq ft; filter is 20' by 40' (= 800 sq ft)

Step 6. Size sedimentation chamber.

Size the sedimentation chamber as wet storage with a 2.5' depth. Determine the pretreatment volume as:

P_v = (0.25) (10,781 cf)

= 2,695 cf

Therefore,

A_s = (2,695 cf)/(2.5')

= 1,078 sf (Use 20'X55' or 1,100 sf)

Step 7. Compute V_{min}.

V_{min} = ¾(WQ_v) or 0.75 (10,781 cubic feet) = 8,086 cubic feet

Step 8. Compute volume within practice.

Volume within filter bed (V_f): $V_f = A_f (d_f) (n)$; n = 0.4 for sand

V_f = (800 sq ft) (1.5') (0.4) = 480 cf

temporary storage above filter bed ($V_{f\text{-}temp}$): $V_{f\text{-}temp} = 2h_fA_f$

$V_{f\text{-}temp}$ = 2 (2.17') (800 sq ft) = 3,472 cf

Compute storage in the sedimentation chamber (V_s):

V_s = (2.5')(1,100 sf)+4.33'(1,100 sf) = 7,513 cf

$V_f + V_{f\text{-}temp} + V_s$ = 480 cf + 3,472 cf + 7,513 cf = 11,465 cf

11,465 > 8,086 OK.

Pass flow through to the distribution chamber using a 12" orifice with an inverted elbow (see Figure 8.17).

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Step 9. Compute sedimentation chamber and filter bed overflow weir sizes.

Assume overflow that needs to be handled is equivalent to the 12" orifice discharge under a head of 3.5 ft (i.e., the head in the diversion chamber associated with the 10-year peak discharge).

$Q = CA(2gh)^{1/2}$

$Q = 0.6(0.79\ ft^2)[(2)(32.2\ ft/s^2)(3.5\ ft)]^{1/2}$

$Q = 7.1 cfs$

Size the overflow weir from the sediment chamber and the filtration chamber to pass 7.1 cfs (this assumes no attenuation within the practice).

Weir equation: $Q = CLh^{3/2}$, assume a maximum allowable head of 0.5'

$7.1 = 3.1 * L * (0.5\ ft)^{3/2}$

$\underline{L = 6.5\ ft.}$

Adequate outlet protection and energy dissipation (e.g., riprap, plunge pool, etc.) should be provided for the downstream overflow channel.

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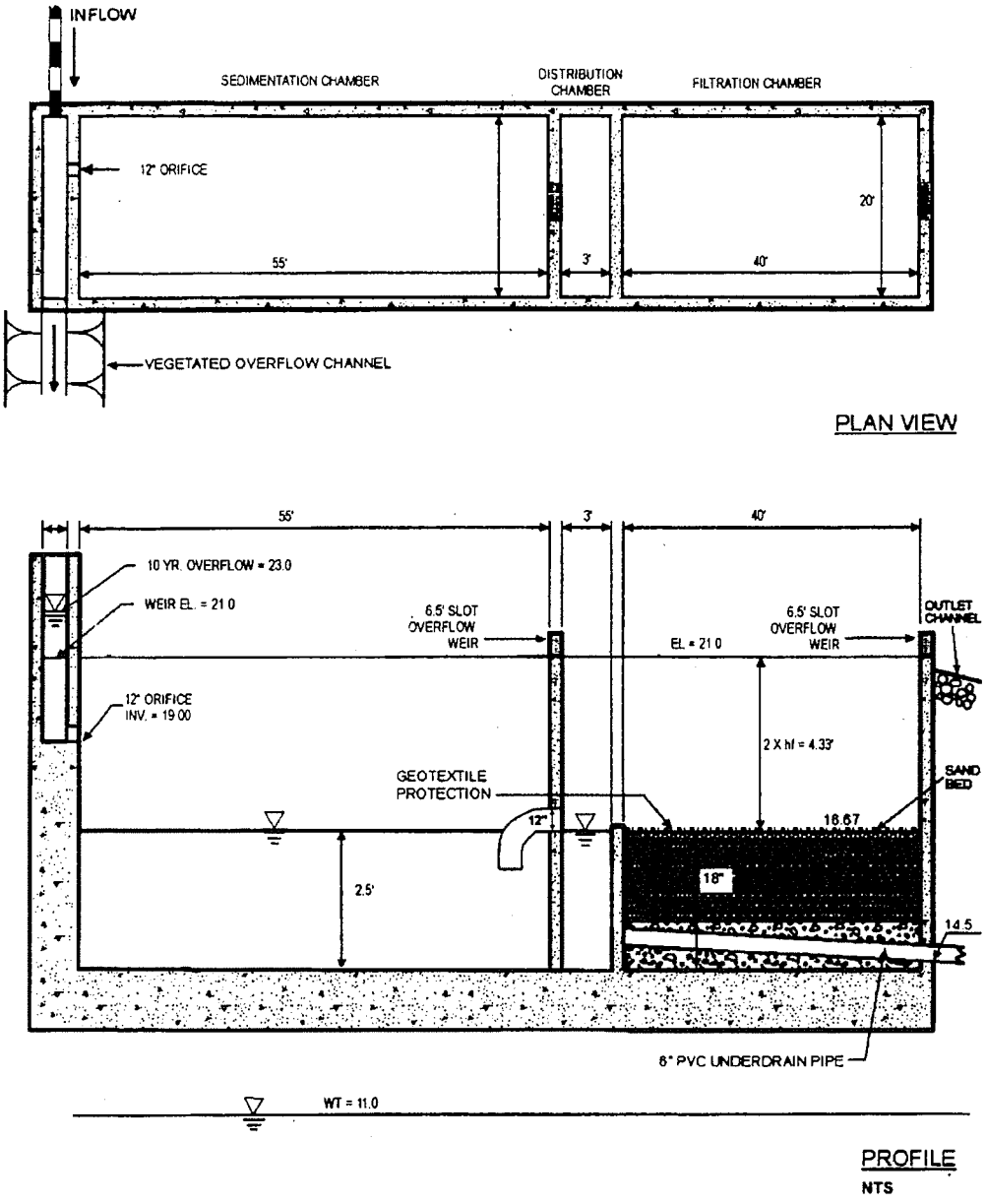
Figure 8.17 Plan and Profile of Surface Sand Filter



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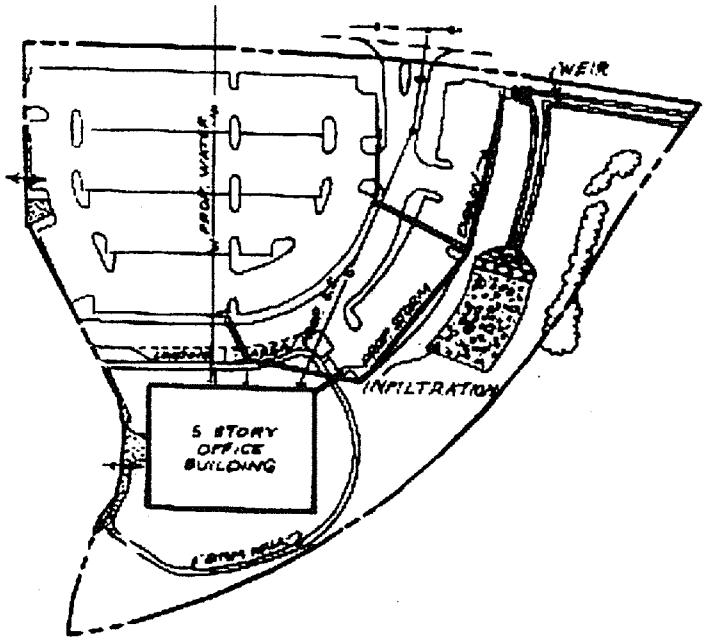
Section 8.4 Infiltration Trench Design Example

This design example focuses on the design of an infiltration trench for a 4.5-acre catchment of the Lake Center, a hypothetical commercial site located in Albany, NY. A five-story office building and associated parking are proposed within this catchment. The layout is shown in Figure 8.18. The catchment has 3.05 acres of impervious cover, resulting in a site impervious cover of 68%. The pre-developed site is a mixture of forest and meadow. On-site soils are predominantly HSG "B" soils.

Figure 8.18 Lake Center Site Plan



Base Data	*Hydrologic Data*		
Location: Albany, NY			
Site Area = Total Drainage Area (A) = 4.5 ac			
Impervious Area = 3.05 ac; or I =3.05/4.50 = 68%		**Pre**	**Post**
Soils Type "B"	CN	58	83
	t_c (hrs)	.44	.10

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This step-by-step example will focus on meeting the water quality requirements. Channel protection control, overbank flood control, and extreme flood control are not addressed in this example. Therefore, a detailed hydrologic analysis is not presented. For an example of detailed sizing calculations, consult section 8.1. In general, the primary function of infiltration practices is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. For this example, the post-development 10-yr peak discharge is provided to appropriately size the necessary by-pass flow splitter. Where quantity control is required, bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults).

Step 1. Compute design volumes and flows using the Unified Stormwater Sizing Criteria.

Design values are presented in Table 8.4 below.

Table 8.4 Site Design Hydrology

Condition	CN	WQ_v	Q_1	Q_2	Q_{10}
		ft³	*cfs*	*cfs*	*cfs*
Pre-Developed	58		0.2	0.4	3
Post-Developed	83	10,781	7	10	19

Step 2. Determine if the development site and conditions are appropriate for the use of an infiltration trench.

Site Specific Data:

Table 8.5 presents site-specific data, such as soil type, percolation rate, and slope, for consideration in the design of the infiltration trench. See Appendix D for infiltration testing requirements and Appendix C for infiltration practice construction specifications.

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Table 8.5 Site Specific Data	
Criteria	**Value**
Soil	Silt Loam
Percolation Rate	0.5"/hour
Ground Elevation at BMP	219'
Seasonally High Water Table	211'
Local Ground Slope	<1%

Step 3. Confirm local design criteria and applicability.

Table 8.6, below, summarizes the requirements that need to be met to successfully implement infiltration practices. On this site, infiltration is feasible, with restrictions on the depth and width of the trench.

Table 8.6 Infiltration Feasibility	
Criteria	**Status**
Infiltration rate (f_c) greater than or equal to 0.5 inches/hour.	• Infiltration rate is 0.5 inches/hour. OK.
Soils have a clay content of less than 20% and a silt/clay content of less than 40%.	• Silt Loam meets both criteria.
Infiltration cannot be located on slopes greater than 6% or in fill soils.	• Slope is <1%; not fill soils. OK.
Hotspot runoff should not be infiltrated.	• Not a hotspot land use. OK.
The bottom of the infiltration facility must be separated by at least two feet vertically from the seasonally high water table.	• Elevation of seasonally high water table: 11' • Elevation of BMP location: 19'. • The difference is 8'. • Thus, the trench can be up to 5' deep. OK.
Infiltration facilities must be located 100 feet horizontally from any water supply well.	• No water supply wells nearby. OK.
Maximum contributing area generally less than 5 acres.	• Area draining to facility is approximately 4.5 acres.
Setback 25 feet down-gradient from structures.	• Trench edge is > 25' from all structures. OK.

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Step 4. Size overflow channel.

Water flows from the edge of the parking lot to a 4' wide, flat bottom channel with 3:1 side slopes and a 2% slope. This channel also provides pretreatment (See Step 6). Use a weir to divert the water quality volume to the infiltration trench, while allowing the 10-year event to an adjacent drainage channel and the water quality storm to flow to the infiltration trench. The peak flow for the water quality storm is 4.6 cfs (see Section 8.3 for an example calculation).

Determine the depth of flow for the water quality storm using Manning's equation. (Several software packages can be used). The following assumptions are made:

Trapezoidal channel with 3:1 side slopes

4' bottom width.

S = 1%

n varies between 0.03 at 1' depth to 0.15 at 4" depth (See Appendix L and Grass Channel Fact Sheet in Chapter 5).

Determine that the water quality storm passes at d = 0.64'.

Size a weir to pass the 10-year peak event, less the water quality peak flow, so that:

Q = 19cfs – 4.6 cfs = 14.4 cfs.

Use a weir length, L, of 4.0'.

By rearranging the weir equation:

$H= (Q/CL)^{2/3} = (14.4/3.1(4))^{2/3} = 1.1'$

Size the channel to pass the 10-year event with 6" of freeboard.

Step 5. Size the infiltration trench.

The area of the trench can be determined by the following equation:

A = WQv/(nd)

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Where:

A = Surface Area

WQ_v = Water Quality volume (ft^3)

n = Porosity

d = Trench depth (feet)

Assume that:

n = 0.4

d = 4 feet

Therefore:

A = 10,781 ft^3 / (0.4 × 4)ft

A = 6,738ft^2

The proposed location for the infiltration trench will accommodate a trench width of up to 65 feet. Therefore, the minimum length required would be:

L = 6,738 ft^2 / 65 ft

L = 104 feet, say 105 feet

Step 6. Size pretreatment.

Pass the 10-year flow event through an overflow channel.

Size pretreatment to treat ¼ of the WQ_v. Therefore, treat 10,781 × 0.25 = 2,695 ft^3.

For pretreatment, use a pea gravel filter layer with filter fabric, a plunge pool, and a grass channel.

Pea Gravel Filter

The pea gravel filter layer covers the entire trench with 2" (see Figure 8.19). Assuming a porosity of 0.32, the pretreatment volume (Pv) provided in the pea gravel filter layer is:

Pv_{filter} = (0.32)(2")(1 ft/12 inches)(125')(50') = 333 ft^3

Plunge Pools

Use a 65 'X20' triangular plunge pool with a two foot depth as flow is diverted to the infiltration trench.

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Pv_{pool} = (65 x 20 ft)/2 *(2 ft) = 1,300 ft^3

Grass Channel

Accounting for the pretreatment volumes provided by the pea gravel filter and plunge pool, the grass channel then needs to treat at least (2,695 - 333 – 1,300)ft^3 = 1,062 ft^3

Currently stormwater flows through a 150' long channel, with parameters described under step 4. For this channel, the flow velocity of the peak flow from the water quality storm (4.6 cfs) is approximately 1.2 fps.

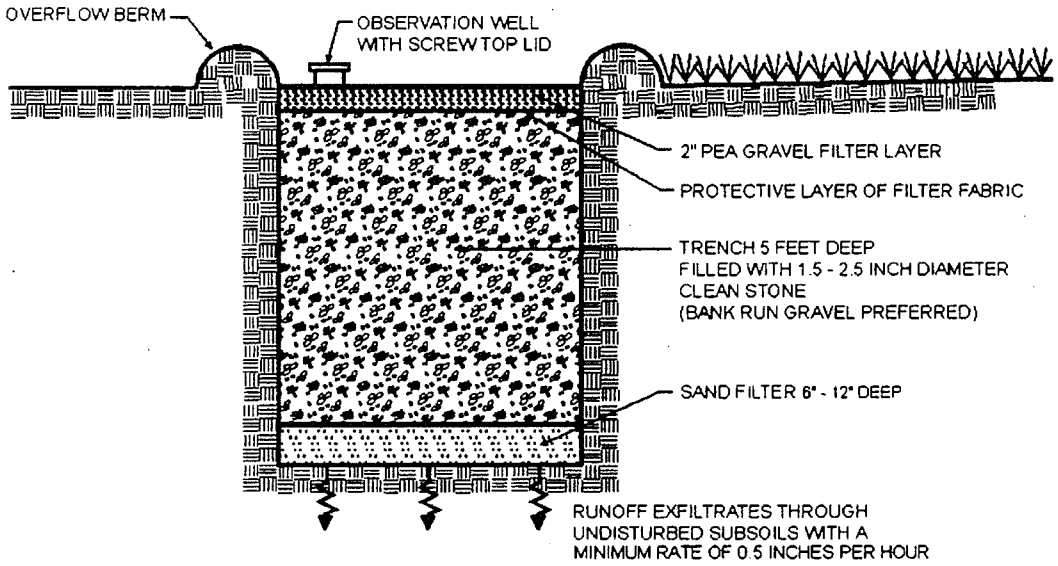
Using a required residence time of 10 minutes (600 seconds), the required length of channel for 100% of the WQ_v (10,781 ft^3) would be 1.2 fps x 600 sec = 720ft.

Adjust the length to account for the volume that must be provided, or:

(720ft) (1,062 ft^3)/(10,781 ft^3) = 71 ft

Therefore, for this example, a grass channel length of at least 71 feet is required. 150' is OK.

Figure 8.19 Schematic Infiltration Trench Cross Section



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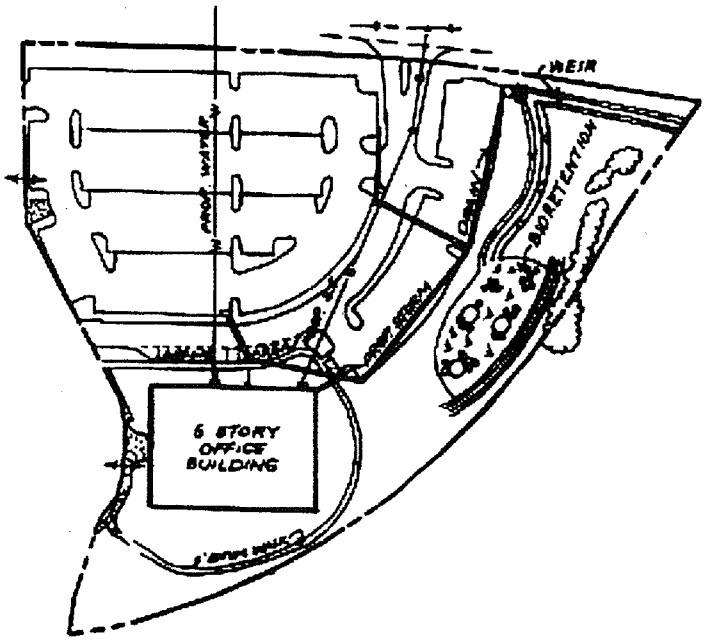
Section 8.5 Bioretention Design Example

This design example focuses on the design of a Bioretention area for a 4.5-acre catchment of Lake Center, a hypothetical commercial site located in Albany, NY. A five-story office building and associated parking are proposed within this catchment. The layout is shown in Figure 8.20. The catchment has 3.05 acres of impervious cover, resulting in 68% impervious cover. The pre-developed site is a mixture of forest and meadow. On-site soils are predominantly HSG "B" soils.

Figure 8.20 Lake Center Site Plan



Base Data
Location: Albany, NY
Site Area = Total Drainage Area (A) = 4.5 ac
Impervious Area = 3.05 ac; or I =3.05/4.50 = 68%
Soils Type "B"

Hydrologic Data

	Pre	Post
CN	58	83
t_c	.44	.10

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This step-by-step example will focus on meeting the water quality requirements. Channel protection control, overbank flood control, and extreme flood control are not addressed in this example. Therefore, a detailed hydrologic analysis is not presented. For an example of detailed sizing calculations, consult section 8.1. In general, the primary function of bioretention is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. For this example, the post-development 2-year and 10-year peaks are used to appropriately size the grass channel leading to the facility.

Step 1. Compute design volumes using the Unified Stormwater Sizing Criteria.

Design volumes are presented in Table 8.7 below.

Table 8.7 Design Hydrology

Condition	CN	WQ_v	Q_1	Q_2	Q_{10}
		ft³	*cfs*	*cfs*	*cfs*
Pre-developed	58		0.3	0.6	4
Post-Developed	83	10,781	9	13	26

Step 2. Determine if the development site and conditions are appropriate for the use of a bioretention area.

Site Specific Data:

Existing ground elevation at practice location is 222.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 211.0 feet and underlying soil is silt loam (ML). Adjacent channel invert is at 213 feet.

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Step 3. Determine size of bioretention filter area.

$A_f = (WQ_v)(d_f) / [(k)(h_f + d_f)(t_f)]$

Where:
- A_f = surface area of filter bed (ft^2)
- d_f = filter bed depth (ft)
- k = coefficient of permeability of filter media (ft/day)
- h_f = average height of water above filter bed (ft)
- t_f = design filter bed drain time (days) (2 days is recommended)

$A_f = (10{,}781\ ft^3)(5') / [(0.5'/day)(0.25' + 5')(2\ days)]$ (With k = 0.5'/day, $h_f = 0.25'$, $t_f = 2$ days)

$A_f =$ 10,267 sq ft

Step 4. Set design elevations and dimensions.

Assume a roughly 2 to 1 rectangular shape. Given a filter area requirement of 10,267 sq ft, say facility is roughly 70' by 150'. Set top of facility at 219.0 feet, with the berm at 220.0 feet. The facility is 5' deep, which will allow 3' of separation distance over the seasonally high water table. See Figure 8.21 for a typical section of the facility.

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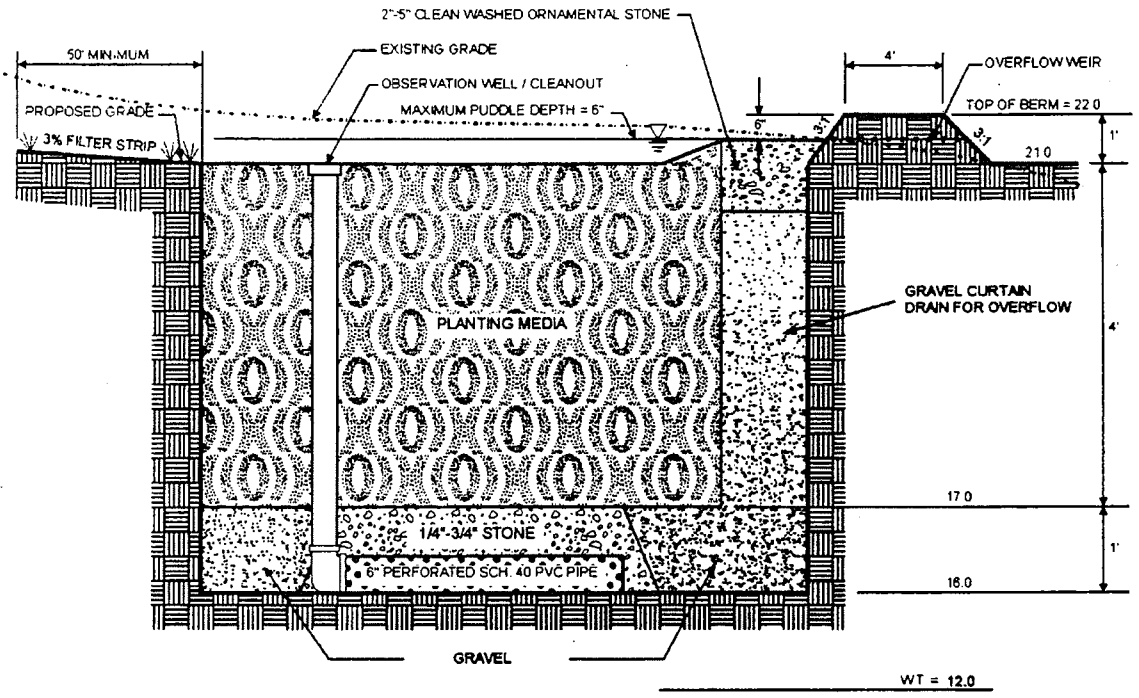
Figure 8.21 Typical Section of Bioretention Facility



Step 5. Size overflow channel.

Assuming the same channel configuration as in Section 8.3, use a 4' weir set 0.63' above the base of the overflow channel. The overflow channel will flow to the adjacent drainage channel, while the water quality storm will be diverted to the bioretention cell.

Step 6. Design Pretreatment

Size pretreatment to treat ¼ of the WQ_v. Therefore, treat $10,781 \times 0.25 = 2,695$ ft^3.

For pretreatment, a grass channel is used. This channel has a 4' width and 3:1 side slopes.

Using the methodologies described in Section 6.3, determine that the length of channel required to treat the entire water quality volume is 720 ft. Adjust the length to correspond to the pretreatment volume, or L = (720 ft)(2,695/10,781) = 180ft.

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Step 7. Size underdrain area.

As a rule of thumb, the length of underdrain should be based on 10% of the A_f or 1,027 sq ft and a three-foot wide zone of influence. Using 8" perforated plastic pipes surrounded by a three-foot wide gravel bed, 10' on center (o.c.), yields the following length of pipe:

(1,027 sq ft)/3' per foot of underdrain = 342' of perforated underdrain

Step 8. Create overdrain design.

To ensure against the planting media clogging, design a small ornamental stone window of 2" to 5" stone connected directly to the gravel curtain drain. This area is based on 5% of the A_f or 514 sq ft. Say 15' by 35' (see Figure 8.23).

Step 9. Choose plants for planting area.

Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Select species locations (i.e., on center planting distances) so species will not "shade out" one another. Do not plant trees and shrubs with extensive root systems (e.g., willows) near pipe work. A potential plant list for this site is presented in Appendix H.

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Glossary

New York State Stormwater Management Design Manual

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Glossary

ANTI-SEEP COLLAR - An impermeable diaphragm usually of sheet metal or concrete constructed at intervals within the zone of saturation along the conduit of a principal spillway to increase the seepage length along the conduit and thereby prevent piping or seepage along the conduit.

ANTI-VORTEX DEVICE - A device designed and placed on the top of a riser or at the entrance of a pipe to prevent the formation of a vortex in the water at the entrance.

AQUATIC BENCH - A ten to fifteen foot wide bench which is located around the inside perimeter of a permanent pool and is normally vegetated with aquatic plants; the goal is to provide pollutant removal and enhance safety in areas using stormwater pond SMP's.

AQUIFER - A geological formation which contains and transports groundwater.

"AS-BUILT" - Drawing or certification of conditions as they were actually constructed.

BAFFLES - Guides, grids, grating or similar devices placed in a pond to deflect or regulate flow and create a longer flow path.

BANKFULL FLOW - The condition where streamflow just fills a stream channel up to the top of the bank and at a point where the water begins to overflow onto a floodplain.

BARREL - The closed conduit used to convey water under or through an embankment: part of the principal spillway.

BASE FLOW - The stream discharge from ground water.

BERM - A shelf that breaks the continuity of a slope; a linear embankment or dike.

BIORETENTION - A water quality practice that utilizes landscaping and soils to treat urban stormwater runoff by collecting it in shallow depressions, before filtering through a fabricated planting soil media.

CHANNEL - A natural stream that conveys water; a ditch or channel excavated for the flow of water.

CHANNEL STABILIZATION - Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, structural linings, vegetation and other measures.

CHECK DAM - A small dam constructed in a gully or other small watercourse to decrease the stream flow velocity (by reducing the channel gradient), minimize channel scour, and promote deposition of sediment.

CHUTE - A high velocity, open channel for conveying water to a lower level without erosion.

CLAY (SOILS) - 1. A mineral soil separate consisting of particles less than 0.002 millimeter in equivalent diameter. 2. A soil texture class. 3. (Engineering) A fine grained soil (more than 50 percent passing the No. 200 sieve) that has a high plasticity index in relation to the liquid limit. (Unified Soil Classification System)

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COCONUT ROLLS - Also known as coir rolls, these are rolls of natural coconut fiber designed to be used for streambank stabilization.

COMPACTION (SOILS) - Any process by which the soil grains are rearranged to decrease void space and bring them in closer contact with one another, thereby increasing the weight of solid material per unit of volume, increasing the shear and bearing strength and reducing permeability.

CONDUIT - Any channel intended for the conveyance of water, whether open or closed.

CONTOUR - 1. An imaginary line on the surface of the earth connecting points of the same elevation. 2. A line drawn on a map connecting points of the same elevation.

CORE TRENCH - A trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

CRADLE - A structure usually of concrete shaped to fit around the bottom and sides of a conduit to support the conduit, increase its strength and in dams, to fill all voids between the underside of the conduit and the soil.

CREST - 1. The top of a dam, dike, spillway or weir, frequently restricted to the overflow portion. 2. The summit of a wave or peak of a flood.

CRUSHED STONE - Aggregate consisting of angular particles produced by mechanically crushing rock.

CURVE NUMBER (CN) - A numerical representation of a given area's hydrologic soil group, plant cover, impervious cover, interception and surface storage derived in accordance with Natural Resources Conservation Service methods. This number is used to convert rainfall volume into runoff volume.

CUT - Portion of land surface or area from which earth has been removed or will be removed by excavation; the depth below original ground surface to excavated surface.

CUT-AND-FILL - Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

CUTOFF - A wall or other structure, such as a trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

CZARA - Acronym used for the Coastal Zone Act Reauthorization Amendments of 1990. These amendments sought to address the issue of nonpoint source pollution issue by requiring states to develop Coastal Nonpoint Pollution Control Programs in order to receive federal funds.

DAM - A barrier to confine or raise water for storage or diversion, to create a hydraulic head, to prevent gully erosion, or for retention of soil, sediment or other debris.

DETENTION - The temporary storage of storm runoff in a SMP with the goals of controlling peak discharge rates and providing gravity settling of pollutants.

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DETENTION STRUCTURE - A structure constructed for the purpose of temporary storage of stream flow or surface runoff and gradual release of stored water at controlled rates.

DIKE - An embankment to confine or control water, for example, one built along the banks of a river to prevent overflow or lowlands; a levee.

DISTRIBUTED RUNOFF CONTROL (DRC) - A stream channel protection criteria which utilizes a non-uniform distribution of the storage stage-discharge relationship within a SMP to minimize the change in channel erosion potential from predeveloped to developed conditions.

DISTURBED AREA - An area in which the natural vegetative soil cover has been removed or altered and, therefore, is susceptible to erosion.

DIVERSION - A channel with a supporting ridge on the lower side constructed across the slope to divert water from areas where it is in excess to sites where it can be used or disposed of safely. Diversions differ from terraces in that they are individually designed.

DRAINAGE - 1. The removal of excess surface water or ground water from land by means of surface or subsurface drains. 2. Soils characteristics that affect natural drainage.

DRAINAGE AREA (WATERSHED) - All land and water area from which runoff may run to a common (design) point.

DROP STRUCTURE - A structure for dropping water to a lower level and dissipating surplus energy; a fall. The drop may be vertical or inclined.

DRY SWALE - An open drainage channel explicitly designed to detain and promote the filtration of stormwater runoff through an underlying fabricated soil media.

EMERGENCY SPILLWAY - A dam spillway designed and constructed to discharge flow in excess of the principal spillway design discharge.

ENERGY DISSIPATOR - A designed device such as an apron of rip-rap or a concrete structure placed at the end of a water transmitting apparatus such as pipe, paved ditch or paved chute for the purpose of reducing the velocity, energy and turbulence of the discharged water.

EROSION - 1. The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. 2. Detachment and movement of soil or rock fragments by water, wind, ice or gravity. The following terms are used to describe different types of water erosion:

Accelerated erosion - Erosion much more rapid than normal, natural or geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of other animals or natural catastrophes that expose base surfaces, for example, fires.

Gully erosion - The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 or 2 feet to as much as 75 to 100 feet.

Rill erosion - An erosion process in which numerous small channels only several inches deep are formed. See rill.

Sheet erosion - The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not subsequently be removed by surface runoff.

EROSIVE VELOCITIES - Velocities of water that are high enough to wear away the land surface. Exposed soil will generally erode faster than stabilized soils. Erosive velocities will vary according to the soil type, slope, structural, or vegetative stabilization used to protect the soil.

EXFILTRATION - The downward movement of water through the soil; the downward flow of runoff from the bottom of an infiltration SMP into the soil.

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EXTENDED DETENTION (ED) - A stormwater design feature that provides for the gradual release of a volume of water over a 12 to 48 hour interval in order to increase settling of urban pollutants and protect downstream channels from frequent storm events.

EXTREME FLOOD (Q_f) - The storage volume required to control those infrequent but large storm events in which overbank flows approach the floodplain boundaries of the 100-year flood.

FILTER BED - The section of a constructed filtration device that houses the filter media and the outflow piping.

FILTER FENCE - A geotextile fabric designed to trap sediment and filter runoff.

FILTER MEDIA - The sand, soil, or other organic material in a filtration device used to provide a permeable surface for pollutant and sediment removal.

FILTER STRIP - A strip of permanent vegetation above ponds, diversions and other structures to retard flow of runoff water, causing deposition of transported material, thereby reducing sediment flow.

FINES (SOIL) - Generally refers to the silt and clay size particles in soil.

FLOODPLAIN - Areas adjacent to a stream or river that are subject to flooding or inundation during a storm event that occurs, on average, once every 100 years (or has a likelihood of occurrence of 1/100 in any given year).

FLOW SPLITTER - An engineered, hydraulic structure designed to divert a percentage of storm flow to a SMP located out of the primary channel, or to direct stormwater to a parallel pipe system, or to bypass a portion of baseflow around a SMP.

FOREBAY - Storage space located near a stormwater SMP inlet that serves to trap incoming coarse sediments before they accumulate in the main treatment area.

FREEBOARD (HYDRAULICS) - The distance between the maximum water surface elevation anticipated in design and the top of retaining banks or structures. Freeboard is provided to prevent overtopping due to unforeseen conditions.

FOURTH ORDER STREAM - Designation of stream size where many water quantity requirements may not be needed. A first order stream is identified by "blue lines" on USGS quad sheets. A second order stream is the confluence of two first order streams, and so on.

FRENCH DRAIN - A type of drain consisting of an excavated trench refilled with pervious material, such as coarse sand, gravel or crushed stone, through whose voids water percolates and flows to an outlet.

GABION - A flexible woven-wire basket composed of two to six rectangular cells filled with small stones. Gabions may be assembled into many types of structures such as revetments, retaining walls, channel liners, drop structures and groins.

GABION MATTRESS - A thin gabion, usually six or nine inches thick, used to line channels for erosion control.

GRADE - 1. The slope of a road, channel or natural ground. 2. The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction, like paving or laying a conduit. 3. To finish the surface of a canal bed, roadbed, top of embankment or bottom of excavation.

GRASS CHANNEL - A open vegetated channel used to convey runoff and to provide treatment by filtering out pollutants and sediments.

GRAVEL - 1. Aggregate consisting of mixed sizes of 1/4 inch to 3 inch particles which normally occur in or near old streambeds and have been worn smooth by the action of water. 2. A soil having particle sizes, according to the Unified Soil Classification System, ranging from the No. 4 sieve size angular in shape as produced by mechanical crushing.

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GRAVEL DIAPHRAGM - A stone trench filled with small, river-run gravel used as pretreatment and inflow regulation in stormwater filtering systems.

GRAVEL FILTER - Washed and graded sand and gravel aggregate placed around a drain or well screen to prevent the movement of fine materials from the aquifer into the drain or well.

GRAVEL TRENCH - A shallow excavated channel backfilled with gravel and designed to provide temporary storage and permit percolation of runoff into the soil substrate.

GROUND COVER - Plants which are low-growing and provide a thick growth which protects the soil as well as providing some beautification of the area occupied.

GULLY - A channel or miniature valley cut by concentrated runoff through which water commonly flows only during and immediately after heavy rains or during the melting of snow. The distinction between gully and rill is one of depth. A gully is sufficiently deep that it would not be obliterated by normal tillage operations, whereas a rill is of lessor depth and would be smoothed by ordinary farm tillage.

HEAD (HYDRAULICS) - 1. The height of water above any plane of reference. 2. The energy, either kinetic or potential, possessed by each unit weight of a liquid expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various terms such as pressure head, velocity head, and head loss.

HERBACEOUS PERENNIAL (PLANTS) - A plant whose stems die back to the ground each year.

HI MARSH - A pondscaping zone within a stormwater wetland which exists from the surface of the normal pool to a six inch depth and typically contains the greatest density and diversity of emergent wetland plants.

HI MARSH WEDGES - Slices of shallow wetland (less than or equal to 6 inches) dividing a stormwater wetland.

HOT SPOT - Area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

HYDRAULIC GRADIENT - The slope of the hydraulic grade line. The slope of the free surface of water flowing in an open channel.

HYPOXIA - Lack of oxygen in a waterbody resulting from eutrophication.

HYDROGRAPH - A graph showing variation in stage (depth) or discharge of a stream of water over a period of time.

HYDROLOGIC SOIL GROUP (HSG) - A Natural Resource Conservation Service classification system in which soils are categorized into four runoff potential groups. The groups range from A soils, with high permeability and little runoff production, to D soils, which have low permeability rates and produce much more runoff.

HYDROSEED - Seed or other material applied to areas in order to revegetate after a disturbance.

IMPERVIOUS COVER (I) - Those surfaces in the urban landscape that cannot effectively infiltrate rainfall consisting of building rooftops, pavement, sidewalks, driveways, etc.

INDUSTRIAL STORMWATER PERMIT - An NPDES permit issued to a commercial industry or group of industries which regulates the pollutant levels associated with industrial storm water discharges or specifies on-site pollution control strategies.

INFILTRATION RATE (F_c) - The rate at which stormwater percolates into the subsoil measured in inches per hour.

INFLOW PROTECTION - A water handling device used to protect the transition area between any water conveyance (dike, swale, or swale dike) and a sediment trapping device.

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LEVEL SPREADER - A device for distributing stormwater uniformly over the ground surface as sheet flow to prevent concentrated, erosive flows and promote infiltration.

MANNING'S FORMULA (HYDRAULICS) - A formula used to predict the velocity of water flow in an open channel or pipeline:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where V is the mean velocity of flow in feet per second; R is the hydraulic radius; S is the slope of the energy gradient or for assumed uniform flow the slope of the channel, in feet per foot; and n is the roughness coefficient or retardance factor of the channel lining.

MICROPOOL - A smaller permanent pool which is incorporated into the design of larger stormwater ponds to avoid resuspension or settling of particles and minimize impacts to adjacent natural features.

MICROTOPOGRAPHY - The complex contours along the bottom of a shallow marsh system, providing greater depth variation which increases the wetland plant diversity and increases the surface area to volume ratio of a stormwater wetland.

MULCH - Covering on surface of soil to protect and enhance certain characteristics, such as water retention qualities.

MUNICIPAL STORMWATER PERMIT - A SPDES permit issued to municipalities to regulate discharges from municipal separate storm sewers for compliance with EPA established water quality standards and/or to specify stormwater control strategies.

NPDES - Acronym for the National Pollutant Discharge Elimination System, which regulates point source and non-point source discharge.

NITROGEN-FIXING (BACTERIA) - Bacteria having the ability to fix atmospheric nitrogen, making it available for use by plants. Inoculation of legume seeds is one way to insure a source of these bacteria for specified legumes.

NORMAL DEPTH - Depth of flow in an open conduit during uniform flow for the given conditions.

OUTFALL - The point where water flows from a conduit, stream, or drain.

OFF-LINE - A stormwater management system designed to manage a storm event by diverting a percentage of stormwater events from a stream or storm drainage system.

ON-LINE - A stormwater management system designed to manage stormwater in its original stream or drainage channel.

ONE YEAR STORM ($Q_{P\,1}$) - A stormwater event which occurs on average once every year or statistically has a 100% chance on average of occurring in a given year.

ONE HUNDRED YEAR STORM ($Q_{P\,100}$) A extreme flood event which occurs on average once every 100 years or statistically has a 1% chance on average of occurring in a given year.

OPEN CHANNELS - Also known as swales, grass channels, and biofilters. These systems are used for the conveyance, retention, infiltration and filtration of stormwater runoff.

OUTLET - The point at which water discharges from such things as a stream, river, lake, tidal basin, pipe, channel or drainage area.

OUTLET CHANNEL - A waterway constructed or altered primarily to carry water from man-made structures such as terraces, subsurface drains, diversions and impoundments.

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PEAK DISCHARGE RATE - The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

PERMANENT SEEDING - Results in establishing perennial vegetation which may remain on the area for many years.

PERMEABILITY - The rate of water movement through the soil column under saturated conditions

PERMISSIBLE VELOCITY (HYDRAULICS) - The highest average velocity at which water may be carried safely in a channel or other conduit. The highest velocity that can exist through a substantial length of a conduit and not cause scour of the channel. A safe, non-eroding or allowable velocity

pH - A number denoting the common logarithm of the reciprocal of the hydrogen ion concentration. A pH of 7.0 denotes neutrality, higher values indicate alkalinity, and lower values indicate acidity.

PIPING - Removal of soil material through subsurface flow channels or "pipes" developed by seepage water.

PLUGS - Pieces of turf or sod, usually cut with a round tube, which can be used to propagate the turf or sod by vegetative means.

POCKET POND - A stormwater pond designed for treatment of small drainage area (< 5 acres) runoff and which has little or no baseflow available to maintain water elevations and relies on ground water to maintain a permanent pool.

POCKET WETLAND - A stormwater wetland design adapted for the treatment of runoff from small drainage areas (< 5 acres) and which has little or no baseflow available to maintain water elevations and relies on ground water to maintain a permanent pool.

POND BUFFER - The area immediately surrounding a pond which acts as filter to remove pollutants and provide infiltration of stormwater prior to reaching the pond. Provides a separation barrier to adjacent development.

POND DRAIN - A pipe or other structure used to drain a permanent pool within a specified time period.

PONDSCAPING - Landscaping around stormwater ponds which emphasizes native vegetative species to meet specific design intentions. Species are selected for up to six zones in the pond and its surrounding buffer, based on their ability to tolerate inundation and/ or soil saturation.

POROSITY - Ratio of pore volume to total solids volume.

PRETREATMENT - Techniques employed in stormwater SMPs to provide storage or filtering to help trap coarse materials before they enter the system.

PRINCIPAL SPILLWAY - The primary pipe or weir which carries baseflow and storm flow through the embankment.

REDEVELOPMENT - New development activities on previously developed land.

RETENTION - The amount of precipitation on a drainage area that does not escape as runoff. It is the difference between total precipitation and total runoff.

REVERSE-SLOPE PIPE - A pipe which draws from below a permanent pool extending in a reverse angle up to the riser and which determines the water elevation of the permanent pool.

RIGHT-OF-WAY - Right of passage, as over another's property. A route that is lawful to use. A strip of land acquired for transport or utility construction.

RIP-RAP - Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves); also applies to brush or pole mattresses, or brush and stone, or similar materials used for soil erosion control.

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RISER - A vertical pipe or structure extending from the bottom of a pond SMP and houses the control devices (weirs/orifices) to achieve the discharge rates for specified designs.

ROUGHNESS COEFFICIENT (HYDRAULICS) - A factor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.

RUNOFF (HYDRAULICS) - That portion of the precipitation on a drainage area that is discharged from the area in the stream channels. Types include surface runoff, ground water runoff or seepage.

RUNOFF COEFFICIENT (R_V) - A value derived from a site impervious cover value that is applied to a given rainfall volume to yield a corresponding runoff volume.

SAFETY BENCH - A flat area above the permanent pool and surrounding a stormwater pond designed to provide a separation from the pond pool and adjacent slopes.

SAND - 1. (Agronomy) A soil particle between 0.05 and 2.0 millimeters in diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System, a soil particle larger than the No. 200 sieve (0.074mm) and passing the No. 4 sieve (approximately 1/4 inch).

SEDIMENT - Solid material, both mineral and organic, that is in suspension, being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

SEEPAGE - 1. Water escaping through or emerging from the ground.2. The process by which water percolates through the soil.

SEEPAGE LENGTH - In sediment basins or ponds, the length along the pipe and around the anti-seep collars that is within the seepage zone through an embankment.

SETBACKS - The minimum distance requirements for location of a structural SMP in relation to roads, wells, septic fields, other structures.

SHEET FLOW - Water, usually storm runoff, flowing in a thin layer over the ground surface.

SIDE SLOPES (ENGINEERING) - The slope of the sides of a channel, dam or embankment. It is customary to name the horizontal distance first, as 1.5 to 1, or frequently, 1 ½: 1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

SILT - 1. (Agronomy) A soil separate consisting of particles between 0.05 and 0.002 millimeter in equivalent diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System a fine grained soil (more than 50 percent passing the No. 200 sieve) that has a low plasticity index in relation to the liquid limit.

SOIL TEST - Chemical analysis of soil to determine needs for fertilizers or amendments for species of plant being grown.

SPILLWAY - An open or closed channel, or both, used to convey excess water from a reservoir. It may contain gates, either manually or automatically controlled to regulate the discharge of excess water.

STABILIZATION - Providing adequate measures, vegetative and/or structural that will prevent erosion from occurring.

STAGE (HYDRAULICS) - The variable water surface or the water surface elevation above any chosen datum.

STILLING BASIN - An open structure or excavation at the foot of an outfall, conduit, chute, drop, or spillway to reduce the energy of the descending stream of water.

STORMWATER FILTERING - Stormwater treatment methods which utilize an artificial media to filter out pollutants entrained in urban runoff.

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STORMWATER PONDS - A land depression or impoundment created for the detention or retention of stormwater runoff.

STORMWATER WETLANDS - Shallow, constructed pools that capture stormwater and allow for the growth of characteristic wetland vegetation.

STREAM BUFFERS - Zones of variable width which are located along both sides of a stream and are designed to provided a protective natural area along a stream corridor.

STREAM CHANNEL PROTECTION (Cp_V) - A design criteria which requires 24 hour detention of the one year postdeveloped, 24 hour storm event for the control of stream channel erosion.

STRUCTURAL SMPs - Devices which are constructed to provide temporary storage and treatment of stormwater runoff.

SUBGRADE - The soil prepared and compacted to support a structure or a pavement system.

TAILWATER - Water, in a river or channel, immediately downstream from a structure.

TECHNICAL RELEASE No. 20 (TR-20) - A Soil Conservation Service (now NRCS) watershed hydrology computer model that is used to compute runoff volumes and route storm events through a stream valley and/or ponds.

TECHNICAL RELEASE No. 55 (TR-55) - A watershed hydrology model developed by the Soil Conservation Service (now NRCS) used to calculate runoff volumes and provide a simplified routing for storm events through ponds.

TEMPORARY SEEDING - A seeding which is made to provide temporary cover for the soil while waiting for further construction or other activity to take place.

TEN YEAR STORM ($Q_{P\ 10}$) - The peak discharge rate associated with a 24 hour storm event that occurs on average once every ten years (or has a likelihood of occurrance of 1/10 in a given year).

TIME OF CONCENTRATION - Time required for water to flow from the most remote point of a watershed, in a hydraulic sense, to the outlet.

TOE (OF SLOPE) - Where the slope stops or levels out. Bottom of the slope.

TOE WALL - Downstream wall of a structure, usually to prevent flowing water from eroding under the structure.

TOPSOIL - Fertile or desirable soil material used to top dress roadbanks, subsoils, parent material, etc.

TOTAL SUSPENDED SOLIDS - The total amount of soil particulate matter, including both organic and inorganic material, suspended in the water column.

TRASH RACK - Grill, grate or other device at the intake of a channel, pipe, drain or spillway for the purpose of preventing oversized debris from entering the structure.

TROUT WATERS - Waters classified as (T) or (TS) by the New York State DEC.

TWO YEAR STORM ($Q_{P\ 2}$) - The peak discharge rate associated with a 24 hour storm event that occurs on average once every two years (or has a likelihood of occurrance of 1/2 in a given year).

ULTIMATE CONDITION - Full watershed build-out based on existing zoning.

ULTRA-URBAN - Densely developed urban areas in which little pervious surface exists.

VELOCITY HEAD - Head due to the velocity of a moving fluid, equal to the square of the mean velocity divided by twice the acceleration due to gravity (32.16 feet per second per second).

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VOLUMETRIC RUNOFF COEFFICIENT (R_v) - The value that is applied to a given rainfall volume to yield a corresponding runoff volume based on the percent impervious cover in a drainage basin.

WATER QUALITY VOLUME (WQ_v) - The storage needed to capture and treat 90% of the average annual stormwater runoff volume.

WATER SURFACE PROFILE - The longitudinal profile assumed by the surface of a stream flowing in an open channel; the hydraulic grade line.

WEDGES - Design feature in stormwater wetlands which increases flow path length to provide for extended detention and treatment of runoff.

WET SWALE - An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.

WETTED PERIMETER - The length of the line of intersection of the plane or the hydraulic cross-section with the wetted surface of the channel.

WING WALL - Side wall extensions of a structure used to prevent sloughing of banks or channels and to direct and confine overfall.

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Appendix A: The Simple Method to Calculate Urban Stormwater Loads

This appendix presents data and methodologies for using the Simple Method (Schueler, 1987) to estimate pollutant load from a site or drainage area. This appendix is meant for planning purposes only, and should not be used for SMP design.

The Simple Method estimates stormwater runoff pollutant loads for urban areas. The technique requires a modest amount of information, including the subwatershed drainage area and impervious cover, stormwater runoff pollutant concentrations, and annual precipitation. With the Simple Method, the investigator can either break up land use into specific areas, such as residential, commercial, industrial, and roadway and calculate annual pollutant loads for each type of land, or utilize more generalized pollutant values for urban runoff. It is also important to note that these values may vary depending on other variables such as the age of development.

The Simple Method estimates pollutant loads for chemical constituents as a product of annual runoff volume and pollutant concentration, as:

$$\mathbf{L = 0.226 * R * C * A}$$

Where:	L	=	Annual load (lbs)
	R	=	Annual runoff (inches)
	C	=	Pollutant concentration (mg/l)
	A	=	Area (acres)
	0.226	=	Unit conversion factor

For bacteria, the equation is slightly different, to account for the differences in units. The modified equation for bacteria is:

$$\mathbf{L = 103 * R * C * A}$$

Where:	L	=	Annual load (Billion Colonies)
	R	=	Annual runoff (inches)
	C	=	Bacteria concentration (1,000/ ml)
	A	=	Area (acres)
	103	=	Unit conversion factor

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A.1 Pollutant Concentrations

Stormwater pollutant concentrations can be estimated from local or regional data, or from national data sources. Table A.1 presents typical concentration data for pollutants in urban stormwater.

Table A.1 National Median Concentrations for Chemical Constituents in Stormwater

Constituent	Units	Urban Runoff
TSS	mg/l	54.5[1]
TP	mg/l	0.26[1]
TN	mg/l	2.00[1]
Cu	ug/l	11.1[1]
Pb	ug/l	50.7[1]
Zn	ug/l	129[1]
F Coli	1,000 col/ ml	1.5[2]

Source:

1: Pooled NURP/USGS (Smullen and Cave, 1998)

2: Schueler (1999)

In addition, some source areas appear to be particularly important for some pollutants. Table A.2 summarizes these data for several key source areas. It is important to note that, because the Simple Method computes runoff based on an impervious area fraction, it cannot be easily used to isolate pervious sources, such as lawns. However, a user can evaluate particular hotspots, such as auto recyclers, separately. In addition, a composite runoff concentration can be developed based on the fraction of lawn, driveway, and roof on a residential site, for example.

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Table A.2 Pollutant Concentrations from Source Areas							
Constituent	**TSS[1]**	**TP[2]**	**TN[3]**	**F Coli[1]**	**Cu[1]**	**Pb[1]**	**Zn[1]**
	mg/l	mg/L	mg/l	1,000 col/ ml	ug/l	ug/l	ug/l
Resid Roof	19	0.11	1.5	0.26	20	21	312
Comm Roof	9	0.14	2.1	1.1	7	17	256
Indust Roof	17	-	-	5.8	62	43	1,390
C/R Parking	27	0.15	1.9	1.8	51	28	139
Indust Parking	228	-	-	2.7	34	85	224
Res Street	172	0.55	1.4	37	25	51	173
Comm Street	468	-	-	12	73	170	450
Rural Highway	51	-	22	-	22	80	80
Urban Highway	142	0.32	3.0	-	54	400	329
Lawns	602	2.1	9.1	24	17	17	50
Landscaping	37	-	-	94	94	29	263
Driveway	173	0.56	2.1	17	17	-	107
Gas Station	31	-	-	-	88	80	290
Auto Recycler	335	-	-	-	103	182	520
Heavy Industrial	124	-	-	-	148	290	1600

1: Claytor and Schueler (1996)

2: Average of Steuer et al. (1997),Bannerman (1993) and Waschbusch (2000)

3: Steuer et al. (1997)

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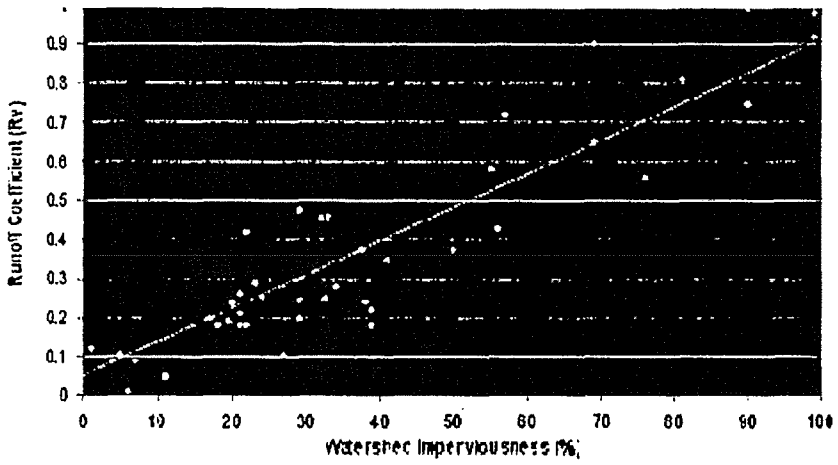
Figure A.1 Relationship Between Watershed Imperviousness and the Stormwater Runoff Coefficient



A.2 Annual Runoff

The Simple Method calculates annual runoff as a product of annual runoff volume, and a runoff coefficient (Rv). Runoff volume is calculated as:

$$R = P * P_j * Rv$$

Where:
- R = Annual runoff (inches)
- P = Annual rainfall (inches)
- P_j = Fraction of annual rainfall events that produce runoff (usually 0.9)
- Rv = Runoff coefficient

In the Simple Method, the runoff coefficient is calculated based on impervious cover in the subwatershed. This relationship is shown in Figure A.1. Although there is some scatter in the data, watershed imperviousness does appear to be a reasonable predictor of Rv.

The following equation represents the best fit line the dataset (N=47, R^2=0.71).

$$Rv=0.05+0.9Ia$$

Where: Ia = Impervious fraction

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A.3 Impervious Cover Data

The Simple Method uses different impervious cover values for separate land uses within a subwatershed. Representative impervious cover data, are presented in Table A.3. These numbers are derived from a recent study conducted by the Center for Watershed Protection under a grant from the U.S. Environmental Protection Agency to update impervious cover estimates for a variety of land uses. (Cappiella and Brown, 2001). In addition, some jurisdictions may have detailed impervious cover information if they maintain a detailed land use/land cover GIS database.

Table A.3 Land Use and Impervious Cover Estimates

Land Use Category	Mean Impervious Cover
Agriculture	**2**
Open Urban Land*	**9**
2 Acre Lot Residential	**11**
1 Acre Lot Residential	**14**
1/2 Acre Lot Residential	**21**
1/4Acre Lot Residential	**28**
1/8 Acre Lot Residential	**33**
Townhome Residential	**41**
Multifamily Residential	**44**
Institutional**	**31-38%**
Light Industrial	**50-56%**
Commercial	**70-74%**

* Open urban land includes developed park land, recreation areas, golf courses, and cemeteries.

** Institutional is defined as places of worship, schools, hospitals, government offices, and police and fire stations

A.4 Limitations of the Simple Method

The Simple Method should provide reasonable estimates of changes in pollutant export resulting from urban development activities. However, several caveats should be kept in mind when applying this method.

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The Simple Method is most appropriate for assessing and comparing the relative stormflow pollutant load changes of different land use and stormwater management scenarios. The Simple Method provides estimates of storm pollutant export that are probably close to the "true" but unknown value for a development site, catchment, or subwatershed. However, it is very important not to over emphasis the precision of the results obtained. For example, it would be inappropriate to use the Simple Method to evaluate relatively similar development scenarios (e.g., 34.3% versus 36.9% Impervious cover). The simple method provides a general planning estimate of likely storm pollutant export from areas at the scale of a development site, catchment or subwatershed. More sophisticated modeling may be needed to analyze larger and more complex drainages.

In addition, the Simple Method only estimates pollutant loads generated during storm events. It does not consider pollutants associated with baseflow volume. Typically, baseflow is negligible or non-existent at the scale of a single development site, and can be safely neglected, unless wastewater sources such as illicit connections and wastewater treatment plans are significant. However, catchments and subwatersheds do generate baseflow volume. Pollutant loads in baseflow are generally low and can seldom be distinguished from natural background levels (NVPDC, 1980). Consequently, baseflow pollutant loads normally constitute only a small fraction of the total pollutant load delivered from an urban area. Nevertheless, it is important to remember that the load estimates refer only to storm event derived loads and should not be confused with the total pollutant load from an area. This is particularly important when the development density of an area is low. For example, in a large low density residential subwatershed (Imp. Cover < 5%), as much as 75% of the annual runoff volume may occur as baseflow. In such a case, the annual baseflow nutrient load may be equivalent to the annual stormflow nutrient load.

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A.5 SMP Pollutant Removal

The removal efficiencies of various SMP practices also help determine final annual pollutant loads. Table A.4 provides estimates of the average pollutant removal efficiency of the five SMP categories.

Table A.4. Suggested Removal Rates for SMPs

	TSS	TP	TN	Metals[1]	Bacteria
Wet Ponds	80	50 (51)	35 (33)	60 (62)	70
Stormwater Wetlands	80[2] (76)	50 (49)	30	40 (42)	80 (78)
Filtering Practices	85 (86)	60 (59)	40 (38)	70 (69)	35 (37)
Infiltration Practices [4]	90[3] (95)	70	50 (51)	90[3] (99)	90[4]
Water Quality Swales	85 (84)	40 (39)	50[5] (84)	70	0 (-25)[6]

1. Average of zinc and copper. Only zinc for infiltration
2. Many wetland practices in the database were poorly designed, and we consequently adjusted sediment removal upward.
3. It is assumed that no practice is greater than 90% efficient.
4. Data inferred from sediment removal.
5. Actual data is based on only two highly performing practices.
6. Assume 0 rather than a negative removal.

Note: Data in parentheses represent median pollutant removal data reported in the *National Pollutant Removal Database - Revised Edition* (Winer, 2000). These data were adjusted for convenience and to reflect biases in the data.

These efficiencies represent ideal pollutant removal rates that cannot be achieved at all sites, or at a watershed level. Typically, they need to be "discounted" to account for site constraints, and other factors that reduce practice efficiency. For example, the removal rate should be adjusted to reflect the fraction of runoff captured by a practice on an annual basis (90% if this guidance is followed). For more detail on how to apply these discounts, consult Caraco (2001)..

One particularly important consideration is how to account for practices applied in series (e.g., two ponds applied in sequence). If the volume within the practices adds up to the total water quality volume, they are assumed to act as a single practice with that volume. Otherwise, total pollutant removal should be determined by the following equation:

$$R = L\,[(E_1)+(1-E_1)E_2+(1-((E_1)+(1-E_1)E_2)E_3+\ldots]$$

Where:

R = Pollutant Removal (lbs)

L = Annual Load from Simple Method (lbs.)

E_i = Efficiency of the ith practice in a series

Another adjustment can be made to these removals to account for loss of effectiveness and "irreducible concentrations." Evidence suggests that, at low concentrations, SMPs can no longer remove pollutants.

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Table A.5 depicts typical outflow concentrations for various SMPs. Another simplified way to account for this phenomenon is to reduce the efficiency of a second or third practice in a series. For example, the removal efficiency could be cut in half to reflect inability to remove fine particles.

Table A.5. Typical SMP Effluent Concentrations

	TSS	TP	TN	Cu	Zn
Wet Ponds	17	0.11	1.3	5.0	30
Wetlands	22	0.20	1.7	7.0	31
Filtering Practices	11	0.10	1.12	10	21
Infiltration Practices	17[2]	0.05[2]	3.8[2]	4.8[2]	39[2]
Open Channel Practices	14	0.19	1.12	10	53

1. Units for Zn and Cu are micrograms per liter
2. Data based on fewer than five data points

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Appendix B

New York State Stormwater Management Design Manual

Appendix B: Hydrologic Analysis Tools

This Appendix presents two hydrologic and hydraulic analysis tools that can be used to size stormwater management practices (SMPs). The first is the TR-55 (NRCS, 1986) "short-cut" sizing technique, used to size practices designed for extended detention, slightly modified to incorporate the small flows necessary to provide channel protection. The second is a method used to determine the peak flow from water quality storm events. (This is often important when the water quality storm is diverted to a water quality practice, with other larger events bypassed).

B.1 Storage Volume Estimation

This section presents a modified version of the TR-55 short cut sizing approach. The method was modified by Harrington (1987), for applications where the peak discharge is very small compared with the uncontrolled discharge. This often occurs in the 1-year, 24-hour detention sizing.

Using TR-55 guidance (NRCS, 1986), the unit peak discharge (qu) can be determined based on the the Curve Number and Time of Concentration. Knowing q_U and T (extended detention time), q_O/q_I (peak outflow discharge/peak inflow discharge) can be estimated from Figure B.1.

Figure B.2 can also be used to estimate V_S/V_r. For a Type II or Type III rainfall distribution, V_S/V_r can also be calculated using the following equation:

$$V_S/V_r = 0.682 - 1.43\,(q_O/q_I) + 1.64\,(q_O/q_I)^2 - 0.804\,(q_O/q_I)^3 \qquad (2.1.16)$$

Where:

V_S = required storage volume (acre-feet)

V_r = runoff volume (acre-feet)

q_O = peak outflow discharge (cfs)

q_I = peak inflow discharge (cfs)

The required storage volume can then be calculated by:

$$V_S = \frac{(V_S/V_r)(Q_d)(A)}{12} \qquad (2.1.17)$$

Where: V_S and V_r are defined above

Q_d = the post-developed runoff for the design storm (inches)

A = total drainage area (acres)

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While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided.

Figure B.1 Detention Time vs. Discharge Ratios (Source: MDE, 2000)

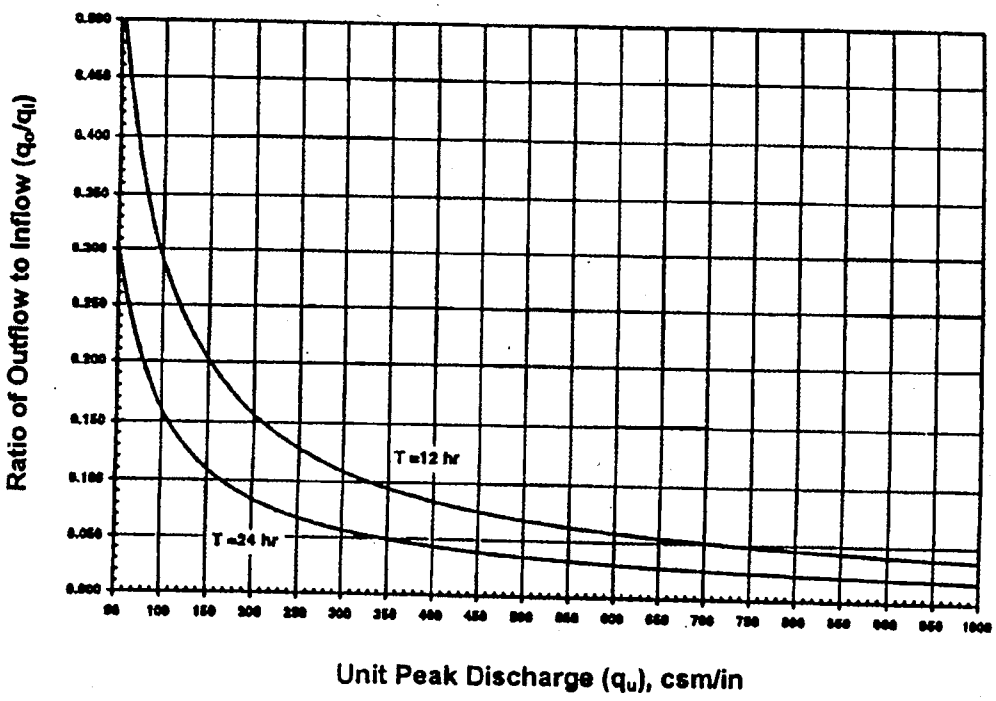
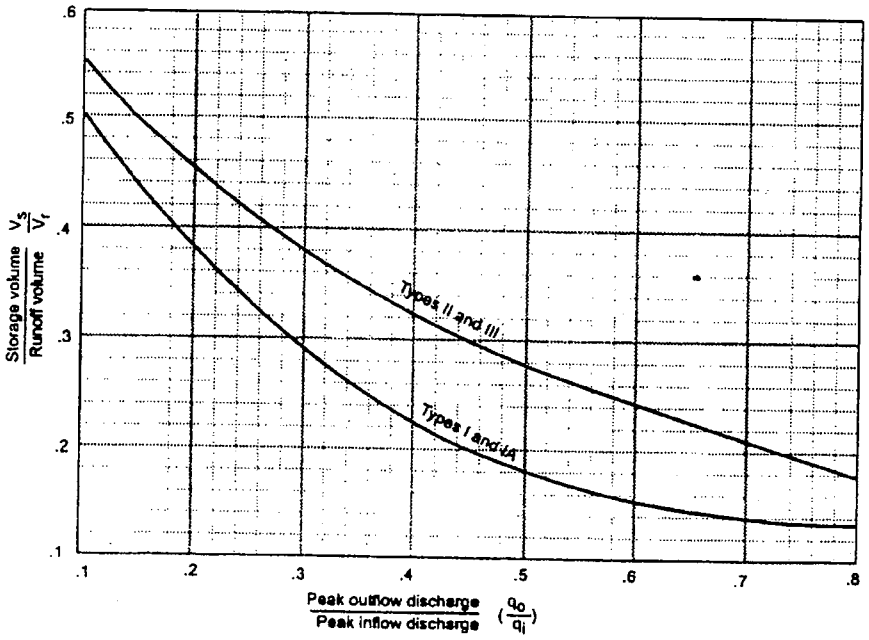


Figure B.2 Approximate Detention Basin Routing For Rainfall Types I, IA, II, and III (Source: NRCS, 1986)



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B.2 Water Quality Peak Flow Calculation

The peak rate of discharge for the water quality design storm is needed for the sizing of diversion structures for off-line practices such as sand filters. An arbitrary storm would need to be chosen using the Rational method, and conventional SCS methods have been found to underestimate the volume and rate of runoff for rainfall events less than 2". This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the filtering treatment practice due to an inadequately sized diversion structure and leads to the design of undersized bypass channels.

The following procedure can be used to estimate peak discharges for small storm events. It relies on the Water Quality Volume and the simplified peak flow estimating method above. A brief description of the calculation procedure is presented below.

Using the water quality volume (WQ_V), a corresponding Curve Number (CN) is computed utilizing the following equation:

$$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25\,QP)^{½}]$$

Where

P = rainfall, in inches (use the 90% rainfall event from Figure 4.1 for the Water Quality Storm)

Q = runoff volume, in inches

Once a CN is computed, the time of concentration (t_c) is computed using guidance provided in TR-55.

Using the computed CN, t_c and drainage area (A), in acres; the peak discharge (Q_p) for the water quality storm event is computed (either Type II or Type III in the State of New York).

Read initial abstraction (Ia), compute Ia/P

Read the unit peak discharge (qu) for appropriate t_c

Using the water quality volume (WQ_V), compute the peak discharge (Q_p)

$$Q_p = q_u * A * WQ_V$$

where Q_p = the peak discharge, in cfs

q_u = the unit peak discharge, in cfs/mi²/inch

A = drainage area, in square miles

WQ_V = Water Quality Volume, in watershed inches

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Appendix C

New York State Stormwater Management Design Manual

Appendix C: Construction Standards and Specifications

C.1 Pond Construction Standards/Specifications

These specifications are generally appropriate to all earthen ponds, and are adapted from NRCS Pond Code 378. Practitioners should always consult the New York State Department of Environmental Conservation – Dam Safety Division for the most recent guidance. All references to ASTM and AASHTO specifications apply to the most recent version.

Site Preparation

Areas designated for borrow areas, embankment, and structural works shall be cleared, grubbed and stripped of topsoil. All trees, vegetation, roots and other objectionable material shall be removed. Channel banks and sharp breaks shall be sloped to no steeper than 1:1. All trees shall be cleared and grubbed within 15 feet of the toe of the embankment.

Areas to be covered by the reservoir will be cleared of all trees, brush, logs, fences, rubbish and other objectionable material unless otherwise designated on the plans. Trees, brush, and stumps shall be cut approximately level with the ground surface. For dry stormwater management ponds, a minimum of a 25-foot radius around the outlet structure shall be cleared.

All cleared and grubbed material shall be disposed of outside and below the limits of the dam and reservoir as directed by the owner or his representative. When specified, a sufficient quantity of topsoil will be stockpiled in a suitable location for use on the embankment and other designated areas.

Earth Fill

Material - The fill material shall be taken from approved designated borrow areas. It shall be free of roots, stumps, wood, rubbish, stones greater than 6", frozen or other objectionable materials. Fill material for the center of the embankment, and cut off trench shall conform to Unified Soil Classification GC, SC, CH, or CL and must have at least 30% passing the #200 sieve. Consideration may be given to the use of other materials in the embankment if designed by a geotechnical engineer. Such special designs must have construction supervised by a geotechnical engineer.

Materials used in the outer shell of the embankment must have the capability to support vegetation of the quality required to prevent erosion of the embankment.

Placement - Areas on which fill is to be placed shall be scarified prior to placement of fill. Fill materials shall be placed in maximum 8 inch thick (before compaction) layers which are to be continuous over the entire length of the fill. The most permeable borrow material shall be placed in the downstream portions of the embankment. The principal spillway must be installed concurrently with fill placement and not excavated into the embankment.

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Compaction - The movement of the hauling and spreading equipment over the fill shall be controlled so that the entire surface of each lift shall be traversed by not less than one tread track of heavy equipment or compaction shall be achieved by a minimum of four complete passes of a sheepsfoot, rubber tired or vibratory roller. Fill material shall contain sufficient moisture such that the required degree of compaction will be obtained with the equipment used. The fill material shall contain sufficient moisture so that if formed into a ball it will not crumble, yet not be so wet that water can be squeezed out.

When required by the reviewing agency the minimum required density shall not be less than 95% of maximum dry density with a moisture content within 2% of the optimum. Each layer of fill shall be compacted as necessary to obtain that density, and is to be certified by the Engineer at the time of construction. All compaction is to be determined by AASHTO Method T-99 (Standard Proctor).

Cut Off Trench - The cutoff trench shall be excavated into impervious material along or parallel to the centerline of the embankment as shown on the plans. The bottom width of the trench shall be governed by the equipment used for excavation, with the minimum width being four feet. The depth shall be at least four feet below existing grade or as shown on the plans. The side slopes of the trench shall be 1 to 1 or flatter. The backfill shall be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability.

Embankment Core - The core shall be parallel to the centerline of the embankment as shown on the plans. The top width of the core shall be a minimum of four feet. The height shall extend up to at least the 10 year water elevation or as shown on the plans. The side slopes shall be 1 to 1 or flatter. The core shall be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability. In addition, the core shall be placed concurrently with the outer shell of the embankment.

Structure Backfill

Backfill adjacent to pipes or structures shall be of the type and quality conforming to that specified for the adjoining fill material. The fill shall be placed in horizontal layers not to exceed four inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material needs to fill completely all spaces under and adjacent to the pipe. At no time during the backfilling operation shall driven equipment be allowed to operate closer than four feet, measured horizontally, to any part of a structure. Under no circumstances shall equipment be driven over any part of a concrete structure or pipe, unless there is a compacted fill of 24" or greater over the structure or pipe.

Structure backfill may be flowable fill meeting the requirements of the New York State Department of Transportation. The mixture shall have a 100-200 psi; 28 day unconfined compressive strength. The flowable fill shall have a minimum pH of 4.0 and a minimum resistivity of 2,000 ohm-cm. Material shall be placed such that a minimum of 6" (measured perpendicular to the outside of the pipe) of flowable fill shall be under (bedding), over and, on the sides of the pipe. It only needs to extend up to the spring line for rigid conduits. Average slump of the fill shall be 7" to assure flowability of the material. Adequate measures shall be taken (sand bags, etc.) to prevent floating the pipe. When using flowable fill, all metal pipe shall be bituminous coated. Any adjoining soil fill shall be placed in horizontal layers not to exceed four inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material shall completely fill all voids adjacent to the flowable fill zone. At no time during the backfilling operation shall driven equipment be allowed to operate closer than four feet, measured horizontally, to any part of a structure. Under no circumstances shall equipment be driven over any part of a structure or pipe unless there is a compacted fill of 24" or greater over the structure or pipe. Backfill material outside the structural backfill (flowable fill) zone shall be of the type and quality conforming to that specified for the core of the embankment or other embankment materials.

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Pipe Conduits

All pipes shall be circular in cross section.

Corrugated Metal Pipe - All of the following criteria shall apply for corrugated metal pipe:

Materials - (Polymer Coated steel pipe) - Steel pipes with polymeric coatings shall have a minimum coating thickness of 0.01 inch (10 mil) on both sides of the pipe. This pipe and its appurtenances shall conform to the requirements of AASHTO Specifications M-245 & M-246 with watertight coupling bands or flanges.

Materials - (Aluminum Coated Steel Pipe) - This pipe and its appurtenances shall conform to the requirements of AASHTO Specification M-274 with watertight coupling bands or flanges. Aluminum Coated Steel Pipe, when used with flowable fill or when soil and/or water conditions warrant the need for increased durability, shall be fully bituminous coated per requirements of AASHTO Specification M-190 Type A. Any aluminum coating damaged or otherwise removed shall be replaced with cold applied bituminous coating compound. Aluminum surfaces that are to be in contact with concrete shall be painted with one coat of zinc chromate primer or two coats of asphalt.

Materials - (Aluminum Pipe) - This pipe and its appurtenances shall conform to the requirements of AASHTO Specification M-196 or M-211 with watertight coupling bands or flanges. Aluminum Pipe, when used with flowable fill or when soil and/or water conditions warrant for increased durability, shall be fully bituminous coated per requirements of AASHTO Specification M-190 Type A. Aluminum surfaces that are to be in contact with concrete shall be painted with one coat of zinc chromate primer or two coats of asphalt. Hot dip galvanized bolts may be used for connections. The pH of the surrounding soils shall be between 4 and 9.

Coupling bands, anti-seep collars, end sections, etc., must be composed of the same material and coatings as the pipe. Metals must be insulated from dissimilar materials with use of rubber or plastic insulating materials at least 24 mils in thickness.

Connections - All connections with pipes must be completely watertight. The drain pipe or barrel connection to the riser shall be welded all around when the pipe and riser are metal. Anti-seep collars shall be connected to the pipe in such a manner as to be completely watertight. Dimple bands are not considered to be watertight.All connections shall use a rubber or neoprene gasket when joining pipe sections. The end of each pipe shall be re-rolled an adequate number of corrugations to accommodate the bandwidth. The following type connections are acceptable for pipes less than 24 inches in diameter: flanges on both ends of the pipe with a circular 3/8 inch closed cell neoprene gasket, pre-punched to the flange bolt circle, sandwiched between adjacent flanges; a 12-inch wide standard lap type band with 12-inch wide by 3/8-inch thick closed cell circular neoprene gasket; and a 12-inch wide hugger type band with o-ring gaskets having a minimum diameter of 1/2 inch greater than the corrugation depth. Pipes 24 inches in diameter and larger shall be connected by a 24 inch long annular corrugated band using a minimum of 4 (four) rods and lugs, 2 on each connecting pipe end. A 24-inch wide by 3/8-inch thick closed cell circular neoprene gasket will be installed with 12 inches on the end of each pipe. Flanged joints with 3/8 inch closed cell gaskets the full width of the flange is also acceptable.

Helically corrugated pipe shall have either continuously welded seams or have lock seams with internal caulking or a neoprene bead.

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Bedding - The pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material shall be removed and replaced with suitable earth compacted to provide adequate support.

Backfilling shall conform to Structure Backfill requirements.

Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

Reinforced Concrete Pipe - All of the following criteria shall apply for reinforced concrete pipe:

Materials - Reinforced concrete pipe shall have bell and spigot joints with rubber gaskets and shall equal or exceed ASTM C-361.

Bedding - Reinforced concrete pipe conduits shall be laid in a concrete bedding / cradle for their entire length. This bedding / cradle shall consist of high slump concrete placed under the pipe and up the sides of the pipe at least 50% of its outside diameter with a minimum thickness of 6 inches. Where a concrete cradle is not needed for structural reasons, flowable fill may be used as described in the Structure Backfill section of this standard. Gravel bedding is not permitted.

Laying pipe - Bell and spigot pipe shall be placed with the bell end upstream. Joints shall be made in accordance with recommendations of the manufacturer of the material. After the joints are sealed for the entire line, the bedding shall be placed so that all spaces under the pipe are filled. Care shall be exercised to prevent any deviation from the original line and grade of the pipe. The first joint must be located within 4 feet from the riser.

Backfilling shall conform to **Structure Backfill** requirements.

Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

Plastic Pipe - The following criteria shall apply for plastic pipe:

1. Materials - PVC pipe shall be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241. Corrugated High Density Polyethylene (HDPE) pipe, couplings and fittings shall conform to the following: 4" through 10" pipe shall meet the requirements of AASHTO M252 Type S, and 12" through 24" pipe shall meet the requirements of AASHTO M294 Type S.

2. Joints and connections to anti-seep collars shall be completely watertight.

3. Bedding -The pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material shall be removed and replaced with suitable earth compacted to provide adequate support.

4. Backfilling shall conform to **Structure Backfill** requirements.

5. Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

Drainage Diaphragms - When a drainage diaphragm is used, a registered professional engineer will supervise the design and construction inspection.

Concrete

Concrete shall meet the requirements of the New York State Department of Transportation.

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Rock Riprap

Rock riprap shall meet the requirements of the New York State Department of Transportation.

Geotextile shall be placed under all riprap and shall meet the requirements of the New York State Department of Transportation.

Care of Water During Construction

All work on permanent structures shall be carried out in areas free from water. The Contractor shall construct and maintain all temporary dikes, levees, cofferdams, drainage channels, and stream diversions necessary to protect the areas to be occupied by the permanent works. The contractor shall also furnish, install, operate, and maintain all necessary pumping and other equipment required for removal of water from various parts of the work and for maintaining the excavations, foundation, and other parts of the work free from water as required or directed by the engineer for constructing each part of the work. After having served their purpose, all temporary protective works shall be removed or leveled and graded to the extent required to prevent obstruction in any degree whatsoever of the flow of water to the spillway or outlet works and so as not to interfere in any way with the operation or maintenance of the structure. Stream diversions shall be maintained until the full flow can be passed through the permanent works. The removal of water from the required excavation and the foundation shall be accomplished in a manner and to the extent that will maintain stability of the excavated slopes and bottom required excavations and will allow satisfactory performance of all construction operations. During the placing and compacting of material in required excavations, the water level at the locations being refilled shall be maintained below the bottom of the excavation.

Stabilization

All borrow areas shall be graded to provide proper drainage and left in a sightly condition. All exposed surfaces of the embankment, spillway, spoil and borrow areas, and berms shall be stabilized by seeding, liming, fertilizing and mulching in accordance with local Natural Resources Conservation Service Standards and Specifications.

Erosion and Sediment Control

Construction operations will be carried out in such a manner that erosion will be controlled and water and air pollution minimized. Federal, State and local laws concerning pollution abatement will be followed. Construction plans shall detail erosion and sediment control measures.

Operation and Maintenance

An operation and maintenance plan in accordance with Local or State Regulations will be prepared for all ponds. As a minimum, a dam inspection checklist shall be included as part of the operation and maintenance plan and performed at least annually. Written records of maintenance and major repairs need to be retained in a file.

Supplemental Stormwater Pond and Wetland Specifications

1. It is preferred to use the same material in the embankment as is being installed for the core trench. If this is not possible, a dam core with a shell may be used. The cross-section of the stormwater facility should show the limits of the dam core (up to the 10-year water surface elevation) as well as the acceptable materials for the shell. The shape of the dam core and the material to be used in the shell should be provided by the geotechnical engineer.

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2. If the compaction tests for the remainder of the site improvements is using Modified Proctor (AASHTO T-180), then to maintain consistency on-site, modified proctor may be used in lieu of standard proctor (AASHTO T-99) for checking embankment compaction. The minimum required density using the modified proctor test method shall be at least 92% of maximum dry density with a moisture content of 2% of the optimum.

3. For all stormwater management facilities, a geotechnical engineer must be present to verify compaction in accordance with the selected test method. This information needs to be provided in a report to the design engineer, so that as-built certification of the facility can be made.

4. A 4-inch layer of topsoil shall be placed on all disturbed areas of the dam embankment. Seeding, liming, fertilizing, mulching, etc. shall be in accordance with NRCS Soil Standards and Specifications or New York State Standards and Specifications for Soil Erosion and Sediment Control. The purpose of the topsoil is to establish a good growth of grass which is not always possible with some of the materials that may be placed for the embankment fill.

5. Filter fabric placed beneath the rip-rap shall meet state or local department of transportation requirements for a Class "C" filter fabric. Some acceptable filter fabrics that meet the Class "C" criteria include:

   Mirafi 180-N

   Amoco 4552

   Webtec N07

   Geolon N70

   Carthage FX-70S

   This is only a partial listing of available filter fabrics based on information provided by the manufacturers to the 1997 Specifier's Guide dated December 1996. It is the responsibility of the engineer to verify the adequacy of the material, as there are changes in the manufacturing process and the type of fabric used, which may affect the continued acceptance.

6. The design engineer and geotechnical engineer should make the determination that the settlement of the pond will not cause excessive joint extension. For further information on joint extension analysis, see NRCS Publication TR-18.

7. Fill placement shall not exceed a maximum of 8-inch lift thickness. Each lift shall be continuous for the entire length of the embankment.

8. The embankment fill **shall not** be placed higher than the centerline of the principle spillway until after the principle spillway has been installed.

9. The side slopes of a cut to repair a dam, install a principle spillway for an excavated pond, or other repair work, shall be stepped and on an average slope of 2:1 or flatter.

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C.2 Construction Specifications for Infiltration Practices

Infiltration Trench General Notes and Specifications

The infiltration trench systems may not receive run-off until the entire contributing drainage area to the infiltration system has received final stabilization.

1. Heavy equipment and traffic shall be restricted from traveling over the infiltration trench to minimize compaction of the soil.

2. Excavate the infiltration trench to the design dimensions. Excavated materials shall be placed away from the trench sides to enhance trench wall stability. Large tree roots must be trimmed flush with the trench sides in order to prevent fabric puncturing or tearing of the filter fabric during subsequent installation procedures. The side walls of the trench shall be roughened where sheared and sealed by heavy equipment.

3. A Class "C" geotextile or better shall interface between the trench side walls and between the stone reservoir and gravel filter layers. A partial list of non-woven filter fabrics that meet the Class "C" criteria is contained below. Any alternative filter fabric must be approved by the local municipality prior to installation.

   Mirafi 180-N
   Amoco 4552
   WEBTEC N70
   GEOLON N70
   Carthage FX-80S

   The width of the geotextile must include sufficient material to conform to trench perimeter irregularities and for a 6-inch minimum top overlap. The filter fabric shall be tucked under the sand layer on the bottom of the infiltration trench for a distance of 6 to 12 inches. Stones or other anchoring objects should be placed on the fabric at the edge of the trench to keep the trench open during windy periods. When overlaps are required between rolls, the uphill roll should lap a minimum of 2 feet over the downhill roll in order to provide a shingled effect.

4. A 6 inch sand layer may be placed on the bottom of the infiltration trench in lieu of filter fabric, and shall be compacted using plate compactors. The sand for the infiltration trench shall be washed and meet AASHTO Std. M-43, Size No. 9 or No. 10. Any alternative sand gradation must be approved by the Engineer or the local municipality.

5. The stone aggregate should be placed in lifts and compacted using plate compactors. A maximum loose lift thickness of 12 inches is recommended. Gravel filling (rounded bank run gravel is preferred) for the infiltration trench shall be washed and meet one of the following: AASHTO Std. M-43; Size No. 2 or No. 3.

6. Following the stone aggregate placement, the filter fabric shall be folded over the stone aggregate to form a 6-inch minimum longitudinal lap. The desired fill soil or stone aggregate shall be placed over the lap at sufficient intervals to maintain the lap during subsequent backfilling.

7. Care shall be exercised to prevent natural or fill soils from intermixing with the stone aggregate. All contaminated stone aggregate shall be removed and replaced with uncontaminated stone aggregate.

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8. Voids can be created between the fabric and the excavation sides and shall be avoided. Removing boulders or other obstacles from the trench walls is one source of such voids, therefore, natural soils should be placed in these voids at the most convenient time during construction to ensure fabric conformity to the excavation sides.

9. Vertically excavated walls may be difficult to maintain in areas where soil moisture is high or where soft cohesive or cohesionless soils are predominate. These conditions may require laying back of the side slopes to maintain stability.

10. PVC distribution pipes shall be Schedule 40 and meet ASTM Std. D 1784. All fittings and perforations (1/2 inch in diameter) shall meet ASTM Std. D 2729. A perforated pipe shall be provided only within the infiltration trench and shall terminate 1 foot short of the infiltration trench wall. The end of the PVC pipe shall be capped.

11. Corrugated metal distribution pipes shall conform to AASHTO Std. M-36, and shall be aluminized in accordance with AASHTO Std. M-274. Coat aluminized pipe in contact with concrete with an inert compound capable of effecting isolation of the deleterious effect of the aluminum on the concrete. Perforated distribution pipe shall be provided only within the infiltration trench and shall terminate 1 foot short of the infiltration trench wall. An aluminized metal plate shall be welded to the end of the pipe.

12. The observation well is to consist of 6-inch diameter PVC Schedule 40 pipe (ASTM Std. D 1784) with a cap set 6 inches above ground level and is to be located near the longitudinal center of the infiltration trench. Preferably the observation well will not be located in vehicular traffic areas. The pipe shall have a plastic collar with ribs to prevent rotation when removing cap. The screw top lid shall be a "Panella" type cleanout with a locking mechanism or special bolt to discourage vandalism. A perforated (1/2 inch in diameter) PVC Schedule 40 pipe shall be provided and placed vertically within the gravel portion of the infiltration trench and a cap provided at the bottom of the pipe. The bottom of the cap shall rest on the infiltration trench bottom.

13. If a distribution structure with a wet well is used, a 4-inch PVC drain pipe shall be provided at opposite ends of the infiltration trench distribution structure. Two (2) cubic feet of porous backfill meeting AASHTO Std. M-43 Size No. 57 shall be provided at each drain.

14. If a distribution structure is used, the manhole cover shall be bolted to the frame.

NOTE: PVC pipe with a wall thickness classification of SDR-35 meeting ASTM standard D3034 is an acceptable substitution for PVC Schedule 40 pipe.

Infiltration Basins Notes and Specifications

1. The sequence of various phases of basin construction shall be coordinated with the overall project construction schedule. A program should schedule rough excavation of the basin (to not less than 2' from final grade) with the rough grading phase of the project to permit use of the material as fill in earthwork areas. The partially excavated basin, however, **cannot** serve as a sedimentation basin.

Specifications for basin construction should state: (1) the earliest point in progress when storm drainage may be directed to the basin, and (2) the means by which this delay in use is to be

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accomplished. Due to the wide variety of conditions encountered among projects, each should be separately evaluated in order to postpone use as long as is reasonably possible.

2. Initial basin excavation should be carried to within 2 feet of the final elevation of the basin floor. Final excavation to the finished grade should be deferred until all disturbed areas on the watershed have been stabilized or protected. The final phase excavation should remove all accumulated sediment. Relatively light tracked equipment is recommended for this operation to avoid compaction of the basin floor. After the final grading is completed, the basin should retain a highly porous surface texture.

3. Infiltration basins may be lined with a 6- to 12-inch layer of filter material such as coarse sand (AASHTO Std. M-43, Sizes 9 or 10) to help prevent the buildup of impervious deposits on the soil surface. The filter layer can be replaced or cleaned when it becomes clogged. When a 6-inch layer of coarse organic material is specified for discing (such as hulls, leaves, stems, etc.) or spading into the basin floor to increase the permeability of the soils, the basin floor should be soaked or inundated for a brief period, then allowed to dry subsequent to this operation. This induces the organic material to decay rapidly, loosening the upper soil layer.

4. Establishing dense vegetation on the basin side slopes and floor is recommended. A dense vegetative stand will not only prevent erosion and sloughing, but will also provide a natural means of maintaining relatively high infiltration rates. Erosion protection of inflow points to the basin shall also be provided.

5. Selection of suitable vegetative materials for the side slope and all other areas to be stabilized with vegetation and application of required lime, fertilizer, etc. shall be done in accordance with the NRCS Standards and Specifications or your local Standards and Specifications for Soil Erosion and Sediment Control.

6. Grasses of the fescue family are recommended for seeding primarily due to their adaptability to dry sandy soils, drought resistance, hardiness, and ability to withstand brief inundations. The use of fescues will also permit long intervals between mowings. This is important due to the relatively steep slopes which make mowing difficult. Mowing twice a year, once in June and again in September, is generally satisfactory.

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C.3 Construction Specifications for Bioretention, Sand Filters and Open Channels

Sand Filter Specifications

Material Specifications for Sand Filters

The allowable materials for sand filter construction are detailed in Table 1.

Sand Filter Testing Specifications

Underground sand filters, facilities within sensitive groundwater aquifers, and filters designed to serve urban hot spots are to be tested for water tightness prior to placement of filter layers. Entrances and exits should be plugged and the system completely filled with water to demonstrate water tightness.

All overflow weirs, multiple orifices and flow distribution slots to be field-tested as to verify adequate distribution of flows.

Sand Filter Construction Specifications

Provide sufficient maintenance access; 12-foot-wide road with legally recorded easement. Vegetated access slopes to be a maximum of 10%; gravel slopes to 15%; paved slopes to 25%.

Absolutely no runoff is to enter the filter until all contributing drainage areas have been stabilized.

Surface of filter bed to be *completely level.*

All sand filters should be clearly delineated with signs so that they may be located when maintenance is due.

Surface sand filters shall be planted with appropriate grasses as specified in your local NRCS Standards and Specifications guidance.

Pocket sand filters (and residential bioretention facilities treating areas larger than an acre) shall be sized with an ornamental stone window covering approximately 10% of the filter area. This surface shall be 2" to 5" size stone on top of a pea gravel layer (3/4 inch stone) approximately 4 to 6" of pea gravel.

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Specifications Pertaining to Underground Sand Filters

Provide manhole and/or grates to all underground and below grade structures. Manholes shall be in compliance with standard specifications for each jurisdiction but diameters should be 30" minimum (to comply with OSHA confined space requirements) but not too heavy to lift. Aluminum and steel louvered doors are also acceptable. Ten-inch long (minimum) manhole steps (12" o.c.) shall be cast in place or drilled and mortared into the wall below each manhole. A 5= minimum height clearance (from the top of the sand layer to the bottom of the slab) is required for all permanent underground structures. Lift rings are to be supplied to remove/replace top slabs. Manholes may need to be grated to allow for proper ventilation; if required, place manholes *away* from areas of heavy pedestrian traffic.

Underground sand filters shall be constructed with a dewatering gate valve located just above the top of the filter bed should the bed clog.

Underground sand beds shall be protected from trash accumulation by a wide mesh geotextile screen to be placed on the surface of the sand bed; screen is to be rolled up, removed, cleaned and re-installed during maintenance operations.

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Table C-1 Sand Filter Material Specifications

Parameter	Specification	Size	Notes
Sand	Clean AASHTO M-6 or ASTM C-33 concrete sand	0.02" to 0.04"	Sand substitutions such as Diabase and Graystone #10 are not acceptable. No calcium carbonated or dolomitic sand substitutions are acceptable. "Rock dust" cannot be substituted for sand.
Peat	Ash content: < 15% PH range: 5.2 to 4.9 Loose bulk density 0.12 to 0.15 g/cc	n/a	The material must be Reed-Sedge Hemic Peat, shredded, uncompacted, uniform, and clean.
Underdrain Gravel	AASHTO M-43 No. 67	0.25" to 0.75"	
Geotextile Fabric (if required)	ASTM D-751 (puncture strength - 125 lb.) ASTM D-1117 (Mullen Burst Strength - 400 psi) ASTM D-1682 (Tensile Strength - 300 lb.)	0.08" thick equivalent opening size of #80 sieve	Must maintain 125 gpm per sq. ft. flow rate. Note: a 4" pea gravel layer may be substituted for geotextiles meant to separate sand filter layers.
Impermeable Liner (if required)	ASTM D 751 (thickness) ASTM D 412 (tensile strength 1,100 lb., elongation 200%) ASTM D 624 (Tear resistance - 150 lb./in) ASTM D 471 (water adsorption: +8 to -2% mass)	30mil thickness	Liner to be ultraviolet resistant. A geotextile fabric should be used to protect the liner from puncture.
Underdrain Piping	ASTM D-1785 or AASHTO M-278	6" rigid schedule 40 PVC	3/8" perf. 6" on center, 4 holes per row; minimum of 3" of gravel over pipes; not necessary underneath pipes
Concrete (Cast-in-place)	See local DOT Standards and Specs. f=c = 3500 psi, normal weight, air-entrained; re-inforcing to meet ASTM 615-60	n/a	on-site testing of poured-in-place concrete required: 28 day strength and slump test; all concrete design (cast-in-place or pre-cast) *not using previously approved State or local standards* requires design drawings sealed and approved by a licensed professional structural engineer.
Concrete (pre-cast)	per pre-cast manufacturer	n/a	SEE ABOVE NOTE
Non-rebar steel	ASTM A-36	n/a	structural steel to be hot-dipped galvanized ASTM A123

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Specifications for Bioretention

Material Specifications

The allowable materials to be used in bioretention area are detailed in Table G.2.

Planting Soil

The soil shall be a uniform mix, free of stones, stumps, roots or other similar objects larger than two inches. No other materials or substances shall be mixed or dumped within the bioretention area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The planting soil shall be free of noxious weeds.

The planting soil shall be tested and shall meet the following criteria:

pH range	5.2 - 7.0
organic matter	1.5 - 4%
magnesium	35 lb./ac
phosphorus P_2O_5	75 lb./ac
potassium K_2O	85 lb./ac
soluble salts	not to exceed 500 ppm

All bioretention areas shall have a minimum of one test. Each test shall consist of both the standard soil test for pH, phosphorus, and potassium and additional tests of organic matter, and soluble salts. A textural analysis is required from the site stockpiled topsoil. If topsoil is imported, then a texture analysis shall be performed for each location where the top soil was excavated.

Since different labs calibrate their testing equipment differently, all testing results shall come from the same testing facility.

Should the pH fall out of the acceptable range, it may be modified (higher) with lime or (lower) with iron sulfate plus sulfur.

Compaction

It is very important to minimize compaction of both the base of the bioretention area and the required backfill. When possible, use excavation hoes to remove original soil. If bioretention areas are excavated using a loader, the contractor should use wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high pressure tires will cause excessive compaction resulting in reduced infiltration rates and storage volumes and is not acceptable. Compaction will significantly contribute to design failure.

Compaction can be alleviated at the base of the bioretention facility by using a primary tilling operation such as a chisel plow, ripper, or subsoiler. These tilling operations are to refracture the soil profile through the 12 inch compaction zone. Substitute methods must be approved by the engineer. Rototillers typically do not till deep enough to reduce the effects of compaction from heavy equipment.

Rototill 2 to 3 inches of sand into the base of the bioretention facility before back filling the required sand layer. Pump any ponded water before preparing (rototilling) base.

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When back filling the topsoil over the sand layer, first place 3 to 4 inches of topsoil over the sand, then rototill the sand/topsoil to create a gradation zone. Backfill the remainder of the topsoil to final grade.

When back filling the bioretention facility, place soil in lifts 12" or greater. Do not use heavy equipment within the bioretention basin. Heavy equipment can be used around the perimeter of the basin to supply soils and sand. Grade bioretention materials by hand or with light equipment such as a compact loader or a dozer/loader with marsh tracks.

Plant Installation

Mulch around individual plants only. Shredded hardwood mulch is the only accepted mulch. Pine mulch and wood chips will float and move to the perimeter of the bioretention area during a storm event and are not acceptable. Shredded mulch must be well aged (6 to 12 months) for acceptance.

The plant root ball should be planted so $1/8^{th}$ of the ball is above final grade surface.

Root stock of the plant material shall be kept moist during transport and on-site storage. The diameter of the planting pit shall be at least six inches larger than the diameter of the planting ball. Set and maintain the plant straight during the entire planting process. Thoroughly water ground bed cover after installation.

Trees shall be braced using 2" X 2" stakes only as necessary and for the first growing season only. Stakes are to be equally spaced on the outside of the tree ball.

Grasses and legume seed shall be tilled into the soil to a depth of at least one inch. Grass and legume plugs shall be planted following the non-grass ground cover planting specifications.

The topsoil specifications provide enough organic material to adequately supply nutrients from natural cycling. The primary function of the bioretention structure is to improve water quality. Adding fertilizers defeats, or at a minimum, impedes this goal. Only add fertilizer if wood chips or mulch is used to amend the soil. Rototill urea fertilizer at a rate of 2 pounds per 1000 square feet.

Underdrains

Under drains to be placed on a 3'-0" wide section of filter cloth. Pipe is placed next, followed by the gravel bedding. The ends of under drain pipes not terminating in an observation well shall be capped.

The main collector pipe for underdrain systems shall be constructed at a minimum slope of 0.5%. Observation wells and/or clean-out pipes must be provided (one minimum per every 1000 square feet of surface area).

Miscellaneous

The bioretention facility may not be constructed until all contributing drainage area has been stabilized.

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Table C.2 Materials Specifications for Bioretention

Parameter	Specification	Size	Notes
Plantings	see your local NRCS Standards and Specifications guidance.	n/a	plantings are site-specific
Planting Soil [4= deep]	sand 35 - 60% silt 30 - 55% clay 10 - 25%	n/a	USDA soil types loamy sand, sandy loam or loam
Mulch	shredded hardwood		aged 6 months, minimum
pea gravel diaphragm and curtain drain	pea gravel: ASTM D 448 ornamental stone: washed cobbles	pea gravel: No. 6 stone: 2" to 5"	
Geotextile	Class "C" apparent opening size (ASTM-D-4751) grab tensile strength (ASTM-D-4632) burst strength (ASTM-D-4833)	n/a	for use as necessary beneath underdrains only
underdrain gravel	AASHTO M-43. No. 67.	0.25" to 0.75"	
underdrain piping	ASTM D 1785 or AASHTO M-278	6" rigid schedule 40 PVC	3/8" perf. @ 6" on center, 4 holes per row; minimum of 3" of gravel over pipes; not necessary underneath pipes
poured in place concrete (if required)	See local DOT Standards and Specs.; f=c = 3500 psi. @ 28 days, normal weight, air-entrained; re-inforcing to meet ASTM 615-60	n/a	on-site testing of poured-in-place concrete required: 28 day strength and slump test; all concrete design (cast-in-place or pre-cast) *not using previously approved State or local standards* requires design drawings sealed and approved by a licensed professional structural engineer.
sand [1= deep]	AASHTO M-6 or ASTM C-33	0.02" to 0.04"	Sand substitutions such as Diabase and Graystone #10 are not acceptable. No calcium carbonated or dolomitic sand substitutions are acceptable. No "rock dust" can be used for sand.

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Specifications for Open Channels and Filter Strips

Material Specifications
The recommended construction materials for open channels and filter strips are detailed in Table G.3.

Dry Swales

Roto-till soil/gravel interface approximately 6" to avoid a sharp soil/gravel interface.

Permeable soil mixture (20" to 30" deep) should meet the bioretention planting soil specifications.

Check dams, if required, shall be placed as specified.

System to have 6" of freeboard, minimum.

Side slopes to be 3:1 minimum; (4:1 or greater preferred).

No gravel or perforated pipe is to be placed under driveways.

Bottom of facility to be above the seasonably high water table.

Seed with flood/drought resistant grasses; see your local NRCS Standards and Specifications guidance.

Longitudinal slope to be 1 to 2%, maximum [up to 5% with check dams].

Bottom width to be 8'= maximum to avoid braiding; larger widths may be used if proper berming is supplied. Width to be 2'= minimum.

Wet Swales
Follow above information for dry swales, with the following exceptions: the seasonally high water table may inundate the swale; but not above the design bottom of the channel [NOTE: if the water table is stable within the channel; the WQv storage may start at this point]

Excavate into undisturbed soils; do not use an underdrain system.

Filter Strips

Construct pea gravel diaphragms 12" wide, minimum, and 24" deep minimum.

Pervious berms to be a sand/gravel mix (35-60% sand, 30-55% silt, and 10-25% gravel). Berms to have overflow weirs with 6 inch minimum avilable head.

Slope range to be 2% minimum to 6% maximum.

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Table C.3 Open Vegetated Swale and Filter Strip Materials Specifications

Parameter	Specification	Size	Notes
Dry swale soil	USCS; ML, SM, SC	n/a	soil with a higher percent organic content is preferred
Dry Swale sand	ASTM C-33 fine aggregate concrete sand	0.02" to 0.04"	
Check Dam (pressure treated)	AWPA Standard C6	6" by 6" or 8" by 8"	*do not* coat with creosote; embed at least 3= into side slopes
Check Dam (natural wood)	Black Locust, Red Mulberry, Cedars, Catalpa, White Oak, Chestnut Oak, Black Walnut	6" to 12" diameter; notch as necessary	*do not* use the following, as these species have a predisposition towards rot: Ash, Beech, Birch, Elm, Hackberry, hemlock, Hickories, Maples, Red and Black Oak, Pines, Poplar, Spruce, Sweetgum, Willow
Filter Strip sand/gravel pervious berm	sand: per dry swale sand gravel; AASHTO M-43 No. 57	sand: 0.02" to 0.04" gravel: 2" to 1"	mix with approximately 25% loan soil to support grass cover crop; see Bioretention planting soil notes for more detail.
pea gravel diaphragm and curtain drain	ASTM D 448	varies (No. 6) or (1/8" to 3/8")	use clean bank-run gravel
under drain gravel	AASHTO M-43 No. 67	0.25" to 0.75"	
under drain	ASTM D -1785 or AASHTO M-278	6" rigid Schedule 40 PVC	3/8" perf. @ 6" o.c.; 4 holes per row
Geotextile	See local DOT Standards and Specs	n/a	
rip rap	per local DOT criteria	size per New York State DOT requirements based on 10-year design flows	

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Appendix D

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Appendix D: Infiltration Testing Requirements

General Notes Pertinent to All Testing

1. For infiltration practices, a minimum field infiltration rate (f_c) of 0.5 inches per hour is required; areas yielding a lower rate preclude these practices. If the minimum f_c exceeds two inches per hour, half of the WQ_v must be treated by an upstream SMP that does allow infiltration. For F-1 and F-6 practices, no minimum infiltration rate is required if these facilities are designed with a "day-lighting" underdrain system; otherwise these facilities require a 0.5 inch per hour rate.

2. Number of required borings is based on the size of the proposed facility. Testing is done in two phases, (1) Initial Feasibility, and (2) Concept Design Testing.

3. Testing is to be conducted by a qualified professional. This professional shall either be a registered professional engineer in the State of New York, a soils scientist or geologist also licensed in the State of New York.

Initial Feasibility Testing

Feasibility testing is conducted to determine whether full-scale testing is necessary, and is meant to screen unsuitable sites, and reduce testing costs. A soil boring is not required at this stage. However, a designer or landowner may opt to engage Concept Design Borings per Table H-1 at his or her discretion, without feasibility testing.

Initial testing involves either one field test per facility, regardless of type or size, or previous testing data, such as the following:

* septic percolation testing on-site, within 200 feet of the proposed SMP location, and on the same contour [can establish initial rate, water table and/or depth to bedrock]
* previous written geotechnical reporting on the site location as prepared by a qualified geotechnical consultant
* NRCS County Soil Mapping *showing an unsuitable soil group* such as a hydrologic group "D" soil in a low-lying area, or a Marlboro Clay

If the results of initial feasibility testing as determined by a qualified professional show that an infiltration rate of greater than 0.5 inches per hour is probable, then the number of *concept design test* pits shall be per the following table. An encased soil boring may be substituted for a test pit, if desired.

R0080450

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Table D-1 Infiltration Testing Summary Table

Type of Facility	Initial Feasibility Testing	Concept Design Testing (initial testing yields a rate greater than 0.5"/hr)	Concept Design Testing (initial testing yields a rate lower than 0.5"/hr)
I-1 (trench)	1 field percolation test, test pit not required	1infiltration test and 1 test pit per 50' of trench	not acceptable practice
I-2 (basin)	1 field percolation test, test pit not required	1 infiltration test* and 1 test pit per 200 sf of basin area	not acceptable practice
F-1(sand filter)	1 field percolation test, test pit not required	1 infiltration test and 1 test pit per 200 sf of filter area (no underdrains required**)	underdrains required
F-6 (bioretention)	1 field percolation test, test pit not required	1 infiltration test and 1 test pit per 200 sf of filter area (no underdrains required**)	underdrains required

*feasibility test information already counts for one test location
** underdrain installation still strongly suggested

Documentation

Infiltration testing data shall be documented, which shall also include a description of the infiltration testing method, if completed. This is to ensure that the tester understands the procedure.

Test Pit/Boring Requirements

a. excavate a test pit or dig a standard soil boring to a minimum depth of 4 feet below the proposed facility bottom elevation

b. determine depth to groundwater table (if within 4 feet of proposed bottom) upon initial digging or drilling, and again 24 hours later

c. conduct Standard Penetration Testing (SPT) every 2' to a depth of 4 feet below the facility bottom

d. determine USDA or Unified Soil Classification System textures at the proposed bottom and 4 feet below the bottom of the SMP

e. determine depth to bedrock (if within 4 feet of proposed bottom)

f. The soil description should include all soil horizons.

g. The location of the test pit or boring shall correspond to the SMP location; test pit/soil boring stakes are to be left in the field for inspection purposes and shall be clearly labeled as such.

Infiltration Testing Requirements

a. Install casing (solid 5 inch diameter, 30" length) to 24" below proposed SMP bottom (see Figure D-1).

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b. Remove any smeared soiled surfaces and provide a natural soil interface into which water may percolate. Remove all loose material from the casing. Upon the tester's discretion, a two (2) inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring and sediment. Fill casing with *clean* water to a depth of 24" and allow to pre-soak for twenty-four hours

c. Twenty-four hours later, refill casing with another 24" of clean water and monitor water level (measured drop from the top of the casing) for 1 hour. Repeat this procedure (filling the casing each time) three additional times, for a total of four observations. Upon the tester's discretion, the final field rate may either be the average of the four observations, or the value of the last observation. The final rate shall be reported in *inches per hour*.

d. May be done though a boring or open excavation.

e. The location of the test shall correspond to the SMP location.

f. Upon completion of the testing, the casings shall be immediately pulled, and the test pit shall be back-filled.

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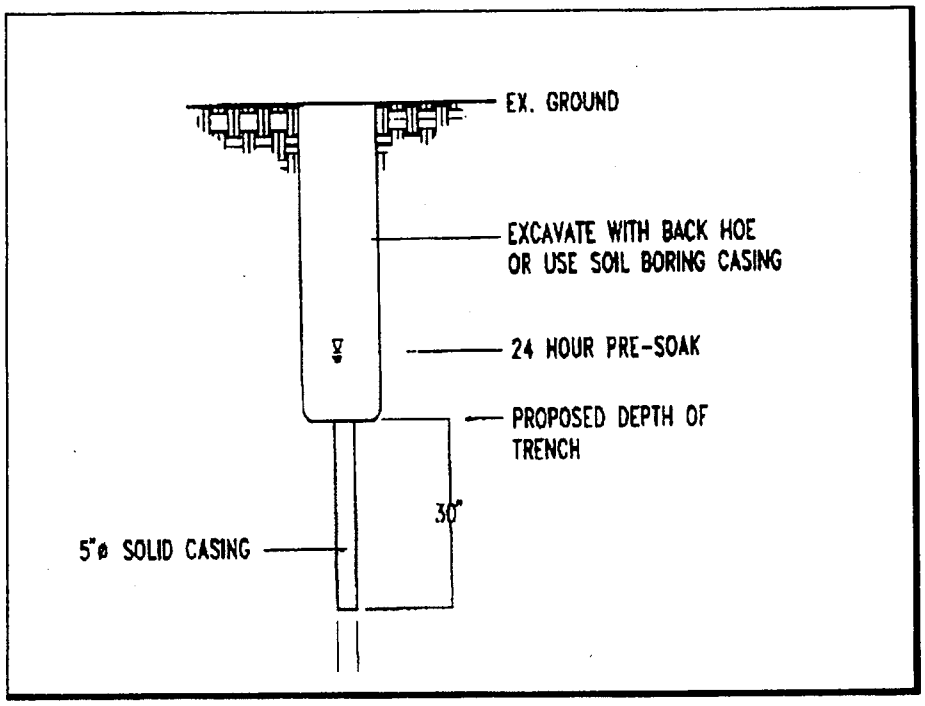
Figure D.1 Infiltration Testing Requirements



Laboratory Testing

a. Grain-size sieve analysis and hydrometer tests where appropriate may be used to determine USDA soils classification and textural analysis. Visual field inspection by a qualified professional may also be used, provided it is documented. *The use of lab testing to establish infiltration rates is prohibited.*

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Bioretention Testing

All areas to be used as bioretention facilities shall be back-filled with a suitable sandy loam planting media. The borrow source of this media, which may be the same or different location from the bioretention area itself, must be tested as follows:

If the borrow area is virgin, undisturbed soil, one test is required per 200 sf of borrow area; the test consists of "grab" samples at one foot depth intervals to the bottom of the borrow area. All samples at the testing location are then mixed, and the resulting sample is then lab-tested to meet the following criteria:

a) USDA minimum textural analysis requirements: A textural analysis is required from the site stockpiled topsoil. If topsoil is imported, then a texture analysis shall be performed for each location where the top soil was excavated.

Minimum requirements:

sand	35 - 60%
silt	30 - 55%
clay	10 - 25%

b) The soil shall be a uniform mix, free of stones, stumps, roots or other similar objects larger than two inches.

c) Consult the bioretention construction specifications (Appendix J) for further guidance on preparing the soil for a bioretention area.

R0080454

SARB_007601

Appendix E

New York State Stormwater Management Design Manual

Example Checklist for Preliminary/Concept Stormwater Management Plan Preparation and Review

- ☐ Applicant information
- ☐ Name, legal address, and telephone number
- ☐ Common address and legal description of site
- ☐ Vicinity map
- ☐ Existing and proposed mapping and plans (recommended scale of 1" = 50'.) which illustrate at a minimum:
  - ▸ Existing and proposed topography (minimum of 2-foot contours recommended)
  - ▸ Perennial and intermittent streams
  - ▸ Mapping of predominant soils from USDA soil surveys
  - ▸ Boundaries of existing predominant vegetation and proposed limits of clearing
  - ▸ Location and boundaries of resource protection areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks)
  - ▸ Location of existing and proposed roads, buildings, and other structures
  - ▸ Existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
  - ▸ Location of existing and proposed conveyance systems such as grass channels, swales, and storm drains
  - ▸ Flow paths
  - ▸ Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
  - ▸ Preliminary location and dimensions of proposed channel modifications, such as bridge or culvert crossings
  - ▸ Preliminary location, size, and limits of disturbance of proposed stormwater treatment practices
- ☐ Hydrologic and hydraulic analysis including:
  - ▸ Existing condition analysis for runoff rates, volumes, and velocities presented showing methodologies used and supporting calculations
  - ▸ Proposed condition analysis for runoff rates, volumes, and velocities showing the methodologies used and supporting calculations
  - ▸ Preliminary analysis of potential downstream impact/effects of project, where necessary
  - ▸ Preliminary selection and rationale for structural stormwater management practices
  - ▸ Preliminary sizing calculations for stormwater treatment practices including contributing drainage area, storage, and outlet configuration
- ☐ Preliminary landscaping plans for stormwater treatment practices and any site reforestation or revegetation
- ☐ Preliminary erosion and sediment control plan that at a minimum meets the requirements outlined in local Erosion and Sediment Control guidelines
- ☐ Identification of preliminary waiver requests

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Example Checklist for Final Stormwater Management Plan Preparation and Review

- ☐ Applicant information
  Name, legal address, and telephone number
- ☐ Common address and legal description of site
- ☐ Signature and stamp of registered engineer/surveyor and design/owner certification
- ☐ Vicinity map
- ☐ Existing and proposed mapping and plans (recommended scale of 1" = 50' or greater detail) which illustrate at a minimum:
  - ▸ Existing and proposed topography (minimum of 2-foot contours recommended)
  - ▸ Perennial and intermittent streams
  - ▸ Mapping of predominant soils from USDA soil surveys as well as location of any site-specific borehole investigations that may have been performed.
  - ▸ Boundaries of existing predominant vegetation and proposed limits of clearing
  - ▸ Location and boundaries of resource protection areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks)
  - ▸ Location of existing and proposed roads, buildings, and other structures
  - ▸ Location of existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
  - ▸ Location of existing and proposed conveyance systems such as grass channels, swales, and storm drains
  - ▸ Flow paths
  - ▸ Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
  - ▸ Location and dimensions of proposed channel modifications, such as bridge or culvert crossings
  - ▸ Location, size, maintenance access, and limits of disturbance of proposed structural stormwater Management practices
- ☐ Representative cross-section and profile drawings and details of structural stormwater Management practices and conveyances (i.e., storm drains, open channels, swales, etc.) which include:
  - ▸ Existing and proposed structural elevations (e.g., invert of pipes, manholes, etc.)
  - ▸ Design water surface elevations
  - ▸ Structural details of outlet structures, embankments, spillways, stilling basins, grade control structures, conveyance channels, etc.
  - ▸ Logs of borehole investigations that may have been performed along with supporting geotechnical report.

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- ☐ Hydrologic and hydraulic analysis for all structural components of stormwater system (e.g., storm drains, open channels, swales, Management practices, etc.) for applicable design storms including:
  - Existing condition analysis for time of concentrations, runoff rates, volumes, velocities, and water surface elevations showing methodologies used and supporting calculations
  - Proposed condition analysis for time of concentrations, runoff rates, volumes, velocities, water surface elevations, and routing showing the methodologies used and supporting calculations
  - Final sizing calculations for structural stormwater Management practices including, contributing drainage area, storage, and outlet configuration
  - Stage-discharge or outlet rating curves and inflow and outflow hydrographs for storage facilities (e.g., stormwater ponds and wetlands)
  - Final analysis of potential downstream impact/effects of project, where necessary
  - Dam breach analysis, where necessary
- ☐ Final landscaping plans for structural stormwater Management practices and any site reforestation or revegetation
- ☐ Structural calculations, where necessary
- ☐ Applicable construction specifications
- ☐ Erosion and sediment control plan that at a minimum meets the requirements of the local Erosion and Sediment Control Guidelines
- ☐ Sequence of construction
- ☐ Maintenance plan which will include:
  - Name, address, and phone number of responsible parties for maintenance.
  - Description of annual maintenance tasks
  - Description of applicable easements
  - Description of funding source
  - Minimum vegetative cover requirements
  - Access and safety issues
  - Testing and disposal of sediments that will likely be necessary
- ☐ Evidence of acquisition of all applicable local and non-local permits
- ☐ Evidence of acquisition of all necessary legal agreements (e.g., easements, covenants, land trusts)
- ☐ Waiver requests
- ☐ Review agency should have inspector's checklist identifying potential features to be inspected on site visits

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Appendix F

New York State Stormwater Management Design Manual

R0080459
SARB_007606

Stormwater/Wetland Pond Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Pre-Construction/Materials and Equipment		
Pre-construction meeting		
Pipe and appurtenances on-site prior to construction and dimensions checked		
1. Material (including protective coating, if specified)		
2. Diameter		
3. Dimensions of metal riser or pre-cast concrete outlet structure		
4. Required dimensions between water control structures (orifices, weirs, etc.) are in accordance with approved plans		
5. Barrel stub for prefabricated pipe structures at proper angle for design barrel slope		
6. Number and dimensions of prefabricated anti-seep collars		
7. Watertight connectors and gaskets		
8. Outlet drain valve		
Project benchmark near pond site		
Equipment for temporary de-watering		

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CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
2. Subgrade Preparation		
Area beneath embankment stripped of all vegetation, topsoil, and organic matter		
3. Pipe Spillway Installation		
Method of installation detailed on plans		
A. Bed preparation		
Installation trench excavated with specified side slopes		
Stable, uniform, dry subgrade of relatively impervious material (If subgrade is wet, contractor shall have defined steps before proceeding with installation)		
Invert at proper elevation and grade		
B. Pipe placement		
Metal / plastic pipe		
1. Watertight connectors and gaskets properly installed		
2. Anti-seep collars properly spaced and having watertight connections to pipe		
3. Backfill placed and tamped by hand under "haunches" of pipe		
4. Remaining backfill placed in max. 8 inch lifts using small power tamping equipment until 2 feet cover over pipe is reached		

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CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
3. Pipe Spillway Installation		
Concrete pipe		
1. Pipe set on blocks or concrete slab for pouring of low cradle		
2. Pipe installed with rubber gasket joints with no spalling in gasket interface area		
3. Excavation for lower half of anti-seep collar(s) with reinforcing steel set		
4. Entire area where anti-seep collar(s) will come in contact with pipe coated with mastic or other approved waterproof sealant		
5. Low cradle and bottom half of anti-seep collar installed as monolithic pour and of an approved mix		
6. Upper half of anti-seep collar(s) formed with reinforcing steel set		
7. Concrete for collar of an approved mix and vibrated into place (protected from freezing while curing, if necessary)		
8. Forms stripped and collar inspected for honeycomb prior to backfilling. Parge if necessary.		
C. Backfilling		
Fill placed in maximum 8 inch lifts		
Backfill taken minimum 2 feet above top of anti-seep collar elevation before traversing with heavy equipment		

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CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
4. Riser / Outlet Structure Installation		
Riser located within embankment		
A. Metal riser		
Riser base excavated or formed on stable subgrade to design dimensions		
Set on blocks to design elevations and plumbed		
Reinforcing bars placed at right angles and projecting into sides of riser		
Concrete poured so as to fill inside of riser to invert of barrel		
B. Pre-cast concrete structure		
Dry and stable subgrade		
Riser base set to design elevation		
If more than one section, no spalling in gasket interface area; gasket or approved caulking material placed securely		
Watertight and structurally sound collar or gasket joint where structure connects to pipe spillway		
C. Poured concrete structure		
Footing excavated or formed on stable subgrade, to design dimensions with reinforcing steel set		
Structure formed to design dimensions, with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place (protected from freezing while curing, if necessary)		
Forms stripped & inspected for "honeycomb" prior to backfilling; parge if necessary		

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CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
5. Embankment Construction		
Fill material		
Compaction		
Embankment		
1. Fill placed in specified lifts and compacted with appropriate equipment		
2. Constructed to design cross-section, side slopes and top width		
3. Constructed to design elevation plus allowance for settlement		
6. Impounded Area Construction		
Excavated / graded to design contours and side slopes		
Inlet pipes have adequate outfall protection		
Forebay(s)		
Pond benches		
7. Earth Emergency Spillway Construction		
Spillway located in cut or structurally stabilized with riprap, gabions, concrete, etc.		
Excavated to proper cross-section, side slopes and bottom width		
Entrance channel, crest, and exit channel constructed to design grades and elevations		

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SARB_007611

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
8. Outlet Protection		
A. End section		
Securely in place and properly backfilled		
B. Endwall		
Footing excavated or formed on stable subgrade, to design dimensions and reinforcing steel set, if specified		
Endwall formed to design dimensions with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place (protected from freezing, if necessary)		
Forms stripped and structure inspected for "honeycomb" prior to backfilling; parge if necessary		
C. Riprap apron / channel		
Apron / channel excavated to design cross-section with proper transition to existing ground		
Filter fabric in place		
Stone sized as per plan and uniformly place at the thickness specified		
9. Vegetative Stabilization		
Approved seed mixture or sod		
Proper surface preparation and required soil amendments		
Excelsior mat or other stabilization, as per plan		

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CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
10. Miscellaneous		
Drain for ponds having a permanent pool		
Trash rack / anti-vortex device secured to outlet structure		
Trash protection for low flow pipes, orifices, etc.		
Fencing (when required)		
Access road		
Set aside for clean-out maintenance		
11. Stormwater Wetlands		
Adequate water balance		
Variety of depth zones present		
Approved pondscaping plan in place Reinforcement budget for additional plantings		
Plants and materials ordered 6 months prior to construction		
Construction planned to allow for adequate planting and establishment of plant community (April-June planting window)		
Wetland buffer area preserved to maximum extent possible		

Comments:

R0080466

SARB_007613

Actions to be Taken:

R0080467

SARB_007614

Infiltration Trench Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Soil permeability tested		
Groundwater / bedrock sufficient at depth		
2. Excavation		
Size and location		
Side slopes stable		
Excavation does not compact subsoils		
3. Filter Fabric Placement		
Fabric specifications		
Placed on bottom, sides, and top		

R0080468

SARB_007615

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Aggregate Material		
Size as specified		
Clean / washed material		
Placed properly		
5. Observation Well		
Pipe size		
Removable cap / footplate		
Initial depth =_____feet		
6. Final Inspection		
Pretreatment facility in place		
Contributing watershed stabilized prior to flow diversion		
Outlet		

Comments:

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SARB_007616

Actions to be Taken:

R0080470

SARB_007617

Infiltration Basin Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Runoff diverted		
Soil permeability tested		
Groundwater / bedrock depth		
2. Excavation		
Size and location		
Side slopes stable		
Excavation does not compact subsoils		
3. Embankment		
Barrel		
Anti-seep collar or Filter diaphragm		
Fill material		

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SARB_007618

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
4. Final Excavation		
Drainage area stabilized		
Sediment removed from facility		
Basin floor tilled		
Facility stabilized		
5. Final Inspection		
Pretreatment facility in place		
Inlets / outlets		
Contributing watershed stabilized before flow is routed to the factility		

Comments:

Actions to be Taken:

R0080472
SARB_007619

Sand/Organic Filter System Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Pre-construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
Facility location staked out		
2. Excavation		
Size and location		
Side slopes stable		
Foundation cleared of debris		
If designed as exfilter, excavation does not compact subsoils		
Foundation area compacted		
3. Structural Components		
Dimensions and materials		
Forms adequately sized		
Concrete meets standards		
Prefabricated joints sealed		
Underdrains (size, materials)		

R0080473
SARB_007620

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Completed Facility Components		
24 hour water filled test		
Contributing area stabilized		
Filter material per specification		
Underdrains installed to grade		
Flow diversion structure properly installed		
Pretreatment devices properly installed		
Level overflow weirs, multiple orifices, distribution slots		
5. Final Inspection		
Dimensions		
Surface completely level		
Structural components		
Proper outlet		
Ensure that site is properly stabilized before flow is directed to the structure.		

R0080474

SARB_007621

Comments:

Actions to be Taken:

R0080475
SARB_007622

Bioretention Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
If designed as exfilter, soil testing for permeability		
Facility location staked out		
2. Excavation		
Size and location		
Lateral slopes completely level		
If designed as exfilter, ensure that excavation does not compact susoils.		
Longitudinal slopes within design range		

R0080476
SARB_007623

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
3. Structural Components		
Stone diaphragm installed correctly		
Outlets installed correctly		
Underdrain		
Pretreatment devices installed		
Soil bed composition and texture		
4. Vegetation		
Complies with planting specs		
Topsoil adequate in composition and placement		
Adequate erosion control measures in place		
5. Final Inspection		
Dimensions		
Proper stone diaphragm		
Proper outlet		
Soil/ filter bed permeability testing		
Effective stand of vegetation and stabilization		
Construction generated sediments removed		
Contributing watershed stabilized before flow is diverted to the practice		

R0080477

SARB_007624

Comments:

Actions to be Taken:

R0080478

SARB_007625

Open Channel System Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

Construction Sequence	Satisfactory / Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility location staked out		
2. Excavation		
Size and location		
Side slope stable		
Soil permeability		
Groundwater / bedrock		
Lateral slopes completely level		
Longitudinal slopes within design range		
Excavation does not compact subsoils		
3. Check dams		
Dimensions		
Spacing		
Materials		

R0080479
SARB_007626

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Structural Components		
Underdrain installed correctly		
Inflow installed correctly		
Pretreatment devices installed		
5. Vegetation		
Complies with planting specifications		
Topsoil adequate in composition and placement		
Adequate erosion control measures in place		
6. Final inspection		
Dimensions		
Check dams		
Proper outlet		
Effective stand of vegetation and stabilization		
Contributing watershed stabilized before flow is routed to the factility		

Comments:

R0080480
SARB_007627

Actions to be Taken:

R0080481

SARB_007628

Appendix G

R0080482
SARB_007629

Stormwater Pond/Wetland Operation, Maintenance and Management Inspection Checklist

Project _____
Location: _____
Site Status: _____

Date: _____
Time: _____

Inspector: _____

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
1. Embankment and emergency spillway (Annual, After Major Storms)		
1. Vegetation and ground cover adequate		
2. Embankment erosion		
3. Animal burrows		
4. Unauthorized planting		
5. Cracking, bulging, or sliding of dam		
a. Upstream face		
b. Downstream face		
c. At or beyond toe		
downstream		
upstream		
d. Emergency spillway		
6.Pond, toe & chimney drains clear and functioning		
7.Seeps/leaks on downstream face		
8.Slope protection or riprap failure		
9. Vertical/horizontal alignment of top of dam "As-Built"		

R0080483
SARB_007630

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
10. Emergency spillway clear of obstructions and debris		
11. Other (specify)		
2. Riser and principal spillway (Annual)		
Type: Reinforced concrete _____ Corrugated pipe _____ Masonry _____ 1. Low flow orifice obstructed		
2. Low flow trash rack. a. Debris removal necessary		
b. Corrosion control		
3. Weir trash rack maintenance a. Debris removal necessary		
b. corrosion control		
4. Excessive sediment accumulation insider riser		
5. Concrete/masonry condition riser and barrels a. cracks or displacement		
b. Minor spalling (<1")		
c. Major spalling (rebars exposed)		
d. Joint failures		
e. Water tightness		
6. Metal pipe condition		
7. Control valve a. Operational/exercised		
b. Chained and locked		
8. Pond drain valve a. Operational/exercised		
b. Chained and locked		
9. Outfall channels functioning		
10. Other (specify)		

R0080484

SARB_007631

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
3. Permanent Pool (Wet Ponds) (monthly)		
1. Undesirable vegetative growth		
2. Floating or floatable debris removal required		
3. Visible pollution		
4. Shoreline problem		
5. Other (specify)		
4. Sediment Forebays		
1.Sedimentation noted		
2. Sediment cleanout when depth < 50% design depth		
5. Dry Pond Areas		
1. Vegetation adequate		
2. Undesirable vegetative growth		
3. Undesirable woody vegetation		
4. Low flow channels clear of obstructions		
5. Standing water or wet spots		
6. Sediment and / or trash accumulation		
7. Other (specify)		
6. Condition of Outfalls (Annual , After Major Storms)		
1. Riprap failures		
2. Slope erosion		
3. Storm drain pipes		
4.Endwalls / Headwalls		
5. Other (specify)		
7. Other (Monthly)		
1. Encroachment on pond, wetland or easement area		

R0080485

SARB_007632

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
2. Complaints from residents		
3.Aesthetics a. Grass growing required		
b. Graffiti removal needed		
c. Other (specify)		
4. Conditions of maintenance access routes.		
5. Signs of hydrocarbon build-up		
6. Any public hazards (specify)		
8. Wetland Vegetation (Annual)		
1. Vegetation healthy and growing Wetland maintaining 50% surface area coverage of wetland plants after the second growing season. (If unsatisfactory, reinforcement plantings needed)		
2. Dominant wetland plants: Survival of desired wetland plant species Distribution according to landscaping plan?		
3. Evidence of invasive species		
4. Maintenance of adequate water depths for desired wetland plant species		
5. Harvesting of emergent plantings needed		
6. Have sediment accumulations reduced pool volume significantly or are plants "choked" with sediment		
7. Eutrophication level of the wetland.		
8. Other (specify)		

Comments:

R0080486

SARB_007633

Actions to be Taken:

R0080487

SARB_007634

Infiltration Trench Operation, Maintenance, and Management Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Trench surface clear of debris		
Inflow pipes clear of debris		
Overflow spillway clear of debris		
Inlet area clear of debris		
2. Sediment Traps or Forebays (Annual)		
Obviously trapping sediment		
Greater than 50% of storage volume remaining		
3. Dewatering (Monthly)		
Trench dewaters between storms		
4. Sediment Cleanout of Trench (Annual)		
No evidence of sedimentation in trench		
Sediment accumulation doesn't yet require cleanout		
5. Inlets (Annual)		

R0080488
SARB_007635

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
Good condition		
No evidence of erosion		
6. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repair		
No evidence of erosion		
7. Aggregate Repairs (Annual)		
Surface of aggregate clean		
Top layer of stone does not need replacement		
Trench does not need rehabilitation		

Comments:

Actions to be Taken:

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Sand/Organic Filter Operation, Maintenance and Management Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Contributing areas clean of debris		
Filtration facility clean of debris		
Inlet and outlets clear of debris		
2. Oil and Grease (Monthly)		
No evidence of filter surface clogging		
Activities in drainage area minimize oil and grease entry		
3. Vegetation (Monthly)		
Contributing drainage area stabilized		
No evidence of erosion		
Area mowed and clipping removed		
4. Water Retention Where Required (Monthly)		
Water holding chambers at normal pool		
No evidence of leakage		
5. Sediment Deposition (Annual)		

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MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
Filter chamber free of sediments		
Sedimentation chamber not more than half full of sediments		
6. Structural Components (Annual)		
No evidence of structural deterioration		
Any grates are in good condition		
No evidence of spalling or cracking of structural parts		
7. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repairs		
No evidence of erosion (if draining into a natural channel)		
8. Overall Function of Facility (Annual)		
Evidence of flow bypassing facility		
No noticeable odors outside of facility		

Comments:

Actions to be Taken:

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Bioretention Operation, Maintenance and Management Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Bioretention and contributing areas clean of debris		
No dumping of yard wastes into practice		
Litter (branches, etc.) have been removed		
2. Vegetation (Monthly)		
Plant height not less than design water depth		
Fertilized per specifications		
Plant composition according to approved plans		
No placement of inappropriate plants		
Grass height not greater than 6 inches		
No evidence of erosion		
3. Check Dams/Energy Dissipaters/Sumps (Annual, After Major Storms)		
No evidence of sediment buildup		

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MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
Sumps should not be more than 50% full of sediment		
No evidence of erosion at downstream toe of drop structure		
4. Dewatering (Monthly)		
Dewaters between storms		
No evidence of standing water		
5. Sediment Deposition (Annual)		
Swale clean of sediments		
Sediments should not be > 20% of swale design depth		
6. Outlet/Overflow Spillway (Annual, After Major Storms)		
Good condition, no need for repair		
No evidence of erosion		
No evidence of any blockages		
7. Integrity of Filter Bed (Annual)		
Filter bed has not been blocked or filled inappropriately		

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Comments:

Actions to be Taken:

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Open Channel Operation, Maintenance, and Management Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Contributing areas clean of debris		
2. Check Dams or Energy Dissipators (Annual, After Major Storms)		
No evidence of flow going around structures		
No evidence of erosion at downstream toe		
Soil permeability		
Groundwater / bedrock		
3. Vegetation (Monthly)		
Mowing done when needed		
Minimum mowing depth not exceeded		
No evidence of erosion		
Fertilized per specification		
4. Dewatering (Monthly)		
Dewaters between storms		

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MAINTENANCE ITEM	SATISFACTORY/ UNSATISFACTORY	COMMENTS
5. Sediment deposition (Annual)		
Clean of sediment		
6. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repairs		
No evidence of erosion		

Comments:

Actions to be Taken:

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Appendix H

New York State Stormwater Management Design Manual

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Appendix H: Landscaping Guidance/Plant Lists

H.1 Ponds and Wetlands

For areas that are to be planted within a stormwater pond, it is necessary to determine what type of hydrologic zones will be created within the pond. The following six zones describe the different conditions encountered in stormwater management facilities. Every facility does not necessarily reflect all of these zones. The hydrologic zones designate the degree of tolerance the plant exhibits to differing degrees of inundation by water.

Table H.5 at the end of this appendix designates appropriate zones for each plant. There may be other zones listed outside of these brackets. The plant materials may occur within these zones, but are not typically found in them. Plants suited for specific hydrologic conditions may perish when those conditions change, exposing the soil, and therefore, increasing the chance for erosion.

Each zone has its own set of plant selection criteria based on the hydrology of the zone, the stormwater functions required of the plant and the desired landscape effect. The hydrologic zones are as follows:

Table H.1 Hydrologic Zones

Zone #	Zone Description	Hydrologic Conditions
Zone 1	Deep Water Pool	1-6 feet deep Permanent Pool
Zone 2	Shallow Water Bench	6 inches to 1 foot deep
Zone 3	Shoreline Fringe	Regularly inundated
Zone 4	Riparian Fringe	Periodically inundated
Zone 5	Floodplain Terrace	Infrequently inundated
Zone 6	Upland Slopes	Seldom or never inundated

Zone 1: Deep Water Area ***(1- 6 Feet)***

Ponds and wetlands both have deep pool areas that comprise Zone 1. These pools range from one to six feet in depth, and are best colonized by submergent plants, if at all.

This pondscaping zone has not been routinely planted for several reasons. First, the availability of plant materials that can survive and grow in this zone is limited, and it is also feared that plants could clog the stormwater facility outlet structure. In many cases, these plants will gradually become established through natural recolonization (e.g., transport of plant fragments from other ponds via the feet and legs of waterfowl). If submerged plant material becomes more commercially available and clogging concerns are addressed, this area can be planted. The function of the planting is to reduce resedimentation and improve oxidation while creating a greater aquatic habitat.

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- Plant material must be able to withstand constant inundation of water of one foot or greater in depth.
- Plants may be submerged partially or entirely.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, desirable insects, and other aquatic life.

Zone 2: Shallow Water Bench ***(Normal Pool To 1 Foot)***

Zone 2 includes all areas that are inundated below the normal pool to a depth of one foot, and is the primary area where emergent plants will grow in a stormwater wetlands. Zone 2 also coincides with the aquatic bench found in stormwater ponds. This zone offers ideal conditions for the growth of many emergent wetland species. These areas may be located at the edge of the pond or on low mounds of earth located below the surface of the water within the pond. When planted, Zone 2 can be an important habitat for many aquatic and nonaquatic animals, creating a diverse food chain. This food chain includes predators, allowing a natural regulation of mosquito populations, thereby reducing the need for insecticidal applications.

- Plant material must be able to withstand constant inundation of water to depths between six inches and one foot deep.
- Plants will be partially submerged.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, desirable insects and other aquatic life.

Plants will stabilize the bottom of the pond, as well as the edge of the pond, absorbing wave impacts and reducing erosion, when water level fluctuates. Plant also slow water velocities and increase sediment deposition rates. Plants can reduce resuspension of sediments caused by the wind. Plants can also soften the engineered contours of the pond, and can conceal drawdowns during dry weather.

Zone 3: Shoreline Fringe ***(Regularly Inundated)***

Zone 3 encompasses the shoreline of a pond or wetland, and extends vertically about one foot in elevation from the normal pool. This zone includes the safety bench of a pond, and may also be periodically inundated if storm events are subject to extended detention. This zone occurs in a wet pond or shallow marsh and can be the most difficult to establish since plants must be able to withstand inundation of water during storms, when wind might blow water into the area, or the occasional drought during the summer. In order to stabilize the soil in this zone, Zone 3 must have a vigorous cover.

- Plants should stabilize the shoreline to minimize erosion caused by wave and wind action or water fluctuation.
- Plant material must be able to withstand occasional inundation of water. Plants will be partially submerged at this time.
- Plant material should, whenever possible, shade the shoreline, especially the southern exposure. This will help to reduce the water temperature.

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- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, songbirds, and wildlife. Plants could also be selected and located to control overpopulation of waterfowl.
- Plants should be located to reduce human access, where there are potential hazards, but should not block the maintenance access.
- Plants should have very low maintenance requirements, since they may be difficult or impossible to reach.
- Plants should be resistant to disease and other problems which require chemical applications (since chemical application is not advised in stormwater ponds).

Zone 4: Riparian Fringe ***(Periodically Inundated)***

Zone 4 extends from one to four feet in elevation above the normal pool. Plants in this zone are subject to periodic inundation after storms, and may experience saturated or partly saturated soil conditions. Nearly all of the temporary ED area is included within this zone.

- Plants must be able to withstand periodic inundation of water after storms, as well as occasional drought during the warm summer months.
- Plants should stabilize the ground from erosion caused by run-off.
- Plants should shade the low flow channel to reduce the pool warming whenever possible.
- Plants should be able to enhance pollutant uptake.
- Plant material should have very low maintenance, since they may be difficult or impossible to access.
- Plants may provide food and cover for waterfowl, songbirds and wildlife. Plants may also be selected and located to control overpopulation of waterfowl.
- Plants should be located to reduce pedestrian access to the deeper pools.

Zone 5: Floodplain Terrace ***(Infrequently Inundated)***

Zone 5 is periodically inundated by flood waters that quickly recedes in a day or less. Operationally, Zone 5 extends from the maximum two year or Cpv water surface elevation up to the 10 or 100 year maximum water surface elevation. Key landscaping objectives for Zone 5 are to stabilize the steep slopes characteristic of this zone, and establish a low maintenance, natural vegetation.

- Plant material should be able to withstand occasional but brief inundation during storms, although typical moisture conditions may be moist, slightly wet, or even swing entirely to drought conditions during the dry weather periods.
- Plants should stabilize the basin slopes from erosion.
- Ground cover should be very low maintenance, since they may be difficult to access on steep slopes or if frequency of mowing is limited. A dense tree cover may help reduce maintenance and discourage resident geese.
- Plants may provide food and cover for waterfowl, songbirds, and wildlife.

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- Placement of plant material in Zone 5 is often critical, as it often creates a visual focal point and provides structure and shade for a greater variety of plants.

Zone 6: Upland Slopes *(Seldom or Never Inundated)*

The last zone extends above the maximum 100 year water surface elevation, and often includes the outer buffer of a pond or wetland. Unlike other zones, this upland area may have sidewalks, bike paths, retaining walls, and maintenance access roads. Care should be taken to locate plants so they will not overgrow these routes or create hiding places that might make the area unsafe.

- Plant material is capable of surviving the particular conditions of the site. Thus, it is not necessary to select plant material that will tolerate any inundation. Rather, plant selections should be made based on soil condition, light, and function within the landscape.
- Ground covers should emphasize infrequent mowing to reduce the cost of maintaining this landscape.
- Placement of plants in Zone 6 is important since they are often used to create a visual focal point, frame a desirable view, screen undesirable views, serve as a buffer, or provide shade to allow a greater variety of plant materials. Particular attention should be paid to seasonal color and texture of these plantings.

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H.2 Bioretention

Planting Soil Bed Characteristics

The characteristics of the soil for the bioretention facility are perhaps as important as the facility location, size, and treatment volume. The soil must be permeable enough to allow runoff to filter through the media, while having characteristics suitable to promote and sustain a robust vegetative cover crop. In addition, much of the nutrient pollutant uptake (nitrogen and phosphorus) is accomplished through adsorption and microbial activity within the soil profile. Therefore, the soils must balance soil chemistry and physical properties to support biotic communities above and below ground.

The planting soil should be a sandy loam, loamy sand, loam (USDA), or a loam/sand mix (should contain a minimum 35 to 60% sand, by volume). The clay content for these soils should by less than 25% by volume. Soils should fall within the SM, or ML classifications of the Unified Soil Classification System (USCS). A permeability of at least 1.0 feet per day (0.5"/hr) is required (a conservative value of 0.5 feet per day is used for design). The soil should be free of stones, stumps, roots, or other woody material over 1" in diameter. Brush or seeds from noxious weeds. Placement of the planting soil should be in lifts of 12 to 18", loosely compacted (tamped lightly with a dozer or backhoe bucket). The specific characteristics are presented in Table H.2.

Table H.2 Planting Soil Characteristics

Parameter	Value
PH range	5.2 to 7.00
Organic matter	1.5 to 4.0%
Magnesium	35 lbs. per acre, minimum
Phosphorus (P_2O_5)	75 lbs. per acre, minimum
Potassium (K_2O)	85 lbs. per acre, minimum
Soluble salts	≤ 500 ppm
Clay	10 to 25%
Silt	30 to 55%
Sand	35 to 60%

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Mulch Layer

The mulch layer plays an important role in the performance of the bioretention system. The mulch layer helps maintain soil moisture and avoid surface sealing which reduces permeability. Mulch helps prevent erosion, and provides a micro-environment suitable for soil biota at the mulch/soil interface. It also serves as a pretreatment layer, trapping the finer sediments which remain suspended after the primary pretreatment.

The mulch layer should be standard landscape style, single or double, shredded hardwood mulch or chips. The mulch layer should be well aged (stockpiled or stored for at least 12 months), uniform in color, and free of other materials, such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of three inches. Grass clippings should not be used as a mulch material.

Planting Plan Guidance

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an ecosystem consisting of an upland-oriented community dominated by trees, but having a distinct community, or sub-canopy, of understory trees, shrubs and herbaceous materials. The intent is to establish a diverse, dense plant cover to treat stormwater runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention facility (Figure H.1). The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports a slightly drier group of plants, but still tolerates fluctuating water levels. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions. When using Table A.5 to identify species, use the following guideline:

Lowest Zone: Zones 2-3

Middle Zone: Zones 3-4

Outer Zone: Zones 5-6

The layout of plant material should be flexible, but should follow the general principals described in Table H.3. The objective is to have a system which resembles a random and natural plant layout, while maintaining optimal conditions for plant establishment and growth.

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Figure H.1 Planting Zones for Bioretention Facilities

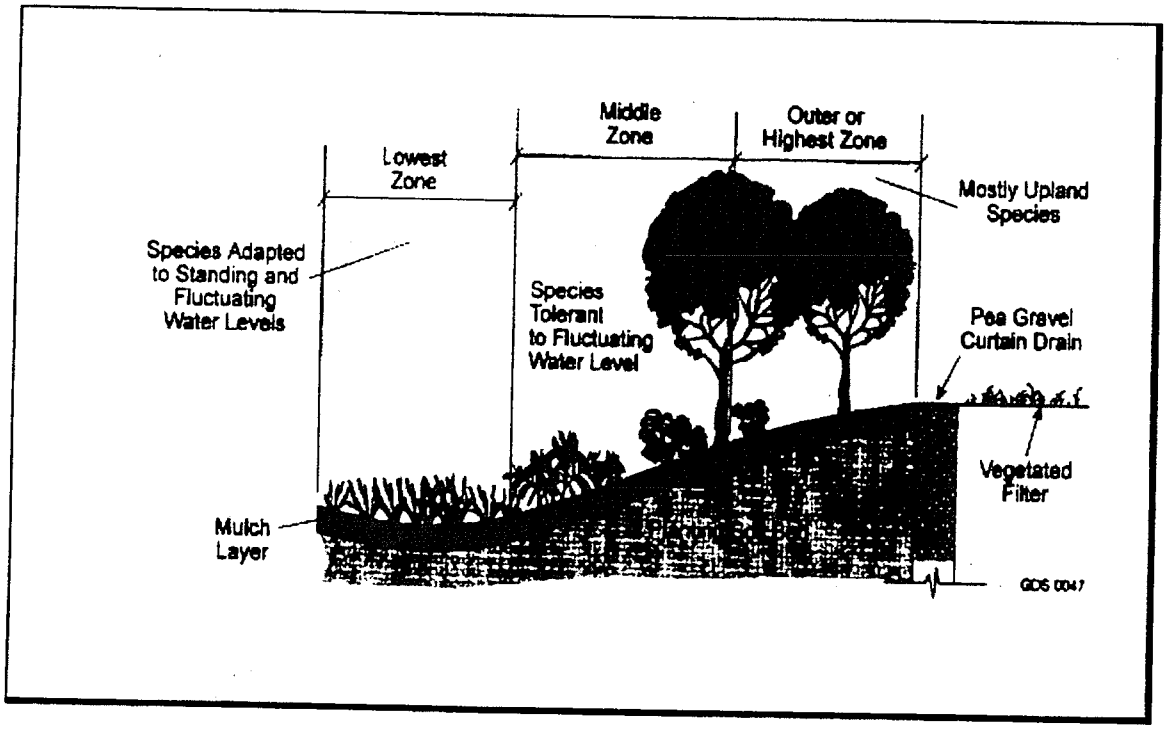

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Table H.3 Planting Plan Design Considerations
Native plant species should be specified over exotic or foreign species.
Appropriate vegetation should be selected based on the zone of hydric tolerance (see Figure H.1).
Species layout should generally be random and natural.
A canopy should be established with an understory of shrubs and herbaceous materials.
Woody vegetation should not be specified in the vicinity of inflow locations.
Trees should be planted primarily along the perimeter of the bioretention area.
Urban stressors (e.g., wind, sun, exposure, insect and disease infestation, drought) should be considered when laying out the planting plan.
Noxious weeds should not be specified.
Aesthetics and visual characteristics should be a prime consideration.
Traffic and safety issues must be considered.
Existing and proposed utilities must be identified and considered.

Plant Material Guidance

Plant materials should conform to the American Standard Nursery Stock, published by the American Association of Nurserymen, and should be selected from certified, reputable nurseries. Planting specifications should be prepared by the designer and should include a sequence of construction, a description of the contractor's responsibilities, a planting schedule and installation specifications, initial maintenance, and a warranty period and expectations of plant survival. Table H.4 presents some typical issues for planting specifications.

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Table H.4 Planting Specification Issues for Bioretention Areas	
Specification Element	**Elements**
Sequence of Construction	Describe site preparation activities, soil amendments, etc.; address erosion and sediment control procedures; specify step-by-step procedure for plant installation through site clean-up.
Contractor's Responsibilities	Specify the contractors responsibilities, such as watering, care of plant material during transport, timeliness of installation, repairs due to vandalism, etc.
Planting Schedule and Specifications	Specify the materials to be installed, the type of materials (e.g., B&B, bare root, containerized); time of year of installations, sequence of installation of types of plants; fertilization, stabilization seeding, if required; watering and general care.
Maintenance	Specify inspection periods; mulching frequency (annual mulching is most common); removal and replacement of dead and diseased vegetation; treatment of diseased trees; watering schedule after initial installation (once per day for 14 days is common); repair and replacement of staking and wires.
Warranty	Specify the warranty period, the required survival rate, and expected condition of plant species at the end of the warranty period.

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)						
Plant Name	**Zone**	**Form**	**Available**	**Inundation Tolerance**	**Wildlife Value**	**Notes**
Trees and Shrubs						
American Elm *(Ulmus americana)*	4,5,6	Dec. Tree	yes	Irregular-seasonal saturation	High. Food (seeds,browsing), cover, nesting for birds & mammals	Susceptible to diesease (short-lived). Sun to full shade, tolerates drought and wind/ice damage.
Arrowwood Viburnium *(Viburrium dentatum)*	3,4	Dec. Shrub	yes	yes	High. Songbirds and mammals	Grows best in sun to partial shade
Bald Cypress *(Taxodium distichum)*	3,4	Dec. Tree	yes	yes	Little food value, but good perching site for waterfowl	Forested Coastal Plain. North of normal range. Tolerates drought.
Bayberry *(Myrica pensylvanica)*	4,5,6	Dec. Shrub	yes	yes	High. Nesting, food, cover. Berries last into winter	Coastal Plain only. Roots fix N_2 Tolerates slightly acidic soils.
Black Ash *(Fraxinus nigra)*	3,4,5	Dec. Tree	yes	Irregular-seasonal saturation	High. Food (seeds, sap), cover, nesting for birds & mammals. Fruit persists in winter	Rapid growth. Requires full sun. Susceptible to wind/ice damage & disease. Tolerates drought and infrequent flooding by salt water.
Black Cherry *(Prunus serotina)*	5,6	Dec. Tree	yes	no	High. Food	Moist soils or wet bottomland areas
Blackgum or Sourgum *(Nyssa sylvatica)*	4,5,6	Dec. Tree	yes	yes	High. Songbirds, egrets, herons, raccoons, owls	Can be difficult to transplant. Prefers sun to partial shade
Black Willow *(Salix nigra)*	3,4,5	Dec. Tree	yes	yes	High. Browsing and cavity nesters.	Rapid growth, stabilizes stream-banks. Full sun
Buttonbush *(Cepahlanthus occidentalis)*	2,3,4,5	Dec. Shrub	yes	yes	High. Ducks and shorebirds. Seeds, nectar and nesting.	Full sun to partial shade. Will grow in dry areas.
Common Spice Bush *(Lindera benzoin)*	3,4,5	Dec. Shrub	yes	yes	Very high. Songbirds	Shade and rich soils. Tolerates acidic soils. Good understory species

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Eastern Cottonwood *(Populus deltoides)*	4,5	Dec. Tree	yes	yes	Moderate. Cover, food.	Shallow rooted, subject to windthrow. Invasive roots. Rapid growth.
Eastern Hemlock *(Tsuga canadensis)*	5,6	Conif Tree	yes	yes	Moderate. Mostly cover and some food	Tolerates all sun/shade conditions. Tolerates acidic soil.
Eastern Red Cedar *(Juniperus virginiana)*	4,5,6	Conif Tree	yes	no	High. Fruit for birds. Some cover.	Full sun to partial shade. Common in wetlands, shrub bogs and edge of stream
Elderberry *(Sambucus canadensis)*	3,4,5,6	Dec. Shrub	yes	yes	Extremely high. Food and cover, birds and mammals.	Full sun to partial shade.
Green Ash, Red Ash *(Fraxinus pennsylvania)*	4,5	Dec. Tree	yes	yes	Moderate. Songbirds.	Rapid growing streambank stabilizer. Full sun to partial shade.
Hackenberry *(Celtis occidentalis)*	5,6	Dec. Tree	yes	some	High. Food and cover	Full sun to partial shade.
Larch, Tamarack *(Larix latricina)*	3,4	Conif Tree	no	yes	Low. Nest tree and seeds.	Rapid initial growth. Full sun, acidic boggy soil.
Pin Oak *(Quercus palustris)*	3,4,5,6	Dec. Tree	yes	yes	High. Tolerates acidic soil	Gypsy moth target. Prefers well drained, sandy soils.
Red Choke Berry *(Pyrus arbutifolia)*	3,4,5	Dec. Shrub	no	yes	Moderate. Songbirds.	Bank stabilizer. Partial sun.
Red Maple *(Acer rubrum)*	3,4,5,6	Dec. Tree	yes	yes	High seeds and browse. Tolerates acidic soil.	Rapid growth.
River Birch *(Betula nigra)*	3,4,5	Dec. Tree	yes	yes	Low. Good for cavity nesters.	Bank erosion control. Full sun.
Shadowbush, Serviceberry *(Amelanchier*	4,5,6	Dec. Shrub	yes	yes	High. Nesting, cover, food. Birds and	Prefers partial shade. Common in forested

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
canadensis)					mammals.	wetlands and upland woods.
Silky Dogwood *(Cornus amomium)*	3,4,5	Dec. Shrub	yes	yes	High. Songbirds, mammals.	Shade and drought tolerant. Good bank stabilizer.
Slippery Elm *(Ulnus rubra)*	3,4,5	Dec. Tree	rare	yes	High. Food (seeds, buds) for birds & mammals (browse). Nesting	Rapid growth, no salinity tolerance. Tolerant to shade and drought.
Smooth Alder *(Alnus serrulata)*	3,4,5	Dec. Tree	no	yes	High. Food, cover.	Rapid growth. Stabilizes streambanks.
Speckled Alder *(Alnus rugosa)*	3,4	Dec. Shrub	yes	yes	High. Cover, browse for deer, seeds for bird.	
Swamp White Oak *(Quercus bicolor)*	3,4,5	Dec. Tree	yes	yes	High. Mast	Full sun to partial shade. Good bottomland tree.
Swamp Rose *(Rosa Palustrus)*	3,4	Dec. Shrub		Irregular, seasonal, or regularly saturated	High. Food (hips) for birds including turkey, ruffed grouse and mammals. Fox cover.	Prefers full sun. Easy to establish. Low salt tolerance.
Sweetgum *(Liquidambar styraciflua)*	4,5,6	Dec. Tree	yes	yes	Moderate. Songbirds	Tolerates acid or clay soils. Sun to partial shade.
Sycamore *(Platanus occidentalis)*	4,5,6,	Dec. Tree	yes	yes	Low. Food, cavities for nesting.	Rapid growth. Common in floodplains and alluvial woodlands.
Tulip Tree *(Liriodendron tulipifera)*	5,6	Dec. Tree	yes	no	Moderate. Seeds and nest sites	Full sun to partial shade. Well drained soils. Rapid growth.
Tupelo *(Nyssa sylvatica vari biflora)*	3,4,5	Dec. Tree	yes	yes	High. Seeds and nest sites	Ornamental

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
White Ash *(Fraxinus americana)*	5,6	Dec. Tree	yes	no	High. Food	All sunlight conditions. Well drained soils.
Winterberry *(Ilex verticillata)*	3,4,5	Dec. Shrub	yes	yes	High. Cover and fruit for birds. Holds berries into winter.	Full sun to partial shade. Seasonally flooded areas.
Witch Hazel *(Hamamelis virginiana)*	4,5	Dec. Shrub	yes	no	Low. Food for squirrels, deer, and ruffed grouse.	Prefers shade. Ornamental.
Herbaceous Plants						
Arrow arum *(Peltandra virginica)*	2,3	Emergent	yes	up to 1 ft.	High. Berries are eaten by wood ducks.	Full sun to partial shade.
Arrowhead, Duck Potato *(Saggitaria latifolia)*	2,3	Emergent	yes	up to 1 ft.	Moderate. Tubers and seeds eaten by ducks.	Aggressive colonizer.
Big Bluestem (*Andropogon gerardi*)	4,5	Perimeter	yes	Irregular or seasonal inundation.	High. Seeds for songbirds. Food for deer	Requires full sun.
Birdfoot deervetch (*Lotus Corniculatus*)	4,5,6	Perimeter	yes	Infrequent inundation	High. Food for birds.	Full sun. Nitrogen fixer.
Blue Flag Iris *(Iris versicolor)*	2,3	Emergent	yes	Regular or permanently, up to ½ ft or saturated	Moderate. Food muskrat and wildfowl. Cover, marshbirds	Slow growth. Full sun to partial shade. Tolerates clay. Fresh to moderately brackish water.
Blue Joint (*Calamagrotis canadensis*)	2,3,4	Emergent	yes	Regular or permanent inundation up to 0.5 ft.	Moderate. Food for game birds and moose.	Tolerates partial shade
Broomsedge *(Andropogon virginicus)*	2,3	Perimeter	yes	up to 3 in.	High. Songbirds and browsers. Winter food and cover.	Tolerant of fluctuation water levels & partial shade.
Bushy Beardgrass *(Andropogon glomeratus)*	2,3	Emergent	yes	up to 1 ft.		Requires full sun.
Cardinal flower (*Lobelia cardinalis*)	4,5,6	Perimeter	yes	Some. Tolerates saturation up to 100% of season.	High. Nectar for hummingbird, oriole, butterflies.	Tolerates partial shade

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Cattail *(Typha sp.)*	2,3	Emergent	yes	up to 1 ft.	Low. Except as cover	Aggressive. May eliminate other species. Volunteer. High pollutant treatment
Coontail *(Ceratophyllum demersum)*	1	Submergent	no	yes	Low food value. Good habitat and shelter for fish and invertebrates.	Free floating SAV. Shade tolerant. Rapid growth.
Common Three-Square *(Scirpus pungens)*	2	Emergent	yes	up to 6 in.	High. Seeds, cover. Waterfowl and fish.	High metal removal.
Duckweed *(Lemma sp.)*	1,2	Submergent/ Emergent	yes	yes	High. Food for waterfowl and fish.	High metal removal.
Fowl mannagrass (*Glyceria striata*)	4,5	Perimeter	yes	Irregular or seasonal inundation	High. Food for waterfowl, muskrat, and deer.	Partial to full shade.
Hardstem Bulrush *(Scirpus acutus)*	2	Emergent	yes	up to 3 ft.	High. Cover, food (achenes, rhizomes) ducks, geese, muskrat, fish. Nesting for bluegill and bass.	Quick to establish, fresh to brackish. Good for sediment stabilization and erosion control.
Giant Burreed *(Sparganium eurycarpum)*	2,3	Emergent	rare	Regular to permanently inundated. up to 1 ft.	High. Food (seeds, plant) waterfowl, beaver & other mammals. Cover for marshbirds, waterfowl.	Rapid spreading . Tolerates partial sun. Good for shoreline stabilization.. Salinity <0.5 ppt
Lizard's Tail *(Saururus cernuus)*	2	Emergent	yes	up to 1 ft.	Low, except wood ducks.	Rapid growth. Shade tolerant
Long-leaved Pond Weed *(Potamogeton nodosus)*	1,2	Rooted submerged aquatic	yes	up to 1-6 ft. depending on turbidity	High. Food (seeds, roots) waterfowl, aquatic fur-bearers, deer, moose. Habitat for fish	Rapid spread. Salinity <0.5 ppt. Flowers float on surface, Aug.-Sept.

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Marsh Hibiscus *(Hibiscus moscheutos)*	2,3	Emergent	yes	up to 3 in.	Low. Nectar.	Full sun. Can tolerate periodic dryness.
Pickerelweed *(Pontederia cordata)*	2,3	Emergent	yes	up to 1 ft.	Moderate. Ducks. Nectar for butterflies.	Full sun to partial shade.
Pond Weed, Sago *(Potamogeton pectinatus*	1	Submergent	yes	yes	Extremely high. Waterfowl, marsh and shorebirds.	Removes heavy metals.
Redtop (*Agrostis alba*)	3,4,5	Perimeter	yes	Up to 25% of season	Moderate. Rabbits and some birds.	Quickly established but not highly competitive.
Rice Cutgrass *(Leersia oryzoides)*	2,3	Emergent	yes	up to 3 in.	High. Food and cover.	Full sun although tolerant of shade. Shoreline stabilization.
Sedges *(Carex spp.)*	2,3	Emergent	yes	up to 3 in.	High waterfowl, songbirds.	Many wetland and upland species.
Tufted Hairgrass (*Deschampsia caespitosa*)	3,4,5	Perimeter	yes	Regular to irregular inundation.	High.	Full sun. May become invasive.
Soft-stem Bulrush *(Scirpus validus)*	2,3	Emergent	yes	up to 1 ft.	Moderate. Good cover and food.	Full sun. Aggressive colonizer. High pollutant removal.
Smartweed *(Polygonum spp.)*	2,3,4	Emergent	yes	up to 1 ft.	High. Waterfowl, songbirds. Seeds and cover.	Fast colonizer. Avoid weedy aliens such as *P. perfoliatum.*
Soft Rush *(Juncus effusus)*	2,3,4	Emergent	yes	up to 3 in.	Moderate.	Tolerates wet or dry conditions.
Spatterdock *(Nuphar luteum)*	2	Emergent	yes	up to 3 ft.	Moderate for food but high for cover.	Fast colonizer. Tolerant of fluctuating water levels.
Switchgrass *(Panicum virgatum)*	2,3,4,5,6	Perimeter	yes	up to 3 in.	High. Seeds, cover for waterfowl, songbirds.	Tolerates wet/dry conditions.

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)						
Plant Name	**Zone**	**Form**	**Available**	**Inundation Tolerance**	**Wildlife Value**	**Notes**
Sweet Flag *(Acorus calamus)*	2,3	Herbaceous	yes	up to 3 in.	Low.	Tolerant of dry periods. Not a rapid colonizer. Tolerates acidic conditions.
Waterweed *(Elodea canadensis)*	1	Submergent	yes	yes	Low.	Good water oxygenator. High nutrient, copper, manganese and chromium removal.
Wild Celery *(Valisneria americana)*	1	Submergent	yes	yes	High. Food for waterfowl. Habitat for fish and invertebrates.	Tolerant of murkey water and high nutrient loads.
Wild Rice *(Zizania aquatica)*	2	Emergent	yes	up to 1 ft.	High. Food for birds.	Prefers full sun
Wool Grass *(Scirpus cyperinus)*	2,3	Emergent	yes	Irregularly to seasonally indundated	Moderate. Cover, Food.	Requires full sun. Can tolerate acidic soils, drought. Colonizes disturbed areas, moderate growth.

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Appendix I

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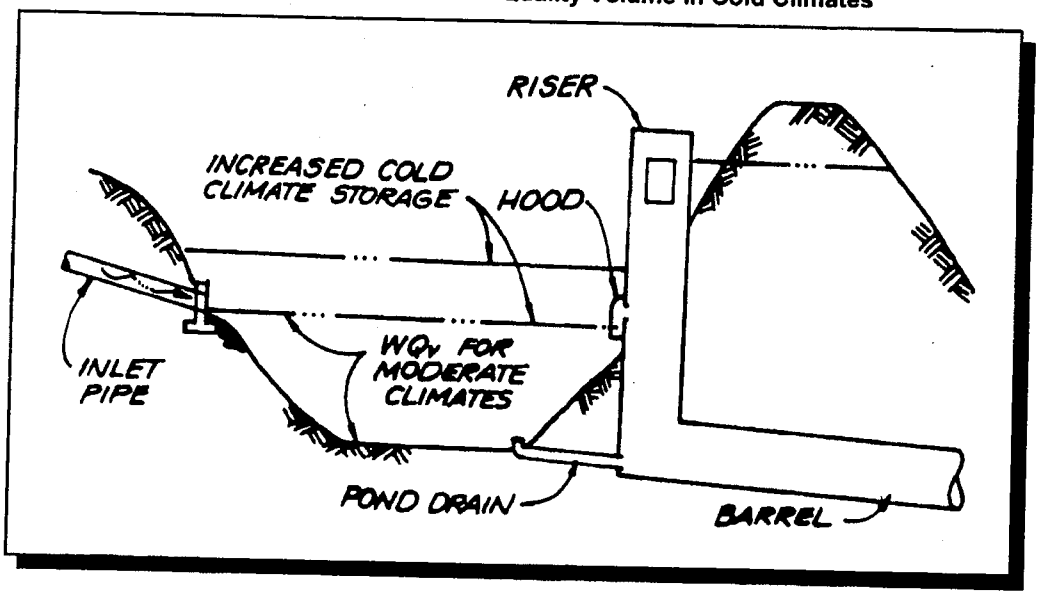
Traditional SMP sizing criteria are based on the hydrology and climatic conditions of moderate climates. These criteria are not always applicable to cold climate regions due to snowmelt, rain-on-snow and frozen soils. This chapter identifies methods to adjust both water quality (Section I.1) and water quantity (Section I.2) sizing criteria for cold climates.

I.1 Water Quality Sizing Criteria

The water quality volume is the portion of the SMP reserved to treat stormwater either through detention, filtration, infiltration or biological activity. Base criteria developed for SMP sizing nationwide are based on rainfall events in moderate climates (e.g., Schueler, 1992). Designers may wish to increase the water quality volume of SMPs to account for the unique conditions in colder climates, particularly when the spring snowfall represents a significant portion of the total rainfall. Spring snowmelt, rain-on-snow and rain-on-frozen ground may warrant higher treatment volumes. It is important to note that **the base criteria required by a region must always be met**, regardless of calculations made for cold climate conditions.

Figure I.1 Increased Water Quality Volume in Cold Climates



The goal of treating 90% of the annual pollutant load (Schueler, 1992), can be applied to snowmelt runoff and rain-on snow events. In the following conditions, cold climate sizing may be greater than base criteria sizing:

- Snowfall represents more than 10% of total annual precipitation. This value is chosen because, at least some portion of the spring snowmelt needs to be treated in order to treat 90% of annual runoff in these conditions. Using the rule of thumb that the moisture content of snowfall has about 10% moisture content, this rule can be simplified as:

  Oversize when average annual snowfall depth is greater than or equal to annual precipitation depth.

- The area is in a coastal or Great Lakes region with more than 3' of snow annually. In these regions, rain-on-snow events occur frequently enough to justify oversizing stormwater SMPs for water quality.

The following caveats apply to the sizing criteria presented in this section:

- These criteria are not appropriate for very deep snowpacks (i.e., greater than 4') because the volume to be treated would be infeasible, and often unnecessary.
- Sizing for snow storage areas is described in Appendix C.
- Snowmelt is a complicated process, with large annual variations. While the criteria presented here address the

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affects of snowmelt and rain-on-snow, several simplifying assumptions are made. Where local data or experience are available, more sophisticated methods should be substituted.

I.1.1 Water Quality Volume for Snowmelt

In order to treat 90% of annual runoff volume, sizing for snowmelt events needs to be completed in the context of the precipitation for the entire year. In relatively dry regions that receive much of their precipitation as snowfall, the sizing is heavily influenced by the snowmelt event. On the other hand, in regions with high annual rainfall, storm events are more likely to carry the majority of pollutants annually. The sizing criteria for this section are based on three assumptions: 1) SMPs should be sized to treat the spring snowmelt event 2)Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture 3) No more than five percent of the annual runoff volume should bypass treatment during the spring snowmelt event and 4) SMPs can treat a snowmelt volume greater than their size.

- *SMPs should be sized to treat the spring snowmelt runoff event*

  Snowmelt occurs throughout the winter in small, low-flow events. These events have high concentrations of soluble pollutants such as chlorides and metals, because of "preferential elution" from the snowpack (Jeffries, 1988). Although these events have significant pollutant loads, the flows are very low intensity, and generally will not affect SMP sizing decisions.

  The spring snowmelt, on the other hand, is higher in suspended solids and hydrophobic elements, such as hydrocarbons, which can remain in the snowpack until the last five to ten percent of water leaves the snowpack (Marsalek, 1991). In addition, a large volume of runoff occurs over a comparatively short period of time (i.e., approximately two weeks). Most SMPs rely on settling to treat pollutants, and the pollutants carried in the spring snowmelt are more easily treated by these mechanisms. In addition, the large flow volume during this event may be the critical water quality design event in many cold regions.

- *Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture*

  Because of small snowmelt events that occur throughout the winter, losses through sublimation, and management practices such as hauling snow to other locations, the snowpack only contains a fraction of the moisture from the winter snowfall. Thus, the remaining moisture in the snowpack can be estimated by:

  $$M=0.1 \cdot S-L_1-L_2-L_3 \qquad \text{Equation I.1}$$

  Where:

  M=Moisture in the Spring Snowpack (inches)
  S=Annual Snowfall (inches)
  L_1, L_2 and L_3 = Losses to Hauling, Sublimation and Winter Melt, respectively.

  The volume of snow hauled off site can be determined based on available information on current plowing practices. In New York, sublimation to the atmosphere is not very important

  The design examples in this section use a simple "rule of thumb" approach, to estimate winter snowmelt for simplicity (Table I.1). The method assumes that winter snowmelt is influenced primarily by temperature, as represented by the average daily temperature for January. One half of the snow (adjusted for plowing and sublimation) is assumed to melt during the winter in very cold regions (Average T_{max} <25°F) and two thirds is assumed to melt during the winter in moderately cold regions (Average T_{max} <35°F). Winter snowmelt can be estimated using several methods, such as the simple degree-day method, or through more complex continuous modeling efforts.

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Table I.1 Winter Snowmelt*

Adjusted Snowfall Moisture Equivalent	Winter Snowmelt (January T_{max}<25°F)	Winter Snowmelt (January T_{max}<35°F)
2"	1.0"	1.3"
4"	2.0"	2.7"
6"	3.0"	4.0"
8"	4.0"	5.3"
10"	5.0"	6.7"
12"	6.0"	8.0"

* Snowmelt occuring before the spring snowmelt event, based on the moisture content in the annual snowfall. The value in the first column is adjusted for losses due to sublimation and plowing off site.

Snowmelt is converted to runoff when the snowmelt rate exceeds the infiltration capacity of the soil. Although the rate of snowmelt is slow compared with rainfall events, snowmelt can cause significant runoff because of frozen soil conditions. The most important factors governing the volume of snowmelt runoff are the water content of the snowpack and the soil moisture content at the time the soil freezes (Granger et al., 1984). If the soil is relatively dry when it freezes, its permeability is retained. If, on the other hand, the soil is moist or saturated, the ice formed within the soil matrix acts as an impermeable layer, reducing infiltration. Section I.1.3 outlines a methodology for computing snowmelt runoff based on this principle.

- *No more than 5% of the **annual runoff volume** should bypass treatment during spring snowmelt* In order to treat 90% of the annual runoff volume, at least some of the spring snowmelt, on average, will go un-treated. In addition, large storm events will bypass treatment during warmer months. Limiting the volume that bypasses treatment during the spring snowmelt to 5% of the annual runoff volume allows for these large storm events to pass through the facility untreated, while retaining the 90% treatment goal.

The resulting equation is:

$T=(R_s-0.05R)A/12$ (Equation I.2)

Where:

T = Volume Treated (acre-feet)

R_s = Snowmelt Runoff [See Section I.1.3]

R = Annual Runoff Volume (inches) [See Section I.1.2]

A = Area (acres)

- *SMPs can treat a volume greater than their normal size.*

Snowmelt occurs over a long period of time, compared to storm events. Thus, the SMP does not have to treat the entire water quality treatment volume computed over twenty four hours, but over a week or more. As a result, the necessary water quality volume in the structure will be lower than the treatment volume. For this manual, we have assumed a volume of ½ of the value of the computed treatment volume (T) calculated in equation I.2.

Thus,

$WQ_s = ½ T$ (Equation I.3)

I.1.2 Base Criteria/ Annual Runoff

The base criterion is the widely-used, traditional water quality sizing rule. This criterion, originally developed for moderate climates, represents the minimum recommended water quality treatment volume. In this manual, the runoff from a one inch rainfall event is used as the base criteria. The basis behind this sizing criteria is that approximately 90% of the storms are treated using this event. This value may vary nationwide, depending on local historical rainfall frequency distribution data. However, the one inch storm is used as a simplifying assumption. The base criteria included in this manual is chosen because it incorporates impervious area in the sizing of urban SMPs, and modifications are used nationwide. The cold climate sizing modifications used in this manual may be applied to any

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base criteria, however.

Runoff for rain events can be determined based on the Simple Method (Schueler, 1987).

$r = p(.05+.9I)$ (Equation I.4)

Where: r = Event Rainfall Runoff (inches)
p = Event Precipitation (inches)
I = Impervious Area Fraction

Thus, the water quality volume for the base criteria can be determined by:

$WQ_v = (0.05+.9I)\ A/12$ (Equation I.5)

Where: WQ_v =Water Quality Volume (acre-feet)
I= Impervious Fraction
A=Area (acres)

The Simple Method can also be used to determine the annual runoff volume. An additional factor, P_j, is added because some storms do not cause runoff. Assume $P_j = 0.9$ (Schueler, 1987). Therefore, annual runoff volume from rain can be determined by:

$R = 0.9\ P\ (0.05+.9I)$ (Equation I.6)

Where: R = Annual Runoff (inches)
P = Annual Rainfall (inches)

I.1.3 Calculating the Snowmelt Runoff

To complete water quality sizing, it is necessary to calculate the snowmelt runoff. Several methods are available, including complex modeling measures. For the water quality volume, however, simpler sizing methods can be used since the total water quality volume, not peak flow, is critical. One method, modified from Granger et al. (1984) is proposed here. Other methods can be used, particularly those adjusted to local conditions.

According to Granger et al. (1984) the infiltration into pervious soils is primarily based on the saturation of the soils prior to freezing. While saturated soils allow relatively little snowmelt to infiltrate, dry soils have a high capacity for infiltration. Thus, infiltration volumes vary between wet, moderate and dry soil conditions (Figure I.2).

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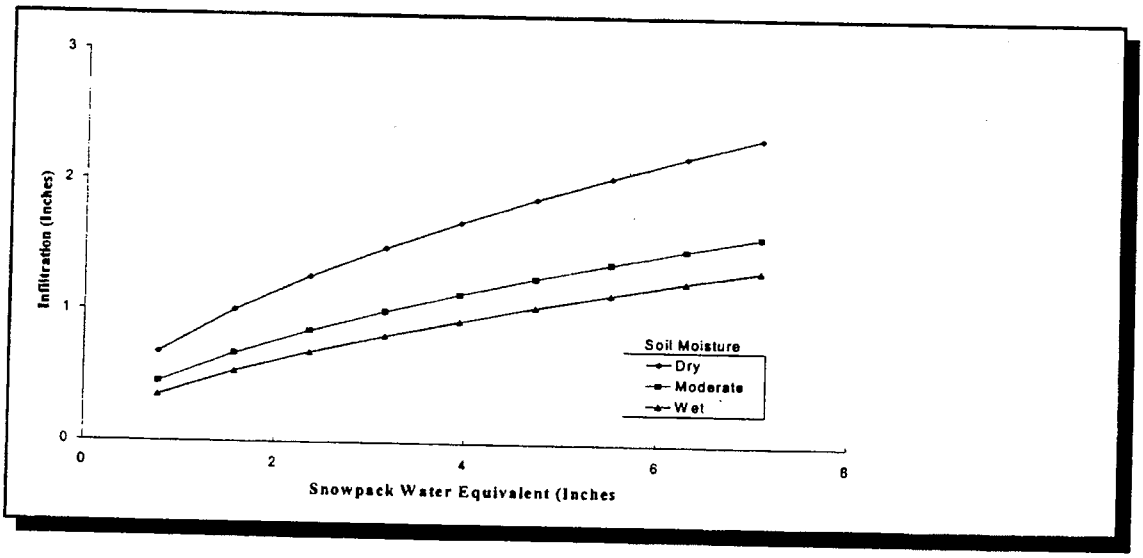
Figure I.2 Snowmelt Infiltration Based on Soil Moisture



Assume also that impervious area produces 100% runoff. The actual percent of snowmelt converted to runoff from impervious areas such as roads and sidewalks may be less than 100% due to snow removal, deposition storage and sublimation. However, stockpiled areas adjacent to paved surfaces often exhibit increased runoff rates because of the high moisture content in the stockpiled snow (Buttle and Xu, 1988). This increased contribution from pervious areas off-sets the reduced runoff rates from cleared roads and sidewalks.

The resulting equation to calculate snowmelt runoff volume based on these assumptions is:

R_S = [runoff generated from the pervious areas] + [runoff from the impervious areas]

$R_s = [(1 - I)(M\text{-}Inf)] + [(I)(1)(M)]$ (Equation I.7)

where:

R_S = Snowmelt Runoff
I = Impervious Fraction
M = Snowmelt (inches)
Inf = Infiltration (inches)

Sizing Example 1: Snowpack Treatment

Scenario:
50 Acre Watershed
40% Impervious Area
Average Annual Snowfall= 5'=60"
Average Daily Maximum January Temperature= 20°
Average Annual Precipitation = 30"
20% of snowfall is hauled off site
Sublimation is not significant
Prewinter soil conditions: moderate moisture.

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Sizing Example 1: Snowpack Treatment

Step 1: Determine if oversizing is necessary
Since the average annual precipitaiton is only ½ of average annual snowfall depth, oversizing is needed.

Step 2: Determine the annual losses from sublimation and snow plowing.
Since snow hauled off site is about 20% of annual snowfall, the loss from snow hauling, L_1, can be estimated by:

$L_1 = (0.2)(0.1)S$

Where: L_1 = Water equivalent lost to hauling snow off site (inches)
S = Annual snowfall (inches)
0.1 = Factor to convert snowfall to water equivalent

Therefore, the loss to snow hauling is equal to:
$L_1 = (0.2)(0.1)(60")$
$L_1 = 1.2"$

Since sublimation is negligible, $L_2 = 0$

Step 3: Determine the annual water equivalent loss from winter snowmelt events
Using the information in Step 2, the moisture equivalent in the snowpack remaining after hauling is equal to:

$60" \cdot 0.1 - 1.2" = 4.8"$

Substituting this value into Table I.1, and interpolating, find the volume lost to winter melt, L_3.
$L_3 = 2.4"$

Step 4: Calculate the final snowpack water equivalent, M
$M = 0.1 \cdot S - L_1 - L_2 - L_3$ (Equation I.1)
$S = 60"$
$L_1 = 1.2"$
$L_1 = 0"$
$L_3 = 2.4"$

Therefore, $M = 2.4"$

Step 5: Calculate the snowmelt runoff volume, R_s
$R_s = (1-I)(M-Inf) + I \cdot M$ Equation I.7
$M = 2.4"$
$I = 0.4$
$Inf = 0.8"$ (From figure I.2; assume average moisture)
Therefore, $R_S = 1.9"$

Step 6: Determine the annual runoff volume, R
Use the Simple Method to calculate rainfall runoff:
$R = 0.9(0.05 + 0.9*I)P$ (Equation I.6)
$I = 0.4$
$P = 30"$
Therefore, $R = 11"$

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Sizing Example 1: Snowpack Treatment

Step 7: Determine the runoff to be treated
Treatment, T should equal:
$T = (R_s - 0.05*R)\ A/12$ (Equation I.2)
$R_s = 1.9"$
$R = 11"$
A = 50 Acres
Therefore, T=5.6 acre-feet

Step 8: Size the SMP
The volume treated by the base criteria would be:
$WQ_v = (.05+.9*.4)(1'/12")(50\ acres) = 1.7$ acre-feet (Equation I.5)

For cold climates:
$WQ_v = 1/2(T) = 2.8$ acre-feet (Equation I.3)
The cold climate sizing criteria is larger, and should be used to size the SMP.

I.1.4 Rain-on-Snow Events

For water quality volume, an analysis of rain-on-snow events is important in coastal regions. In non-coastal regions, rain-on-snow events may occur annually but are not statistically of sufficient volume to affect water quality sizing, especially after snowpack size is considered. In coastal regions, on the other hand, flooding and annual snowmelt are often driven by rain-on-snow events (Zuzel et al., 1983). Nearly 100% of the rain from rain-on-snow events and rain immediately following the spring melt is converted to runoff (Bengtsson, 1990). Although the small rainfall events typically used for SMP water quality do not produce a significant amount of snowmelt (ACOE, 1956), runoff produced by these events is high because of frozen and saturated ground under snow cover.

Many water quality volume sizing rules are based on treating a certain frequency rainfall event, such as treating the 1-year, 24-hour rainfall event. The rationale for treating 90% of the pollutant load (Schueler, 1992) can also be applied to rain-on-snow events, as shown in the following example.

Sizing Example 2: Rain-on-Snow

Step 1: Develop a rain-on-snow data set.
Find all the rainfall events that occur during snowy months. Rainfall from December through April were included. Please note that precipitation data includes both rainfall and snowfall, and only data from days without snowfall should be included. Exclude non-runoff-producing events (less than 0.1"). Some of these events may not actually occur while snow is on the ground, but they represent a fairly accurate estimate of these events.

Step 2: Calculate a runoff distribution for rain-on-snow events
Since rain-on-snow events contribute directly to runoff, the runoff distribution is the same as the precipitation distribution in Figure I.3.

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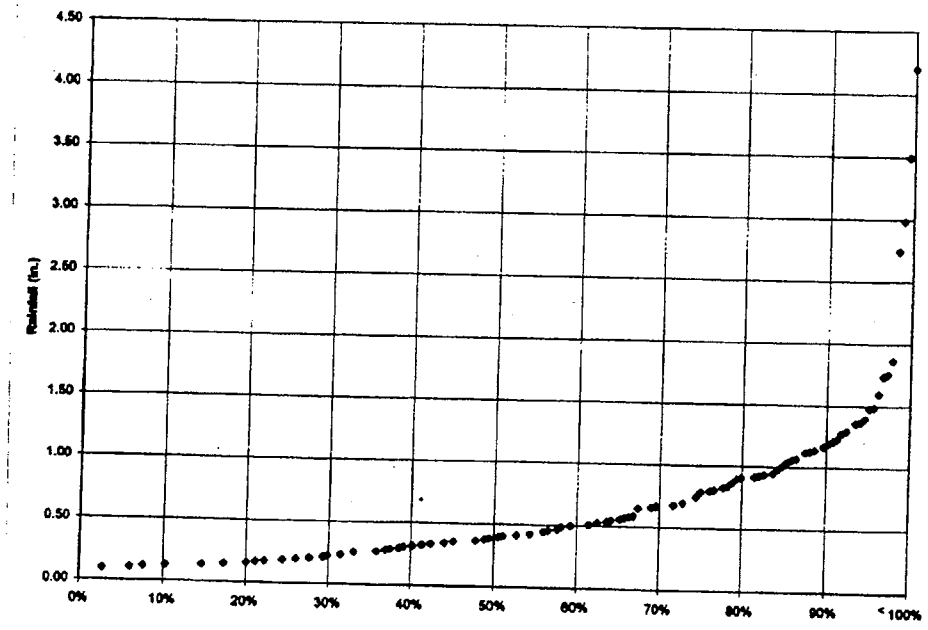
Sizing Example 2: Rain-on-Snow

Figure I.3 Rainfall Distribution for Snowy Months



Step 3: Calculate a rainfall distribution for non-snow months.
Develop a distribution of rainfall for months where snow is not normally on the ground. The rainfall distribution for May through November is included in Figure I.4.

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Sizing Example 2: Rain-on-Snow

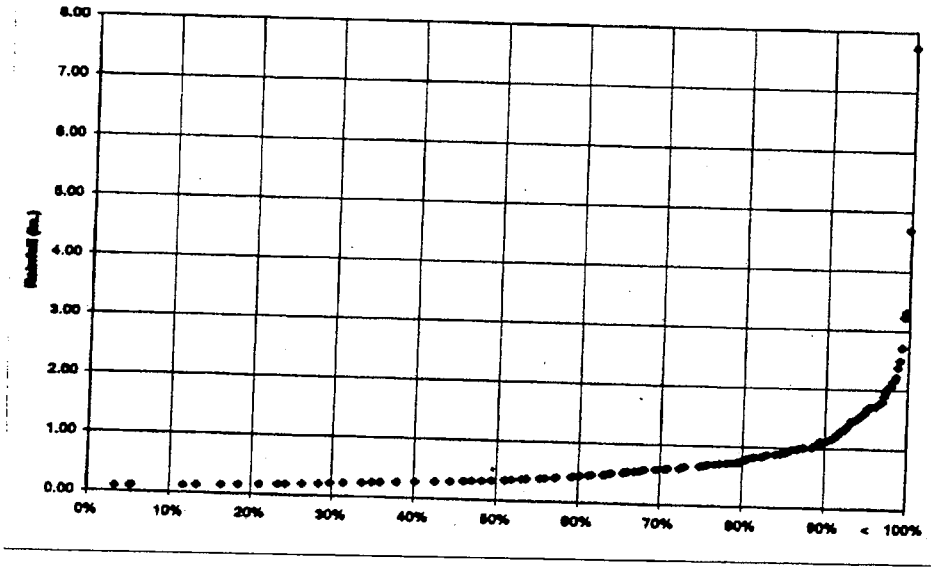

Figure I.4

Rainfall Distribution for Non-Snowy Months

Step 4: Calculate the runoff distribution for non-snow months.
Use a standard method to convert rainfall to runoff, particularly methods that are calibrated to local conditions. For this example, use the Simple Method. Runoff is calculated as:

$$r=(0.05+0.9\ I)p \quad \text{(Equation I.4)}$$

For this example, I=0.3 (30% impervious area), so:

$$r=0.32\ p$$

The runoff distribution for non-snow months is calculated by multiplying the rainfall in Figure I.4 by 0.32.

Step 5: Combine the runoff distributions calculated in Steps 2 and 4 to produce an annual runoff distribution. The resulting runoff distribution (Figure I.5) will be used to calculate the water quality volume.

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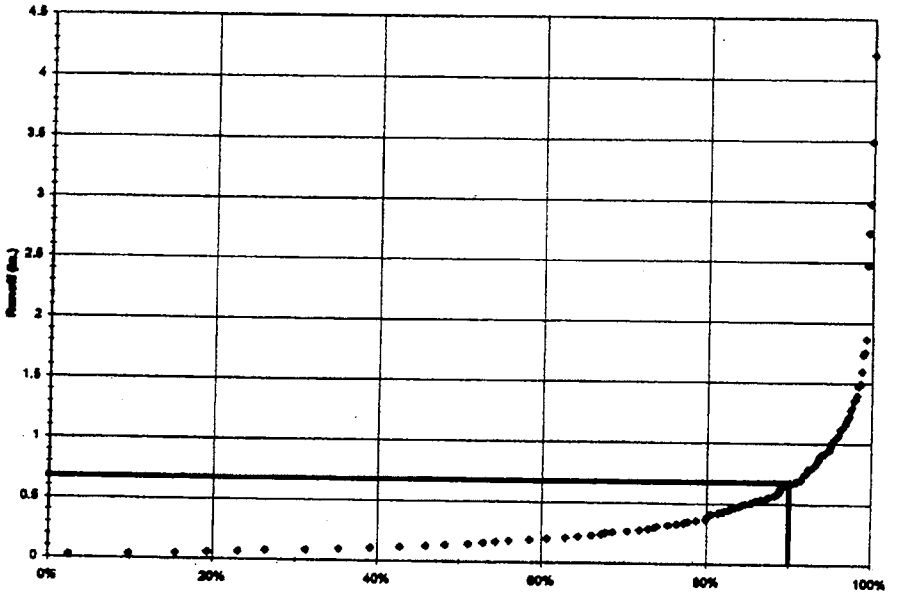
Sizing Example 2; Rain-on-Snow

Figure I.5 Annual Runoff Distribution



Step 6: Size the SMP.

In this case, use the 90% frequency runoff event (Figure I.4), or 0.65 watershed inches. This value is greater than the base criteria of 0.32 watershed inches (1" storm runoff). Therefore, the greater value is used.

WQ_v=(0.65 inches) (1 foot/12 inches) (50 acres) = 2.7 acre-feet

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Appendix J

New York State Stormwater Management Design Manual

Appendix J: Geomorphic Assessment

Distributed Runoff Control Methodology
Pond Outlet Structure Design Example

The following design example illustrates a step-by-step methodology for the design of a weir for the control of instream erosion potential using a Stormwater Management (SWM) wet pond design based on the Distributed Runoff Control (DRC) approach. The DRC approach incorporates boundary material composition and its sensitivity to erosion (entrainment and transport) into the design protocol. The boundary materials are characterized at the point of maximum boundary shear stress on the bed and the point of secondary maximum boundary shear stress on the bank. By examining the channel at selected sites downstream of the SWM facility the DRC protocol provides a pseudo 3-dimensional assessment of the impact of development and the SWM facility on the receiving channel.

This design example involves 5 Steps as listed in Table J.1.

Table J.1 Overview of Key Steps in the DRC Design Approach

1) Determine the "stability" and "mode-of-adjustment" of the receiving channel
2) Complete a Diagnostic Geomorphic Survey of the receiving channel
3) Determine channel sensitivity to an alteration in the sediment-flow regime
4) Approximate the elevation-discharge curve for the pond.
5) Size the DRC weir

Step 1. Determine Channel "Stability" and "Mode-of-Adjustment"

Channel stability is determined using a Rapid Geomorphic Assessment (RGA) of the channel downstream of the outlet of the proposed Stormwater Management (SWM) pond. The RGA protocol involves the identification of the presence of in-stream features resulting from a variety of geomorphic processes to provide a semi-quantitative assessment of a stream's stability and mode-of-adjustment. The processes are represented by four Factors: aggradation (AF), widening (WF), downcutting (DF), and planimetric form adjustment (PF)). Each Factor is composed of 7 to 10 indices for which a "present" or "absent" response is required. The total number of "present" or "yes" responses is summed and divided by the total number of responses (both "yes" and "no") to derive a value for each Factor. An index that is not relevant is not assigned a response. An example of an RGA Form is provided in Table J.2.

A Stability Index (SI) value is determined from the Factor values using the following equation:

$$SI = \frac{\{AF + DF + WF + PF\}}{m} \quad \text{.....[J.1]}$$

where 'm' is the number of Factors (typically 4 for alluvial streams).

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Table J.2 Rapid Geomorphic Assessment Form					
FORM/ PROCESS	GEOMORPHIC INDICATOR		PRESENT		FACTOR VALUE
	No.	Description	No	Yes	
Evidence of Aggradation (AI)	1	Lobate bar	1		1/7=0.143
	2	Coarse material in riffles embedded		1	
	3	Siltation in pools	1		
	4	Medial bars	1		
	5	Accretion on point bars	1		
	6	Poor longitudinal sorting of bed materials	1		
	7	Deposition in the overbank zone	1		
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	-	-	2/6=0.333
	2	Exposed sanitary/storm sewer/pipeline/etc.	-	-	
	3	Elevated stormsewer outfall(s)	-	-	
	4	Undermined gabion baskets/concrete aprons/etc.	-	-	
	5	Scour pools d/s of culverts/stormsewer outlets	1		
	6	Cut face on bar forms	1		
	7	Head cutting due to knick point migration	1		
	8	Terrace cut through older bar material		1	
	9	Suspended armor layer visible in bank		1	
	10	Channel worn into undisturbed overburden/bedrock	1		
Evidence of Widening (WI)	1	Fallen/leaning trees/fence posts/etc.		1	3/10=0.30
	2	Occurrence of Large Organic Debris		1	
	3	Exposed tree roots		1	
	4	Basal scour on inside meander bends	1		
	5	Basal scour on both sides of channel through riffle	1		
	6	Gabion baskets/concrete walls/armor stone/etc. out flanked	1		
	7	Length of basal scour >50% through subject reach	1		
	8	Exposed length of previously buried pipe/cable/etc.	1		
	9	Fracture lines along top of bank	1		
	10	Exposed building foundation	1		
Evidence of Planimetric Form Adjustment (PI)	1	Formation of cute(s)	1		0/7=0
	2	Evolution of single thread channel to multiple channel	1		
	3	Evolution of pool-riffle form to low bed relief form	1		
	4	Cutoff channel(s)	1		
	5	Formation of island(s)	1		
	6	Thalweg alignment out of phase with meander geometry	1		
	7	Bar forms poorly formed/reworked/removed	1		
STABILITY INDEX (SI) = (AI+DI+WI+PI)/m				SI= 0.19	

The Stability Index (SI) provides an indication of the stability of the creek channel at a given time based on the guidelines provided in Table J.3. The SI Value, however, does not differentiate between current and past disturbances.

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Table J.3 Interpretation of the RGA Stability Index Value		
Stability Index Value	**Stability Class**	**Description**
0.0<SI<0.25	Stable	Metrics describing channel form are within the expected range of variance (typically accepted as one standard deviation from the mean) for stable channels of similar type
0.25<SI<0.4	Transitional	Metrics are within the expected range of variance as defined above but with evidence of stress
0.4<SI<1.0	In Adjustment	Metrics are outside of the expected range of variance for channels of similar type.

The guidelines presented in Table J.3 for the interpretation of the SI Value will vary with the field experience and the bias of the observer. The SI Values however, have been shown to be consistent between observers indicating that the protocol, once calibrated to the observer provides a reliable means of screening the channel for stability and mode-of-adjustment.

The RGA protocol is applied to channel segments of two meanders in length or the equivalent of 20 bankfull channel widths (the width of the channel at the geomorphically dominant discharge, recurrence interval of between 1 and 2 years or 1.5 years on average).

The segment chosen for application of the RGA assessment is selected to be representative of the morphology of the channel for some distance up and downstream of the surveyed segment. That is, the parameters defining channel cross-section and plan form (e.g. width, depth, meander wavelength, etc.) are within a consensual level of variance for this reach of channel. An acceptable level of variance is typically defined as within one standard deviation of the mean. These reaches are referred to as being of "like" morphology. Since the morphology of the channel will vary in the longitudinal direction with changes in flow, slope, physiography, etc., it will be necessary to re-apply the RGA protocol where the parameters characterizing the morphology of the channel have changed beyond the consensual level of variance from the previous survey reach. In this manner the channel is divided into a series of reaches of "like" morphology.

Having determined the length of the survey reach, the longitudinal profile can be plotted from topographic mapping as illustrated in Figure J.1 (Topo). Examination of Figure J.1 (topographic map data) suggests that the channel can be differentiated into three distinct reaches. In the first reach (length L=146 ft, the channel has an average slope of S=0.00385 ft/ft and a meander-pool-riffle morphology. In the middle reach (L≈356 ft; S≈0.0142 ft/ft) the channel has cascade morphology. The third reach (L≈258 ft; S≈0.00794 ft/ft) returns to the meander-pool-riffle form.

Land use through the study reach is homogeneous (forest) and there are no other features (e.g. bridges, dams, weirs, instream works, etc.) that would affect the hydraulic characteristics of the active channel. Consequently, a preliminary definition of "like" reaches includes the three morphologies described above.

A synoptic geomorphic survey was conducted through the subject reach with an RGA assessment completed for each of the three reaches of "like" morphology. The results of the RGA assessment for the first reach (Reach 1) are reported in Tables J.2 and J.4. Referring to Table J.2, the Stability Index (SI) value was found to be SI=0.19, which is less than 0.25, therefore the channel is considered to be "stable" (Table J.3).

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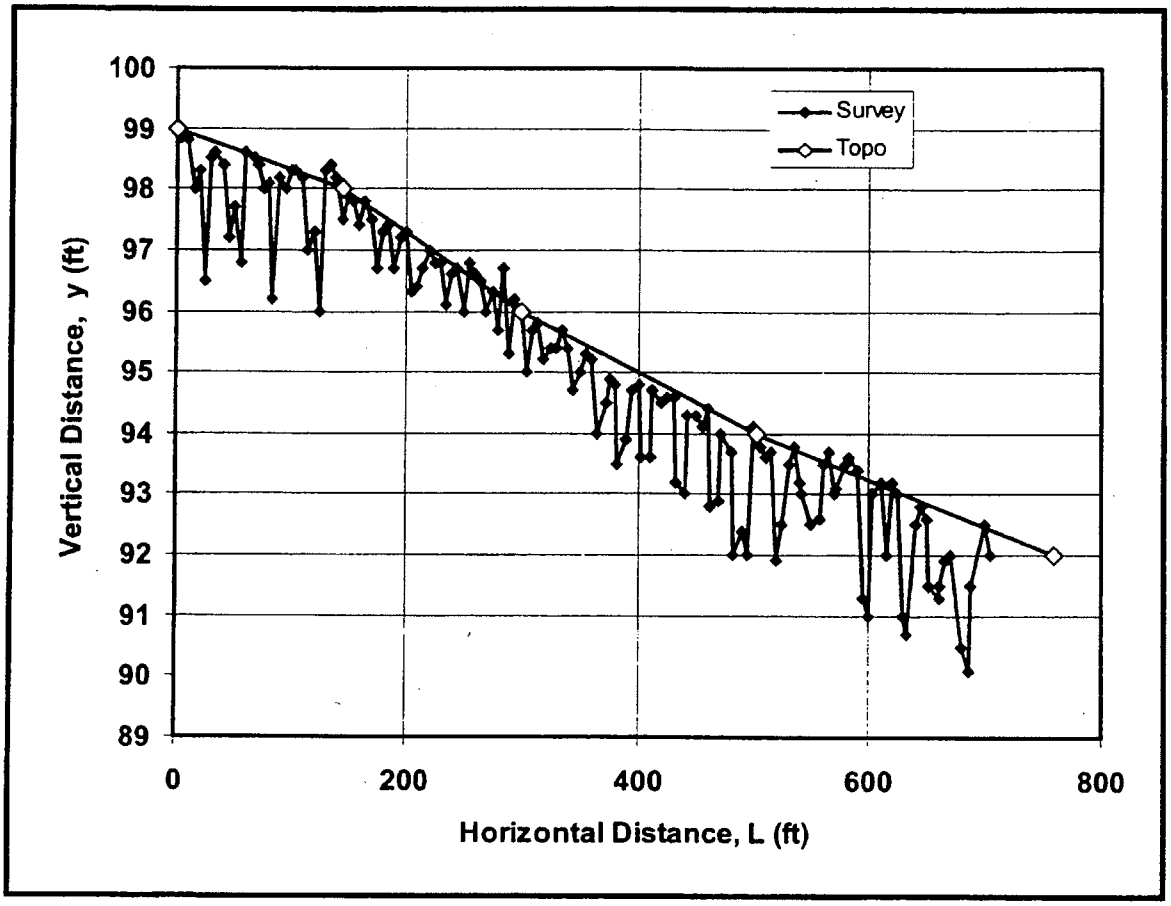

Figure J.1 Longitudinal Profile from Topographic Mapping and Field Survey of Channel Thalweg

Table J.4 Summary of Average Longitudinal Slope and Pool-Riffle Dimensions			
Parameter	**Reach 1**	**Reach 2**	**Reach 3**
Longitudinal Gradient, S (ft/ft)	0.00385	0.0142	0.00794
Riffle Length, LRIF (ft)	16	34	27
Pool Length, LPOL (ft)	37	10	18
Total Pool-Riffle Length, LTOT (ft)	53	44	45

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Step 2. Diagnostic Geomorphic Survey

Following completion of the identification of reaches of "like" morphology and the synoptic survey to finalize the delineation of the "like" reaches, a diagnostic geomorphic survey is undertaken to characterize the morphological attributes of the channel. This information has two primary functions.

1. The optimization of the erosion control benefit of the pond; and,
2. The provision for establishing a baseline condition from which it is possible to assess the performance of the SWM measures.

A detailed diagnostic survey includes a collection of a comprehensive set of parameters to assess and evaluate stream geomorphic conditions. A complete survey is typically required when:

a) A post-construction monitoring program is mandated; and,
b) Data are required for the design and construction of instream works.

Only a partial diagnostic survey is needed where the above issues are not relevant to the project. The following lists those parameters required for the partial diagnostic survey:

1. In the absence of flow measurements, a field estimate of Manning's 'n' value is obtained for comparison with sediment computed estimates.
2. Detailed survey of the channel cross-section, including the floodplain, to determine hydraulic geometry metrics at a so called "Master cross-section" and the relative location of bank material strata.
3. The longitudinal profile of the bed along the channel thalweg and the water surface at the time of survey over a distance of one meander wavelength or 10 bankfull widths. These data are used to determine the longitudinal gradient of the channel from riffle crest to riffle crest and to determine the dimensions of the pool-riffle complex.
4. At least one estimate of bankfull depth (the depth of flow at the dominate discharge) at the Master cross-section and all ancillary cross-sections (3 alternative methods are described in this example for illustrative purposes).
5. Bed material characteristics based on pebble counts of the bed material at a riffle crossover. These data are collected to help assess roughness coefficients, bed material resistance, and provide an alternate method for the estimation of bankfull depth.
6. Soil pits in the banks to map bank stratigraphy and to determine bank material composition using soil consistency tests (stickiness, plasticity and firmness) or particle size analysis (percent silt clay) with Atterberg Limits (Plasticity Index) for each stratigraphic unit. These data are required to help assess historic degradation or aggradation patterns and determine bank material resistance.
7. Map riparian vegetation and root zone characteristics in the soil pits for assessment of the affect of root binding on bank material resistance.

The cross-section data and bank material characterization is completed at a Master cross-section within the representative segment of each "like" reach. The Master cross-section is typically located at a riffle crossover on a straight reach between meander bends. Ancillary cross-sections are located in the lower one third of the meander bends and riffle crossover points up and downstream of the Master cross-section. Data collected at the ancillary cross-sections includes a cross-section profile (typically 7 to 9 ordinates) and estimates of bankfull stage. The longitudinal profile is collected throughout the survey segment along with characterization of plan form geometry.

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Design Case: Diagnostic Geomorphic Survey

The longitudinal survey of the channel along the thalweg is presented in Figure J.1 ("Survey" data points). This profile more clearly demonstrates the differences between the three reaches as represented by slope and pool-riffle dimensions (Table J.4). Other parameter values derived from the geomorphic survey are summarized in Table J.5. These data are combined with the cross-section, soils and sediment data to generate values for key parameters as described in the following series of calculations.

The following calculations are required to determine the 3 different estimates of the dominant discharge.

Estimate of Geomorphic Referenced Dominant Discharge

1. The longitudinal data are plotted to generate estimates of the channel gradient in order of priority as follows:
   (1) Water surface profile based on estimates of bankfull stage from the Master and ancillary cross-sections.
   (2) Bed slope (riffle crest to riffle crest), and
   (3) Water surface profile (dry weather flow at the time of the survey).
2. The pebble count data (length, width and breadth) are transformed into an equivalent diameter and used to generate a mass curve wherein cumulative percent finer by mass is plotted as a function of particle diameter;
3. The D_{50} and D_{84} particle size values (the particle diameter below which 50 and 84% of the particles are finer by mass, respectively) are determined from the mass curve;
4. Manning's roughness coefficient is estimated at bankfull stage using:
   (1) Standard field guides, and
   (2) Empirical relations such as: the Strickler (1923) and Limerinos (1970) equations.
5. The cross-section ordinates collected at the Master cross-section are plotted to produce a cross-section profile and a stage-area curve;
6. The stage-area curve is combined with the longitudinal gradient (S) and the estimate of Manning's roughness coefficient (n) to generate the stage-discharge curve for the cross-section using Manning's equation,

$$Q = \frac{1.49}{n} A R^{(\frac{2}{3})} S^{\frac{1}{2}}, \quad \text{.....[J.2]}$$

in which Q represents the flow rate (cfs) at depth 'y' above the thalweg, 'A' is the cross-section area of the channel at depth 'y', 'R' represents the hydraulic radius at depth 'y' and 'S' is the longitudinal gradient of the channel (ft/ft). An example of a stage-discharge curve is provided in Figure J.2;

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Table J.5 Summary of Hydraulic and Sediment Parameters

Reach No.	Rosgen Stream Type	Parameter						
		2 Year Flow Q_{2YR} (cfs)	W/d Ratio	Width W_{BFL} (ft)	Depth d_{BFL} (ft)	Flow Q_{BFL} (cfs)	Base B (ft)	Wetted Perimeter P (ft)
1	C3	8.9	3.00	3.00	1.00	4.76	2.00	4.24
2	B3	9.54	3.23	2.75	0.85	5.10	1.90	3.80
3	C3	10.1	2.87	2.83	0.99	5.40	1.85	4.06

Reach No.	Parameter						
	Bed Material Mean Particle Size		Area	Hydraulic Radius	Slope	Velocity	Riparian Vegetation Type
	D_{50} (in)	D_{84} (in)	A_{BFL} (ft^2)	R (ft)	S (ft/ft)	v (fps)	
1	2.8	3.3	2.50	0.590	.00385	1.90	Woody
2	5.1	7.5	1.99	0.521	.0142	2.57	Woody
3	3.7	5.2	2.32	0.570	.00794	2.35	Woody

Reach No.	Parameter									
	Bank Material Composition						Critical Shear Stress		Depth of Stratigraphic Unit	Excess Boundary Shear Stress τ_{CRT} (lbs/ft^2)	
	Soil Class		Soil Consistence Test				Bank (*) τ_{CRT} (lbs/ft^2)	Bed τ_{CRT} (lbs/ft^2)			
	Class	Unit No.	X1	X2	X3	SCORE			h (ft)	Bank	Bed
1	SiLm	1	1	2	1	4		0.548	0.36<h≤1.00	0.057	-0.334
	SiSa	2	0	0	1	1	0.120		0.10<h≤0.36		
	CoGr	3	N/a	N/a	N/a	N/a			0.0<h≤0.10		
2	CoBo	1	N/a	N/a	N/a	N/a	0.573	1.206	0.39<h≤0.85	-0.016	-0.526
	GrCo	2	N/a	N/a	N/a	N/a			0.0<h≤0.39		
3	SiLm	1	2	1	3	6		0.878	0.32<h≤0.99	0.03	-0.446
	SiCl	2	2	2	2	6	0.329		0.12<h≤0.32		
	SiCl	3	2	3	2	7			0.0<h≤0.12		

(*) Least resistant lower bank stratigraphic unit corresponding to the zone of secondary maximum boundary shear stress.

7. The dominant discharge (Q_{GEO}) is determined from the stage-discharge curve and field estimate of bankfull stage (d_{BFL}). For Reach 1 in this example, d_{BFL}=1.0 ft, consequently Q_{GEO}=4.76 cfs (Figure J.2). This procedure is repeated for each cross-section within the reach and the flow rate most common to all cross-sections is adopted as the geomorphic referenced estimate of the dominant discharge. If a wide disparity exists between estimates of (Q_{GEO}) than the determination of slope, Manning's 'n' value and the geomorphic indicators of bankfull stage are revisited to determine if a miss-interpretation of the data or an error in calculations has occurred.

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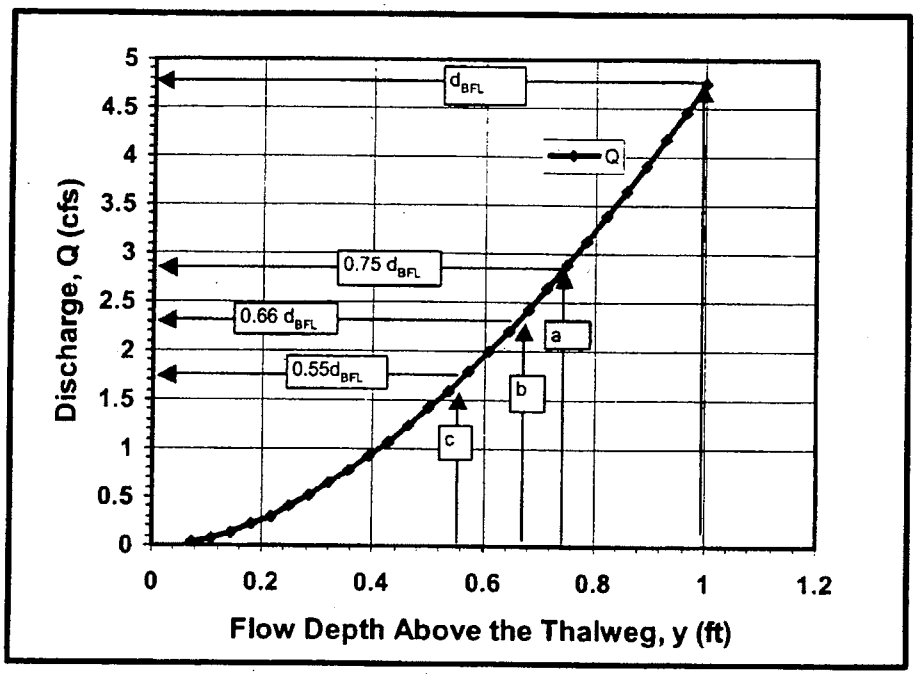

Figure J.2 Stage-Discharge Curve for Reach 1 Downstream of the Proposed Development

Estimate of Bed Material Critical Shear Stress

8. Critical shear stress is estimated for the ϕ_{84} particle size value of the bed material using procedures such as:
   (1) The modified Shield's equation (Vanoni, 1977), or
   (2) Various empirical relations (from the literature) that express critical shear stress as a function of particle size, one such is Eqn J.3 proposed by Lane (1955)

$$(\tau_{CRT})_{BED} = 0.164\phi_{84} \quad \text{.....[J.3]}$$

in which ϕ_{84} is the particle size for which 84% of the materials are finer (inches) and τ_{CRT} represents the critical shear stress (lbs/ft^2). Applying Eqn, [J.3] :

$(\tau_{CRT})_{BED} = 0.164\phi_{84} = 0.164\ (3.34\ \text{in}) = 0.548\ \text{lbs/ft}^2$

at the Master cross-section (Reach 1);

Estimate of Instantaneous Bed Shear Stress

9. A stage-shear stress curve is generated for the Master cross-section using DuBoy's relation for average shear stress and a channel shape adjustment factor proposed by Lane (1955) as follows:

$$\tau_0 = k_b \rho g (d - d_p) S \quad \text{.....[J.4]}$$

and,

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$$k_b = 0.000547\left(\frac{B}{d}\right)^3 - 0.0121\left(\frac{B}{d}\right)^2 + 0.092\left(\frac{B}{d}\right) + 0.75, \ldots\ldots\ldots\ldots\ldots\ldots [J.5]$$

in which τ_0 represents the instantaneous boundary shear stress at point 'P' on the bed (lbs/ft s^2), k_b is a channel shape adjustment factor (dimensionless; Fig. J.3), ρ is the density of the sediment-water mixture being conveyed by the channel (62.4 lbs/ft^3), 'g' is acceleration due to gravity (32.2 ft/s^2), 'd' is the depth of the flow above the thalweg (ft), d_P is the depth of flow above the thalweg at point 'P' (ft), 'S' represents the longitudinal gradient of the flow at depth 'd' and 'B' is the bottom width of the channel (assuming a trapezoidal configuration). In this design case, a mapping of the isovels through the Master cross-section indicates that the point of maximum boundary shear stress occurs at the thalweg. Since the thalweg is the deepest part of the channel, the term d_P=0 in Eqn. J.4. A stage-shear stress curve for Reach 1 is illustrated in Figure J.4. Note that the units for τ_0 are reported in lbs/ft^2 to be consistent with the estimate of critical shear stress reported in Task 8. To obtain units of lbs/ft^2 remove 'g' from Eqn. J.4.

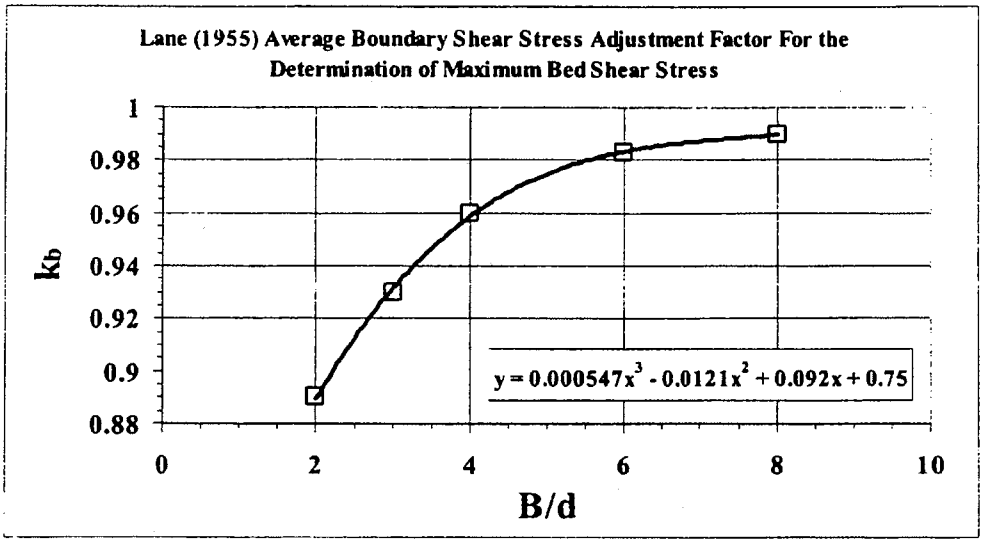

Figure J.3 Determination of k_B for the Adjustment of Average Boundary Shear Stress For Variations in Channel Shape Assuming A Trapezoidal Channel Cross-Section Configuration

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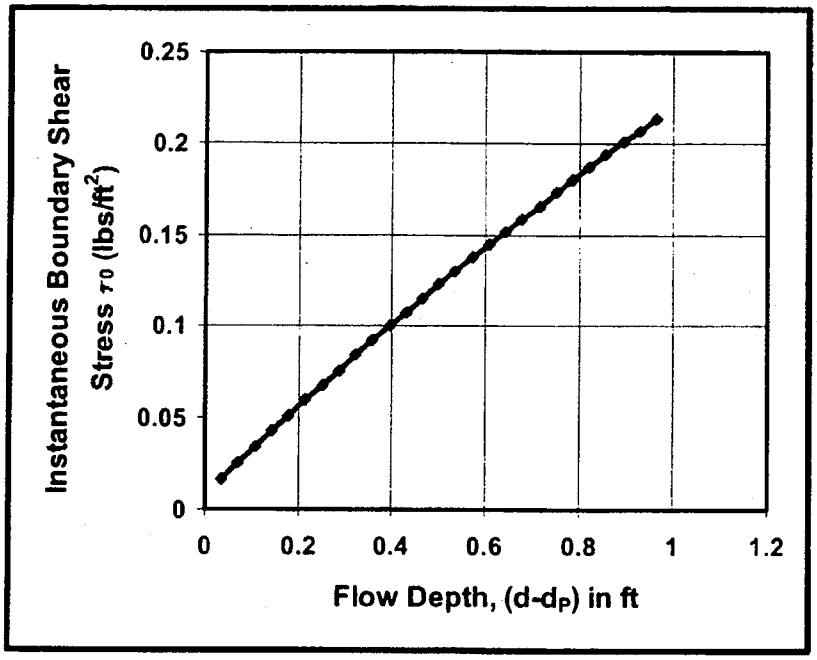

Figure J.4. Stage-Shear Stress Curve for Reach 1 (Master Cross-section): Bed Station.

Estimate the Sediment Referenced Dominant Discharge

10. The stage-shear stress curve is used to determine the depth of flow at which the boundary shear stress on the bed is equal to the critical shear stress of the ϕ_{R4} particle size fraction. This depth is transformed into an estimate of flow rate from the stage-discharge curve (Task 5 above), providing a second, independent estimate of the dominant discharge (Q_{SED}). This calculation also provides a basis for determination of the sensitivity of the bed material to an alteration in the sediment-flow regime. This assessment is described in Task 21 below;

Estimate The Flow Recurrence Interval of the Referenced Dominant Discharge

11. A flow time series is generated using:
    (1) Flow gauge data if available, or
    (2) A continuous hydrologic model to generate a synthetic flow time series of 6 to 13 years in length.
12. The flow time series is used to derive a flood frequency curve from which a third independent estimate of the dominant discharge (Q_{RI}) is determined as the flow having a recurrence interval between 1 and 2 years (average RI=1.5 years);

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Finalize the Estimate of Dominant Discharge

13. The three estimates of dominant discharge are compared for consistency. If consistent (e.g. the range is equal to or less than 20% of the mean), then the mean value of the dominant discharge can be accepted with a higher degree of confidence

Step 3. Determine the Sensitivity of the Boundary Materials

A) Sensitivity of the Bed Material

14. Using the stage-shear stress relationship developed in Task 9 and the estimate of flow depth (d_{BFL}, Task 10) from the dominant discharge (Task 13), determine the boundary shear stress $(\tau_0)_{BED}$ being applied to the bed at point 'P' at the dominant discharge. Point 'P' is located on the bed within the zone of maximum boundary shear stress. In this example the value of maximum instantaneous boundary shear stress at a depth of d_{BFL}= 1.0 ft was found to be $(\tau_0)_{BED}$ = 0.214 lbs/ft^2 at the Master cross-section in Reach 1 (Figure J.4). Similarly, for Reaches 2 and 3 the maximum value of instantaneous boundary shear stress was found to be $(\tau_0)_{BED}$ = 0.680 and 0.432 lbs/ft^2 respectively.
15. Compute the value of $(\tau_c)_{BED}$ for the Master cross-section knowing $(\tau_0)_{BED}$ and $(\tau_{CRT})_{BED}$ as,

$$(\tau_e)_{BED} = (\tau_0 - \tau_{CRT})_{BED} \quad \text{.....[J.6]}$$

in which $(\tau_c)_{BED}$ represents the effective boundary shears stress, τ_0 is the instantaneous boundary shear stress at the dominant discharge and τ_{CRT} is the critical shear stress of the bed material at point 'P'.

16. Repeat the bed shear stress analysis for all Master cross-sections in all reaches of "like" morphology.
17. Compare the value of $(\tau_c)_{BED}$ for all Master cross-sections through the study reach and select the Master cross-section for which the value of $(\tau_c)_{BED}$ is greatest. The reach represented by the Master cross-section having the highest value of $(\tau_c)_{BED}$ is referred to as the "Control Reach".

In this example, effective boundary shear stress on the bed was found to range from between -0.526 and -0.334 (Table J.5). The negative values infer that the channel bed is armored and the bed material is mobile under flood flow events in excess of the dominant discharge. However, of the three Master cross-sections the value of $(\tau_c)_{BED}$ was greatest for Reach 1, consequently, Reach 1 was identified as the "Control Reach".

B) Sensitivity of the Bank Material

18. The bank material for the "Control Reach" is classified according to soil type for each stratigraphic unit using:
    (1) Soil consistency tests; or
    (2) Particle size analysis and Atterberg Limits.

    In this example the bank materials were mapped and differentiated into stratigraphic units as summarized for the three reaches in Table J.5. The soil consistency test results determined using standard soil classification guidelines (as quantified by MacRae, 1991)), are summarized below and reported in Table J.5.
    - i) Assign a value for the stickiness of the material, e.g. not sticky, (X1=0) to extremely sticky (X1=4),
    - ii) Assign a value for the plasticity of the material, e.g. not plastic (X2=0) to extremely plastic (X2=4),
    - iii) Assign a value for the firmness of the material, e.g. loose, no structure (X3=0) to

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stiff (X4=4).

(3) Sum the consistency test values,

$$SCORE = \sum_{i=1}^{3} x_i \quad \text{.....[J.7]}$$

in which SCORE represents the sum of the values assigned for stickiness, plasticity and firmness.

19. Construct stage-shear stress curves for selected bank stations approximated by $0.25d_{BFL}$, $0.33d_{BFL}$, $0.4d_{BFL}$. More than one bank station may be required in a stratigraphic unit depending upon the thickness of the unit. The curves may be approximated as follows:

$$\tau_0 = k_S(\rho g(d - d_p)S) \quad \text{.....[J.8]}$$

in which k_S is a correction factor for points on the channel bank determined as a function of channel shape (see Eqn. J.9, Figure J.5), 'd' is the depth of flow (ft), ρ is the density of water (62.4 lbs/ft^3), 'g' is acceleration due to gravity (32.2 ft/s^2) and d_P is the depth of flow at the elevation of the boundary station (ft).

$$k_S = 0.7236\left(\frac{B}{d}\right)^{0.0241} \quad \text{.....[J.9]}$$

in which B is the channel bottom (ft) width and 'd' is the depth of flow (ft). Note, to obtain units of lbs/ft^2 remove the constant 'g' from Eqn. J.8.

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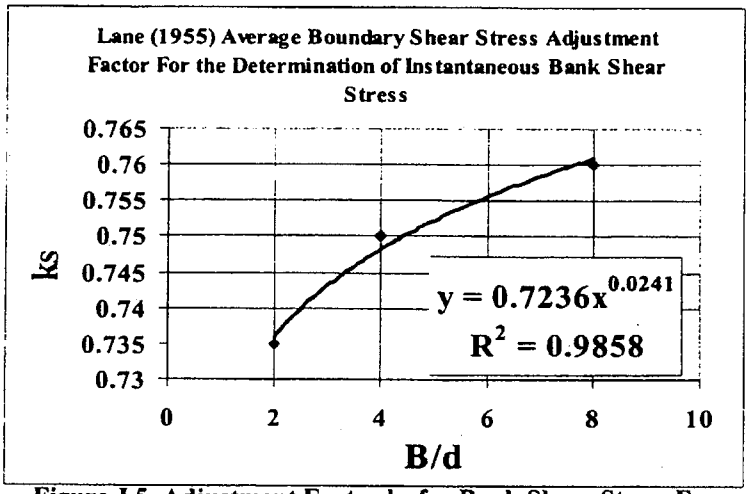

Figure J.5 Adjustment Factor k_S for Bank Shear Stress For Channels Approximating a Trapezoidal Shape

20. Estimate the critical shear stress (τ_{CRT}) within each stratigraphic unit using available empirical relationships. These relations are typically based on percent silt and clay content, degree of compaction, particle size (Vanoni, 1977) or the SCORE value (MacRae, 1991);

21. Compute the excess boundary shear stress for each bank station at a flow depth of between 0.6 and 0.75 feet by reading the boundary shear stress off the stage-shear stress curve for each boundary station and subtracting the critical shear stress as described in DuBoy's relation,

$$(\tau_e)_{BNK} = (\tau_0 - \tau_{CRT})_{BNK}, \quad \text{[J.10]}$$

in which $(\tau_c)_{BNK}$ represents the excess boundary shear stress (lbs/ft^2) at the selected boundary station (P), τ_0 is the instantaneous boundary shear stress (lbs/ft^2) at any specified depth of flow at point P and τ_{CRT} represent the critical shear stress (lbs/ft^2) of the boundary material at point P.

22. Compare the estimates of excess boundary shear stress $(\tau_c)_{BNK}$ at each bank station and select that station having the highest value of $(\tau_c)_{BNK}$ as the bank station controlling bank response (controlling stratigraphic unit) to a change in the flow regime. Using the guidelines presented in Table J.6 determine channel sensitivity to an alteration in the sediment-flow regime and the corresponding Over Control (OC) curve and Inflection Point

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Table J.6 General Guidelines for the Application of the DRC Approach Based on Bank Material Sensitivity Using SCORE Values							
BANK SENSITIVITY		**BED SENSITIVITY**				**DRC PARAMETERS**	
Excess Shear Stress $(\tau_c)_{BED}$	Sensitivity Class	Excess Shear Stress $(\tau_c)_{BNK}$	Bank Resistance		Sensitivity Class	Over Control Multiplier R_{OC}	Inflection Point
			Soil Class	SCORE			
<0	**L**	<0	Very Stiff	N/a	L	1.0 –0.9	a
		≈0	Stiff	10-12	ML	0.9 - 0.7	a
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	**N/a**			**0.5 - 0.2**	**c**
≈0	ML	<0	N/a			0.9 - 0.7	a
		≈0	Stiff	10-12	ML	0.9 - 0.7	a
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	N/a			0.5 - 0.2	c
	M	<0	N/a			0.7 - 0.5	b
		≈0	Stiff	N/a		0.7 - 0.5	b
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	N/a			0.5 - 0.2	c
	H	N/a				0.5 - 0.2	c
>0	H	N/a				0.5 - 0.2	c

The multiplier (R_{OC}) in Table J.6 is used in the following manner:

a) The 2 year peak flow attenuation technique is used to derive the stage-discharge curve for the erosion control component of the SWM pond.

b) A multiplier of unity is equivalent to the traditional 2-year peak flow attenuation approach.

c) The multiplier is used to adjust the 2-year stage-discharge curve to account for differences in the erodability of the boundary materials. The adjustment is performed by multiplying each ordinate of the stage-discharge curve by R_{OC}. For stiff materials, the multiplier approaches unity ($R_{OC} \rightarrow 1.0$). For very sensitive materials, the multiplier is between 0.2 and 0.3, which is equivalent to 80%OC to 70%OC respectively.

Bank materials may be grouped according to the SCORE value if the soil consistency tests apply (i.e. fine-grained material with few stones). For coarse-grained materials, resistance can be determined from observation of bank erosion following a high flow event. As an alternative the resistance of the coarse-grained stratigraphic unit can be inferred from bank form and shear stress distribution through comparison with adjoining strata of fine-grained material.

Finally, relations expressing critical shear stress as a function of particle size are available in the literature. Many of these relations were derived from flume experiments using disturbed material that has been re-compacted. These relations tend to underestimate the resistance of the material as it is observed in the field. Consequently, these relations should be employed with caution or corrected to account for root binding, imbrication, compaction and structurization.

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Step 4. Approximate the Elevation-Discharge Curve For the DRC Pond.

The DRC outflow control structure can be constructed as set of pipes or nested weirs. This design example is for a nested, sharp crested weir.

Determine the stage-discharge curve for the flow rate having a recurrence interval of 2 years for the baseline land use condition. For this example, the baseline condition is the reforested land use scenario. The flow having a recurrence interval 2 years was determined previously as between 8.9 and 10.1 cfs for Reaches 1 through 3 respectively (Table J.5).

Construct the 2 year stage-discharge curve using an equation for sharp crested weirs with end contractions:

$$Q = C_e L_e h_e^{\left(\frac{3}{2}\right)} \quad \text{.....[J.11]}$$

in which, 'Q' represents the rate of flow (cfs), 'C_e' is the effective weir coefficient (C=3.19, Brater and King, 1982), L_e is the effective length of the weir (ft) and 'h_e' is the effective depth of flow above the weir crest (ft). Set the invert of the weir at 628.0 ft. The terms L_e, C_e and h_e are adjusted to account for losses due to end contractions (Brater and King, 1982). In this illustration it is assumed that the stage-volume curve has already been derived and that the approximate head at Q_{BFL}=8.9 cfs is h=2.25 ft.

Re-arranging Eqn. J.11 and solving for 'L_e' at $Q=(Q_{2YR})_{PRE}$=8.9 cfs yields,

$$L_e = \frac{Q}{C_e h_e^{\left(\frac{3}{2}\right)}} = \frac{8.9}{3.19(2.25)^{\left(\frac{3}{2}\right)}} = 0.83\text{ft} \quad \text{.....[J.12]}$$

Compute the stage-discharge curve for the 2-year weir using Eqn. J.11 as illustrated in Figure J.6 (Q_{2YR}, curve AB. This stage-discharge curve represents the rating curve for the 2-year post- to pre-development peak flow attenuation approach.

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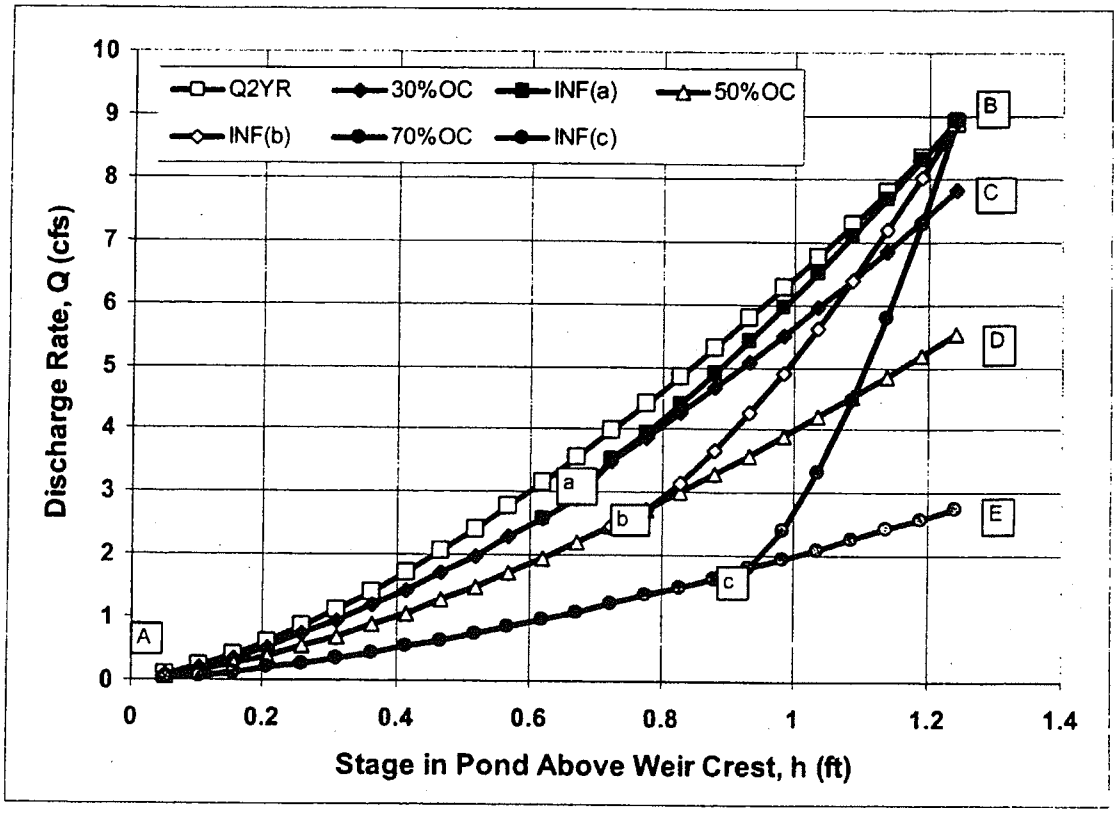

Figure J.6. The 2 Year Peak Flow Attenuation and DRC Rating Curves for 30%OC, 50%OC and 70%OC

Construct the DRC stage-discharge curve as follows:

- Determine the level of OC control and the inflection point from Table J.6.
  - Since $(\tau_c)_{BED}<0$ (Table J.5) then the bed is classified as "Low" sensitivity (shaded boxes in the first two columns of Table J.6);
  - The value of $(\tau_c)_{BNK}>0$ consequently, Row 3 of Column 3 (shaded box in Table J.6) was selected;
  - The bank material was classified as soft (SCORE=1), consequently, the 4th Row of Column 4 was chosen providing a range of R_{OC} between 0.5 and 0.2 with an inflection point at "c". In this case $R_{OC}=0.3$ was selected in accordance with the guidelines in Table J.6. Note: 70%OC means that the multiplier for the 2 year curve is $R_{OC}=0.3$
  - The 70%OC curve (designated as curve AE in Figure J.6) is created by multiplying the ordinance of the 2 year stage-discharge curve (Q_{2YR} in Figure J.6) by the multiplier $R_{OC}=0.3$.
  - The inflection point (c) is determined using the guidelines provided in Table J.7.

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Table J.7 Guidelines For Determination of the Flow Rate for the DRC Curve Inflection Point (Reach 1)					
Inflection Point	Ratio of Inflection Point Depth to Bankfull Depth d_i/d_{BFL} (dim)	Bankfull Depth d_{BFL} (ft)	Inflection Point Depth d_i (ft)	Dominant Discharge Q_{BFL} (cfs)	Flow Rate at Inflection Point Q_i (cfs)
a	.75	1.0	.75	4.76	2.88
b	.67		.67		2.30
c	.55		.55		1.74

The point d_c=0.55 ft, d_{BFL}=1.0 ft, characterize the Control Reach, consequently the ratio,

$$\frac{d_c}{d_{BFL}} = \frac{0.55ft}{1.0ft} = 0.55, \quad \text{[J.12]}$$

- The flow rate at d_c/d_{BFL}=0.55 was estimated from Figure J.6 to be Q_c=1.74 cfs.
- Point (c) can be located on curve AE at a flow corresponding to Q_c=1.74 cfs.

- The DRC stage-discharge curve follows the curve A(c)B in Figure J.6. For the purpose of illustration, the stage-discharge curves for 30%OC (inflection point (a)) and 50%OC (inflection point (b)) are also provided in Figure J.6.

Step 5. Sizing the DRC Weir

After establishing the DRC stage-discharge curve the next step is to size the DRC weir. This is done using a nested weir configuration as illustrated in Figure J.7. The equation for the nested weir can be approximated from Eqn. J.14 for sharp crested weirs as,

$$Q = \left(C_c L_c h_c^{\left(\frac{3}{2}\right)} \right)_{INSET} + \left(C_c (L_c^* - L_c)(h_c^* - h_c)^{\left(\frac{3}{2}\right)} \right), \quad \text{[J.14]}$$

in which Q represents the discharge from the nested weir, 'C_c' is a coefficient (3.19) adjusted to account for end contractions, L_c is the length of the inset weir, h_c represents the height of the inset weir where $0 \le h_c \le h_2$ (h_2 represents the total height of the nested weir) and h_c^* is the depth of flow through the nested weir above the inset weir ($h_c \le h_c^* \le h_2$).

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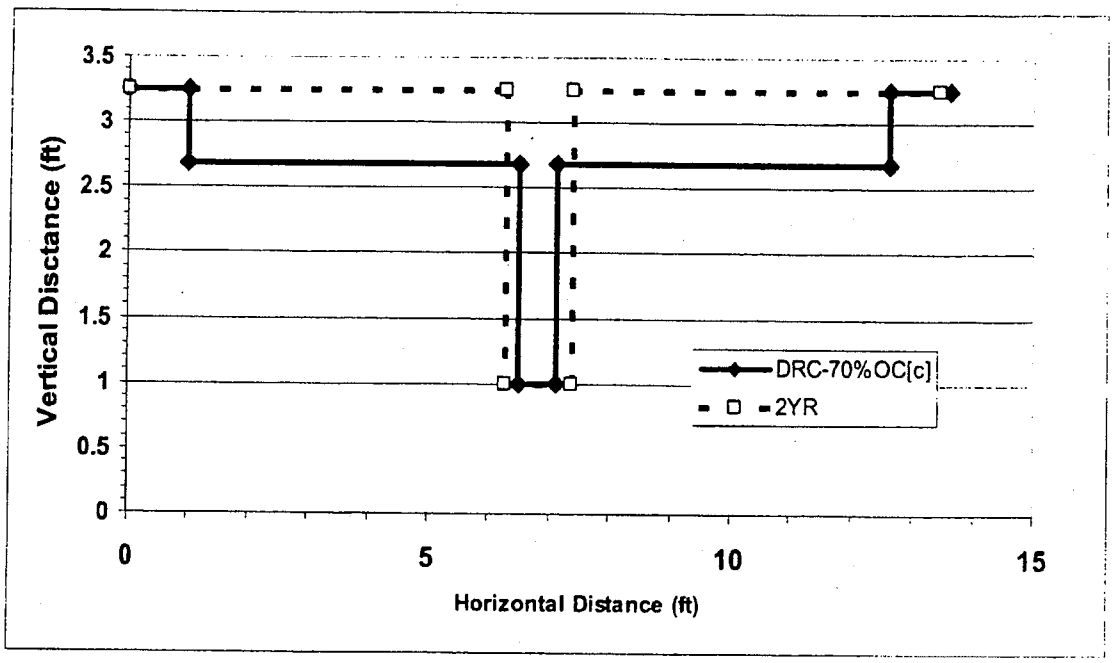

Figure J.7 Comparison of the 70% OC DRC Weir with Inflection Point at [c] and the Traditional 2-year Peak Flow Attenuation Weir

Solving Eqn. D.14 for results in the dimensions and flow values reported in Table J.8.

Table J.8. Summary of Dimensions and Flow Characteristics For a Nested DRC Weir: Reach 1

Parameter	DRC Weir			2 Year Weir
	Inflection Point (a)	Inflection Point (b)	Inflection Point (c)	
L_c (ft)	1.77	1.00	0.62	N/A
h_c (ft)	0.67	0.78	0.93	
Q_i at h_c (cfs)	2.89	2.21	1.74	
L_c (ft)	0.80	4.32	11.0	0.83
h_2 (ft)	2.25			
Q at h_2 (cfs)	8.94			

Parameters in Table J.8 are defined in the preceding text.

Note: the weir dimensions for DRC stage discharge curves 30%OC (inflection point 'a') and 50%OC (inflection point 'b') are provided for comparison with the selected option (inflection point 'c').

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Appendix K

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New York State Stormwater Management Design Manual

Appendix K. Miscellaneous Details

Miscellaneous Design Schematics for Compliance with Performance Criteria

Figure K-1: Trash Rack for Low Flow Orifice
Figure K-2: Expanded Trash Rack Protection for Low Flow Orifice
Figure K-3: Internal Control for Orifice Protection
Figure K-4: Observation Well for Infiltration Practices
Figure K-5: On-line Versus Off-line Schematic
Figure K-6: Isolation/Diversion Structure
Figure K-7: Half Round CMP Hood
Figure K-8: Half Round CMP Weir
Figure K-9: Concrete Level Spreader
Figure K-10: Baffle Weir for Cold Climates
Figure K-11: Hooded Outlet with Hood Below Ice Layer
Figure K-12: Shallow Angle Trash Rack to Prevent Icing

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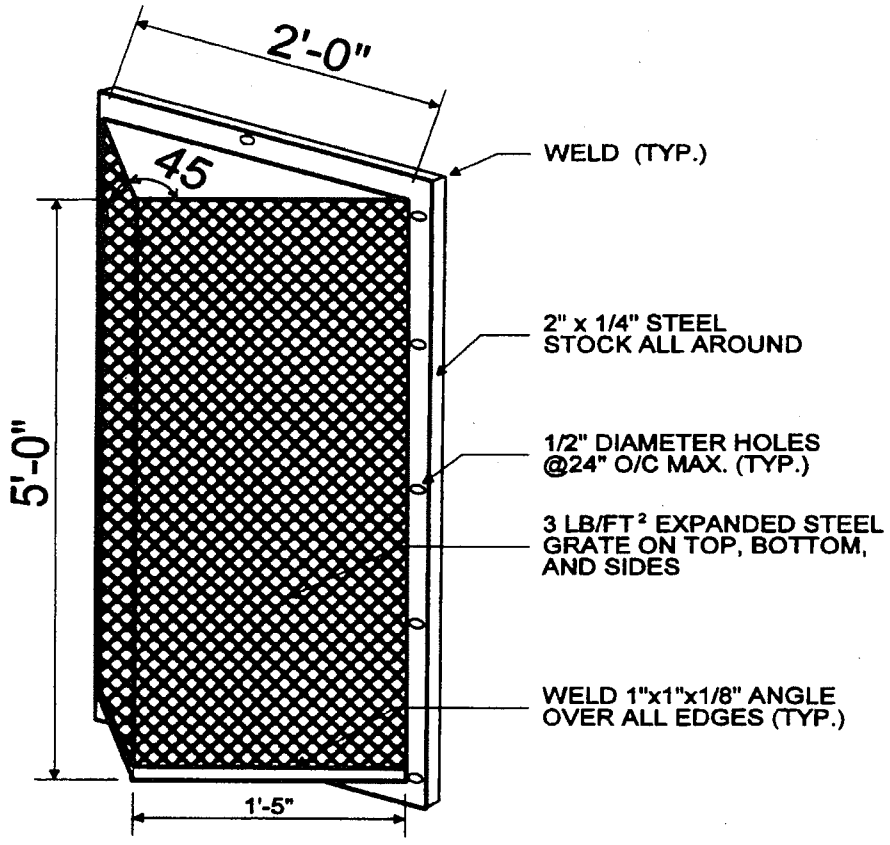
Figure K.1 Trash Rack Protection for Low Flow Orifice



NOTES FOR TRASH RACK

1. TRASH RACK TO BE CENTERED OVER OPENING.
2. STEEL TO CONFORM TO ASTM A-36.
3. ALL SURFACES TO BE COATED WITH ZRC COLD GALVANIZING COMPOUND AFTER WELDING.

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Figure K.2 Expanded Trash Rack Protection for Low Flow Orifice

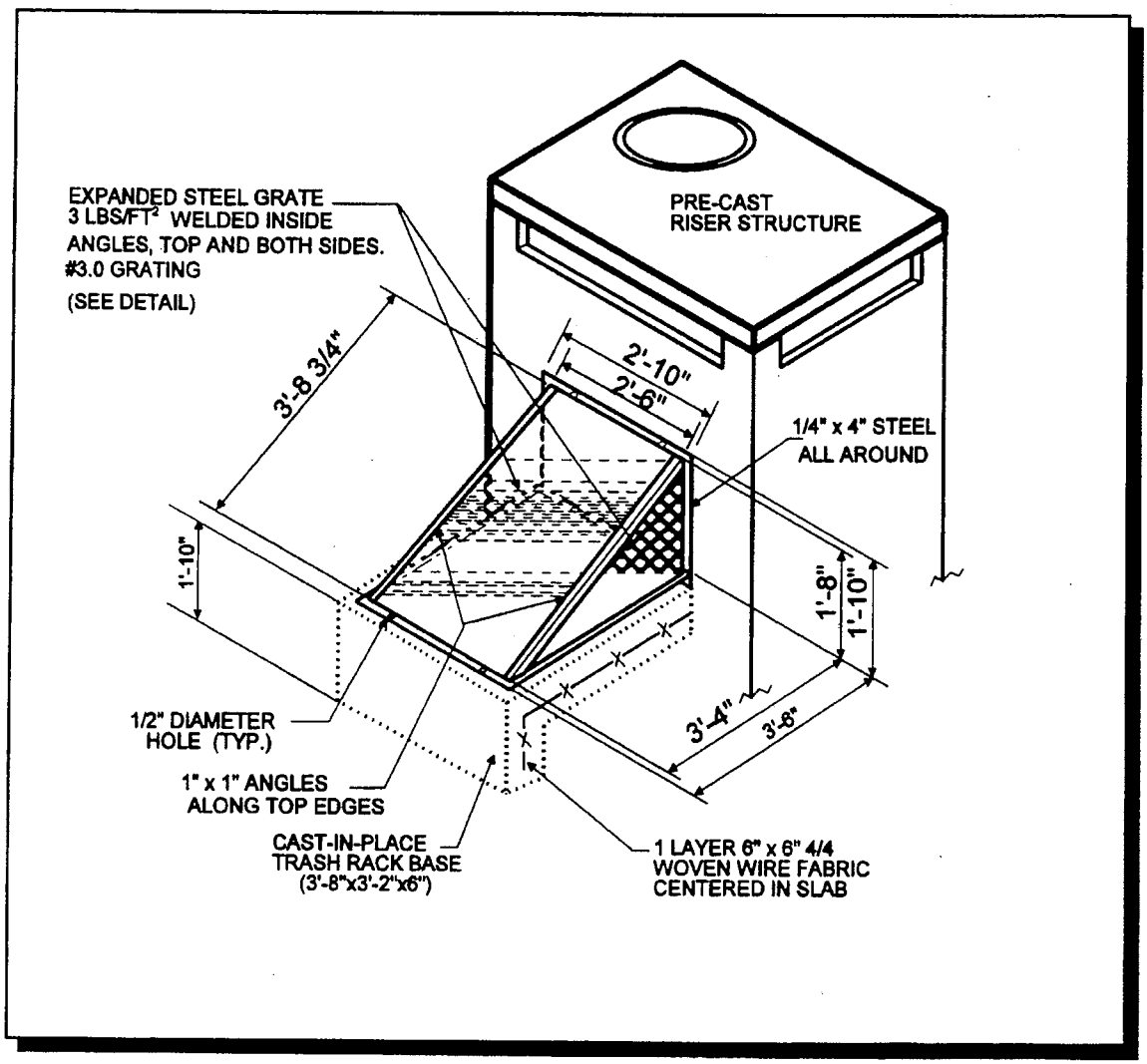

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Figure K.3 Internal Control for Orifice Protection

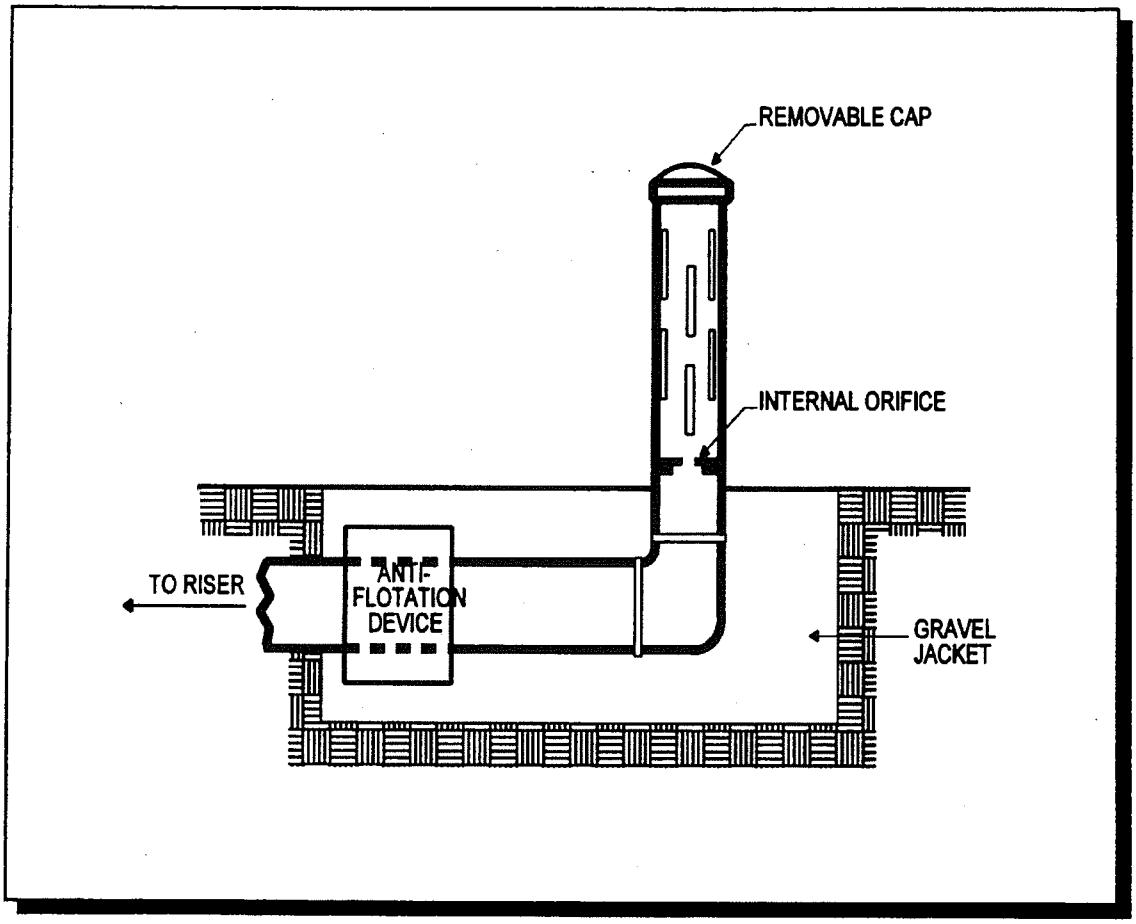

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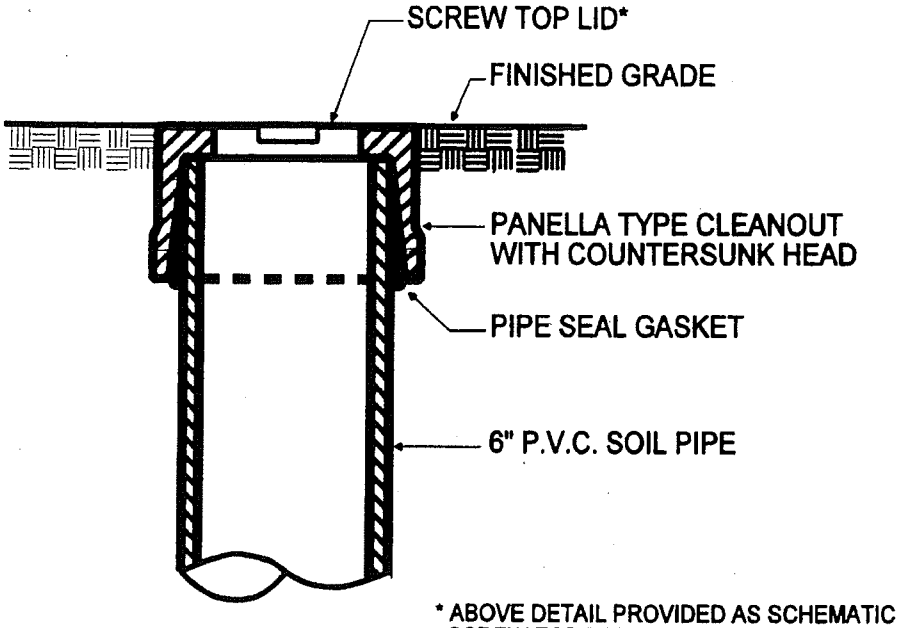
Figure K.4 Observation Well for Infiltration Practices



EACH OBSERVATION WELL / CLEANOUT SHALL INCLUDE THE FOLLOWING:

1. FOR AN UNDERGROUND FLUSH MOUNTED OBSERVATION WELL / CLEANOUT, PROVIDE A TUBE MADE OF NON-CORROSIVE MATERIAL, SCHEDULE 40 OR EQUAL, AT LEAST THREE FEET LONG WITH AN INSIDE DIAMETER OF AT LEAST 6 INCHES.

2. THE TUBE SHALL HAVE A FACTORY ATTACHED CAST IRON OR HIGH IMPACT PLASTIC COLLAR WITH RIBS TO PREVENT ROTATION WHEN REMOVING SCREW TOP LID. THE SCREW TOP LID SHALL BE CAST IRON OR HIGH OMPACT PLASTIC THAT WILL WITHSTAND ULTRA-VIOLET RAYS.

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Figure K.5 On-Line Versus Off-Line Schematic

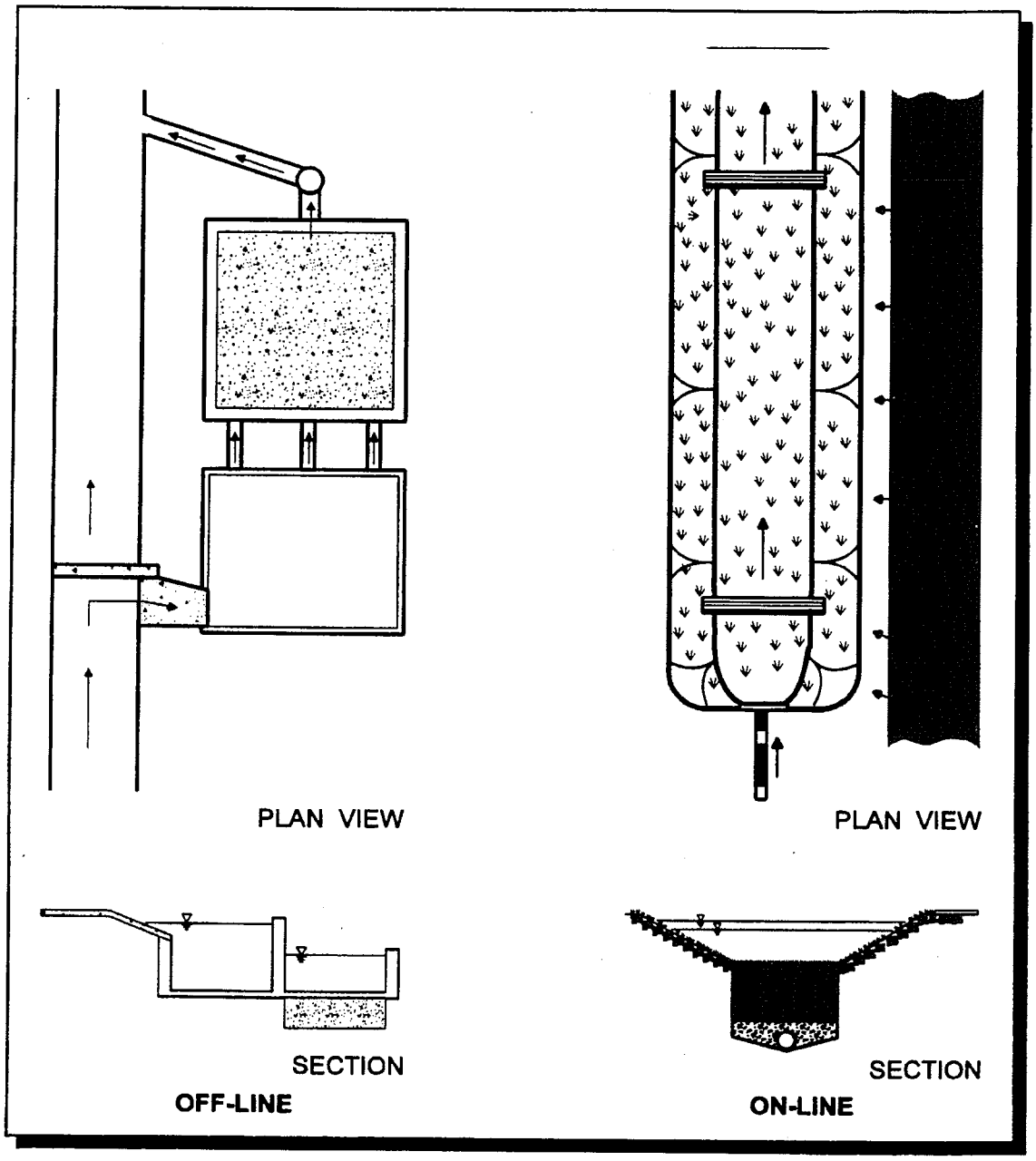

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Figure K. 6 Isolation Diversion Structure

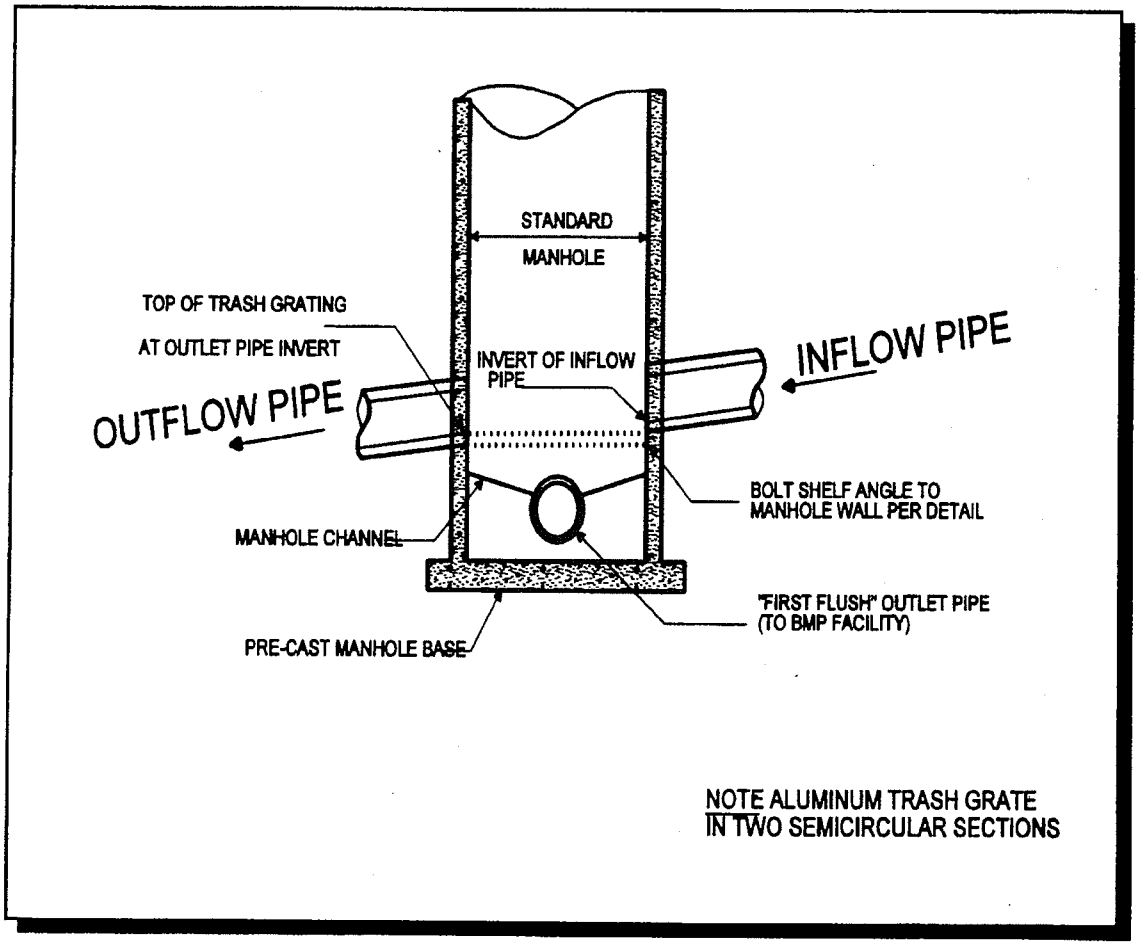

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Figure K.7 Half Round CMP Hood

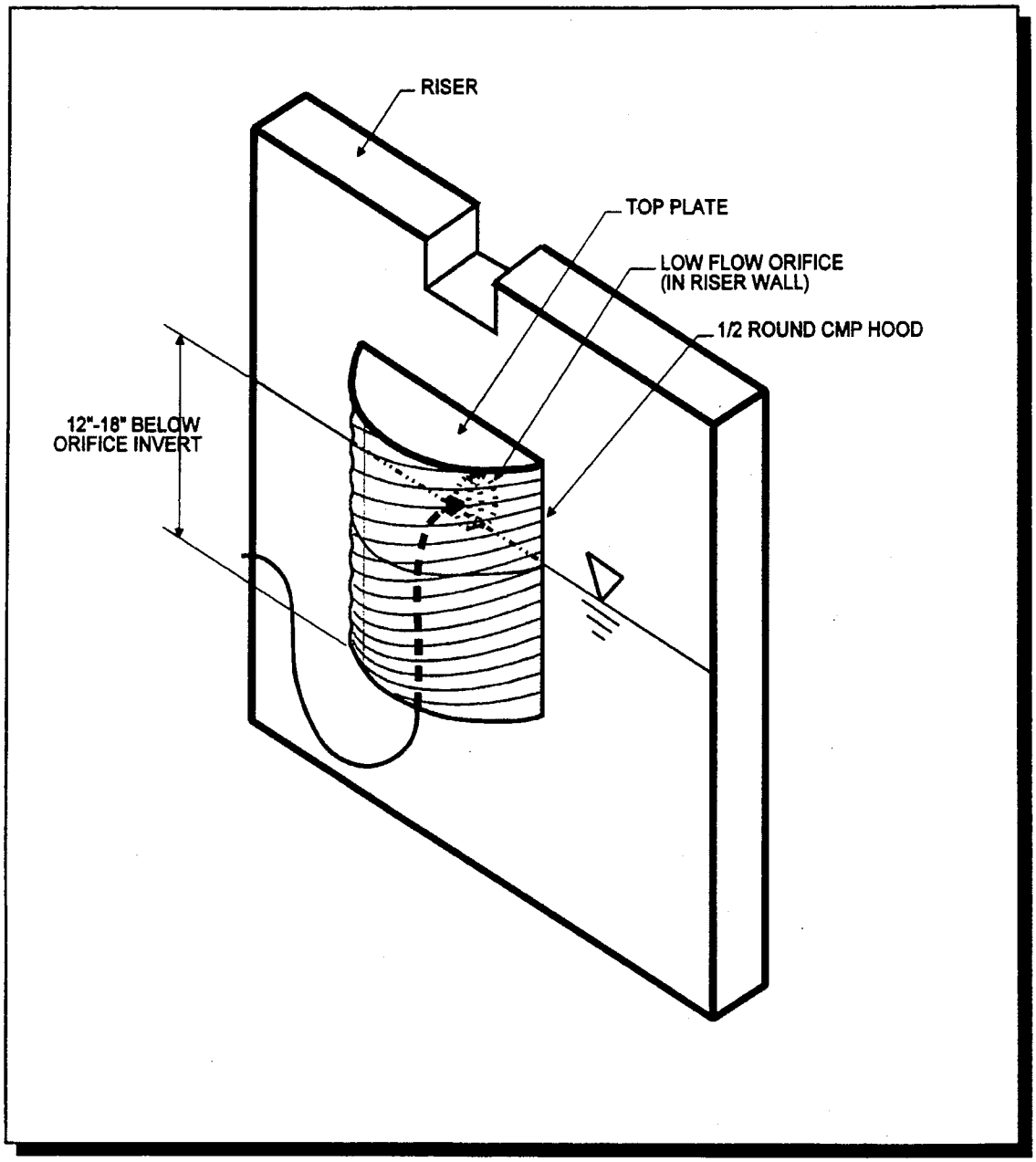

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Figure K.8 Half Round CMP Weir

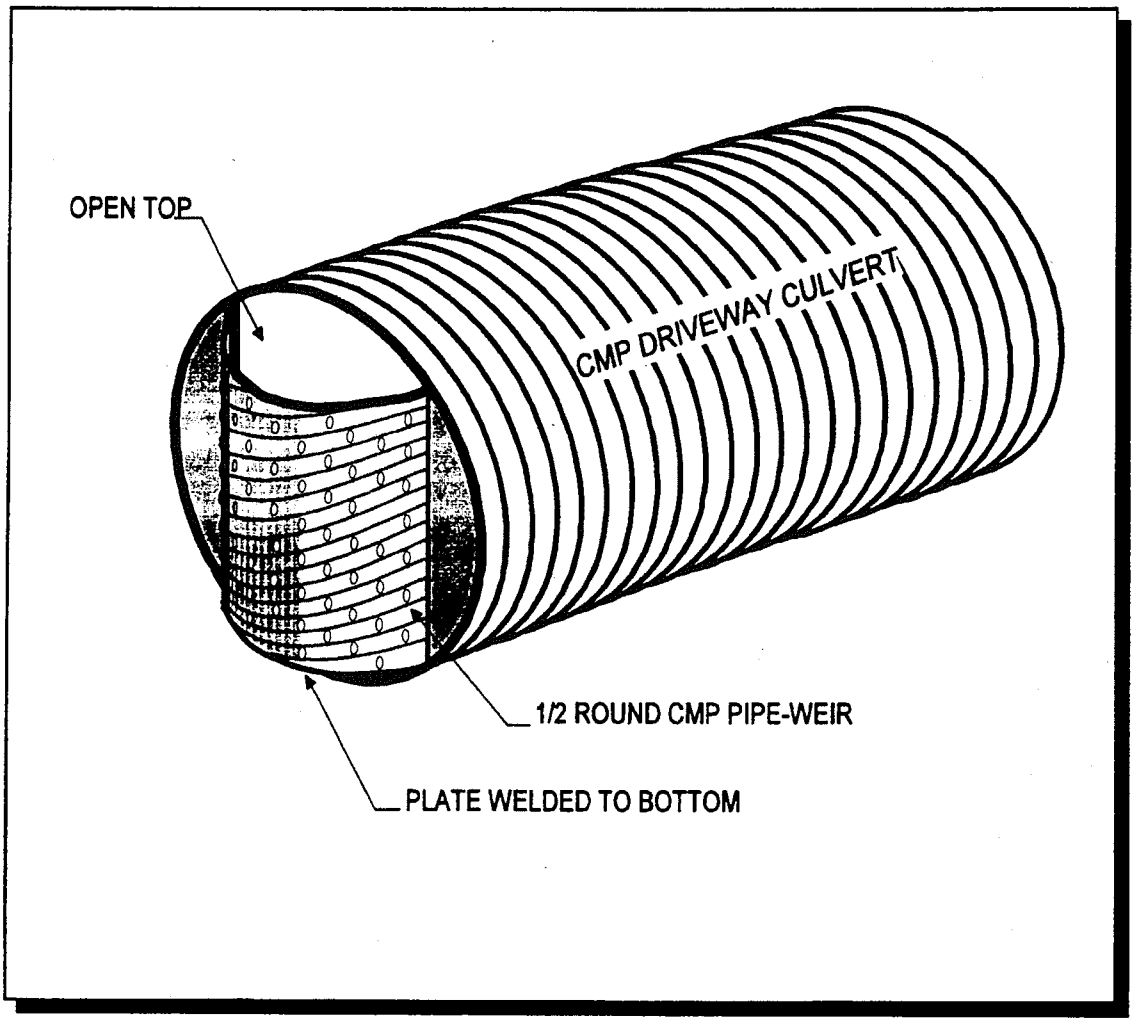

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Figure K.9 Concrete Level Spreader

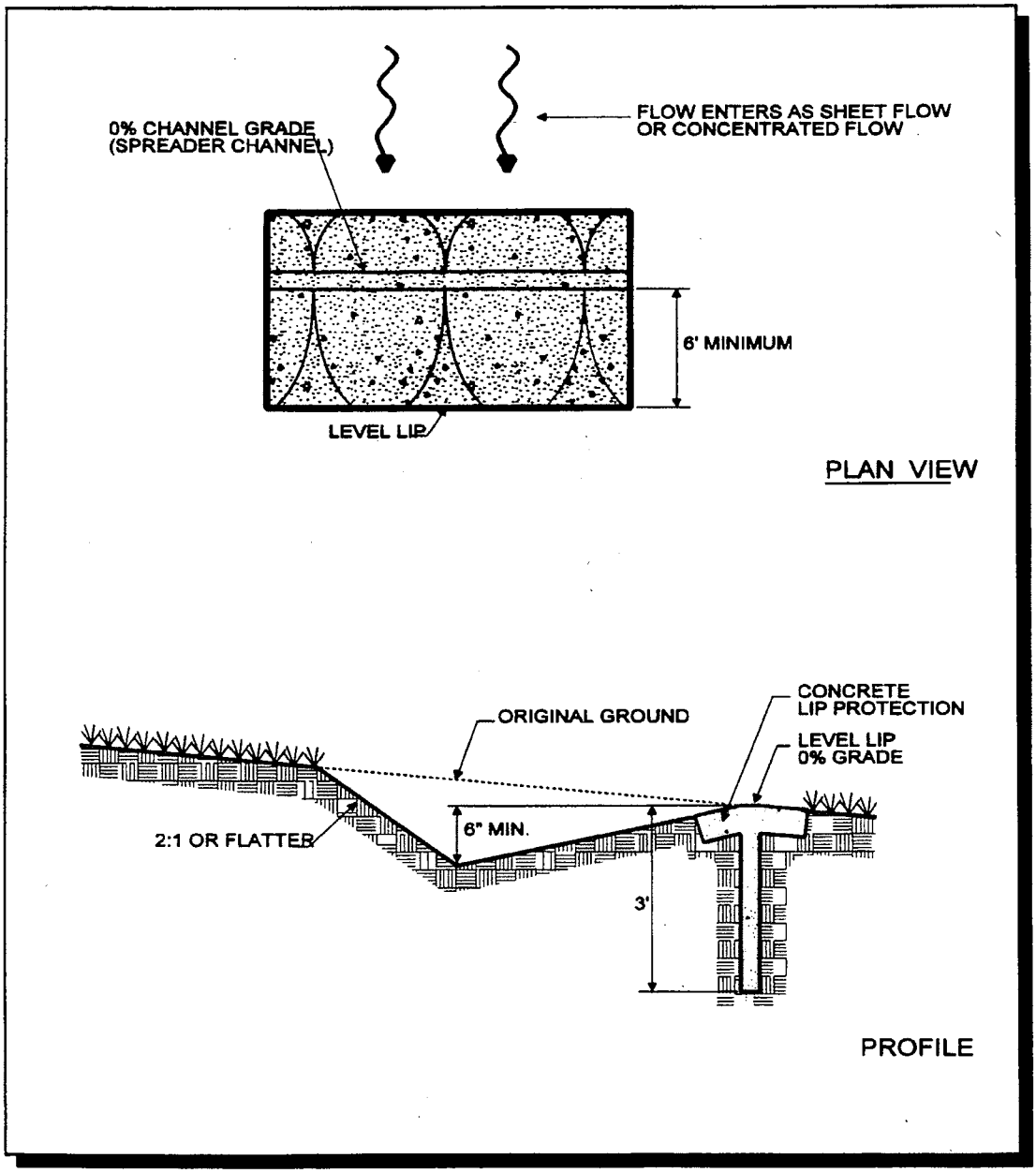

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Figure K.10 Baffle Weir for Cold Climates

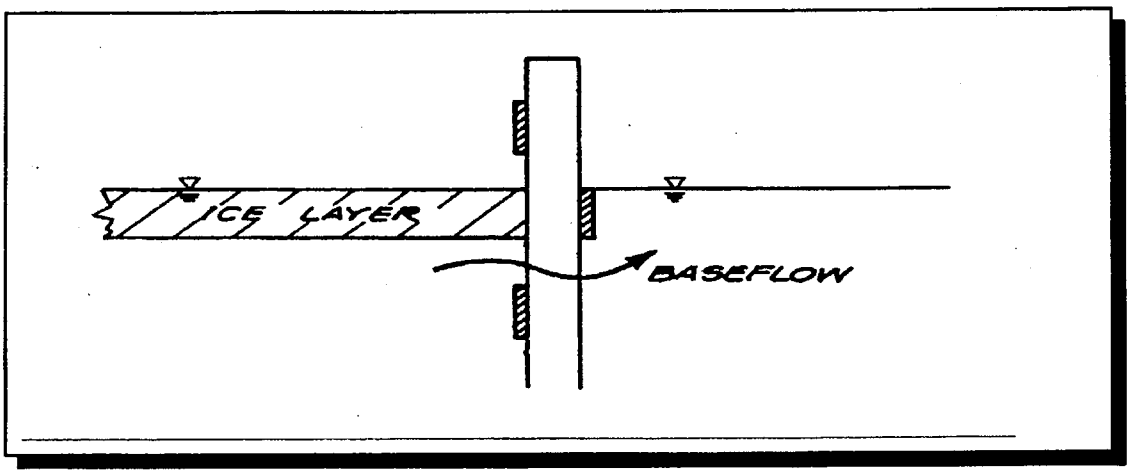

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Figure K.11 Hooded Outlet with Hood Below Ice Layer

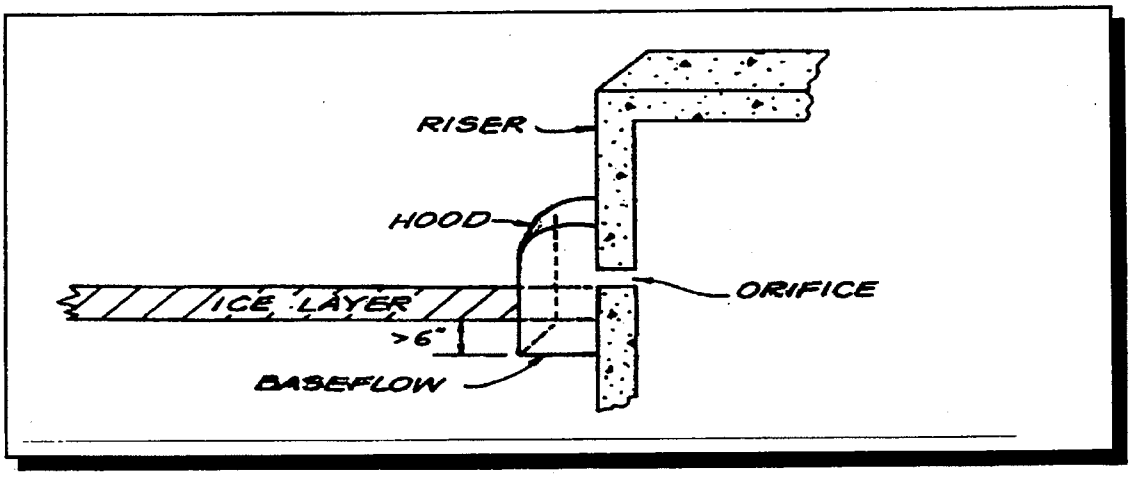

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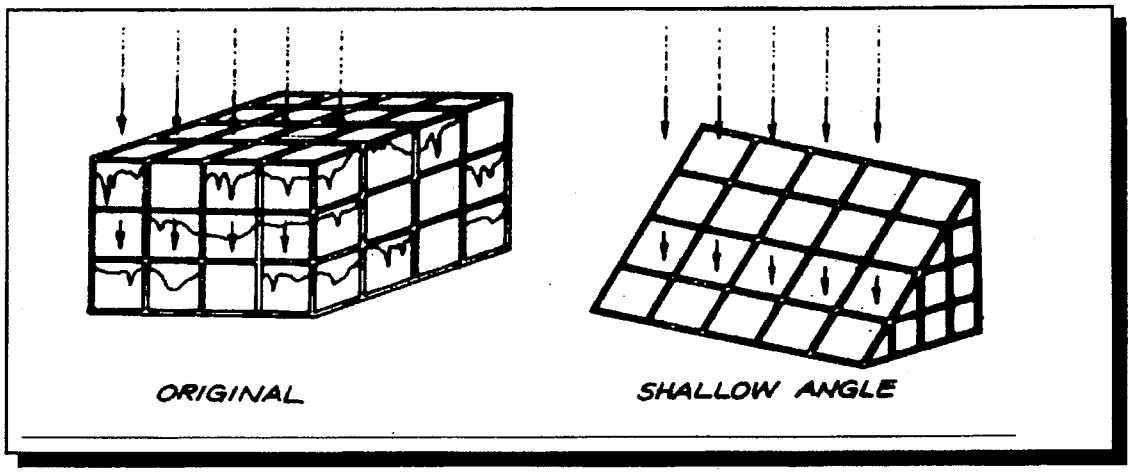
Figure K.12 Shallow Angle Trash Rack to Prevent Icing



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Appendix L

New York State Stormwater Management Design Manual

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Appendix L: Critical Erosive Velocities for Grass and Soil

Velocity

Maximum permissible velocities of flow in vegetated channels absent of permanent turf reinforcement matting shall not exceed the values shown in the following table:

Table L.1 Permissible Velocities for Channels Lined with Vegetation

Channel Slope	Lining	Permissible Velocity[1] (ft/sec)
0-5%	Reed canarygrass Tall fescue Kentucky bluegrass	5
	Grass-legume mixture	4
	Red fescue Redtop Serices lespedeza Annual lespedeza Small grains	2.5
5-10%	Reed canarygrass Tall fescue Kentucky bluegrass	4
	Grass-legume mixture	3
Greater than 10%	Reed canarygrass Tall fescue Kentucky bluegrass	3

Source: Soil and Water Conservation Engineering, Schwab, *et al.*

For vegetated earth channels having permanent turf reinforcement matting, the permissible flow velocity shall not exceed 8 ft/sec. Turf reinforcement matting shall be a machine produced mat of nondegradable fibers or elements having a uniform thickness and distribution of weave throughout. Matting shall be installed per manufacturer's recommendations with appropriate fasteners as required. Examples of acceptable products include but are not limited to:

- North American Green "C350" or "P300"
- Greenstreak "PEC-MAT"
- Tensar "Erosion Mat"

1 For highly erodible soils, permissible velocities should be decreased 25%. An erodibility factor (K) greater than 0.35 would indicate a highly erodible soil. Erodibility factors (K-factors) can be obtained from local NRCS offices.

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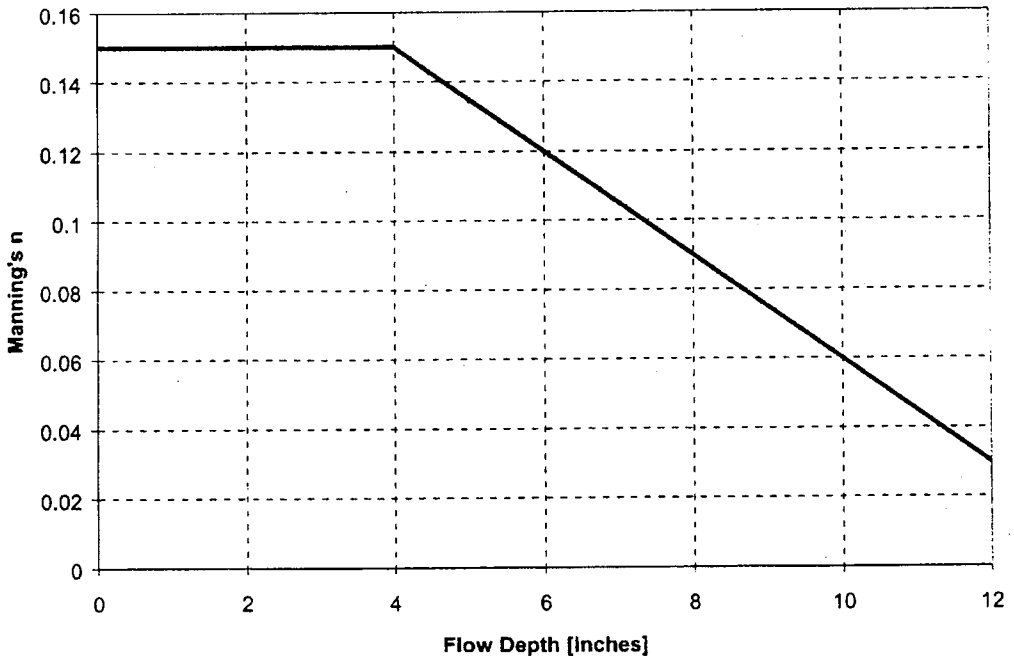
Manning's n value

The roughness coefficient, n, varies with the type of vegetative cover and flow depth. At very shallow depths, where the vegetation height is equal to or greater than the flow depth, the n value should be approximately 0.15. This value is appropriate for flow depths up to 4 inches typically. For higher flow rates and flow depths, the n value decreases to a minimum of 0.03 for grass channels at a depth of approximately 12 inches. The n value must be adjusted for varying flow depths between 4" and 12" (see Figure L.1).

Figure L.1 Manning's n Value with Varying Flow Depth (Source: Claytor and Schueler, 1986)



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STORMWATER MANAGEMENT MANUAL

SEPTEMBER 2004

REVISION #3





ENVIRONMENTAL SERVICES
CITY OF PORTLAND
CLEAN RIVER WORKS

City of Portland

Stormwater Management Manual

Revision 3
September 1, 2004

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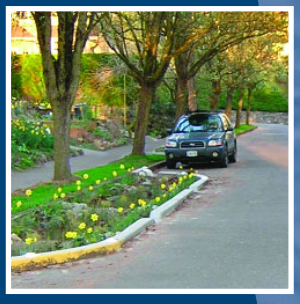




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Chapter **Page**

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Appendix B: Vendor Submission Guidance for Evaluating Stormwater Treatment Technologies

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HOW TO USE THIS MANUAL

This section includes:

- **"How To Use This Manual" Flowchart**
- Case examples for:
  - **#1 Single-family house (Southeast Portland)**
  - **#2 Single-family house (Northwest Portland)**
  - **#3 Rowhouse with private driveway (Northeast Portland)**
  - **#4 Rowhouse with private driveway (Southwest Portland)**
  - **#5 Commercial site development with parking lot (North Portland)**
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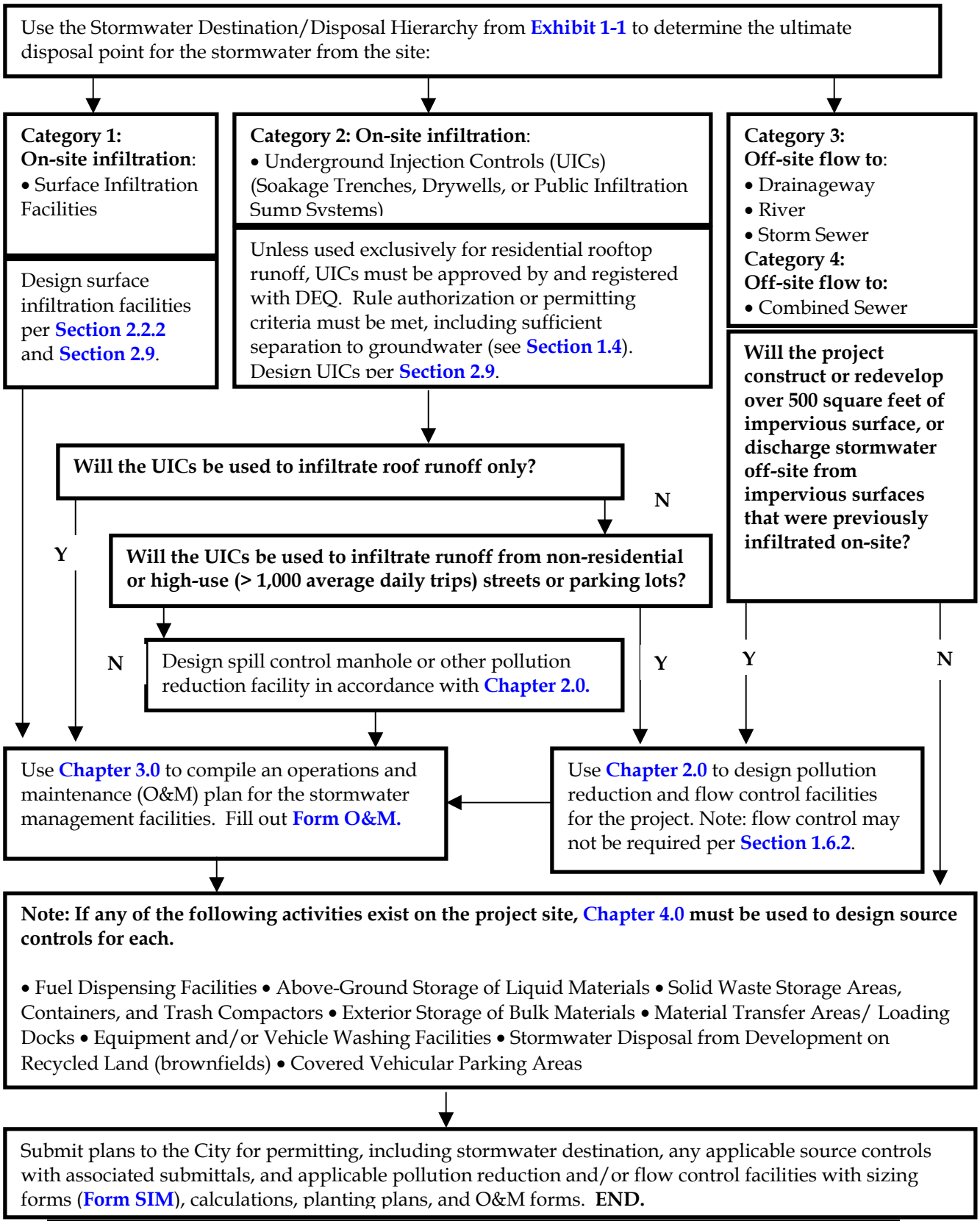
The purpose of this section is to help the user navigate the *Stormwater Management Manual* and apply it to projects of varying size, type, and complexity. The goal is a higher number of successful permit applications, resulting in fewer check-sheet revisions.

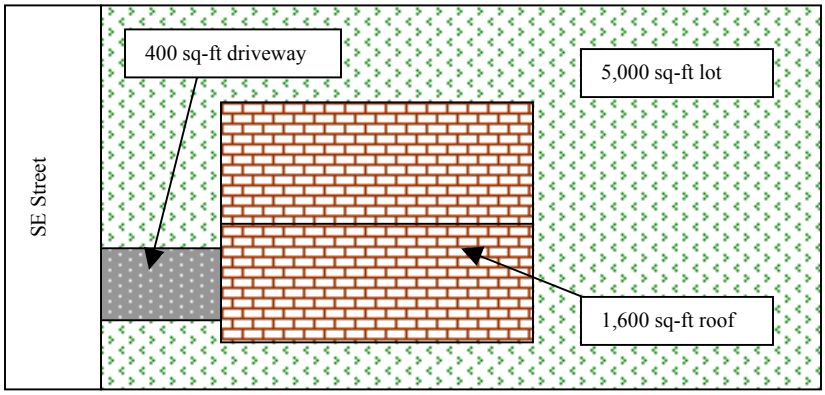


"HOW TO USE THIS MANUAL" FLOWCHART



CASE EXAMPLE #1: Single-Family House (Southeast Portland)

A single-family house with a footprint of 1,600 square feet and a driveway with a footprint of 400 square feet will be constructed on a 5,000 square-foot lot in Southeast Portland. Preliminary geotechnical research indicates that the soil in the area belongs to hydrologic soil group B (from the USDA/NRCS Soil Survey of Multnomah County, Oregon), and depth to groundwater is approximately 100 feet. The lot has slopes less than 2 percent.



Step 1: Determine the stormwater disposal point for the site. Use **Exhibit 1-1**: **Stormwater Destination/Disposal Hierarchy** (in Chapter 1.0)

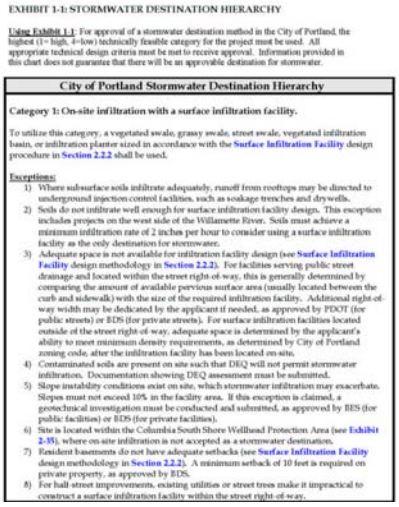


EXHIBIT 1-1: STORMWATER DESTINATION HIERARCHY

Using Exhibit 1-1: For approval of a stormwater destination method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

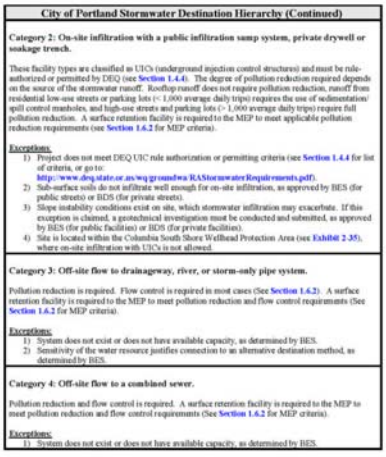
City of Portland Stormwater Destination Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

To utilize this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter sized in accordance with the Surface Infiltration Facility design procedure in Section 2.2.2 shall be used.

Exceptions:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour to consider using a surface infiltration facility as the only destination for stormwater.
3) Adequate space is not available for infiltration facility design (see Surface Infiltration Facility design methodology in Section 2.2.2). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on-site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
6) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration is not accepted as a stormwater destination.
7) Resident basements do not have adequate setbacks (see Surface Infiltration Facility design methodology in Section 2.2.2). A minimum setback of 10 feet is required on private property, as approved by BDS.
8) For half-street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.



City of Portland Stormwater Destination Hierarchy (Continued)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see Section 1.4.4). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the MEP to meet applicable pollution reduction requirements (see Section 1.6.2 for MEP criteria).

Exceptions:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see Section 1.4.4 for list of criteria, or go to: http://www.deq.state.or.us/wq/groundwa/RAStormwaterRequirements.pdf).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration with UICs is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (See Section 1.6.2). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control is required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

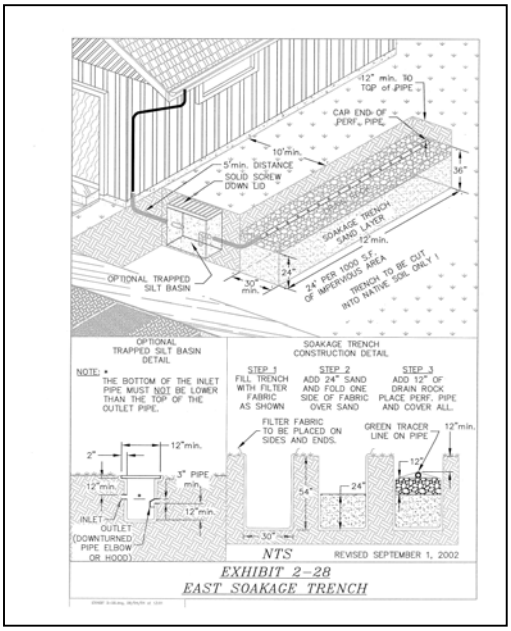
Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.

Under category #1, the Stormwater Destination/Disposal Hierarchy states that where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells. In this case, with B-type soils and mild slopes, on-site infiltration is most likely feasible. The Environmental Soils section of the Bureau of Development Services (BDS) may be contacted to confirm the viability of infiltration on private property at 503-823-7790. In addition to drywells and soakage trenches, other options include surface infiltration facilities such as vegetated or grassy swales, infiltration planters, or vegetated infiltration basins. In addition to the options listed above, the driveway may use pervious pavement or be graded to sheet flow into adjacent lawn areas.

Step 2: Design drywells, soakage trenches, or surface infiltration facilities in accordance with **Chapter 2.0**: **Stormwater Management Facility Design**.

Soakage Trenches: If soakage trenches are used to infiltrate stormwater from the rooftop areas, **Exhibit 2-28**: **East Soakage Trench** is used. In accordance with this exhibit, 24 feet of soakage trench is required per 1,000 square feet of rooftop area. In this example, the length of soakage trench needed to dispose of stormwater from the roof area will be: 1,600 x (24/1,000) = 38.4 feet in length. If used for the roof *and* the driveway, the soakage trench will need to be: 2,000 x (24/1,000) = 48 feet. The design criteria presented in the soakage trench section of Chapter 2.0 must be used to design the trench, and to locate the facility on-site. Setbacks from building structure must be considered. The detailed design and location must be shown on the permit drawings.



Drywells: If drywells are used to infiltrate stormwater from the rooftop areas, **Exhibit 2-34**: **Drywell Sizing** is used. In accordance with this exhibit, a 10-foot deep, 28-inch diameter drywell or a 5-foot deep, 48-inch diameter drywell is required to infiltrate stormwater from impervious areas between 1,000 and 2,000 square feet in size. The design criteria presented in the private drywell section of Chapter 2.0 must be used to design the drywell, and to locate the facility on-site. Setbacks from building structure must be considered (see **Exhibit 2-36**). The detailed design and location must be shown on the permit drawings.

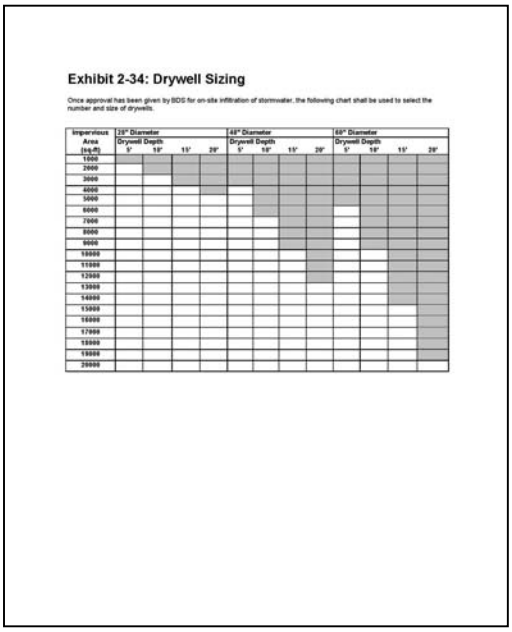


Exhibit 2-34: Drywell Sizing

Once approval has been given by BDS for on-site infiltration of stormwater, the following chart shall be used to select the number and size of drywells.

Impervious Area (sq-ft)	25" Diameter Drywell Depth				48" Diameter Drywell Depth				60" Diameter Drywell Depth			
	5'	10'	15'	20'	5'	10'	15'	20'	5'	10'	15'	20'
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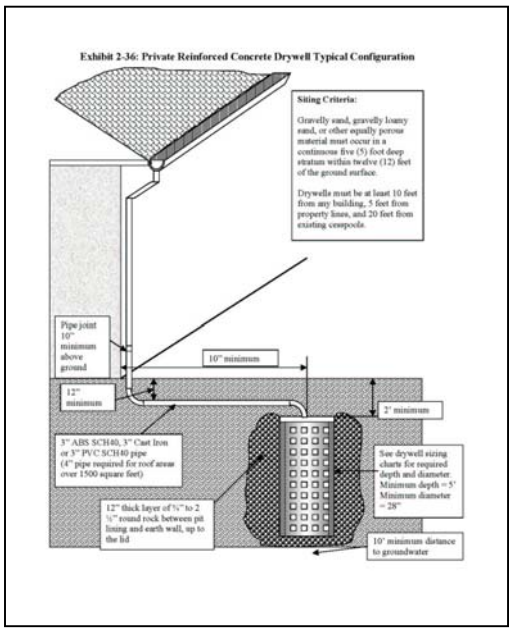
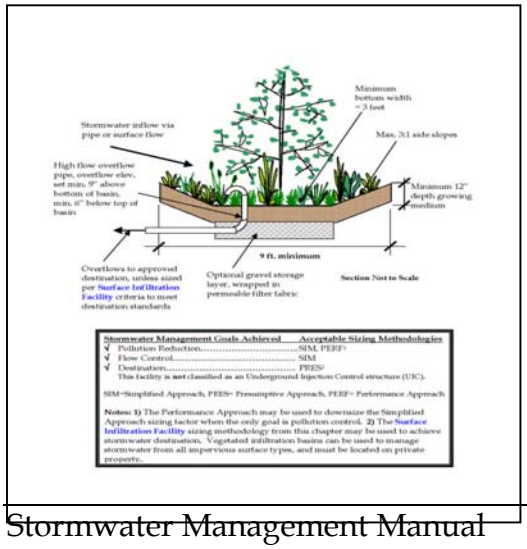
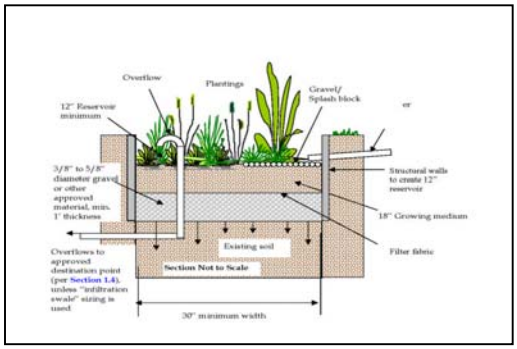


Surface Infiltration Facilities: If surface infiltration facilities are used to infiltrate stormwater from the rooftop areas, **Section 2.2.2** is used. In accordance with the surface infiltration design approach from this section, enough storage volume must be provided in the facility to contain the runoff from a 10-year, 24-hour storm. For the rooftop, this volume is: 0.28 feet x 1,600 square feet = 448 cubic feet. For the rooftop and the driveway, this volume is approximated by the following equation: 0.28 feet x 2,000 square feet = 560 cubic feet. The design criteria presented in each applicable section of Chapter 2.0 must be used to design the facility, and to locate the facility on-site. Setbacks from building structure must be considered. The detailed design and location must be shown on the permit drawings.





Step 3: Use **Chapter 3.0**: **Operations & Maintenance** to compile an operations and maintenance plan for the drywells, soakage trenches, or other stormwater management facilities used on the site. **Form O&M** must be filled out and recorded with the applicable county prior to submission to the city with the permit drawings.



FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)

REQUIRED IN ACCORDANCE WITH CITY CODE CHAPTER 17.38



Soakage Trenches

Operations & Maintenance Plan

Soakage Trenches consist of drain rock and sand, and receive stormwater from roof downspouts and/or area drains. There are various components within the system - piping, silt basin and the trench itself. The **Conveyance Piping** consists of an inlet pipe (downspout or area drain), an outlet pipe located between the silt basin and the soakage trench, and a perforated pipe, located on top of the aggregate bed of the soakage trench. The **Silt Basin** is a structure receiving runoff from an inlet pipe and conveying it to the soakage trench. The silt basin serves as the pre-treatment system for the soakage trench, removing sediments and other debris that can impact its proper functioning. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first two years from the date of installation, then two times per year afterwards, or within 48 hours after each major storm. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated.

Soakage trench infiltration: If water is noticed on top of the trench within 48 hours of a major storm, the soakage trench may be clogged.

- Check for debris/sediment accumulation, rake and remove and evaluate upland causes (erosion, surface or roof debris, etc.
- Assess the condition of the aggregate and the filter fabric in the trench. If there is sediment in the aggregate, excavate and replace.
- If there is a tear in the filter fabric, repair or replace.

Conveyance Piping: If water ponds over the trench for more than 48 hours after a major storm and no other cause if identified, it may be necessary to remove the filter fabric to determine if the perforated pipe is clogged with sediment or debris.

- Any debris or algae growth located on top of the soakage trench should be removed and disposed of properly.
- If the piping has settled more than 1-inch, add fill material. If there are cracks or releases, replace or repair the pipe. If there are signs of erosion around the pipe, this may be an indication of water seeping due to a crack or break.

Silt Basin: If water remains in the soakage trench for 36-48 hours after storm, check for sediment accumulation in the silt basin.

- If less than 50% capacity remains in the basin or 6" of sediment has accumulated, remove and dispose the sediment.

Spill Prevention: Virtually all sites, including residential and commercial, present dangers from spills. All homes contain a wide variety of toxic materials including gasoline for lawn mowers, antifreeze for cars, nail polish remover, pesticides, and cleaning aids that can adversely affect groundwater if spilled. It is important to exercise caution when handling substances that can contaminate stormwater.

- Activities that pose the chance of hazardous material spills shall not take place near soakage trenches.

A **Shut-Off Valve or Flow-Blocking Mechanism** may have been required with the construction of the soakage trench to temporarily prevent stormwater from flowing into it, in the event of an accidental toxic material spill. This may also involve mats kept on-site that can be used to cover inlet drains in parking lots. The shut-off valve shall remain in good working order, or if mats or other flow-blocking mechanisms are used, they shall be kept in stock on-site.

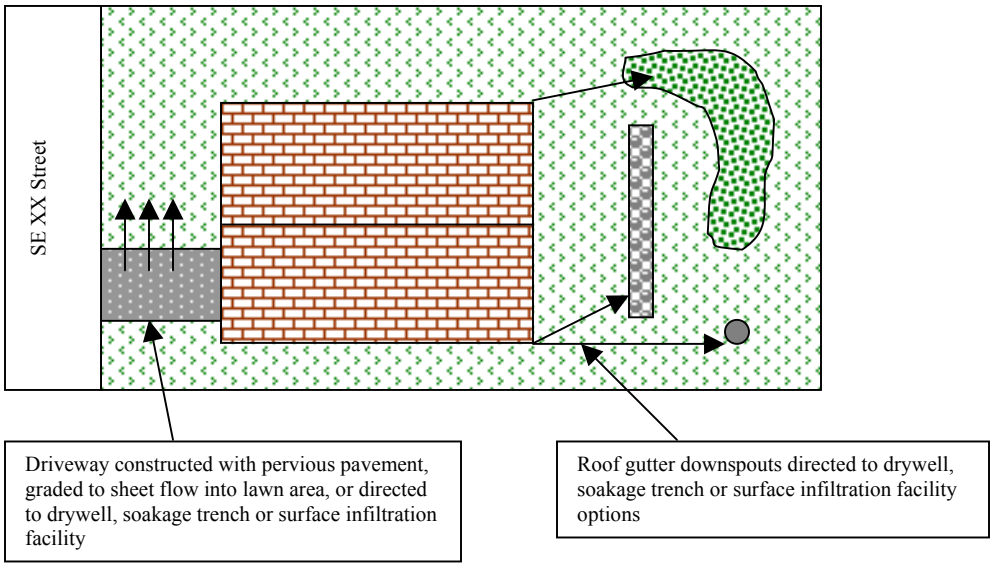
Training and/or written guidance information for operating and maintaining soakage trenches shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the soakage trench is required for efficient maintenance. Egress and ingress routes will be maintained to design standards at inspections.

Insects & Rodents shall not be harbored in the soakage trench. Pest control measures shall be taken when insects/rodents are found to be present.

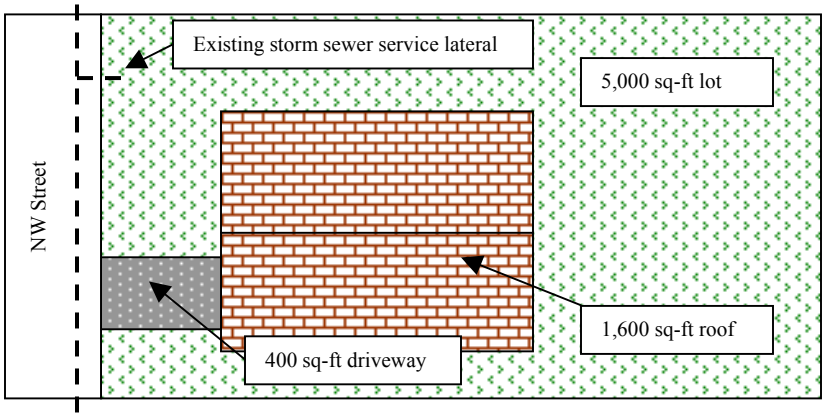
- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the soakage trench shall be filled.

Step 4: Submit the house plans to the city for permitting. The drywell, soakage trench, or other stormwater management facilities must be shown on the drawings, along with applicable details, and the recorded O&M plan must be attached. **END**.



CASE EXAMPLE #2: Single-Family House (Northwest Portland)

A single-family house with a footprint of 1,600 square feet and a driveway with a footprint of 400 square feet will be constructed on a 5,000 square-foot lot in Northwest Portland. Preliminary geotechnical research indicates that the soil in the area belongs to hydrologic soil group C (from the USDA/NRCS Soil Survey of Multnomah County, Oregon), and the lot has slopes that range from 10 to 20 percent. There is an existing public storm sewer pipe in the frontage street with an existing service lateral to the property.



Step 1: Determine the stormwater disposal point for the site. Use **Exhibit 1-1**: **Stormwater Destination/Disposal Hierarchy** (in Chapter 1.0)

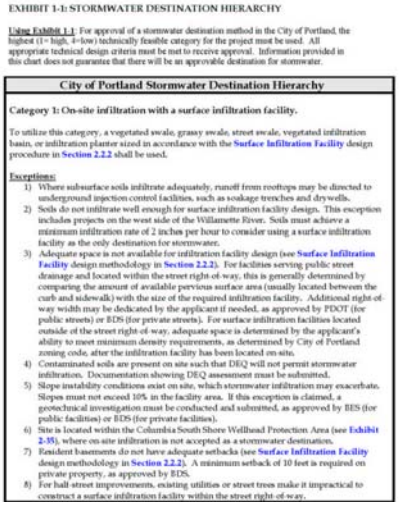


EXHIBIT 1-1: STORMWATER DESTINATION HIERARCHY

Using Exhibit 1-1: For approval of a stormwater destination method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

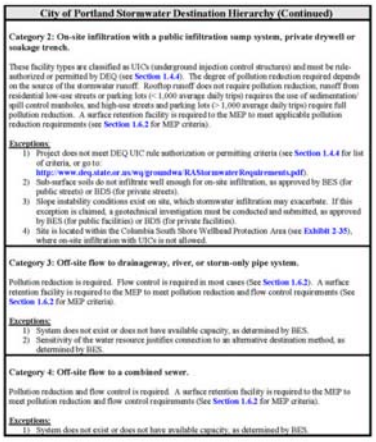
City of Portland Stormwater Destination Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

To utilize this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter sized in accordance with the Surface Infiltration Facility design procedure in Section 2.2.2 shall be used.

Exceptions:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour to consider using a surface infiltration facility as the only destination for stormwater.
3) Adequate space is not available for infiltration facility design (see Surface Infiltration Facility design methodology in Section 2.2.2). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on-site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
6) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration is not accepted as a stormwater destination.
7) Resident basements do not have adequate setbacks (see Surface Infiltration Facility design methodology in Section 2.2.2). A minimum setback of 10 feet is required on private property, as approved by BDS.
8) For half street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.



City of Portland Stormwater Destination Hierarchy (Continued)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see Section 1.4.4). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the MEP to meet applicable pollution reduction requirements (see Section 1.6.2 for MEP criteria).

Exceptions:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see Section 1.4.4 for list of criteria, or go to: http://www.deq.state.or.us/wq/groundwa/RAStormwaterRequirements.pdf).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration with UICs is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (See Section 1.6.2). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control is required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

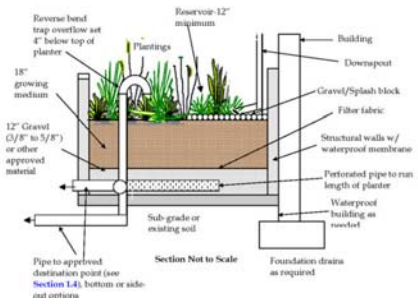
1) System does not exist or does not have available capacity, as determined by BES.

Category #1 (surface infiltration facilities) and category #2 (on-site infiltration with drywell or soakage trench) depend on project site soils that infiltrate relatively well (2 inches per hour minimum). In this example, with C-type soils and moderate slopes, on-site infiltration is not likely feasible. The Environmental Soils section of the Bureau of Development Services (BDS) may be contacted to confirm the viability of infiltration on private property at 503-823-7790. Category #3 (off-site flow to drainageway, river, or storm-only pipe system) depends on the availability of such resources. Portlandmaps.com or other city maps available at the Development Services Center (1900 SW 4th Avenue) can be used to identify off-site stormwater conveyance systems. In this case, there is an existing storm sewer service lateral that the property will use. Pollution reduction and flow control are required prior to discharge into the storm sewer.

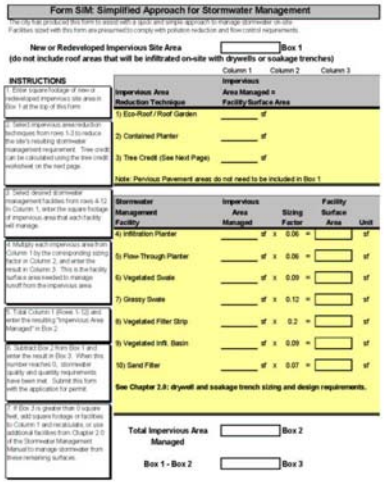
Step 2: Choose pollution reduction and flow control facilities from **Chapter 2.0**: **Stormwater Management Facility Design**. There are many facility types to choose from that will achieve both pollution reduction and flow control. **Exhibit 2-1** can be used to help choose a facility type that can use the simplified approach for sizing. In this example, flow-through planters will be used to manage stormwater from the rooftop, and the overflow and underdrain pipes from the planters will be connected to the storm sewer service lateral. The driveway may use pervious pavement; may be graded to sheet flow into adjacent lawn areas if sufficiently sized in accordance with vegetated filter design criteria (at least 1 square foot of lawn area per 5 square feet of driveway area, lawn area must be at least 10 feet by 10 feet); or may be directed to the flow-through planters.

Exhibit 2-1: Stormwater Management Facility Application Table

Stormwater Management Facility Type	Credit Given with Associated Design Approach		
	Pollution Reduction	Flow Control	Destination
Eco-roof & roof garden	Simplified[1]	Simplified	NA
Pervious pavement	Simplified[1]	Simplified	Performance
Contained planter	Simplified[1]	Simplified	NA
Tree credit	Simplified[1]	Simplified	NA
Infiltration planter	Simplified[1]	Simplified	Presumptive[2]
Flow-through planter	Simplified[1]	Simplified	NA
Vegetated swale	Simplified[1]	Simplified	Presumptive[2]
Grassy swale < 15,000 sq.ft impervious area	Simplified[1]	Simplified	Presumptive[2]
Grassy swale > 15,000 sq.ft impervious area	Presumptive	NA	Presumptive[2]
Street swales	Simplified[1]	Simplified	Presumptive[2]
Vegetated filter strip	Simplified[1]	Simplified	Presumptive[2]
Vegetated infil. basin	Simplified[1]	Simplified	Presumptive[2]
Sand filter	Simplified[1]	Simplified	Presumptive[2]
Wet pond	Presumptive	NA	NA
Extended wet det. pond	Presumptive	Presumptive	NA
Dry detention pond	Presumptive[3]	Presumptive	NA
Treatment wetland	Presumptive	Presumptive	NA
Manufactured treatment technology	Performance	NA	NA
Structural det. facility	NA	Presumptive	NA
Oil/water separator	Presumptive[4]	NA	NA
Rainwater harvesting	Performance	Performance	NA
Private soakage trench	NA	Presumptive	Presumptive
Public infil. sump	NA	Presumptive	Presumptive
Private drywell	NA	Presumptive	Presumptive



Step 3: Design pollution reduction and flow control facilities from **Chapter 2.0**: **Stormwater Management Facility Design**. Form SIM will be used to size the flow-through planters to meet pollution reduction and flow control requirements. From this form, the sizing factor for flow-through planters is 0.06. The required square-footage of planters is the square footage of the roof multiplied by the sizing factor: 1,600 square feet x 0.06 = 96 square feet. The planters can be split up and located at each roof downspout, or the downspouts can be plumbed to one large planter, as long as 96 square feet of flow-through planter is provided and all the planters are connected to the storm sewer service lateral.



Form SIM: Simplified Approach for Stormwater Management

New or Redeveloped Impervious Site Area (do not include roof areas that will be infiltrated on-site with drywells or soakage trenches) — Box 1

INSTRUCTIONS

Impervious Area Reduction Technique	Impervious Area Managed = Facility Surface Area
1) Eco-Roof / Roof Garden	sf
2) Contained Planter	sf
3) Tree Credit (See Next Page)	sf

Note: Pervious Pavement areas do not need to be included in Box 1

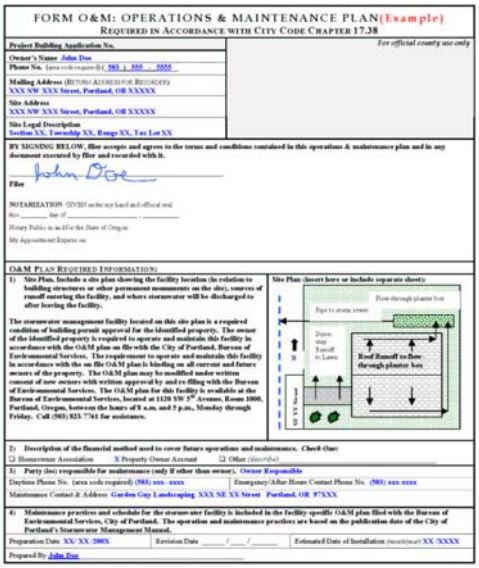
Stormwater Management Facility	Impervious Area Managed		Sizing Factor		Facility Surface Area	Unit
4) Infiltration Planter	sf	x	0.06	=		sf
5) Flow-Through Planter	sf	x	0.06	=		sf
6) Vegetated Swale	sf	x	0.09	=		sf
7) Grassy Swale	sf	x	0.12	=		sf
8) Vegetated Filter Strip	sf	x	0.2	=		sf
9) Vegetated Infil. Basin	sf	x	0.09	=		sf
10) Sand Filter	sf	x	0.07	=		sf

See Chapter 2.0: drywell and soakage trench sizing and design requirements.

Total Impervious Area Managed — Box 2

Box 1 - Box 2 — Box 3

Step 4: Use **Chapter 3.0**: **Operations & Maintenance** to compile an operations and maintenance plan for the flow-through planters used on the site. Form O&M must be filled out and recorded with the applicable county prior to submission to the city with the permit drawings.



FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)
REQUIRED IN ACCORDANCE WITH CITY CODE CHAPTER 17.38

Project Building Application No. — For official county use only

Owner's Name: John Doe
Phone No. (area code required): (503) 555-5555
Mailing Address (RETURN ADDRESS FOR RECORDS): XXX NW XXX Street, Portland, OR XXXXX
Site Address: XXX NW XXX Street, Portland, OR XXXXX
Site Legal Description: Section XX, Township XX, Range XX, Tax Lot XX

BY SIGNING BELOW, filer accepts and agrees to the terms and conditions contained in this operations & maintenance plan and in any document executed by filer and recorded with it.

John Doe
Filer

NOTARIZATION: GIVEN under my hand and official seal this _____ day of _____
Notary Public in and for the State of Oregon
My Appointment Expires on:

O&M PLAN REQUIRED INFORMATION:

1) Site Plan. Include a site plan showing the facility location (in relation to building structures or other permanent monuments on the site), sources of runoff entering the facility, and where stormwater will be discharged to after leaving the facility.

The stormwater management facility located on this site plan is a required condition of building permit approval for the identified property. The owner of the identified property is required to operate and maintain this facility in accordance with the O&M plan on file with the City of Portland, Bureau of Environmental Services. The requirement to operate and maintain this facility in accordance with the on file O&M plan is binding on all current and future owners of the property. The O&M plan may be modified under written consent of new owners with written approval by and re-filing with the Bureau of Environmental Services. The O&M plan for this facility is available at the Bureau of Environmental Services, located at 1120 SW 5th Avenue, Room 1000, Portland, Oregon, between the hours of 8 a.m. and 5 p.m., Monday through Friday. Call (503) 823-7761 for assistance.

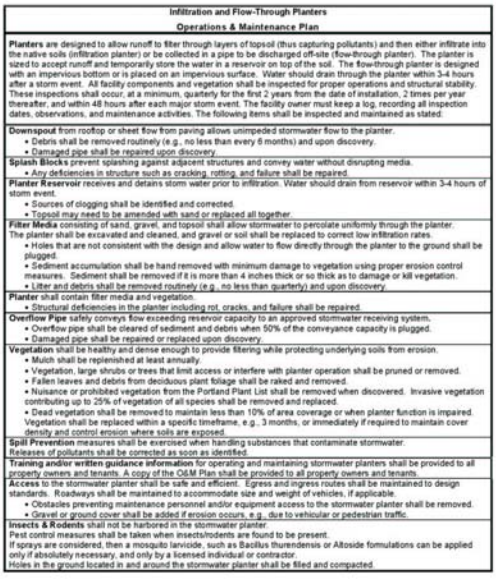
Site Plan (insert here or include separate sheet):

2) Description of the financial method used to cover future operations and maintenance. Check One:
☐ Homeowner Association X Property Owner Account ☐ Other (describe)

3) Party (ies) responsible for maintenance (only if other than owner): Owner Responsible
Daytime Phone No. (area code required): (503) xxx-xxxx — Emergency/After-Hours Contact Phone No. (503) xxx-xxxx
Maintenance Contact & Address: Garden Guy Landscaping XXX NE XX Street Portland, OR 97XXX

4) Maintenance practices and schedule for the stormwater facility is included in the facility-specific O&M plan filed with the Bureau of Environmental Services, City of Portland. The operation and maintenance practices are based on the publication date of the City of Portland's Stormwater Management Manual.

Preparation Date: XX/XX/200X — Revision Date: ___/___/___ — Estimated Date of Installation (month/year): XX/XXXX
Prepared By: John Doe



Infiltration and Flow-Through Planters
Operations & Maintenance Plan

Planters are designed to allow runoff to filter through layers of topsoil (thus capturing pollutants) and then either infiltrate into the native soils (infiltration planter) or be collected in a pipe to be discharged off-site (flow-through planter). The planter is sized to accept runoff and temporarily store the water in a reservoir on top of the soil. The flow-through planter is designed with an impervious bottom or is placed on an impervious surface. Water should drain through the planter within 3-4 hours after a storm event. All facility components and vegetation shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation, 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Downspout from rooftop or sheet flow from paving allows unimpeded stormwater flow to the planter.
- Debris shall be removed routinely (e.g., no less than every 6 months) and upon discovery.
- Damaged pipe shall be repaired upon discovery.

Splash Blocks prevent splashing against adjacent structures and convey water without disrupting media.
- Any deficiencies in structure such as cracking, rotting, and failure shall be repaired.

Planter Reservoir receives and detains storm water prior to infiltration. Water should drain from reservoir within 3-4 hours of storm event.
- Sources of clogging shall be identified and corrected.
- Topsoil may need to be amended with sand or replaced all together.

Filter Media consisting of sand, gravel, and topsoil shall allow stormwater to percolate uniformly through the planter. The planter shall be excavated and cleaned, and gravel or soil shall be replaced to correct low infiltration rates.
- Holes that are not consistent with the design and allow water to flow directly through the planter to the ground shall be plugged.
- Sediment accumulation shall be hand removed with minimum damage to vegetation using proper erosion control measures. Sediment shall be removed if it is more than 4 inches thick or so thick as to damage or kill vegetation.
- Litter and debris shall be removed routinely (e.g., no less than quarterly) and upon discovery.

Planter shall contain filter media and vegetation.
- Structural deficiencies in the planter including rot, cracks, and failure shall be repaired.

Overflow Pipe safely conveys flow exceeding reservoir capacity to an approved stormwater receiving system.
- Overflow pipe shall be cleared of sediment and debris when 50% of the conveyance capacity is plugged.
- Damaged pipe shall be repaired or replaced upon discovery.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion.
- Mulch shall be replenished at least annually.
- Vegetation, large shrubs or trees that limit access or interfere with planter operation shall be pruned or removed.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance or prohibited vegetation from the Portland Plant List shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed and replaced.
- Dead vegetation shall be removed to maintain less than 10% of area coverage or when planter function is impaired. Vegetation shall be replaced within a specific timeframe, e.g., 3 months, or immediately if required to maintain cover density and control erosion where soils are exposed.

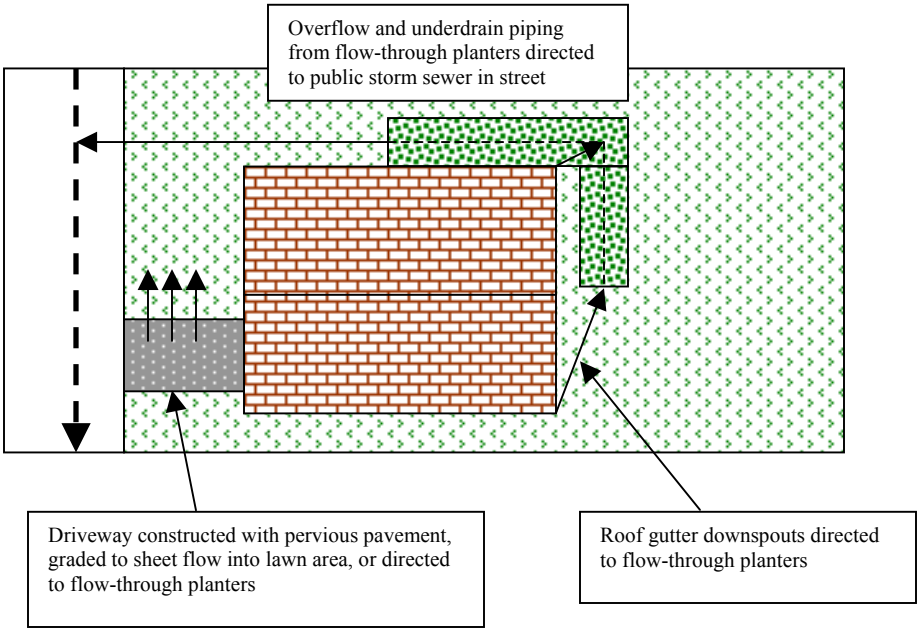
Spill Prevention measures shall be exercised when handling substances that contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining stormwater planters shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the stormwater planter shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.
- Obstacles preventing maintenance personnel and/or equipment access to the stormwater planter shall be removed.
- Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored in the stormwater planter.
Pest control measures shall be taken when insects/rodents are found to be present.
If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
Holes in the ground located in and around the stormwater planter shall be filled and compacted.

Step 5: Submit the house plans to the city for permitting. The stormwater destination (pipe connection to the storm sewer service lateral) must be clearly identified on the drawings, along with flow-through planter locations and applicable details, and the completed Form SIM and recorded O&M plan must be attached. **END**.



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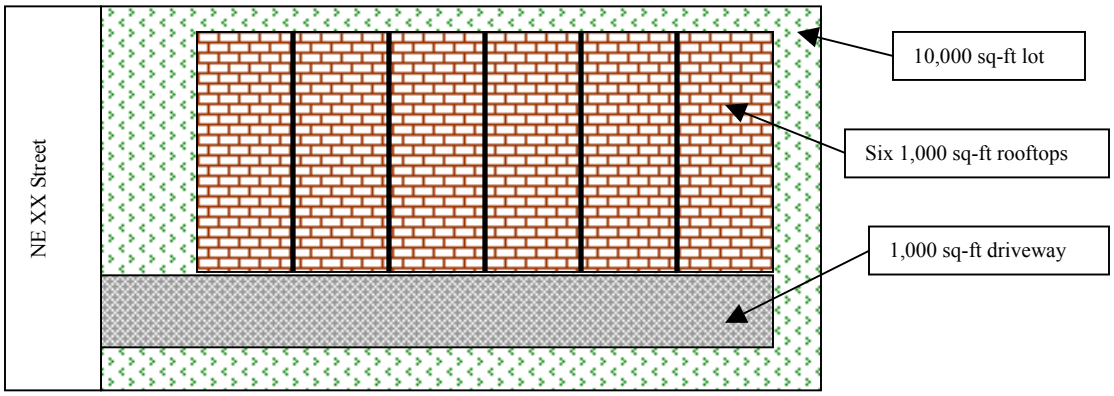
CASE EXAMPLE #3: Rowhouse Development w/ Private Driveway (Northeast Portland)

A rowhouse development with six 1,000 square-foot rooftops and a driveway with a footprint of 1,000 square feet will be constructed on a 10,000 square-foot lot in Northeast Portland. Preliminary geotechnical research indicates that the soil in the area belongs to hydrologic soil group B (from the USDA/ NRCS Soil Survey of Multnomah County, Oregon), and the depth to groundwater is approximately 130 feet. The lot has slopes less than 2 percent.



Step 1: Determine the stormwater disposal point for the site. Use **Exhibit 1-1**: **Stormwater Destination/Disposal Hierarchy**.

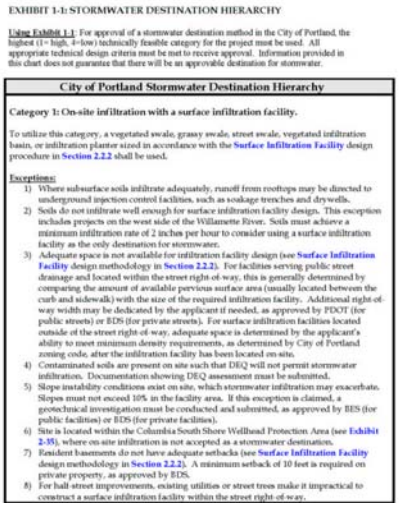


EXHIBIT 1-1: STORMWATER DESTINATION HIERARCHY

Using Exhibit 1-1: For approval of a stormwater destination method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

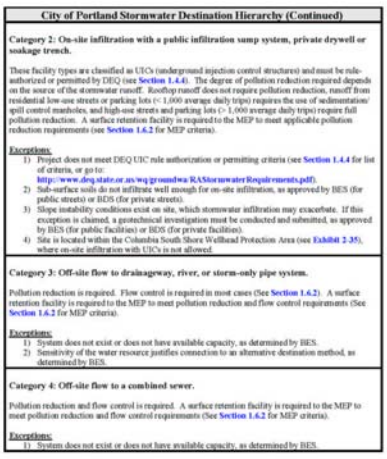
City of Portland Stormwater Destination Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

To utilize this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter sized in accordance with the Surface Infiltration Facility design procedure in Section 2.2.2 shall be used.

Exceptions:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour to consider using a surface infiltration facility as the only destination for stormwater.
3) Adequate space is not available for infiltration facility design (see Surface Infiltration Facility design methodology in Section 2.2.2). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on-site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
6) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration is not accepted as a stormwater destination.
7) Resident basements do not have adequate setbacks (see Surface Infiltration Facility design methodology in Section 2.2.2). A minimum setback of 10 feet is required on private property, as approved by BDS.
8) For half-street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.



City of Portland Stormwater Destination Hierarchy (Continued)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see Section 1.4.4). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/ spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the MEP to meet applicable pollution reduction requirements (see Section 1.6.2 for MEP criteria).

Exceptions:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see Section 1.4.4 for list of criteria, or go to: http://www.deq.state.or.us/wq/groundwa/RAStormwaterRequirements.pdf).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration with UICs is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (See Section 1.6.2). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control is required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

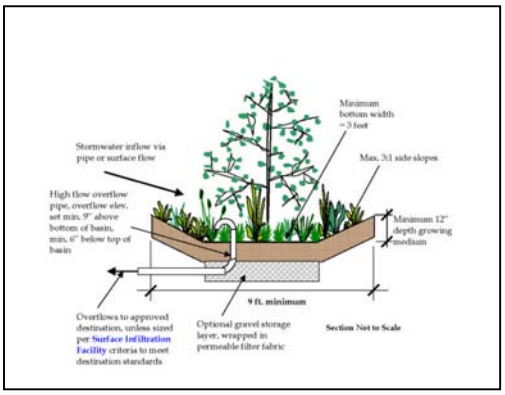
Exceptions:

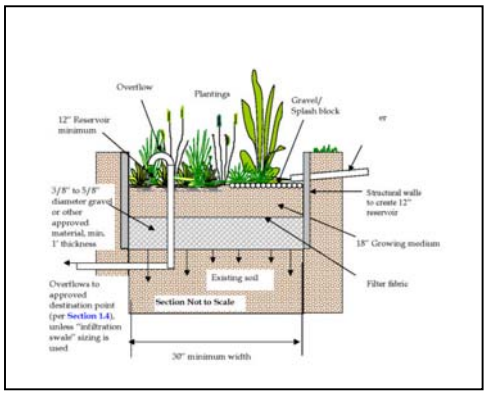
1) System does not exist or does not have available capacity, as determined by BES.

Under category #1, the Stormwater Destination Hierarchy states that where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells. In this case, with B-type soils and mild slopes, on-site infiltration is most likely feasible. The Environmental Soils section of the Bureau of Development Services (BDS) may be contacted to confirm the viability of infiltration on private property at 503-823-7790. In addition to drywells and soakage trenches, other options generally include surface infiltration facilities such as vegetated or grassy swales, infiltration planters, or vegetated infiltration basins.

In accordance with the surface infiltration design approach from **Section 2.2.2**, enough storage volume must be provided in the surface infiltration facility to contain the runoff from a 10-year, 24-hour storm. For the rooftop areas, this volume is: 0.28 feet x 6,000 square feet = 1,680 cubic feet. In this example, there is not adequate space on-site to construct surface infiltration facilities for the rooftop areas.

Under category #1, the 1,000-square-foot driveway must be evaluated for surface infiltration. In accordance with the surface infiltration design approach in **Section 2.2.2**, enough storage volume must be provided in the surface infiltration facility to contain the runoff from a 10-year, 24-hour storm. For the driveway, this volume is: 0.28 feet x 1,000 square feet = 280 cubic feet. The design criteria presented in each applicable section of Chapter 2.0 must be used to design the surface infiltration facility itself, and locate the facility on-site. Setbacks from building structure must be considered. The detailed design and location must be shown on the permit drawings.



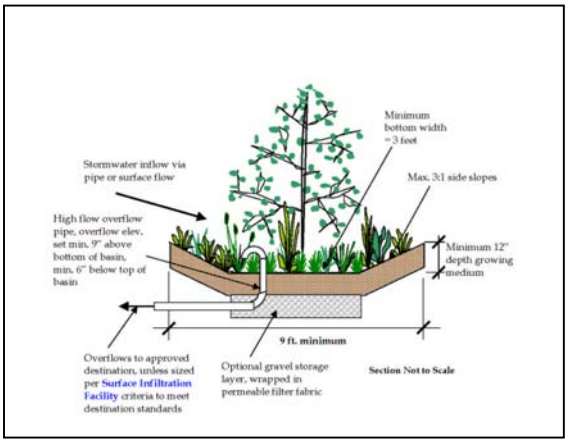


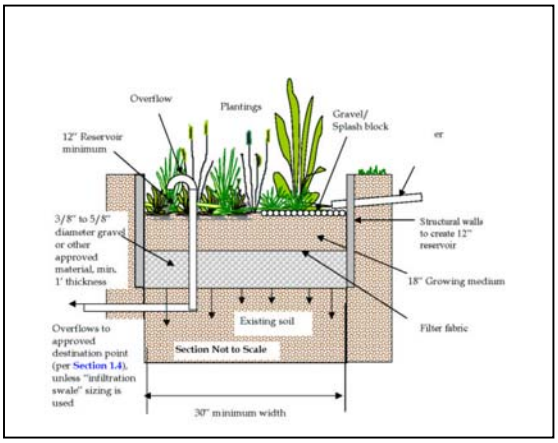
If there is not adequate space on-site to use a surface infiltration facility to infiltrate stormwater from the driveway, under category #2 the runoff from the driveway may be infiltrated on-site with a private drywell or soakage trench. In

that case, a spill control manhole or other pollution reduction facility is also required. Drywells or soakage trenches must be registered with DEQ per **Section 1.4.4**.

Step 2: Design the drywells, soakage trenches, surface infiltration facilities, and/or pollution reduction facilities in accordance with **Chapter 2.0**: **Stormwater Management Facility Design**.

If surface infiltration facilities such as swales, infiltration planters, or vegetated infiltration basins are used to infiltrate stormwater from the driveway area, **Section 2.2.2** is used. As discussed under step 1, 280 cubic feet of storage volume must be provided. The design criteria presented in each applicable section of Chapter 2.0 must be used to design the facility, and to locate the facility on-site. Setbacks from building structure must be considered. The detailed design and location must be shown on the permit drawings.





If there is not sufficient space to locate a surface infiltration facility on-site for the driveway runoff, a drywell or soakage trench may be used. In that case, a pollution reduction facility sized in accordance with the simplified approach from Chapter 2.0 must be used to meet pollution reduction requirements. **Exhibit 2-1** can be used to help select a facility type that can use the simplified approach for sizing. If the driveway will generate fewer than 1,000 average daily trips, a spill control manhole from Chapter 2.0 may be used instead of a pollution reduction facility to meet the pollution reduction requirements.

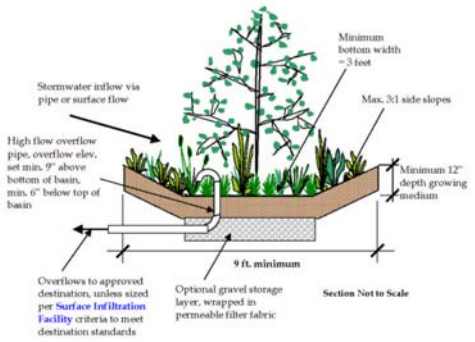
The following discussion assumes there is sufficient space for an on-site surface infiltration facility to manage stormwater from the driveway. A vegetated swale will be used, and the overflow from the swale will be connected to an on-site drywell or soakage trench. Drywells and soakage trenches must be registered

with the Oregon Department of Environmental Quality (DEQ), in accordance with **Section 1.4.4**.

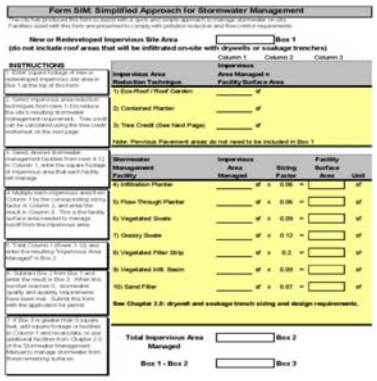


Exhibit 2-1: Stormwater Management Facility Application Table

Stormwater Management Facility Type	Credit Given with Associated Design Approach		
	Pollution Reduction	Flow Control	Destination
Eco-roof & roof garden	Simplified[1]	Simplified	NA
Pervious pavement	Simplified[1]	Simplified	Performance
Contained planter	Simplified[1]	Simplified	NA
Tree credit	Simplified[1]	Simplified	NA
Infiltration planter	Simplified[1]	Simplified	Presumptive[2]
Flow-through planter	Simplified[1]	Simplified	NA
Vegetated swale	Simplified[1]	Simplified	Presumptive[2]
Grassy swale < 15,000 sq-ft impervious area	Simplified[1]	Simplified	Presumptive[2]
Grassy swale > 15,000 sq-ft impervious area	Presumptive	NA	Presumptive[2]
Street swales	Simplified[1]	Simplified	Presumptive[2]
Vegetated filter strip	Simplified[1]	Simplified	Presumptive[2]
Vegetated infil. basin	Simplified[1]	Simplified	Presumptive[2]
Sand filter	Simplified[1]	Simplified	Presumptive[2]
Wet pond	Presumptive	NA	NA
Extended wet det. pond	Presumptive	Presumptive	NA
Dry detention pond	Presumptive[3]	Presumptive	NA
Treatment wetland	Presumptive	Presumptive	NA
Manufactured treatment technology	Performance	NA	NA
Structural det. facility	NA	Presumptive	NA
Oil/water separator	Presumptive[4]	NA	NA
Rainwater harvesting	Performance	Performance	NA
Private soakage trench	NA	Presumptive	Presumptive
Public infil. sump	NA	Presumptive	Presumptive
Private drywell	NA	Presumptive	Presumptive



Form SIM will be used to size the vegetated swale to meet pollution reduction requirements. From this form, the sizing factor for vegetated swales is 0.09. The required square-footage of swale is: 1,000 square feet x 0.09 = 90 square feet. The swale will be 5 feet wide by 18 feet long, and will include an overflow catch basin plumbed to the site's drywell or soakage trench.



If a drywell is used to infiltrate stormwater from the rooftop or driveway areas, **Exhibit 2-34**: **Drywell Sizing** is used. In accordance with that exhibit, a 10-foot deep, 48-inch diameter drywell is required to infiltrate stormwater from the 6,000 square-foot impervious rooftop area. If the drywell will be used to infiltrate stormwater from both the rooftop and driveway areas (7,000 square-feet of impervious area), a 15-foot deep, 48-inch diameter drywell is required. The design criteria presented in the private drywell section of Chapter 2.0 must be used to design the drywell, and to locate the facility on-site. Setbacks from building structure must be considered (see **Exhibit 2-36**). The detailed design and location must be shown on the permit drawings.

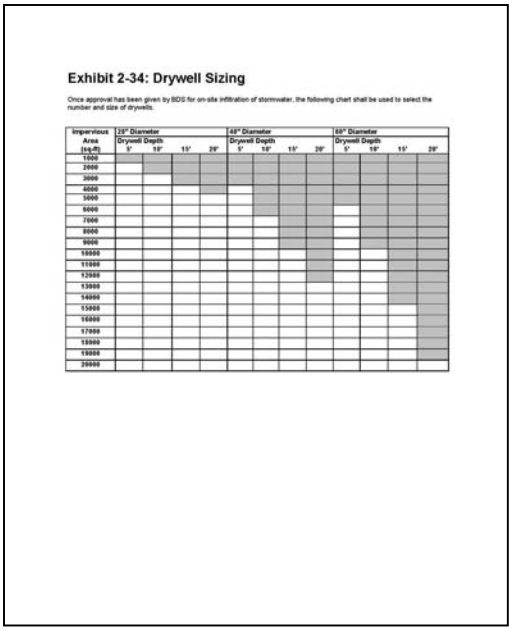


Exhibit 2-34: Drywell Sizing

Once approval has been given by BDS for on-site infiltration of stormwater, the following chart shall be used to select the number and size of drywells.

Impervious Area (sq.ft)	25" Diameter Drywell Depth				48" Diameter Drywell Depth				60" Diameter Drywell Depth			
	5'	10'	15'	20'	5'	10'	15'	20'	5'	10'	15'	20'
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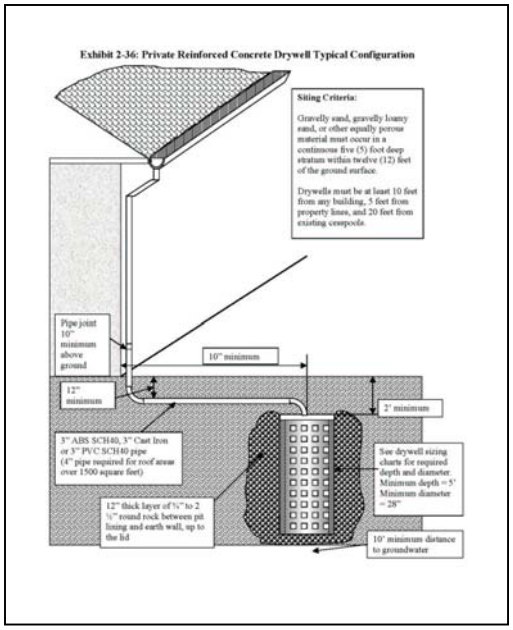
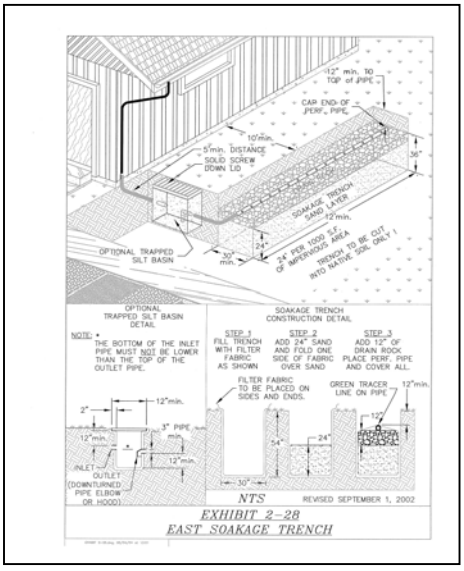


If a soakage trench is used to infiltrate stormwater from the rooftop or driveway areas, **Exhibit 2-28**: **East Soakage Trench** is used. In accordance with this exhibit, 24 feet of soakage trench is required per 1,000 square feet of rooftop area. In this example, the length of soakage trench to handle the roof runoff will be: 6,000 * (24/1,000) = 144 feet in length. If used for the roof *and* the driveway, the soakage trench will be: 7,000 * (24/1,000) = 168 feet. The design criteria presented in the soakage trench section of Chapter 2.0 must be used to design the trench, and to locate the facility on-site. Setbacks from building structure must be considered. The detailed design and location must be shown on the permit drawings.



Step 3: Use **Chapter 3.0**: **Operations & Maintenance** to compile an operations and maintenance plan for the drywell, soakage trench, or other stormwater management facilities used on the site. **Form O&M** must be filled out and recorded with the applicable county prior to submission to the city with the permit drawings.



FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)

REQUIRED IN ACCORDANCE WITH CITY CODE CHAPTER 17.38



Soakage Trenches

Operations & Maintenance Plan

Soakage Trenches consist of drain rock and sand, and receive stormwater from roof downspouts and/or area drains. There are various components within the system - piping, silt basin and the trench itself. The **Conveyance Piping** consists of an inlet pipe (downspout or area drain), an outlet pipe located between the silt basin and the soakage trench, and a perforated pipe, located on top of the aggregate bed of the soakage trench. The **Silt Basin** is a structure receiving runoff from an inlet pipe and conveying it to the soakage trench. The silt basin serves as the pre-treatment system for the soakage trench, removing sediments and other debris that can impact its proper functioning. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first two years from the date of installation, then two times per year afterwards, or within 48 hours after each major storm. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated.

Soakage trench infiltration: If water is noticed on top of the trench within 48 hours of a major storm, the soakage trench may be clogged.

- Check for debris/sediment accumulation, rake and remove and evaluate upland causes (erosion, surface or roof debris, etc.
- Assess the condition of the aggregate and the filter fabric in the trench. If there is sediment in the aggregate, excavate and replace.
- If there is a tear in the filter fabric, repair or replace.

Conveyance Piping: If water ponds over the trench for more than 48 hours after a major storm and no other cause if identified, it may be necessary to remove the filter fabric to determine if the perforated pipe is clogged with sediment or debris.

- Any debris or algae growth located on top of the soakage trench should be removed and disposed of properly.
- If the piping has settled more than 1-inch, add fill material. If there are cracks or releases, replace or repair the pipe. If there are signs of erosion around the pipe, this may be an indication of water seeping due to a crack or break.

Silt Basin: If water remains in the soakage trench for 36-48 hours after storm, check for sediment accumulation in the silt basin.

- If less than 50% capacity remains in the basin or 6" of sediment has accumulated, remove and dispose the sediment.

Spill Prevention: Virtually all sites, including residential and commercial, present dangers from spills. All homes contain a wide variety of toxic materials including gasoline for lawn mowers, antifreeze for cars, nail polish remover, pesticides, and cleaning aids that can adversely affect groundwater if spilled. It is important to exercise caution when handling substances that can contaminate stormwater.

- Activities that pose the chance of hazardous material spills shall not take place near soakage trenches.

A **Shut-Off Valve or Flow-Blocking Mechanism** may have been required with the construction of the soakage trench to temporarily prevent stormwater from flowing into it, in the event of an accidental toxic material spill. This may also involve mats kept on-site that can be used to cover inlet drains in parking lots. The shut-off valve shall remain in good working order, or if mats or other flow-blocking mechanisms are used, they shall be kept in stock on-site.

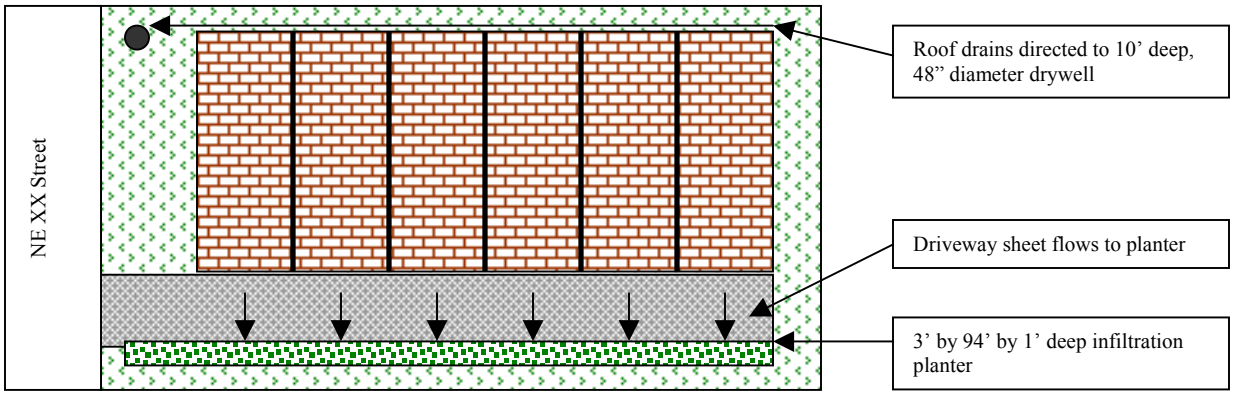
Training and/or written guidance information for operating and maintaining soakage trenches shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.
Access to the soakage trench is required for efficient maintenance. Egress and ingress routes will be maintained to design standards at inspections.

Insects & Rodents shall not be harbored in the soakage trench. Pest control measures shall be taken when insects/rodents are found to be present.

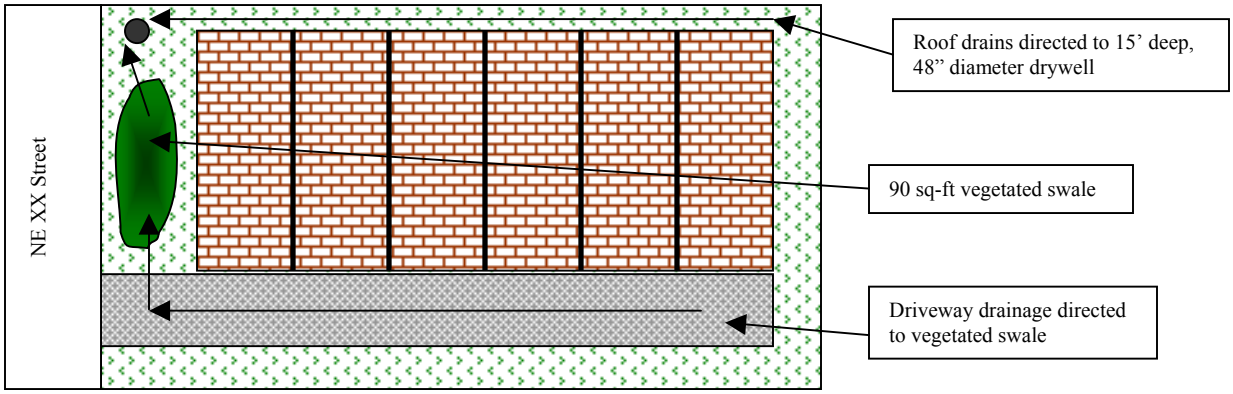
- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the soakage trench shall be filled.

Step 4: Submit the plans to the city for permitting. The drywell, soakage trenches, or other stormwater management facilities must be shown on the drawings, along with applicable details, and the recorded O&M plan must be attached. **END**.

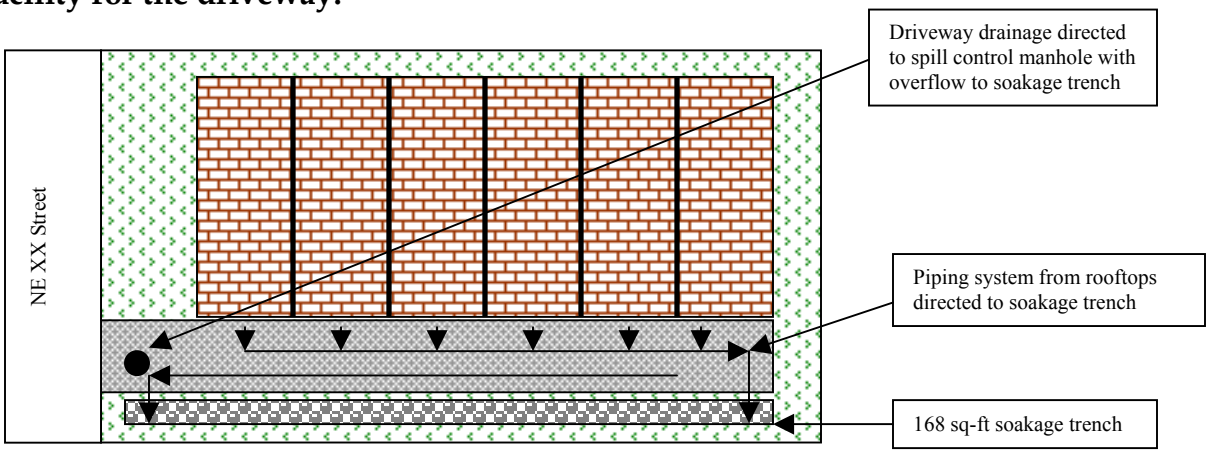
Drywell used for rooftops, surface infiltration used for driveway:



Drywell used for rooftops and driveway, with pollution reduction facility for driveway:

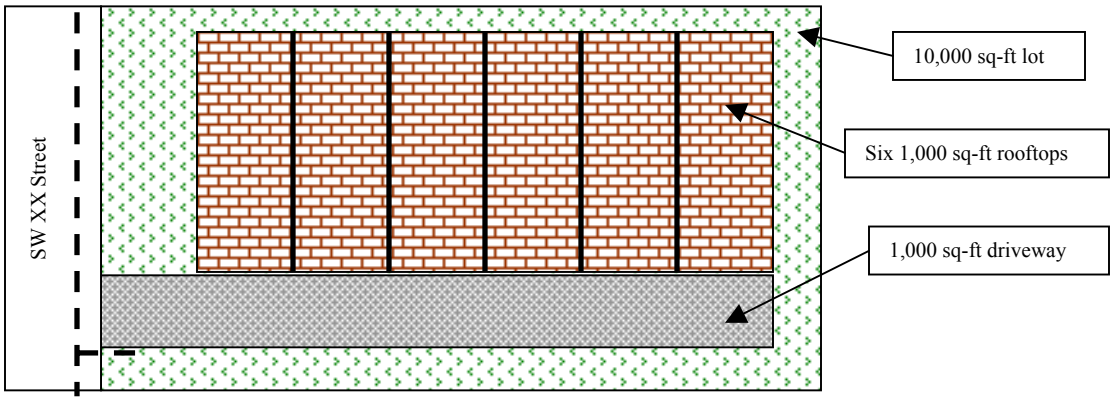


Soakage trenches used for rooftops and driveway, with a pollution reduction facility for the driveway:



CASE EXAMPLE #4: Rowhouse Development w/ Private Driveway (Southwest Portland)

A rowhouse development with six 1,000 square-foot rooftops and a driveway with a footprint of 1,000 square feet will be constructed on a 10,000 square-foot lot in Southwest Portland. Preliminary geotechnical research indicates that the soil in the area belongs to hydrologic soil group C (from the USDA/NRCS Soil Survey of Multnomah County, Oregon), and the lot has slopes that range from 5 to 15 percent. There is an existing public storm sewer pipe in the frontage street with an existing service lateral to the property.



Step 1: Determine the stormwater disposal point for the site. Use **Exhibit 1-1**: **Stormwater Destination/Disposal Hierarchy**.

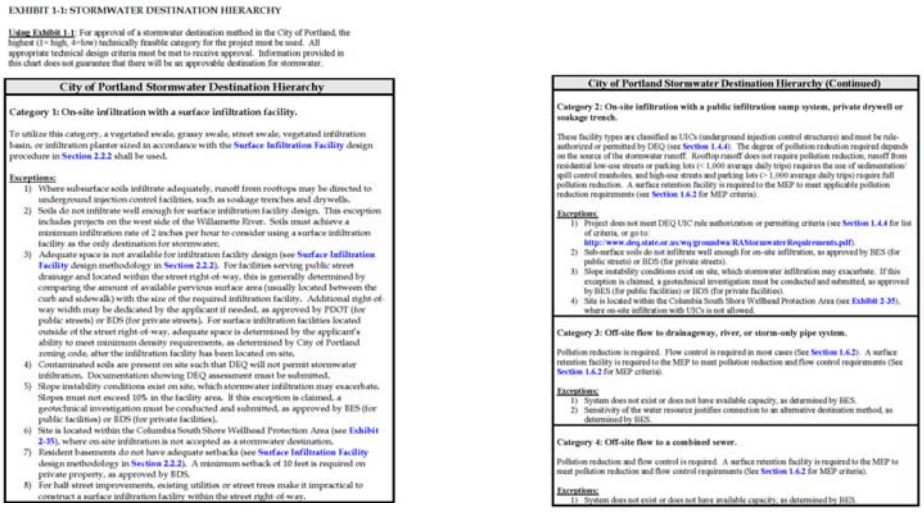


EXHIBIT 1-1: STORMWATER DESTINATION HIERARCHY

Using Exhibit 1.1: For approval of a stormwater destination method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

City of Portland Stormwater Destination Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

To utilize this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter sized in accordance with the Surface Infiltration Facility design procedure in Section 2.2.2 shall be used.

Exceptions:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour to consider using a surface infiltration facility as the only destination for stormwater.
3) Adequate space is not available for infiltration facility design (see Surface Infiltration Facility design methodology in Section 2.2.2). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on-site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
6) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration is not accepted as a stormwater destination.
7) Resident basements do not have adequate setbacks (see Surface Infiltration Facility design methodology in Section 2.2.2). A minimum setback of 10 feet is required on private property, as approved by BDS.
8) For half street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.

City of Portland Stormwater Destination Hierarchy (Continued)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see Section 1.4.4). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the MEP to meet applicable pollution reduction requirements (see Section 1.6.2 for MEP criteria).

Exceptions:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see Section 1.4.4 for list of criteria, or go to: http://www.deq.state.or.us/wq/groundwa/RAStormwaterRequirements.pdf).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration with UICs is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (See Section 1.6.2). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control is required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.

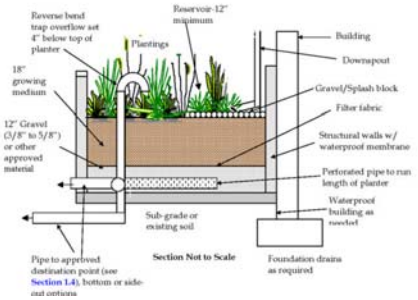
Category #1 (surface infiltration facilities) and category #2 (on-site infiltration with drywell or soakage trench) depend on project site soils that infiltrate relatively well (2 inches per hour minimum). In this example, with C-type soils

and moderate slopes, on-site infiltration is not likely feasible. The Environmental Soils section of the Bureau of Development Services (BDS) may be contacted to confirm the viability of infiltration on private property at 503-823-7790. Category #3 (off-site flow to drainageway, river, or storm-only pipe system) depends on the availability of such resources. **http://www.portlandmaps.com/** or other City maps available at the Development Services Center (1900 SW 4th Avenue) can be used to identify off-site stormwater conveyance systems. In this example, there is an existing storm sewer service lateral that the property will use. Pollution reduction and flow control are required prior to discharge into the storm sewer.

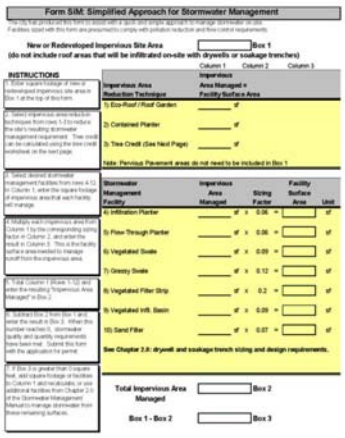
Step 2: Choose pollution reduction and flow control facilities from **Chapter 2.0**: **Stormwater Management Facility Design**. There are many facility types to choose from that will achieve both pollution reduction and flow control. Exhibit 2-1 can be used to help choose a facility type that can use the simplified approach for sizing. In this example, a flow-through planter will be used to manage stormwater from the rooftops, and the overflow and underdrain pipes from the planters will be connected to the storm sewer service lateral. The driveway may use pervious pavement with underdrains connected to the storm sewer, or the runoff may be directed to the flow-through planter.

Exhibit 2-1: Stormwater Management Facility Application Table

Stormwater Management Facility Type	Credit Given with Associated Design Approach		
	Pollution Reduction	Flow Control	Destination
Eco-roof & roof garden	Simplified[1]	Simplified	NA
Pervious pavement	Simplified[1]	Simplified	Performance
Contained planter	Simplified[1]	Simplified	NA
Tree credit	Simplified[1]	Simplified	NA
Infiltration planter	Simplified[1]	Simplified	Presumptive[2]
Flow-through planter	Simplified[1]	Simplified	NA
Vegetated swale	Simplified[1]	Simplified	Presumptive[2]
Grassy swale < 15,000 sq-ft impervious area	Simplified[1]	Simplified	Presumptive[2]
Grassy swale > 15,000 sq-ft impervious area	Presumptive	NA	Presumptive[2]
Street swales	Simplified[1]	Simplified	Presumptive[2]
Vegetated filter strip	Simplified[1]	Simplified	Presumptive[2]
Vegetated infil. basin	Simplified[1]	Simplified	Presumptive[2]
Sand filter	Simplified[1]	Simplified	Presumptive[2]
Wet pond	Presumptive	NA	NA
Extended wet det. pond	Presumptive	Presumptive	NA
Dry detention pond	Presumptive[3]	Presumptive	NA
Treatment wetland	Presumptive	Presumptive	NA
Manufactured treatment technology	Performance	NA	NA
Structural det. facility	NA	Presumptive	NA
Oil/water separator	Presumptive[4]	NA	NA
Rainwater harvesting	Performance	Performance	NA
Private soakage trench	NA	Presumptive	Presumptive
Public infil. sump	NA	Presumptive	Presumptive
Private drywell	NA	Presumptive	Presumptive

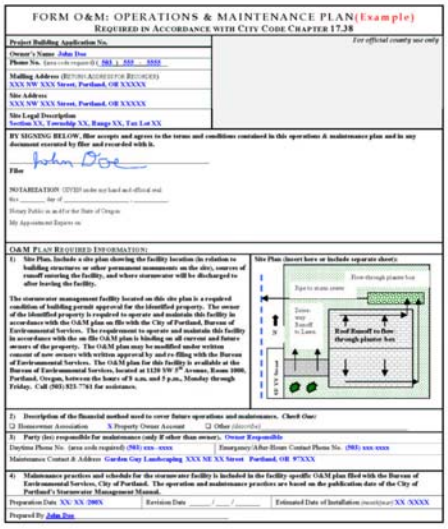


Step 3: Design pollution reduction and flow control facilities from **Chapter 2.0**: **Stormwater Management Facility Design**. Form SIM will be used to size the flow-through planters to meet pollution reduction and flow control requirements. From this form, the sizing factor for flow-through planters is 0.06. The required square-footage of planters is: 7,000 square feet (rooftops + driveway) x 0.06 = 420 square feet. The planter can be split up and



located at each roof downspout, or the downspouts can be plumbed to one large planter, as long as 360 square feet of flow-through planter is provided and all the planters are connected to the storm sewer service lateral.

Step 4: Use **Chapter 3.0**: **Operations & Maintenance** to compile an operations and maintenance plan for the flow-through planter used on the site. Form O&M must be filled out and recorded with the applicable county prior to submission to the city with the permit drawings.

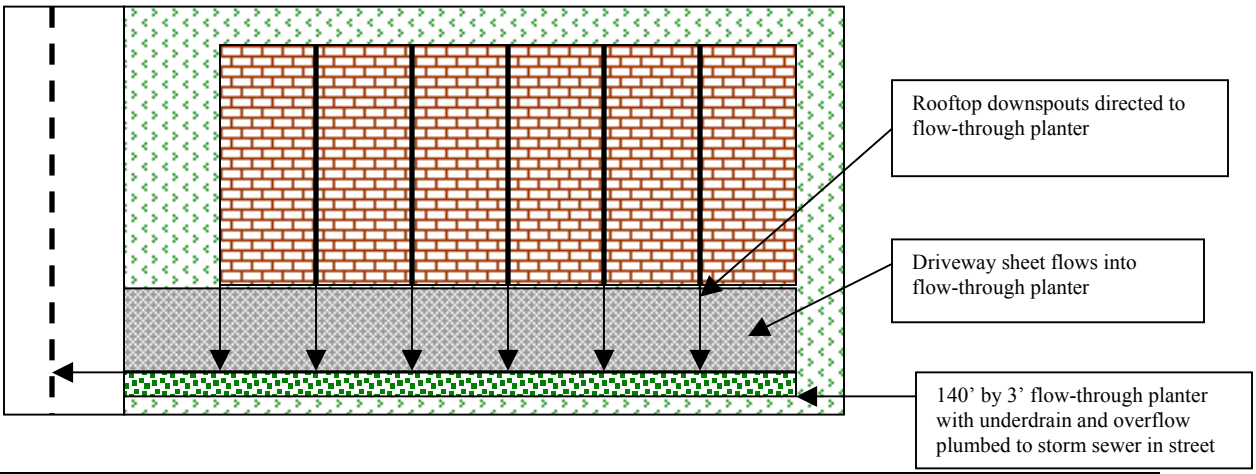


FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)
REQUIRED IN ACCORDANCE WITH CITY CODE CHAPTER 17.38



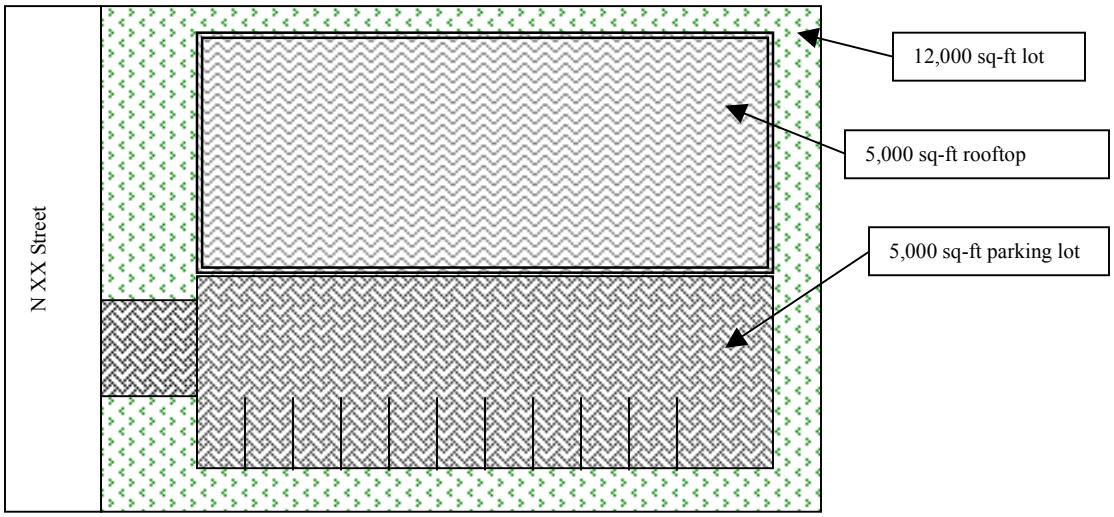
Infiltration and Flow-Through Planters
Operations & Maintenance Plan

Step 5: Submit the plans to the city for permitting. The stormwater destination (pipe connection to the storm sewer service lateral) must be clearly identified on the drawings, along with flow-through planter locations and applicable details, and the completed Form SIM and recorded O&M plan must be attached. **END**.



CASE EXAMPLE #5: Commercial Development w/ Parking Lot (North Portland)

A commercial building development with a 5,000 square-foot building footprint and a 5,000 square-foot parking lot will be constructed on a 12,000 square-foot lot in North Portland. Preliminary geotechnical research indicates that the soil in the area belongs to hydrologic soil group B (from the USDA/NRCS Soil Survey of Multnomah County, Oregon), and the depth to groundwater is approximately 70 feet. The lot has slopes less than 2 percent.



Step 1: Determine the stormwater disposal point for the site. Use **Exhibit 1-1**: **Stormwater Destination/Disposal Hierarchy**.

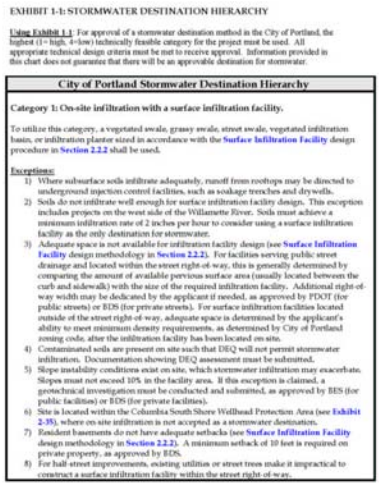


EXHIBIT 1-1: STORMWATER DESTINATION HIERARCHY

Using Exhibit 1.1: For approval of a stormwater destination method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

City of Portland Stormwater Destination Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

To utilize this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter sized in accordance with the Surface Infiltration Facility design procedure in Section 2.2.2 shall be used.

Exceptions:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour to consider using a surface infiltration facility as the only destination for stormwater.
3) Adequate space is not available for infiltration facility design (see Surface Infiltration Facility design methodology in Section 2.2.2). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
6) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration is not accepted as a stormwater destination.
7) Resident basements do not have adequate setbacks (see Surface Infiltration Facility design methodology in Section 2.2.2). A minimum setback of 10 feet is required on private property, as approved by BDS.
8) For half-street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.



City of Portland Stormwater Destination Hierarchy (Continued)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see Section 1.4.4). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the MEP to meet applicable pollution reduction requirements (see Section 1.6.2 for MEP criteria).

Exceptions:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see Section 1.4.4 for list of criteria, or go to: http://www.deq.state.or.us/wq/groundwa/RAStormwaterRequirements.pdf).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration with UICs is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (See Section 1.6.2). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control is required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.

Under category #1, the Stormwater Destination/Disposal Hierarchy states that where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells. In this case, with B-type soils and mild slopes, on-site infiltration is most likely feasible. The Environmental Soils section of the Bureau of Development Services (BDS) may be contacted to confirm the viability of infiltration on private property at 503-823-7790. In addition to drywells and soakage trenches, other options generally include surface infiltration facilities such as vegetated or grassy swales, infiltration planters, or vegetated infiltration basins. In accordance with the surface infiltration design approach from **Section 2.2.2**, enough storage volume must be provided in the surface infiltration facility to contain the runoff from a 10-year, 24-hour storm. For the rooftop areas, this volume can be approximated by: 0.28 feet x 5,000 square feet = 1,400 cubic feet. In this example, there is not adequate space on-site to construct surface infiltration facilities for the rooftop areas.

Under category #1, the 5,000 square-foot parking lot must be evaluated for surface infiltration. In accordance with the surface infiltration design approach in **Section 2.2.2**, enough storage volume must be provided in the surface infiltration facility to contain the runoff from a 10-year, 24-hour storm. For the parking lot, this volume is: 0.28 feet x 5,000 square feet = 1,400 cubic feet. In this example, there is not adequate space on-site to construct surface infiltration facilities to completely dispose of stormwater from the parking lot areas.

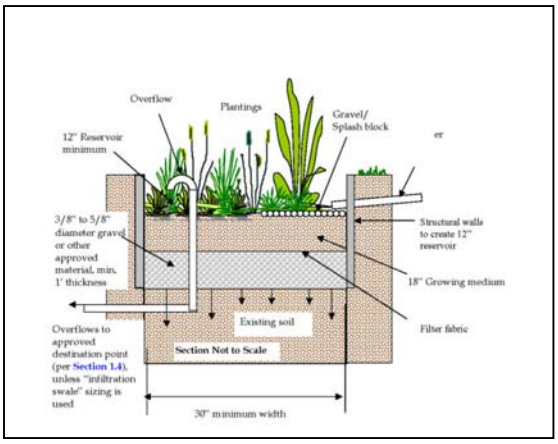
Because there is not enough space on-site for complete surface infiltration, under category #2 the runoff from the parking lot may be infiltrated on-site with a private drywell or soakage trench. A pollution reduction facility or a spill control manhole must also be used to meet pollution reduction requirements.

Step 2: Design the drywells, soakage trenches, surface infiltration facilities, and/or pollution reduction facilities in accordance with **Chapter 2.0**: **Stormwater Management Facility Design**. **Exhibit 2-1** can be used to help select a facility type that can utilize the simplified approach for sizing.

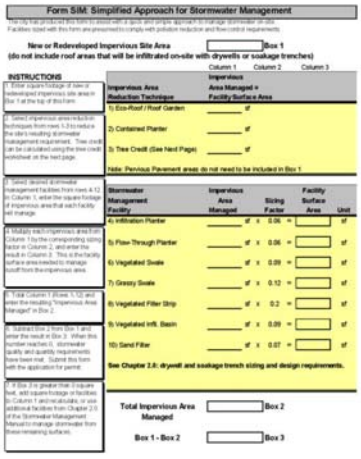
In this example, an infiltration planter will be used to manage stormwater from the parking lot, and the overflow from the planter will be connected to the site's drywell. Drywells and soakage trenches must be registered with DEQ in accordance with **Section 1.4.4**.

Exhibit 2-1: Stormwater Management Facility Application Table

Stormwater Management Facility Type	Credit Given with Associated Design Approach		
	Pollution Reduction	Flow Control	Destination
Eco-roof & roof garden	Simplified[1]	Simplified	NA
Pervious pavement	Simplified[1]	Simplified	Performance
Contained planter	Simplified[1]	Simplified	NA
Tree credit	Simplified[1]	Simplified	NA
Infiltration planter	Simplified[1]	Simplified	Presumptive[2]
Flow-through planter	Simplified[1]	Simplified	NA
Vegetated swale	Simplified[1]	Simplified	Presumptive[2]
Grassy swale < 15,000 sq-ft impervious area	Simplified[1]	Simplified	Presumptive[2]
Grassy swale > 15,000 sq-ft impervious area	Presumptive	NA	Presumptive[2]
Street swales	Simplified[1]	Simplified	Presumptive[2]
Vegetated filter strip	Simplified[1]	Simplified	Presumptive[2]
Vegetated infil. basin	Simplified[1]	Simplified	Presumptive[2]
Sand filter	Simplified[1]	Simplified	Presumptive[2]
Wet pond	Presumptive	NA	NA
Extended wet det. pond	Presumptive	Presumptive	NA
Dry detention pond	Presumptive[3]	Presumptive	NA
Treatment wetland	Presumptive	Presumptive	NA
Manufactured treatment technology	Performance	NA	NA
Structural det. facility	NA	Presumptive	NA
Oil/water separator	Presumptive[3]	NA	NA
Rainwater harvesting	Performance	Performance	NA
Private soakage trench	NA	Presumptive	Presumptive
Public infil. sump	NA	Presumptive	Presumptive
Private drywell	NA	Presumptive	Presumptive



Form SIM will be used to size the infiltration planter to meet pollution reduction requirements. From this form, the sizing factor is 0.06. The required square-footage of planter is: 5,000 square feet (parking lot area) x 0.06 = 300 square feet. The planter will be 3 feet wide by 100 feet long, and will include an overflow catch basin plumbed to an on-site drywell or soakage trench.


Form SIM: Simplified Approach for Stormwater Management

New or Redeveloped Impervious Site Area (do not include roof areas that will be infiltrated on-site with drywells or soakage trenches) — Box 1

INSTRUCTIONS

Impervious Area Reduction Technique — Impervious Area Managed = Facility Surface Area (Column 1 / Column 2 / Column 3)

1) Eco-Roof / Roof Garden
2) Contained Planter
3) Tree Credit (See Next Page)

Note: Pervious Pavement areas do not need to be included in Box 1.

Stormwater Management Facility — Impervious Area Managed — Sizing Factor — Facility Surface Area — Unit

4) Infiltration Planter — sf x 0.06 =
5) Flow-Through Planter — sf x 0.06 =
6) Vegetated Swale — sf x 0.09 =
7) Grassy Swale — sf x 0.12 =
8) Vegetated Filter Strip — sf x 0.2 =
9) Vegetated Infil. Basin — sf x 0.09 =
10) Sand Filter — sf x 0.07 =

See Chapter 2.0: drywell and soakage trench sizing and design requirements.

Total Impervious Area Managed — Box 2

Box 1 - Box 2 — Box 3

If a drywell is used to infiltrate stormwater from the rooftop, driveway, or parking lot, **Exhibit 2-34**: **Drywell Sizing** is used. In accordance with this exhibit, a 10-foot-deep, 48-inch-diameter drywell is required to infiltrate stormwater from the 5,000 square-foot impervious rooftop area. If the drywell will be used to infiltrate stormwater from the rooftop and parking lot (10,000 square-feet of impervious area), a 20-foot-deep, 48-inch-diameter drywell is required. The design criteria presented in the private drywell section of Chapter 2.0 must be used to design the drywell, and to locate the facility on-site. Setbacks from building structure must be considered (see **Exhibit 2-36**). The detailed design and location must be shown on the permit drawings.

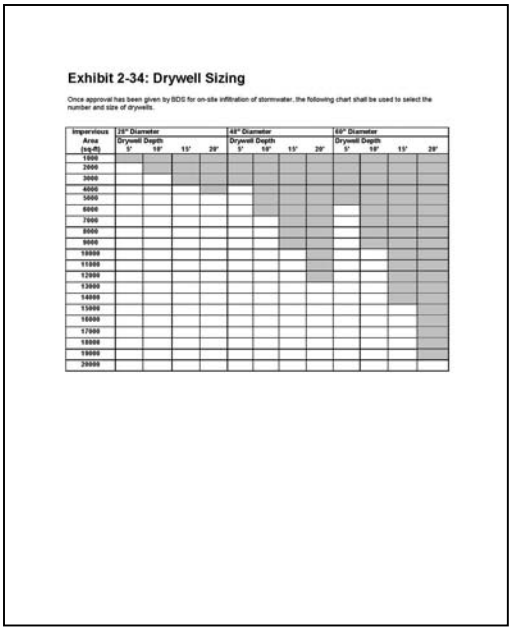


Exhibit 2-34: Drywell Sizing

Once approval has been given by BDS for on-site infiltration of stormwater, the following chart shall be used to select the number and size of drywells.

Impervious Area (sq-ft)	25" Diameter Drywell Depth				48" Diameter Drywell Depth				60" Diameter Drywell Depth			
	5'	10'	15'	20'	5'	10'	15'	20'	5'	10'	15'	20'
1000												
2000												
3000												
4000												
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6000												
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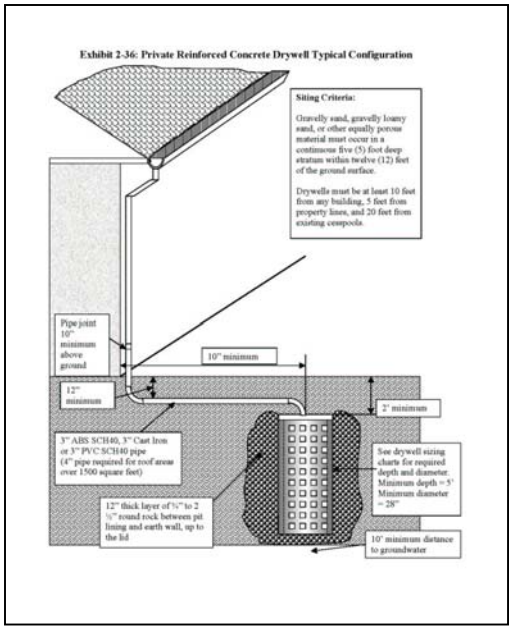
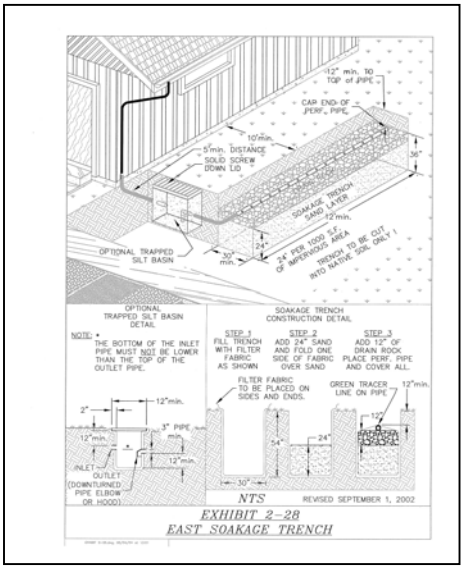


If a soakage trench is used to infiltrate stormwater from the rooftop or parking lot, **Exhibit 2-28**: **East Soakage Trench** is used. In accordance with this exhibit, 24 feet of soakage trench is required per 1,000 square feet of rooftop area. In this example, the length of soakage trench to handle the roof runoff will be: 5,000 * (24/1,000) = 120 feet in length. If used for the roof *and* the parking lot, the soakage trench will be: 10,000 * (24/1,000) = 240 feet. The design criteria presented in the soakage trench section of Chapter 2.0 must be used to design the trench, and to locate the facility on-site. Setbacks from building structure must be considered. The detailed design and location must be shown on the permit drawings.



Step 3: Use **Chapter 3.0**: **Operations & Maintenance** to compile an operations and maintenance plan for the drywell, soakage trench, or other stormwater management facilities used on the site. **Form O&M** must be filled out and recorded with the applicable county prior to submission to the city with the permit drawings.

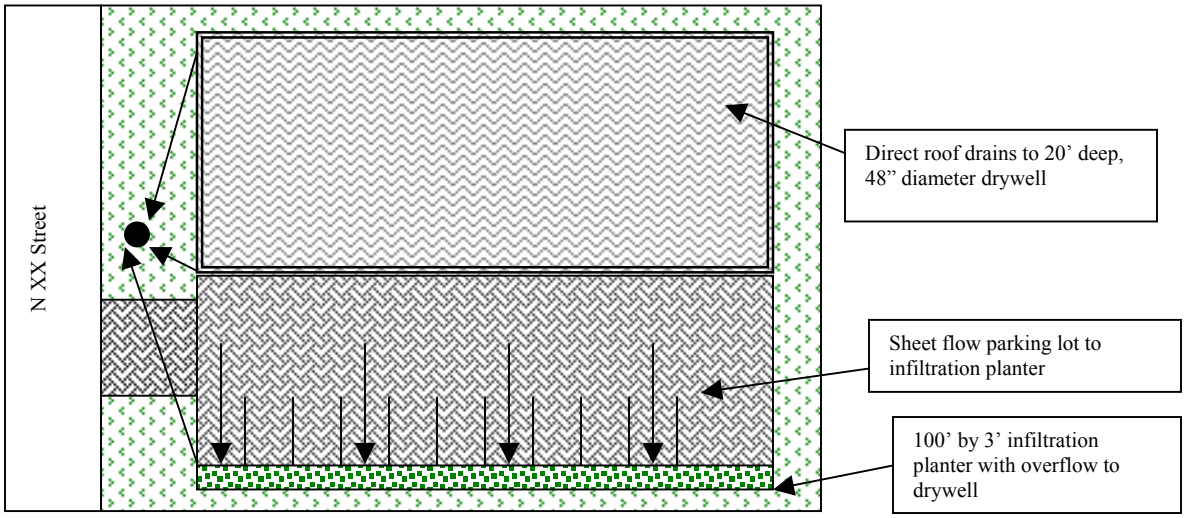


FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)
Required in Accordance with City Code Chapter 17.38



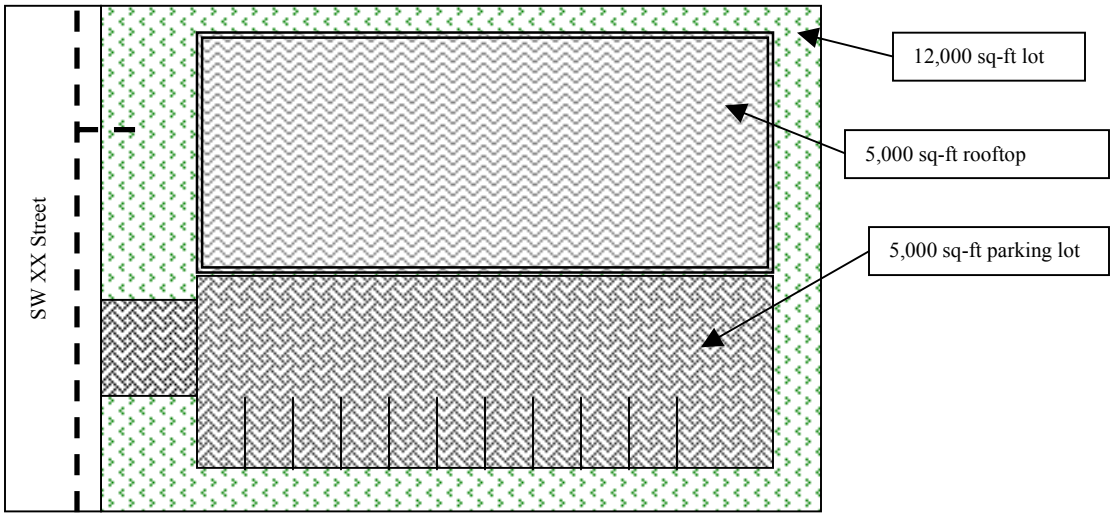
Soakage Trenches
Operations & Maintenance Plan

Step 4: Submit the plans to the city for permitting. The drywell, soakage trenches, or other stormwater management facilities must be shown on the drawings, along with applicable details, Form SIM, and the recorded O&M plan must be attached. **END**.



CASE EXAMPLE #6: Commercial Development w/ Parking Lot (Southwest Portland)

A commercial building development with a 5,000 square-foot building footprint and a 5,000 square-foot parking lot will be constructed on a 12,000 square-foot lot in Southwest Portland. Preliminary geotechnical research indicates that the soil in the area belongs to hydrologic soil group C (from the USDA/NRCS Soil Survey of Multnomah County, Oregon), and the lot has slopes that range from 2 to 5 percent. There is an existing public combined sewer pipe in the frontage street with an existing service lateral to the property.



Step 1: Determine the stormwater disposal point for the site. Use **Exhibit 1-1**: **Stormwater Destination/Disposal Hierarchy**.



EXHIBIT 1-1: STORMWATER DESTINATION HIERARCHY

Using Exhibit 1-1: For approval of a stormwater destination method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

City of Portland Stormwater Destination Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

To utilize this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter sized in accordance with the **Surface Infiltration Facility** design procedure in **Section 2.2.2** shall be used.

Exceptions:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour to consider using a surface infiltration facility as the only destination for stormwater.
3) Adequate space is not available for infiltration facility design (see **Surface Infiltration Facility** design methodology in **Section 2.2.2**). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on-site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
6) Site is located within the Columbia South Shore Wellhead Protection Area (see **Exhibit 2-35**), where on-site infiltration is not accepted as a stormwater destination.
7) Resident basements do not have adequate setbacks (see **Surface Infiltration Facility** design methodology in **Section 2.2.2**). A minimum setback of 10 feet is required on private property, as approved by BDS.
8) For half-street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.



City of Portland Stormwater Destination Hierarchy (Continued)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see **Section 1.4.4**). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the MEP to meet applicable pollution reduction requirements (see **Section 1.4.2** for MEP criteria).

Exceptions:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see **Section 1.4.4** for list of criteria, or go to: http://www.deq.state.or.us/wq/groundwa/UICStormwaterRequirements.pdf).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see **Exhibit 2-35**), where on-site infiltration with UICs is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (See **Section 1.4.2**). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See **Section 1.4.2** for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control is required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See **Section 1.4.2** for MEP criteria).

Exceptions:

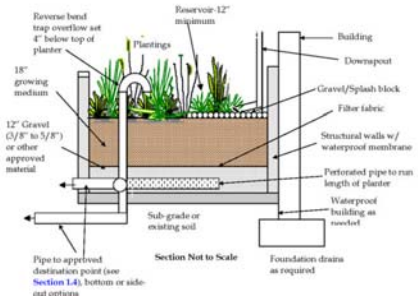
1) System does not exist or does not have available capacity, as determined by BES.

Category #1 (surface infiltration facilities) and category #2 (on-site infiltration with drywell or soakage trench) depend on project site soils that infiltrate relatively well (2 inches per hour minimum). In this example, with C-type soils and moderate slopes, on-site infiltration is not likely feasible. The Environmental Soils section of the Bureau of Development Services (BDS) may be contacted to confirm the viability of infiltration on private property at 503-823-7790. Category #3 (off-site flow to drainageway, river, or storm-only pipe system) depends on the availability of such resources. Portlandmaps.com or other City maps available at the Development Services Center (1900 SW 4th Avenue) can be used to identify off-site storm systems. In this example, there are no existing storm-only conveyance systems available to serve the site. Where on-site infiltration is not possible, and there is not an available storm-only system to serve the site, category #4 (off-site flow to a combined sewer) may be evaluated for use.

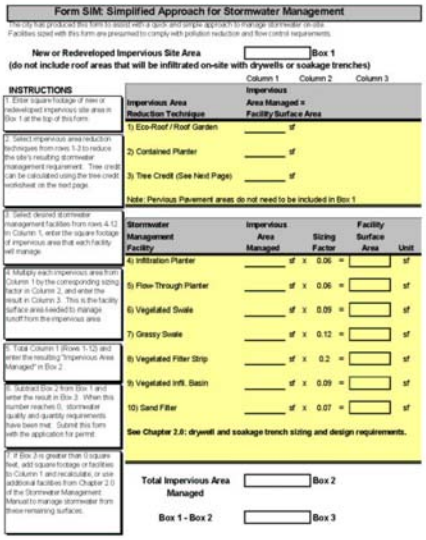
Step 2: Choose pollution reduction and flow control facilities from **Chapter 2.0**: **Stormwater Management Facility Design**. There are many facility types to choose from that will achieve both pollution reduction and flow control. Options that retain water on-site are required to the maximum extent practicable. Exhibit 2-1 can be used to help choose a facility type that can use the simplified approach for sizing. In this example, flow-through planters will be used to manage stormwater from the rooftop and parking lot, and the overflow and underdrain pipes from the planters will be connected to the public combined sewer in the street. The driveway may use pervious pavement with underdrains connected to the combined sewer, or the runoff may be directed to the flow-through planter.

Exhibit 2-1: Stormwater Management Facility Application Table

Stormwater Management Facility Type	Credit Given with Associated Design Approach		
	Pollution Reduction	Flow Control	Destination
Eco-roof & roof garden	Simplified[1]	Simplified	NA
Pervious pavement	Simplified[1]	Simplified	Performance
Contained planter	Simplified[1]	Simplified	NA
Tree credit	Simplified[1]	Simplified	NA
Infiltration planter	Simplified[1]	Simplified	Presumptive[2]
Flow-through planter	Simplified[1]	Simplified	NA
Vegetated swale	Simplified[1]	Simplified	Presumptive[2]
Grassy swale < 15,000 sq.ft impervious area	Simplified[1]	Simplified	Presumptive[2]
Grassy swale > 15,000 sq.ft impervious area	Presumptive	NA	Presumptive[2]
Street swales	Simplified[1]	Simplified	Presumptive[2]
Vegetated filter strip	Simplified[1]	Simplified	Presumptive[2]
Vegetated infil. basin	Simplified[1]	Simplified	Presumptive[2]
Sand filter	Simplified[1]	Simplified	Presumptive[2]
Wet pond	Presumptive	NA	NA
Extended wet det. pond	Presumptive	Presumptive	NA
Dry detention pond	Presumptive[3]	Presumptive	NA
Treatment wetland	Presumptive	Presumptive	NA
Manufactured treatment technology	Performance	NA	NA
Structural det. facility	NA	Presumptive	NA
Oil/water separator	Presumptive[4]	NA	NA
Rainwater harvesting	Performance	Performance	NA
Private soakage trench	NA	Presumptive	Presumptive
Public infil. sump	NA	Presumptive	Presumptive
Private drywell	NA	Presumptive	Presumptive



Step 3: Design pollution reduction and flow control facilities from **Chapter 2.0**: **Stormwater Management Facility Design**. Form SIM will be used to size the flow-through planters to meet pollution reduction and flow control requirements. From this form, the sizing factor for flow-through planters is 0.06. The required square-footage of planters is: 10,000 square feet x 0.06 = 600 square feet for the roof drainage and the parking lot. The planter can be split up and located at each roof downspout, or the downspouts can be plumbed to one large planter, as long as 300 square feet of flow-through planter is provided for the roof, 300 square feet of planter is provided for the parking lot, and all the planters are connected to the public combined sewer in the street.



Form SIM: Simplified Approach for Stormwater Management

New or Redeveloped Impervious Site Area (do not include roof areas that will be infiltrated on-site with drywells or soakage trenches) — Box 1

INSTRUCTIONS

Impervious Area Reduction Technique	Impervious Area Managed = Facility Surface Area
1) Eco-Roof / Roof Garden	sf
2) Contained Planter	sf
3) Tree Credit (See Next Page)	sf

Note: Pervious Pavement areas do not need to be included in Box 1

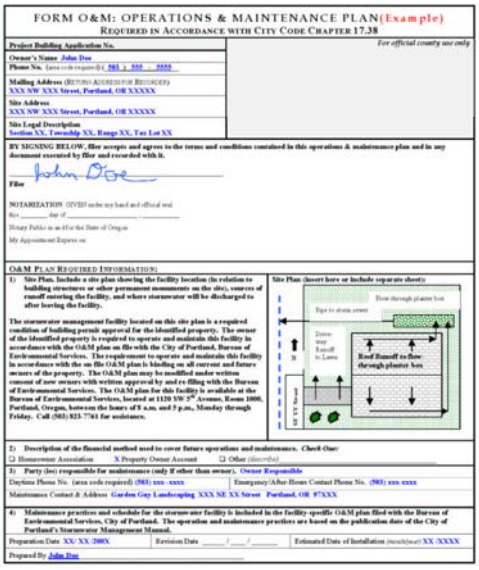
Stormwater Management Facility	Impervious Area Managed		Sizing Factor		Facility Surface Area	Unit
4) Infiltration Planter	sf	x	0.06	=		sf
5) Flow-Through Planter	sf	x	0.06	=		sf
6) Vegetated Swale	sf	x	0.09	=		sf
7) Grassy Swale	sf	x	0.12	=		sf
8) Vegetated Filter Strip	sf	x	0.2	=		sf
9) Vegetated Infil. Basin	sf	x	0.09	=		sf
10) Sand Filter	sf	x	0.07	=		sf

See Chapter 2.0: drywell and soakage trench sizing and design requirements.

Total Impervious Area Managed — Box 2

Box 1 - Box 2 — Box 3

Step 4: Use **Chapter 3.0**: **Operations & Maintenance** to compile an operations and maintenance plan for the flow-through planters used on the site. Form O&M must be filled out and recorded with the applicable county prior to submission to the city with the permit drawings.



FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)
REQUIRED IN ACCORDANCE WITH CITY CODE CHAPTER 17.38

Project Building Application No.

For official county use only

Owner's Name John Doe
Phone No. (area code required) (503) xxx – xxxx

Mailing Address (RETURN ADDRESS FOR RECORDER)
XXX NW XXX Street, Portland, OR XXXXX

Site Address
XXX NW XXX Street, Portland, OR XXXXX

Site Legal Description
Section XX, Township XX, Range XX, Tax Lot XX

BY SIGNING BELOW, filer accepts and agrees to the terms and conditions contained in this operations & maintenance plan and in any document executed by filer and recorded with it.

John Doe
Filer

NOTARIZATION: GIVEN under my hand and official seal this _____ day of _____, _____.

Notary Public in and For the State of Oregon

My Appointment Expires on _____

O&M PLAN REQUIRED INFORMATION:

1) Site Plan. Include a site plan showing the facility location (in relation to building structures or other permanent monuments on the site), sources of runoff entering the facility, and where stormwater will be discharged to after leaving the facility.

Site Plan (insert here or include separate sheet):

The stormwater management facility located on this site plan is a required condition of building permit approval for the identified property. The owner of the identified property is required to operate and maintain this facility in accordance with the O&M plan on file with the City of Portland, Bureau of Environmental Services. The requirement to operate and maintain this facility in accordance with the on file O&M plan is binding on all current and future owners of the property. The O&M plan may be modified under written consent of new owners with written approval by and re-filing with the Bureau of Environmental Services. The O&M plan for this facility is available at the Bureau of Environmental Services, located at 1120 SW 5th Avenue, Room 1000, Portland, Oregon, between the hours of 8 a.m. and 5 p.m., Monday through Friday. Call (503) 823-7761 for assistance.

2) Description of the financial method used to cover future operations and maintenance. Check One:

☐ Homeowner Association X Property Owner Account ☐ Other (describe) _____

3) Party (ies) responsible for maintenance (only if other than owner): Owner Responsible

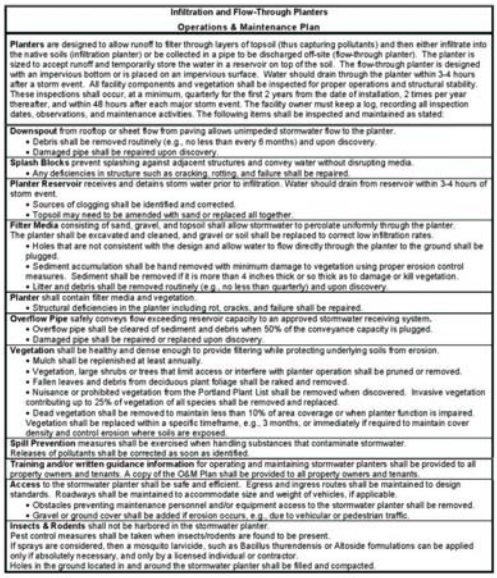
Daytime Phone No. (area code required) (503) xxx - xxxx ; Emergency/After-Hours Contact Phone No. (503) xxx-xxxx

Maintenance Contact & Address: Garden Guy Landscaping XXX NE XX Street Portland, OR 97XXX

4) Maintenance practices and schedule for the stormwater facility is included in the facility-specific O&M plan filed with the Bureau of Environmental Services, City of Portland. The operation and maintenance practices are based on the publication date of the City of Portland's Stormwater Management Manual.

Preparation Date XX/XX/200X ; Revision Date ___/___/_____ ; Estimated Date of Installation (month/year) XX /XXXX

Prepared By: John Doe



Infiltration and Flow-Through Planters
Operations & Maintenance Plan

Planters are designed to allow runoff to filter through layers of topsoil (thus capturing pollutants) and then either infiltrate into the native soils (infiltration planter) or be collected in a pipe to be discharged off-site (flow-through planter). The planter is sized to accept runoff and temporarily store the water in a reservoir on top of the soil. The flow-through planter is designed with an impervious bottom or is placed on an impervious surface. Water should drain through the planter within 3-4 hours after a storm event. All facility components and vegetation shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation, 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Downspout from rooftop or sheet flow from paving allows unimpeded stormwater flow to the planter.
- Debris shall be removed routinely (e.g., no less than every 6 months) and upon discovery.
- Damaged pipe shall be repaired upon discovery.

Splash Blocks prevent splashing against adjacent structures and convey water without disrupting media.
- Any deficiencies in structure such as cracking, rotting, and failure shall be repaired.

Planter Reservoir receives and detains storm water prior to infiltration. Water should drain from reservoir within 3-4 hours of storm event.
- Sources of clogging shall be identified and corrected.
- Topsoil may need to be amended with sand or replaced all together.

Filter Media consisting of sand, gravel, and topsoil shall allow stormwater to percolate uniformly through the planter. The planter shall be excavated and cleaned, and gravel or soil shall be replaced to correct low infiltration rates.
- Holes that are not consistent with the design and allow water to flow directly through the planter to the ground shall be plugged.
- Sediment accumulation shall be hand removed with minimum damage to vegetation using proper erosion control measures. Sediment shall be removed if it is more than 4 inches thick or so thick as to damage or kill vegetation.
- Litter and debris shall be removed routinely (e.g., no less than quarterly) and upon discovery.

Planter shall contain filter media and vegetation.
- Structural deficiencies in the planter including rot, cracks, and failure shall be repaired.

Overflow Pipe safely conveys flow exceeding reservoir capacity to an approved stormwater receiving system.
- Overflow pipe shall be cleared of sediment and debris when 50% of the conveyance capacity is plugged.
- Damaged pipe shall be repaired or replaced upon discovery.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion.
- Mulch shall be replenished at least annually.
- Vegetation, large shrubs or trees that limit access or interfere with planter operation shall be pruned or removed.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance or prohibited vegetation from the Portland Plant List shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed and replaced.
- Dead vegetation shall be removed to maintain less than 10% of area coverage or when planter function is impaired. Vegetation shall be replaced within a specific timeframe, e.g., 3 months, or immediately if required to maintain cover density and control erosion where soils are exposed.

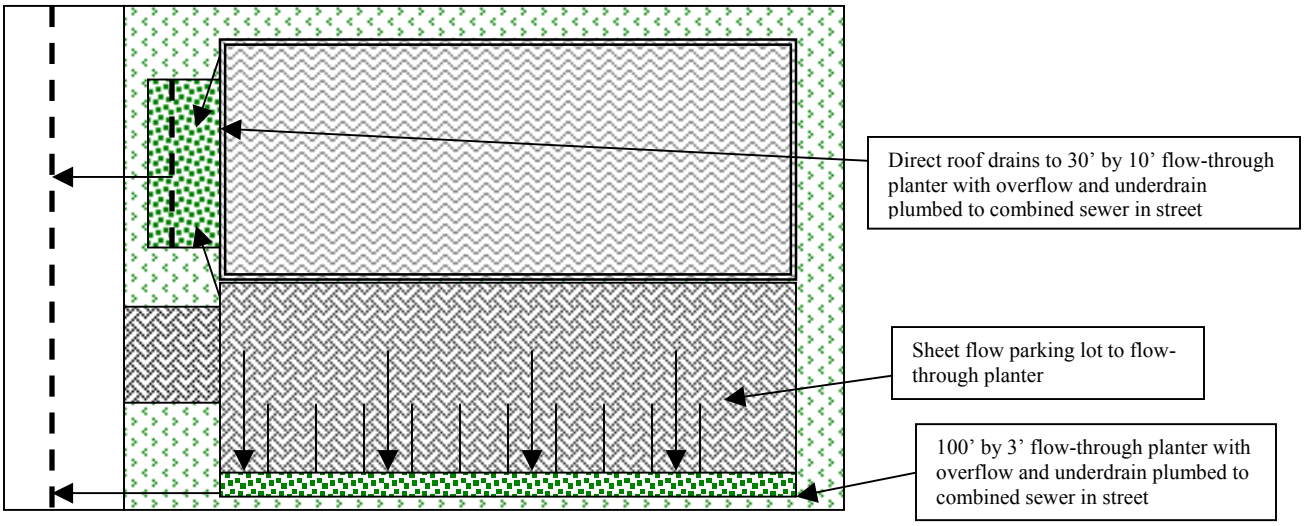
Spill Prevention measures shall be exercised when handling substances that contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining stormwater planters shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the stormwater planter shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.
- Obstacles preventing maintenance personnel and/or equipment access to the stormwater planter shall be removed.
- Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored in the stormwater planter.
Pest control measures shall be taken when insects/rodents are found to be present.
If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
Holes in the ground located in and around the stormwater planter shall be filled and compacted.

Step 5: Submit the plans to the city for permitting. The stormwater destination (pipe connection to the combined sewer service lateral) must be clearly identified on the drawings, along with flow-through planter locations and applicable details, and the completed Form SIM and recorded O&M plan must be attached. **END**.



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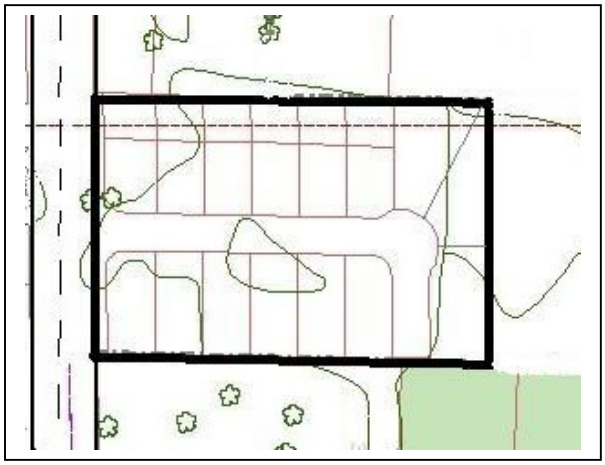
CASE EXAMPLE #7: Subdivision w/ Public Street Improvement (Southeast Portland)

A residential subdivision will be developed in Southeast Portland with 14 single-family house lots and public street improvements. Each lot is approximately 5,000 square-feet in size, and the public street improvement will consist of 500 feet of 26-foot-wide street with 6-foot-wide sidewalks on each side. Total street and sidewalk impervious area is 19,000 square-feet. Preliminary geotechnical research indicates that the soil in the area belongs to hydrologic soil group B (from the USDA/NRCS Soil Survey of Multnomah County, Oregon), and the depth to groundwater is approximately 20 feet. The property has slopes less than 2 percent.



Step 1: Determine the stormwater disposal point for the site. Use **Exhibit 1-1**: **Stormwater Destination/Disposal Hierarchy**.



EXHIBIT 1-1: STORMWATER DESTINATION HIERARCHY

Using Exhibit 1.1: For approval of a stormwater destination method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

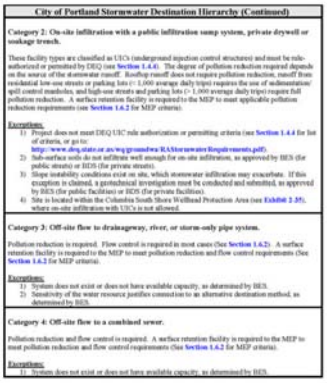
City of Portland Stormwater Destination Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

To utilize this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter sized in accordance with the Surface Infiltration Facility design procedure in Section 2.2.2 shall be used.

Exceptions:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour to consider using a surface infiltration facility as the only destination for stormwater.
3) Adequate space is not available for infiltration facility design (see Surface Infiltration Facility design methodology in Section 2.2.2). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
6) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration is not accepted as a stormwater destination.
7) Resident basements do not have adequate setbacks (see Surface Infiltration Facility design methodology in Section 2.2.2). A minimum setback of 10 feet is required on private property, as approved by BDS.
8) For half street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.



City of Portland Stormwater Destination Hierarchy (Continued)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see Section 1.4.4). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the MEP to meet applicable pollution reduction requirements (see Section 1.6.2 for MEP criteria).

Exceptions:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see Section 1.4.4 for list of criteria, or go to: http://www.deq.state.or.us/wq/groundwa/RAStormwaterRequirements.pdf).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see Exhibit 2-35), where on-site infiltration with UICs is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (See Section 1.6.2). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control is required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See Section 1.6.2 for MEP criteria).

Exceptions:

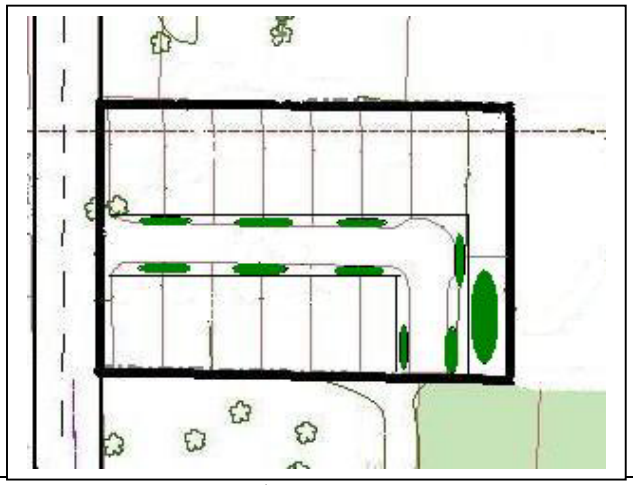
1) System does not exist or does not have available capacity, as determined by BES.

Private Home Sites: Under category #1, the Stormwater Destination/Disposal Hierarchy states that where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells. In this case, with B-type soils and mild slopes, on-site infiltration is most likely feasible. The Environmental Soils section of the Bureau of Development Services (BDS) may be contacted to confirm the viability of infiltration on private property at 503-823-7790. Drywells and soakage trenches must have at least 10 feet of separation to the seasonally high groundwater table. In addition to drywells and soakage trenches, other options include surface infiltration facilities such as vegetated or grassy swales, infiltration planters, or vegetated infiltration basins. In addition to the options listed above, the driveways may use pervious pavement or be graded to sheet flow into adjacent lawn areas.

Public Streets: Under category #1, surface infiltration facilities must be evaluated for the public street and sidewalk impervious surfaces. To do this, Section 2.2.2 must be used to determine the square-footage of surface infiltration facility that would be needed, as follows:

1) Determine the preliminary facility size by using **Section 2.2.2** to calculate the runoff volume generated by the 10-year, 24-hour storm. Runoff volume (cubic feet) = 0.28 feet x impervious area (square-feet) = 0.28 feet x 19,000 square-feet = **5,320 cubic feet**. The facility will need to be capable of containing this volume of runoff through a combination of above-ground storage and below-ground storage within voids in subsurface base rock. Check the subdivision for available surface infiltration areas, which can be located within the public rights-of-way between the curb and sidewalk, or on private property in a separate stormwater tract.

Potential surface infiltration areas:



2) If there are sufficient areas on-site to use surface infiltration facilities to meet stormwater destination requirements, infiltration tests must be done to verify that the minimum rate of 2 inches per hour is met, and that the maximum drawdown time for all surface infiltration facilities will not exceed 30 hours.

If there are not sufficient areas on-site to use surface infiltration facilities, or the minimum infiltration rate or maximum drawdown requirements are not met, go to destination hierarchy category #2: on-site infiltration with a public infiltration sump system, private drywell, or soakage trench. For the management of public street stormwater, public infiltration sump systems may be used if Oregon Department of Environmental Quality (DEQ) rule authorization criteria (presented in **Section 1.4.4**) can be met, including sufficient separation distance to groundwater and drinking water wells. In this case, adequate separation distance to groundwater (10 feet) does not exist; another option must therefore be pursued. Lots may need to be rearranged or sacrificed to provide more room for surface infiltration facilities.

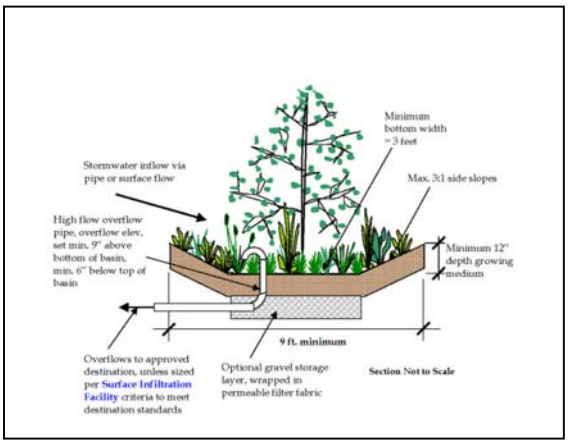
Half-Street Improvements along Existing Public Streets: Half-street improvements along existing public streets that lack curbs, sidewalks, or both are often required at the time of development, and can pose particular stormwater management challenges. Where adequate stormwater destinations exist (existing sump systems, ditches, storm or combined sewer systems), tree mitigation may be used in some cases to meet pollution reduction and flow control obligations. Where this is not possible, the design and construction of a pollution reduction and flow control facility will be required, or in cases where a facility is not practicable and special circumstances are present (see **Section 1.11**), the off-site management fee may be paid.

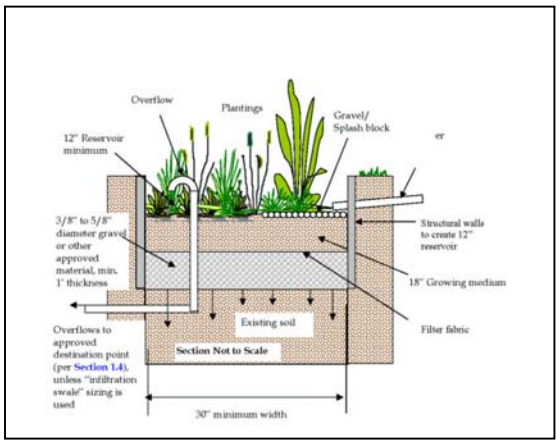
Step 2: Design the surface infiltration facilities and drywells or soakage trenches in accordance with **Chapter 2.0**: **Stormwater Management Facility Design**.

See **Case Example #1** for the design of drywells, soakage trenches, and surface infiltration facilities for single-family homes.

If surface infiltration facilities are used to infiltrate stormwater from the street and sidewalk areas, they must have a storage volume of 5,320 cubic feet, as discussed under Step 1. If the facilities are to be located within the public right-of-way, the design criteria presented in the street swale section of Chapter 2.0 must be used. For a 7-foot-wide swale with 3-foot by 3-foot rock trench underneath (void ratio = 30 percent), there is approximately 5.5 cubic feet of storage per linear foot. Approximately 970 linear feet of swale would be needed to provide 5,320 cubic feet of storage. Because the new public street is only 500

feet long, and 15 driveways will cross the planting strip between the curb and sidewalk (interrupting the area to be used for swales) there is not enough area within the public right-of-way. A combination of swales within the right-of-way and a surface infiltration facility located in a separate stormwater tract, or a single facility in a separate stormwater tract providing 5,320 cubic feet of storage could be used. The detailed design and location must be shown on the permit drawings.





Step 3: Use **Chapter 3.0**: **Operations & Maintenance** to compile an operations and maintenance plan for the surface infiltration facilities, drywells, soakage trenches, or other stormwater management facilities used on the site. **Form O&M** must be filled out and recorded with the applicable county prior to submission to the city with the permit drawings.


FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)
Required in Accordance with City Code Chapter 17.38


Soakage Trenches
Operations & Maintenance Plan

Soakage Trenches consist of drain rock and sand, and receive stormwater from roof downspouts and/or area drains. There are various components within the system - piping, silt basin and the trench itself. The Conveyance Piping consists of an inlet pipe (downspout or area drain), an outlet pipe located between the silt basin and the soakage trench, and a perforated pipe, located on top of the aggregate bed of the soakage trench. The Silt Basin is a structure receiving runoff from an inlet pipe and conveying it to the soakage trench. The silt basin serves as the pre-treatment system for the soakage trench, removing sediments and other debris that can impact its proper functioning. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first two years from the date of installation, then two times per year afterwards, or within 48 hours after each major storm. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated.

Soakage trench infiltration. If water is noticed on top of the trench within 48 hours of a major storm, the soakage trench may be clogged.
- Check for debris/sediment accumulation, rake and remove and evaluate upland causes (erosion, surface or roof debris, etc.
- Assess the condition of the aggregate and the filter fabric in the trench. If there is sediment in the aggregate, excavate and replace.
- If there is a tear in the filter fabric, repair or replace.

Conveyance Piping. If water ponds over the trench for more than 48 hours after a major storm and no other cause if identified, it may be necessary to remove the filter fabric to determine if the perforated pipe is clogged with sediment or debris.
- Any debris or algae growth located on top of the soakage trench should be removed and disposed of properly.
- If the piping has settled more than 1-inch, add fill material. If there are cracks or releases, replace or repair the pipe. If there are signs of erosion around the pipe, this may be an indication of water seeping due to a crack or break.

Silt Basin. If water remains in the soakage trench for 36-48 hours after storm, check for sediment accumulation in the silt basin.
- If less than 50% capacity remains in the basin or 6" of sediment has accumulated, remove and dispose the sediment.

Spill Prevention. Virtually all sites, including residential and commercial, present dangers from spills. All homes contain a wide variety of toxic materials including gasoline for lawn mowers, antifreeze for cars, nail polish remover, pesticides, and cleaning aids that can adversely affect groundwater if spilled. It is important to exercise caution when handling substances that can contaminate stormwater.
- Activities that pose the chance of hazardous material spills shall not take place near soakage trenches.

A Shut-Off Valve or Flow-Blocking Mechanism may have been required with the construction of the soakage trench to temporarily prevent stormwater from flowing into it. In the event of an accidental toxic material spill. This may also involve mats kept on-site that can be used to cover inlet drains in parking lots. The shut-off valve shall remain in good working order, or if mats or other flow-blocking mechanisms are used, they shall be kept in stock on-site.

Training and/or written guidance information for operating and maintaining soakage trenches shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the soakage trench is required for efficient maintenance. Egress and ingress routes will be maintained to design standards at inspections.

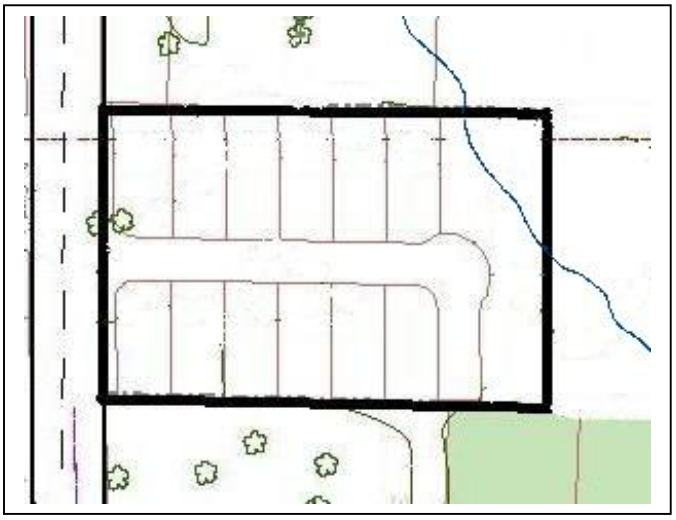
Insects & Rodents shall not be harbored in the soakage trench. Pest control measures shall be taken when insects/rodents are found to be present.
- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the soakage trench shall be filled.

Step 4: Submit the construction plans to the city for permitting. The stormwater management facilities must be shown on the drawings, along with applicable details. The recorded O&M plans for the private facilities must also be included in the submittal. **END**.

SARB_007752

CASE EXAMPLE #8: Subdivision w/ Public Street Improvement (Northwest Portland)

A residential subdivision will be developed in Northwest Portland with 12 single-family house lots and public street improvements. Each lot is approximately 5,000 square-feet in size, and the public street improvement will consist of 500 feet of 26-foot-wide street with 6-foot-wide sidewalks on each side. Total street and sidewalk impervious surface is 19,000 square-feet. Preliminary geotechnical research indicates that the soil in the area belongs to hydrologic soil group C (from the USDA/NRCS Soil Survey of Multnomah County, Oregon), and the property has slopes that range from 2 to 10 percent. There is an existing natural drainageway through the eastern portion of the site.



Step 1: Determine the stormwater disposal point for the site. Use **Exhibit 1-1**: **Stormwater Destination/Disposal Hierarchy**.

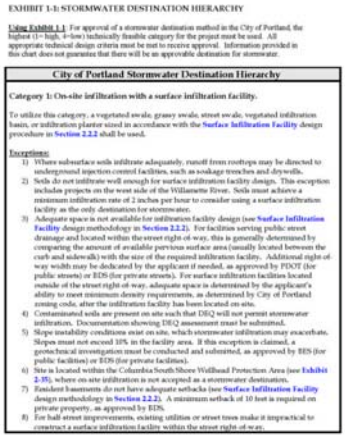


EXHIBIT 1-1: STORMWATER DESTINATION HIERARCHY

Using Exhibit 1-1: For approval of a stormwater destination method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

City of Portland Stormwater Destination Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

To utilize this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter sized in accordance with the **Surface Infiltration Facility** design procedure in **Section 2.2.2** shall be used.

Exceptions:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour to consider using a surface infiltration facility as the only destination for stormwater.
3) Adequate space is not available for infiltration facility design (see **Surface Infiltration Facility** design methodology in **Section 2.2.2**). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on-site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
6) Site is located within the Columbia South Shore Wellhead Protection Area (see **Exhibit 2.35**), where on-site infiltration is not accepted as a stormwater destination.
7) Resident basements do not have adequate setbacks (see **Surface Infiltration Facility** design methodology in **Section 2.2.2**). A minimum setback of 10 feet is required on private property, as approved by BDS.
8) For hall street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.



City of Portland Stormwater Destination Hierarchy (Continued)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see **Section 1.4.4**). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the MEP to meet applicable pollution reduction requirements (see **Section 1.4.2** for MEP criteria).

Exceptions:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see **Section 1.4.4** for list of criteria, or go to: http://www.deq.state.or.us/wq/groundwa/RAStormwaterRequirements.pdf).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see **Exhibit 2.35**), where on-site infiltration with UIC's is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (See **Section 1.4.2**). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See **Section 1.4.2** for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control is required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (See **Section 1.4.2** for MEP criteria).

Exceptions:

1) System does not exist or does not have available capacity, as determined by BES.

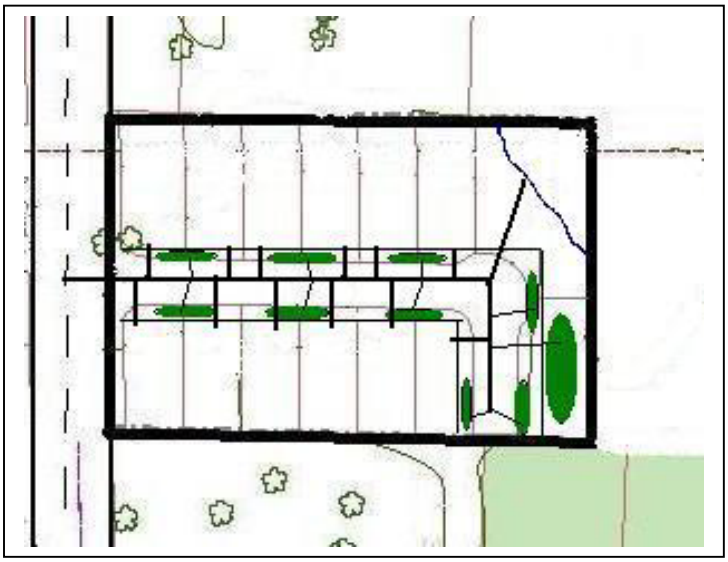
Category #1 (surface infiltration facilities) and category #2 (on-site infiltration with drywell or soakage trench) depend on project site soils that infiltrate relatively well (2 inches per hour minimum). In this example, with C-type soils and moderate slopes, on-site infiltration is not likely feasible. The Environmental Soils section of the Bureau of Development Services (BDS) may be contacted to confirm the viability of infiltration on private property at 503-823-7790. Category #3 (off-site flow to drainageway, river, or storm-only pipe system) depends on the availability of such resources. Portlandmaps.com or other City maps available at the Development Services Center (1900 SW 4th Avenue) can be used to identify off-site storm systems. In this example, there is an existing natural drainageway that will be used, in combination with a public storm sewer extension down the length of the new public street with service laterals to each lot. A Public Works Permit will be required for the construction of the new public storm sewer. When stormwater is being discharged off-site, pollution reduction and flow control are required.

Step 2: Choose pollution reduction and flow control facilities from **Chapter 2.0**: **Stormwater Management Facility Design**. For the single-family home sites, there are many facility types to choose from that will achieve both pollution reduction and flow control. Exhibit 2-1 can be used to help choose a facility type that can use the simplified approach for sizing, such as flow-through planters of vegetated swales.

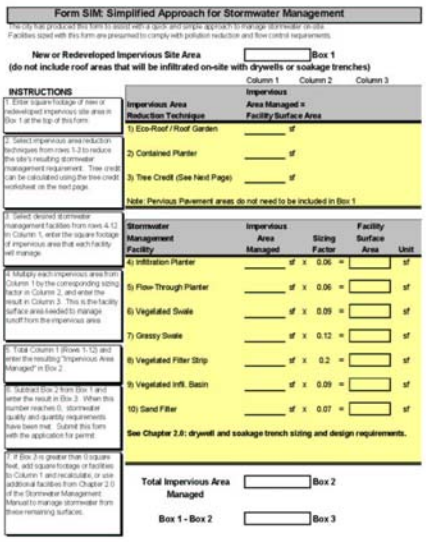
Facilities will be needed on each lot, with overflows piped to the new public storm sewer in the street. Driveways may use pervious pavement; may be graded to sheet flow into adjacent lawn areas if sufficiently sized in accordance with vegetated filter design criteria (at least 1 square foot of lawn area per 5 square feet of driveway area, lawn area must be at least 10 feet by 10 feet); or may be directed to the flow-through planters or vegetated swales.

For the public street and sidewalk areas, vegetated swales within the public right-of-way will be used to meet pollution reduction and flow control requirements.

Potential vegetated street swale locations, with new public storm sewer extension:



Step 3: Design pollution reduction and flow control facilities from **Chapter 2.0**: **Stormwater Management Facility Design**. Form SIM will be used to size the vegetated street swales to meet pollution reduction and flow control requirements. From this form, the sizing factor for vegetated swales is 0.09. The required square-footage of swales is: 19,000 square feet x 0.09 = 1,710 square feet. If the width of the swales is 7 feet, the required total length of swales is 244 feet.



Form SIM: Simplified Approach for Stormwater Management

New or Redeveloped Impervious Site Area _____ Box 1
(do not include roof areas that will be infiltrated on-site with drywells or soakage trenches)

INSTRUCTIONS	Impervious Area Reduction Technique	Column 1 Impervious Area Managed = Facility Surface Area	Column 2	Column 3
	1) Eco-Roof / Roof Garden	_____ sf		
	2) Contained Planter	_____ sf		
	3) Tree Credit (See Next Page)	_____ sf		

Note: Pervious Pavement areas do not need to be included in Box 1

Stormwater Management Facility	Impervious Area Managed		Sizing Factor		Facility Surface Area	Unit
4) Infiltration Planter	_____ sf	x	0.06	=		sf
5) Flow-Through Planter	_____ sf	x	0.06	=		sf
6) Vegetated Swale	_____ sf	x	0.09	=		sf
7) Grassy Swale	_____ sf	x	0.12	=		sf
8) Vegetated Filter Strip	_____ sf	x	0.2	=		sf
9) Vegetated Infil. Basin	_____ sf	x	0.09	=		sf
10) Sand Filter	_____ sf	x	0.07	=		sf

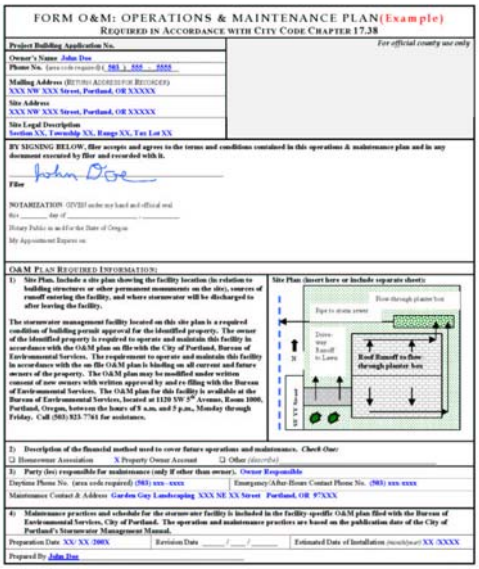
See Chapter 2.0: drywell and soakage trench sizing and design requirements.

Total Impervious Area Managed _____ Box 2

Box 1 - Box 2 _____ Box 3

SARB_007755

Step 4: Use **Chapter 3.0**: **Operations & Maintenance** to compile an operations and maintenance plan for the private stormwater management facilities used on the site. Form O&M must be filled out and recorded with the applicable county prior to submission to the city with the permit drawings.



FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)
REQUIRED IN ACCORDANCE WITH CITY CODE CHAPTER 17.38

Project Building Application No. — For official county use only

Owner's Name: John Doe
Phone No. (area code required): (503) 823-7761

Mailing Address (RETURN ADDRESS FOR RECORDER):
XXX NW XXX Street, Portland, OR XXXXX

Site Address:
XXX NW XXX Street, Portland, OR XXXXX

Site Legal Description:
Section XX, Township XX, Range XX, Tax Lot XX

BY SIGNING BELOW, filer accepts and agrees to the terms and conditions contained in this operations & maintenance plan and in any document executed by filer and recorded with it.

John Doe
Filer

NOTARIZATION: GIVEN under my hand and official seal this _____ day of _____
Notary Public in and for the State of Oregon
My Appointment Expires on:

O&M PLAN REQUIRED INFORMATION:

1) Site Plan. Include a site plan showing the facility location (in relation to building structures or other permanent monuments on the site), sources of runoff entering the facility, and where stormwater will be discharged to after leaving the facility.

The stormwater management facility located on this site plan is a required condition of building permit approval for the identified property. The owner of the identified property is required to operate and maintain this facility in accordance with the O&M plan on file with the City of Portland, Bureau of Environmental Services. The requirement to operate and maintain this facility in accordance with the on file O&M plan is binding on all current and future owners of the property. The O&M plan may be modified under written consent of new owners with written approval by and re-filing with the Bureau of Environmental Services. The O&M plan for this facility is available at the Bureau of Environmental Services, located at 1120 SW 5th Avenue, Room 1000, Portland, Oregon, between the hours of 8 a.m. and 5 p.m., Monday through Friday. Call (503) 823-7761 for assistance.

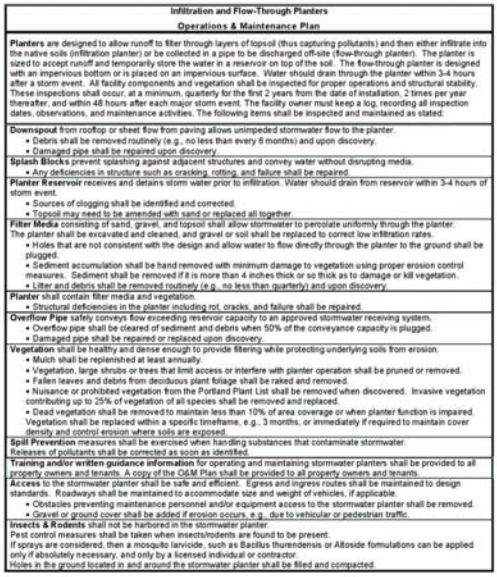
Site Plan (insert here or include separate sheet):

2) Description of the financial method used to cover future operations and maintenance. Check One:
☐ Homeowner Association X Property Owner Account ☐ Other (describe)

3) Party (ies) responsible for maintenance (only if other than owner): Owner Responsible
Daytime Phone No. (area code required): (503) xxx-xxxx | Emergency/After-Hours Contact Phone No. (503) xxx-xxxx
Maintenance Contact & Address: Garden Guy Landscaping XXX NE XX Street Portland, OR 97XXX

4) Maintenance practices and schedule for the stormwater facility is included in the facility-specific O&M plan filed with the Bureau of Environmental Services, City of Portland. The operation and maintenance practices are based on the publication date of the City of Portland's Stormwater Management Manual.

Preparation Date: XX/XX/200X | Revision Date: ____/___/_____ | Estimated Date of Installation (month/year): XX /XXXX
Prepared By: John Doe



Infiltration and Flow-Through Planters
Operations & Maintenance Plan

Planters are designed to allow runoff to filter through layers of topsoil (thus capturing pollutants) and then either infiltrate into the native soils (infiltration planter) or be collected in a pipe to be discharged off-site (flow-through planter). The planter is sized to accept runoff and temporarily store the water in a reservoir on top of the soil. The flow-through planter is designed with an impervious bottom or is placed on an impervious surface. Water should drain through the planter within 3-4 hours after a storm event. All facility components and vegetation shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation, 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated.

Downspout from rooftop or sheet flow from paving allows unimpeded stormwater flow to the planter.
- Debris shall be removed routinely (e.g., no less than every 6 months) and upon discovery.
- Damaged pipe shall be repaired upon discovery.

Splash Blocks prevent splashing against adjacent structures and convey water without disrupting media.
- Any deficiencies in structure such as cracking, rotting, and failure shall be repaired.

Planter Reservoir receives and detains storm water prior to infiltration. Water should drain from reservoir within 3-4 hours of storm event.
- Sources of clogging shall be identified and corrected.
- Topsoil may need to be amended with sand or replaced all together.

Filter Media consisting of sand, gravel, and topsoil shall allow stormwater to percolate uniformly through the planter. The planter shall be excavated and cleaned, and gravel or soil shall be replaced to correct low infiltration rates.
- Holes that are not consistent with the design and allow water to flow directly through the planter to the ground shall be plugged.
- Sediment accumulation shall be hand removed with minimum damage to vegetation using proper erosion control measures. Sediment shall be removed if it is more than 4 inches thick or so thick as to damage or kill vegetation.
- Liter and debris shall be removed routinely (e.g., no less than quarterly) and upon discovery.

Planter shall contain filter media and vegetation.
- Structural deficiencies in the planter including rot, cracks, and failure shall be repaired.

Overflow Pipe safely conveys flow exceeding reservoir capacity to an approved stormwater receiving system.
- Overflow pipe shall be cleared of sediment and debris when 50% of the conveyance capacity is plugged.
- Damaged pipe shall be repaired or replaced upon discovery.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion.
- Mulch shall be replenished at least annually.
- Vegetation, large shrubs or trees that limit access or interfere with planter operation shall be pruned or removed.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance or prohibited vegetation from the Portland Plant List shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed and replaced.
- Dead vegetation shall be removed to maintain less than 10% of area coverage or when planter function is impaired. Vegetation shall be replaced within a specific timeframe, e.g., 3 months, or immediately if required to maintain cover density and control erosion where soils are exposed.

Spill Prevention measures shall be exercised when handling substances that contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining stormwater planters shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the stormwater planter shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.
- Obstacles preventing maintenance personnel and/or equipment access to the stormwater planter shall be removed.
- Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored in the stormwater planter.
Pest control measures shall be taken when insects/rodents are found to be present.
If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
Holes in the ground located in and around the stormwater planter shall be filled and compacted.

Step 5: Submit the plans to the city for permitting. The stormwater management facilities must be clearly identified on the drawings, along with applicable details, and the completed Form SIM and recorded O&M plan must be attached. **END**.

Chapter 1.0
GENERAL REQUIREMENTS & POLICIES

Summary of Chapter 1.0

This chapter outlines the City of Portland's stormwater management requirements and identifies who is required to conform to them. It includes:

1.1 Purpose and Applicability of Manual
1.2 Summary of Manual Contents
1.3 Definitions
1.4 Stormwater Destination/ Disposal
1.5 Pollution Reduction
1.6 Flow Control
1.7 Open Drainageway Policies
1.8 Non-Conforming Use Parking Lots
1.9 Discharging to Existing Stormwater Management Facilities
1.10 Public vs. Private Stormwater Management
1.11 Special Circumstances

1.1 PURPOSE AND APPLICABILITY OF MANUAL

1.1.1 Purpose of Manual

Stormwater management is a key element in maintaining and enhancing the City's livability. As the City is developed, the impervious surfaces that are created increase the amount of runoff during rainfall events, disrupting the natural hydrologic cycle. Without control, these conditions erode stream channels, prevent groundwater recharge, and are the cause of combined sewer overflows (CSOs) and basement sewer backups. Parking lots, roadways, rooftops, and other impervious surfaces increase the pollution levels and temperature of stormwater runoff that is transported to streams, rivers, and groundwater resources. Protecting these waters is vital for a great number of reasons, including fish and wildlife habitat, human health, recreation, and drinking water.

The purpose of this *Stormwater Management Manual* is to provide stormwater management principles and techniques that help preserve or mimic the natural hydrologic cycle, minimize sewer system problems, and achieve water quality goals. The manual provides developers and design professionals with specific

requirements for reducing the impacts of increased stormwater runoff flow quantity and pollution resulting from new development and redevelopment.

1.1.2 Applicability of Manual

This manual's requirements apply to all projects within the City of Portland, whether public or private.

- Projects of any size are required to comply with stormwater destination/ disposal requirements as identified in **Section 1.4** of this manual. Specific facility designs that meet these requirements are presented in **Chapter 2.0**.

- All projects developing or redeveloping over 500 square feet of impervious surface, or existing properties proposing new stormwater discharges off-site, are required to comply with pollution reduction and flow control requirements, presented in **Sections 1.5** and **1.6**, respectively. Specific facility designs that meet these requirements are presented in **Chapter 2.0**.

- All projects constructing destination/disposal, pollution reduction, or flow control facilities are also required to comply with operations and maintenance requirements, as outlined in **Chapter 3.0**.

- Projects that are classified as high risk because of certain site characteristics or activities (listed in **Section 4.1.1**) must comply with the source control requirements identified in **Chapter 4.0**.

1.2 SUMMARY OF MANUAL CONTENTS

How to Use This Manual, provides a flow chart for the navigation of the manual for projects of all sizes and types. It also takes a number of example projects step-by-step through the manual.

Chapter 1.0: General Requirements & Policies, outlines the purpose and applicability of this manual and defines terms. It outlines pollution reduction, flow control, and destination/disposal requirements, explains the rules for connecting to existing systems, and differentiates public and private stormwater management systems. This chapter also discusses the City's policies regarding the protection of open drainageways. Finally, it identifies special circumstances that may make it impractical to implement on-site pollution reduction or flow control to the standards specified in this manual.

Chapter 2.0: Stormwater Management Facility Design, provides methods for selecting and designing stormwater management facilities that accomplish

pollution reduction, flow control, and/or destination/disposal standards. The "simplified," "presumptive," and "performance" approaches are presented.

Chapter 3.0: Operations & Maintenance, presents operations and maintenance (O&M) requirements and provides templates for stormwater management facility O&M plans.

Chapter 4.0: Source Controls, addresses site activities and characteristics with the potential to generate pollutants that may not be addressed solely through the pollution reduction facilities presented in Chapter 2.0. It identifies when and what kinds of source controls are required.

Appendix A: City Code Chapter 17.38, Policy Framework, Appeals & Update Process, contains the section of City Code that includes stormwater management policies and standards and that officially recognizes the City's *Stormwater Management Manual*. The appendix also includes the policy framework for the City's stormwater management requirements, the appeals process, and the process for updating this manual.

Appendix B: Vendor Submission Guidance for Evaluating Stormwater Treatment Technologies, describes the City's testing protocol for acceptance of stormwater pollution reduction facilities. It includes a detailed definition of the City's basic pollution reduction requirement of 70 percent total suspended solids (TSS) removal.

Appendix C: Santa Barbara Urban Hydrograph Method, describes the Santa Barbara Urban Hydrograph method of computing stormwater runoff hydrographs. It includes the City's 24-hour rainfall depths, formulas for computing time of concentration, and runoff curve numbers.

Appendix D: Simplified Approach Sizing Calculations, provides a sample of the method used to calculate the simplified approach sizing factors.

Appendix E: Pollution Reduction Storm Report, outlines the rationale behind the development of Portland's pollution reduction storm intensity and volume, and the associated goal of treating 90 percent of the average annual runoff.

Appendix F: Facility Planting & Soil Recommendations, presents recommended plant species, soil, and design information for landscaped stormwater management facilities.

Appendix G: Supplemental Drawings, includes color cross-section and plan view drawings of many stormwater management facilities, as well as example planting plans.

Appendix H: Stormwater Facility Photos, provides a number of stormwater management facility photos, with site addresses.

References & Resources

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1.3 DEFINITIONS

Note: All definitions are used in this manual and are intended to be consistent with City Code Chapters 17.34, 17.38, and 17.39. Some references to specific chapters or sections are included to assist the user in manual navigation.

Above-Ground Storage of Liquid Materials (**Section 4.3**): Places where exterior storage (either permanent or temporary) of liquid chemicals, food products, waste oils, solvents, or petroleum products in above-ground containers, in quantities of 50 gallons or more exist.

***Aboveground Storage Tank (AST)*:** A stationary container, vessel, or other permanent holding device designated for the storage and/or distribution of a liquid product.

Applicant: Any person, company, or agency that applies for a permit through the City of Portland.

Approved Receiving System (Destination): Any system approved by BES to receive stormwater runoff or other discharges. Receiving systems include, but are not limited to, groundwater; on-site, off-site, or public stormwater, sanitary, or combined sewers; and waters of the state.

***Batch Discharge*:** The controlled discharge of a discrete, contained volume of water or wastewater. Batch discharges into the public sewer system must conform to the requirements of City Code sections 17.34- Industrial Wastewater Discharges; and 17.39- Stormwater Discharge.

BDS: Bureau of Development Services, City of Portland.

BES: Bureau of Environmental Services, City of Portland.

Bioretention Facility: A facility that utilizes soils and both woody and herbaceous plants to remove pollutants from stormwater runoff. Examples of bioretention facilities in this manual can include vegetated swales, flow-through and infiltration planters, vegetated filters, and vegetated infiltration basins.

***Bulk Fuel Terminal*:** Any area with its primary function dedicated to the storage and distribution of fuel to distributors (such as gas stations).

***Bulk Materials*:** Non-containerized materials.

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***Bulk Material Transportation Route*:** Any path routinely used to transport materials regulated in **Section 4.5** onto, off of, or within a site.

Capacity: The capacity of a stormwater drainage system is the flow volume or rate that a facility (e.g., pipe, pond, vault, swale, ditch, drywell, etc.) is designed to safely contain, receive, convey, reduce pollutants from or infiltrate stormwater to meet a specific performance standard. There are different performance standards for pollution reduction, flow control, conveyance, and destination/ disposal, depending on location.

Catch Basin: A structural facility located just below the ground surface, used to collect stormwater runoff for conveyance purposes. Generally located in streets and parking lots, catch basins have grated lids, allowing stormwater from the surface to pass through for collection. Catch basins also include a sumped bottom and submerged outlet pipe (downturned 90 degree elbow, hood, or baffle board) to trap coarse sediment and oils.

Combined (or Combination) Sewers: Pipes that convey both sanitary sewage and stormwater.

Constructed Treatment Wetlands: A wetland-like facility designed and constructed for the specific purpose of providing stormwater management. Unlike natural wetlands (see definition), constructed treatment wetlands are not regulated by the Corps of Engineers or the Division of State Lands. See **Chapter 2.0** for information regarding the design of constructed treatment wetlands.

Contained Planter: A structural facility filled with topsoil and planted with vegetation. When placed over impervious surfaces such as sidewalks or flat rooftops, contained planters intercept rainfall that would otherwise contribute to stormwater runoff. See **Chapter 2.0** for information regarding the design of contained planters.

***Containerized*:** The storage of any product, by-product, or waste that is completely held or included on all sides, within a discrete volume or area.

***Containment*:** The temporary storage of potentially contaminated stormwater or process wastewater when a City sanitary sewer is not available for appropriate discharge.

Control Structure: A device used to hold back or direct a calculated amount of stormwater to or from a stormwater management facility. Typical control structures include vaults or manholes fitted with baffles, weirs, or orifices. See **Chapter 2.0** for information regarding the design of control structures.

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Conveyance: The transport of stormwater or wastewater from one point to another.

Covered Vehicle Parking Areas (**Section 4.9**): Covered vehicle parking structures used to cover parked vehicles other than single-level covers, such as canopies, overhangs, and carports.

CSO (Combined Sewer Overflow): A discharge of a mixture of sanitary sewage and stormwater at a point in the combination sewer system designed to relieve surcharging flows.

DEQ: The Oregon Department of Environmental Quality.

Destination: The ultimate discharge point for the stormwater from a particular site, also known as the stormwater disposal point. Destinations can include on-site infiltration (surface infiltration facilities, drywells, sumps, and soakage trenches) and off-site flow to ditches, drainageways, rivers and streams, off-site storm pipes, and off-site combination sewers. See **Section 1.4** for information regarding destination requirements.

Detention Facility: A facility designed to receive and hold stormwater and release it at a slower rate, usually over a number of hours. The full volume of stormwater that enters the facility is eventually released.

Detention Tank, Vault, or Oversized Pipe: A structural subsurface facility used to provide flow control for a particular drainage basin. See **Chapter 2.0** for information regarding the design of detention tanks, vaults, and oversized pipes.

Development: Any human-induced change to improved or unimproved real estate, whether public or private, for which a permit is required, including but not limited to construction, installation, or expansion of a building or other structure, land division, street construction, drilling, and site alteration such as dredging, grading, paving, parking or storage facilities, excavation, filling, or clearing. Development encompasses both new development and redevelopment.

Development Footprint: The new or redeveloped area covered by buildings or other roof structures and other impervious surface areas, such as roads, parking lots, and sidewalks.

Disposal: See definition of *Destination*.

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Drainage Basin: A specific area that contributes stormwater runoff to a particular point of interest, such as a stormwater management facility, drainageway, wetland, river, or pipe.

Drainageway: An open linear depression, whether constructed or natural, which functions for the collection and drainage of surface water. It may be permanently or temporarily inundated.

Driveway**:** The area that provides vehicular access to a site. A driveway begins at the property line and extends into the site. In parking areas, the driveway does not include vehicular parking, maneuvering, or circulation areas.

Dry Detention Pond: A surface vegetated basin used to provide flow control for a particular drainage basin. Stormwater temporarily fills the dry detention pond during large storm events and is slowly released over a number of hours, reducing peak flow rates. See **Chapter 2.0** for information regarding the design of dry detention ponds.

Drywell: A structural subsurface cylinder or vault with perforated sides and/or bottom, used to infiltrate stormwater into the ground. See **Chapter 2.0** for information regarding the design and use of drywells.

Ecoroof: A lightweight low-maintenance vegetated roof system used in place of a conventional roof. Ecoroofs provide stormwater management by capturing, filtering, and evaporating rainfall. See **Chapter 2.0** for information regarding the design of ecoroofs.

Equipment and/or Vehicle Washing Facilities (**Section 4.7**): Designated equipment and/or vehicle washing or steam cleaning areas. This includes smaller activity areas such as wheel washing stations.

Extended Wet Detention Pond: A surface vegetated basin with a permanent pool of water and additional storage volume, used to provide pollution reduction and flow control for a particular drainage basin. The permanent pool of water provides a storage volume for pollutants to settle out. During large storm events, stormwater temporarily fills the additional storage volume and is slowly released over a number of hours, reducing peak flow rates. See **Chapter 2.0** for information regarding the design of extended wet detention ponds.

Exterior Materials Storage Area**:** Any outdoor materials storage location that is not completely enclosed by a roof and sidewalls.

Exterior Storage of Bulk Materials (**Section 4.5**): Outdoor areas used to stockpile erodible materials.

Flow Control: The practice of limiting the release of peak flow rates and volumes from a site. Flow control is intended to protect downstream properties, infrastructure, and natural resources from the increased stormwater runoff peak flow rates and volumes resulting from development.

Flow Control Facility: Any structure or drainage device that is designed, constructed, and maintained to collect, retain, infiltrate, or detain surface water runoff during and after a storm event for the purpose of controlling post-development quantity leaving the site.

Flow-Through Planter: A structural facility filled with topsoil and gravel and planted with vegetation. The planter is completely sealed, and a perforated collection pipe is placed under the soil and gravel, along with an overflow provision, and directed to an acceptable destination point. The stormwater planter receives runoff from impervious surfaces, which is filtered and retained for a period of time. See **Chapter 2.0** for information regarding the design of flow-through planters.

Fuel Dispensing Facilities (**Section 4.2**): Areas where fuel is transferred from bulk storage tanks to vehicles, equipment, and/or mobile containers (including fuel islands, above ground fuel tanks, fuel pumps, and the surrounding pad). This definition applies to large-sized gas stations as well as single-pump fueling operations.

Grassy Swale (or Bioswale): A long and narrow, trapezoidal or semicircular-shaped channel, planted with a dense grass mix. Stormwater runoff from impervious surfaces is directed through the swale, where it is slowed and in some cases infiltrated, allowing pollutants to settle and filter out. See **Chapter 2.0** for information regarding the design of grassy swales.

Hazardous Material**:** Any material or combination of materials that, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may cause or significantly contribute to an increase in mortality or an increase in serious, irreversible, or incapacitating reversible illness; or that may pose a present or potential hazard to human health, safety, or welfare, or to animal or aquatic life or the environment when improperly used, stored, transported or disposed of, or otherwise managed. For purposes of chemical regulation by this manual, moderate to high toxicity and confirmed human carcinogenicity are the criteria used to identify hazardous substances.
(Note: This manual does not use the Resource Conservation and Recovery Act (RCRA) definition of hazardous. For the purpose of this manual, hazardous material is intended to include hazardous, toxic, and other harmful substances.)

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***Hazardous Material Containment Zone (HMC Zone)*:** An area where a specific individual activity involving use of a hazardous material takes place, and where chemical quantities at that location are expected to exceed defined thresholds. HMCs may include (but are not limited to) storage and/or process areas, transportation routes, work areas, and loading/unloading facilities.

High-Risk Site: A site with characteristics and/or activities that have the potential to generate pollutants that may not be addressed solely through the pollution reduction facilities presented in Chapter 2.0. High-risk site characteristics and activities are listed in **Section 4.1.1**.

Impervious Surface/Area: Any surface that has a runoff coefficient greater than 0.8 (as defined in BES's *Sewer Design Manual*, Chart 10: Runoff Coefficients). Types of impervious surface include rooftops, traditional asphalt and concrete parking lots, driveways, roads, sidewalks, and pedestrian plazas. *Note:* Slatted decks are considered pervious. Gravel surfaces are considered pervious unless they cover impervious surfaces or are compacted to a degree that causes their runoff coefficient to exceed 0.8.

Infiltration: The percolation of water into the ground.

Infiltration Planter: A structural facility filled with topsoil and gravel and planted with vegetation. The planter has on open bottom, allowing water to infiltrate into the ground. Stormwater runoff from impervious surfaces is directed into the planter, where it is filtered and infiltrated into the surrounding soil. See **Chapter 2.0** for information regarding the design of infiltration planters.

Inlet: A structure located just below the ground surface, used to collect stormwater runoff. Generally located in streets and parking lots, inlets have grated lids, allowing stormwater from the surface to pass through for collection. The term "inlet" is also used in reference to the point at which stormwater from impervious surfaces or conveyance piping enters a stormwater management facility.

Landscaping: See definition of *Stormwater Facility Landscaping*.

***LD-50*:** The lethal dose of a substance that is expected to kill approximately 50 percent of experimental animals through oral ingestion. (Refer to product Material Safety Data Sheet.)

***Local Dispensing Location*:** An area within 15 feet of an aboveground storage tank (AST) and used to dispense fuel directly from the AST, typically through a flexible hose.

Manufactured Stormwater Treatment Technology: A proprietary structural facility or device used to remove pollutants from stormwater. Refer to **Chapter 2.0** and **Appendix B** for approval criteria related to manufactured stormwater treatment technologies.

Material Transfer Areas/Loading Docks (**Section 4.6**): Areas designed to accommodate a truck/trailer being backed up to or into them, and used specifically to receive or distribute materials to and/or from trucks/trailers. Includes loading/unloading facilities with docks, and large bay doors without docks.

Maximum Extent Practicable (MEP): See definition of *Practicable*. A term used in the Clean Water Act.

***Multi-Level Parking Structure*:** Any parking facility with greater than one continuous level of parking.

Off-site stormwater facility: Any stormwater management facility located outside the property boundaries of a specific development, but designed to provide stormwater management benefits for that development.

On-site stormwater facility: Any stormwater management facility located within the property boundaries of a specific development, and designed to provide stormwater management benefits for that development.

Open Channel: A fluid passageway which allows part of the fluid to be exposed to the atmosphere.

Operations and Maintenance (O&M): The continuing activities required to keep stormwater management facilities and their components functioning in accordance with design objectives. See **Chapter 3.0** regarding operations and maintenance requirements for stormwater management facilities.

Outfall: A location where collected and concentrated water is discharged. Outfalls can include discharge from stormwater management facilities, drainage pipe systems, and constructed open channels. See **Chapter 2.0** for information regarding the design of outfalls.

***Parking Area*:** The area of a site devoted to the temporary or permanent storage, maneuvering, or circulation of motor vehicles. Parking areas do not include driveways or areas devoted exclusively to non-passenger loading.

PDOT: Portland Department of Transportation.

Permeable Pavement: See definition of *Pervious Pavement*.

Pervious Pavement: The numerous types of pavement systems that allow stormwater to percolate through them and into subsurface drainage systems or the ground. See **Chapter 2.0** for design requirements related to pervious pavement. Also referred to as porous or permeable pavement.

Pollutant: An elemental or physical material that can be mobilized or dissolved by water or air and creates a negative impact to human health and/ or the environment. Pollutants include suspended solids (sediment), heavy metals (such as lead, copper, zinc, and cadmium), nutrients (such as nitrogen and phosphorus), bacteria and viruses, organics (such as oil, grease, hydrocarbons, pesticides, and fertilizers), floatable debris, and increased temperature.

Pollutants of Concern: Watershed-specific parameters identified by the Oregon Department of Environmental Quality (DEQ) as having a negative impact on the receiving water body. Pollutants of concern can include suspended solids, heavy metals, nutrients, bacteria and viruses, organics, floatable debris, and increased temperature.

Pollution Reduction: The practice of filtering, retaining, or detaining surface water runoff during and after a storm event for the purpose of maintaining or improving surface and/or groundwater quality.

Pollution Reduction Facility: A structure, landscape, or drainage device that is designed, constructed, and maintained to collect and filter, retain, or detain surface water runoff during and after a storm event for the purpose of maintaining or improving surface and/or groundwater quality.

Porous Pavement: See definition of *Pervious Pavement*.

Post-Developed Condition: As related to new or redevelopment: A site's ground cover and grading after development.

Practicable: Available and capable of being done as determined by the BES Director, after taking into consideration cost, existing technology, and logistics in light of overall project purpose.

Pre-Developed Condition: As related to new development: A site's ground cover and grading prior to development. Pre-developed condition, as related to redevelopment, is a site's ground cover and grading prior to any development taking place, i.e. Lewis & Clark days.

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Public Facility: A street, right-of-way, sewer, drainage, stormwater management, or other facility that is either currently owned by the City or will be conveyed to the City for maintenance responsibility after construction. A new stormwater management facility that receives direct stormwater runoff from a public right-of-way shall become a public (City-maintained) facility unless the right-of-way is not part of the City's road maintenance system.

Public Works Project: Any development (excluding public buildings) conducted or financed by a local, state, or federal governmental body, including local improvements and public improvements, as defined in Portland City Code Title 17, PUBLIC IMPROVEMENTS.

Rainwater Harvesting: The practice of collecting and using stormwater for purposes such as irrigation and toilet flushing. See **Chapter 2.0** for information regarding rainwater harvesting.

Recycled Land (**Section 4.8**): Land that currently has or previously has had pollutants detected in the soil or groundwater at concentrations that exceed risk-based cleanup levels or state/federal cleanup standards for the particular pollutant(s). Requirements of Section 4.8 may also apply to development projects that are bordered by these properties.

Redevelopment: Any development that requires demolition or complete removal of existing structures or impervious surfaces at a site and replacement with new impervious surfaces. Maintenance activities such as top-layer grinding, re-paving, and re-roofing are not considered to be redevelopment. Interior remodeling projects and tenant improvements are also not considered to be redevelopment. Utility trenches in streets are not considered redevelopment unless more than 50% of the street width is removed and re-paved.

Retention Facility: A facility designed to receive and hold stormwater runoff. Rather than storing and releasing the entire runoff volume, retention facilities permanently retain a portion of the water on-site, where it infiltrates, evaporates, or is absorbed by surrounding vegetation. In this way, the full volume of stormwater that enters the facility is not released off-site.

Roadway**:** Any paved surface used to carry vehicular traffic (cars/trucks, forklifts, farm machinery, or any other large machinery).

Roof Garden: A heavyweight roof system of waterproofing material with a thick soil and vegetation cover. Roof gardens provide stormwater management by capturing, filtering, and evaporating rainfall. See **Chapter 2.0** for information regarding the design of roof gardens.

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Runoff: Stormwater flows across the ground surface during and after a rainfall event. Also simply referred to as stormwater.

Sand Filter: A structural facility with a layer of sand, used to filter pollutants from stormwater. See **Chapter 2.0** for information regarding the design of sand filters.

Santa Barbara Urban Hydrograph (SBUH): A hydrologic method used to calculate runoff hydrographs. See **Appendix C** for information regarding the use of the Santa Barbara Urban Hydrograph method.

Soakage Trench: A linear excavation backfilled with sand and gravel, used to filter pollutants and infiltrate stormwater. See **Chapter 2.0** for information regarding the design of soakage trenches.

Solid Waste Storage Areas, Containers, and Trash Compactors (**Section 4.4**): Outdoor areas with one or more facilities that store solid waste (both food and non-food waste). Single-family residential sites are exempt from the requirements of Section 4.4.

Stormwater: Water runoff that originates as precipitation on a particular site, basin, or watershed. Also referred to as runoff.

Stormwater Facility Landscaping: The vegetation (plantings), topsoil, rocks, and other surface elements associated with stormwater management facility design. See **Chapter 2.0** for stormwater facility landscaping requirements.

Stormwater Management: The overall culmination of techniques used to reduce pollutants from, detain and/or retain, and provide a destination for stormwater to best preserve or mimic the natural hydrologic cycle, to accomplish goals of reducing combined sewer overflows or basement sewer backups, or to fit within the capacity of existing infrastructure.

Stormwater Management Facility: A technique used to reduce pollutants from, detain and/or retain, or provide a destination for stormwater to best preserve or mimic the natural hydrologic cycle, to accomplish goals of reducing combined sewer overflows or basement sewer backups, or to fit within or improve the capacity of existing infrastructure.

Stormwater Re-use: See definition of *Rainwater Harvesting*.

Street Swale: A vegetated or grassy swale (or bioswale) located next to a public or private street for the purpose of managing stormwater. See **Chapter 2.0** for information regarding the design of street swales.

Sump: A large public drywell (see definition) used to infiltrate stormwater from public streets. Sumps are generally 48 inches in diameter and 30 feet deep. The term "sump" is also used to reference to any volume of a facility below the point of outlet, in which water can accumulate. See **Chapter 2.0** for information regarding the use and design of sumps.

Surface Conveyance: The transport of stormwater on the ground surface from one point to another.

Surface Infiltration Facility: A facility designed to receive and infiltrate stormwater runoff at the ground surface to meet stormwater destination/ disposal requirements. Pollution reduction and flow control requirements can also be met with surface infiltration facilities.

Surface Retention Facility: A facility designed to receive and hold stormwater runoff at the ground surface. Rather than storing and releasing the entire runoff volume, surface retention facilities permanently retain a portion of the water on-site, where it infiltrates, evaporates, or is absorbed by surrounding vegetation.

Tenant Improvements: Structural upgrades made to the interior or exterior of buildings. Tenant improvements may trigger **Chapter 4.0** Source Controls if they take place on sites with specified high-risk activities.

Time of Concentration (T of C): The amount of time it takes stormwater runoff to travel from the most distant point (measured by travel time) on a particular site or drainage basin to a particular point of interest. See **Appendix C** for calculations related to time of concentration.

Total Suspended Solids (TSS): Matter suspended in stormwater excluding litter, debris, and other gross solids exceeding 1 millimeter in diameter.

Underground Injection Control (UIC): A federal program under the Safe Drinking Water Act, delegated to the Oregon Department of Environmental Quality (DEQ), which regulates the injection of water below ground. The intent of the program is to protect groundwater aquifers, primarily those used as a source of drinking water, from contamination. See **Section 1.4.4** for information regarding the UIC program.

Vegetated Facilities: Stormwater management facilities that rely on plantings to enhance their performance. Plantings can provide wildlife habitat and enhance many facility functions, including infiltration, pollutant removal, water cooling, flow calming, and prevention of erosion.

Vegetated Filter: A gently sloping, densely vegetated area used to filter, slow, and infiltrate stormwater. See **Chapter 2.0** for information regarding the design of vegetated filters.

Vegetated Infiltration Basin: A vegetated facility that temporarily holds and infiltrates stormwater into the ground. See **Chapter 2.0** for information regarding the design of vegetated infiltration basins.

Vegetated Swale: A long and narrow, trapezoidal or semicircular channel, planted with a variety of trees, shrubs, and grasses. Stormwater runoff from impervious surfaces is directed through the swale, where it is slowed and in some cases infiltrated, allowing pollutants to settle out. Check dams are used to create small ponded areas to facilitate infiltration. See **Chapter 2.0** for information regarding the design of vegetated swales.

Water Body: Water bodies include coastal waters, rivers, sloughs, continuous and intermittent streams and seeps, ponds, lakes, aquifers, and wetlands.

Water Quality: See definition of *Pollution Reduction*.

Watercourse: A channel in which a flow of water occurs, either continuously or intermittently, with some degree of regularity. Watercourses may be either natural or artificial.

Wet Pond: A vegetated basin with a permanent pool of water, used to provide pollution reduction for a particular drainage basin. The permanent pool of water provides a storage volume for pollutants to settle out. See **Chapter 2.0** for information regarding the design of wet ponds.

Wetland: An area that is inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands include swamps, marshes, bogs, and similar areas except those constructed as pollution reduction or flow control facilities. Specific wetland designations shall be made by the Corps of Engineers and the Division of State Lands.

1.4 STORMWATER DESTINATION/DISPOSAL

1.4.1 The Purpose of Stormwater Destination/Disposal

Stormwater destination or disposal refers to the ultimate discharge point for stormwater generated by large, intense rainfall events from a particular development site. Destinations can be grouped into two general categories: on-site infiltration and off-site flow. On-site infiltration methods include surface infiltration techniques, soakage trenches, private drywells, and public infiltration sumps. Off-site flow methods include discharge to drainageways (including roadside ditches and natural drainages and streams), rivers, off-site storm sewers, and off-site combined sewers. The appropriate destination or disposal point is site-specific and depends on a number of factors, including soil type, slopes, and availability of public and private infrastructure.

While many of the stormwater management facilities in Chapter 2.0 are designed to provide pollution reduction, flow control, or both, not all of them infiltrate stormwater from large, intense rainfall events sufficiently enough to be considered the only stormwater disposal point for the site. Unless disposal credit is given, additional destination/ disposal measures are required and must be approved by BES (for off-site flow or infiltration within the public right-of-way) or BDS (for infiltration on private property). It should be noted that the disposal method might have an impact on the pollution reduction and flow control requirements for a site. Therefore, it is advantageous to determine the method of stormwater disposal first.

1.4.2 Destination/Disposal Requirements

Exhibit 1-1: Stormwater Destination/Disposal Hierarchy must be used to determine the ultimate discharge point for stormwater from a development site. The hierarchy is set up to protect watershed health and mimic predeveloped hydrologic conditions by requiring on-site infiltration wherever practicable. This also serves to protect the capacity of downstream infrastructure and minimize the occurrence of combined sewer overflows and basement sewer backups in the combined sewer system. The hierarchy is also intended to protect groundwater resources by limiting the use of infiltration in some cases. It requires infiltration at the ground surface where practicable, and pollution reduction where it isn't. Where on-site infiltration is not practicable, the hierarchy dictates the use of off-site storm-only systems for stormwater discharge if feasible, before discharge to combination sewer systems can be considered.

Section 1.4.3 identifies the standards that must be met for on-site infiltration and off-site flow conveyance.

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EXHIBIT 1-1: STORMWATER DESTINATION/DISPOSAL HIERARCHY

Using Exhibit 1-1: For approval of a stormwater destination/disposal method in the City of Portland, the highest (1= high, 4=low) technically feasible category for the project must be used. All appropriate technical design criteria must be met to receive approval. Information provided in this chart does not guarantee that there will be an approvable destination for stormwater.

City of Portland Stormwater Destination/ Disposal Hierarchy

Category 1: On-site infiltration with a surface infiltration facility.

Under this category, a vegetated swale, grassy swale, street swale, vegetated infiltration basin, or infiltration planter shall be used, sized in accordance with the **Surface Infiltration Facility** design procedure in **Section 2.2.2**. This sizing procedure results in larger facilities than the simplified approach, which is used to meet pollution reduction and flow control goals only.

This category is not required if any of the following conditions exist:

1) Where subsurface soils infiltrate adequately, runoff from rooftops may be directed to underground injection control facilities, such as soakage trenches and drywells.
2) Soils do not infiltrate well enough for surface infiltration facility design. This exception includes projects on the west side of the Willamette River. Soils must achieve a minimum infiltration rate of 2 inches per hour.
3) Adequate space is not available for surface infiltration facility design (see **Surface Infiltration Facility** design methodology in **Section 2.2.2**). For facilities serving public street drainage and located within the street right-of-way, this is generally determined by comparing the amount of available pervious surface area (usually located between the curb and sidewalk) with the size of the required infiltration facility. Resident basements must have adequate setbacks. A minimum setback of 10 feet is required on private property, as approved by BDS. Additional right-of-way width may be dedicated by the applicant if needed, as approved by PDOT (for public streets) or BDS (for private streets). For surface infiltration facilities located outside of the street right-of-way, adequate space is determined by the applicant's ability to meet minimum density requirements, as determined by City of Portland zoning code, after the infiltration facility has been located on-site.
4) Contaminated soils are present on site such that DEQ will not permit stormwater infiltration. Documentation showing DEQ assessment must be submitted.
5) Slope instability conditions exist on site, as documented by a geotechnical investigation, which stormwater infiltration may exacerbate. Slopes must not exceed 10% in the facility area.
6) Site is located within the Columbia South Shore Wellhead Protection Area (see **Exhibit 2-33**), where on-site infiltration is not accepted for stormwater disposal.
7) For half-street improvements, existing utilities or street trees make it impractical to construct a surface infiltration facility within the street right-of-way.

City of Portland Stormwater Destination/ Disposal Hierarchy (Cont.)

Category 2: On-site infiltration with a public infiltration sump system, private drywell or soakage trench.

These facility types are classified as UICs (underground injection control structures) and must be rule-authorized or permitted by DEQ (see **Section 1.4.4**). The degree of pollution reduction required depends on the source of the stormwater runoff. Rooftop runoff does not require pollution reduction, runoff from residential low-use streets or parking lots (< 1,000 average daily trips) requires the use of sedimentation/ spill control manholes, and high-use streets and parking lots (> 1,000 average daily trips) require full pollution reduction. A surface retention facility is required to the maximum extent practicable (MEP) to meet applicable pollution reduction requirements (see **Section 1.6.2** for MEP criteria).

This category is not required if any of the following conditions exist:

1) Project does not meet DEQ UIC rule authorization or permitting criteria (see **Section 1.4.4** for list of criteria, or go to: **http://www.deq.state.or.us/wq/groundwa/RAStormwaterRequirements.pdf**).
2) Sub-surface soils do not infiltrate well enough for on-site infiltration, as approved by BES (for public streets) or BDS (for private streets).
3) Slope instability conditions exist on site, which stormwater infiltration may exacerbate. If this exception is claimed, a geotechnical investigation must be conducted and submitted, as approved by BES (for public facilities) or BDS (for private facilities).
4) Site is located within the Columbia South Shore Wellhead Protection Area (see **Exhibit 2-33**), where on-site infiltration with UICs is not allowed.

Category 3: Off-site flow to drainageway, river, or storm-only pipe system.

Pollution reduction is required. Flow control is required in most cases (see **Section 1.6.2**). A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (see **Section 1.6.2** for MEP criteria).

This category is not required if any of the following conditions exist:

1) System does not exist or does not have available capacity, as determined by BES.
2) Sensitivity of the water resource justifies connection to an alternative destination method, as determined by BES.

Category 4: Off-site flow to a combined sewer.

Pollution reduction and flow control are required. A surface retention facility is required to the MEP to meet pollution reduction and flow control requirements (see **Section 1.6.2** for MEP criteria).

This category is not accepted if the following condition exists:

1) System does not exist or does not have available capacity, as determined by BES.

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1.4.3 Destination/Disposal Standards

ON-SITE INFILTRATION

Where complete on-site infiltration is used for the destination/disposal of stormwater, the following standards shall apply:

Surface Infiltration Facilities (public or private): Surface infiltration facilities must demonstrate the ability to store and infiltrate the 10-year, 24-hour storm. See **Section 2.2.2** for detailed surface infiltration facility sizing and design procedures, including safety factors.

Public Infiltration Sump Systems: The peak flow rate from a 10-year storm must be calculated using the Rational Method (Q=C*I*A), and a safety factor of 2 applied. The intensity shall correspond to the calculated time of concentration (5-minute minimum; see the City of Portland's *Sewer Design Manual* for rainfall intensity charts; for 5-minute time of concentration, intensity = 2.86 "/hr). The infiltration sump system must demonstrate the ability to steadily infiltrate stormwater at this rate.

Private Drywells and Soakage Trenches: Where the Bureau of Development Services (BDS) pre-approves on-site infiltration, drywell sizing charts or soakage trench sizing guidelines shall be used. See Chapter 2.0 for detailed drywell and soakage trench sizing and design procedures. Where on-site infiltration is not pre-approved, but the design professional wishes to prove the viability of on-site infiltration, the drywell testing procedure outlined in Chapter 2.0 shall be used.

OFF-SITE DISCHARGE TO SURFACE FLOW

Where stormwater is discharged to an off-site surface flow conveyance facility, such as a ditch, drainageway, stream, or river, the following standards shall apply:

Beginning at the point of discharge from the site, the surface conveyance facility must have the capacity to convey flows from the 25-year storm from all contributing upstream drainage areas. The 25-year storm flow rate shall be calculated using the Rational Method (Q=C*I*A), with intensity corresponding to the calculated time of concentration (5-minute minimum), or other approved hydrologic modeling method for conveyance. See the City of Portland's *Sewer Design Manual* for rainfall intensity charts and list of approved hydrologic modeling methods.

OFF-SITE DISCHARGE TO PIPED FLOW

Where stormwater is discharged to an off-site piped conveyance facility, such as a storm sewer or combined sewer, the following standards shall apply:

For new development or redevelopment with an increase in net impervious area: Beginning at the point of discharge from the site, the piped conveyance facility must have the capacity to convey flows from the 10-year storm from all contributing upstream drainage areas without surcharge. The piped conveyance facility may surcharge during the 25-year storm, but the hydraulic grade line must remain below ground surface level. Combined sewers, or sewers in the Cascade Station/Portland International Center and Columbia South Shore Plan Districts (**Exhibit 2-33**) must have the capacity to convey flows from the 25-year storm without surcharge. The 10- and 25-year storm flow rates shall be calculated using the Rational Method (Q=C*I*A), with intensity corresponding to the calculated time of concentration (5-minute minimum), or other approved hydrologic modeling method for conveyance. See the City of Portland's *Sewer Design Manual* for rainfall intensity charts and list of approved hydrologic modeling methods.

For redevelopment with no net increase in impervious area: Existing downstream pipe conveyance facilities may be allowed to surcharge under certain circumstances. See the City of Portland's *Sewer Design Manual* for allowable surcharge criteria.

100-YEAR ESCAPE ROUTE

All projects must demonstrate where stormwater from the 100-year storm event will go, and that public safety concerns and property damage will be avoided. This may include storage in parking lot, street, or landscaping areas.

Also see the City of Portland's *Sewer Design Manual* for more information regarding the conveyance and destination of stormwater.

1.4.4 Requirements for Underground Injection Control Structures (UICs)

This section provides general information only. The full regulations and requirements are available on the Oregon Department of Environmental Quality (DEQ) website: **http://www.deq.state.or.us/wq/groundwa/uichome.htm**

The federal Underground Injection Control (UIC) Program (under the Safe Drinking Water Act) regulates the injection of water below the ground. The intent of the program is to protect groundwater aquifers, primarily those used as a source of drinking water, from contamination. DEQ administers the UIC Program in Oregon.

DEQ defines a UIC as any system, structure, or activity that discharges fluid below the ground or subsurface. UICs can pollute groundwater and surface water if not properly designed, sited, and operated. Stormwater systems such as sumps, drywells, and soakage trenches are examples of UICs subject to DEQ regulation. Surface infiltration facilities such as pervious pavements, swales, planters, and vegetated infiltration basins are not classified as UICs.

Owners or operators of new and existing UICs are required to register and provide inventory data to DEQ. UICs that serve privately owned single-family residential roof and footing drains are exempt from these requirements. This information helps DEQ determine if the UIC is eligible for "rule authorization." Rule authorization allows the owner or operator to operate the UIC without a permit from DEQ. UICs that do not qualify for rule authorization must either be closed, modified to meet requirements for rule authorization, or the owner must submit a water pollution control facility permit application to DEQ and obtain a permit.

CRITERIA FOR RULE AUTHORIZATION

UICs must be registered and approved by DEQ before construction. DEQ has set minimum criteria for rule authorization, identified below:

- No other waste is mixed with stormwater.
- Site development, design, construction, and management practices have minimized stormwater runoff.
- No other stormwater destination is appropriate. Note: Discharge to the combined sewer system is not considered appropriate if on-site infiltration is possible.
- No domestic drinking water wells are present within 500 feet.
- No public drinking water supply wells are present within 500 feet or a two-year time of travel.
- No soil or groundwater contamination is present.
- The UIC is not deeper than 100 feet and does not discharge within 10 feet of the highest seasonal groundwater level.

- A confinement barrier or filtration medium is present, or best management practices (BMPs) are used to prevent or treat stormwater contamination. Stormwater management efforts should focus on maximizing source controls, use of vegetated pollution controls, and infiltration through surface infiltration or shallow subsurface facilities.
- Design and operation prevents accidental or illicit spills and allows for temporary blocking.

Compliance with these criteria must be demonstrated during the registration process. Compliance can generally be more readily accomplished if stormwater management efforts focus on maximizing source controls, using surface vegetated pollution control options such as swales and planters, and disposing of stormwater through surface infiltration or shallow subsurface facilities.

Exhibit 1-1 identifies stormwater destination/disposal options, prioritized to guide attainment of the rule authorization criteria.

RULE AUTHORIZATION PROCESS

The City of Portland is managing the rule authorization process for public facilities (UICs that drain public right-of-ways). To allow adequate time to complete the UIC process, registration and inventory information for proposed public UICs should be submitted to the City of Portland as soon as possible after it has been determined that new or existing public right-of-way will be constructed or improved. Contact BES Development Services at 503-823-7651 to get the public UIC process started.

Registration and inventory information for UICs proposed to serve private property should be submitted directly to Mr. Rodney Weick, Oregon DEQ, (503) 229-5886.

Registration and inventory data should be submitted at least 60 days in advance of potential start of work. In some cases, DEQ and the City will need additional information from the applicant to determine the potential use of a UIC. City approval for public or private facilities will not be given until DEQ determines that the proposed UIC can be rule authorized or permitted.

The registration, rule authorization, and permit process is explained in more detail on DEQ's permit webpage: **http://www.deq.state.or.us/pubs/permithandbook/wquic.htm** For technical questions, call the DEQ UIC Program at 503-229-5945. For copies of UIC registration applications or forms, call 503-229-5189.

1.5 POLLUTION REDUCTION

1.5.1 The Purpose of Pollution Reduction

Urbanization is recognized as having a serious impact on Portland's waters. As land is developed, impervious area and surface runoff increase. This runoff collects and transports pollutants to downstream receiving waters and the City sewer system.

General pollutants of concern include:

- Suspended solids (sediment)
- Heavy metals (dissolved and particulate, such as lead, copper, zinc, and cadmium)
- Nutrients (such as nitrogen and phosphorus)
- Bacteria and viruses
- Organics (such as oil, grease, hydrocarbons, pesticides, and fertilizers)
- Floatable debris
- Increased thermal load (temperature)

In response to the water quality impacts of urbanization, Congress passed the Clean Water Act amendments of 1987, mandating the U.S. Environmental Protection Agency (EPA) to issue regulations to control urban stormwater pollution. The regulations, published in 1990, require larger cities ("Phase I") such as Portland to obtain a National Pollutant Discharge Elimination System (NPDES) stormwater discharge permit for their municipal separate storm sewer discharges. Compliance with the NPDES permit requires the City to establish a comprehensive stormwater management program. Portland's citywide management program includes design standards for source control devices as well as best management practices designed to improve stormwater quality. This *Stormwater Management Manual* is part of Portland's NPDES stormwater management program to improve the quality of Portland's waters.

As noted in Section 1.4.4, the federal Underground Injection Control (UIC) Program (under the Safe Drinking Water Act) also requires pollution reduction in many cases prior to UIC infiltration.

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1.5.2 Pollution Reduction Requirements

The City of Portland has a citywide pollution reduction requirement for all development projects with over 500 square feet of impervious development footprint area, and all existing sites that propose to create new off-site stormwater discharges. This requirement is summarized as follows:

- 70 percent removal of total suspended solids[1] is required from 90 percent of the average annual runoff.[2]
- Projects in watersheds that have established total maximum daily loads (TMDLs) must also select and use a pollution reduction facility that is capable of reducing the pollutants of concern, as approved by BES.

[1] See **Appendix B** for a more detailed definition of "70% removal of TSS," which is actually a function of influent TSS concentration.

[2] In Portland, flow rate-based pollution reduction facilities (such as swales and filters) designed to treat runoff generated by a rainfall intensity of 0.19 inches per hour (depending on time of concentration; see chart below), and flow volume-based facilities (such as wet ponds) designed to treat runoff generated by 0.83 inches of rainfall over 24 hours (with NRCS Type 1A rainfall distribution) with a Vb/Vr (volume of basin/ volume of runoff) ratio of 2, will treat roughly 90 percent of the average annual runoff. Facilities that must be sized by routing a hydrograph through the facility (rate-based facilities with a storage volume component) may utilize a continuous simulation program (with a minimum of 20 years of Portland rainfall data) or single-storm hydrograph-based analysis method, such as SBUH (with 0.83 inches of rainfall over 24 hours and NRCS Type 1A rainfall distribution) to demonstrate treatment of 90 percent of the average annual runoff volume. See **Appendix E** for more detailed information regarding the formulation of Portland's pollution reduction standards.

Rainfall intensity needed to treat 90% of the average annual runoff in Portland

Site's Time of Concentration (Minutes)	Rainfall Intensity (Inches per Hour)
5	0.19
10	0.16
20	0.13

One of the three design methodologies from **Chapter 2.0** must be used to design pollution reduction facilities to meet these requirements. The above rainfall intensities are to be used in the Rational Method (Q=CIA) equation to calculate pollution reduction runoff rates. These flow rates are used to size rate-based pollution reduction facilities unless the **Simplified Approach** from Chapter 2.0 is used.

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TOTAL MAXIMUM DAILY LOAD (TMDL) REQUIREMENTS

In addition to the basic "70 percent TSS removal" requirement, projects discharging to water bodies that have established total maximum daily loads (TMDLs) must also select and use a pollution reduction facility that is capable of reducing the pollutants of concern, as approved by BES.

TMDL Parameters by Watershed (As of September 1, 2004)					
Columbia River	**Willamette River**	**Columbia Slough**	**Johnson Creek**	**Fanno Creek Ash Creek**	**Tryon Creek**
· Bacteria · Temperature · Nutrients · PCB · Dioxin · Trace Metals	· Bacteria · Temperature · PCB · Dioxin · PAH · Trace Metals	· Bacteria · Temperature · Nutrients · PCB · Dioxin · Trace Metals	· Bacteria · Temperature · PAH	· Bacteria · Temperature · Nutrients	· Temperature

- Development projects in watersheds with established TMDLs may use vegetated pollution reduction facilities from **Chapter 2.0** without submitting additional data on TMDL pollutant removal.

- If a project in a watershed with established TMDLs uses non-vegetated facilities from **Chapter 2.0** for pollution reduction, the applicant shall also demonstrate through the performance approach (**see Section 2.2.3**) that the development proposal is consistent with specific TMDL requirements. Unless a specific TMDL implementation plan has been adopted for a watershed with established TMDLs, the basic requirement is to select and use a stormwater management facility that is capable of reducing the pollutants of concern, as approved by BES.

Exhibit 1-2 provides guidance on the pollution reduction or prevention capabilities of the facilities in Chapter 2.0, pertaining to TMDL parameters.

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Exhibit 1-2: Pollution Reduction Facility Removal Capabilities For TMDL Parameters

The facility can likely remove or prevent the parameter.
The facility can potentially remove or prevent the parameter, depending on design.
The facility cannot likely remove or prevent the parameter.

Pollution Reduction or Prevention Facility	Bacteria	Temperature	Nutrients	Pesticides (DDT, Dieldrin, Aldrin)	PCB	2,3,7,8 TCDD (Dioxin)	PAH	Trace Metals (Pb, As, Fe, Mn)
Ecoroof	■	■			▒	■	■	
Roof garden	▒	■			▒	■	■	
Pervious pavement	■	■	▒	▒	▒	▒	▒	▒
Tree credit		■						
Contained planter		■				■	■	
Rainwater Harvesting	■	■	■	▒	■	■	■	▒
Infiltration planter	■	■	■	▒	■	■	■	■
Flow-through planter	■	■	■	▒	■	■	■	■
Vegetated swale	▒	▒	▒	▒	▒	▒	▒	▒
Grassy swale	▒	▒	▒	▒	▒	▒	▒	▒
Street swale	▒	▒	▒	▒	▒	▒	▒	▒
Vegetated filter	▒	▒	▒	▒	▒	▒	▒	▒
Vegetated infiltration basin	■	■	■	▒	■	■	■	■
Wet pond	▒	▒	▒	▒	■	■	■	■
Extended wet detention pond	▒	▒	▒	▒	■	■	■	■
Constructed treatment wetland	▒	■	■	▒	■	■	■	■
Sand filter	■	■	■	▒	■	■	■	■
Manufactured filtration device	■	▒	■	▒	■	■	■	■

Note: This table is based on limited information and should be used for guidance only. Actual pollutant reduction and prevention capabilities are based on specific facility design and site conditions.

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POLLUTION REDUCTION IN COMBINED SEWER AREAS

Because most combined sewers overflow to the Willamette River in wet conditions, it is essential to keep as much stormwater out of the combined sewer system as possible. For this reason, on-site infiltration is required to the maximum extent practicable. Pollution reduction is also required, unless all of the following conditions are met:

- The combined sewer system to which the development is connecting does not backup into basements or overflow during a 25-year storm event.
- The development has used on-site surface retention facilities within the project area to the maximum extent practicable, as approved by BES.
- The development pays the off-site stormwater management fee. See **Section 1-11** for information regarding current off-site stormwater management fee rates.

OIL CONTROL FOR VEHICLE AND EQUIPMENT TRAFFIC AREAS

Vehicle and equipment traffic areas are required to incorporate oil controls into the stormwater management design if they have the following characteristics:

- Commercial or industrial parking lots that store wrecked or impounded vehicles.
- Areas with a high likelihood of oil and grease loadings, such as fast-food restaurant drive-thru and parking, grocery and convenient store parking, vehicle repair, vehicle sales, and vehicle fueling services.

Oil controls can include spill control manholes (**Exhibit 2-26**) or the incorporation of Lynch-type catch basins within the parking lot or at the outlet to swales or other pollution reduction facilities. The discharge of stormwater with a visible sheen off-site or into on-site UICs is prohibited. Vehicle and equipment traffic areas that trigger these requirements must be paved with an impervious material. Because gasoline can react with asphalt pavement, it is preferable to pave the areas with concrete.

POLLUTION REDUCTION EXEMPTION FOR ROOFTOPS THAT INFILTRATE ON-SITE

Projects that infiltrate rooftop stormwater runoff with private soakage trenches, drywells, or surface infiltration facilities are not required to provide pollution reduction prior to infiltration. This exemption does not apply to projects that discharge stormwater off-site. Refer to **Section 1.4.4** for requirements specific to underground injection control structures (UICs).

1.6 FLOW CONTROL

1.6.1 The Purpose of Flow Control

Prior to development, runoff either appears as streamflow, evaporates into the atmosphere, or infiltrates into the ground where it recharges groundwater aquifers or surface water bodies. Urbanization results in the loss of forest, agricultural land, and open space and increases the amount of impervious area. As a result, development can have the following hydrologic impacts:

- Increased stormwater flow rates
- Increased stormwater runoff volumes
- Decreased groundwater recharge and base flows into streams
- Seasonal flow volume shifts

Flow control is intended to protect downstream properties, infrastructure, and natural resources from the increases in stormwater runoff peak flow rates and volumes resulting from development.

The City's policy is to ensure that runoff leaving the post-development site:

- Does not exceed the capacity of the receiving conveyance facility or water body.
- Does not increase the potential for stream bank and stream channel erosion.
- Does not add significant volume to an existing closed depression, such as Holgate Lake or other similar geologic features found throughout the City.
- Does not create or increase any upstream or downstream flooding problems.
- Does not create or increase the occurrence of CSOs or basement sewer backups.

The basic design concept for flow control (detention and retention) is simple: water from developed areas is managed with a variety of flow control techniques and released to downstream conveyance systems at a slower rate (detention) and lower volume (retention). Managing flows in this way attempts to mimic the site's natural rainfall runoff response prior to development (see **Exhibit 1-3**).

Detention facilities, such as ponds, tanks, vaults, or oversized pipes temporarily store stormwater runoff. The water is slowly released from the facility, typically over a number of hours.

Retention facilities also store stormwater runoff. Rather than storing and releasing the entire runoff volume, however, the facility permanently retains a portion of the water on-site, where it infiltrates and recharges the groundwater aquifer, and in the case of surface retention facilities, evaporates or is absorbed and used by surrounding vegetation. In this way, retention facilities reduce the total volume of water released

downstream. Examples of retention facilities include surface treatments (such as eco-roofs or pervious pavements) that cover or replace traditional impervious surfaces and vegetated facilities such as swales, filters, ponds, and planter boxes.

In the past, flow control plans often relied solely on detention facilities. Facilities that control only peak flow rates, however, allow the duration of high flows to increase, causing the potential for increased erosion downstream. For example, after development with detention, the magnitude of the 2-year peak flow rate may not increase, but the amount of time (duration) that the flow rate occurs will increase, and the frequency that the 2-year peak flow rate occurs will also increase. Retention systems, on the other hand, are particularly effective at lowering the overall runoff volume, reducing the amount of time (duration) that the peak flow rate occurs, as well as the frequency. In addition, by infiltrating stormwater, retention systems recharge groundwater that serves as the base flow for streams during the dry season. Therefore, stream systems that require erosion protection, including salmonid habitat streams, warrant the use of retention systems. Where retention systems cannot be used, detention systems that control the duration of the geomorphically significant flow (i.e., flow capable of moving sediment) shall be used. Such detention systems employ lower release rates and are therefore larger in volume.

Time of concentration (the time it takes rainfall to accumulate and run off a site) is another important factor in determining downstream hydrologic impacts created by development. Flow rates from individual sites may be controlled, but when they are combined quickly in fast-flowing conveyance pipes, the downstream effect will still be increased in-stream flow rates and volumes. Breaking flow patterns up into surface retention systems helps increase a site's time of concentration and lessens downstream impacts.

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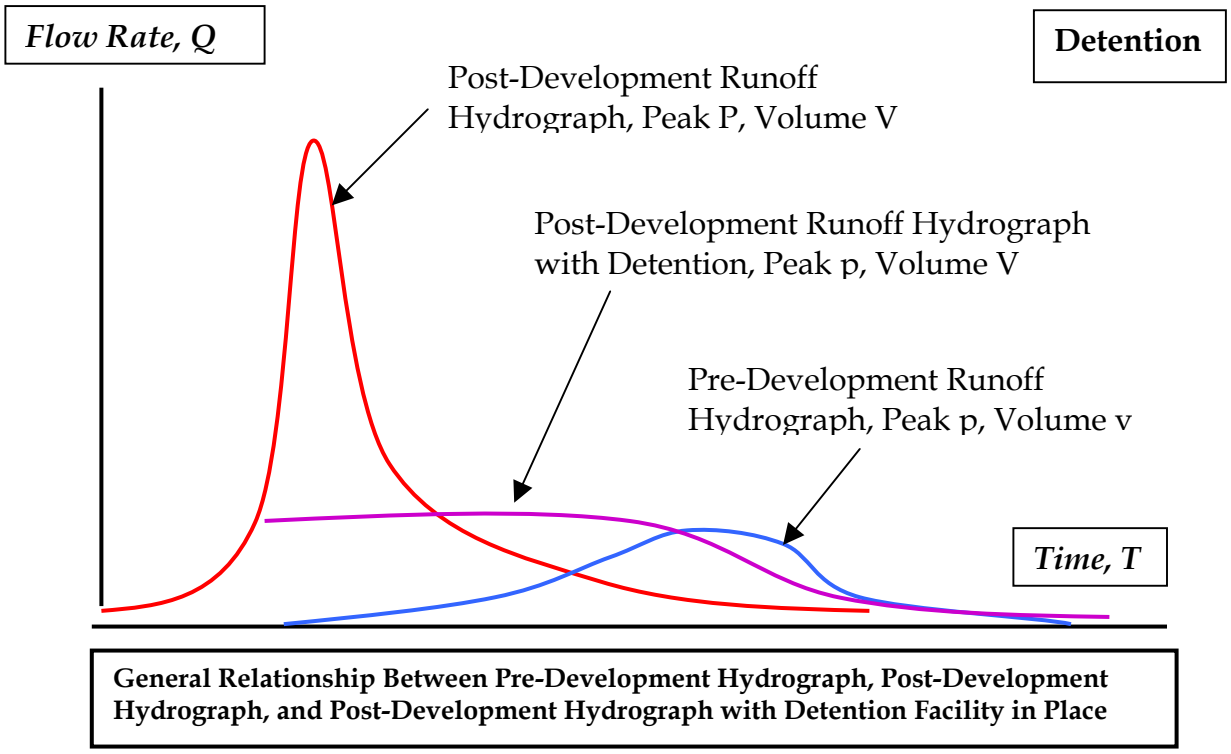
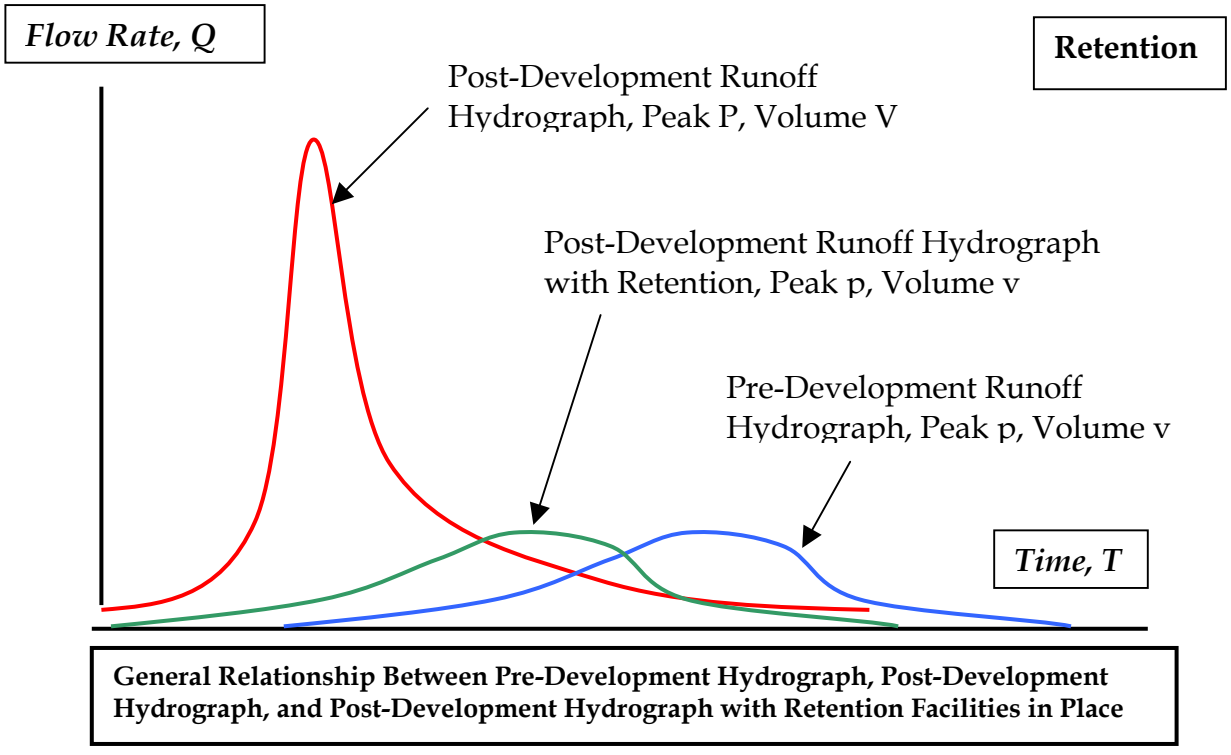
Exhibit 1-3: The Effect of Detention and Retention Facilities on Post-Developed Hydrographs (Large Storm Events)



General Relationship Between Pre-Development Hydrograph, Post-Development Hydrograph, and Post-Development Hydrograph with Detention Facility in Place



General Relationship Between Pre-Development Hydrograph, Post-Development Hydrograph, and Post-Development Hydrograph with Retention Facilities in Place

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1.6.2 Flow Control Requirements

On-site infiltration is required to the maximum extent practicable to control stormwater volumes and flow rates. (See **Exhibit 1-1**: Stormwater Destination/Disposal Hierarchy.) Where complete on-site infiltration is not practicable, other on-site retention techniques (such as pervious pavement, ecoroofs, planters, swales, and other surface vegetated facilities) are required to the maximum extent practicable to reduce runoff volumes, with the following exceptions:

- Space constraints prohibit the construction of on-site retention facilities. Required setbacks from buildings and property lines need to be considered for each facility type.
- The use of surface retention is not practicable or safe because of soil or slope conditions. The City may require an investigation and recommendation of a qualified geotechnical engineer or engineering geologist to demonstrate that this exception applies to a site. It should be noted that some surface retention facilities, such as flow-through planter boxes, are lined and therefore do not infiltrate stormwater into surrounding soils.
- Contaminated soils limit the use of retention approaches.
- Required source controls for high-risk sites (as identified in **Chapter 4.0**) conflict with the use of on-site retention facilities.
- The development is located in an area of Portland where flow control is not required (See **Exhibit 1-4**) **and** discharges to a storm-only system with adequate capacity**.**

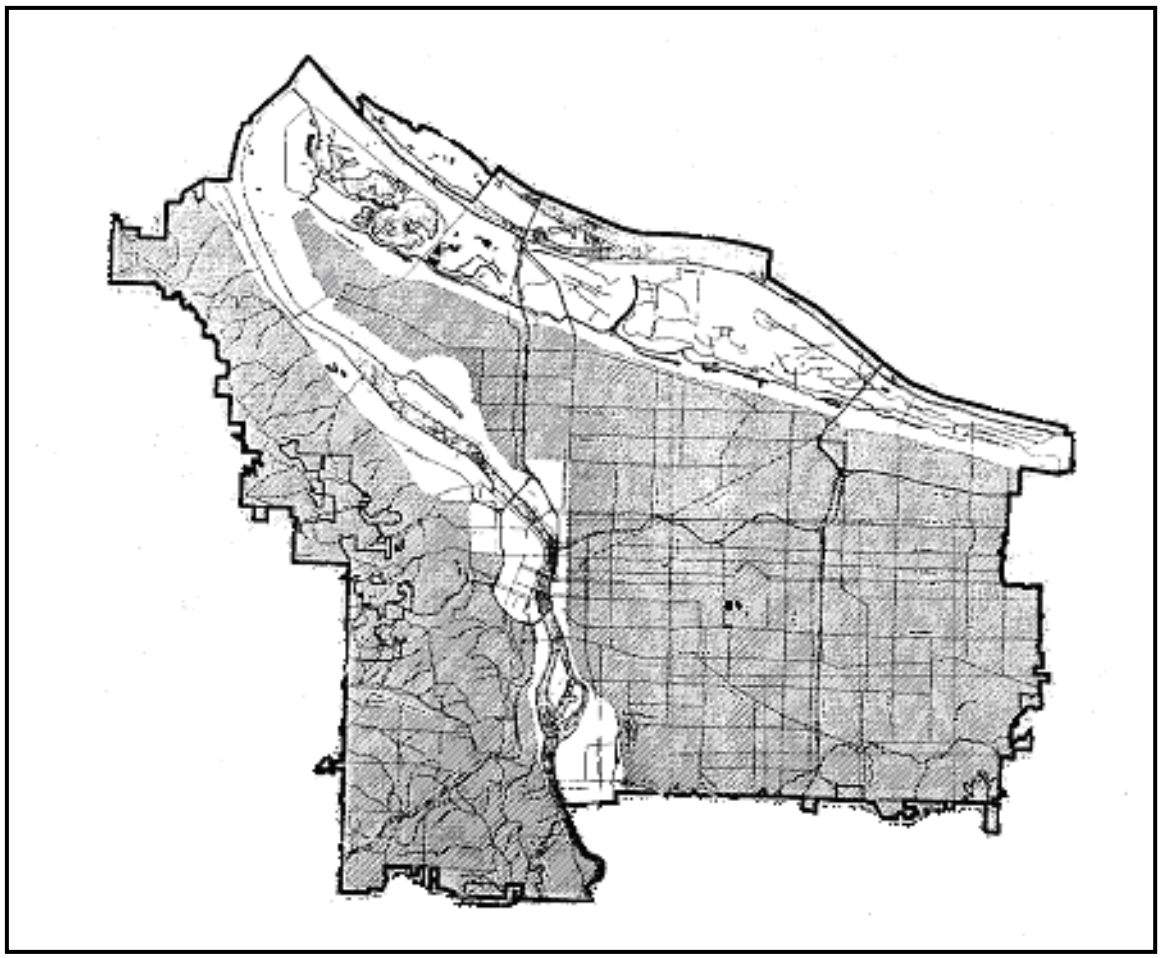
Where complete on-site infiltration or the use of retention facilities is not practicable, flow control (detention) shall be sufficient to maintain peak flow rates at their pre-development levels for the 2-year, 5-year, and 10-year, 24-hour runoff events. Note that for redevelopment projects, pre-development condition is defined as undeveloped land. (See definition of pre-developed condition in **Section 1.3**)

Because of minimum orifice size specifications (2 inches for public facilities, 1 inch for private facilities), detention facilities that rely on orifice structures to control flows for small projects (under 15,000 square feet of impervious development footprint area) may not be effective. In these cases, rather than constructing a detention facility on-site, the applicant may pay the flow control portion of the off-site stormwater management fee (see **Section 1.11**).

CIRCUMSTANCES WHEN FLOW CONTROL IS NOT REQUIRED

New development and redevelopment are exempt from flow control requirements if they discharge stormwater runoff directly into either the Willamette River, Columbia River, or Columbia Slough through a private storm sewer, separated public storm sewer, or Multnomah Country Drainage District system with available capacity. Although not always the case, these areas generally fall within the unshaded areas of Exhibit 1-4.

Exhibit 1-4: General Areas Where On-Site Flow Control May Not Be Required (Shown as unshaded areas of this map)



IMPORTANT NOTES:

- This exemption is for flow control only; pollution reduction requirements still apply.
- Development must still properly dispose of stormwater using approved methods in accordance with **Section 1.4** of this manual.

CIRCUMSTANCES WHEN MORE RESTRICTIVE FLOW CONTROL IS REQUIRED

Most tributary streams in Portland show evidence of excessive stream bank and channel erosion. Any development that discharges stormwater off-site that eventually flows to a tributary stream shall be designed to a more restrictive requirement to reduce the potential for further aggravation of instream erosion problems. This applies to all tributaries and storm sewers that drain to tributaries within the Portland area, except the Columbia Slough.

The added controls are based on the geomorphically significant flow, which is the flow that initiates sediment movement in the channels. The erosion-causing flow varies from channel to channel. Unless more specific data are available, the City assumes that the erosion-causing flow is one-half of the 2-year, 24-hour pre-developed (Lewis & Clark era) peak flow, and the requirements of this manual are based on that assumption. **Specifically, the more restrictive control requirement is to limit the 2-year, 24-hour post-development peak flow rate to the pre-development erosion-initiating rate (one-half of the 2-year, 24-hour flow rate). The facilities shall also control the post-development flows from the 5-, 10-, and 25-year, 24-hour peak flows to the pre-development 5-, 10-, and 25-year, 24 hour levels**.

Development projects proposing to discharge stormwater off-site must evaluate the capacity of the off-site receiving system (storm sewer, combination sewer, ditch, drainageway, etc.) against the standards presented in **Section 1.4.3**. Additional flow control may be required on-site if off-site receiving systems do not have sufficient capacity to accept the additional flows.

FLOW CONTROL REQUIREMENTS SPECIFIC TO DEVELOPMENTS DISCHARGING TO THE COMBINED SEWER SYSTEM

Substantial stormwater volumes in the combined sewer system result in combined sewer overflows (CSOs) and basement flooding in many areas served by combined sewers. Stormwater that enters the combined sewer system during low-flow periods is treated at the City's wastewater treatment plants, using costly energy and other resources. For these reasons, it is important to limit the quantity of stormwater entering the combined sewer system, and development projects in combined sewer areas are subject to the requirement to **infiltrate stormwater on-site to the maximum extent practicable**. For developments that are served by combined sewers but are unable to infiltrate on-site, the following requirements apply:

- Development projects that are allowed to discharge to a combined sewer system (cannot infiltrate on-site) are not required to provide detention for the 2- and 5-year

storm events. Detention facilities must be designed to control post-development flows from the 25-year peak flow to the pre-developed 10-year peak flow rate.

- Redevelopment projects that result in an equal or decreased coverage of impervious surface and that discharge into a combined sewer system with available capacity (no overflows during 25-year storm event, as determined by BES) are not required to provide flow control.

SUMMARY OF THE CITY'S FLOW CONTROL REQUIREMENTS:

1) On-site infiltration is required to the maximum extent practicable.
2) Where complete on-site infiltration is not practicable, on-site retention (flow volume control) facilities must be used to the maximum extent practicable.
3) Where complete on-site infiltration or retention is not practicable, flow control requirements below shall apply, after the **Stormwater Destination/ Disposal Hierarchy** from Section 1.4 has been applied to determine the point of stormwater discharge.
4) Piping systems that provide conveyance from a site to an ultimate discharge point must have adequate capacity per BES's standard, or additional flow control on-site may be required.

Discharge Point	Retention Requirement	Detention Requirement
Direct discharge to the Willamette River, Columbia River, or Columbia Slough, or discharge to a storm-only piping system or Multnomah Country Drainage District system with capacity that directly discharges to one of the above water bodies	Use on-site retention (flow volume control) facilities and infiltrate on-site to the maximum extent practicable.	None.
Discharge to any other overland storm drainage system, including ditches, drainageways, and streams, or any storm pipe system that eventually discharges to an overland drainage system	Use on-site retention (flow volume control) facilities and infiltrate on-site to the maximum extent practicable.	Limit 2-year post-development peak runoff rate to one-half of the 2-year pre-development peak rate; 5-year post to 5-year pre; 10-year post to 10-year pre; and 25-year post to 25-year pre-peak runoff rate.
Combined sewer	Use on-site retention (flow volume control) facilities and infiltrate on-site to the maximum extent practicable.	Limit 25-year post-development peak runoff rate to 10-year pre-development peak rate, unless sewer has available capacity.

1.7 OPEN DRAINAGEWAY POLICIES

A drainageway is an open linear depression, whether constructed or natural, that functions for the collection and drainage of surface water. It may be permanently or temporarily inundated. Drainageways provide many important functions to both the stormwater conveyance system and the environment. Drainageways provide both flow management (regulation of stream flow, retention and detention of water, flood control, contribution to seasonal base flows, and groundwater recharge) and water quality protection (filtration of pollutants and reduction of stormwater temperatures).

The City of Portland protects open drainageways by requiring them to be placed in drainage reserves. Drainage reserve requirements may be imposed during land use reviews, building permit reviews, or other development processes that require Bureau of Environmental Services review. The requirement to place the drainage reserve in a dedicated tract may be imposed during partition or subdivision land use reviews only.

Storm drainage reserves shall remain in natural topographic condition, or in the case of man-made drainages such as street ditches, the topographic condition at the time of the proposed development. No private structures, culverts, excavations, or fills shall be constructed within drainage reserves unless authorized by the BES Chief Engineer.

Sizing of Drainageway Reserves: Drainage reserves shall be sized to assure that the current flow rate and pattern of the drainageway continues to be adequately conveyed through the development site. Current flow volumes and/or drainageway capacities will be determined by reviewing existing data, which may include available hydrologic records, drainage basin hydrology, historical data, high-water marks, soil inundation records, photographs of past flooding, and other similar information. Reserves shall be placed on a proposed development site in one of the following manners:

1) 15 feet from the centerline of the channel; or
2) 15 feet from the delineated edge of a designated water feature (i.e. seep, spring, wetland); or
3) Within the boundary of a designated environmental zone; or
4) Over a designated seep, spring, or stream tract.

Exemptions: Drainage reserves shall not be required for drainageways located within a FEMA designated and mapped area.

Disturbances or Development within Drainage Reserves: Disturbances or development within the drainage reserve shall only be allowed when all of the following conditions exist:

1) The disturbance or development will not impede or reduce flows within the drainageway.
2) The disturbance or development will not cause detrimental impacts on habitat values or downstream water bodies for the migration, rearing, feeding, or spawning of fish.
3) Where the development involves a constructed crossing of the drainageway for vehicular or pedestrian access, there are no practicable alternatives with fewer impacts.
4) The development location, design, and construction method has the least significant detrimental impact to identified functional values of the drainageway of other practicable and different alternatives, including alternatives outside of the drainageway resource.

1.8 NON-CONFORMING USE PARKING LOTS

Non-Conforming Use Parking Lot Requirements

City Code Title 33.266: *Parking and Loading,* describes dimensions, landscaping, and other requirements for parking lots within the City of Portland. Title 33.248: *Landscaping and Screening* describes planting requirements for parking lots and other site uses. (See **Appendix F** for a list of approved parking lot trees.)

Existing parking lots required to meet the non-conforming use landscaping requirements under Title 33.258.070 must use surface retention facilities from **Chapter 2.0** where practicable in the newly required landscaped areas to manage stormwater from the parking lot. The appropriate sizing requirements shown on **Form SIM (Chapter 2.0)** shall be used to calculate the area needed for the applied measures. This requirement does not apply where it is not practical for runoff to flow into landscaped areas.

The following exceptions and/or conditions to these requirements may apply. If an exception is claimed, the applicant must still fulfill all other relevant requirements of this manual.

1. Contaminated soil conditions on the site preclude the use of landscape infiltration. Each site that has contaminated soils conditions must be evaluated by DEQ to determine if areas on the property are suitable for infiltration without the risk of mobilizing contaminants in the soil or groundwater. If it is determined that there are no suitable areas for infiltration, landscape facilities may be used for stormwater management, but must be lined to prevent infiltration.

2. The parking lot has been approved without landscaping, or has landscaping conditions that conflict with the use of the landscaping for stormwater management. (For example, if landscaping were required in a location that cannot receive stormwater as gravity flow, that portion of the landscaping would not have to be used for stormwater management)

1.9 DISCHARGING TO EXISTING STORMWATER MANAGEMENT FACILITIES

The City of Portland operates and maintains many stormwater management facilities. These facilities are designed to receive stormwater runoff from certain defined areas. A development may discharge to an existing **publicly** operated stormwater facility (see definition of public facility in **Section 1.3)** if all of the following criteria are met:

- The conveyance system and facility to which the development is discharging have capacity (see definition of capacity in **Section 1.3**). Stormwater runoff from development on private property shall not be discharged into new or existing public infiltration sump systems.

- The stormwater management facility is adequately designed in accordance with the most recent version of the *Stormwater Management Manual*, and was designed to include the development area in question.

- The applicant shows that private on-site infiltration facilities are being used to the maximum extent practicable, unless a previous land-use review case approved the development without such measures.

In addition to publicly owned and operated stormwater management facilities, many private facilities exist. A development may discharge to an existing **private** stormwater management facility if all of the following criteria are met:

- The conveyance system and facility to which the development is discharging has capacity (see definition of capacity in **Section 1.3**).

- The development's owner enters into a written agreement with the owner of the private stormwater management facility. BES and BDS must review and approve this agreement.

- There is no history of maintenance violations at the facility to which the development will be discharging, as determined by BES and BDS. BES may choose to conduct a site investigation to determine if the existing facility is being maintained adequately.

- The stormwater management facility is adequately designed in accordance with the most recent version of the *Stormwater Management Manual*, and was designed to include the development area in question.

1.10 PUBLIC VERSUS PRIVATE STORMWATER MANAGEMENT

Stormwater draining from private property shall be managed on private property, in privately maintained facilities. However, an applicant may construct and use a public facility for private and public stormwater management if **all** of the following conditions are met:

1) Public street improvements will require the construction of a public stormwater management facility.

2) The applicant has shown that private stormwater management facilities cannot be constructed on-site to manage the private runoff.

1.11 SPECIAL CIRCUMSTANCES

Special circumstances on a proposed site may make it impractical to implement on-site pollution reduction or flow control to the standards specified in this manual. Applicants who cite special circumstances shall submit **Form SC: Special Circumstances** (provided at the end of this section).

Properties are not eligible for special circumstances if they were divided or partitioned after this *Stormwater Management Manual* was adopted (July 1, 1999), and the division or partition resulted in the special circumstance (e.g., structural or other physical limitations at the site).

BES will determine if all or a portion of the stormwater management obligations may be fulfilled off-site. The applicant shall account for the management of all stormwater runoff from the site. If BES approves a special circumstances claim, the applicant must construct an appropriately sized off-site facility, or a fee must be paid to the City to construct off-site facilities. This fee is currently **$1.46** per square-foot of unmanaged impervious surface. The fee will be pro-rated to account for portions of the stormwater management obligation met on-site (as determined by the City's review of proposed on-site facilities). The unit cost will be further divided into pollution reduction and flow control components (**$0.73** per square-foot of impervious surface each) to account for differences in the development's ability to satisfy each component on-site.

No exceptions to meeting the stormwater management obligations are allowed. The developer shall either construct stormwater management facilities or pay the City to build off-site facilities. Except as listed above, on-site stormwater management shall be achieved to the maximum extent practicable, as approved by BES, in all cases before any off-site facilities or fees will be allowed.

In reviewing the applicant's plan submittal, the City will use the following criterion to determine if a special circumstance claim is allowed:

- Has the applicant made maximum use of on-site facilities identified in Chapter 2.0 for pollution reduction and/or flow control?

Applicants who are citing special circumstances are encouraged to obtain early assistance from BES by calling Development Assistance at 503-823-7761. BES will publish public notice of all requests for special circumstances.

Form SC	Special Circumstances

See Section 1.11 for requirements pertaining to Special Circumstances.

Part I: Identification of Special Circumstance(s)

Check all special circumstance(s) that apply:

☐ The site contains sensitive ecological or cultural features, or natural features that provide significant water quality or environmental benefits that should not be disturbed. There is no opportunity to avoid impact from facilities.

☐ On-site management would significantly increase the risk of landslides and slope instability.

☐ The project is declared emergency work, where there is a hazard posing imminent danger to life or property.

☐ Structural or other physical limitations at the site constrain the function, placement, or necessary maintenance of on-site pollution reduction or flow control measures.

☐ BES has determined that the use of an off-site regional facility is a better approach to achieve pollution reduction and flow control benefits.

☐ The project is a "linear" facility (e.g., sidewalk, bike lane) in an existing public right-of-way, and site conditions make it impractical to construct an on-site facility, as determined by BES.

Note: *Properties are <u>not</u> eligible for special circumstances if they were divided or partitioned after this Stormwater Management Manual was adopted (July 1, 1999), and the division or partition caused the special circumstance to occur (e.g., structural or other physical limitations at the site).*

Form SC **(Continued)**	**Special Circumstances**

Part II: Effects on Construction of On-site Stormwater Management

Describe the limiting effect(s) of the special circumstance(s) on the construction of on-site stormwater management facilities (pollution reduction, flow control, and destination):

Part III: Stormwater Management Percentages Achieved On and Off-Site

Indicate the portion of the site to be managed for pollution reduction:

On-site:	**Off-site:**

Indicate the portion of the site to be managed for flow control:

On-site:	**Off-site:**

Part IV: Proposed On and Off-site Stormwater Management Method(s)

Describe the destination/disposal method for the site. Also describe the on and off-site stormwater management methods to be used for pollution reduction and flow control. State "off-site management fee" if applicable.

Chapter 2.0
STORMWATER MANAGEMENT FACILITY DESIGN

Summary of Chapter 2.0

This chapter provides procedures for selecting and designing facilities that provide stormwater pollution reduction, flow control, and/or disposal benefits. It includes:

2.1 Introduction & Applicability
2.2 Design Methodologies
- **2.2.1 Simplified Approach**
  - **Form SIM**
- **2.2.2 Presumptive Approach**
  - **Surface Infiltration Facility Design Approach for Disposal**
- **2.2.3 Performance Approach**

2.3 Hydrologic Analysis Requirements
2.4 Infiltration Testing
2.5 Control Structures for Detention Systems
2.6 Access for Operations and Maintenance
2.7 Landscaping Requirements
2.8 Outfall Design
2.9 Facility Design Criteria

To Use This Chapter:

1) Use **Chapter 1.0** to determine the pollution reduction, flow control, and destination/ disposal requirements for the project.
2) Select stormwater management facilities from **Section 2.9: Facility Design Criteria** to meet pollution reduction, flow control, and/or disposal requirements for the project.
3) Size facilities using the **simplified approach**, **presumptive approach**, or **performance approach** presented in this chapter. For simplified approach facilities, use **Form SIM** for sizing. For presumptive approach facilities, use specific sizing criteria presented with each facility type and hydrologic analysis methods listed in **Section 2.3**. Integrate the facilities into the project's overall site plan.
4) Prepare drawings and specifications for each stormwater management facility in accordance with the design criteria in **Section 2.9: Facility Design Criteria**.
5) Consult **Chapter 3.0** for the operations and maintenance requirements for each stormwater management facility.

2.1 INTRODUCTION & APPLICABILITY

Facilities presented in this chapter receive credit for pollution reduction, flow control, disposal, or in some cases a combination of the three. Three methodologies are included in this chapter for the sizing and design of stormwater management facilities: the simplified, presumptive, and performance approach. Each design approach has limitations on applicability. See **Exhibit 2-1** for a list of the facility types, their applicable design methodologies, and stormwater management credits given.

Exhibit 2-1: Stormwater Management Facility Application Table

Stormwater Management Facility Type	Credit Given with Associated Design Approach		
	Pollution Reduction	Flow Control	Destination/ Disposal
Ecoroof & roof garden	Simplified	Simplified	NA
Pervious pavement	Simplified	Simplified	Performance
Contained planter	Simplified	Simplified	NA
Tree credit	Simplified	Simplified	NA
Infiltration planter	Simplified[1]	Simplified	Presumptive[3]
Flow-through planter	Simplified[1]	Simplified	NA
Vegetated swale	Simplified[1]	Simplified	Presumptive[3]
Grassy swale < 15,000 sq-ft impervious area	Simplified[1]	Simplified	Presumptive[3]
Grassy swale > 15,000 sq-ft impervious area	Presumptive	NA	Presumptive[3]
Street swales	Simplified[1]	Simplified	Presumptive[3]
Vegetated filter	Simplified[1]	Simplified	Presumptive[3]
Vegetated infil. basin	Simplified[1]	Simplified	Presumptive[3]
Sand filter	Simplified[1]	Simplified	Presumptive[3]
Wet pond	Presumptive	NA	NA
Extended wet det. pond	Presumptive	Presumptive	NA
Dry detention pond	Presumptive[4]	Presumptive	NA
Treatment wetland	Presumptive	Presumptive	NA
Manufactured treatment technology	Presumptive[5]	NA	NA
Structural det. facility	NA	Presumptive	NA
Spill control manhole	Presumptive[2]	NA	NA
Rainwater harvesting	Performance	Performance	NA
Private soakage trench	Presumptive	Presumptive	Presumptive
Public infiltration sump system	Presumptive[6]	Presumptive	Presumptive
Private drywell	NA	Presumptive	Presumptive

Exhibit 2-1 Notes:
[1] The performance approach may be used to downsize these simplified approach facilities when flow control is not required (**See Section 1.6.2**).
[2] Spill control manholes receive credit for oil removal only; additional pollution reduction facilities will be required to meet basic TSS removal requirements.
[3] The surface infiltration facility design criteria presented in **Section 2.2.2** must be used to receive disposal credit.
[4] Vegetated or grassy swales must be integrated into the bottom of dry detention ponds to receive pollution reduction credit.
[5] Manufactured treatment technologies must be pre-approved by BES to receive presumptive approach credit for pollution reduction.
[6] Public infiltration sump systems (sedimentation manhole and infiltration sump) will only receive credit for pollution reduction if used in residential low-use streets (< 1,000 average daily trips).

2.2 DESIGN METHODOLOGIES

2.2.1 Simplified Approach

The simplified approach is a relatively easy process for selecting and designing pollution reduction and flow control facilities, intended to save the project developer and the City time and expense. Combination facilities can be more practical to build than separate pollution reduction and flow control facilities. Facilities sized using the simplified approach retain stormwater near the ground surface, which provides a number of benefits, including pollution reduction, groundwater recharge and protection, peak flow reduction, and volume reduction. Rather than detaining stormwater and releasing it off-site at increased post-developed volumes, these facilities help infiltrate or retain water on-site. In areas with surface drainageways and streams, on-site retention lessens the "flashy" high- and low-flow impacts created by development in watershed basins. Stream erosion and temperature impacts are also decreased. In combination sewer areas, on-site retention facilities decrease the rate and volume of stormwater that flows through the system, decreasing the risk of combined sewer overflows and basement flooding. Overall, these facilities help mimic the natural hydrologic cycle by slowing and infiltrating stormwater.

Simplified Approach Sizing

Facilities designed in accordance with the simplified approach are presumed to comply with the City's pollution reduction and flow control requirements (see **Chapter 1.0**). As sized with **Form SIM** sizing factors, the simplified approach facilities do not sufficiently dispose of large storm events. Additional facilities, designed using the presumptive or performance approach, are required that meet the disposal requirements of this manual (See **Section 1.4**).

BES staff conducted a technical process to determine facility designs and sizes that would be effective on development sites. The process included a review of technical literature, review of BES monitoring data, calculations, and theoretical analysis. Sizing factors for the simplified approaches (shown on **Form SIM** below) were developed as a simple and quick tool to use for site planning and to accelerate permit review and approval. Generalized assumptions were used that may result in conservative sizing for some development sites. Manual users have the option to use the sizing factors as given on Form SIM, or follow the performance approach and submit an alternative facility size, along with supporting engineering calculations for BES review and consideration. The performance approach may be used to downsize facilities in circumstances when flow control is not required (see **Section 1.6.2**).

Appendix D: *Simplified Approach Sizing Calculations* provides information about how facility sizing factors were developed, and guidance on how the same methodology can be used to develop alternative facility sizes. An approved hydrologic analysis method (**Section 2.3**), such as a Santa Barbara Urban Hydrograph (SBUH) based approach or continuous simulation model, must be used to generate flow rates and volumes for design analysis. When facilities are downsized to meet pollution reduction requirements only, flows above the pollution reduction design flow must be routed around the facility with an approved diversion structure (**Section 2.5**) unless approved otherwise by BES.

The first three facility types on Form SIM (ecoroofs and roof gardens, contained planter boxes, and tree credits) and pervious pavements are impervious area reduction or mitigation techniques, and should be used first during the site planning and design stage to reduce the overall square-footage of impervious area that requires stormwater management. These facilities intercept rainfall, and are not generally designed to receive stormwater runoff. The second group of facilities listed on Form SIM (infiltration and flow-through planter boxes, vegetated and grassy swales, vegetated filter strips and infiltration basins, and sand filters) is designed to receive stormwater runoff from impervious surfaces.

Simplified Approach Submittal Requirements

Applicants using the simplified approach shall submit **Form SIM** as part of their permit application, along with construction drawings and details. **Page 2 of Form SIM** can be used to claim stormwater management credit for planting new trees and retaining existing tree canopy on-site. A copy of the operations and maintenance plan (see **Chapter 3.0**) shall also be included. In addition, a geotechnical report may be required by BES to evaluate the suitability of the proposed facility location. Projects that utilize simplified approach facilities must also fulfill the requirements identified in **Section 1.4:** Stormwater Destination/ Disposal.

Form SIM: Simplified Approach for Stormwater Management

The city has produced this form to assist with a quick and simple approach to manage stormwater on-site.
Facilities sized with this form are presumed to comply with pollution reduction and flow control requirements.
Stormwater disposal requirements per Section 1.4 must still be met.

New or Redeveloped Impervious Site Area _____ **Box 1**
(do not include roof areas that will be infiltrated on-site with drywells or soakage trenches)

INSTRUCTIONS

1. Enter square footage of new or redeveloped impervious site area in Box 1 at the top of this form.
2. Select impervious area reduction techniques from rows 1-3 to reduce the site's resulting stormwater management requirement. Tree credit can be calculated using the tree credit worksheet on the next page.
3. Select desired stormwater management facilities from rows 4-10. In Column 1, enter the square footage of impervious area that will flow into each facility type.
4. Multiply each impervious area from Column 1 by the corresponding sizing factor in Column 2, and enter the result in Column 3. This is the facility surface area needed to manage runoff from the impervious area.
5. Total Column 1 (Rows 1-10) and enter the resulting "Impervious Area Managed" in Box 2.
6. Subtract Box 2 from Box 1 and enter the result in Box 3. When this number reaches 0, stormwater pollution reduction and flow control requirements have been met. Submit this form with the application for permit.
7. If Box 3 is greater than 0 square feet, add square footage or facilities to Column 1 and recalculate, or use additional facilities from Chapter 2.0 of the Stormwater Management Manual to manage stormwater from these remaining impervious surfaces.

	Column 1	Column 2	Column 3
Impervious Area Reduction Technique	**Impervious Area Managed = Facility Surface Area**		
1) Eco-Roof / Roof Garden	_____ sf		
2) Contained Planter	_____ sf		
3) Tree Credit (See Next Page)	_____ sf		

Note: Pervious Pavement areas do not need to be included in Box 1

Stormwater Management Facility	**Impervious Area Managed**		**Sizing Factor**		**Facility Surface Area**	**Unit**
4) Infiltration Planter	_____ sf	x	0.06	=		sf
5) Flow-Through Planter	_____ sf	x	0.06	=		sf
6) Vegetated Swale	_____ sf	x	0.09	=		sf
7) Grassy Swale	_____ sf	x	0.12	=		sf
8) Vegetated Filter Strip	_____ sf	x	0.2	=		sf
9) Vegetated Infil. Basin	_____ sf	x	0.09	=		sf
10) Sand Filter	_____ sf	x	0.07	=		sf

For drywell and soakage trench sizing and design requirements, see Section 2.9.

Total Impervious Area Managed _____ **Box 2**

Box 1 - Box 2 _____ **Box 3**

Form SIM (Page 2): Tree Credit Worksheet

See **Tree Credits** in Section 2.9 for more information regarding the use of trees to meet stormwater management requirements.

New Evergreen Trees

To receive stormwater management credit, new evergreen trees must be planted within 25 feet of ground-level impervious surfaces. New trees cannot be credited against rooftop surfaces. Minimum tree height (at the time of planting) to receive credit is 6 feet.

Enter number of new evergreen trees that meet qualification requirements in Box A ____ **Box A**

Multiply Box A by 200 and enter result in Box B ____ **Box B**

New Deciduous Trees

To receive stormwater management credit, new deciduous trees must be planted within 25 feet of ground-level impervious surfaces. New trees cannot be credited against rooftop surfaces. Minimum tree caliper (at the time of planting) to receive credit is 2 inches.

Enter number of new deciduous trees that meet qualification requirements in Box C ____ **Box C**

Multiply Box C by 100 and enter result in Box D ____ **Box D**

Existing Tree Canopy

To receive stormwater management credit, existing tree canopy must be preserved during and after construction. Existing tree canopy must be within 25 feet of ground-level impervious surfaces. Existing trees cannot be credited against rooftop surfaces. Minimum tree caliper to receive credit is 4 inches. No credit will be given to existing tree canopy located within environmental zones. Tree canopy is measured around the tree's drip line.

Enter square-footage of existing tree canopy that meets qualification requirements in Box E ____ **Box E**

Multiply Box E by 0.5 and enter the result in Box F ____ **Box F**

Total Tree Credit

Add boxes B, D, and F and enter the result in Box G ____ **Box G**

For sites with less than 1,000 square-feet of new or redeveloped impervious area:

The amount in Box G is to be entered as "Tree Credit" on Form SIM. ** Stop Here **

For sites with more than 1,000 square-feet of new or redeveloped impervious area:

Multiply Box 1 of Form SIM by 0.1 and enter the result in Box H ____ **Box H**

Enter the lesser of Box G and H in Box I. ____ **Box I**

This is the amount to be entered as "Tree Credit" on Form SIM. **Stop Here**

2.2.2 Presumptive Approach

Facilities that utilize this design approach are classified as "presumptive," *presumed* to be in compliance with the City's pollution reduction, flow control, and/or disposal requirements if the presented sizing and design requirements are followed.

There are a few key differences between the presumptive and simplified approach sizing methodologies. Stormwater management goals that require the presumptive approach to be used for a particular facility type do not lend themselves well to simplified sizing. More detailed hydrologic calculations must be performed to adequately design the facility to achieve the desired goal. Another difference is that the presumptive approach presents sizing methodologies that meet the requirements of one particular goal (pollution reduction, flow control, or disposal), rather than multiple goals. See **Exhibit 2-1** for the table that specifies the design approaches that are applicable to each management goal, for each facility type.

Presumptive Approach Submittal Requirements

In addition to detailed construction drawings and specifications shown on permit drawings, all applicants using the presumptive approach for stormwater management are required to submit a detailed stormwater report. This report shall include a general description of the stormwater facility and how it is intended to function. It shall include detailed hydraulic calculations, as summarized in **Exhibit 2-2**. A copy of the operations and maintenance plan (see **Chapter 3.0**) shall also be provided. In addition, a geotechnical report may be required by BES to evaluate the suitability of the proposed facility location. Projects using facilities designed under the performance approach must also fulfill the requirements identified in **Section 1.4:** Stormwater Destination/ Disposal.

Exhibit 2-2:
Checklist of Calculations to be Included in Stormwater Report

Stormwater Facility Type
A= Grassy Swale
B= Wet Pond
C= Extended Wet Detention Pond
D= Dry Detention Pond
E= Constructed Treatment Wetland
F= Detention Tank, Vault, or Pipe
G= Manufactured Treatment Technology or Spill Control Manhole

Parameter or Calculated Value to be Included in the Stormwater Report	A	B	C	D	E	F	G
Site Variables:							
Site soil type (A, B, C, or D)	x	x	x	x	x	x	x
Contributing area (acres)	x	x	x	x	x	x	x
Pre-developed curve number CN			x	x	x	x	
Pre-developed time of concentration T of C (minutes)			x	x	x	x	
Post-developed curve number CN	x	x	x	x	x	x	x
Post-developed time of concentration T of C (minutes)	x	x	x	x	x	x	x
Distance from ground surface to max. height of seasonal groundwater (feet)	x	x	x	x	x	x	x
Hydrographs:							
Pre-developed hydrographs for the 2, 5, 10, 25, and 100-year storms, including peak rates and total volumes			x	x	x	x	
Post-developed hydrographs for the 2, 5, 10, 25, and 100-year storms, including peak rates and total volumes (only if routed through the facility)			x	x	x	x	
Post-developed hydrographs for the 2, 5, 10, 25, and 100-year storms after being routed through the facility, including peak rates and total volumes			x	x	x	x	
Facility Geometry:							
Table showing area and volume of the facility every 6" in elevation		x	x	x	x	x	
Side slopes (h: v or %)	x	x	x	x	x		
Longitudinal slope (h: v or %)	x				x		
Bottom width and length (feet)	x	x	x	x	x		
Overall width and length (feet)	x	x	x	x	x		
Hydraulic Controls:							
Orifice or weir descriptions, sizes, and elevations, including by-pass facilities			x	x	x	x	
Elevation, size, and type of overflow spillway or pipe	x	x	x	x	x	x	x
Calculated Values:							
Pollution reduction flow rate	x						x
Pollution reduction permanent pool volume and elevation		x	x		x		
Forebay volume and elevation		x	x	x	x		
Hydraulic residence time for the pollution control storm	x				x		
Storm routing data showing the peak water surface elevation in the facility for the 2, 5, 10, 25, and 100-year storms (only if routed through the facility)	x	x					x
Detailed storm routing data for the 2, 5, 10, 25, and 100-year storms, showing inflow rate, outflow rate, and water surface elevation in the facility every 10 minutes throughout the storm.			x	x	x	x	

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SURFACE INFILTRATION DESIGN APPROACH FOR DISPOSAL

Where soil conditions allow for percolation near the ground surface, surface infiltration facilities can be used to dispose of stormwater from large storm events. The infiltration of stormwater near the ground surface helps increase the separation to groundwater, providing a greater filtration layer and decreasing the risk of groundwater contamination. It also serves to mimic the predevelopment hydrologic cycle, decreasing downstream impacts by recharging groundwater and increasing evapotranspiration.

Examples of surface infiltration facilities that can be designed under this approach include vegetated, grassy, and street swales, infiltration planters, and vegetated infiltration basins. While the design procedure in this section accounts for complete on-site infiltration of stormwater, facilities sized per the simplified approach are not sized adequately to meet destination/ disposal standards and must include an overflow to an acceptable disposal point. Surface infiltration facilities are not classified as underground injection controls (UICs) by DEQ, and therefore do not need to be registered.

Surface Infiltration Design Approach to Meet Disposal Standards

1) Determine the preliminary facility size by calculating the runoff volume generated by the 10-year storm (3.4 inches of rainfall over 24 hours, NRCS Type 1A rainfall distribution). The SBUH method can be used to determine this volume, or the volume can be approximated by the following formula:

   Runoff Volume (cubic feet) = 0.28 feet * Impervious Area (square-feet)

   The facility will need to be capable of containing this volume of runoff through a combination of above ground storage and below ground storage within voids in a subsurface rock trench.

2) Surface infiltration facilities require infiltration tests during the design phase of the project. For public facilities, double-ring infiltrometer tests shall be conducted, in accordance with ASTM D3385-94, with BES review and approval. For private facilities, the falling head infiltration test procedure specified in **Section 2.4.2** shall be used. The minimum acceptable infiltration rate for surface infiltration facilities to meet disposal standards is 2 inches per hour. A clogging factor of 4 is then applied to the resulting infiltration rate to be used in the design of the facility.

3) The design infiltration rate (measured infiltration rate divided by 4) is then used to check the facility drawdown time. When full, the facility drawdown time shall not exceed 30 hours.

4) The wet seasonal high water table must be determined, and a minimum 4-foot clearance to bottom of facility must be maintained.

5) The 100-year storm inundation area shall be determined and must show that structures will not be flooded and that property damage and safety risks will be avoided.

6) Minimum setbacks from surface infiltration facilities to structures are shown in **Exhibit 2-4**.

7) All areas to be used as surface infiltration facilities shall be back-filled with a suitable sandy loam planting and filtration medium. Minimum depth shall correspond to each facility type's specification. The borrow source of this medium, which may be the same or a different location from the facility area itself, must be tested as follows:

   If the borrow area is virgin, undisturbed soil, one test is required per 200 square-feet of borrow area. The test consists of "grab" samples at 1-foot depth intervals to the bottom of the borrow area. All samples at the testing location are then mixed, and the resulting sample is laboratory tested to meet the following criteria:

   USDA minimum textural analysis requirements: A textural analysis is required from the site-stockpiled topsoil. If topsoil is imported, a textural analysis shall be performed for each location where the topsoil was excavated.

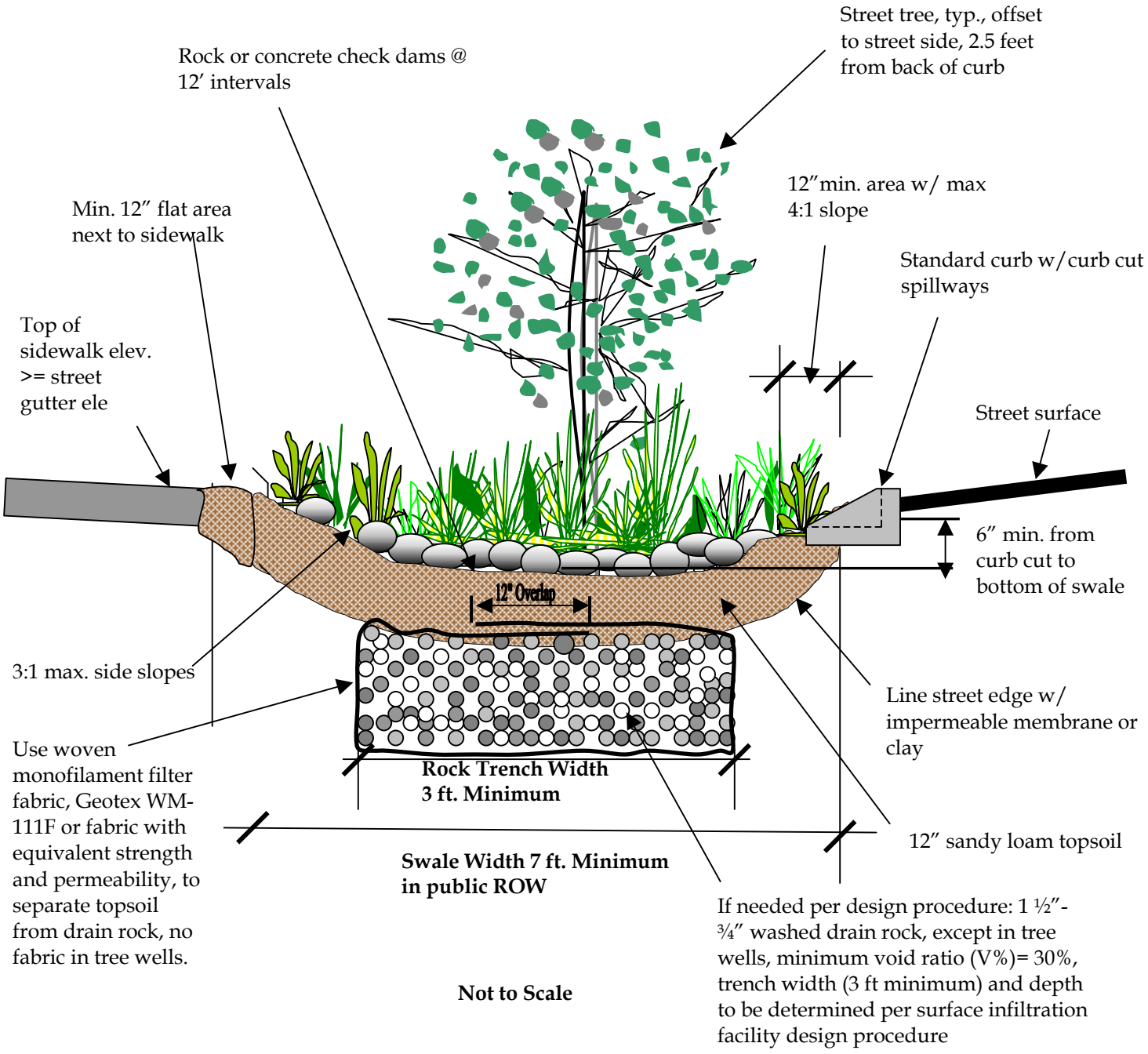
   Requirements:
   Sand 35 – 60%
   Silt 30 – 55% (Loam)
   Clay 10 – 25%

   The soil shall be a uniform mix, free of stones, stumps, roots, or other similar objects larger than two inches.

8) Surface infiltration facility areas shall be clearly marked before site work begins to avoid soil disturbance during construction. No vehicular construction traffic, except that specifically used to construct the facility, shall be allowed within 10 feet of surface infiltration facility areas.

9) For surface infiltration facilities, post-construction field infiltration testing will be required. Methods consistent with those used during design of the facilities shall be used. The resulting infiltration rate must show that the facility drawdown time will not exceed 30 hours.

Exhibit 2-3: Example Cross-Section of Vegetated Street Swale, Modified To Receive Credit for Disposal



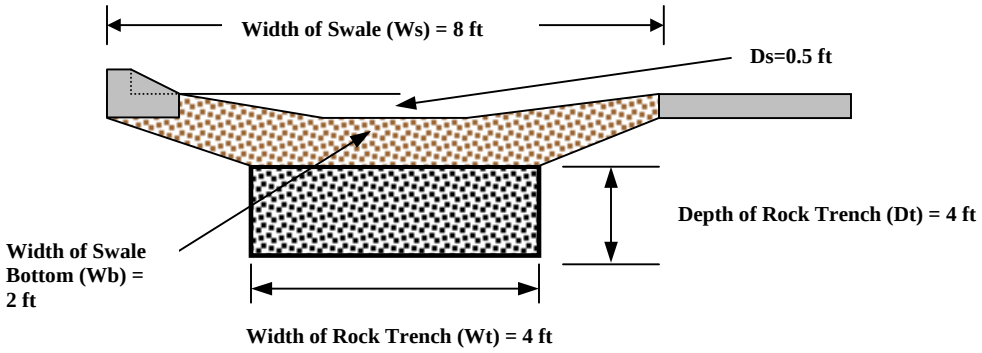
SURFACE INFILTRATION FACILITY SIZING EXAMPLE

Facility Type: Vegetated Street Swale

Objective: Find swale dimensions needed to meet stormwater disposal standards.

Givens: Design Storm (P) = 10 year, 24 hour storm = 3.4 total inches = **0.28 feet**
Maximum Drawdown Time (Td) = **30 hours**
Infiltration Rate Safety Factor = **4**

Site Characteristics:
Impervious Area (Ai) = 200′ x 28′ = **5,600 square feet**
Measured Infiltration Rate (Im), using Double-Ring Infiltrometer Test = 12″/hr = **1′/hr**
Swale width (Ws) = **8 feet**
Swale bottom width (Wb) = **2 feet**
Swale depth (Ds) = **0.5 feet**
Rock trench width (Wt) = **4 feet**
Rock trench depth (Dt) = **4 feet**
Void Ratio of Rock Trench (VR) dimensionless = **0.30**



Calculations:
Runoff Volume (Vr) cubic feet = P * Ai = 0.28 * 5,600 = **1,568 cubic feet**
Design Infiltration Rate (Id) feet per hour = Im / 4 = 1 ft/hr / 4 = **0.25 ft/hr**
Swale Storage Volume (Vs) = L * [(0.5 * Ds * (Ws + Wb)) + (VR * Wt * Dt)]

Check #1: Runoff Volume (Vr) must be less than or equal to Swale Storage Volume (Vs)

$$Vr <= Vs$$

$$(0.28 * Ai) <= L * [(0.5 * Ds * (Ws + Wb)) + (VR * Wt * Dt)]$$

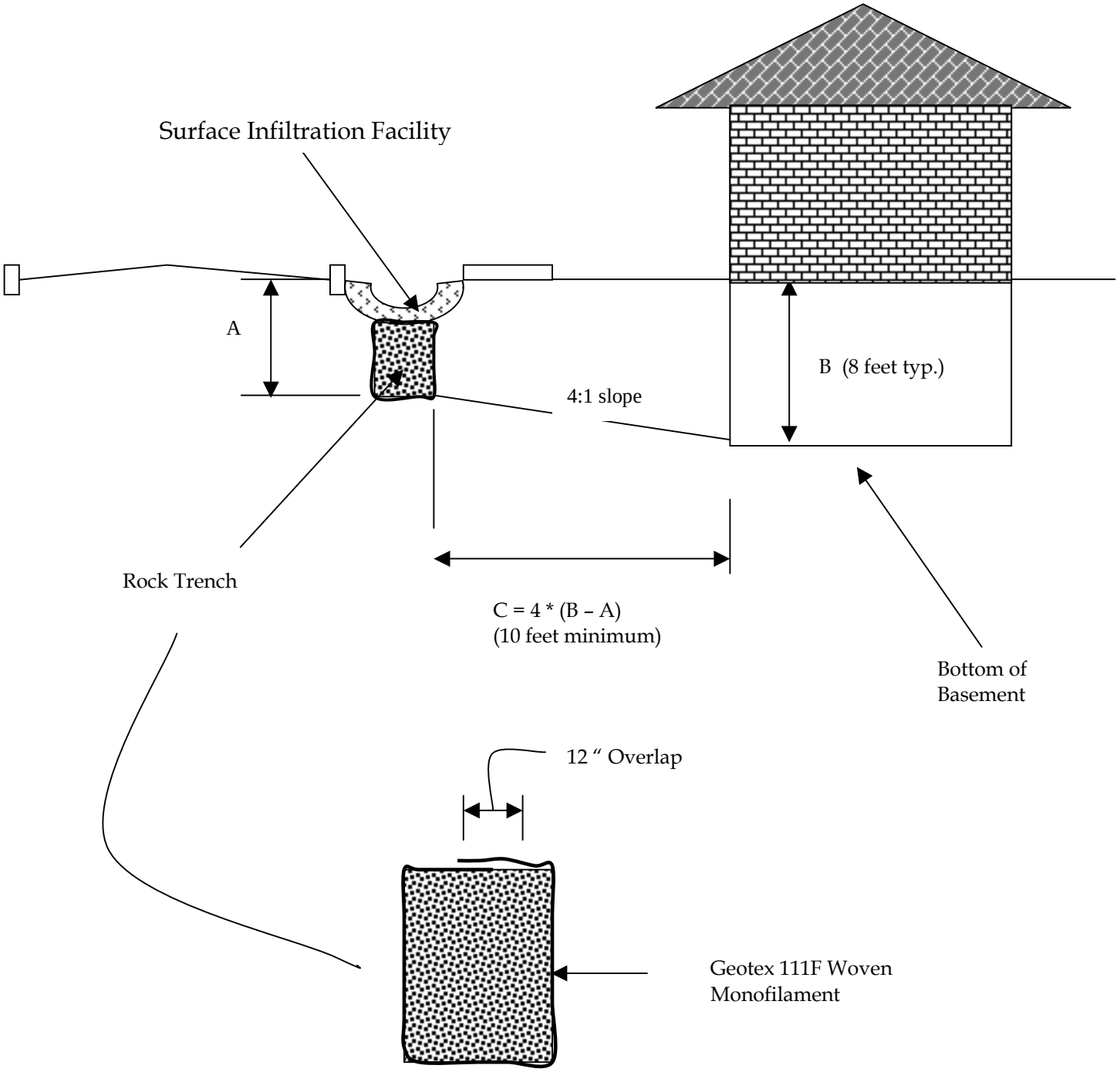
To find L: L = (0.28 * Ai) / [(0.5 * Ds * (Ws + Wb)) + (VR * Wt * Dt)]
L = (0.28 * 5,600) / [(0.5 * 0.5 * (8 + 2)) + (0.30 * 4 * 4)] = 215 feet

Check #2: Swale drawdown time must not exceed maximum allowable (Td) = 30 hours

$$(0.28 * Ai) / (Id * Wt * L) <= 30 \text{ hours}$$

(0.28 * 5,600) / (0.25 * 4 * 215) = 7.3 hours < 30 hours, therefore OK

Exhibit 2-4: Surface Infiltration Facility Setback Detail



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2.2.3 Performance Approach

The list of accepted stormwater management facilities is continually changing as new products are developed and more is learned about the performance of facilities already in use. Design professionals may propose facilities other than those included in this manual by using the performance approach. Design professionals may also use the performance approach to show that a facility is capable of reducing a TMDL pollutant of concern (See **Exhibit 1-2**), or to downsize a simplified approach sizing factor when flow control is not required.

The performance approach requires detailed engineering design and calculations, as well as documented evidence of the proposed design's performance. The City will accept the proposed design for meeting pollution reduction requirements if the design professional demonstrates that it:

- Will perform at the required efficiency: 70 percent total suspended solids (TSS) removal from 90% of the average annual runoff (See **Section 1.5**), and is capable of reducing the TMDL pollutant of concern (if applicable). See **Appendix B**: Vendor Submission Guidance for Evaluating Stormwater Treatment Technologies, for definition of 70 percent total suspended solids removal, which is actually a function of influent concentration. Also see Appendix B for required testing protocol, related definitions, and additional requirements. Documented performance is required and shall include published data, with supporting cited research, demonstrating removal of target pollutants at required levels.

- Can be efficiently maintained to perform at the required level, and for public facilities, will not require more costly maintenance than facilities designed using the simplified or presumptive approach.

Performance Approach Submittal Requirements

In addition to detailed construction drawings and details to be shown on permit drawings, all applicants using the performance approach for stormwater management are required to submit a detailed stormwater report. This report shall include a description of the stormwater facility, how it is intended to function, and documented evidence of the proposed design's performance. It shall include detailed hydraulic calculations as summarized in **Exhibit 2-2** and must demonstrate the performance criteria listed above. A copy of the operations and maintenance plan (see **Chapter 3.0**) shall also be included. In addition, a geotechnical report may be required by BES to evaluate the suitability of the proposed facility location. Projects using facilities designed under the performance approach must also fulfill the requirements identified in **Section 1.4:** Stormwater Destination/ Disposal.

2.3 HYDROLOGIC ANALYSIS REQUIREMENTS

With the exception of pollution reduction and flow control facilities designed using the simplified approach, stormwater management facilities must be designed using hydrologic analysis methods described below. If one of the hydrologic analysis methods discussed below is not used, BES must pre-approve the alternative method before the plans and calculations are submitted. Regardless of how the hydrologic calculations are performed, all hydrologic submittals shall include data necessary to facilitate BES's review. This data is summarized in **Exhibit 2-2**.

2.3.1 Pollution Reduction

Flow Rate-Based Facilities: With the exception of facilities sized using the simplified approach, BES will use the Rational Method with rainfall intensities presented in **Section 1.5.2** to verify flow rates used to size rate-based pollution reduction facilities. BES has verified these intensities, through a continuous simulation model utilizing Portland rainfall data, to treat 90% of the average annual runoff volume. The design professional may also use SBUH, NRCS TR-55, HEC-1, or SWMM to demonstrate treatment of 90% of the average annual runoff volume.

Flow Volume-Based Facilities: Volume-based pollution reduction facilities included in this manual (wet ponds and extended wet detention ponds) are required to use the pre-determined volume of 0.83 inches over 24 hours with a Vb/Vr (volume of basin/ volume of runoff) ratio of 2 to be in presumptive compliance. BES determined this volume, through a continuous simulation model utilizing Portland rainfall data, to provide adequate detention time to treat 90% of the average annual runoff volume.

Combination Rate/Volume-Based Facilities: With the exception of facilities sized using the simplified approach, BES will use a software program based on the Santa Barbara Urban Hydrograph (SBUH) method, or a continuous simulation model with Portland rainfall data, to verify the sizing of flow rate-based pollution reduction facilities that also rely on a storage volume component. An example of this includes the downsizing of simplified approach facilities (such as vegetated swales and infiltration basins) to achieve pollution reduction only. When using SBUH, a 0.83 inch, 24-hour storm with NRCS type 1A rainfall distribution shall be used. The design professional may also use NRCS TR-55, HEC-1, or SWMM to demonstrate treatment of 90% of the average annual runoff volume.

2.3.2 Flow Control

With the exception of facilities sized using the simplified approach, BES will use a software program based on the Santa Barbara Urban Hydrograph (SBUH) to check design calculations for flow control facilities. The design professional may also use

NRCS TR-55, HEC-1, or SWMM to demonstrate compliance with flow control standards.

2.3.3 Destination/ Disposal

The Rational Method must be used to design the infiltration flow rate for public infiltration sumps. If surface infiltration facilities, such as vegetated, grassy, or street swales, vegetated infiltration basins, and infiltration planters are proposed to meet destination/ disposal requirements, the **Surface Infiltration Facility** sizing methodology in Section 2.2.2 must be used to meet presumptive compliance. The surface infiltration facility sizing methodology relies on the determination of the 10-year storm runoff volume, which can be calculated using the simple approximation formula provided, SBUH, NRCS TR-55, HEC-1, or SWMM.

2.3.4 Conveyance

Please reference the City of Portland's *Sewer Design Manual* for acceptable hydrologic analysis methods for stormwater conveyance. The Rational Method will be used to verify design calculations for pipe or surface conveyance facility sizing. HEC-1 or SWMM may be used for projects greater than 100 acres in size.

2.3.5 Hydrologic Analysis Method Resources

The **Santa Barbara Urban Hydrograph (SBUH) Method** (**See Appendix C**) may be applied to small, medium, and large projects. It is a recommended method for completing the analysis necessary for designing flow control facilities when not using the simplified approach.

The **SCS TR-55 Method** may be applied to small, medium, and large projects. This is also one of the recommended methods for completing hydrologic analysis necessary for designing flow control facilities when not using the simplified approach. (Refer to SCS Publication 210-VI-TR-55, Second Edition, June 1986.)

The **HEC-1 Method** may be used on medium and large projects. (Refer to the HEC User's Manual.)

The **SWMM Method** may be used on medium and large projects. (Refer to the SWMM User's Manual.)

2.4 INFILTRATION TESTING

To size stormwater management facilities, it is often necessary to know the infiltration rate of the soil at the actual facility location. The following general criteria apply to all proposed infiltration facilities:

1) For all surface infiltration facilities being designed to meet disposal standards, a minimum infiltration rate of 2 inches per hour is required. Site-specific facility design may require a much higher infiltration rate.
2) Testing can be classified into three categories, (1) initial feasibility testing, (2) design testing, and (3) post-construction testing. (see **Exhibit 2-5**)
3) Testing shall be conducted or observed by a qualified professional. This professional shall either be a registered professional engineer in the State of Oregon, or a soils scientist or geologist licensed in the State of Oregon.
4) All field-testing must be done in the proposed area of the facility.
5) Testing data shall be documented, including a description of the infiltration testing method.

2.4.1 Initial Feasibility Testing

Initial feasibility testing is conducted to determine whether full-scale testing is necessary, and is meant to screen unsuitable sites and reduce testing costs. It involves either one field test per facility (regardless of type or size) or previous testing data, such as the following:

- Pre-approval from the City of Portland Bureau of Development Services Environmental Soils section (Call 503-823-7790 for more information)
- Septic percolation testing on-site, within 200 feet of the proposed facility location and on the same contour
- Previous written geotechnical reporting on the site location as prepared by a qualified geotechnical expert
- NRCS Multnomah County Soil Mapping showing unfeasible conditions such as a hydrologic group "D" soil in a low-lying area
- In the case of public sump systems, pre-approval from BES (Call 503-823-7761 for more information)

If the results of initial feasibility testing as determined by a qualified professional show that an infiltration rate of greater than 0.5 inches per hour is probable, then the design and post-construction testing shall be in accordance with **Exhibit 2-5**. BDS and BES may waive design-testing requirements if it is determined that adequate testing data exist. In the case of infiltration testing, an encased soil boring may be substituted for a test pit, if desired.

Exhibit 2-5: Infiltration Testing Summary Table

Type of Facility	Initial Feasibility Testing (Section 2.4.1)	Design Testing (Section 2.4.2)	Post-Construction Testing (Section 2.4.3)
Private Drywell System	Required	One test pit and one falling head test per drywell, unless waived by BDS.	May be required by BDS. (see **private drywell** section for procedure)
Private Soakage Trench	Required	One test pit and one falling head test per soakage trench, unless waived by BDS.	Not applicable.
Public Infiltration Sump System	Required	Testing of an existing sump in the vicinity, or construction and testing of one sump may be required by BES.	All public infiltration sumps must be field-tested after construction. (see **public infiltration sump** section for procedure)
Surface Infiltration Facility	Required	One double-ring infiltrometer test (for public facilities) or one falling head test (for private facilities) per 200 square-feet of facility area	May be required by BDS (if private) or BES (if public). (see **surface infiltration facility** design section for procedure)

2.4.2 Design Testing

Where required, the following **test pit** procedure shall be followed:

1) Excavate a test pit or dig a standard soil boring to a minimum depth of 4 feet below the proposed facility bottom elevation. Also conduct Standard Penetration Testing (SPT) every 2 feet to a depth of 4 feet below the facility bottom.
2) Determine depth to highest seasonal groundwater table (if within 4 feet of proposed bottom) upon initial digging or drilling.
3) Determine USDA or Unified Soil Classification System textures at the proposed bottom and 4 feet below the bottom of the facility.
4) Determine depth to bedrock (if within 4 feet of proposed bottom).
5) The soil description should include all soil horizons.
6) The location of the test pit or boring shall correspond to the facility location; test pit/soil boring stakes are to be left in the field for inspection purposes and shall be clearly labeled as such.

Where required, the following **falling head infiltration test** procedure shall be followed:

1) Install casing (solid 5-inch diameter, 36-inch length) to 24 inches below proposed facility bottom (see **Exhibit 2-6**).
2) Remove any smeared soiled surfaces and provide a natural soil interface into which water may percolate. Remove all loose material from the casing. Upon the tester's discretion, a 2-inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring and sediment. Fill casing with clean water and allow to pre soak for 24 hours, or until the water has completely infiltrated.
3) Refill casing and monitor water level (measured drop from the top of the casing) for 1 hour. Repeat this procedure (filling the casing each time) three additional times, for a total of four observations. Upon the tester's discretion, the final field rate may either be the average of the four observations or the value of the last observation. The final rate shall be reported in inches per hour.
4) Testing may be done through a boring or open excavation.
5) The location of the test shall correspond to the facility location.
6) Upon completion of the testing, the casings shall be immediately pulled, and the test pit shall be back-filled.

Where required, the **double-ring infiltrometer test** procedure must follow ASTM D3385-94, standard test method for infiltration rate of soils in field using double-ring infiltrometer.

Note: For soils west of the Willamette River or similar soil types known as Cascade silt loams (soils with a fragipan that causes a perched water table in winter months), testing must be done between June 1 and October 1.

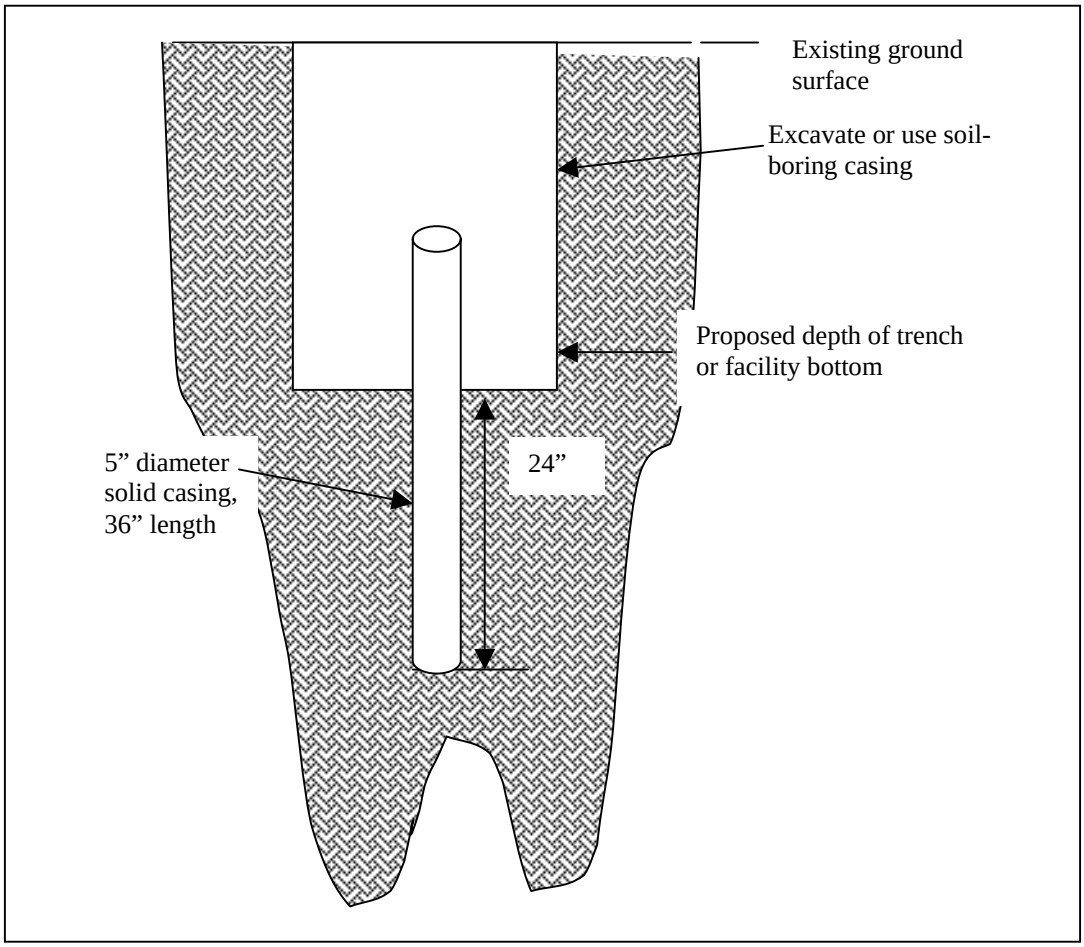
2.4.3 Post-Construction Testing

See surface infiltration facility, sump, and drywell design sections for post-construction infiltration testing requirements.

2.4.4 Laboratory Testing

Grain-size sieve analysis and hydrometer tests where appropriate may be used to determine USDA soils classification and textural analysis. Visual field inspection by a qualified professional may also be used, provided that it is documented. The use of laboratory testing to establish infiltration rates is prohibited.

Exhibit 2-6: Falling Head Test Requirements



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2.5 CONTROL STRUCTURES FOR DETENTION SYSTEMS

This section presents the methods and equations for the design of flow restricting control structures, for use with extended wet detention ponds, dry detention ponds, and structural detention facilities. It includes details and equations for the design of orifices, and equations for rectangular sharp crested weirs and v-notch weirs.

Weir and orifice structures must be enclosed in a catch basin, manhole, or vault, and must be accessible for maintenance.

2.5.1 Design Requirements

The following criteria apply to control structure design.

- The control structure shall be designed to pass the 100-year storm event as overflow without causing flooding of the contributing drainage area.

Orifices

- Orifices may be constructed on a "tee" riser section (see **Exhibit 2-7**) or on a baffle (see **Exhibit 2-8**).

- The minimum allowable diameter for an orifice used to control flows in a public facility is 2 inches. Private facilities may utilize a 1-inch diameter orifice if additional clogging prevention measures are implemented. The orifice diameter shall always be greater than the thickness of the orifice plate.

- Multiple orifices may be necessary to meet the 2- through 25-year design storm performance requirements for a detention system. However, extremely low flow rates may result in the need for small orifices (< 1-inch for private facilities, < 2-inch for public) that are prone to clogging. In these cases, retention facilities that do not rely on orifice structures shall be used to the maximum extent practicable to meet flow control requirements (see **Section 1.6.2**). Where this is not practicable, the applicant must pay the off-site management fee rather than constructing a flow control facility. Large projects may also result in high flow rates that necessitate excessively large orifice sizes that are impractical to construct. In such cases, several orifices may be located at the same elevation to reduce the size of each individual orifice.

Orifice Sizing Equation:

$$Q = C A \sqrt{2gh}$$

where:

Q = Orifice discharge rate, cfs
C = Coefficient of discharge, feet (suggested value = 0.60 for plate orifices)
A = Area of orifice, square feet
h = hydraulic head, feet
g = 32.2 ft/sec^2

The diameter of plate orifices is typically calculated from the given flow. The orifice equation is often useful when expressed as an equivalent orifice diameter in inches.

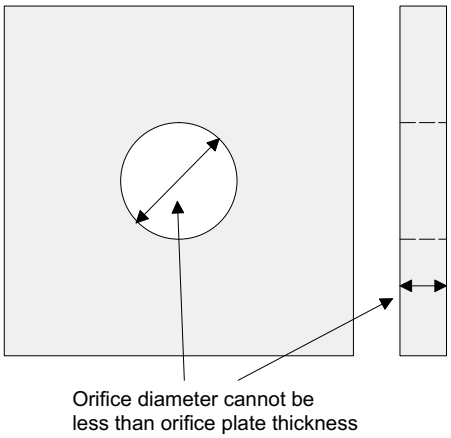
$$d = \sqrt{\frac{36.88\ Q}{\sqrt{h}}}$$

where:

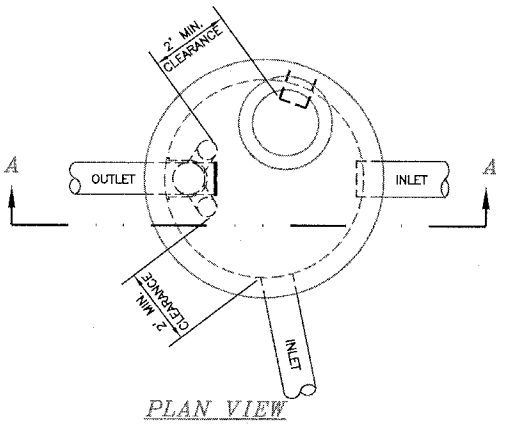
Q = flow, cfs
d = orifice diameter, inches
h = hydraulic head, feet

- Orifices shall be protected within a manhole structure, or by a minimum 18-inch-thick layer of 1½" to 3" evenly graded, washed rock. Orifice holes shall be externally protected by stainless steel or galvanized wire screen (hardware cloth) with a mesh of 3/4" or less. Chicken wire shall not be used for this application.

- Orifice diameter shall be greater than or equal to the thickness of the orifice plate (see diagram).



- If less than 3", the orifice shall not be made of concrete. A thin material (e.g., stainless steel, HDPE or PVC) shall be used to make the orifice plate; the plate shall be attached to the concrete or structure.



PLAN VIEW

NOTES:

1. EXCEPT AS SHOWN OR NOTED, UNITS SHALL BE CONSTRUCTED IN ACCORDANCE WITH THE REQUIREMENTS FOR LARGER PRE CAST CONCRETE MANHOLE, PER C.O.P. STANDARD PLAN 4–08–1.

2. FOR DETAILS SHOWING GRADE RING, STEPS, MANHOLES, AND TOP SLABS, SEE C.O.P. STANDARD PLAN 4–08–1.

3. PIPE SUPPORTS SHALL ANCHORED AT 3' MAX. SPACING BY 3/8 DIA. STAINLESS STEEL EXPANSION BOLTS EMBEDDED 2" IN WALL.

4. THE RESTRICTOR/SEPARATOR SHALL BE FABRICATED FROM SOLID WALL HDPE PIPE, OR APPROVED EQUAL.

5. OUTLET SHALL BE CONNECTED TO RESTRICTOR PIPE WITH A FLEXIBLE COUPLING.

6. THE VERTICAL RISER STEM OF THE RESTRICTOR/ SEPARATOR SHALL BE THE SAME DIAMETER AS THE HORIZONTAL OUTLET PIPE, WITH A 10" MINIMUM DIAMETER.

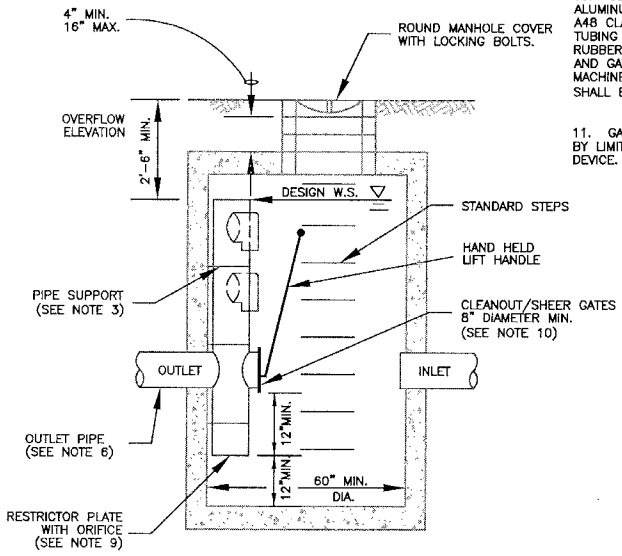
7. FRAME AND STEPS ARE TO BE OFFSET SO THAT:
   A. CLEAN OUT GATE IS VISIBLE FROM TOP
   B. CLIMB–DOWN SPACE IS CLEAR OF RISER AND GATE.
   C. FRAME IS CLEAR OF CURB (IF ANY EXISTS).

8. MULTI–ORIFICE ELBOWS MAY BE LOCATED AS SHOWN OR ALL ON ONE SIDE OF RISER TO ASSURE LADDER CLEARANCE. SIZE OF ELBOWS AND PLACEMENT TO BE CLEARLY LABELED ON THESE PLANS.

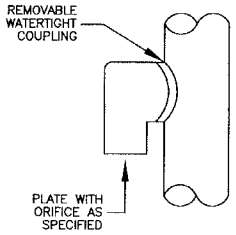
9. RESTRICTOR PLATE WITH ORIFICE AS SPECIFIED ON THESE PLANS. SPECIFIED OPENING TO BE CUT ROUND AND SMOOTH.

10. CLEANOUT/SHEAR GATE: ALUMINUM ALLOY PER B–26–26–32E OR CAST IRON ASTM A48 CLASS 308 AS REQUIRED. LIFT HANDLE EITHER SOLID OR TUBING WITH ADJUSTABLE HOOK AS REQUIRED. NEOPRENE RUBBER GASKET REQUIRED BETWEEN RISER MOUNTING FLANGE AND GATE FLANGE. MATING SURFACES OF LID AND BODY TO BE MACHINED FOR PROPER FIT. FLANGE MOUNTING BOLTS SHALL BE 3/4" DIA. STAINLESS STEEL.

11. GATE SHALL NOT OPEN BEYOND THE CLEAR OPENING BY LIMITED HINGE MOVEMENT, STOP TABS, OR SOME OTHER DEVICE.



SECTION A – A



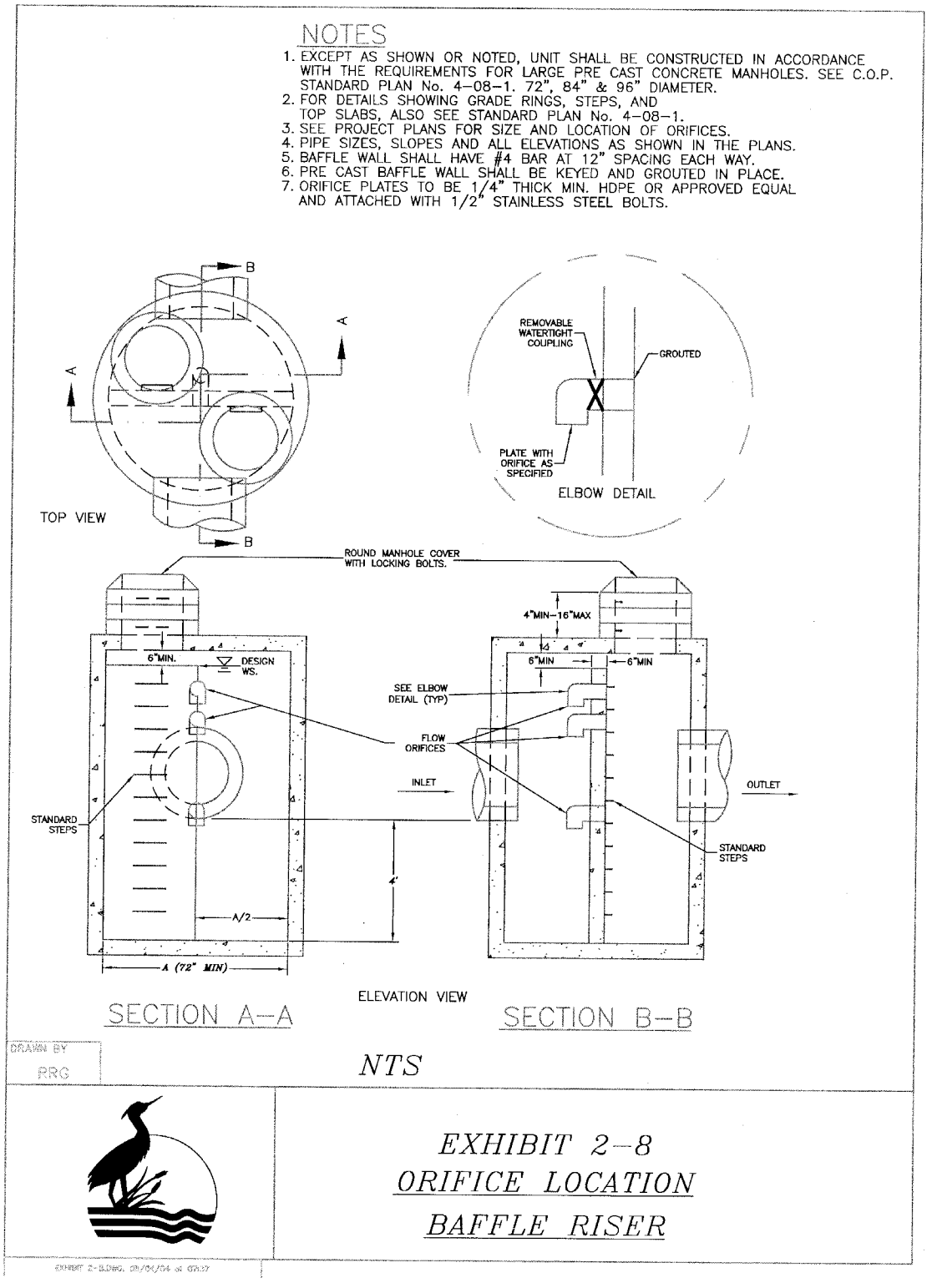
ELBOW DETAIL

DRAWN BY RRG

NTS

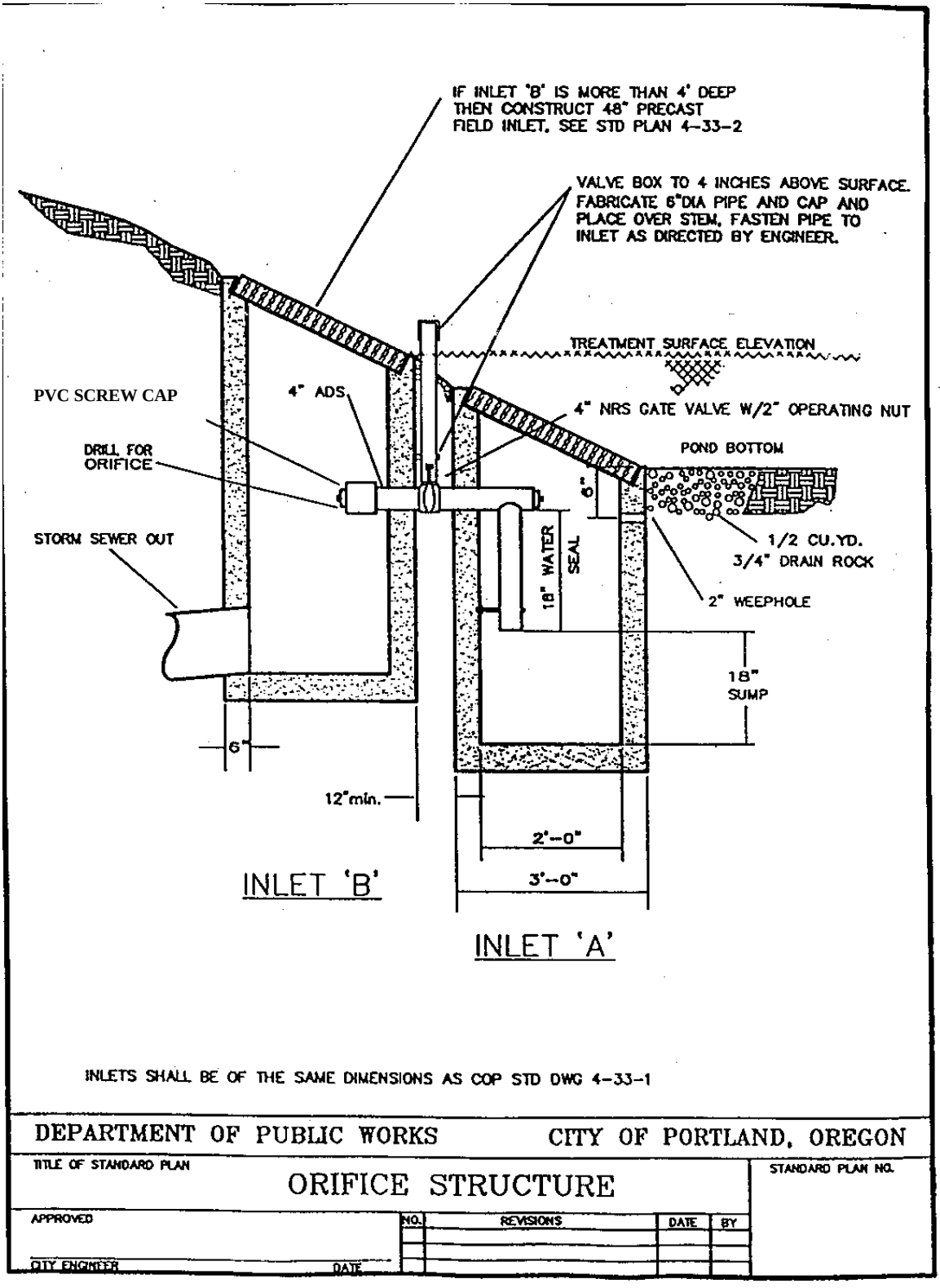
EXHIBIT 2–7
ORIFICE LOCATION
TEE RISER

SARB_007824


NOTES
1. EXCEPT AS SHOWN OR NOTED, UNIT SHALL BE CONSTRUCTED IN ACCORDANCE WITH THE REQUIREMENTS FOR LARGE PRE CAST CONCRETE MANHOLES. SEE C.O.P. STANDARD PLAN No. 4-08-1. 72", 84" & 96" DIAMETER.
2. FOR DETAILS SHOWING GRADE RINGS, STEPS, AND TOP SLABS, ALSO SEE STANDARD PLAN No. 4-08-1.
3. SEE PROJECT PLANS FOR SIZE AND LOCATION OF ORIFICES.
4. PIPE SIZES, SLOPES AND ALL ELEVATIONS AS SHOWN IN THE PLANS.
5. BAFFLE WALL SHALL HAVE #4 BAR AT 12" SPACING EACH WAY.
6. PRE CAST BAFFLE WALL SHALL BE KEYED AND GROUTED IN PLACE.
7. ORIFICE PLATES TO BE 1/4" THICK MIN. HDPE OR APPROVED EQUAL AND ATTACHED WITH 1/2" STAINLESS STEEL BOLTS.
B
A
A
B
TOP VIEW
REMOVABLE WATERTIGHT COUPLING
GROUTED
PLATE WITH ORIFICE AS SPECIFIED
ELBOW DETAIL
ROUND MANHOLE COVER WITH LOCKING BOLTS.
6"MIN.
DESIGN WS.
STANDARD STEPS
A/2
A (72" MIN)
SECTION A--A
SEE ELBOW DETAIL (TYP)
FLOW ORIFICES
INLET
4"MIN-16"MAX
6"MIN
6"MIN
OUTLET
STANDARD STEPS
4'
ELEVATION VIEW
SECTION B--B
DRAWN BY
PRG
NTS
EXHIBIT 2-8
ORIFICE LOCATION
BAFFLE RISER

SARB_007825

Exhibit 2-9:



SARB_007826

Rectangular Notched Sharp Crested Weir

$$Q = C\,(L - 0.2H) * H^{1.5}$$

where:

Q= Weir discharge, cubic feet per second (cfs)
C = 3.27 + 0.40*H/P, feet
P = Height of weir bottom above downstream water surface, feet
H = Height from weir bottom to crest, feet
L = Length of weir, feet*

* For weirs notched out of circular risers, length is the portion of the riser circumference not to exceed 50 percent of the circumference.

V-Notched Sharp Crested Weir

$$Q = C_d\,(\text{Tan}\ \frac{\theta}{2})\ H^{\frac{5}{2}}$$

where:

Q = Weir discharge, cfs
C_d = Contraction coefficient, feet (suggested value = 2.5 for 90 degree weir)
θ = Internal angle of notch, degrees
H = Height from weir bottom to crest, feet

2.6 ACCESS FOR OPERATIONS AND MAINTENANCE

Adequate access for operations and maintenance must be provided to all stormwater management facilities and their components. Public facilities shall have access routes at least 8 feet wide, not to exceed 10 percent in slope, and shall be located adjacent to public rights-of-way wherever feasible. Where structural surfaces are needed to support maintenance vehicles, access routes shall be constructed of gravel or other permeable paving surface where possible. Public facility vehicular access routes shall be designed for H-20 loading.

2.7 LANDSCAPING REQUIREMENTS

Vegetation is a key element in the performance of many stormwater management facilities. Facility-specific planting requirements are given in **Section 2.9**. These requirements are based on BES experience and/or standard landscape industry methods for design and construction, and are required to be covered by a 2-year warranty period.

At the end of the first year and again at the end of the 2-year warranty period, all plants that do not survive must be replaced. Establishment procedures, such as control of invasive weeds, animal and vandal damage, mulching, re-staking, watering, and mesh or tube protection replacement, shall be implemented to the extent needed to ensure plant survival.

Designers may elect to use BES's Watershed Revegetation Program approach, which allows smaller materials to be planted in larger quantities. If this approach is chosen, the following requirements shall apply:

1) A 5-year warranty period from the time of plant installation shall be provided.
2) Plants must be installed during the dormant season, typically defined as December through March.
3) A survival rate of 75 percent (no replacements) must be achieved for all bare root plants measured in the third and fifth year after installation. If the survival rate falls below this threshold, a number of additional plants, sufficient to meet the 75% survival rate must be installed. The number of additional plants required will be based on the mortality rate of the initial planting.
4) Density of plantings shall be at least one tree and one shrub per 50 square feet of facility area. These plants are bare root (seedlings) and range in size from 10 inches to 24 inches tall.
5) Bareroot seedlings must be dormant in order to harvest from farm sites for planting.
6) All plants must be native from local seed sources and found on the Portland Plant List. A minimum of four different species of trees and shrubs must be used. At least half of the trees must be evergreen. Ground covers must be native

grasses and wildflowers from local seed sources. See **Appendix F** for a list of native plant suppliers.

7) During the period between harvest and installation, the plants must be kept in a temperature-controlled facility. Temperature must be kept between 33 and 36 degrees Fahrenheit, and plant roots must be kept moist at all times. Plants must be planted within 24 hours of removal from the temperature-controlled facility.

Applicants may obtain more information from BES's Watershed Revegetation Program.

Stormwater facilities located in the public street right-of-way are not required to use evergreen trees to meet landscaping requirements.

Where the plant material requirements of this manual and Title 33 differ, the designer shall use the larger quantity and sizes. (In calculating quantities, fractions should be rounded to the higher number.) The Watershed Revegetation Program approach uses smaller plants and may not always satisfy Title 33 requirements.

Landscaping required by Title 33 may be counted toward meeting the facility-specific landscape requirements in this chapter if the plantings are located within the facility area. Similarly, plantings that meet the requirements in this chapter may also meet Title 33 landscape requirements.

It is critical that selected plant materials are appropriate for soil, hydrologic, and other facility and site conditions. For facilities located in environmental zones, or BES maintained facilities located outside of the public right-of-way, all plants within the facility area shall be appropriate native species from the **BES recommended plant lists** in **Appendix F** or the latest edition of the Portland Plant List (no nuisance or prohibited plants). The designer may also refer to the Planning Bureau's *Environmental Handbook*.

The design for plantings shall minimize the need for herbicides, fertilizers, pesticides, or soil amendments at any time before, during, and after construction and on a long-term basis. Plantings shall be designed to minimize the need for mowing, pruning, and irrigation.

Grass or wildflower seed shall be applied at the rates specified by the suppliers. If plant establishment cannot be achieved with seeding by the time of substantial completion of the stormwater facility portion of the project, the contractor shall plant the area with wildflower sod, plugs, container plants, or other means to complete the specified plantings and protect against erosion before water is allowed to enter the facility.

Landscaping Submittal Requirements

The design must include elements that ensure landscape plant survival and overall stormwater facility functional success. Construction specifications and/or drawings need to include the following elements:

- Irrigation system to be used for the establishment period and permanent long-term. Note that public stormwater management facilities shall be designed so permanent long-term irrigation systems are not needed.

- Landscape plan showing the location of landscape elements, including size and species of all proposed plantings, and existing plants and trees to be preserved.

- Plant list/table, including scientific name, size at time of planting, quantity, type of container, evergreen or deciduous, appropriate planting season, native or non-native to region, and other information in accordance with the facility-specific planting section and landscape industry standards.

- Topsoil stockpile location, including source of topsoil, if imported. Include erosion protection per the City's *Erosion Control Manual*. Soil analysis for all topsoil to be used within the facility area. (Soil analysis is not required for single-family residential sites.)

2.8 OUTFALL DESIGN

Outfalls shall be located above the downstream mean low water level, except as approved by the City. **Exhibit 2-10** shows a typical outfall layout. Concrete endwalls will be required for all exposed outfall pipes greater than 12 inches in diameter (See **Exhibit 2-13**). Publicly accessible outfalls greater than 18 inches in diameter shall include grated protection in accordance with **Exhibit 2-14**. All outfalls shall be provided with a rock splash pad or other approved erosion control/energy dissipation measures. Rock protection at outfalls from small diameter pipes shall be as follows:

RIP-RAP PAD DIMENSIONS FOR SMALL OUTFALLS
2" Pipe: 12" wide x 24" long x 2" deep, Average Stone Size = 1"
4" Pipe: 24" wide x 36" long x 4" deep, Average Stone Size = 2"
6" Pipe: 36" wide x 48" long x 6" deep, Average Stone Size = 4"

Rock protection at outfalls from pipes greater than 6 inches shall be designed in accordance with **Exhibit 2-11,** unless otherwise approved by the City. **Exhibit 2-12**

shows riprap class selection. All rock protection areas shall be inter-planted with willow stakes or other approved plantings, every two feet on-center, to increase stability, reduce erosion, provide shading, and improve aesthetics.

Engineered energy dissipaters, including stilling basins, drop pools, hydraulic jump basins, baffled aprons, and bucket aprons, are required for outfalls with velocity at design flow greater than 20 feet per second (fps). These shall be designed by a professional engineer using published references such as *Hydraulic Design of Energy Dissipaters for Culverts and Channels* (U.S. Department of Transportation, Federal Highway Administration) and other references. The construction plan submittal shall identify the design reference.

Outfalls to drainageways and rivers are often located in environmental zones. Environmental review may be required as per City Code Title 33.

Drainageways and rivers may have steep slopes or banks and may have unstable landforms (i.e. slump). Geotechnical investigation to determine the stability of the stream or river bank, as reviewed and approved by BES or BDS, may be required for approval.

Exhibit 2-10: Typical Outfall Layout With Energy Dissipation

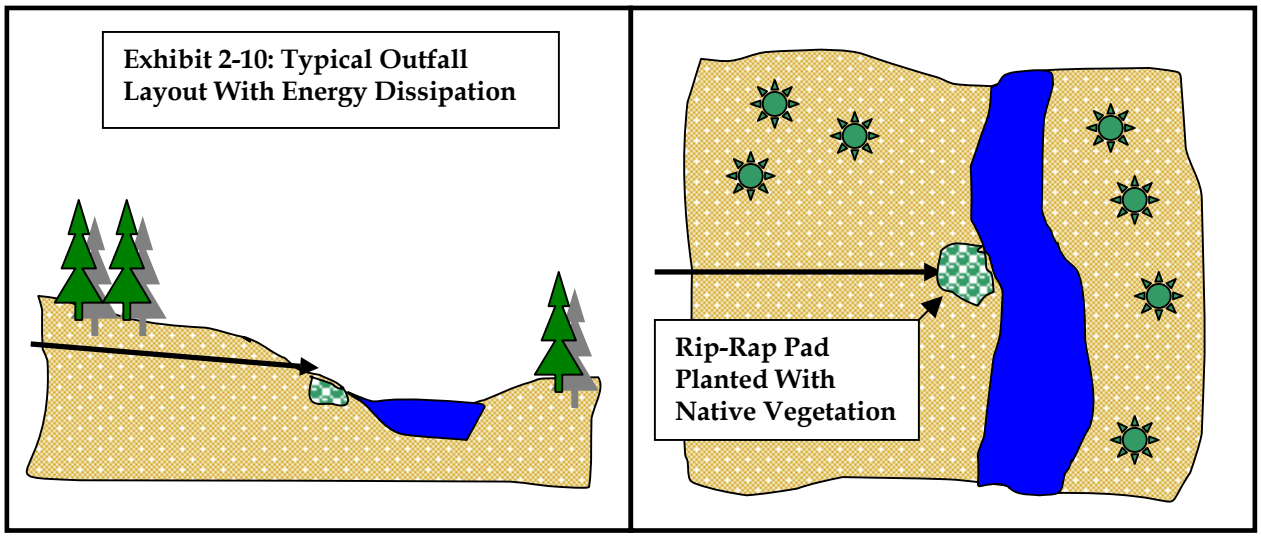


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Exhibit 2-11
ROCK PROTECTION AT OUTFALLS FOR PIPES GREATER THAN 6 INCHES IN DIAMETER

Discharge Velocity at Design Flow (fps)			REQUIRED PROTECTION Minimum Dimensions				
			Type	Depth*	Width	Length**	Height
0	To	5	Riprap*	2 x (max stone size)	Diameter + 6 ft.	As calculated	Crown + 1 ft.
6	To	10	Riprap*	2 x (max stone size)	Diameter + 6 ft. or 3x dia. which-ever is greater	As calculated	Crown + 1 ft.
11	To	20	Gabion or Riprap*	2 x (max stone size)	Diameter + 6 ft. or 4x dia. which-ever is greater	As calculated	Crown +1 ft.
Over 20			Engineered Energy Dissipater Required				

* Riprap size shall be determined using the following formulae*** and the *City of Portland Standard Construction Specifications*, Chapter 610.2.04 Broken Stone

V = Average velocity (ft/s)
Do = Pipe diameter (ft)
ds = Riprap diameter (ft)
Lsp = Apron length (ft)
depth = Thickness (ft)
Fo = $V/(g*Do)^{0.5}$

*Riprap size ds=0.25*Do*Fo (6" minimum)
Depth=2*ds (1 foot minimum)
**Apron length Lsp= Do(8+17*Log Fo)

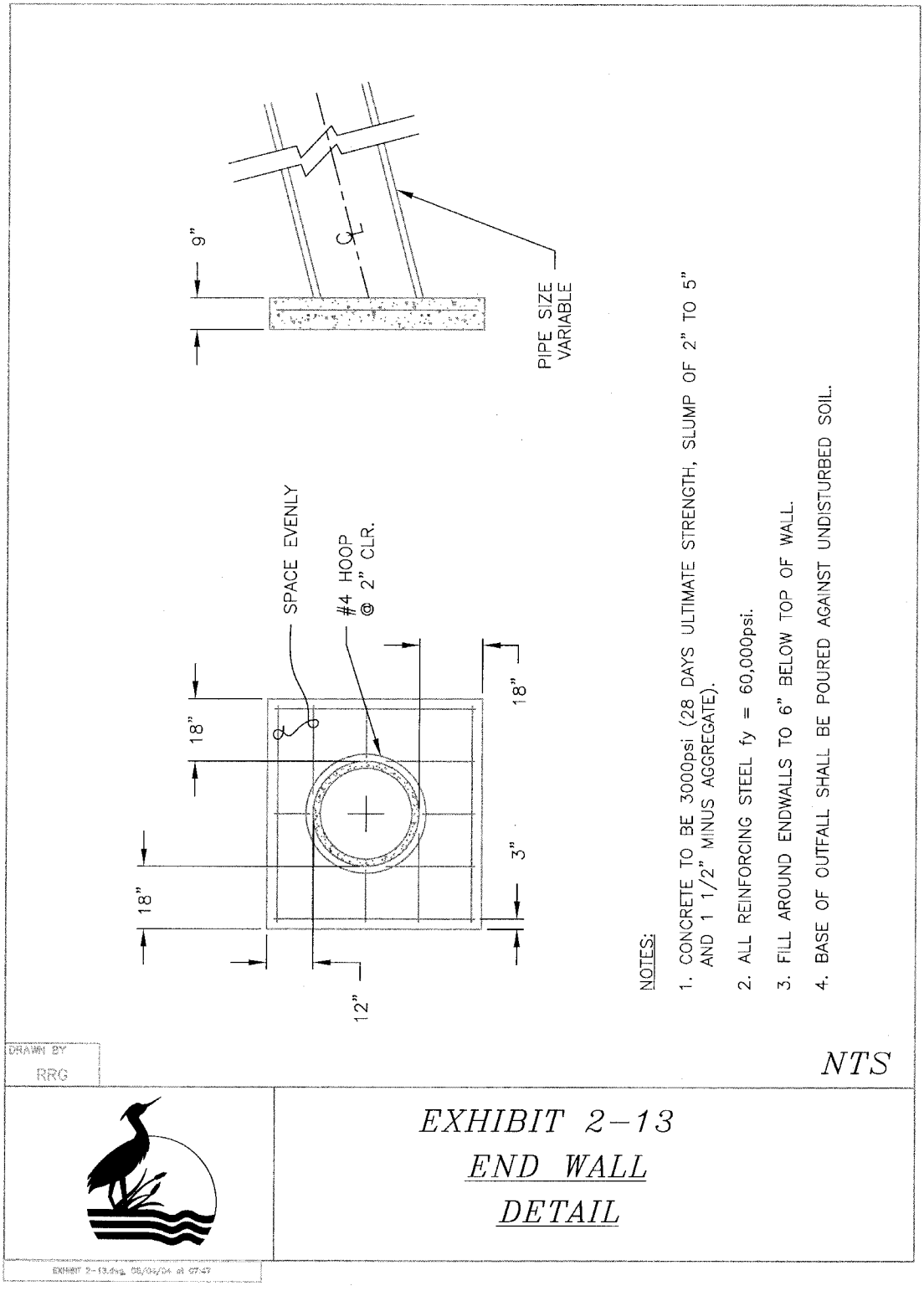
$g = 32.2\ ft/s^2$

***US Army Corps of Engineers design formulas from *Erosion and Riprap Requirements at Culvert and Storm Outlets*, January 1970

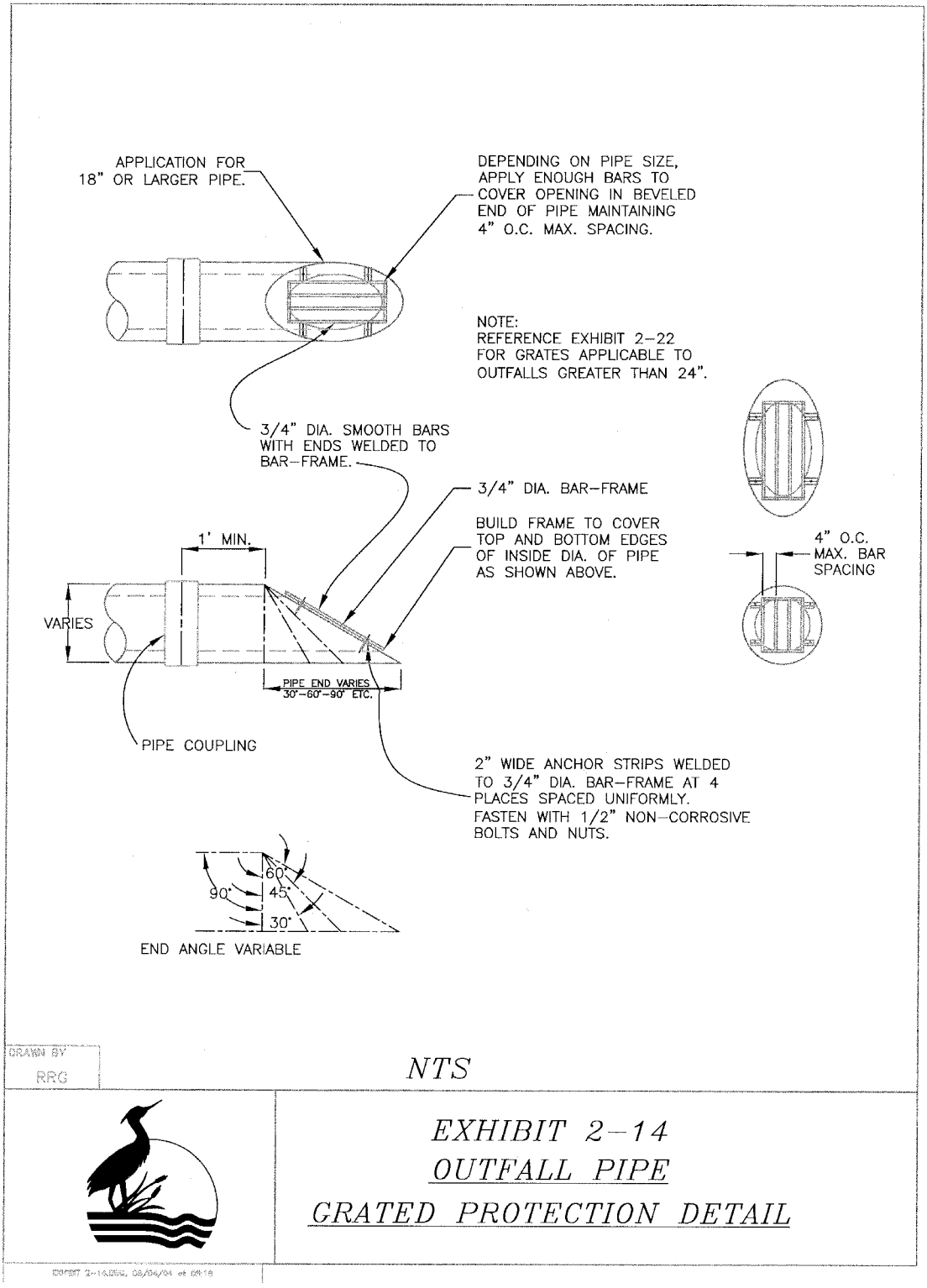
Exhibit 2-12: RIPRAP CLASS SELECTION

Weight (lbs)	Spherical Size (inches)	% by Weight	Average Stone Size (inches)
Class 50			6.3
30 – 50	8.5 – 10	20	
15 – 30	6.7 – 8.5	30	
2 – 15	3.5 – 6.7	40	
0 – 2	0 – 3.5	10	
Class 100			7.6
60 – 100	10.6 – 12.8	20	
25 – 60	8.0 – 10.6	30	
2 – 25	3.5 – 8.0	40	
0 – 2	0 – 3.5	10	
Class 250			11.3
200 – 250	15.0 – 18.0	20	
100 – 200	12.0 – 15.0	30	
10 – 100	6.0 – 12.0	40	
0 – 10	0 – 6.0	10	
Class 700			15.2
500 – 700	21.5 – 24.0	20	
200 – 500	15.9 – 21.5	30	
20 – 200	7.4 – 15.9	40	
0 – 20	0 – 7.4	10	
Class 2000			21.7
1400 – 2000	30.4 – 34.0	20	
700 – 1400	24.0 – 30.4	30	
40 – 700	9.3 – 24.0	40	
0 – 40	0 – 9.3	10	

Reference: Erosion and Riprap Requirements at Culverts and Storm-Drain Outlets
U.S. Army Engineers, Jan 1970


9"
PIPE SIZE VARIABLE
SPACE EVENLY
#4 HOOP @ 2" CLR.
18"
18"
18"
3"
12"
NOTES:
1. CONCRETE TO BE 3000psi (28 DAYS ULTIMATE STRENGTH, SLUMP OF 2" TO 5" AND 1 1/2" MINUS AGGREGATE).
2. ALL REINFORCING STEEL fy = 60,000psi.
3. FILL AROUND ENDWALLS TO 6" BELOW TOP OF WALL.
4. BASE OF OUTFALL SHALL BE POURED AGAINST UNDISTURBED SOIL.
NTS
DRAWN BY
RRG
EXHIBIT 2-13
END WALL
DETAIL

SARB_007834


APPLICATION FOR
18" OR LARGER PIPE.
DEPENDING ON PIPE SIZE,
APPLY ENOUGH BARS TO
COVER OPENING IN BEVELED
END OF PIPE MAINTAINING
4" O.C. MAX. SPACING.
NOTE:
REFERENCE EXHIBIT 2-22
FOR GRATES APPLICABLE TO
OUTFALLS GREATER THAN 24".
3/4" DIA. SMOOTH BARS
WITH ENDS WELDED TO
BAR-FRAME.
3/4" DIA. BAR-FRAME
BUILD FRAME TO COVER
TOP AND BOTTOM EDGES
OF INSIDE DIA. OF PIPE
AS SHOWN ABOVE.
1' MIN.
VARIES
PIPE END VARIES
30°-60°-90° ETC.
PIPE COUPLING
4" O.C.
MAX. BAR
SPACING
2" WIDE ANCHOR STRIPS WELDED
TO 3/4" DIA. BAR-FRAME AT 4
PLACES SPACED UNIFORMLY.
FASTEN WITH 1/2" NON-CORROSIVE
BOLTS AND NUTS.
60°
90°
45°
30°
END ANGLE VARIABLE
DRAWN BY
RRG
NTS
EXHIBIT 2-14
OUTFALL PIPE
GRATED PROTECTION DETAIL

2.9 FACILITY DESIGN CRITERIA

Stormwater Management Design Criteria For:

Ecoroof & roof garden
Pervious pavement
Contained planter
Tree credit
Infiltration planter
Flow-through planter
Vegetated swale
Grassy swale
Street swales
Vegetated filter
Vegetated infiltration basin
Sand filter
Wet, extended wet detention, and dry detention pond
Constructed treatment wetland
Manufactured treatment technology
Structural detention facility
Spill control manhole
Rainwater harvesting
Private soakage trench
Public infiltration sump system
Private drywell

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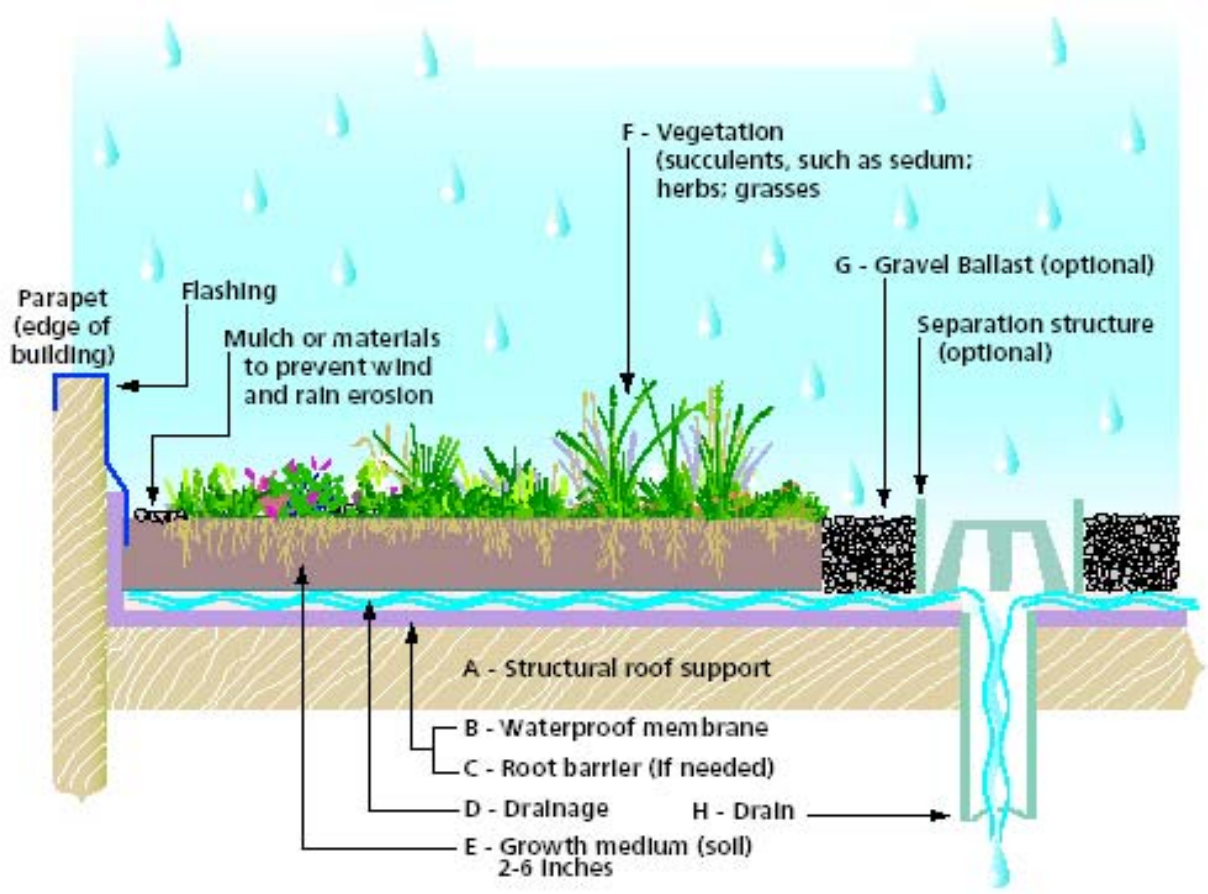
Ecoroof & Roof Garden



Stormwater Management Goals Achieved	**Acceptable Sizing Methodologies**
√ Impervious Area Reduction	SIM
√ Pollution Reduction	SIM
√ Flow Control	SIM
Destination/ Disposal	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) This facility is an impervious surface reduction technique. Its applicability is limited to rooftops or decks above building structures.

Ecoroof & Roof Garden





Ecoroof Description: An ecoroof is a lightweight roof system of waterproofing material with a thin soil/vegetation protective cover. The ecoroof can be used in place of a traditional roof as a way to limit impervious site area. The ecoroof captures and depending on the season, evapotranspirates 10 to 100 percent of the precipitation. Ecoroofs attempt to mimic pre-developed ground cover hydrology, reducing post-developed peak runoff rates to near pre-developed rates. Ecoroofs help mitigate runoff temperatures by keeping roofs cool and retaining most of the runoff in warm seasons. An underdrain system and overflow to an approved conveyance and destination/disposal method per **Section 1.4** will be required.





Ecoroof & Roof Garden

Roof Garden Description: A roof garden is a heavy weight roof system of waterproofing material with a thick soil/vegetation protective cover. The roof garden can be used in place of a traditional roof to limit impervious site area. The roof garden captures and then evapotranspirates 50 to 100% of precipitation, depending on the season. Roof gardens attempt to mimic pre-developed hydrology, therefore reducing post-developed peak runoff rates to near pre-developed rates. They help mitigate runoff temperatures by keeping roofs cool and retaining most of the runoff in warm seasons. Roof gardens should not be used on slopes greater than 10%. A drain system and overflow to an approved conveyance and destination/disposal method per **Section 1.4** will be required.

Design Requirements:

General Specifications: Good quality waterproofing material must be used on the roof surface. Soil of adequate fertility and drainage capacity at depths of 2-6 inches, and weight of 10 to 30 pounds per square foot, shall be applied. The building structure must be shown to be adequate to hold the additional weight. Vegetation shall be self-sustaining plants, without the need for fertilizers or pesticides. Soil coverage to prevent erosion shall be established immediately upon installation by using mulch, vegetation mats, or other approved protection method. Ninety-percent plant coverage shall be achieved within 2 years. Temporary irrigation to establish plants is recommended. A permanent irrigation system using potable water may be used, but an alternative means of irrigation, such as air conditioning condensate or other non-potable sources is recommended. Alternative sources should be analyzed to determine if the source has chemicals that might harm or kill the vegetation. Maximum roof slope shall be 25%, unless the applicant can provide documentation for runoff control on steeper slopes.

A. **Structural Roof Support:** The structural roof support must be sufficient to hold the additional weight of the ecoroof. For retrofit projects, check with an architect, structural engineer, or roof consultant to determine the condition of the existing building structure and what might be needed to support an ecoroof. This might include additional decking, roof trusses, joists, columns, and/or foundations. Generally, the building structure must be adequate to hold an additional 10 to 25 pounds per square-foot (psf) saturated weight, depending on the vegetation and growth medium that will be used. (This is in addition to snow load requirements.) An existing rock ballast roof may be structurally sufficient to hold a 10-12 psf ecoroof. (Ballast typically weighs 10-12 psf.)

   For New Construction the project architects and structural engineers shall address the structural requirements of the ecoroof during the design process.

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Greater flexibility and options are available for new buildings than for re-roofing. The procedures for the remaining components (B through H) are the same for both re-roofing and new construction.

B. Waterproof Membrane (Impermeable Material): Waterproof membranes are made of various materials, such as modified asphalts (bitumens), synthetic rubber (EPDM), hypolan (CPSE), and reinforced PVC. Some of the materials come in sheets or rolls and some are in liquid form. They have different strengths and functional characteristics. Some of these products require root inhibitors (refer to C) and other materials to protect the membrane. Numerous companies manufacture waterproofing materials appropriate for ecoroofs.

Protection Boards or Materials: These materials protect the waterproof membrane from damage during construction and over the life of the system, usually made of soft fibrous materials.

C. Root Barrier (If needed): Root barriers are made of dense materials that inhibit root penetration. The need for a root barrier depends on the waterproof membrane selected. Modified asphalts usually require a root barrier, while synthetic rubber (EPDM) and reinforced PVC generally do not. Check with the manufacturer to determine if a root barrier is required for a particular product. Note: membranes impregnated with pesticides are not allowed. Manufacturers must provide BES with evidence that membranes impregnated with copper will not leach out at concentrations of concern.

D. Drainage Layer (If needed): There are numerous ways to provide drainage. Products range from manufactured perforated plastic sheets to a thin layer of gravel. Some ecoroof designs do not require any drainage layer other than the growth medium itself, depending on roof slope and size (for example, pitched roofs and small flat roofs).

E. Growth Medium (Soil): The growth medium is generally 2 to 6-inches thick and well drained. It weighs from 10 to 25 pounds per square-foot when saturated. A simple mix of one-fourth topsoil, one-fourth compost, and one-half pumice perlite may be sufficient for many applications. Some companies have their own growth medium specifications. Other components could include digested fiber, expanded clay or shale, or coir.

F. Vegetation: Ecoroof and roof garden vegetation should have the following attributes:

- Drought-tolerant, requiring little or no irrigation after establishment

- A growth pattern that allows the plant to thoroughly cover the soil. At least 90% of the overall surface shall be covered.
- Self-sustaining, without the need for fertilizers, pesticides, or herbicides
- Able to withstand heat, cold, and high winds
- Very low-maintenance, needing little or no mowing or trimming
- Perennial or self-sowing
- Fire resistant

A mix of sedum/ succulent plant communities is recommended because they possess many of these attributes. Herbs, forbs, grasses, and other low groundcovers can also be used to provide additional benefits and aesthetics; however, these plants may need more watering and maintenance to survive and keep their appearance.

***Link to Ecoroof Landscaping Plan Example**
***Link to Ecoroof and Roof Garden Recommended Plants**

Installation: Four methods (or combinations of them) are generally used to install the vegetation: vegetation mats, plugs/ potted plants, sprigs, and seeds.

1. **Vegetation mats** are sod-like, pre-germinated mats that achieve immediate full plant coverage. They provide immediate erosion control, do not need mulch, and minimize weed intrusion. They also need minimal maintenance during the establishment period and little ongoing watering and weeding.
2. **Plugs or potted plants** may provide more design flexibility than mats. However, they take longer to achieve full coverage, are more prone to erosion, need more watering during establishment, require mulching and more weeding.
3. **Sprigs** are hand-broadcast. They require more weeding, erosion control, and watering than mats.
4. **Seeds** can be either hand-broadcast or hydraseeded. Like sprigs, they require more weeding, erosion control, and watering than mats.

G. **Gravel Ballast (If needed):** Gravel ballast is sometimes placed along the perimeter of the roof and at air vents or other vertical elements. The need for ballast depends on operational and structural design issues. It is sometimes used to provide maintenance access, especially to vertical elements requiring periodic maintenance. In many cases, very little, if any, ballast is needed. In some situations a header or separation board may be placed between the gravel ballast and adjacent elements (such as soil or drains). If a root barrier is used, it must extend under the gravel ballast and growth medium, and up the side of the vertical elements.

Ecoroof & Roof Garden

H. Drain: As with a conventional roof, an ecoroof must safely drain runoff from the roof to an approved stormwater destination. See **Section 1.4** for stormwater destinations.

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from roof lines
2) Profile view of facility, including typical cross-sections with dimensions
3) Growing medium specification, including weight
4) Filter fabric specification
5) Drainage layer specification
6) Waterproof membrane specification, including root barriers
7) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
8) Planting and irrigation plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Roof Structure	Call for inspection
Waterproof membrane	Call for inspection
Drainage layer/ plumbing & pipes	Call for inspection
Growing medium, plantings & irrigation	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to ecoroof and roof garden O&M form**

Additional photos and drawings:

*** Link to ecoroof and roof garden photos**
*** Link to ecoroof and roof garden drawings**

Ecoroof & Roof Garden

FAR Bonus for Ecoroofs and Roof Gardens in the Central City:

Under City Code Chapter 33.510.210: Floor Area and Height Bonus Options, Option #10 provides an ecoroof bonus option in the Central City. The option is provided below:

10. Ecoroof bonus option. Ecoroofs are encouraged in the Central City because they reduce stormwater run-off, counter the increased heat of urban areas, and provide habitat for birds. An ecoroof is a rooftop stormwater facility that has been certified by the Bureau of Environmental Services (BES). Proposals that include ecoroofs receive bonus floor area. A proposal may not earn bonus floor area for both the ecoroof option and the rooftop gardens option; only one of these options may be used.

    a. Bonus. Proposals that include ecoroofs receive bonus floor area as follows:

        (1) Where the total area of ecoroof is at least 10 percent but less than 30 percent of the building's footprint, each square foot of ecoroof earns one square foot of additional floor area.
        (2) Where the total area of ecoroof is at least 30 percent but less than 60 percent of the building's footprint, each square foot of ecoroof earns two square feet of additional floor area.
        (3) Where the total area of ecoroof is at least 60 percent of the building's footprint, each square foot of ecoroof earns three square feet of additional floor area.

    b. The applicant must submit a letter from BES with the application for land use review. The letter must certify that the ecoroof is approved and must specify the area of the ecoroof.

c. The property owner must execute a covenant with the City ensuring installation, preservation, maintenance, and replacement, if necessary, of the ecoroof. The covenant must comply with the requirements of 33.700.060.

The City is currently exploring options to expand the FAR bonus to other districts.

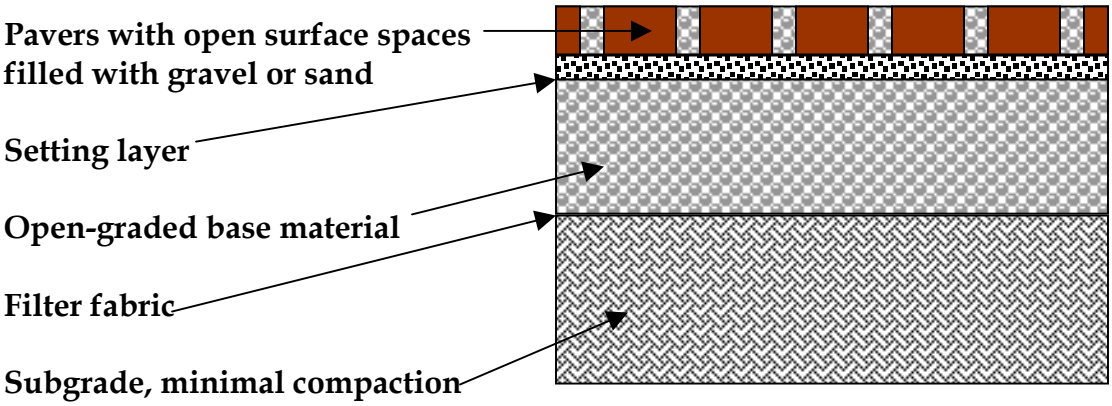
SARB_007844

Ecoroof & Roof Garden

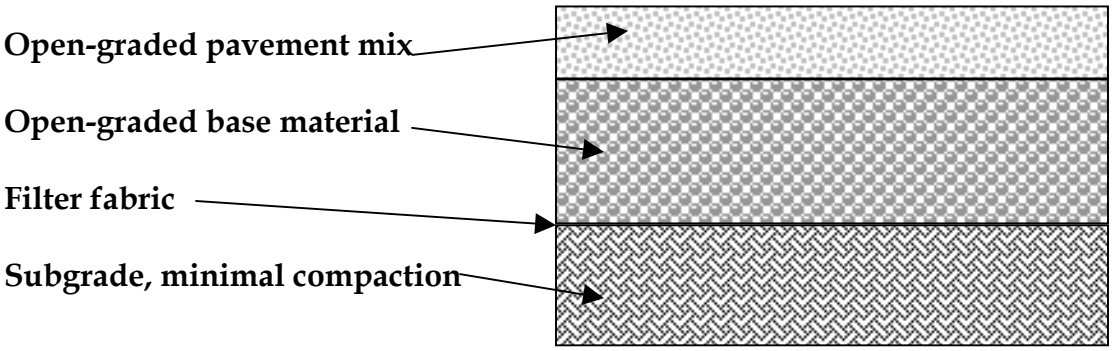
SARB_007845

Pervious Pavement

Pervious Concrete Block or "Paver" Systems



Pervious (Open Graded) Concrete and Asphalt Mixes



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Impervious Area Reduction	
√ Pollution Reduction……....	SIMP
√ Flow Control……	SIMP
√ Destination/ Disposal……	PERF

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) This facility is an impervious surface reduction technique. It is applicable for use in parking lots, driveways, and in some cases streets.

Pervious Pavement





Description: There are many types of pervious pavement on the market today. Numerous products and design approaches are available, including special asphalt paving; manufactured products of concrete, plastic, and gravel; paving stones; and brick. It may be used for walkways, patios, plazas, driveways, parking lots, and some portions of streets, subject to compliance with building codes and PDOT and BES Administrative Rules. To receive credit, the material must be installed and maintained to manufacturer's specifications. These materials may not be allowed in certain areas (see **Chapter 4.0** for restrictions). A professional engineer, registered in the state of Oregon must design pervious pavement systems that will be supporting vehicular traffic. For EPA's "Porous Pavement Phase I Design and Operational Criteria" (EPA-600/2-80-135), go to: **http://www.epa.gov/ednnrmrl/repository/abstrac2/abstra2.htm.** For BES's report on pervious pavement demonstration projects, vendors, and other resources, go to: **http://www.portlandonline.com/bes/index.cfm?&a=41626** .

Design Considerations: When designing pervious pavement systems, the infiltration rate of the native soil is a key element in determining the depth of base rock for the storage of stormwater, or for determining whether an underdrain system is appropriate. Traffic loading and design speed are important considerations in determining which type of pervious pavement is applicable. Pedestrian ADA accessibility, aesthetics, and maintainability are also important considerations, depending on pavement use.

Construction Considerations: Installation procedures are vital to the success of pervious pavement projects, particularly pervious asphalt and concrete pavement mixes. The subgrade cannot be overly compacted with the inclusion of fine particulates or the void ratio critical to providing storage for large storm events will be lost. Weather conditions at the time of installation can affect the final product. Extremely high or low temperatures should be avoided during construction of pervious asphalt and concrete pavements.

Pervious Pavement

Design Requirements:

Soil Suitability: Pervious pavement systems are appropriate for all soil types, but will require underdrain systems to an approved stormwater disposal point (per **Section 1.4**) for soils that do not infiltrate well (less than 2 inches per hour, generally NRCS soil types C and D). There shall be no less than three feet of undisturbed infiltration medium between the bottom of the base rock and any impervious layer (i.e. hardpan, solid rock, high groundwater levels, etc.), unless an underdrain system is used.

Dimensions and Slopes: Minimum/ maximum dimensions and other specifications are product-specific and shall comply with manufacturer's recommendations. Slopes shall be less than 10% in all cases.

Setbacks: Not applicable.

Sizing: Pervious pavement systems are not considered to be impervious surfaces, and therefore do not trigger pollution reduction and flow control requirements. A high-flow overflow or underdrain system must be provided to an approved destination point per **Section 1.4**, unless the performance approach is used by a professional engineer to design the system for complete stormwater disposal.

Limitations: Pervious pavements shall not be used on sites with a likelihood of high oil and grease concentrations. These site uses include vehicle wrecking or impound yards, fast food establishments, automotive repair and sales, and parking lots that receive a high number of average daily trips (> 1,000).

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Pervious pavement materials and installation procedure specifications
4) Subgrade and base course specifications
5) Filter fabric specification (if applicable)
6) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection

Pervious Pavement

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Subgrade	Call for inspection
Filter fabric (if applicable)	
Underdrain piping (if applicable)	Call for inspection
Base rock	
Pervious pavement installation	Call for inspection

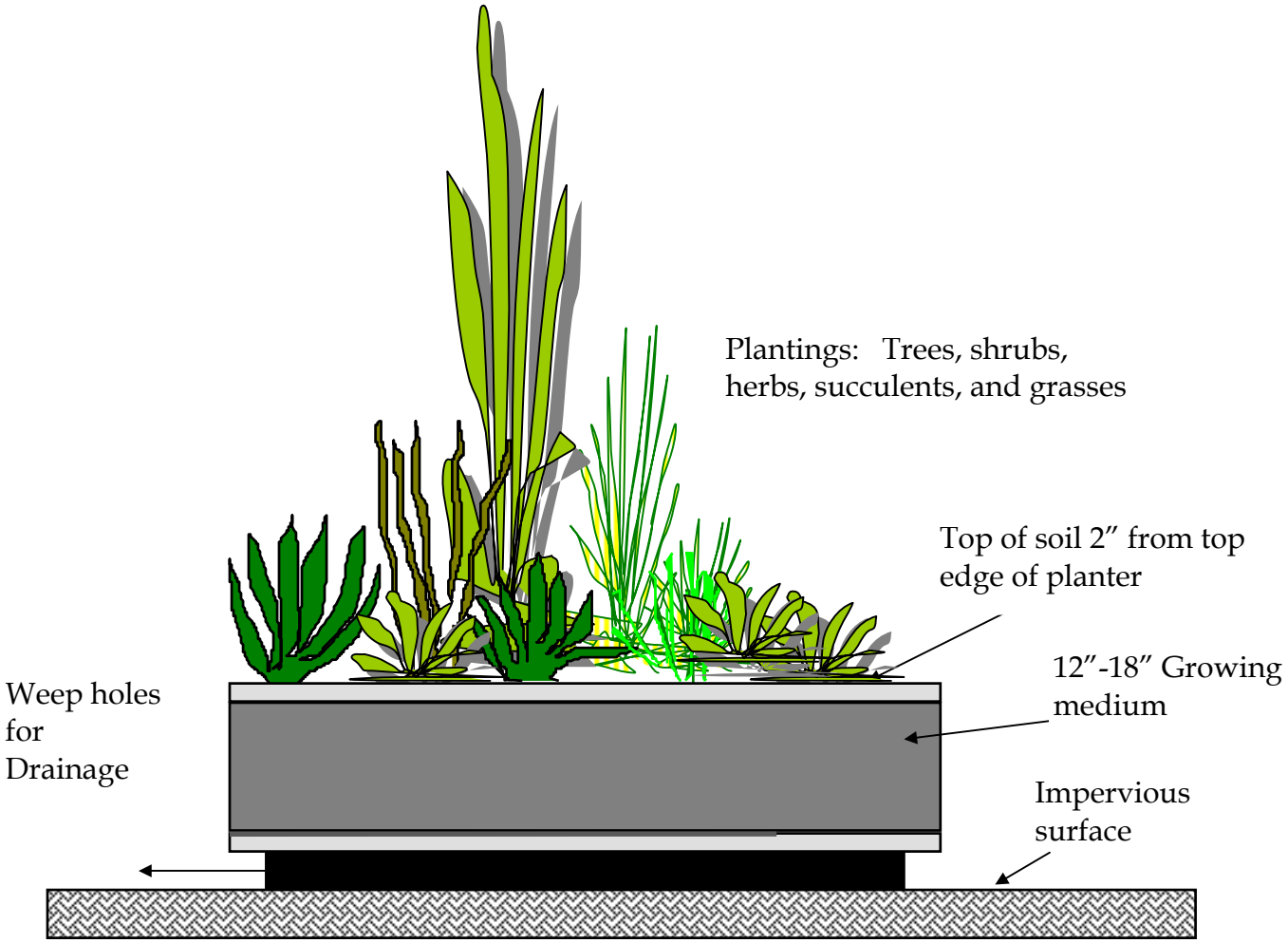
Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to pervious pavement O&M form**

Additional photos and drawings:

*** Link to pervious pavement photos**
*** Link to pervious pavement drawings**
- *** Link to pervious Asphalt drawing**
- *** Link to pervious concrete drawing**
- *** Link to brick drawing**
- *** Link to cobble drawing**
- *** Link to crushed aggregate drawing**
- *** Link to natural stone drawing**
- *** Link to turf block drawing**
- *** Link to unit pavers on sand drawing**

Contained Planter



Section Not to Scale

Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Impervious Area Reduction	SIM
√ Pollution Reduction	SIM
√ Flow Control	SIM
Destination/ Disposal	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) This facility is an impervious surface reduction technique. It may be placed over sidewalk, parking lot, flat roof, and plaza areas to reduce the effective impervious area.

Contained Planter


1100 block of bus mall, downtown Portland


Federal Building (1200 block of SW 3rd Ave.)

Description: Contained planters are used for planting trees, shrubs, and ground cover to be placed over impervious surface. The planter may be a prefabricated pot of various dimensions or may be constructed in place and have an infinite variety of shapes and sizes. Contained planters accept precipitation only, not stormwater runoff. Planters are placed on impervious surfaces, such as sidewalks, plazas and rooftops. Drainage is allowed through the bottom of the planter.

Design Considerations: Plants shall be relatively self-sustaining, with little need for fertilizers or pesticides. Irrigation is optional, although plant viability must be maintained. Trees are encouraged and may receive added stormwater management credit on the tree credit section of Form SIM.

Design Requirements:

Soil Suitability: Contained planters are appropriate for all soil types, as they are placed over impervious surface. Topsoil shall be used within the top 12 to 18 inches of the facility.

Setbacks: Not applicable.

Planter Walls: Planter walls shall be made of stone, concrete, brick, clay, plastic, wood, or other stable material. Chemically treated wood that can leach out toxic chemicals and contaminate stormwater shall not be used.

Sizing: Contained planters are given stormwater management credit for the square-footage of impervious surface that they cover, at a 1 to 1 ratio.

Landscaping: Contained planters shall be planted to cover at least 50% of the planter surface.

Contained Planter

***Link to Planter Recommended Plants**

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Planter wall material specification
4) Growing medium specification
5) Landscaping plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Structural planter components	
Growing medium	
Plantings	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to contained planter O&M form**

Additional photos and drawings:

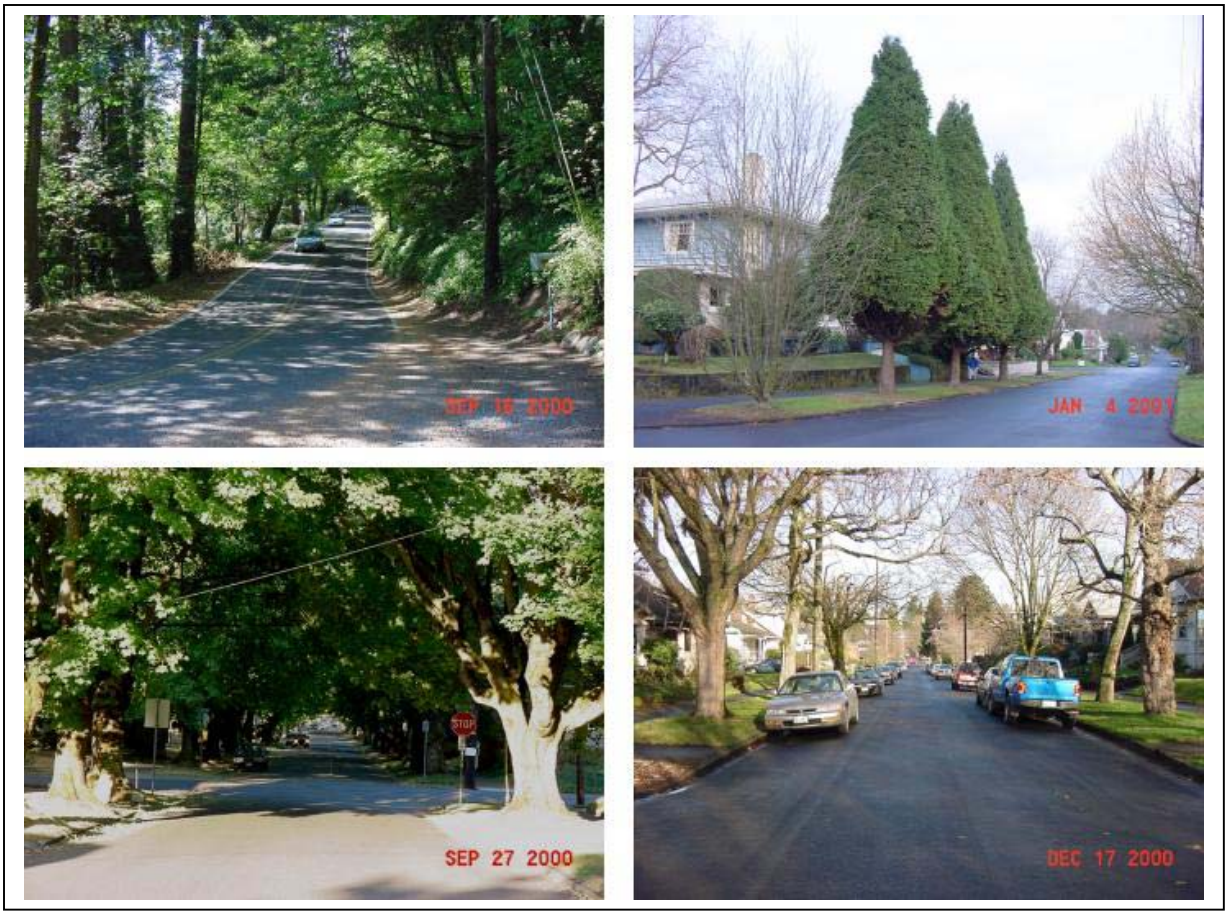
*** Link to contained planter photos**
*** Link to contained planter drawings**

SARB_007852

Contained Planter

SARB_007853

Tree Credits



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Impervious Area Reduction……..	SIM
√ Pollution Reduction……..……..	SIM
√ Flow Control…….……	SIM
Destination/ Disposal……	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) This facility intercepts rainfall and provides shade for impervious surfaces. Trees may only receive credit against the construction of ground-level impervious surfaces.

Tree Credits



Description: Trees intercept precipitation and provide several stormwater management benefits:

- Flow control: Trees hold water on the leaves and branches and allow it to evaporate, retaining flow and dissipating the energy of runoff. These functions are most measurable for storms of less than 0.5 inches over 24 hours, typical of Portland storm events. While deciduous trees are not as effective during winter months, evergreen trees are effective year round for these smaller storms and portions of larger storms. Generally, large trees with small leaves are the most efficient rainfall interceptors. Trees also facilitate stormwater infiltration and groundwater recharge.

- Pollution reduction/ stormwater cooling: Trees can provide shade over large areas of impervious surface. This provides two direct benefits. First, the hard surface is protected from direct solar exposure, which reduces heat gain. The less heat gain there is in pavement, the less heat is absorbed by stormwater as it flows over the surface. Second, by shading pavement, the trees help reduce or minimize air temperature increases caused by the hot pavement. Cooler air may help prevent stream temperature increases associated with air temperatures.

New trees planted within 25 feet of ground-level impervious surfaces are eligible for stormwater management credit. 100 square feet of credit is given for new deciduous trees, and 200 square feet of credit is given for new evergreen trees (See minimum sizes below). Stormwater management credits also apply to existing trees kept on a site if the trees' canopies are within 25 feet of ground-level impervious surfaces. The credit is the square-footage equal to one-half of the existing tree canopy. No credit will be given for existing trees within an environmental zone. For sites with over 1,000 square-feet of impervious surface to manage, no more than 10% can be mitigated through the use of trees.

Tree Credits

Trees used for stormwater management credit shall be clearly labeled on permit drawings. A note shall be included on the permit drawings that calls for City inspection after the tree has been planted, or in the case of existing tree canopy, after the site grading has been completed.

NEW EVERGREEN AND DECIDUOUS TREES:

Trees shall be maintained and protected on the site after construction and for the life of the development (50-100 years or until any approved redevelopment occurs in the future). During the life of the development, trees approved for stormwater credit shall not be removed without approval from the City. Trees that are removed or die shall be replaced within 6 months with like species. Trees may be pruned for safety purposes only; however, if a tree is planted near a building, pruning to protect the structure is recommended.

The trees selected shall be suitable species for the site conditions and the design intent. Trees should be relatively self-sustaining and long-lived. Native conifers are highly encouraged, as many of these trees naturally grow in harsh/rocky conditions. Long-term irrigation is not required. New deciduous trees must be at least 2 caliper inches and new evergreen trees must be at least 6 feet tall to receive simplified approach credit. Trees planted to meet stormwater facility planting requirements cannot also receive simplified approach credit.

By City ordinance, the City Forester is authorized to set standards for tree sizes planted on publicly owned lands and public rights-of-way. A permit is required from Urban Forestry to plant, prune, or remove right-of-way trees. Right-of-way trees shall be at least 2 caliper inches for residential and 3.5 caliper inches for other zones, including commercial areas. For parks and other public areas, the tree standard is 3.5 caliper inches.

Approved Trees

The following tree and arborescent shrub* species are approved outright for use as simplified approach tree credits. Other species may be given credit, as approved by BES.

Acer macrophyllum	Juniperus occidentalis*	Quercus garryana
Alnus rubra	Libocendrus decurrens	Rhamnus purshiana
Arbutus menziesii	Pinus contorta	Sequoia sempervirens
Castanopsis chrysophylla*	Pinus monticola	Thuja plicata
Chamacyparis lawsoniana	Pinus ponderosa	Tsuga heterophylla

SARB_007856

Tree Credits

Cornus nuttallii	Pseudotsuga menziesii	Umbellularia californica
Fraxinus latifolia	Quercus chrysolepis*	

EXISTING TREES:

Mature evergreen and deciduous trees can have significant benefits in addition to stormwater management. They already provide habitat for urban wildlife, energy and cost conservation, aesthetics, visual screens, heritage value, windbreaks, and recreation.

The stormwater credit applies to existing trees of 4-inch caliper or larger. Credit is based on one-half of the square footage of the tree canopy, measured within the drip-line. An existing tree for which protection is required by City Title 33 code is not eligible for credits.

Protection during construction shall be in the form of minimizing disruption of the root system. Construction shall not encroach within a space measured 10 feet outside of the drip line to the tree trunk, unless the City Forester approves exemptions to this requirement. The applicant will have to provide documentation required by the Forester to ensure the tree will remain healthy after construction and during the life of the project. During the life of the development, trees approved for stormwater credit shall not be removed without approval from the City. Stormwater management functions of any removed trees shall be replaced on the site with other trees or stormwater management approaches. Trees that die shall be replaced within 6 months. Trees may be pruned for safety purposes only; however, if a tree is near a building, pruning to protect the structure is recommended.

Checklist of minimal information to be shown on the permit drawings:

1) Trees to be given stormwater management credit shall be clearly labeled as such, with the size and species included.
2) Approximate setbacks from property lines and structures shall be shown.
3) Temporary irrigation measures shall be shown, if applicable.
4) Form SIM must be submitted, clearly showing that less than 10% of the impervious area is being mitigated for with tree credits if the project impervious area exceeds 1,000 square feet.

Operations and Maintenance requirements: See **Chapter 3.0**.

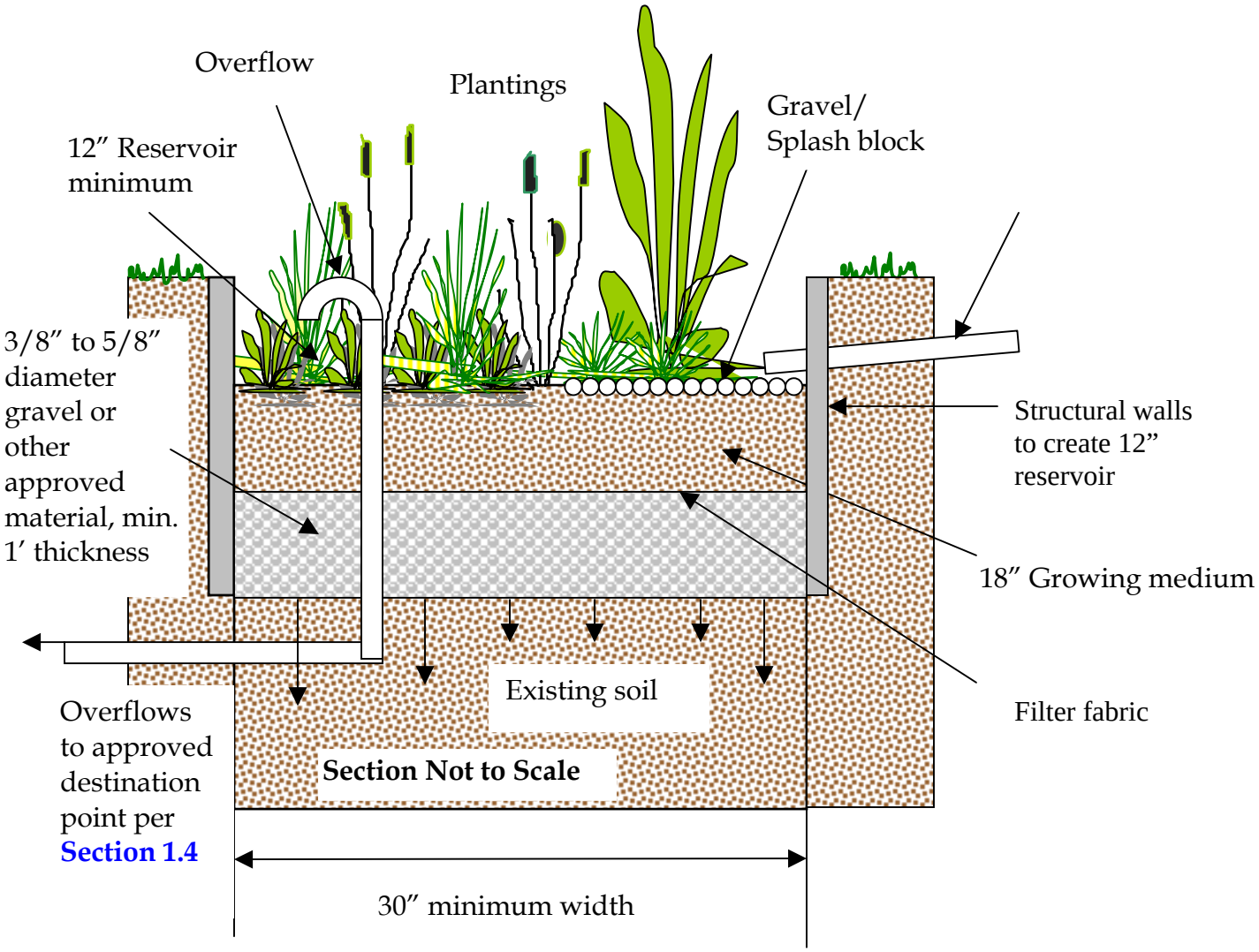
*** Link to new tree O&M form**

Additional photos:

*** Link to tree photos**

SARB_007857

Infiltration Planter



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction	SIM, PERF[1]
√ Flow Control	SIM
√ Destination/ Disposal	PRES[2]

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) The Performance Approach may be used to downsize the Simplified Approach sizing factor when the only goal is pollution control. **2)** The surface infiltration facility design procedure from **Section 2.2.2** may be used to receive credit for stormwater disposal.
Infiltration planters may be designed to manage runoff from rooftops, and if submerged into the ground, parking lots and streets in many cases.

Infiltration Planter





Description: Infiltration planters are structural landscaped reservoirs used to collect, filter, and infiltrate stormwater runoff, allowing pollutants to settle and filter out as the water percolates through the planter soil and infiltrates into the ground. In addition to providing pollution reduction, flow rates and volumes can also be managed with infiltration planters. Planters can be used to help fulfill a site's required landscaping area requirement and should be integrated into the overall site design. Numerous design variations of shape, wall treatment, and planting scheme can be used to fit the character of a site. An overflow to an approved conveyance and disposal method per **Section 1.4** will be required, unless the facility is sized per surface infiltration facility guidelines presented in **Section 2.2.2**.

Design Considerations: When designing infiltration planters, the infiltration rate of the native soil is a key element in determining size and viability.

Construction Considerations: Infiltration planter areas should be clearly marked before site work begins to avoid soil disturbance during construction. No vehicular traffic, except that specifically used to construct the facility, should be allowed within 10 feet of planter areas.

Design Requirements:

Soil Suitability: Infiltration planters are appropriate for soils with a minimum infiltration rate of 2 inches per hour (NRCS soil types A and B). There shall be no less than three feet of undisturbed infiltration medium between the bottom of the facility and any impervious layer (i.e. hardpan, solid rock, high groundwater levels, etc.) Topsoil shall be used within the top 18 inches of the facility.

Dimensions and Slopes: Facility storage depth must be at least 12 inches, unless a larger-than-required planter square-footage is used. Minimum planter width is 30 inches. Planters shall be constructed without slope.

Infiltration Planter

Setbacks: Required setback from property lines is 5 feet, and 10 feet from building foundations. Proposed variances to this standard must request an exception to the building code through BDS.

Planter Walls: Planter walls shall be made of stone, concrete, brick, wood, or other durable material. Chemically treated wood that can leach out toxic chemicals and contaminate stormwater shall not be used.

Sizing: Individual infiltration planters sized with the simplified approach shall be designed to receive less than 15,000 square-feet of impervious area runoff. For these projects, a simplified approach sizing factor of 0.06 may be used to receive credit for pollution and flow control. A high-flow overflow must be provided, or to receive credit for stormwater destination, the surface infiltration facility design criteria from **Section 2.2.2** must be used. In cases when pollution reduction is the only stormwater management goal, the performance approach may be used in conjunction with a measured infiltration rate to downsize the simplified approach sizing factor. Planters shall be designed to pond water for less than 12 hours after each storm event.

Landscaping: Plantings shall be designed at the following quantities per **100** square feet of facility area. Facility area is equivalent to the area of the planter calculated from Form SIM.

4 - Large shrubs/small trees	3-gallon containers or equivalent.
6 - Shrubs/large grass-like plants	1-gallon containers or equivalent

Ground cover plants:	1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the facility shall be planted with grasses or grass-like plants.

Note: Tree planting is not required in planters, but is encouraged where practical. Tree planting is also encouraged near planters.

***Link to Flow-Through Planter Landscaping Plan Example**
***Link to Planter Recommended Plants**

Checklist of minimal information to be shown on the permit drawings:

Infiltration Planter

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Planter wall material and waterproofing membrane specification
4) Growing medium specification
5) Drain rock specification
6) Filter fabric specification
7) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
8) Landscaping plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Planter grading/ excavation	
Structural components/ liner	Call for inspection
Piping	Call for inspection
Drain rock	
Filter fabric	
Growing medium	
Plantings	Call for inspection

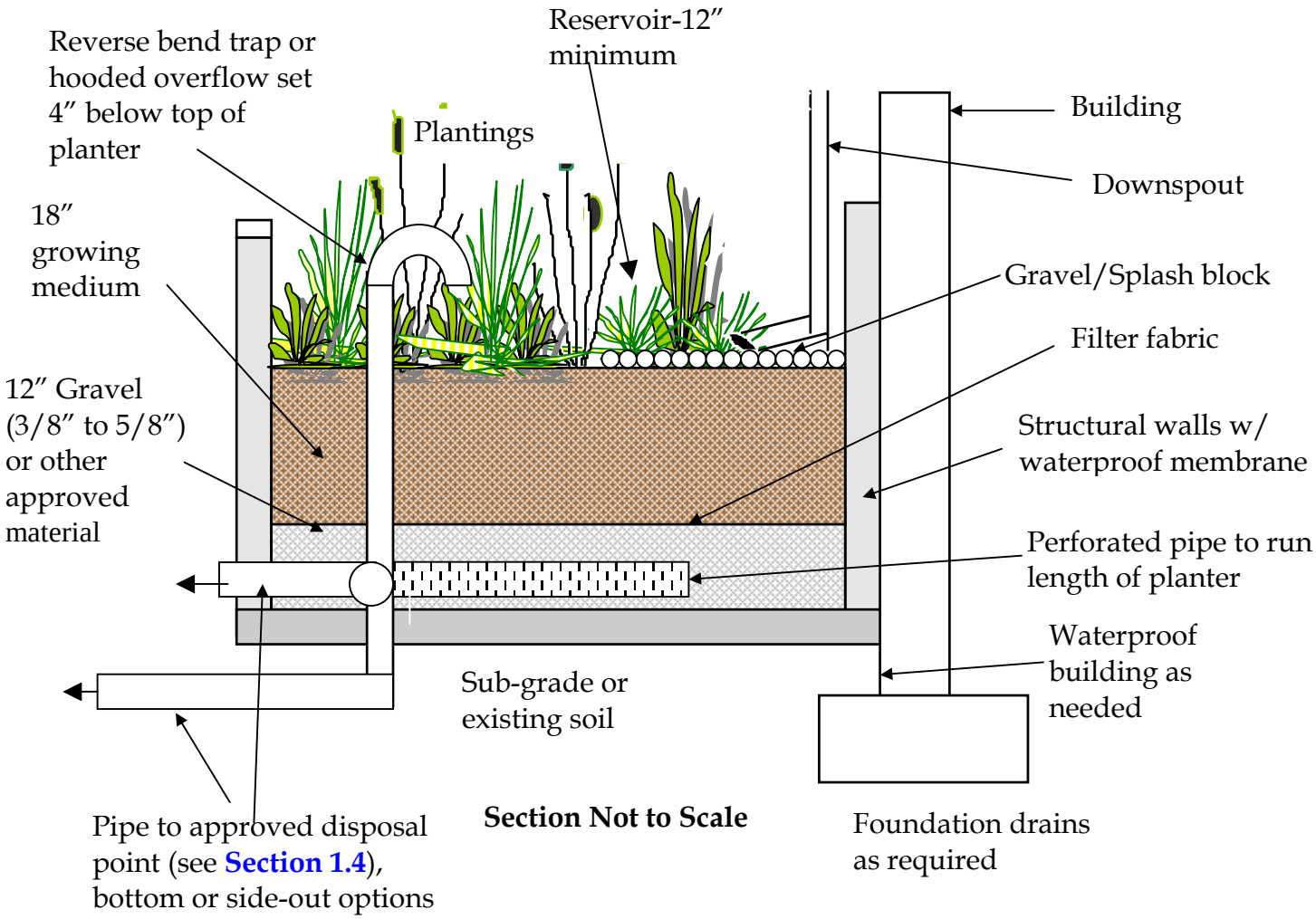
Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to infiltration planter O&M form**

Additional photos and drawings:

*** Link to infiltration planter photos**
*** Link to infiltration planter drawings**

Flow-Through Planter



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction	SIM, PERF[1]
√ Flow Control	SIM
Destination/ Disposal	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) The Performance Approach may be used to downsize the simplified approach sizing factor when the only goal is pollution reduction. Flow-through planters may be designed to manage runoff from rooftops, and if submerged into the ground, parking lots and streets in some cases.

Flow-Through Planter





Description: Flow-through planters are structural landscaped reservoirs used to collect and filter stormwater runoff, allowing pollutants to settle and filter out as the water percolates through the planter soil. In addition to providing pollution reduction, flow rates and volumes can also be managed with flow-through planters. Planters should be integrated into the overall site design and can be used to help fulfill a site's required landscaping area requirement. Numerous design variations of shape, wall treatment, and planting scheme can be used to fit the character of a site. Because they include a waterproof lining, flow-through planters are extremely versatile and can be used next to foundation walls, adjacent to property lines (if less than 30" in height), or on slopes. An overflow to an approved conveyance and destination/ disposal method per **Section 1.4** will be required.

Design Considerations: When designing flow-through planters, the structural walls can often times be incorporated with building foundation plans.

Construction Considerations: Special attention needs to be paid to the planter waterproofing if constructed adjacent to building structures.

Design Requirements:

Soil Suitability: Flow-through planters are appropriate for all soil types. Topsoil shall be used within the top 18 inches of the facility.

Dimensions and Slopes: Facility storage depth must be at least 12 inches, unless a larger-than-required planter square-footage is used. Minimum planter width is 18 inches. Planter slopes shall be less than 0.5%.

Setbacks: Required setback from property lines is 5 feet, unless the planter height is less than 30 inches.

Flow-Through Planter

Planter Walls: Planter walls shall be made of stone, concrete, brick, or wood. Chemically treated wood that can leach out toxic chemicals and contaminate stormwater shall not be used.

Sizing: Individual flow-through planters sized with the simplified approach shall be designed to receive less than 15,000 square-feet of impervious area runoff. For these projects, a simplified approach sizing factor of 0.06 may be used to receive credit for pollution reduction and flow control. A high-flow overflow must be provided to an approved disposal point per **Section 1.4**. In cases when pollution reduction is the only stormwater management goal, the performance approach may be used to downsize the simplified approach sizing factor. Planters shall be designed to pond water for less than 12 hours after each storm event.

Landscaping: Plantings shall be designed at the following minimum quantities per **100** square feet of facility area. Facility area is equivalent to the area of the planter calculated from Form SIM.

4 - Large shrubs/small trees	3-gallon containers or equivalent.
6 - Shrubs/large grass-like plants	1-gallon containers or equivalent

Ground cover plants:	1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the facility shall be planted with grasses or grass-like plants.

Note: Tree planting is not required in planters, but is encouraged where practical. Tree planting is also encouraged near planters.

***Link to Flow-Through Planter Landscaping Plan Example**
***Link to Planter Recommended Plants**

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Planter wall material and waterproofing membrane specification
4) Growing medium specification

Flow-Through Planter

5) Drain rock specification
6) Filter fabric specification
7) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
8) Landscaping plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Planter grading/ excavation	
Structural components/ liner	Call for inspection
Piping	Call for inspection
Drain rock	
Filter fabric	
Growing medium	
Plantings	Call for inspection

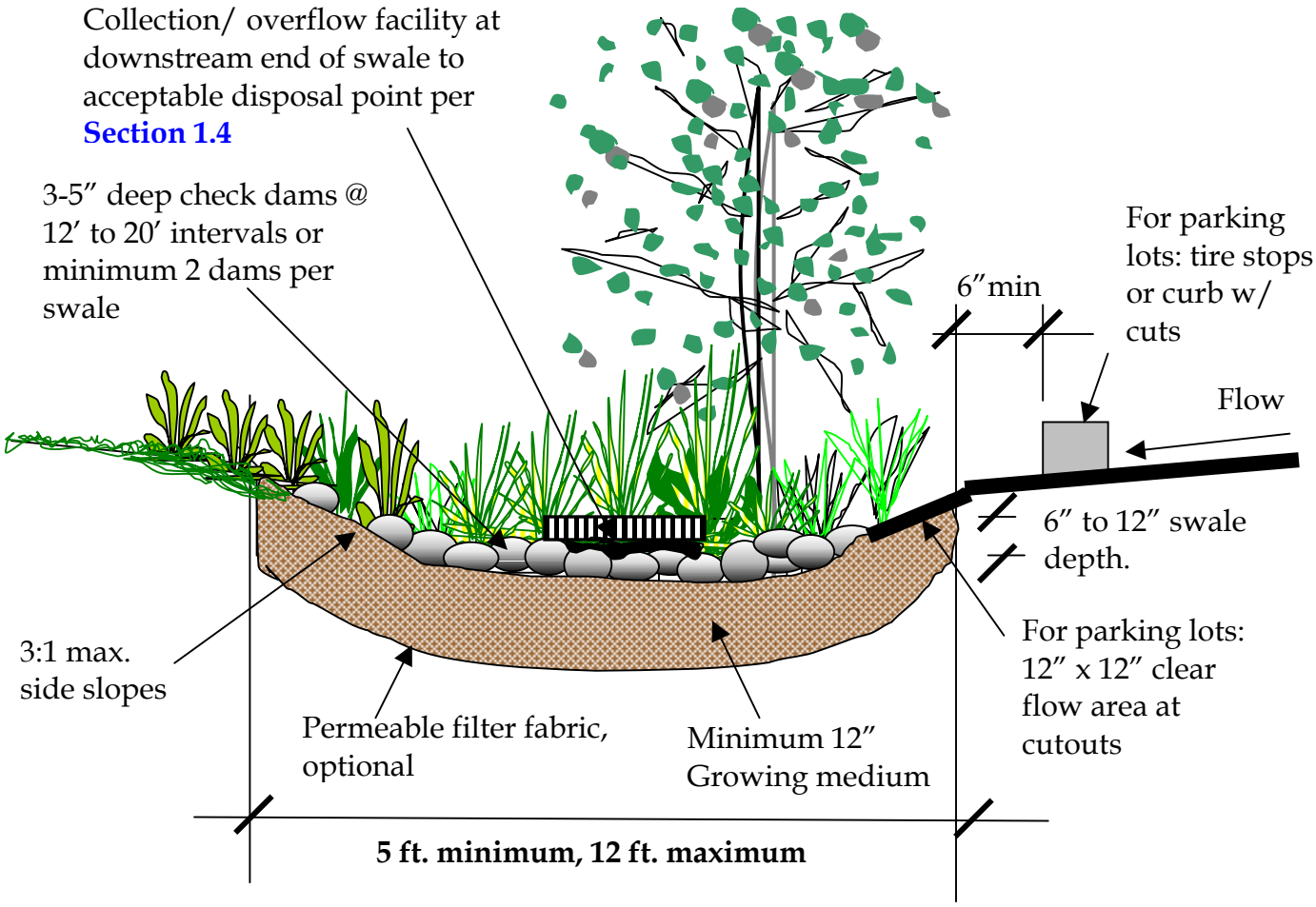
Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to flow-through planter O&M form**

Additional photos and drawings:

*** Link to flow-through planter photos**
*** Link to flow-through planter drawings**

Vegetated Swale



Section Not to Scale

Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction	SIM, PERF[1]
√ Flow Control	SIM
√ Destination/ Disposal	PRES[2]

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) The performance approach may be used to downsize the simplified approach sizing factor when the only goal is pollution reduction. Vegetated swales can be used to manage runoff from parking lots, rooftops, and private streets. For public street runoff, the street swale criteria must be used. **2)** The surface infiltration facility design procedure from **Section 2.2.2** may be used to receive credit for stormwater disposal.

Vegetated Swale





Description: Vegetated swales are long narrow landscaped depressions used to collect and convey stormwater runoff, allowing pollutants to settle and filter out as the water infiltrates into the ground or flows from one bay to the next through the facility. In addition to providing pollution reduction, flow rates and volumes can also be managed with vegetated swales, as check dams are provided every 12 to 20 feet to slow and pool water. Swales should be integrated into the overall site design and can be used to help fulfill a site's required landscaping area requirement. An approved conveyance and destination/ disposal method per **Section 1.4** will be required at the end of the swale.

Design Considerations: When designing vegetated swales, slopes and depth should be kept as mild as possible to avoid safety risks, improve aesthetics, and prevent erosion within the facility.

Construction Considerations: Vegetated swale areas should be clearly marked before site work begins to avoid soil disturbance and compaction during construction. No vehicular traffic, except that specifically used to construct the facility, should be allowed within 10 feet of swale areas.

Design Requirements:

Soil Suitability: Vegetated swales are appropriate for all soil types. Topsoil shall be used within the top 12 inches of the facility, or the soil shall be amended per **Appendix F** to support plant growth.

Dimensions and Slopes: Facility storage depth may vary from 6 to 12 inches. Maximum side slopes are 3 horizontal to 1 vertical. Minimum flat bottom width is 2 feet for private swales, and 4 feet for public swales. Maximum longitudinal slope is 6%.

Vegetated Swale

Setbacks: Required setback from centerline of swale to property lines is 5 feet, and 10 feet from building foundations unless lined with impermeable fabric or approved by BES and BDS.

Sizing: Vegetated swales sized with the Simplified Approach shall be designed to receive less than 15,000 square-feet of impervious area runoff. For these projects, a simplified approach sizing factor of 0.09 may be used to receive credit for pollution reduction and flow control. A high-flow by-pass mechanism will not be required in these cases, but a high-flow overflow must be provided at the downstream end of the swale to an approved disposal point, per **Section 1.4**. In cases when pollution reduction is the only stormwater management goal, the performance approach may be used in conjunction with a measured infiltration rate to downsize the simplified approach sizing factor.

Check Dams: Check dams shall be constructed of durable, non-toxic materials such as rock, brick, or concrete, or soil by integrating them into the grading of the swale. Check dams shall be 12 inches in length, by the width of the swale, by 3 to 6 inches in height.

Landscaping: Vegetation helps improve infiltration functions, protects from rain and wind erosion, and enhances aesthetic conditions. The "facility area" is equivalent to the area of the swale, including bottom and side slopes, as calculated from Form SIM. Minimum plant material quantities per 100 square feet of facility area are as follows:

1 - Evergreen or deciduous tree (planted around the perimeter of the swale):		
	Evergreen trees:	Minimum height: 6 feet
	Deciduous trees:	Minimum caliper: 1 ½ inches at 6 inches above base.
4 - Large shrubs/small trees:		3-gallon containers or equivalent.
6 - Shrubs/large grass-like plants:		1-gallon containers or equivalent

Ground cover plants:	1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the facility shall be planted with grasses or grass-like plants.

Wildflowers, native grasses, and ground covers used for BES-maintained facilities shall be designed not to require mowing. Where mowing cannot be avoided, facilities shall be designed to require mowing no more than once annually. Turf and lawn areas are not allowed for BES-maintained facilities; any exceptions will require BES approval.

Vegetated Swale

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Growing medium specification
4) Filter fabric specification (if applicable)
5) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
6) Landscaping plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Swale grading	Call for inspection
Piping	Call for inspection
Filter fabric (if applicable)	
Growing medium	
Plantings	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

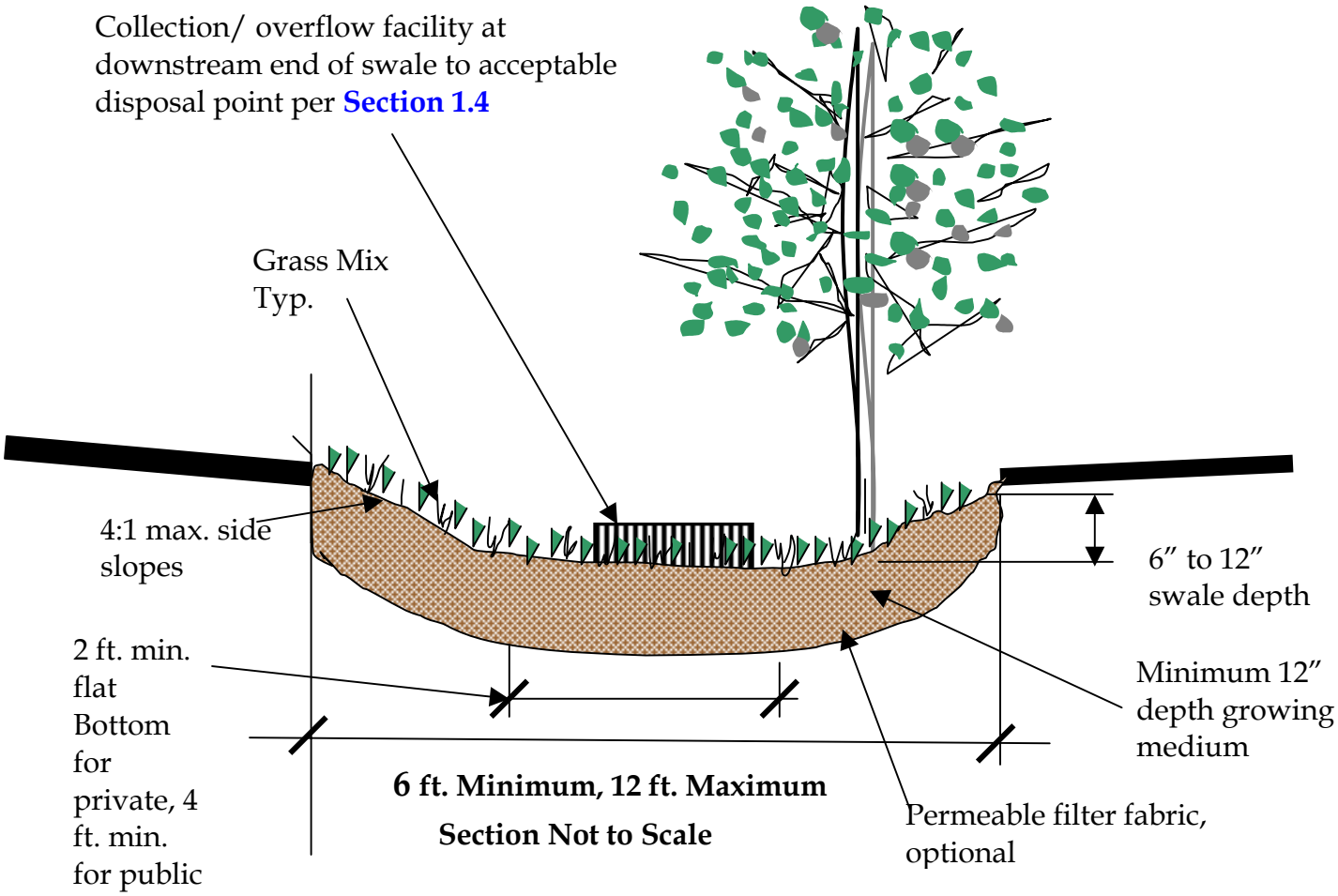
*** Link to vegetated swale O&M form**

Additional photos and drawings:

*** Link to vegetated swale photos**
*** Link to vegetated swale drawings**

SARB_007869

Grassy Swale



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction……..	SIM[1], PRES[2]
√ Flow Control……..	SIM[1]
√ Destination/ Disposal……..	PRES[3]

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) Flow and volume control credit will only be given for projects with less than 15,000 square-feet of impervious area to manage. **2)** For projects with more than 15,000 square-feet of impervious area to manage, the presumptive approach must be used to size the swale for pollution reduction, and additional facilities may be required to meet flow control requirements. Grassy swales can be used to manage runoff from parking lots, rooftops, and private streets. For public street runoff, the street swale criteria must be used. **3)** The surface infiltration facility design procedure from Section 2.2.2 may be used to receive credit for stormwater disposal

Grassy Swale





Description: Grassy swales are long narrow grassy depressions used to collect and convey stormwater runoff, allowing pollutants to settle and filter out as the water infiltrates into the ground or flows through the facility. In addition to providing pollution reduction, flow rates and volumes can also be managed for small projects (<15,000 square feet of impervious surface) with grassy swales. Swales should be integrated into the overall site design and can be used to help fulfill a site's required landscaping area requirement. An approved conveyance and disposal method per **Section 1.4** will be required at the end of the swale.

Design Considerations: When designing grassy swales, slopes and depth should be kept as mild as possible to avoid safety risks and prevent erosion within the facility.

Construction Considerations: Grassy swale areas should be clearly marked before site work begins to avoid soil disturbance during construction. No vehicular traffic, except that specifically used to construct the facility, should be allowed within 10 feet of swale areas.

Design Requirements:

Soil Suitability: Grassy swales are appropriate for all soil types. Topsoil shall be used within the top 12 inches of the facility, or the soil shall be amended per **Appendix F** to support plant growth.

Dimensions and Slopes: Facility storage depth may vary from 6 to 12 inches. Maximum side slopes are 4 horizontal to 1 vertical. Minimum flat bottom width is 2 feet for private swales, and 4 feet for public swales. Maximum longitudinal slope is 5%, while minimum slope is 0.5%. Maximum surrounding ground slopes shall be 10%.

Grassy Swale

Setbacks: Required setback from centerline of swale to property lines is 5 feet, and 10 feet from building foundations unless lined with impermeable fabric.

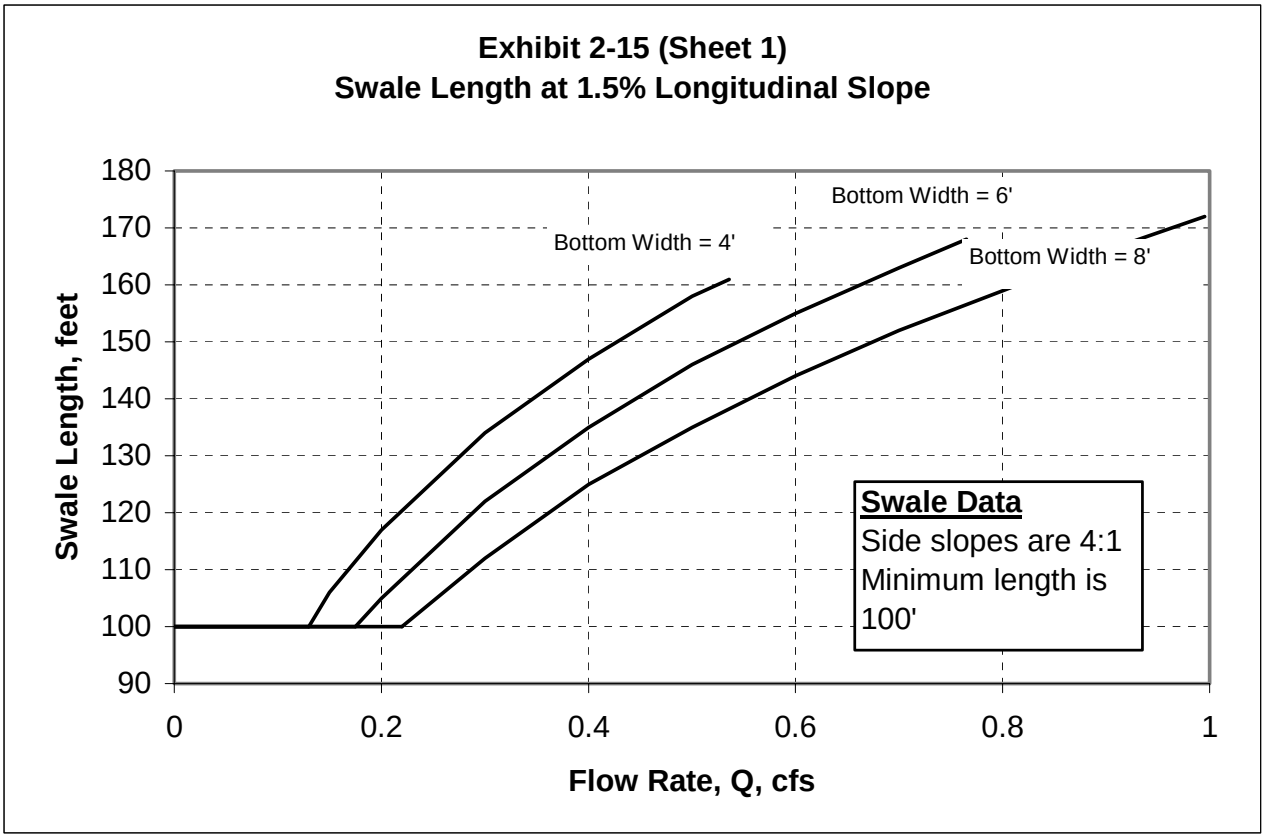
Sizing: Grassy swales sized with the simplified approach shall be designed to receive less than 15,000 square-feet of impervious area runoff. For these projects, a simplified approach sizing factor of 0.1 may be used to receive credit for pollution reduction and flow control. A high-flow by-pass mechanism will not be required in these cases, but a high-flow overflow must be provided at the downstream end of the swale to an approved disposal point, per **Section 1.4**. In cases when pollution reduction is the only stormwater management goal, or there is more than 15,000 square feet of impervious area to manage, the presumptive approach must be used size the swale for pollution reduction, and additional facilities will be required to meet flow control requirements, where applicable.

Presumptive Approach Sizing Criteria:

Exhibit 2-15 shows swale side slopes of 4:1 and lengthwise slopes of 1½ percent, 3 percent, and 5 percent. These charts are based on the City standards shown below and may be used to easily determine swale length, given the peak flow rate and the desired swale bottom width.

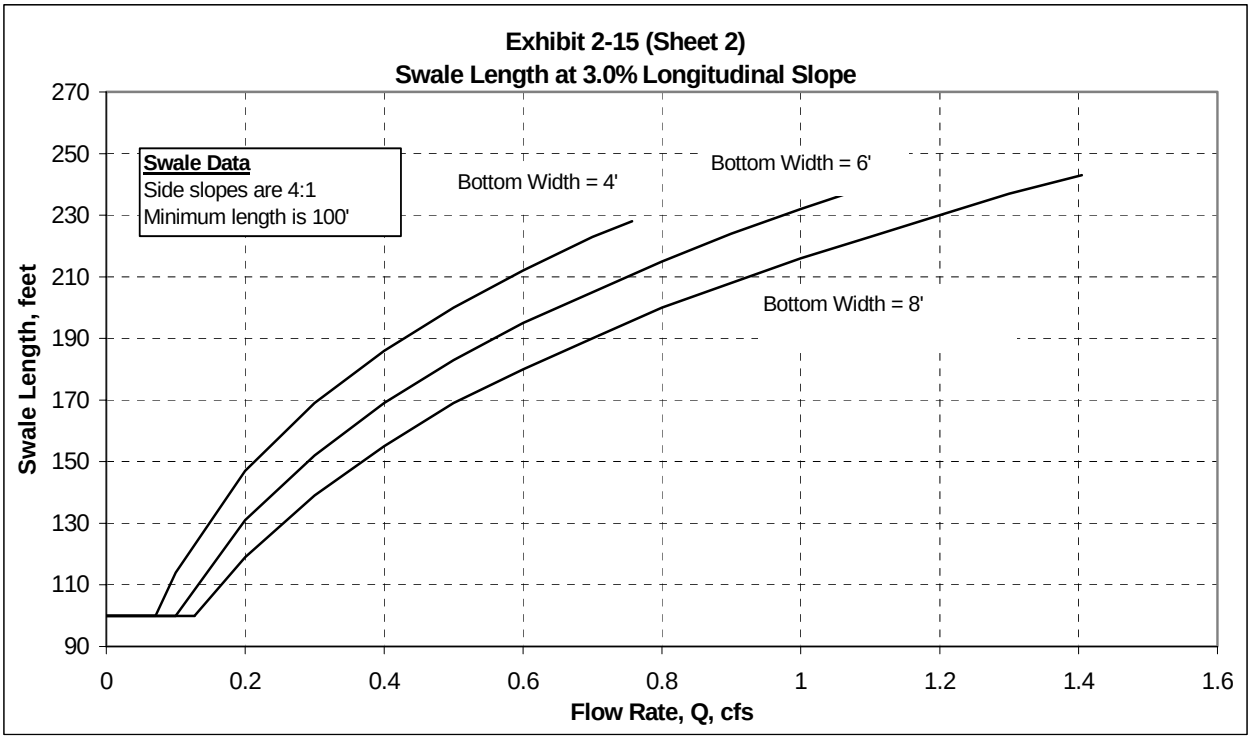
SARB_007872

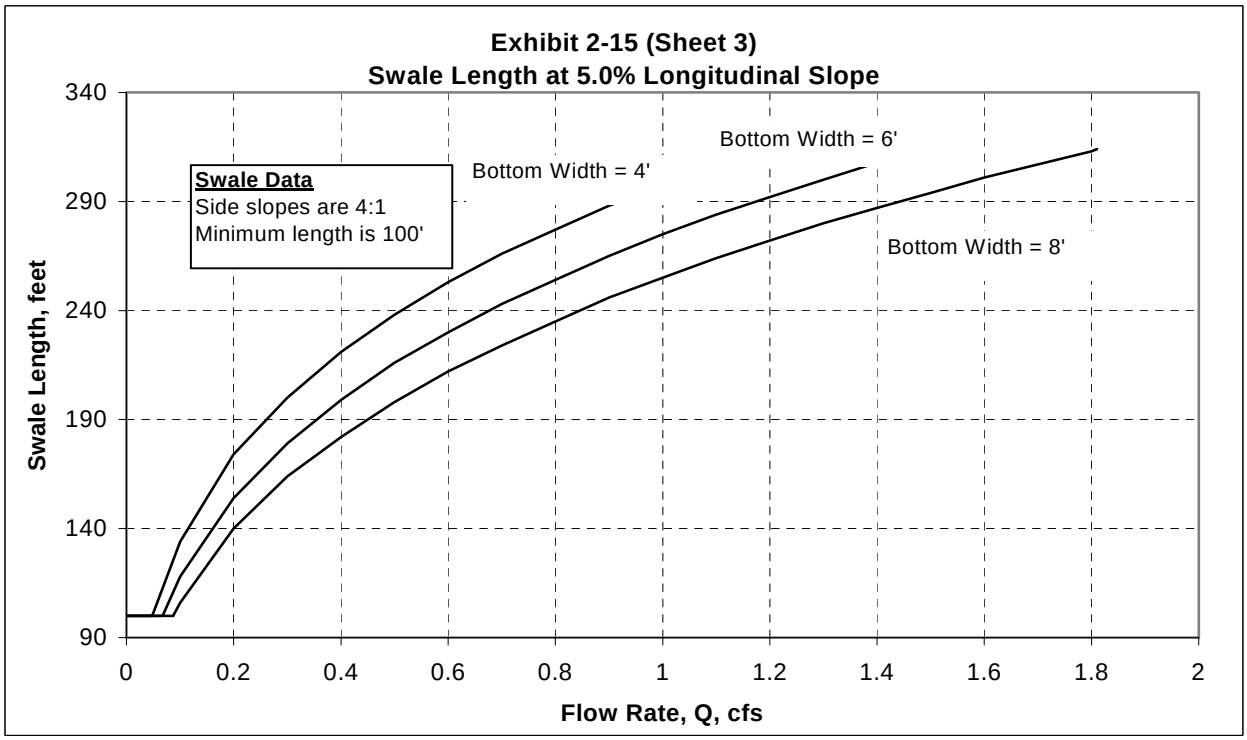
Grassy Swale



SARB_007873

Grassy Swale





Grassy Swale

1) The swale width and profile shall be designed to convey runoff from the pollution reduction design storm intensity (see **Section 1.5.2**) at:

- Maximum design depth of 0.33 feet.
- Maximum design velocity of 0.9 feet per second.
- Minimum hydraulic residence time (time for Q_{design} to pass through the swale) of 9 minutes.
- Minimum longitudinal slope of 0.5 percent, maximum slope of 5 percent. For slopes greater than 5 percent, check dams shall be used (one 6-inch high dam every 10 feet).
- Designed using a Manning "n" value of 0.25.
- 4:1 (or flatter) side slopes in the treatment area.
- Minimum length of 100 feet.

A minimum of 1 foot of freeboard above the water surface shall be provided for facilities not protected by high-flow storm diversion devices. Swales without high-flow diversion devices shall be sized to safely convey the 25-year storm event, analyzed using the Rational Method (peak 25-year, 5 minute intensity = 3.32 inches per hour).

Velocity through the facility shall not exceed 3 feet per second (fps) during the high-flow events (i.e., when flows greater than those resulting from the pollution reduction design intensity are not passed around the facility).

2) The swale shall incorporate a flow-spreading device at the inlet. The flow spreader shall provide a uniform flow distribution across the swale bottom. In swales with a bottom width greater than 6 feet, a flow spreader shall be installed at least every 50 feet.

3) To minimize flow channelization, the swale bottom shall be smooth, with uniform longitudinal slope, and with a minimum bottom width of 2 feet for private facilities and 4 feet for public facilities. Maximum bottom width shall be 8 feet.

4) Grasses or sod shall be established as soon as possible after the swale is completed, and before water is allowed to enter the facility.

5) Unless vegetation is established, biodegradable erosion control matting appropriate for low-velocity flows (approximately 1 foot per second) shall be installed in the flow area of the swale before allowing water to flow through the swale.

Grassy Swale

6) Access routes to the swale for maintenance purposes must be shown on the plans. Public swales will need to provide a minimum 8-foot wide access route, not to exceed 10 percent in slope.

Stormwater Report Requirements For Presumptive Approach: See **Exhibit 2-2**.

Landscaping: Plantings shall be designed at the following quantities per **200** square feet of facility area. Facility area is equivalent to the area of the swale calculated from Form SIM. (Note: Facilities smaller than 200 square feet shall have a minimum of one tree per facility.):

1 Evergreen or Deciduous tree:

Evergreen trees:	Minimum height: 6 feet.
Deciduous trees:	Minimum caliper: 1 ½ inches at 6 inches above base.

Grass: Seed or sod is required to completely cover the grassy swale bottom and side slopes. (Shrubs are optional)

For the swale flow path, approved native grass mixes are preferable and may be substituted for standard swale seed mix. Seed shall be applied at the rates specified by the supplier. The applicant shall have plants established at the time of facility completion (at least 3 months after seeding). No runoff shall be allowed to flow in the swale until grass is established. Trees and shrubs may be allowed in the flow path within swales if the swale exceeds the minimum length and widths specified.

Native wildflowers, grasses, and ground covers used for BES-maintained facilities shall be designed not to require mowing. Where mowing cannot be avoided, facilities shall be designed to require mowing no more than once or twice annually. Turf and lawn areas are not allowed for BES-maintained facilities; any exceptions will require BES approval.

Environmental zones shall meet requirements established by Title 33 for grass in E-zones.

***Link to Grassy Swale Recommended Seed Mixes**

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

Grassy Swale

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Growing medium specification
4) Filter fabric specification (if applicable)
5) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
6) Landscaping plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Swale grading	Call for inspection
Piping	Call for inspection
Filter fabric (if applicable)	
Growing medium	
Plantings/ seeding/ sod	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to grassy swale O&M form**

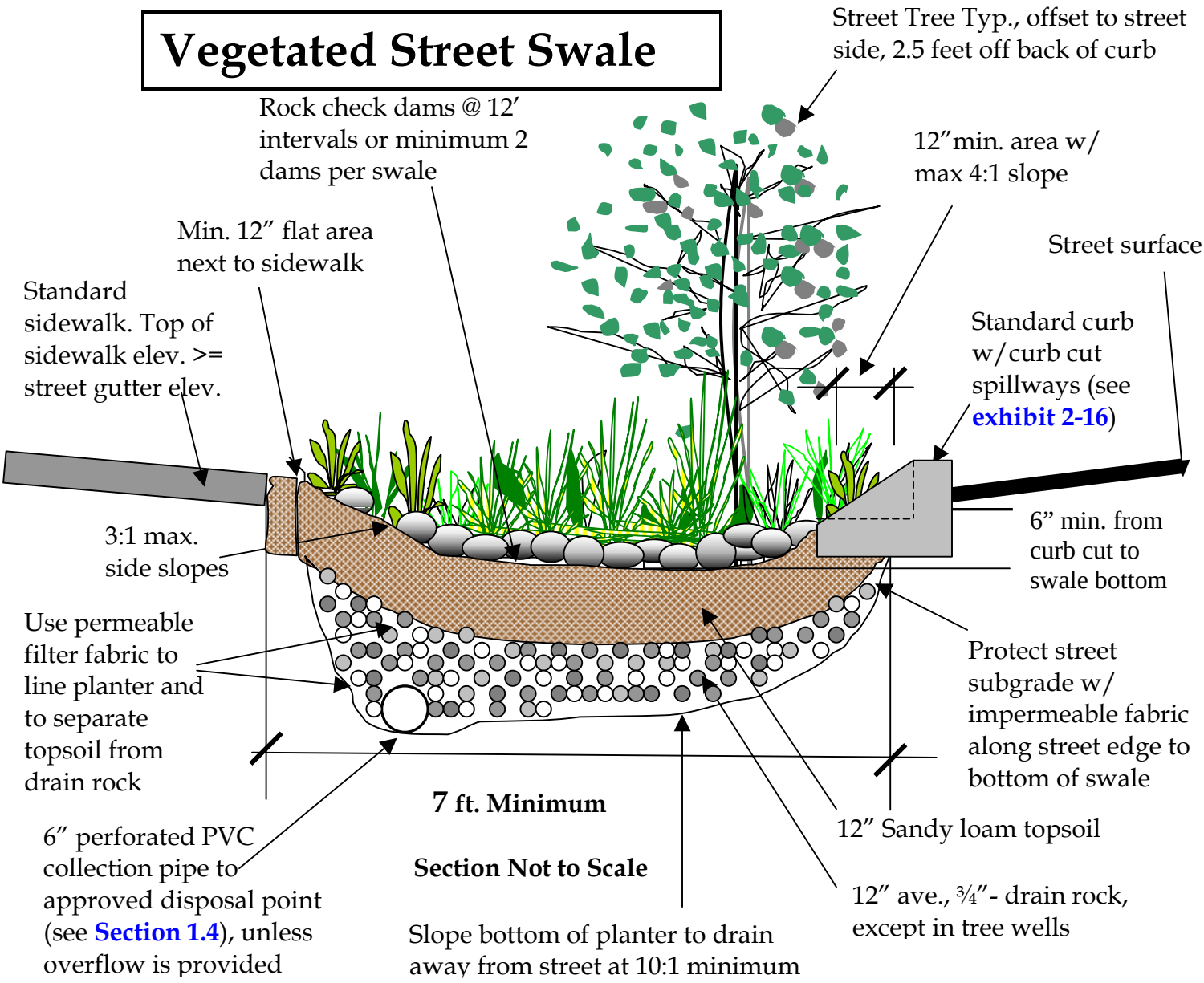
Additional photos and drawings:

*** Link to grassy swale photos**
*** Link to grassy swale drawings**

SARB_007877

Street Swales

Vegetated Street Swale



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction	SIM
√ Flow Control	SIM
√ Destination/ Disposal	PRES[1]

This facility is **not** classified as an Underground Injection Control structure (UIC).

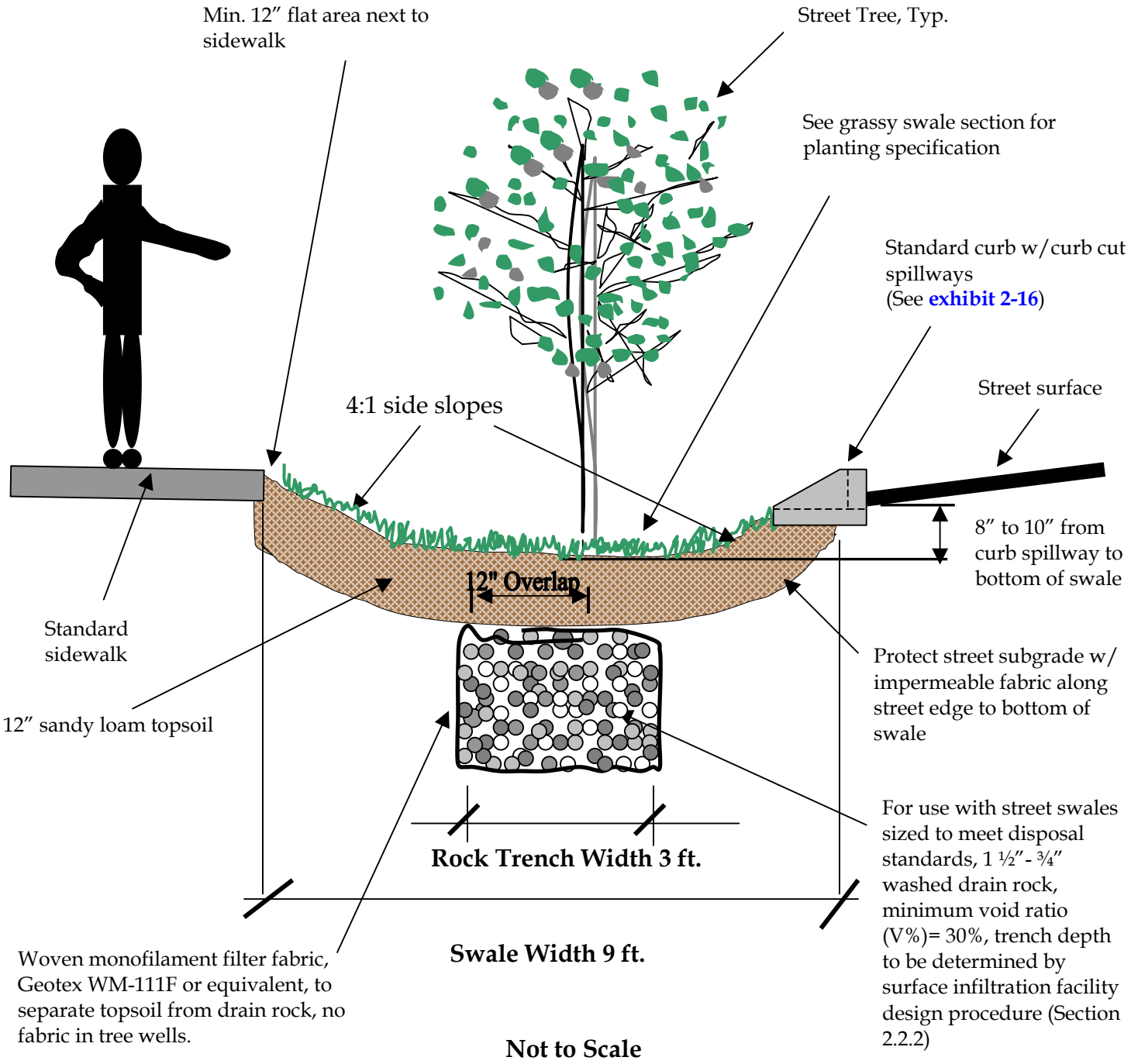
SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) The surface infiltration facility sizing criteria from **Section 2.2.2** may be used to size the street swale for complete stormwater infiltration. This facility may be used on private property or in the public right-of-way.

SARB_007878

Street Swales

Grassy Street Swale



Note: Overflow to an approved disposal point is required, unless swale is sized in accordance with surface infiltration facility design procedure presented in **Section 2.2.2**.

Street Swales





Description: Street construction poses particular challenges related to stormwater management design. Lack of available space is often the most difficult hurdle in locating stormwater pollution reduction and flow control facilities in or near allocated rights-of-way. BES and the Portland Office of Transportation have developed specific street swale designs that incorporate pollution reduction and flow control into the cross-section of the street. For more information and ideas about stormwater friendly street designs, Metro has developed three handbooks: "Creating Livable Streets," "Green Streets," and "Trees for Green Streets." These handbooks can be purchased from Metro at: **www.metro-region.org.**

Street swales are long narrow landscaped depressions used to collect and convey stormwater runoff, allowing pollutants to settle and filter out as the water infiltrates into the ground or flows from one bay to the next through the facility. In addition to providing pollution reduction, flow rates and volumes can also be managed with street swales, as check dams are provided every 12 to 20 feet to slow and pool water. Swales should be integrated into the overall site design and can be used to help fulfill a site's required landscaping area requirement. An approved conveyance and disposal method per **Section 1.4** will be required at the end of the swale, unless the swale is designed per the surface infiltration facility criteria presented in **Section 2.2.2**.

Design Considerations: When designing street swales, slopes and depth should be kept as mild as possible to avoid safety risks, improve aesthetics, and prevent erosion within the facility. All applicable PDOT, BDS, and Urban Forestry requirements for other street elements (curbs, sidewalks, trees, etc.) must be met.

Construction Considerations: Street swale areas should be clearly marked before site work begins to avoid soil disturbance and compaction during construction.

Street Swales

No vehicular traffic, except that specifically used to construct the facility, should be allowed within 10 feet of swale areas.

Design Requirements:

Soil Suitability: Street swales are appropriate for all soil types. Topsoil shall be used within the top 12 inches of the facility, or the soil shall be amended per **Appendix F** to support plant growth.

Dimensions and Slopes: Facility storage depth may vary from 6 to 12 inches. Maximum side slopes are 3 horizontal to 1 vertical for vegetated swales, and 4 horizontal to 1 vertical for grassy swales (to accommodate for mowing). Minimum flat bottom width is 2 feet. Maximum longitudinal slope is 6%.

Setbacks: Required setback from building foundations is 10 feet unless lined with impermeable fabric.

Sizing: To meet pollution reduction and flow control requirements, the square-footage of street swales is to be determined using vegetated or grassy swale sizing criteria (shown on **Form SIM**), depending on which surface treatment is being used. The minimum width for street swales is 7 feet for vegetated, and 9 feet for grassy. Street swales sized with the simplified approach shall be designed to receive less than 15,000 square-feet of impervious area runoff. For these projects, a simplified approach sizing factor of 0.09 may be used to receive credit for pollution reduction and flow control. A high-flow by-pass mechanism will not be required in these cases, but a high-flow overflow must be provided at the downstream end of the swale to an approved disposal point, per **Section 1.4**.

Check Dams: Check dams shall be constructed of durable, non-toxic materials such as rock, brick, or concrete, or soil by integrated them into the grading of the swale. Check dams shall be 12 inches in length, by the width of the swale, by 3 to 5 inches in height.

Landscaping: Vegetation helps improve infiltration functions, protects from rain and wind erosion, and enhances aesthetic conditions. The "facility area" is equivalent to the area of the swale, including bottom and side slopes, as calculated from Form SIM. Turf grass may be used to cover the entire swale surface area. If plantings are chosen to landscape the swale, the minimum plant material quantities per 100 square feet of facility area shall be as follows:

4 - Large shrubs/small trees:	3-gallon containers or equivalent.
6 - Shrubs/large grass-like plants:	1-gallon containers or equivalent

SARB_007881

Street Swales

Ground cover plants:	1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the facility shall be planted with grasses or grass-like plants.

Wildflowers, native grasses, and ground covers used for BES-maintained facilities shall be designed not to require mowing. Where mowing cannot be avoided, facilities shall be designed to require mowing no more than once annually.

Recommended street trees in or near street swales:

With overhead power lines	**Without overhead power lines**
Carpinus caroliniana	Acer campestre 'Evelyn'
Cercis Canadensis	Betula jacquemontii
Fraxinus pennsylvanica 'Johnson'	Celtis occidentalis
Gleditsia triacanthos 'Impcole'	Gleditsia triacanthos 'Skycole'
Koelreuteria paniculata	Nyssa sylvatica
Prunus virginiana 'Canada Red'	Quercus shumardii

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Growing medium specification
4) Filter fabric specification (if applicable)
5) All curb cut details and stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
6) Landscaping plan

SARB_007882

Street Swales

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Swale grading	Call for inspection
Curbs / curb cuts	Call for inspection
Piping (if applicable)	Call for inspection
Filter fabric (if applicable)	
Growing medium	
Plantings	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to vegetated and grassy swale O&M form**

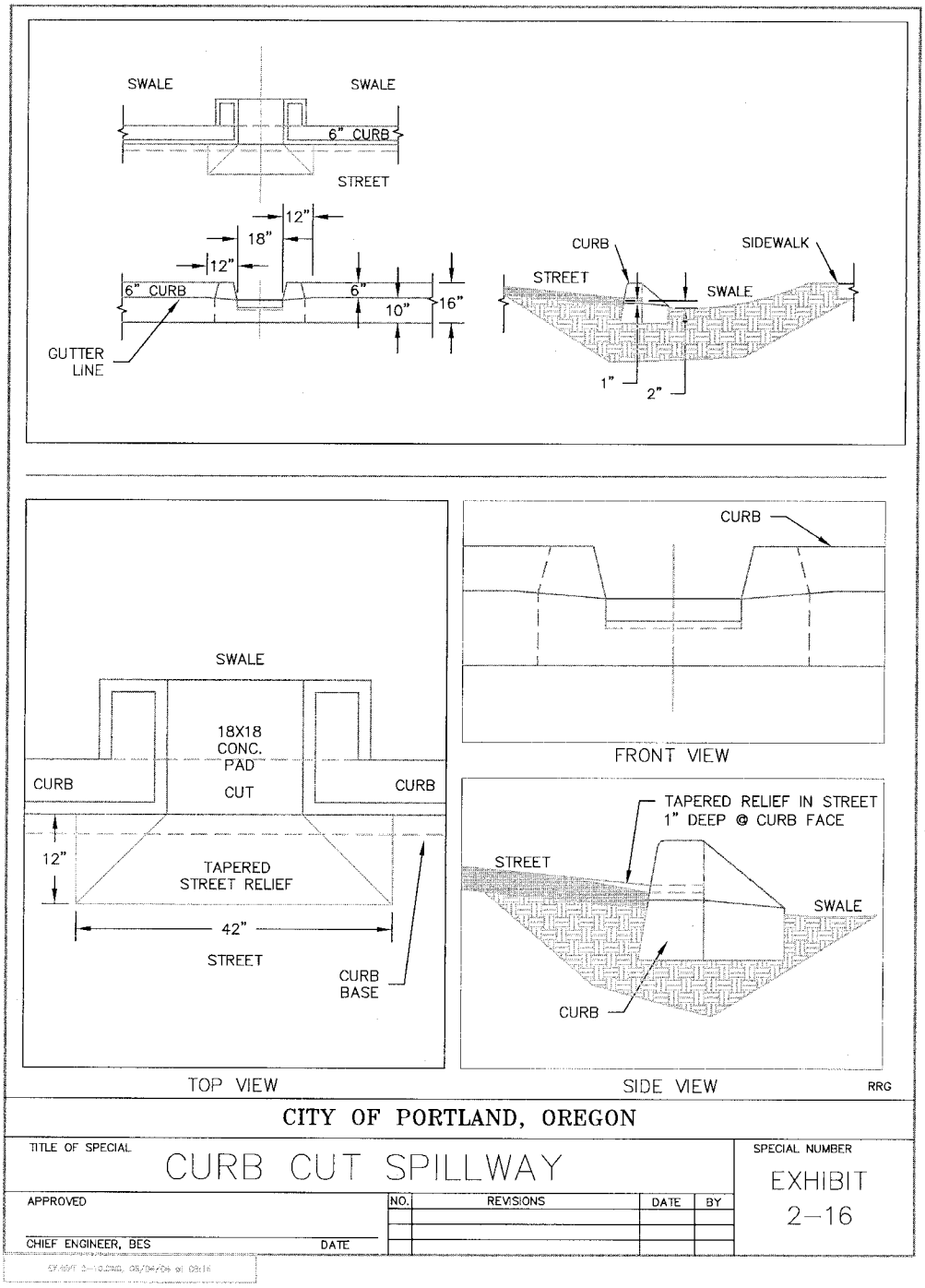
Additional photos and drawings:

*** Link to street swale photos**

*** Link to street swale drawings**

SARB_007883

Street Swales

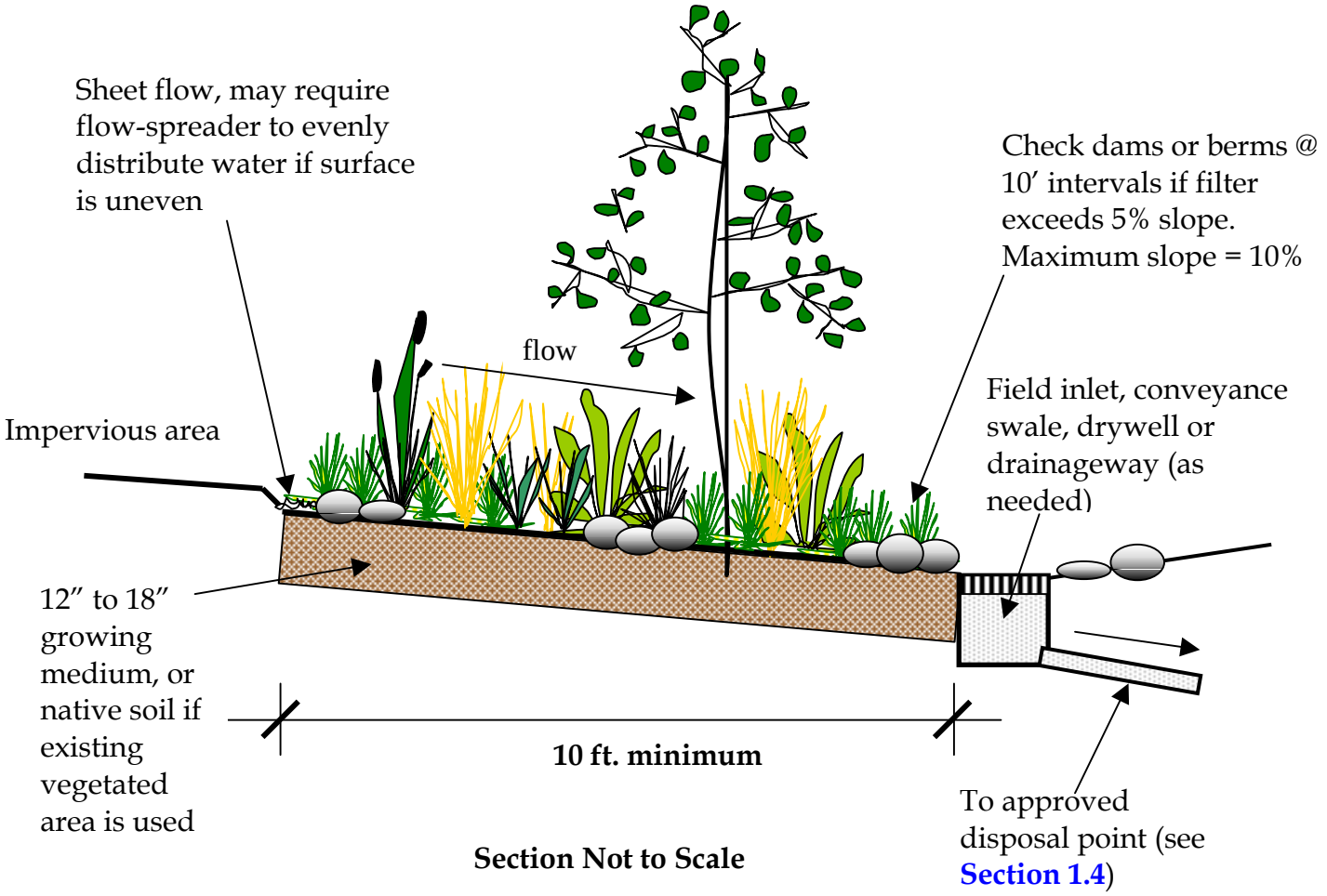


SARB_007884

Street Swales

SARB_007885

Vegetated Filter



Section Not to Scale

Stormwater Management Goals Achieved	**Acceptable Sizing Methodologies**
√ Pollution Reduction	SIM, PERF[1]
√ Flow Control	SIM
√ Destination/ Disposal[2]	PRES[2]

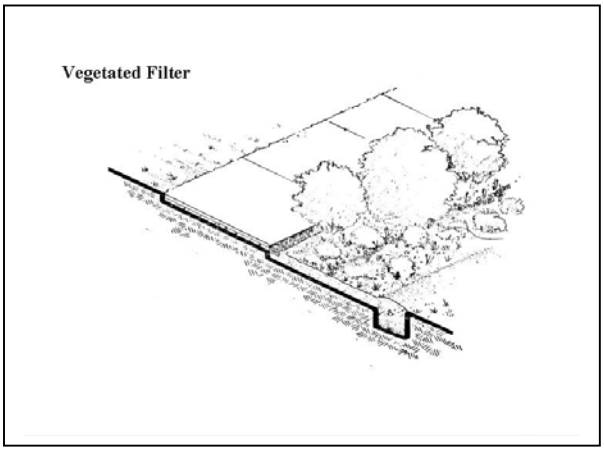
This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) The Performance Approach may be used to downsize the simplified approach sizing factor when the only goal is pollution reduction. Vegetated filters can be used to manage stormwater from rooftops, pathways, parking lots, and potentially streets (with flow spreaders or if the runoff is left as unconcentrated sheet flow). **2)** Where soils infiltrate sufficiently per BDS, stormwater disposal credit may be given for projects with less than 500 square feet of impervious surfaces to manage.

Vegetated Filter


SW Community Center (6820 SW 45th Ave.)



Description: Vegetated filter strips, or vegetated filters, are gently sloping areas used to filter, slow, and infiltrate stormwater flows. Stormwater enters the filter as sheet flow from an impervious surface or is converted to sheet flow using a flow spreader. Flow control is achieved using the relatively large surface area and for slopes greater than 5%, a generous proportion of check dams or berms. Pollutants are removed through filtration and sedimentation. Filters can be planted with a variety of trees, shrubs, and ground covers, including grasses. Sod may be used for single-family residential sites, where a simple downspout disconnection into lawn or landscaping is used. There can be many ways to fit this concept into site designs and designers are encouraged to use the site landscape areas for this purpose. Unless designed for stormwater disposal, an approved conveyance and disposal method per **Section 1.4** will be required at the end of the filter.

Design Considerations: When designing vegetated filters, slopes should be kept as flat as possible to prevent erosion. Spreading the flow evenly across the filter is also important in ensuring that the facility functions correctly and avoids flow channeling.

Construction Considerations: Vegetated filter areas should be clearly marked before site work begins to avoid soil disturbance during construction. No vehicular traffic, except that specifically used to construct the facility, should be allowed within 10 feet of filter areas. Flow spreaders must be constructed perfectly level to distribute flows evenly across the filter, and for public facilities must be surveyed after construction.

Design Requirements:

Soil Suitability: Vegetated filters are appropriate for all soil types. Unless existing vegetated areas are used for the filter, topsoil shall be used within the

top 12 inches of the facility, or the soil shall be amended per **Appendix F** to support plant growth.

Dimensions and Slopes: Maximum allowable vegetated filter slopes are 10%. Terraces may be used to decrease ground slopes. Minimum slopes are 0.5%.

Setbacks: Required setback from property lines is 5 feet, and 10 feet from building foundations unless lined with impermeable fabric.

Sizing: Unless used for very long, narrow projects such as pathways and trails, vegetated filters cannot be used to manage flow from more than 2,000 square-feet of impervious area. Filters shall be a minimum of 10 feet wide x 10 feet long. A simplified approach sizing factor of 0.2 may be used to receive credit for pollution reduction and flow control. A high-flow by-pass mechanism will not be required in these cases, but a high-flow overflow must be provided at the downstream end of the filter to an approved disposal point, per **Section 1.4**. In cases when pollution reduction is the only stormwater management goal, the performance approach may be used in conjunction with a measured infiltration rate to downsize the simplified approach sizing factor.

Check Dams: Check dams shall be constructed of durable, non-toxic materials such as rock, brick, or concrete, or graded into the native soils. Check dams shall be 12 inches in length, by the width of the filter, by 3 to 5 inches in height.

Landscaping: Vegetation helps improve infiltration functions, protects from rain and wind erosion, and enhances aesthetic conditions. Sod may be used for single-family residential sites, where a simple downspout disconnection into lawn or landscaping is used. For other projects, minimum plant material quantities per **100** square feet of facility area are as follows. The "facility area" is equivalent to the area of the filter, as calculated from Form SIM.

1 - Evergreen or deciduous tree (planted around the perimeter of the swale):		
	Evergreen trees:	Minimum height: 6 feet
	Deciduous trees:	Minimum caliper: 1 ½ inches at 6 inches above base.
4 - Large shrubs/small trees:		3-gallon containers or equivalent.
6 - Shrubs/large grass-like plants:		1-gallon containers or equivalent

Ground cover plants: 1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the facility shall be planted with grasses or grass-like plants.

Vegetated Filter

Wildflowers, native grasses, and ground covers used for BES-maintained facilities shall be designed not to require mowing. Where mowing cannot be avoided, facilities shall be designed to require mowing no more than once annually. Turf and lawn areas are not allowed for BES-maintained facilities; any exceptions will require BES approval.

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Growing medium specification (if applicable)
4) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
5) Landscaping plan
6) Flow spreader details and specifications
7) Check dam or terrace details and specifications

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Filter grading (if applicable)	Call for inspection
Flow spreaders/Terraces (if applicable)	Call for inspection
Piping (if applicable)	Call for inspection
Growing medium (if applicable)	
Plantings	Call for inspection

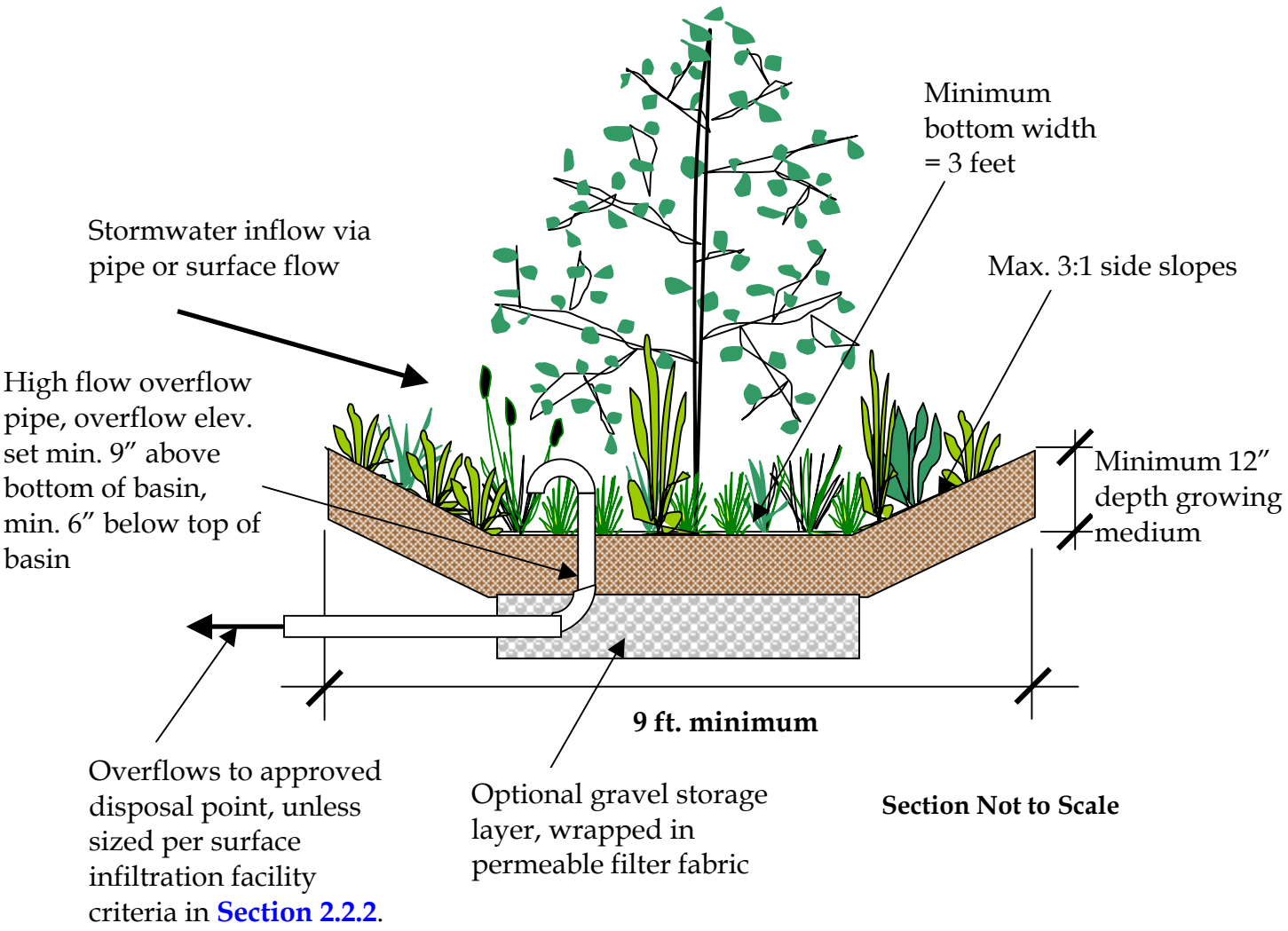
Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to vegetated filter O&M form**

Additional photos and drawings:

*** Link to vegetated filter photos**
*** Link to vegetated filter drawings**

Vegetated Infiltration Basin



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction	SIM, PERF[1]
√ Flow Control	SIM
√ Destination/ Disposal	PRES[2]

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) The performance approach may be used to downsize the simplified approach sizing factor when the only goal is pollution control. **2)** The surface infiltration facility sizing methodology from Section 2.2.2 may be used to achieve stormwater disposal. Vegetated infiltration basins can be used to manage stormwater from all impervious surface types, and must be located on private property.

Vegetated Infiltration Basin





Description: Vegetated infiltration basins are shallow landscaped depressions used to collect and hold stormwater runoff, allowing pollutants to settle and filter out as the water infiltrates into the ground. In addition to providing pollution reduction, flow rates and volumes can also be managed with vegetated infiltration basins. They should be integrated into the overall site design and can be used to help fulfill a site's required landscaping area requirement. As shown in the example photos, the design can be formal or informal in character and planting scheme. An overflow mechanism to an approved conveyance and disposal method per **Section 1.4** will be required, unless the basin is designed per surface infiltration facility guidelines presented in **Section 2.2.2**.

Design Considerations: When designing vegetated infiltration basins, the infiltration rate of the native soil is a key element in determining size and viability. Slopes and depth should be minimized to avoid safety risks.

Construction Considerations: Infiltration basin areas should be clearly marked before site work begins to avoid soil disturbance during construction. No vehicular traffic, except that specifically used to construct the facility, should be allowed within 10 feet of infiltration basin areas.

Design Requirements:

Soil Suitability: Vegetated infiltration basins are appropriate for soils with a minimum infiltration rate of 2 inches per hour (NRCS soil types A and B). There shall be no less than three feet of undisturbed infiltration medium between the bottom of the facility and any impervious layer (i.e. hardpan, solid rock, high groundwater levels, etc.). Topsoil shall be used within the top 12 inches of the facility, or the soil shall be amended per **Appendix F** to support plant growth.

Vegetated Infiltration Basin

Dimensions: Facility storage depth may vary from 9 to 18 inches. Maximum side slopes are 3 horizontal to 1 vertical. Minimum bottom width is 2 feet.

Setbacks: Required setback from property lines is 5 feet, and 10 feet from building foundations. Infiltration basins shall meet the following setback requirements from downstream slopes: minimum of 100 feet from slopes of 10%; add 5 feet of setback for each additional percent of slope up to 30%; infiltration trenches shall not be used where slopes exceed 30%.

Sizing: Vegetated infiltration basins sized with the simplified approach shall be designed to receive less than 15,000 square-feet of impervious area runoff. For these projects, a simplified approach sizing factor of 0.09 may be used to receive credit for pollution reduction and flow control. A high-flow overflow must be provided, or to receive credit for complete stormwater infiltration, the surface infiltration facility design criteria from **Section 2.2.2** must be used. In this case, pre and post-construction infiltration tests are required to demonstrate infiltration performance. In cases when pollution reduction is the only stormwater management goal, the performance approach may be used in conjunction with a measured infiltration rate to downsize the simplified approach sizing factor. Drawdown time (time for the basin to empty when full) shall not exceed 30 hours.

Landscaping: Vegetation helps improve infiltration functions, protects from rain and wind erosion, and enhances aesthetic conditions. The "facility area" is equivalent to the area of the basin, including bottom and side slopes, plus a 10-foot buffer around the basin. Minimum plant material quantities per 300 square feet of facility area are as follows:

1 - Evergreen or deciduous tree (planted around the perimeter of the basin):

Evergreen trees:	Minimum height: 6 feet
Deciduous trees:	Minimum caliper: 1 ½ inches at 6 inches above base.
4 - Large shrubs/small trees:	3-gallon containers or equivalent.
6 - Shrubs/large grass-like plants:	1-gallon containers or equivalent
Ground cover plants:	1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the facility shall be planted with grasses or grass-like plants.

Wildflowers, native grasses, and ground covers used for BES-maintained facilities shall be designed not to require mowing. Where mowing cannot be

avoided, facilities shall be designed to require mowing no more than once annually. Turf and lawn areas are not allowed for BES-maintained facilities; any exceptions will require BES approval.

For public vegetated infiltration basins, the following additional design criteria shall apply:

1) Two staff gauges shall be installed at opposite ends of the bottom of the basin, to enable maintenance staff to measure the depth of accumulated silts.
2) A soil scientist, or suitably trained person working under the supervision of an Oregon licensed professional geotechnical engineer, shall inspect the soil after the system is excavated to confirm that soils remain in suitable condition for infiltration.

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Growing medium specification
4) Filter fabric specification (if applicable)
5) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
6) Landscaping plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Basin grading	Call for inspection
Piping	Call for inspection
Filter fabric	
Growing medium	
Plantings	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

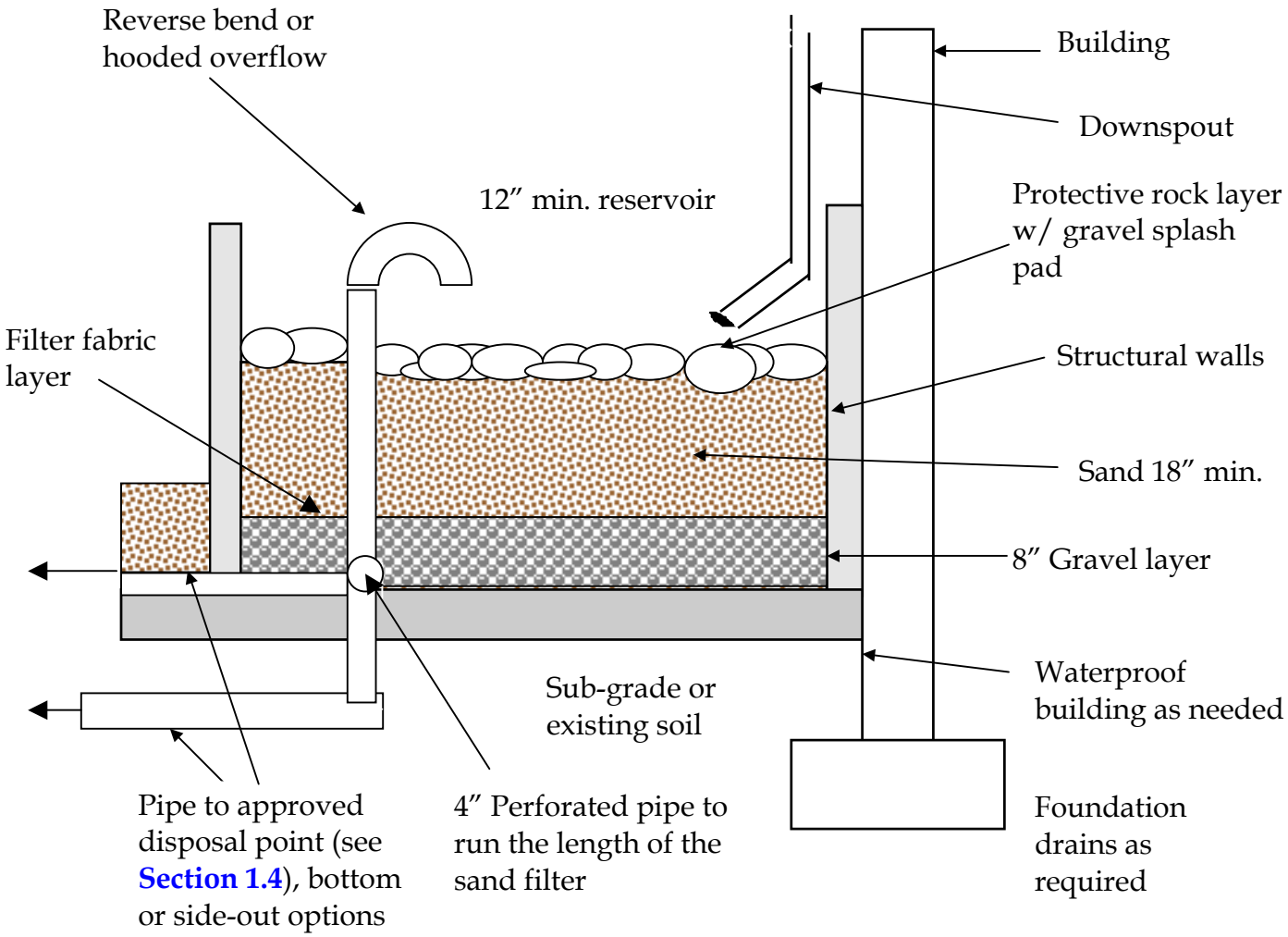
*** Link to vegetated infiltration basin O&M form**

Additional photos and drawings:

*** Link to vegetated infiltration basin photos**

*** Link to vegetated infiltration basin drawings**

Sand Filter



Section not to scale

Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction	SIM, PERF[1]
√ Flow Control	SIM
√ Destination/ Disposal	PRES[2]

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) The performance approach may be used to downsize the simplified approach sizing factor when the only goal is pollution reduction. Sand filters can be used to manage stormwater from any impervious surface, and must be located on private property. **2)** The surface infiltration facility design procedure from Section 2.2.2 may be used to receive credit for stormwater disposal.

Sand Filter





Description: There are two sand filter options. One is designed with an impervious bottom or is placed on an impervious surface. It can be used for all soil types. The other option, for native soils with a minimum infiltration rate of 2 inches per hour (NRCS soil types A and B), allows filtered water to infiltrate into the ground. For both options, pollutant reduction is achieved as the water filters through the sand; flow control is obtained by slowing the discharge rate as the water filters through the sand. Filters may be constructed in-ground or above grade. Because they can include a waterproof lining, sand filters are extremely versatile and can be used next to foundation walls, adjacent to property lines (if less than 30" in height), or on slopes. An overflow to an approved conveyance and disposal method per **Section 1.4** will be required.

Design Considerations: When designing sand filters, the structural walls can often times be incorporated with building foundation plans.

Construction Considerations: Special attention needs to be paid to the filter waterproofing if constructed adjacent to building structures.

Design Requirements:

Soil Suitability: Lined sand filters are appropriate for all soil types. Filters designed to infiltrate into native soils are appropriate in soils with a minimum infiltration rate of 2 inches per hour (NRCS soil types A and B).

Dimensions and Slopes: Facility storage depth must be at least 12 inches, unless a larger-than-required planter square-footage is used. Minimum sand filter width is 18 inches. Filter slopes shall be less than 0.5%.

Setbacks: Required setback from property lines is 5 feet, unless the sand filter height is less than 30 inches. Required setback from building structures is 10 feet, unless the sand filter is properly lined.

Sand Filter

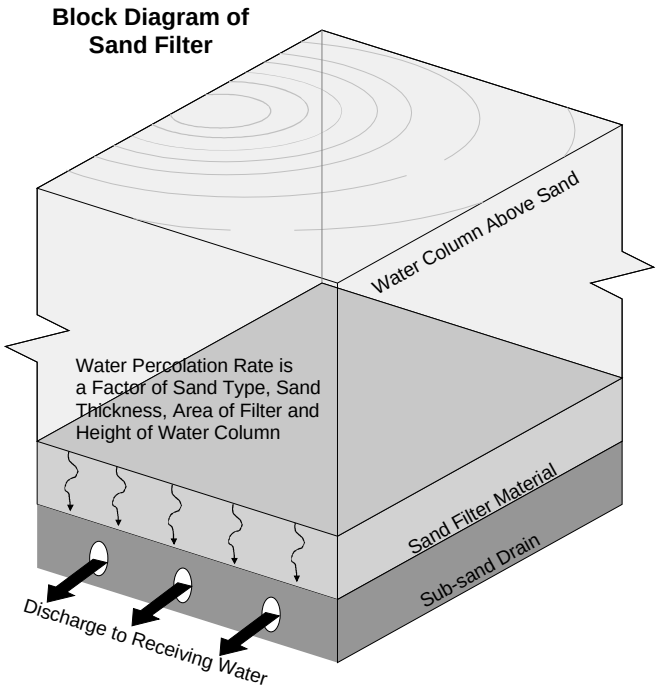
Structural Walls: Sand filter walls shall be made of stone, concrete, brick, or wood. Chemically treated wood that can leach out toxic chemicals and contaminate stormwater shall not be used.

Sizing: Sand filters sized with the simplified approach shall be designed to receive less than 15,000 square-feet of impervious area runoff. For these projects, a simplified approach sizing factor of 0.06 may be used to receive credit for pollution reduction and flow control. For projects with more than 15,000 square-feet of impervious surface, additional facilities may be required to meet flow control requirements. A high-flow overflow must be provided to an approved disposal point per **Section 1.4**. In cases when pollution reduction is the only stormwater management goal, the performance approach may be used to downsize the simplified approach sizing factor. Sand filters shall be designed to pond water for less than 4 hours after each storm event.

Vegetation: Plantings are optional in sand filters. For aesthetic purposes, potted plants may be submerged in the sand filter.

For public sand filters, the following additional criteria shall apply:

The sand filter consists of an inlet structure, sand bed, underdrain piping, and basin liner. Criteria for these components are provided below.



Inlet Structure

1) The inlet structure shall spread the flow of incoming water uniformly across the surface of the filter medium during all anticipated flow conditions. This flow shall be spread in a manner that prevents roiling or otherwise disturbing the filter medium.

Sand Bed/ Filter Medium

1) The length-to-width ratio shall be 2:1 or greater.

2) The sand bed configuration may be either of the two configurations shown in **Exhibit 2-17**. All depths shown are final depths. The effects of consolidation and/or compaction must be taken into account when placing medium materials. The surface of the filter medium shall be level.

3) Sand used as filter medium shall be certified by a testing laboratory as meeting or exceeding the specifications presented below:

The filter bed medium shall consist of clean medium to fine sand with no organic material, or other deleterious materials and meeting the following gradation:

Sieve Size	Percent Passing
3/8″	100
#4	95-100
#8	80-100
#16	45-85
#30	15-60
#50	3-15
#100	< 4

Sand Bed with Gravel Filter (**Exhibit 2-17:A**)

1) The top layer shall be a minimum of 18 inches of approved sand.

2) The sand shall be placed over an acceptable geofabric material covering a layer of ½- to 2-inch washed drain rock. The finished depth of this drain rock shall be sufficient to provide a minimum of 2 inches of cover over the underdrain piping system.

3) No gravel is required below the underdrain piping system.

Sand Bed Using Trench Design (**Exhibit 2-17:B**)

1) The top layer shall be a minimum of 12 inches of approved sand.

2) The sand shall be placed over an acceptable geotextile fabric material covering a layer of ½ to 2-inch washed drain rock. The finished depth of this drain rock shall be sufficient to provide a minimum of 2 inches of cover over the underdrain piping system.

3) The piping and gravel shall be underlain with geotextile fabric.

Sand Filter

Underdrain Piping

1) The underdrain piping system shall consist of appropriately sized (minimum 4-inch diameter) collector manifold with perforated lateral branch lines. The pipe used in this conveyance system shall be schedule 40 polyvinyl chloride (PVC) material or an approved equal. Lateral spacing shall not exceed 10 feet.

2) The underdrain laterals shall be placed with positive gravity drainage to the collector manifold.

3) The collector manifold shall have a minimum 1 percent grade toward the discharge point.

4) All laterals and collector manifolds shall have cleanouts installed, accessible from the surface without removing or disturbing filter media.

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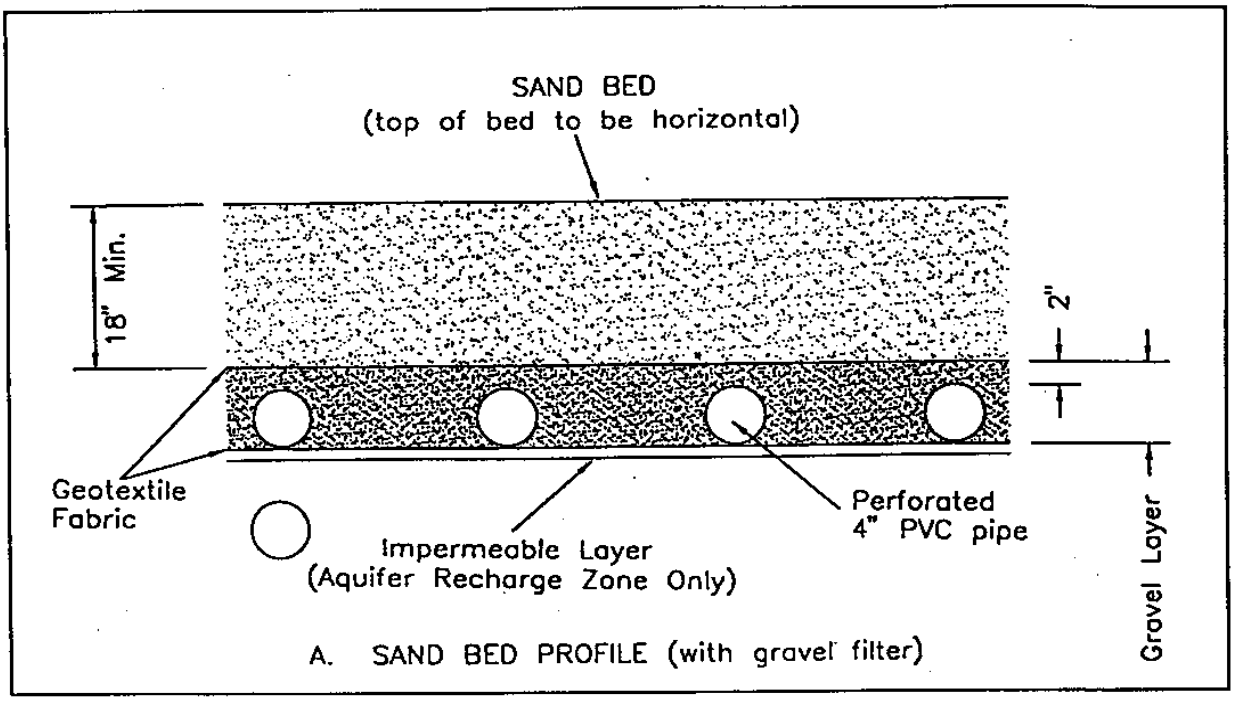
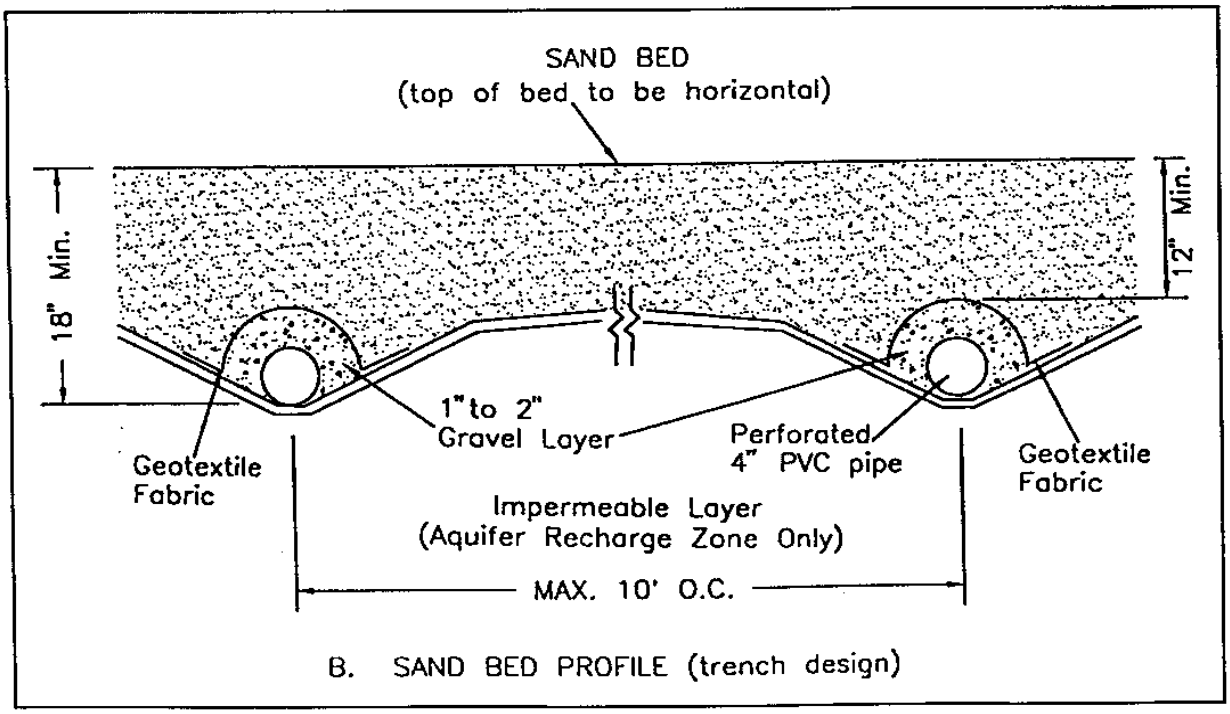
Sand Filter

Exhibit 2-17



A. SAND BED PROFILE (with gravel filter)



B. SAND BED PROFILE (trench design)

SARB_007899

Sand Filter

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Structural wall material specification
4) Sand specification
5) Filter fabric specification
6) Rock surface layer specification
7) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Sand filter grading	Call for inspection
Structural walls	Call for inspection
Piping	Call for inspection
Sand	
Filter fabric	
Rock layer	Call for inspection
Plantings (if applicable)	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

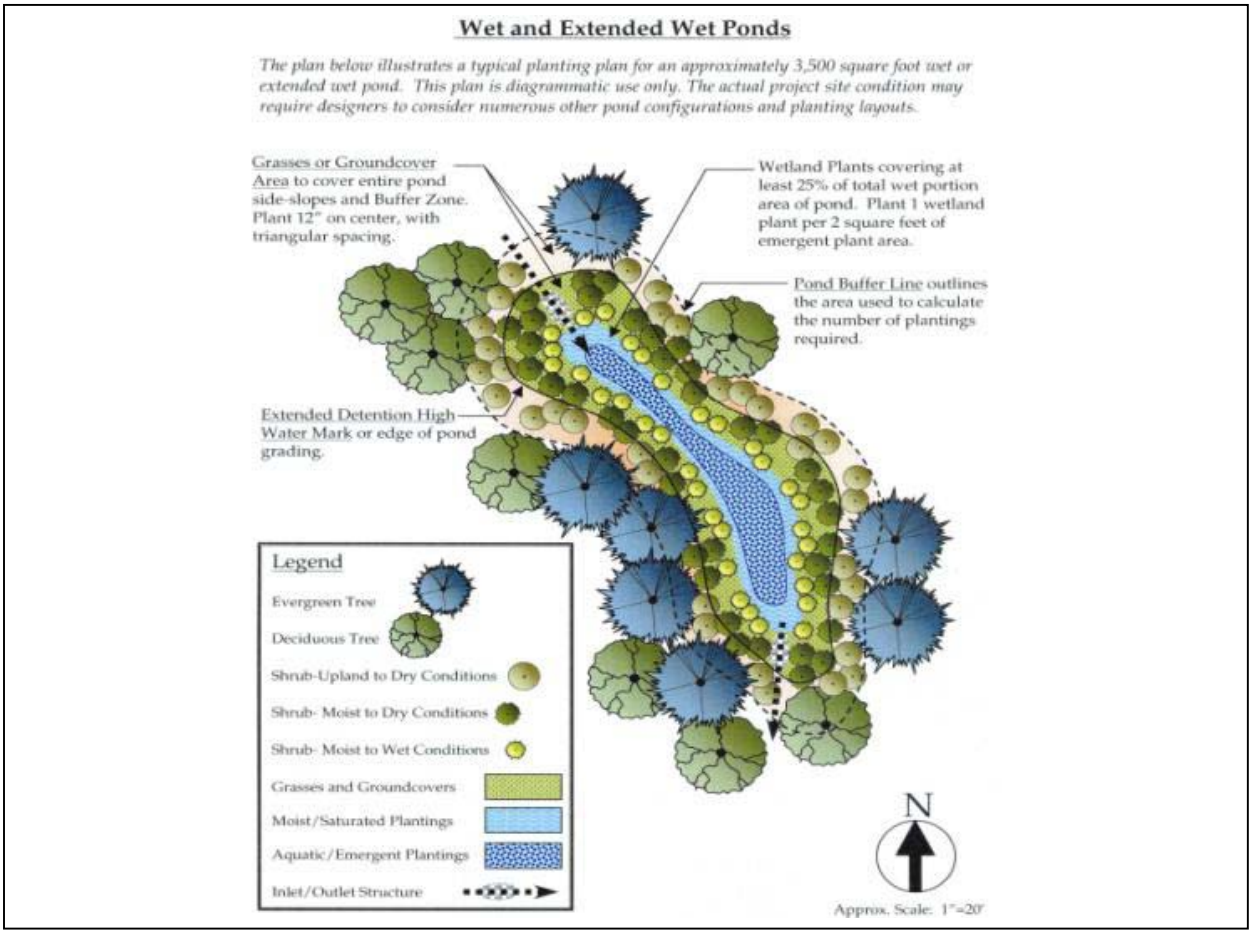
*** Link to sand filter O&M form**

Additional photos and drawings:

*** Link to sand filter photos**

Sand Filter

Wet, Extended Wet, & Dry Detention Pond



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction……..	PRES[1]
√ Flow Control……..……	PRES[2]
Destination/ Disposal……	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) Wet and extended wet detention ponds receive credit for pollution reduction. For dry detention ponds to receive credit for pollution reduction, the bottom flow path of the pond must be designed as a vegetated or grassy swale, with sizing and design in accordance with criteria presented in this chapter. **2)** Only extended wet detention and dry detention ponds receive credit for flow control. All ponds must overflow to an acceptable stormwater disposal point per **Section 1.4**. Wet and extended wet detention ponds can be used to provide pollution reduction for any impervious surfaces, and must be located outside of public rights-of-way.

Wet, Extended Wet, & Dry Detention Pond



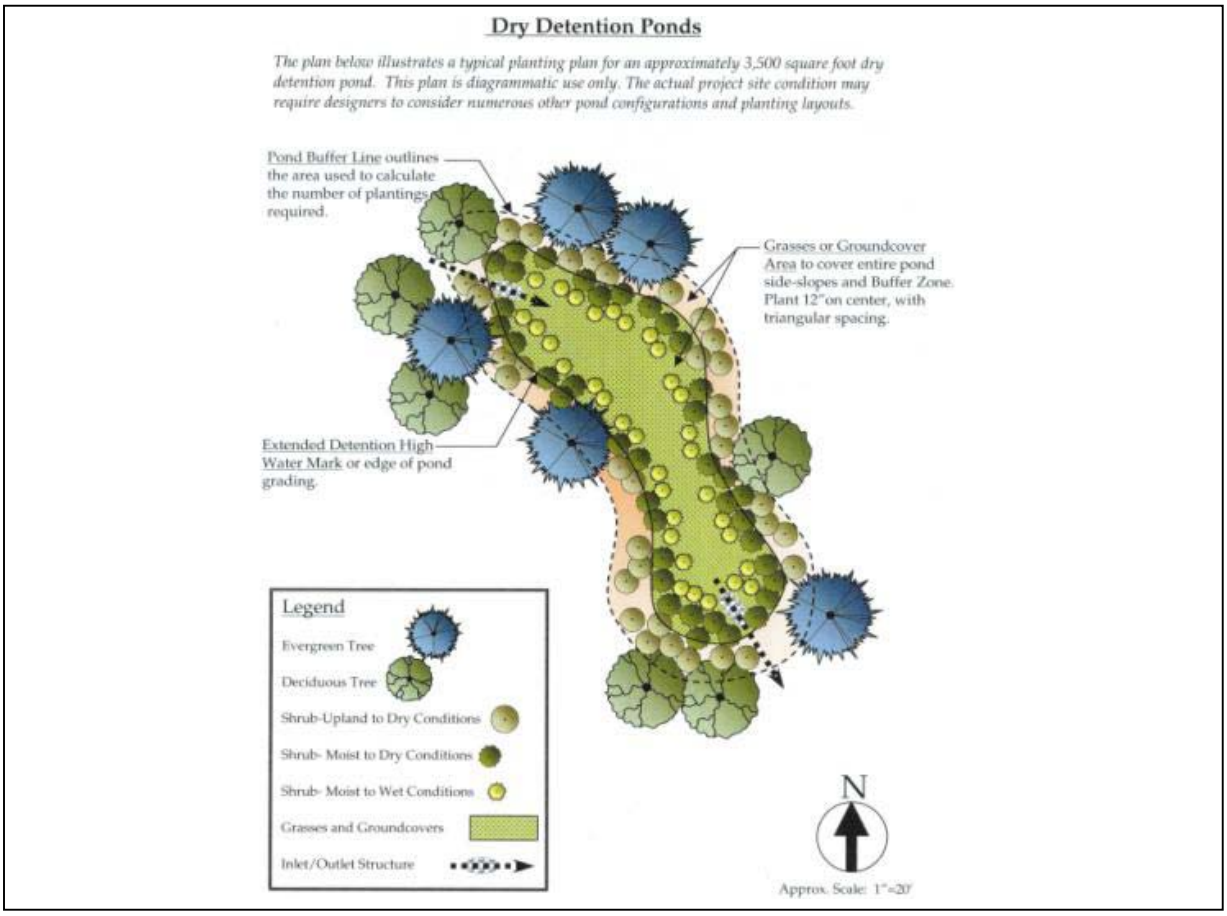


Wet Pond Description: Wet ponds are constructed with a permanent pool of water (called pool storage or dead storage). Stormwater runoff enters the pond at one end and displaces water from the permanent pool. Pollutants are removed from stormwater through gravitational settling and biologic processes. When the sizing criteria presented in this section is used, pollution reduction requirements are presumed to be met. Additional facilities will be required to meet flow control requirements, as applicable. An overflow mechanism to an approved conveyance and disposal method per **Section 1.4** will be required.

Extended Wet Detention Pond Description: Extended wet detention ponds are constructed with a permanent pool of water (called pool storage or dead storage) and additional storage above, which fills during storm events and releases water slowly over a number of hours. The permanent pool is sized to provide pollution reduction, and the additional storage above (extended detention area) is sized to meet flow control requirements. Pollutants are removed from stormwater through gravitational settling and biologic processes. When the sizing criteria presented in this section is used, pollution reduction requirements are presumed to be met. The extended detention portion of this facility must be designed using acceptable hydrologic modeling techniques (see **Section 2.3**) to meet applicable flow control requirements (see **Section 1.6.2**). An overflow mechanism to an approved conveyance and disposal method per **Section 1.4** will be required.

Dry Detention Pond Description: Dry detention ponds are vegetated basins designed to fill during storm events and slowly release the water over a number of hours. Dry detention ponds must be designed using acceptable hydrologic modeling techniques (see **Section 2.3**) to meet applicable flow control requirements (see **Section 1.6.2**). Additional facilities are required to meet pollution reduction requirements, unless the bottom flow path of the pond is designed as a vegetated or grassy swale, per swale sizing and design criteria. An

overflow mechanism to an approved conveyance and disposal method per **Section 1.4** will be required.







Wet, Extended Wet, & Dry Detention Pond

Design Considerations: Slopes and depth should be kept as mild as possible to avoid safety risks. Wet and extended wet detention ponds should be designed for large drainage areas (5 to 150 acres) to help avoid problems associated with long periods of stagnant water. The City encourages applicants to design ponds to function as multi-purpose facilities (e.g., parks, open space, recreation facilities, or parking lots), provided that any alternative uses are compatible with the primary stormwater functions and maintenance standards. Instream ponds are not encouraged. If used, they require special approvals from the National Marine Fisheries Service, Oregon Department of Fish and Wildlife, Oregon Division of State Lands, and City of Portland, in addition to water rights from the Oregon Division of Water Rights.

Construction Considerations: As pond grading generally requires the topsoil to be removed to form the basin shape of the pond, the resulting top layers of soil must to be amended, or topsoil must be brought back in to ready the soil for planting.

Location and Ownership:

- All open ponds to be maintained by the City of Portland shall be located in a separate open space tract with public sewer easements dedicated to the City.
- Open ponds serving more than one tax lot, or designed to function as multi-use/recreational facilities, shall be located in a separate tract (e.g., Tract A), defined easement, or designated open space.

Setbacks: Ponds shall be constructed to maintain the following setback distances from structures and other facilities. (All distances are measured from the edge of the maximum water surface elevation. The setback limit applies to ponds near the top of slope, not the bottom.)

- Minimum distance from the edge of the pond water surface to property lines and structures: 20 feet, unless an easement with adjacent property owner is provided.
- Distance from the toe of the pond berm embankment to the nearest property line: one-half of the berm height (minimum distance of 5 feet).
- Minimum distance from the edge of the pond water surface to septic tank, distribution box, or septic tank drain field: 50 feet.
- Surrounding slopes shall not exceed 10%. Minimum distance from the edge of the pond water surface to the top of a slope greater than 15 percent: 200 feet, unless a geotechnical report is submitted and approved by BES (**Exhibit 2-18**).
- Minimum distance from the edge of the pond water surface to a well: 100 feet (**Exhibit 2-18**).

Wet, Extended Wet, & Dry Detention Pond

Geometry/ Design Requirements:

- Slopes within the pond shall not exceed 3 horizontal to 1 vertical.
- The distance between all inlets and the outlet shall be maximized to facilitate sedimentation. The minimum length-to-width ratio is 3:1, at the maximum water surface elevation. This ratio is critical to prevent "short-circuiting," where water passes directly through the facility without being detained for any length of time. If area constraints make this ratio unworkable, baffles, islands, or peninsulas may be installed, with City approval, to increase the flow path and prevent short-circuiting.
- The maximum depth of the pond shall not exceed 4 feet. The 0 to 2-foot depth shall be distributed evenly around the perimeter of the pond.
- Minimum freeboard shall be 1 foot above the highest potential water surface elevation (one foot above the emergency overflow structure or spillway elevation).
- Wet and extended wet detention ponds are applicable in NRCS Type C and D soils (A and B soils with impermeable liner). Topsoil shall be used within the top 12 inches of the facility, or the soil shall be amended per **Appendix F** to support plant growth.
- Dry detention ponds are applicable in NRCS type B, C, and D soils (the pond should most likely be designed as an infiltration basin in type A soils). Topsoil shall be used within the top 12 inches of the facility, or the soil shall be amended per **Appendix F** to support plant growth.
- Unless designed with a pollution reduction swale in the bottom flow path, dry detention ponds shall be divided into a minimum of two cells. The first cell (forebay) shall contain approximately 10 percent of the design surface area, and shall provide at least 0.5 feet of dead storage for sediment accumulation.
- Wet and extended wet detention ponds shall be divided into a minimum of two cells. The first cell (forebay) shall contain approximately 10 percent of the design surface area, and shall provide at least 0.5 feet of dead storage for sediment accumulation.
- Public ponds shall be designed with an upstream sedimentation manhole with downturned elbow or tee riser outflow pipe (See **Exhibit 2-32**) to trap oils and reduce the likelihood of a visible sheen on the pond surface.
- Access routes to the pond for maintenance purposes must be shown on the plans. Public ponds will need to provide a minimum 8-foot wide access route, not to exceed 10 percent in slope.
- Where possible, a dewatering outlet with shut-off valve shall be provided to aid in the maintenance of the permanent pool.
- For wet and extended wet detention ponds, a water budget shall be submitted for review. The water budget must demonstrate that the baseflow to the pond is sufficient such that water stagnation/alga matting will not become a problem.

Outlet/ Overflow:

- If a riser pipe outlet is used, it shall be protected by a trash rack and anti-vortex plate. If an orifice plate is used, it shall be protected with a trash rack with at least 10 square feet of open surface area. In both cases, the rack must be hinged or easily removable to allow for cleaning. The rack shall be adequately secured to prevent it from being removed or opened when maintenance is not occurring.
- All ponds shall have an emergency overflow spillway or structure designed to convey the 100- year, 24-hour design storm for post-development site conditions, assuming the pond is full to the overflow spillway or structure crest. The overflow shall be designed to convey these extreme event peak flows around the berm structure for discharge into the downstream conveyance system. The overflow shall be designed and sited to protect the structural integrity of the berm. This will assure that catastrophic failure of the berm is avoided, property damage is avoided, and water quality of downstream receiving water bodies is protected (see **Exhibit 2-20**).
- The subgrade of the spillway shall be set at or above the 100-year overflow elevation of the control structure. The spillway shall be located to direct overflows safely towards the downstream conveyance system and shall be located in existing soil wherever feasible. The emergency overflow spillway shall be armored with riprap or other flow-resistant material that will protect the embankment and minimize erosion. Riprap shall be designed in conformance with **Section 2.8** and shall extend to the toe of each face of the berm embankment. The emergency overflow spillway weir section shall be designed for the maximum design storm event for post-development conditions, using the following formula:

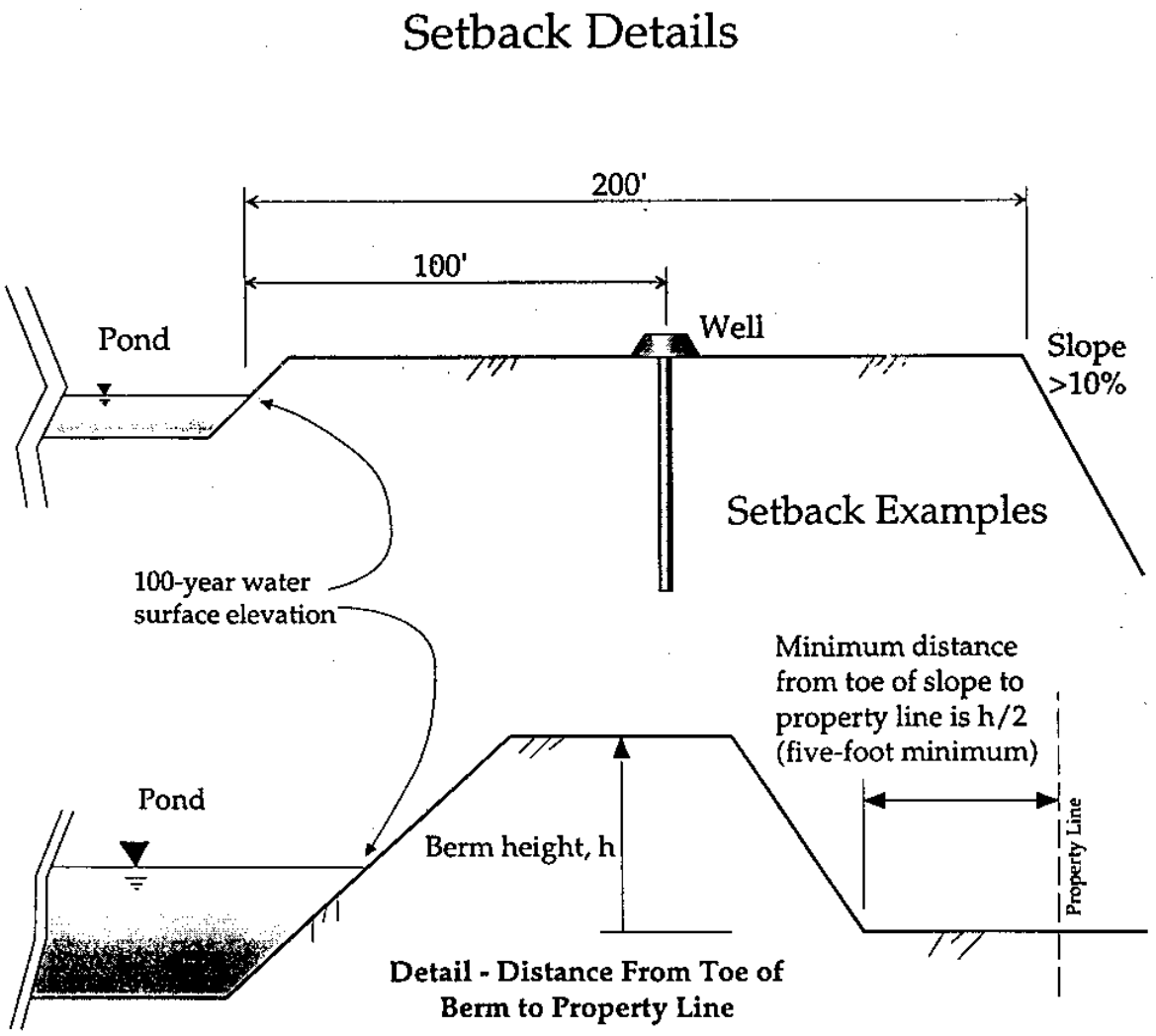
$$L = \frac{Q_{100}}{3.21H^{1.5}} - 2.4\,H$$

where:

L	=	Length of bottom of weir, feet
Q_{100}	=	100-year post-development flow rate, cfs
H	=	Height of emergency overflow water surface, feet

Wet, Extended Wet, & Dry Detention Pond

EXHIBIT 2-18



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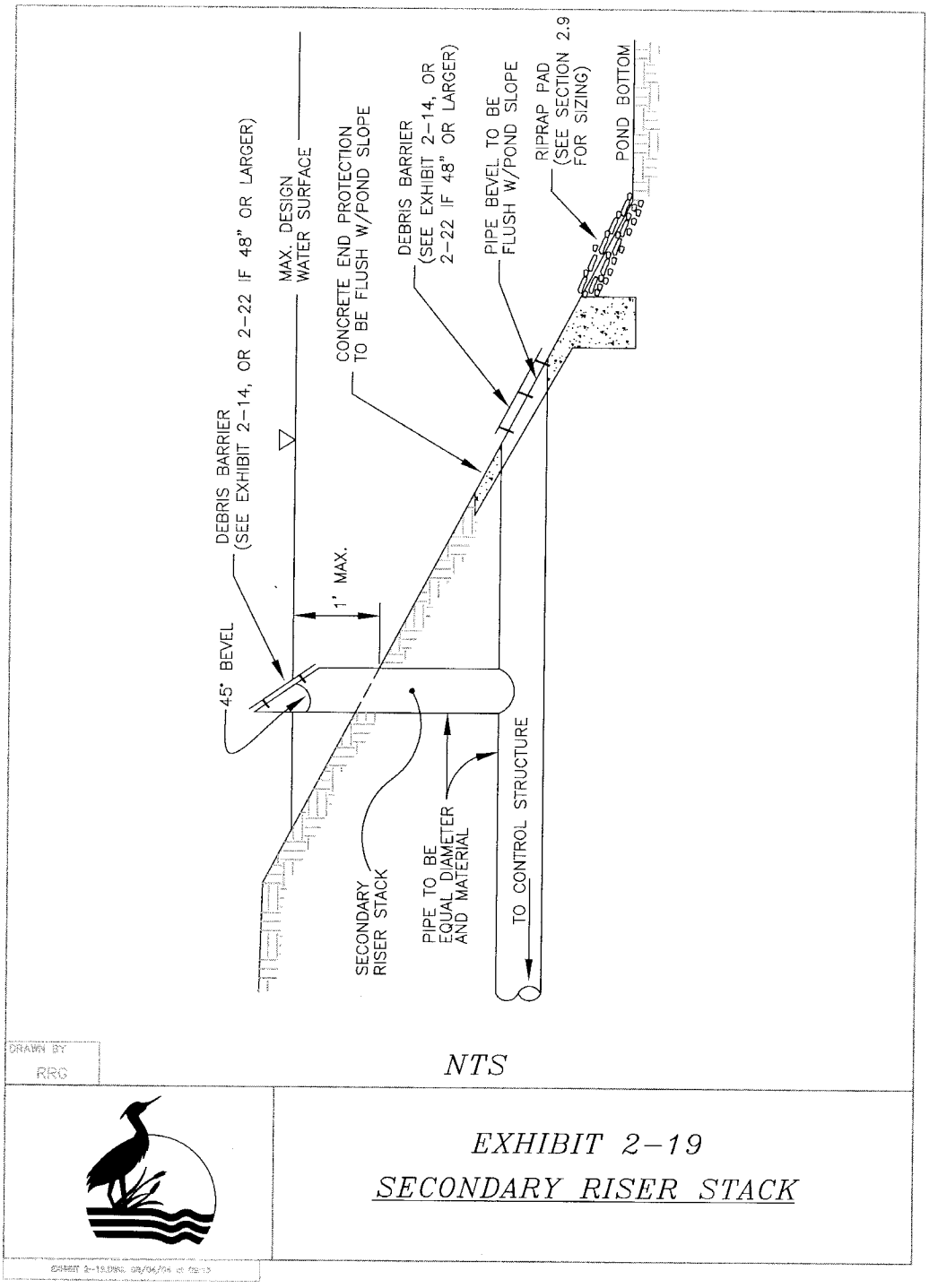
Wet, Extended Wet, & Dry Detention Pond



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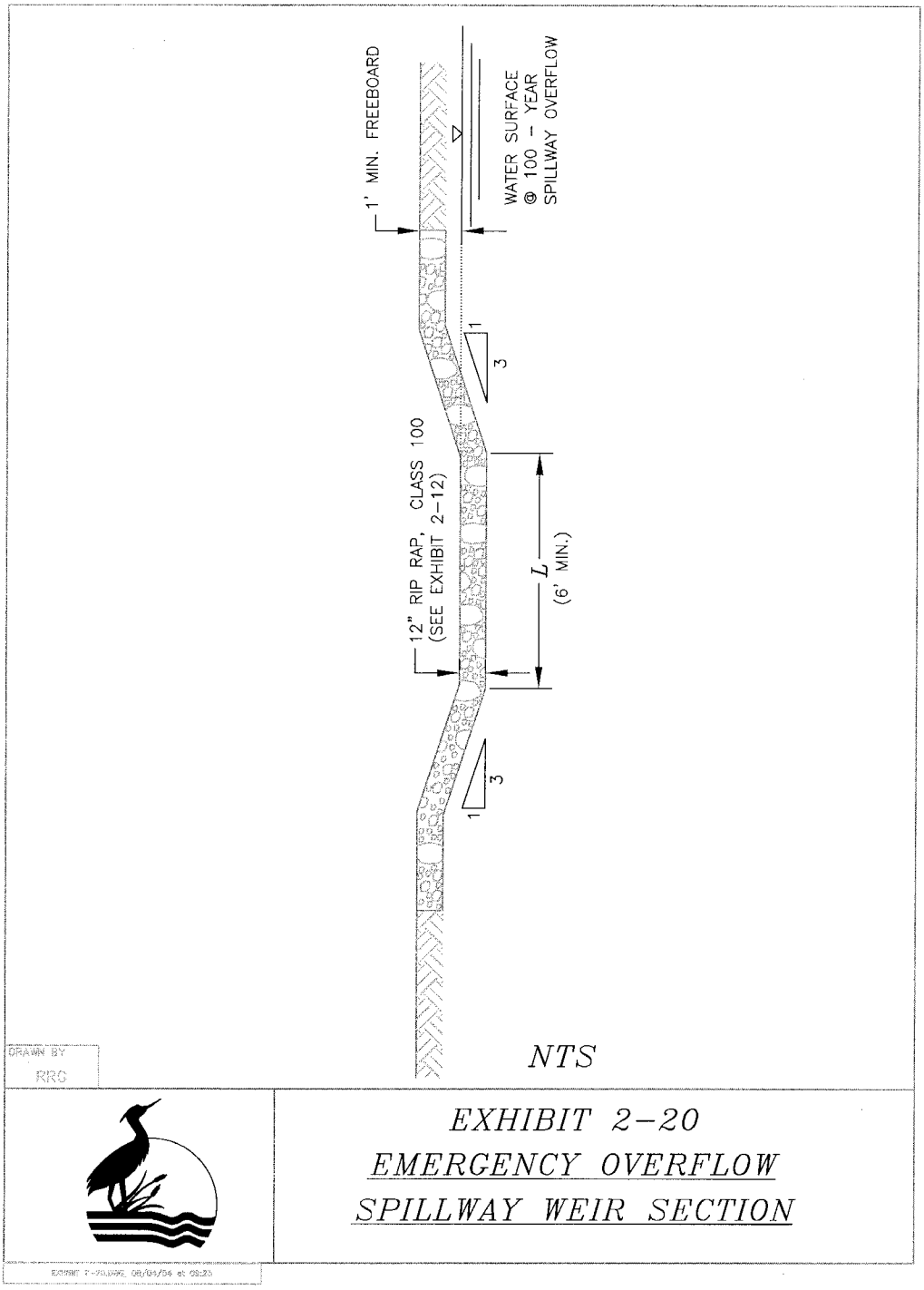

1' MIN. FREEBOARD
WATER SURFACE
@ 100 - YEAR
SPILLWAY OVERFLOW
1
3
12" RIP RAP, CLASS 100
(SEE EXHIBIT 2-12)
L
(6' MIN.)
1
3
NTS
DRAWN BY
RRC
EXHIBIT 2-20
EMERGENCY OVERFLOW
SPILLWAY WEIR SECTION

SARB_007910

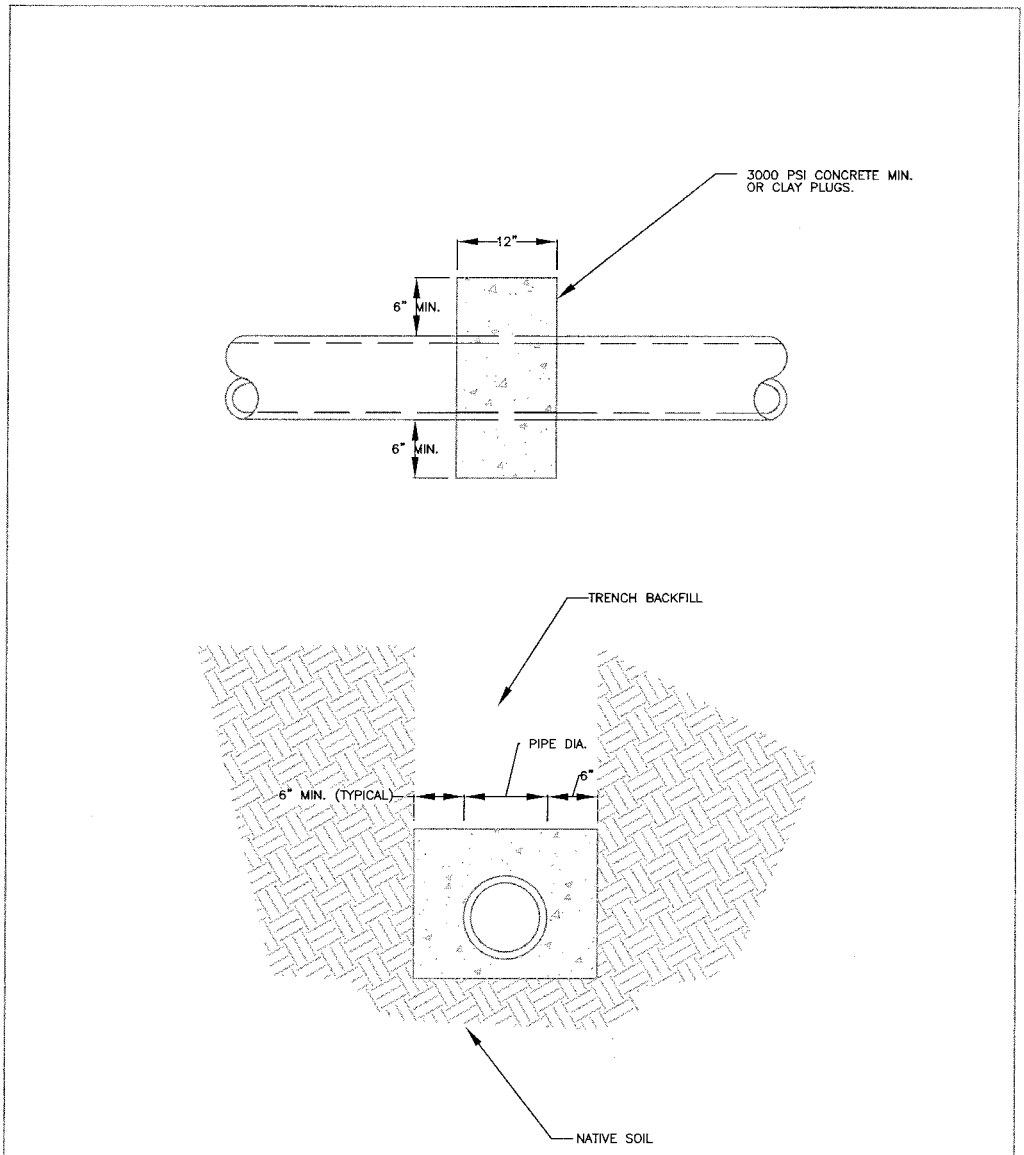
Wet, Extended Wet, & Dry Detention Pond

Berm Embankment/Soil Stabilization:

- Pond berm embankments shall be designed by a civil engineer licensed in the State of Oregon.
- Pond berm embankments shall be constructed on native consolidated soil (or compacted and stable fill soil) that is free of loose surface soil materials, roots, and other organic debris. Topsoil will be required over the consolidated soil to support required plantings.
- Pond berm embankments shall be constructed by excavating a key equal to 50 percent of the berm embankment cross-sectional height and width measured through the center of the berm. (Note: A key in a berm is an excavated trench below the berm filled with soil material used to make the berm. It acts to "key" the berm into the native soil to prevent it from sliding.)
- The berm embankment shall be constructed of compacted soil (95 percent maximum dry density, Modified Proctor Method per ASTM D1557) placed in 6- to 8-inch lifts with hand-held equipment, or 10- to 12-inch lifts with heavy equipment.
- Anti-seepage collars shall be placed on outflow pipes in berm embankments impounding water greater than 8 feet in depth **(**see **Exhibit 2-21).**
- During construction, exposed earth on the pond side slopes shall be sodden or seeded with appropriate seed mixture. Establishment of protective vegetative cover shall be ensured with appropriate surface-protection best management practices (BMPs) and reseeded as necessary. See the City of Portland's *Erosion Control Manual*.
- Pond embankments shall be constructed with a maximum (i.e. steepest) slope of 3H: 1V on the upstream and downstream face. Side slopes **within** the pond shall be sloped no steeper than 3H: 1V. The use of retaining walls in ponds requires pre-approval from BES. Retaining walls shall not exceed one-third of the circumference of the pond. Detailed structural design calculations must be submitted with every retaining wall proposal.
- Pond berm embankments 6 feet or less in height including freeboard, measured through the center of the berm, shall have a minimum top width of 6 feet, or as recommended by a geotechnical engineer.
- Where maintenance access is provided along the top of berm, the minimum width of the top of berm shall be at least 15 feet.

For public ponds, the following additional design criteria shall apply:

- Two staff gauges shall be installed at opposite ends of the bottom of the pond, to enable maintenance staff to measure the depth of accumulated silts.


3000 PSI CONCRETE MIN.
OR CLAY PLUGS.
12"
6" MIN.
6" MIN.
TRENCH BACKFILL
PIPE DIA.
6"
6" MIN. (TYPICAL)
NATIVE SOIL
DRAWN BY
RRG
NTS
EXHIBIT 2-21
POND INLET / OUTLET
ANTI-SEEPAGE COLLAR

Fencing and Signage: Fences are required for all City-maintained ponds with a permanent or temporary pool greater than 18 inches deep, interior side slopes steeper than 3H: 1V, or any walls/bulkheads greater than 24 inches high. Generally, a pond with gently sloping sides (less than 3:1) and including a 10-foot-wide safety bench around the facility at the point of slope transition does not require a fence. Applicants can request BES approval to use fencing if there are safety concerns.

For City-maintained facilities where fencing is not required, the applicant must have BES approval to use fencing. Approval will be granted only if there is no practical alternative. If fencing is required or approved, the design shall address screening requirements.

Fencing for privately owned facilities is at the discretion of the owner. The owner may, however, want to use the criteria for City-maintained facilities.

For both private and City-maintained facilities, Title 33 may prohibit fencing or require screening in some locations. The designer is responsible for determining which sections of Title 33 apply to the project. If fencing is prohibited by Title 33, the designer may have to modify the facility or site design to provide an alternate means of securing the site (for example, reducing the depth of water or side slopes of the facility to minimize safety concerns).

For both private and City-maintained facilities where fencing is used, fences shall be at least 6 feet high. The 6-foot height may not be required in situations where fences are not needed to prevent climbing (e.g., on steep slopes to prevent slipping). For City-maintained facilities, a minimum of one vehicular locking access gate shall be provided. It shall be 10 feet wide, consisting of two swinging sections each 5 feet wide. At least one pedestrian gate shall be provided, with a minimum 4-foot width.

Fencing materials shall be complementary to the site design. If chain link fencing is proposed for a City-maintained facility, it shall be designed to City of Portland *Standard Construction Specifications*.

SARB_007913

Wet, Extended Wet, & Dry Detention Pond

Wet and Extended Wet Detention Permanent Pool Sizing: The permanent pool (or "dead") storage volume, V_{pond}, is equivalent to twice the runoff volume generated by a storm of 0.83 inches over 24 hours (NRCS Type 1A rainfall distribution). This volume can be approximated using the following formula:

Volume = 2 * (2,276 * Impervious Acreage)

Volume = permanent pool volume, cubic feet
Impervious Acreage = area of impervious surfaces to manage, acres

EXAMPLE

A 20-acre site is to be developed. After development, the site will be 60 percent impervious. What is the required volume for a wet pond to meet pollution reduction requirements?

For the post-development condition, the total area is 20 acres and the impervious area has increased to 60 percent, or 12 acres:

Permanent Pool Volume = 2 * (2,276 * 12) = 54,624 cubic feet

Flow Control for Extended Wet Detention and Dry Detention Ponds: To restrict flow rates exiting the pond to those required by **Section 1.6.2**, a control structure designed in accordance with **Section 2.5** must be used. For extended wet detention ponds, this control structure must be located above the permanent pool elevation. The outlet orifice shall be designed to minimize clogging (see **Section 2.5: Control Structures**).

Wet, Extended Wet, & Dry Detention Pond

Landscaping: Shrubs and wetland plantings shall be designed to minimize solar exposure of open water areas. Trees or other appropriate vegetation shall be located around the east, south, and west sides of a facility to maximize shading. Reducing solar exposure has two benefits: it helps reduce heat gain in water before discharging to a receiving water, and it helps maintain a healthy and aesthetic pond condition, reducing algae blooms and the potential for anaerobic conditions to develop.

Facility area is equivalent to the area of the pond, including bottom and side slopes, plus a 10-foot buffer around the pond. Minimum plant material quantities per **250** square feet of the facility area are as follows:

1 - Evergreen or deciduous tree:

Evergreen trees:	Minimum height: 6 feet
Deciduous trees:	Minimum caliper: 1 ½ inches at 6 inches above base.

4 - Large shrubs/small trees 3-gallon containers or equivalent.

6 - Shrubs/large grass-like plants 1-gallon containers or equivalent

Ground cover plants:	1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the facility shall be planted with grasses or grass-like plants.
Wetland plants:	1 per 2 square feet of a pond emergent plant zone. The emergent plant zone shall be at least 25 percent of the total pond water surface area.

Wildflowers, native grasses, and ground covers used for BES-maintained facilities shall be designed not to require mowing. Where mowing cannot be avoided, facilities shall be designed to require mowing no more than once or twice annually. Turf and lawn areas are not allowed for BES-maintained facilities; any exceptions will require BES approval.

Wet, Extended Wet, & Dry Detention Pond

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Growing medium specification
4) Filter fabric specification (if applicable)
5) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
6) Landscaping plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

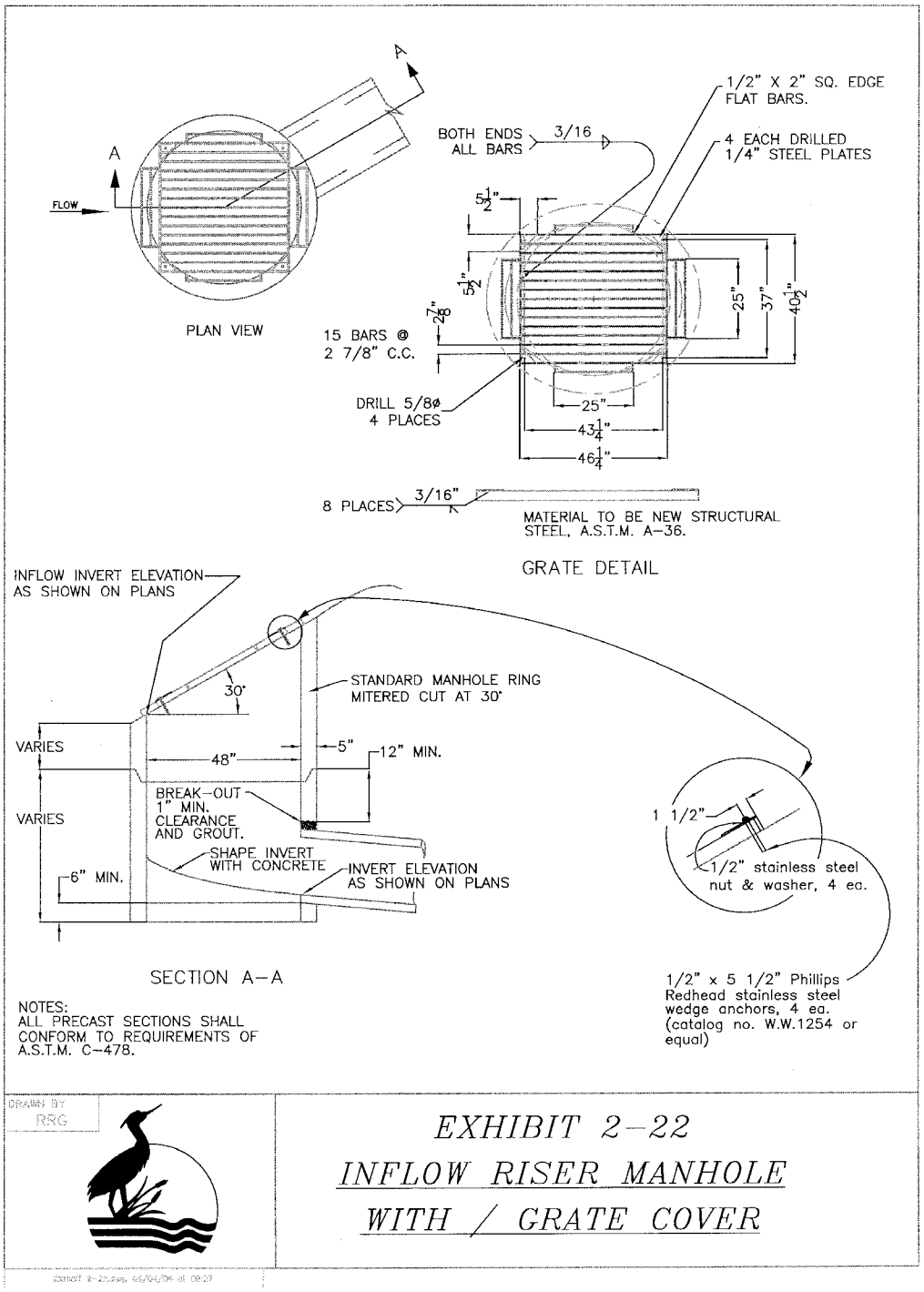
Facility Component	Inspection Requirement
Pond grading	Call for inspection
Piping	Call for inspection
Control (orifice) structure for extended wet detention and dry detention ponds	Call for inspection
Filter fabric or lining (if applicable)	
Growing medium	
Plantings	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to wet, extended wet detention, & dry detention pond O&M form**

Additional photos and drawings:

*** Link to wet and extended wet detention pond photos**
*** Link to wet and extended wet detention pond drawings**
*** Link to dry detention pond photos**
*** Link to dry detention pond drawings**


A
A
FLOW
PLAN VIEW
1/2" X 2" SQ. EDGE FLAT BARS.
BOTH ENDS ALL BARS
3/16
4 EACH DRILLED 1/4" STEEL PLATES
5 1/2"
5 1/2"
7/8"
25"
37"
40 1/2"
15 BARS @ 2 7/8" C.C.
DRILL 5/8ø 4 PLACES
25"
43 1/4"
46 1/4"
8 PLACES
3/16"
MATERIAL TO BE NEW STRUCTURAL STEEL, A.S.T.M. A-36.
GRATE DETAIL
INFLOW INVERT ELEVATION AS SHOWN ON PLANS
30°
STANDARD MANHOLE RING MITERED CUT AT 30°
VARIES
48"
5"
12" MIN.
VARIES
BREAK-OUT 1" MIN. CLEARANCE AND GROUT.
SHAPE INVERT WITH CONCRETE
INVERT ELEVATION AS SHOWN ON PLANS
6" MIN.
SECTION A-A
NOTES:
ALL PRECAST SECTIONS SHALL CONFORM TO REQUIREMENTS OF A.S.T.M. C-478.
1 1/2"
1/2" stainless steel nut & washer, 4 ea.
1/2" x 5 1/2" Phillips Redhead stainless steel wedge anchors, 4 ea. (catalog no. W.W.1254 or equal)
DRAWN BY
RRG
EXHIBIT 2-22
INFLOW RISER MANHOLE
WITH / GRATE COVER

Constructed Treatment Wetland



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction……..	PRES
√ Flow Control……..……	PRES
Destination/ Disposal……	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) Wetlands can be used to manage stormwater from any type of impervious surface.

Constructed Treatment Wetland





Description: A wetland is an area inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Jurisdictional wetlands include swamps, marshes, bogs, and similar areas except those constructed as pollution reduction or flow control facilities. The Corps of Engineers and Division of State Lands make specific wetland designations. Constructed treatment wetlands are wetlands designed and constructed for the specific purpose of providing stormwater management. Unlike natural wetlands, constructed treatment wetlands are not regulated by the Corps of Engineers and the Division of State Lands.

Wetlands remove pollutants through several treatment processes, including sedimentation, filtration, and biological uptake. When enough volume is provided, constructed treatment wetlands can also provide a significant level of flow control.

Design Criteria: To receive pollution reduction credit, the wet portion or permanent pool of the wetland shall be equal to that required for wet ponds, or the residence time of the stormwater volume (calculated as the pollution reduction design storm volume divided by the average facility outflow rate) shall be no less than 36 hours. A design team with experience in hydrology, wetland plants, and engineering will be needed to develop a successful wetland pollution reduction facility. A water budget analysis shall be performed with the design of the facility.

Sizing: Drainage area to be served shall be no less than 10 acres. To meet pollution reduction requirements, dead storage within the wetland must equal or exceed wet pond dead storage criteria. To meet flow control requirements, a detailed hydraulic analysis must be performed by a Professional Engineer,

showing compliance with flow control standards presented in **Section 1.6.2**. For stormwater report requirements, see **Exhibit 2-2**.

Geometry: The configuration of a constructed wetland shall be tailored to each site, rather than limited to one design. Major elements of a wetland can include channels or trenches, shallow marshes, and deeper ponded areas. These elements shall be combined to take advantage of the site topography. Maximum slopes within the wetland area shall be 20%, and maximum slopes of surrounding land shall not exceed 10%. All wetland design shall address habitat, planting, and aesthetic issues.

1) The volume of water to be treated shall be allocated over the treatment area of the facility as follows:

Component	Percent of Design Volume (approx.)	Percent of Facility Surface Area (approx.)
Forebay	10	5
Micropool	10	5
Deep water (> 18″)	50	40
Deep wetland (6″-18″)	20	25
Shallow wetland (<6″)	10	25

Definitions:

Forebay: A relatively deep zone placed where influent water discharges to a stormwater wetland. It traps coarse sediments, reduces incoming velocity, and helps distribute runoff evenly over the wetland.

Micropool: A deep (4 to 6 feet) pool placed at the outlet of a stormwater wetland forebay.

Deep-water: The area within a stormwater wetland that has a water depth greater than 18 inches.

Deep wetland: The area within a stormwater wetland that has a water depth between 6 and 18 inches.

Shallow wetland: The area within a stormwater wetland that has a water depth less than 6 inches.

2) The minimum length-to-width ratio shall be 3:1, unless otherwise approved by the City. If area constraints make this ratio unworkable, baffles, islands, or peninsulas may be installed, with City approval, to increase the flow path and prevent short-circuiting.

3) Where wetland vegetation is to be planted, side slopes shall be no steeper than 5:1. Wetland plant selection shall be consistent with anticipated hydrology.

4) Access routes to the wetland for maintenance purposes must be shown on the plans. Public wetlands will need to provide a minimum 8-foot wide access route, not to exceed 10 percent in slope.

Flow:

1) Flow velocity through the wetland shall average less than 0.01 feet per second for the water quality design storm event (see **Section 1.5.2**). If natural slope does not allow for this velocity, berms shall be used to create ponded benches.

2) Flow through the wetland shall be distributed as uniformly as possible across the marsh and ponded section.

Forebay:

1) The forebay area shall be established along the wetland inflow points to capture sediment. The forebay shall have a water depth of about 3 feet and have at least 10 percent and up to 25 percent of the total treatment wetland volume.

An overflow mechanism to an approved conveyance/ destination method per **Section 1.4** will be required.

Soil Suitability: Constructed treatment wetlands are appropriate for NRCS type C and D soils. Topsoil shall be used within the top 12 inches of the facility, or the soil shall be amended per **Appendix F** to support plant growth.

Setbacks: Required setback from property lines is 5 feet, and 10 feet from building foundations. Infiltration basins shall meet the following setback requirements from downstream slopes: minimum of 100 feet from slopes of 10%; add 5 feet of setback for each additional percent of slope up to 30%; 200-foot

setback for slopes of 30%; infiltration trenches shall not be used where slopes exceed 30%.

Landscaping: Shrubs and wetland plantings shall be designed to minimize solar exposure of open water areas. Trees or other appropriate vegetation shall be located around the east, south, and west sides of a facility to maximize shading. Reducing solar exposure has two benefits: it helps reduce heat gain in water before discharging to a receiving water, and it helps maintain a healthy and aesthetic pond condition, reducing algae blooms and the potential for anaerobic conditions to develop.

Facility area is equivalent to the area of the wetland, including bottom and side slopes, plus a 10-foot buffer around the wetland. Minimum plant material quantities per **200** square feet of the facility area are as follows:

1 - Evergreen or deciduous tree:
- Evergreen trees: Minimum height: 6 feet
- Deciduous trees: Minimum caliper: 1 ½ inches at 6 inches above base.

4 - Large shrubs/small trees: 3-gallon containers or equivalent.

6 - Shrubs/large grass-like plants: 1-gallon containers or equivalent

Ground cover plants: 1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the facility shall be planted with grasses or grass-like plants.

Wetland plants: 1 per 2 square feet of a pond emergent plant zone. The emergent plant zone shall be at least 25 percent of the total pond water surface area.

Wildflowers, native grasses, and ground covers used for BES-maintained facilities shall be designed not to require mowing. Where mowing cannot be avoided, facilities shall be designed to require mowing no more than once or twice annually. Turf and lawn areas are not allowed for BES-maintained facilities; any exceptions will require BES approval.

***Link to Recommended Plants**

Constructed Treatment Wetland

For public constructed treatment wetlands, the following additional design criteria shall apply:

1) Two staff gauges shall be installed at opposite ends of the bottom of the wetland, to enable maintenance staff to measure the depth of accumulated silts.

2) A soil scientist, or suitably trained person working under the supervision of an Oregon licensed professional geotechnical engineer, shall inspect the soil after the system is excavated to confirm that soils remain in suitable condition for planting.

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Growing medium specification
4) Filter fabric specification (if applicable)
5) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection
6) Landscaping plan

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Wetland grading	Call for inspection
Piping	Call for inspection
Filter fabric (if applicable)	
Growing medium	
Plantings	Call for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to constructed treatment wetland O&M form**

Additional photos:

*** Link to constructed treatment wetland photos**

Manufactured Treatment Technology

Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction	PERF
Flow Control	NA
Destination/ Disposal	NA

These facilities may or may not be classified as Underground Injection Control structures (UICs), depending on specific manufacturer design.

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) For a list of currently accepted manufactured stormwater treatment technologies, call BES at 503-823-7761. Manufactured stormwater treatment technologies can be used to provide pollution reduction for any impervious surface. They can be located on private property, and some are approved for use in public right-of-ways.

BES has developed "Vendor Submission Guidance for Evaluating Stormwater Treatment Technologies," located in **Appendix B**. For a manufactured stormwater treatment technology to be approved for general use within the City of Portland, the manufacturer must submit detailed performance testing data that meets the testing protocols included in the "Vendor Submission Guidance".

To be approved for use as a public facility (see **Section 1.10**: Public vs. Private Stormwater Management), the manufacturer must also submit detailed information about the facility's design criteria, construction techniques, operation and maintenance procedures, reliability, and cost. This information will be reviewed by BES's Standards and Practices Committee, which will decide whether or not the facility can be used for public projects.

Manufactured stormwater treatment technologies on BES's approved list must be designed and constructed in accordance with the manufacturer's recommendations. BES may have also placed special design conditions on the acceptance of the technology, such as sizing requirements that go beyond the manufacturer's recommendations, which must also be followed to obtain plan approval.

In addition to design calculations shown in **Exhibit 2-2**, the following must be submitted with each manufactured stormwater treatment technology project:

1) Pollution reduction capacity of the facility
2) Flow-through conveyance capacity (i.e., how much flow can be passed through the facility without stirring up and releasing trapped pollutants)

Manufactured Treatment Technology

An operations and maintenance manual must also be submitted for BES review. See **Chapter 3.0** for O&M plan guidance.

Manufactured stormwater treatment technologies on BES's approved list for general use may not be capable of meeting specific TMDL requirements for certain watersheds. In that case, the treatment technology will not be accepted as a stand-alone pollution reduction facility. Rather, a pollution reduction facility that is presumed by BES to meet the TMDL requirement must be used.

For a list of currently approved manufactured stormwater treatment technologies, contact BES at (503) 823-7761.

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Vault excavation	
Piping	Call for inspection
Vault installation	Cal for inspection

Operations and Maintenance requirements: An operations and maintenance plan will be required, including information from the manufacturer, as per **Chapter 3.0**.

Structural Detention Facility

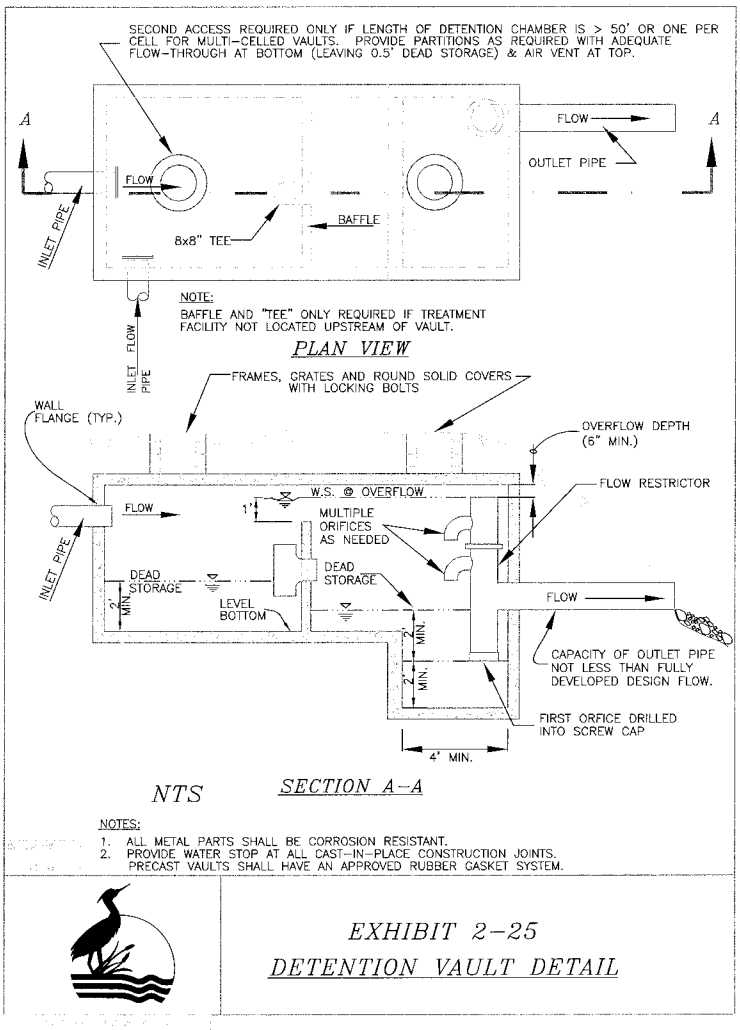


EXHIBIT 2-25
DETENTION VAULT DETAIL

Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
Pollution Reduction…….……..	NA
√ Flow Control…….……..	PRES
Destination/ Disposal……..	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) See **Exhibit 2-2** for hydrologic and hydraulic calculations that must be submitted with structural detention design. Structural detention facilities may be used to provide flow control for any impervious surface type, and may be located on private property or within the public right-of-way.

Structural Detention Facility

Description: Structural detention facilities such as tanks, vaults, and oversized pipes provide underground storage of stormwater as part of a runoff flow control system. As with any underground structure, they must be designed not only for their function as runoff flow control facilities, but also to withstand an environment of periodic inundation, potentially corrosive chemical or electrochemical soil conditions, and heavy ground and surface loadings. They must also be accessible for maintenance. Facilities in this section must be designed using acceptable hydrologic modeling techniques (See **Section 2.3**) to meet applicable flow control requirements. Additional facilities will be required to meet applicable pollution reduction requirements.

Tanks and vaults typically do not have a built-in design feature for containing sediment, as do multi-cell ponds. When tanks or vaults are used for detention storage, therefore, either a surface sediment containment pond shall be placed upstream of the tank or vault, or the tank/vault shall be oversized to allow for the temporary accumulation of sediment. Where the tank or vault is designed to provide sediment containment, a minimum of ½ foot of dead storage shall be provided, and the tank or vault shall be laid flat.

Tanks and vaults can be used in conjunction with other detention storage facilities, such as ponds or parking lot ponds, to provide initial or supplemental storage.

Because of minimum orifice size specifications, structural flow control facilities (such as detention tanks, vaults, and oversized pipes) for projects with less than 15,000 square feet of impervious surface are not effective and will not be required. Projects with less than 15,000 square feet of impervious surface are required to use surface retention facilities to control flows. Where this is not possible, the applicant must pay the off-site management fee (See **Section 1.11**).

Design Requirements:
The following criteria apply to detention tank, vault, and oversized pipe design.

- All areas of a tank or vault shall be within 50 feet of a minimum 36-inch diameter access entry cover. All access openings shall have round, solid locking lids.
- Publicly owned detention tanks, vaults, and pipes are permitted within public rights-of-way. If developments are served with publicly operated and maintained tanks and vaults that are not located within the right-of-way, the tanks/vaults shall be located in separate open space tracts with public sewer easements that are dedicated to the City of Portland. All privately owned and maintained facilities shall be located to allow easy maintenance and access. (**See Chapter 3.0**: Operation and Maintenance)

Structural Detention Facility

- All tanks and vaults shall be designed as flow-through systems, unless separate sediment containment is provided.
- Minimum size for a public detention pipe shall be 36 inches. If the collection system piping is designed also to provide storage, the resulting maximum water surface elevation shall maintain a minimum 1-foot of freeboard in any catch basin below the catch basin grate. Pipe capacity shall be verified using an accepted methodology approved by the City (see BES's Sewer Design Manual). The minimum internal height of a vault or tank shall be 3 feet, and the minimum width shall be 3 feet. The maximum depth of the vault or tank invert shall be 20 feet. Pipe material and surface treatment shall conform to the standards for detention tanks and vaults (see **Exhibits 2-23 and 2-25).**
- Detention tanks and vaults shall have a minimum of ½ foot of dead storage, unless upstream sedimentation is provided (see **Exhibits 2-23 and 2-25**).

Flow Control:

- To restrict flow rates exiting the pond to those required by **Section 1.6.2**, a control structure per **Section 2.5** must be used.

Materials and Structural Stability:

- For public facilities, pipe materials and joints shall conform to the City of Portland *Sewer Design Manual*. For private facilities, the pipe material shall conform to the Unified Plumbing Code.
- All tanks, vaults, and pipes shall meet structural requirements for overburden support and traffic loadings, if appropriate. H-20 live loads shall be accommodated for tanks and vaults under roadways and parking areas. End caps shall be designed for structural stability at maximum hydrostatic loading conditions.
- Detention vaults shall be constructed of structural reinforced concrete (3000 psi, ASTM 405). All construction joints shall be provided with water stops.
- In soils where groundwater may induce flotation and buoyancy, measures shall be taken to counteract these forces. Ballasting with concrete or earth backfill, providing concrete anchors or other counteractive measures shall be required. Calculations shall be required to demonstrate stability.
- Tanks and vaults shall be placed on stable, consolidated native soil with suitable bedding. Tanks and vaults shall not be allowed in fill slopes, unless a geotechnical analysis is performed for stability and construction practices.

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures

2) Profile view of facility, including typical cross-sections with dimensions
3) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

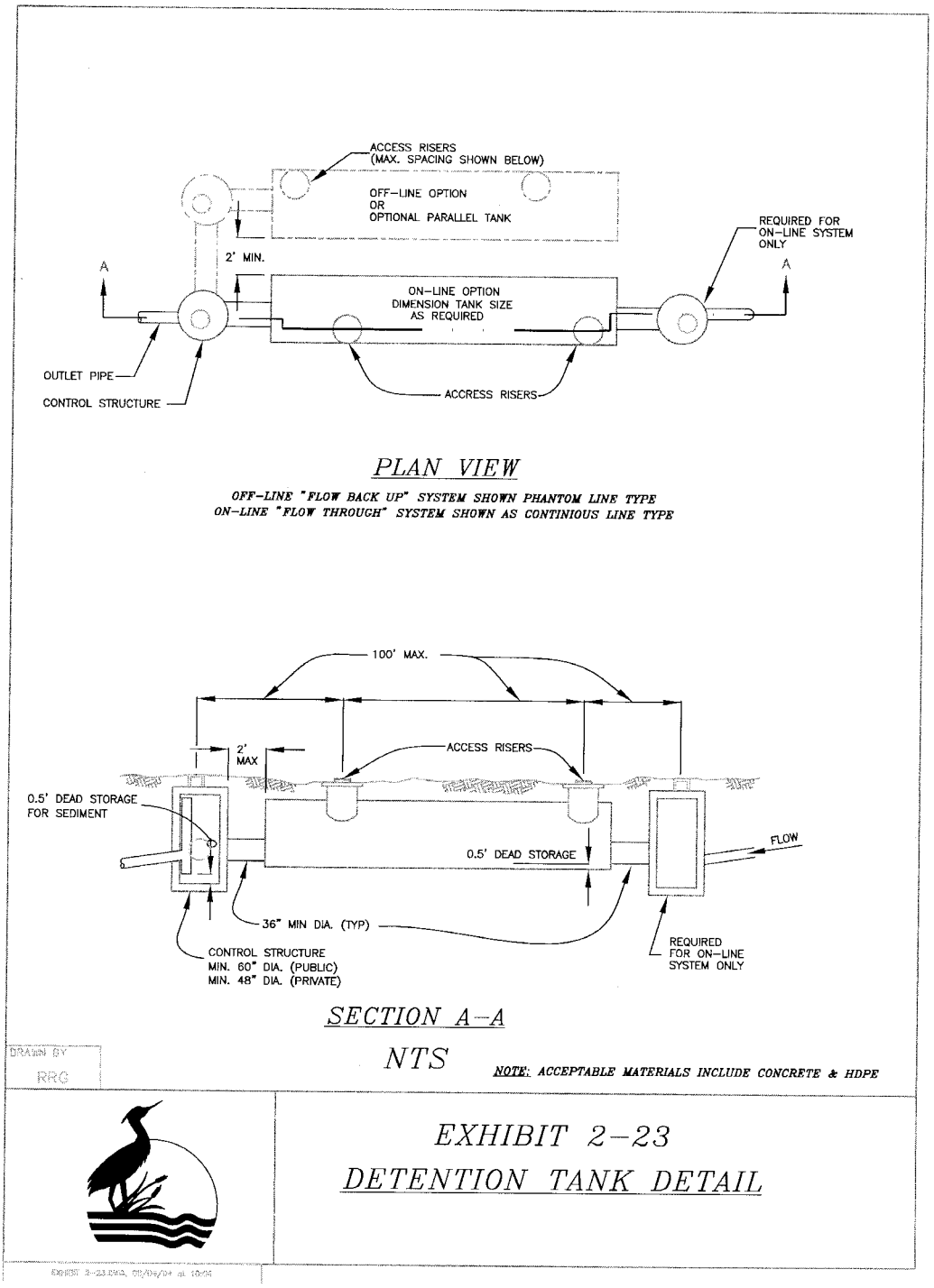
Facility Component	Inspection Requirement
Vault excavation	
Piping	Call for inspection
Vault installation	Call for inspection
Control structure (orifice structure)	Call for inspection

OPERATIONS AND MAINTENANCE REQUIREMENTS: See Chapter 3.0.

*** Link to tank, vault, and oversized pipe O&M form**

STORMWATER REPORT REQUIREMENTS: See **Exhibit 2-2**.

Structural Detention Facility



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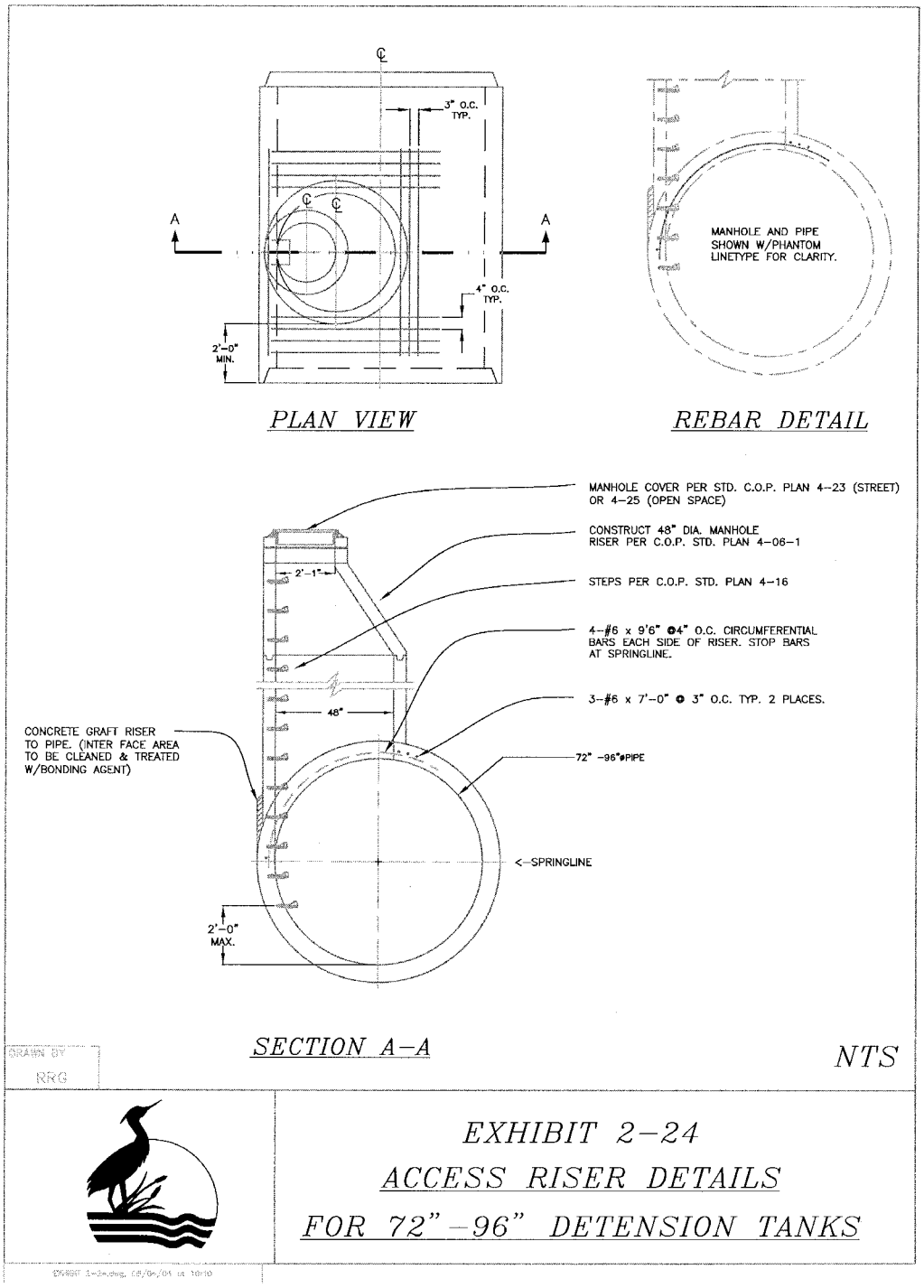
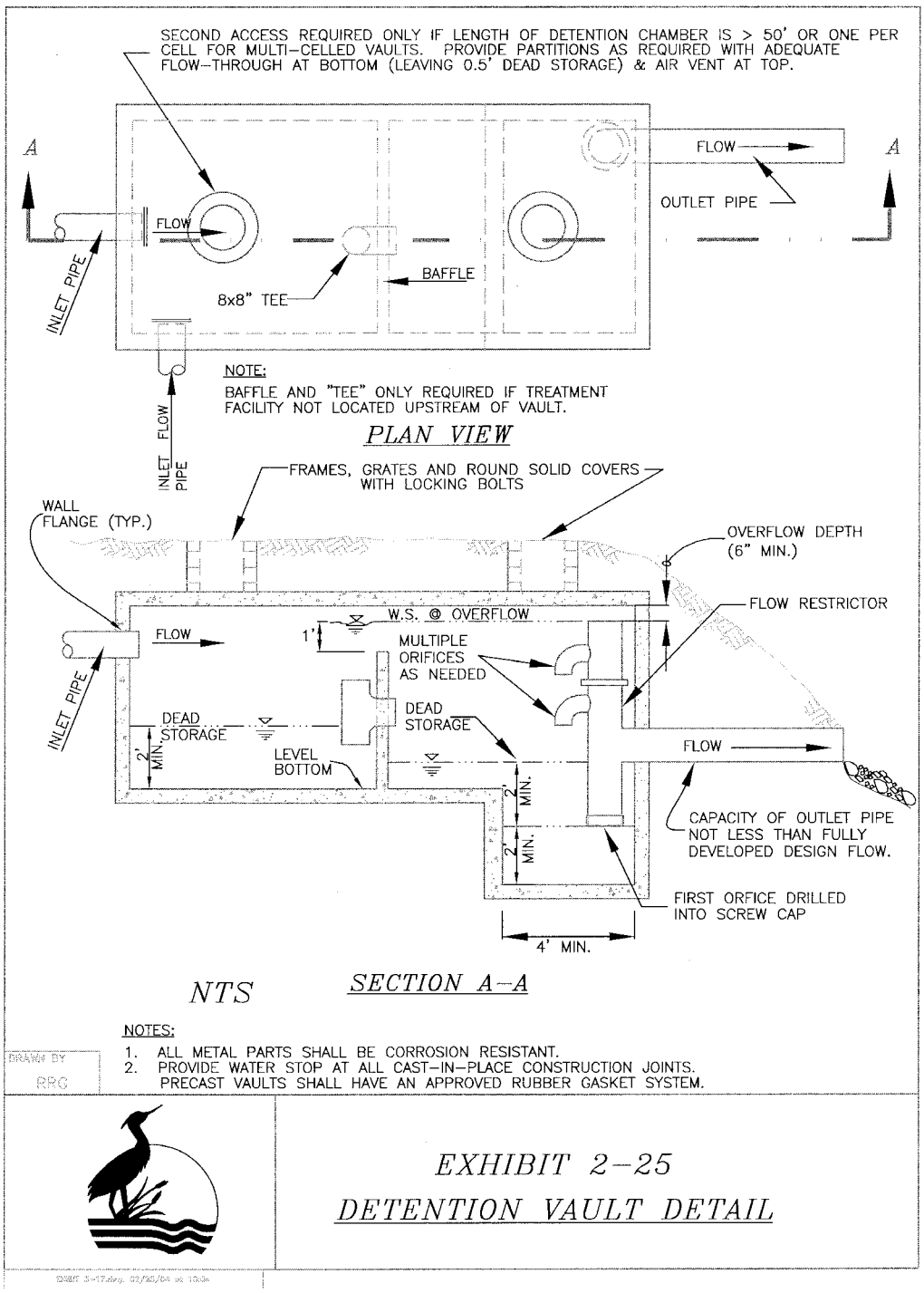
Structural Detention Facility



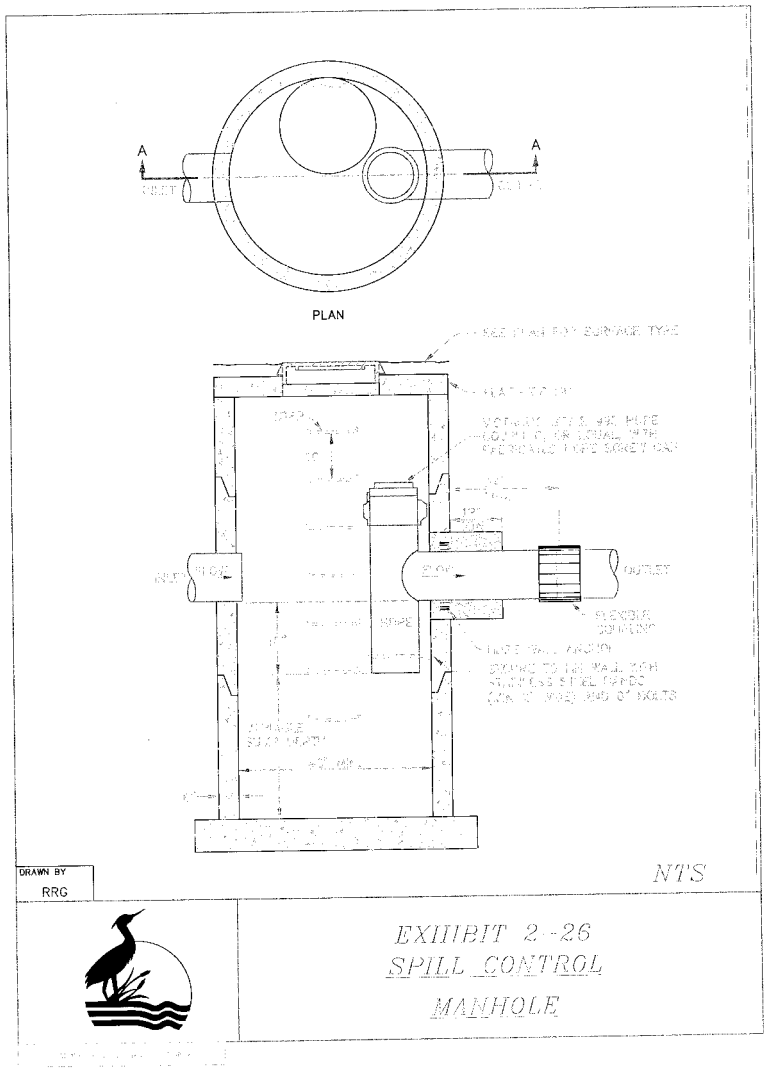
SARB_007931

Structural Detention Facility



Structural Detention Facility

Spill Control Manhole



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction[1] (Oil Only)……..	PRES[1]
Flow Control…….……	NA
Destination/ Disposal……	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) Spill control manholes receive credit for oil removal only. They may be used to remove oil from parking lots and other vehicular access areas.

Spill Control Manhole

Description: Spill control manholes rely on passive mechanisms that take advantage of oil being lighter than water. Oil rises to the surface and can be periodically removed. They consist of a simple underground manhole with a "T" outlet designed to trap small spills. Spill control manholes will not be given credit for basic pollution reduction requirements. They must be used in conjunction with other pollution reduction systems from this chapter to meet oil control and pollution reduction requirements.

Other Options: There may be other acceptable oil controls not listed above. Applicants may propose an alternative oil control option under the performance approach. However, proposal of a new oil control will require an additional review process for approval, which may delay issuance of related building permits.

Design and Sizing Criteria:

- Spill control manholes shall be used in conjunction with an appropriately sized vegetated pollution reduction facility from this chapter to achieve 10 ppm oil effluent from the peak flow generated by the pollution reduction design storm intensity of 0.19 inches per hour. The spill control sump volume shall be 60 cubic feet *or* 20 cubic feet of sump capacity for each cubic feet per second (cfs) of peak pollution reduction design flow, whichever is greater. This treatment train configuration, when sized per the above requirements, will be presumed to meet the 10 ppm effluent design standard.

- To maintain efficiencies and reduce size, all roof drainage shall enter the stormwater system downstream of the spill control manhole, unless sized accordingly.

- Any pumping devices shall be installed downstream of the spill control manhole to prevent oil emulsification in stormwater.

- Engineered calculations are required, using the Rational Method (Q=C*I*A).

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures.

Spill Control Manhole

2) Profile view of facility, including typical cross-section details with dimensions. These details shall match manufacturer specifications and details.
3) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection.

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

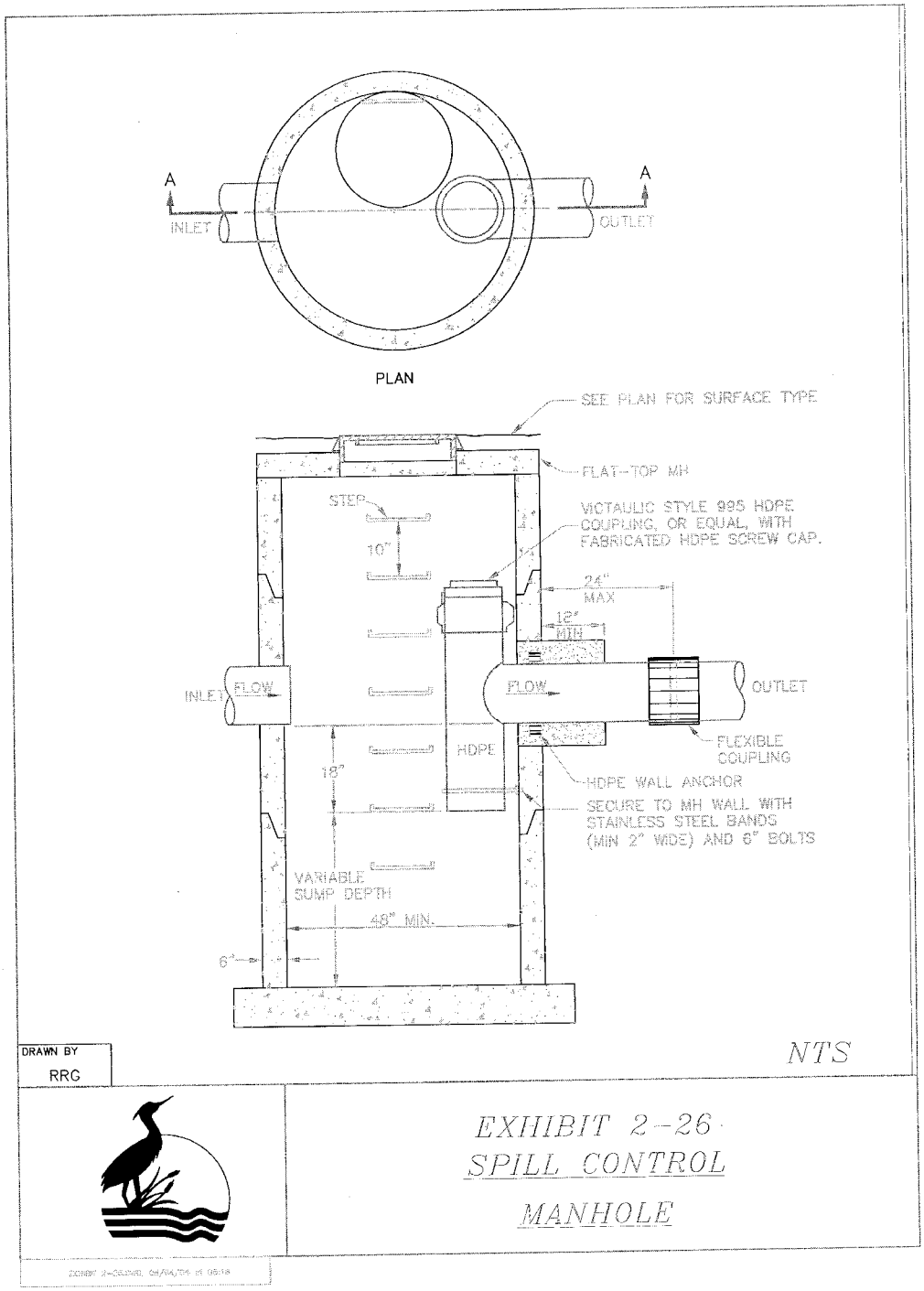
Facility Component	Inspection Requirement
Manhole excavation	
Piping	Call for inspection
Manhole installation	Cal for inspection

OPERATIONS AND MAINTENANCE REQUIREMENTS: See Chapter 3.0.

*** Link to Spill Control Manhole O&M form**

STORMWATER REPORT REQUIREMENTS: See **Exhibit 2-2**.

Spill Control Manhole



SARB_007937

Rainwater Harvesting



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction……..	PERF[1]
√ Flow Control…….……	PERF[1]
Destination/ Disposal……	NA

This facility is **not** classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) The required water storage volume is a function of drainage area, rate of water usage, and stormwater management goal. Rainwater harvesting systems may be used to manage stormwater from rooftops and depending on the water use, other impervious surfaces, and must be located on private property.

SARB_007938

Rainwater Harvesting

Description: Stormwater may be collected and reused for non-potable water uses within a house or building, or for landscape irrigation purposes. Uses can include reusing water in toilets and at hose bibs. Reducing the water used from the City water system can reduce a site's water bill. BDS plumbing approval must be obtained with any such system. Reference the BDS website for more information on re-use guidelines:

http://www.bds.ci.portland.or.us/pubs/CodeGuides/Upc/RES34 1.pdf

Rainwater harvesting can provide several stormwater management benefits:

- Flow control: In many areas of the city where on-site infiltration is not feasible and the only means of stormwater destination is off-site flow to a combination sewer system (including much of the downtown district and inner east side), rainwater harvesting can provide significant flow-reduction benefits. Depending on the size of the water storage facility and the rate of use, a significant percentage of the annual runoff volume can be reused. Where it isn't feasible to meet a development site's full flow control obligation, rainwater harvesting can be used to manage a portion of the flow and lessen the overall flow control requirement.

- Pollution reduction: As a result of the significant reduction in off-site flow volume that can be achieved, a significant reduction in the discharge of pollutants associated with stormwater can also be accomplished. Where it isn't feasible to meet a development site's full pollution reduction obligation, rainwater harvesting can be used to manage a portion of the flow and lessen the overall pollution reduction requirement.

Checklist of minimal information to be shown on the permit drawings, or included with the permit submittal package:

1) Water storage facility details and specifications
2) Pump and associated electrical details and specifications
3) Piping size, material, and placement details and specifications
4) Average daily water use documentation
5) Hydraulic calculations demonstrating compliance with stormwater management requirements (pollution and flow control)
6) Approximate setbacks from property lines and structures shall be shown
7) Overflow connection to approved stormwater destination per **Section 1.4**

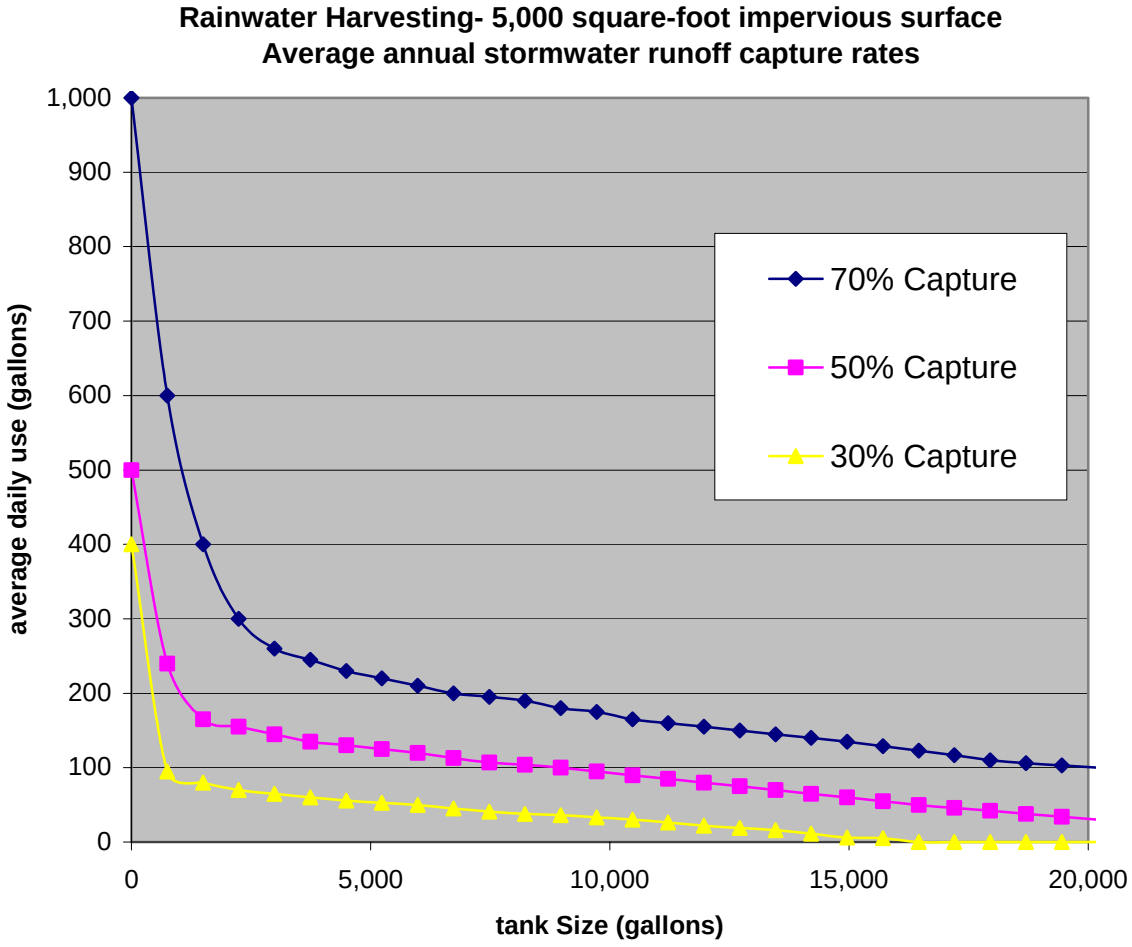
Operations and Maintenance requirements: See **Chapter 3.0**.

Rainwater Harvesting

The following chart represents an analysis done on a 5,000 square-foot project site with 100% impervious surface. 8.5 months of 5-minute rainfall intensity data from the Fernwood rain gage in Portland was used in the analysis, which shows the relationship between water storage volume and average daily water use rate for average annual runoff capture goals of 30%, 50%, and 70%.

For example, if the stormwater management goal is 50% reduction of the annual release volume, the pink line is used to show that if a 2,000-gallon tank were used, the average daily use would need to be approximately 160 gallons per day. A larger tank would necessitate a smaller average daily use rate to achieve the same stormwater management goal of 50% annual volume reduction.

Exhibit 2-27:



SARB_007940

Rainwater Harvesting

SARB_007941

Private Soakage Trench

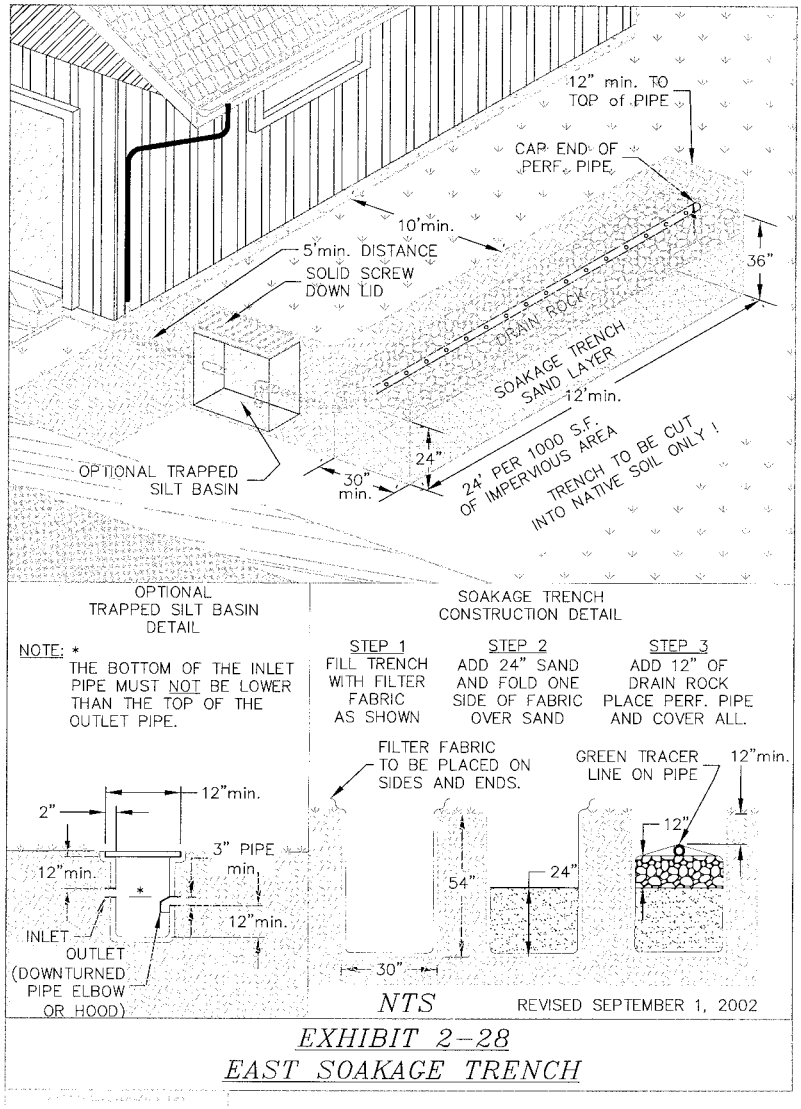


EXHIBIT 2-28
EAST SOAKAGE TRENCH

Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction…….……..	PRES
√ Flow Control……	PRES
√ Destination/ Disposal……	PRES

This facility is classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) Soakage trenches can be used to manage stormwater runoff from private property.

Private Soakage Trench

A soakage or "infiltration" trench is a shallow trench in permeable soil that is backfilled with sand and coarse stone and lined with filter fabric. The trench surface may be covered with grating, stone, sand, grass, or plantings.

Private soakage trenches can be used to provide stormwater disposal by collecting and recharging stormwater runoff into the ground. The use of soakage trenches is highly dependent on soil type and height of the groundwater table.

Note: DEQ has identified soakage trenches as "Class V Injection Wells" under the federal Underground Injection Control (UIC) Program. These facilities must be classified as exempt, authorized by rule, or authorized by permit by DEQ. Since the UIC Program states that these types of wells can have a direct impact on groundwater, pollution reduction is required before disposing stormwater into them, with the exception of soakage trenches that serve rooftops only. All soakage trenches, with the exception of those that drain residential rooftops only, must be registered with DEQ.

More information about the UIC Program can be found in **Section 1.4.4** or at DEQ's website at: **Http://www.deq.state.or.us/wq/groundwa/uichome.htm**

For technical questions call DEQ- UIC Program at 503-229-5886. For copies of applications or forms, call 503-229-5189.

Soakage trenches are recognized as a stormwater disposal point, and with a sufficient layer of sand or soil for filtration, may be used to meet pollution reduction requirements. **Exhibits 2-28 and 2-29** provide detailed drawings of standard soakage trenches.

Soakage trenches are excluded from use within the Columbia South Shore and Cascade Station/ Portland International Center Plan Districts (see **Exhibit 2-33**).

Private Soakage Trench Design and Sizing Method

Soil conditions are critical to the success of soakage trenches. Because of this, the use of soakage trenches must be pre-approved by the Environmental Soils section of BDS. Supporting geotechnical evidence and a documented infiltration test may be required to demonstrate that soakage trenches will work in the project area. Soakage trenches shall be sized in accordance with **Exhibits 2-28 and 2-29**, once BDS approval has been given for on-site infiltration.

Private Soakage Trench

General Requirements:

Maximum area to be served:	15,000 square-feet per trench
Soils requirements: (NRCS classification)	A or B; C soils may be used if drawdown times are met
Maximum ground slopes	20 percent
Soil test requirement	ASTM D 3385-88 or BDS approval

1) If designed as the only stormwater destination, the soakage trench shall infiltrate the entire design storm without overflow.

2) Soakage trenches shall not be accepted in soils with a tested infiltration rate of less than 2 inches per hour.

3) There shall be no less than 4 feet of undisturbed depth of infiltration medium between the bottom of the facility and any impervious layer (hardpan, solid rock, etc.) or seasonal high groundwater levels.

4) Drawdown time when full shall not exceed 10 hours.

5) Soakage trenches shall meet the following setback requirements for downstream slopes: minimum of 100 feet from slopes of 20%; add 5 feet of setback for each additional percent of slope up to 30%; infiltration trenches shall not be used within 200 feet of where slopes exceed 30%.

6) The bottom of the soakage trench shall be flat, or clay check-dams may be used to prevent water from collecting near the downstream end.

7) Drain medium shall have filter fabric between the medium and native soils or backfill.

8) Soakage trench areas shall be clearly marked before site work begins to avoid soil disturbance during construction. No vehicular construction traffic, except that specifically used to construct the facility, shall be allowed within 10 feet of soakage trench areas.

9) A soil scientist, or suitably trained person working under the supervision of an Oregon licensed professional engineer, shall inspect the soil after the system is excavated, before trenches are filled with drain medium, to

confirm that soils remain in suitable condition to perform at anticipated infiltration rates.

10) Soakage trenches should be located down slope of structures, and are required to be setback at least 10 feet from buildings, 5 feet from property lines, and 5 feet from public utility lines.

Checklist of Minimal Information To Be Shown on the Permit Drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility dimensions and setbacks from property lines and structures
2) Profile view of facility, including typical cross-sections with dimensions
3) Drain rock specification
4) Sand specification
5) Filter fabric specification
6) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection

Inspection Requirements and Schedule:

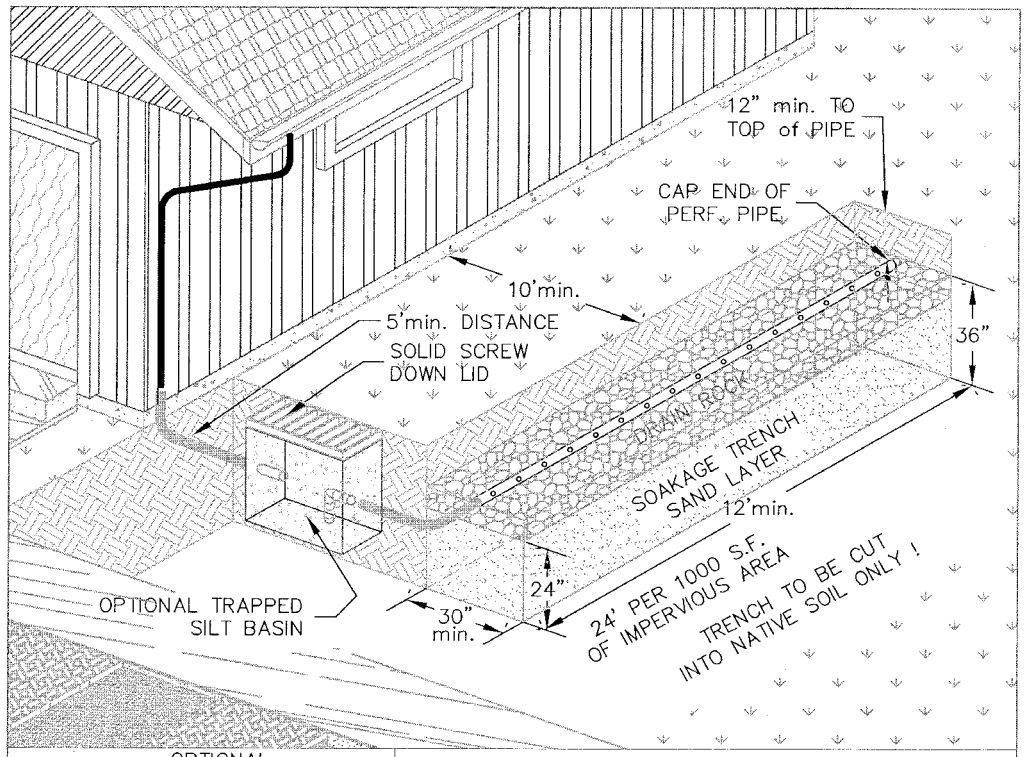
The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Trench grading	Call BDS for inspection
Piping	Call BDS for inspection
Filter fabric	
Sand layer	Call BDS for inspection
Drain rock	Call BDS for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

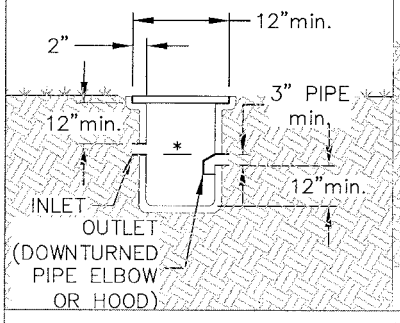
*** Link to private soakage trench O&M form**

Private Soakage Trench



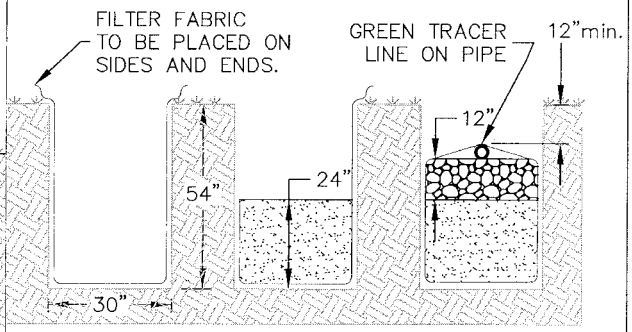
OPTIONAL TRAPPED SILT BASIN DETAIL

NOTE: *
THE BOTTOM OF THE INLET PIPE MUST NOT BE LOWER THAN THE TOP OF THE OUTLET PIPE.



SOAKAGE TRENCH CONSTRUCTION DETAIL

STEP 1	STEP 2	STEP 3
FILL TRENCH WITH FILTER FABRIC AS SHOWN	ADD 24" SAND AND FOLD ONE SIDE OF FABRIC OVER SAND	ADD 12" OF DRAIN ROCK PLACE PERF. PIPE AND COVER ALL.



NTS REVISED SEPTEMBER 1, 2002

EXHIBIT 2-28
EAST SOAKAGE TRENCH

SARB_007946

Private Soakage Trench

East Side Soakage Trench

Applicable to Areas **East** of the Willamette River

Soakage Trench Sizing

For every 1,000 sf of impervious surface, 24 linear feet of 30" wide soakage trench is required, with a minimum 12-foot long trench. Soakage trenches 12 feet long serve a maximum of 500 sf of horizontally projected roof area or other impervious surface.

Trench

- Soakage trench and perforated pipe must be installed level and parallel to contour of finish grade.
- Soakage trench shall be located no closer than 10 feet to any building structure and not closer than 5 feet from property line.
- Unless a separate pollution reduction facility is used upstream of the trench, the sand filter portion of soakage trench must be filled with a minimum of 24" medium sand meeting OAR 340-71-295 (3)(e).
- Minimum 12" of ¾" – 2 ½" round or crushed rock to cover sand separated by one layer of filter fabric.
- The pipe shall be laid on top of this gravel and covered with filter fabric.
- At least 12" minimum of backfill shall be placed over the trench.
- All trenches shall be constructed on native soil and shall not be subject to vehicular traffic or construction work that will compact the soil, thus reducing permeability.
- Slope shall not exceed 20% without a stamped and signed geotechnical report addressing slope stability.
- Trench shall not be constructed under current or future impervious surface.

Sand

Medium sand meeting OAR 340-71-295 (3)(e) will be required. Sieve analysis of the medium sand is required to be made by a qualified party and a report provided to City of Portland plumbing inspector at the time of inspection. Analysis to comply with ASTM C136, Standard Methods for Sieve Analysis of Fine and Coarse Aggregate and in conjunction and accordance with ASTM C-117, Standard Test Method for Materials Finer than No.200 Sieve in Mineral Aggregates by Washing.

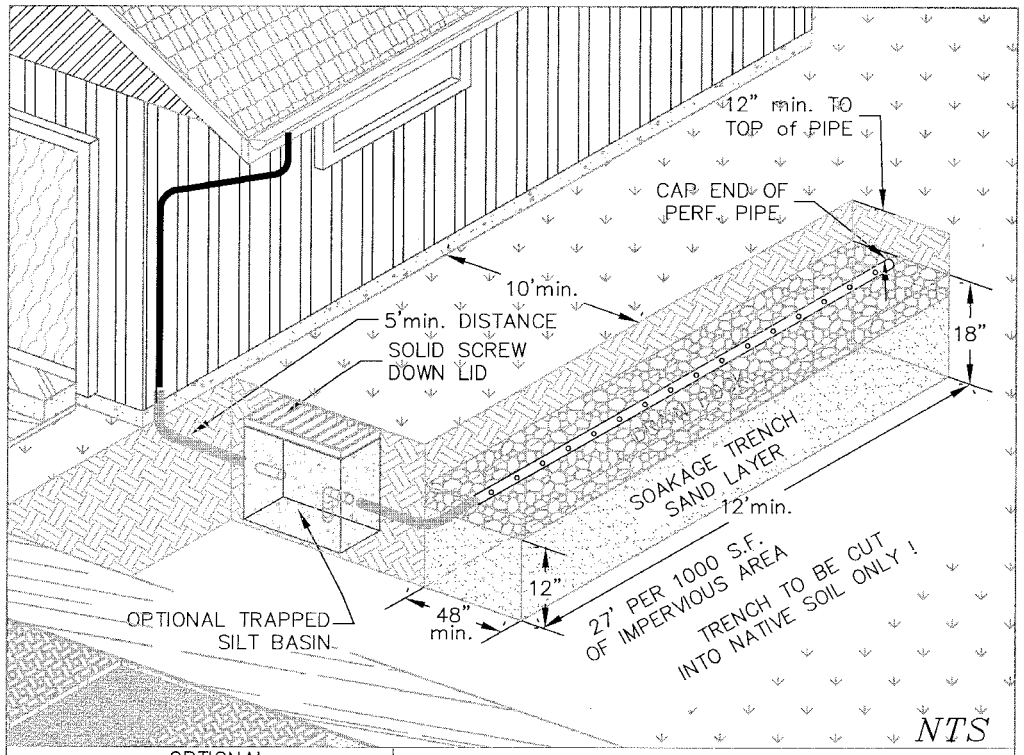
Sieve #	% Passing
3/8	100%
#4	95-100%
#8	80-100%
#16	45-85%
#30	15-60%
#50	3-15%
#100	4% or less

Pipe

- The solid pipe from building or other source to connection with perforated pipe must be installed at a ¼" per foot slope.
- All piping within 10 feet of building must be sch. 40 ABS, sch. 40 PVC, cast iron, sch. 40 ABS, 3" sch. 40 PVC or 3" cast iron pipe may be used for rain drain piping serving not more than 1500 sf of roof or surface area. Use 4" pipe if area is greater than 1500 sf.
- Pipe must have a minimum cover of 12" measured from top of pipe to finished grade.
- The pipe within the trench shall either be PVC D2729 or HDPE Leach field pipe.
- The silt trap shall be installed between the dwelling and the sand filter, a minimum of 5' from the dwelling.

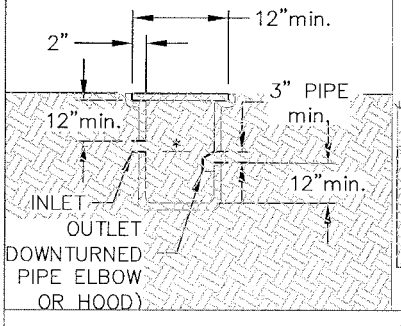
Filter Fabric must be one of the following types/brands: LINQ 125EX; LINQ TYPAR3201; TNS E040; TNS R035; TNS R040; TNS R042; AMOCO 4535; Marafi 140NL.

Private Soakage Trench



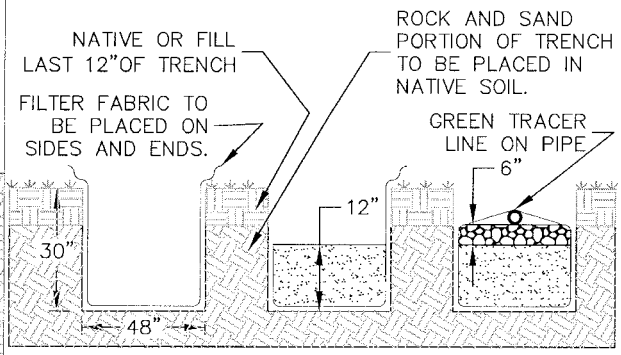
OPTIONAL TRAPPED SILT BASIN DETAIL

NOTE: *
THE BOTTOM OF THE INLET PIPE MUST NOT BE LOWER THAN THE TOP OF THE OUTLET PIPE.



SOAKAGE TRENCH CONSTRUCTION DETAIL

STEP 1	STEP 2	STEP 3
FILL TRENCH WITH FILTER FABRIC AS SHOWN	ADD 12" SAND AND FOLD ONE SIDE OF FABRIC OVER SAND	ADD 6" OF DRAIN ROCK PLACE PERF. PIPE AND COVER ALL.



NTS REVISED SEPTEMBER 1, 2002

EXHIBIT 2-29
WEST SOAKAGE TRENCH

SARB_007948

Private Soakage Trench

West Side Soakage Trench

Applicable to Areas **West** of the Willamette River

Soakage Trench Sizing

For every 1,000 sf of impervious surface, 27 linear feet of 48" wide soakage trench is required, with a minimum 13.5-foot long trench. Soakage trenches 13.5 feet long serve a maximum of 500 sf of horizontally projected roof area or other impervious surface.

Trench

- Soakage trench and perforated pipe must be installed level and parallel to contour of finish grade.
- Soakage trench shall be located no closer than 10 feet to any building structure and not closer than 5 feet from property line.
- Unless a separate pollution reduction facility is used upstream of the trench, the sand filter portion of soakage trench must be filled with a minimum of 12" medium sand meeting OAR 340-71-295 (3)(e).
- Minimum 6" of ¾" – 2 ½" round or crushed rock to cover sand separated by one layer of filter fabric.
- The pipe shall be laid on top of this gravel and covered with filter fabric.
- At least 12" minimum of backfill shall be placed over the trench.
- All trenches shall be constructed on native soil and shall not be subject to vehicular traffic or construction work that will compact the soil, thus reducing permeability.
- Slope shall not exceed 20% without a stamped and signed geotechnical report addressing slope stability.
- Trench shall not be constructed under current or future impervious surface.

Sand

Medium sand meeting OAR 340-71-295 (3)(e) will be required. Sieve analysis of the medium sand is required to be made by a qualified party and a report provided to City of Portland plumbing inspector at the time of inspection. Analysis to comply with ASTM C136, Standard Methods for Sieve Analysis of Fine and Coarse Aggregate and in conjunction and accordance with ASTM C-117, Standard Test Method for Materials Finer than No.200 Sieve in Mineral Aggregates by Washing.

Sieve #	% Passing
3/8	100%
#4	95-100%
#8	80-100%
#16	45-85%
#30	15-60%
#50	3-15%
#100	4% or less

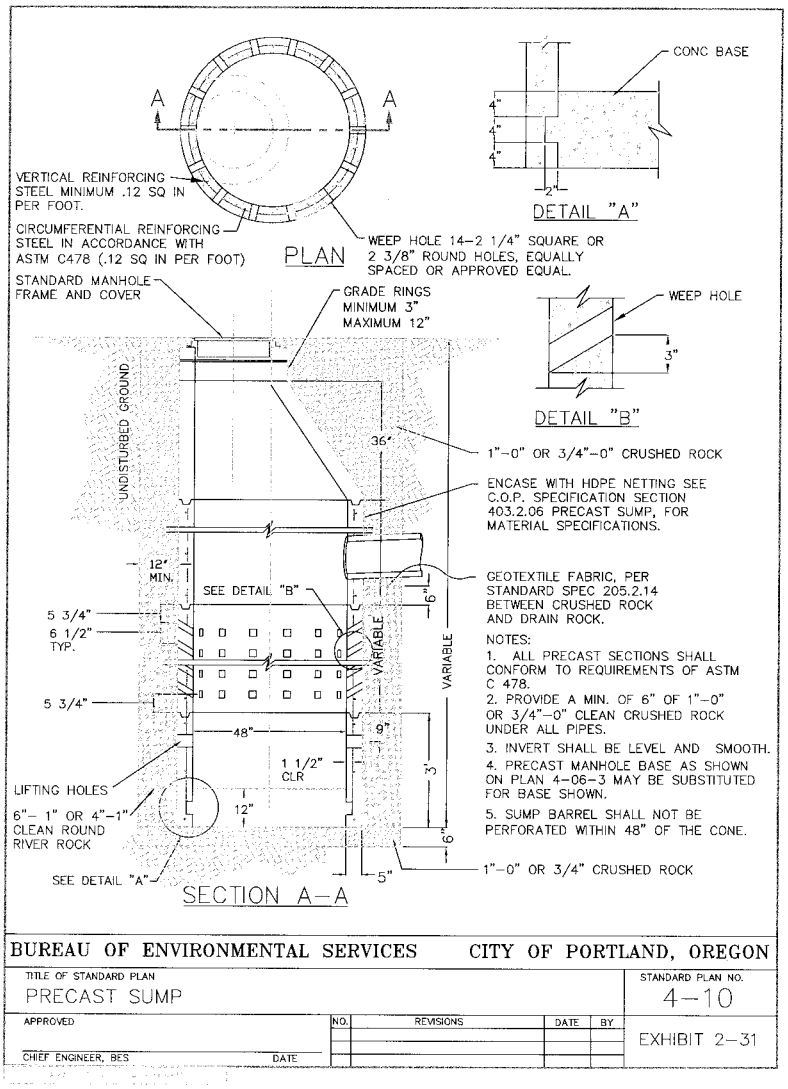
Pipe

- The solid pipe from building or other source to connection with perforated pipe must be installed at a ¼" per foot slope.
- All piping within 10 feet of building must be sch. 40 ABS, sch. 40 PVC, cast iron, sch. 40 ABS, 3" sch. 40 PVC or 3" cast iron pipe may be used for rain drain piping serving not more than 1500 sf of roof or surface area. Use 4" pipe if area is greater than 1500 sf.
- Pipe must have a minimum cover of 12" measured from top of pipe to finished grade.
- The pipe within the trench shall either be PVC D2729 or HDPE Leach field pipe.
- The silt trap shall be installed between the dwelling and the sand filter, a minimum of 5' from the dwelling.

Filter Fabric must be one of the following types/brands: LINQ 125EX; LINQ TYPAR3201; TNS E040; TNS R035; TNS R040; TNS R042; AMOCO 4535; Marafi 140NL.

SARB_007949

Public Infiltration Sump System



Stormwater Management Goals Achieved	Acceptable Sizing Methodologies
√ Pollution Reduction[2]…….……..	PRES[2]
√ Flow Control…….……	PRES
√ Destination/ Disposal……	PRES

This facility is classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) Public infiltration sump systems are used to manage stormwater from public street surfaces. **2)** Pollution reduction credit is only given in low-use (< 1,000 average daily trips) residential scenarios.

Public Infiltration Sump System

PUBLIC INFILTRATION SUMP SYSTEMS

Public infiltration sump systems can be used to provide public street drainage by collecting and recharging stormwater runoff into the ground. The use of sumps is highly dependent on soil type and elevation of the groundwater table.

Note: The Oregon Department of Environmental Quality (DEQ) has identified sumps as "Class V Injection Wells" under the federal Underground Injection Control (UIC) Program. These facilities must be either authorized by rule or authorized by permit by DEQ. In the case of public infiltration sumps, BES administers the rule authorization process with DEQ. Since the UIC Program states that these types of wells can have a direct impact on groundwater, site controls and pollution reduction facilities are required prior to disposing stormwater into them.

More information about the UIC Program can be found in **Section 1.4.4** or at DEQ's website at: **Http://www.deq.state.or.us/wq/groundwa/uichome.htm**

For technical questions call DEQ- UIC Program at 503-229-5886, and for copies of applications or forms call 503-229-5189.

Sumps are recognized as a disposal method for managing stormwater runoff. Sump systems are excluded from use within the following specific areas and land-use types within the City:

- Columbia South Shore and Cascade Station/ Portland International Center Plan Districts (see **Exhibit 2-33**)
- Major City traffic streets (including district collectors) in combined sewer areas, or neighborhood collectors in commercially zoned areas (Refer to *Transportation Element, Comprehensive Plan,* Office of Transportation, 2000)
- Within 500 feet of municipal or domestic drinking water wells, or a two-year time of travel zone, whichever is greater
- In areas with permanent or seasonally-shallow groundwater (< 40 feet below the ground surface)

A "sump system" (see **Exhibit 2-30**) is the total of all sump components at a single location (e.g., an intersection) and consists of inlets, piping, a sedimentation manhole, and one or more sumps. If one sump lacks adequate capacity to handle the design flow, a second sump may be placed in series with the first to provide additional capacity.

Public Infiltration Sump System

Sedimentation manholes with oil traps receive runoff from inlets before stormwater enters the sumps. The sedimentation manholes settle out most of the large particulate material that can clog sumps' drainage holes, decreasing maintenance needs and increasing long-term effectiveness.

Detailed drawings of a standard sump and standard sedimentation manhole can be found as **Exhibits 2-31** and **2-32** of this manual.

When constructed according to the standard design procedures, the sump system achieves both flow control and some pollution reduction benefits. The sedimentation manhole reduces pollution through removal of sediment, oils, and grease. Additional pollution reduction facilities, such as street swales, planters or filters, must be used in non-residential streets, or streets with over 1,000 average daily trips.

Public Sump System Method of Analysis

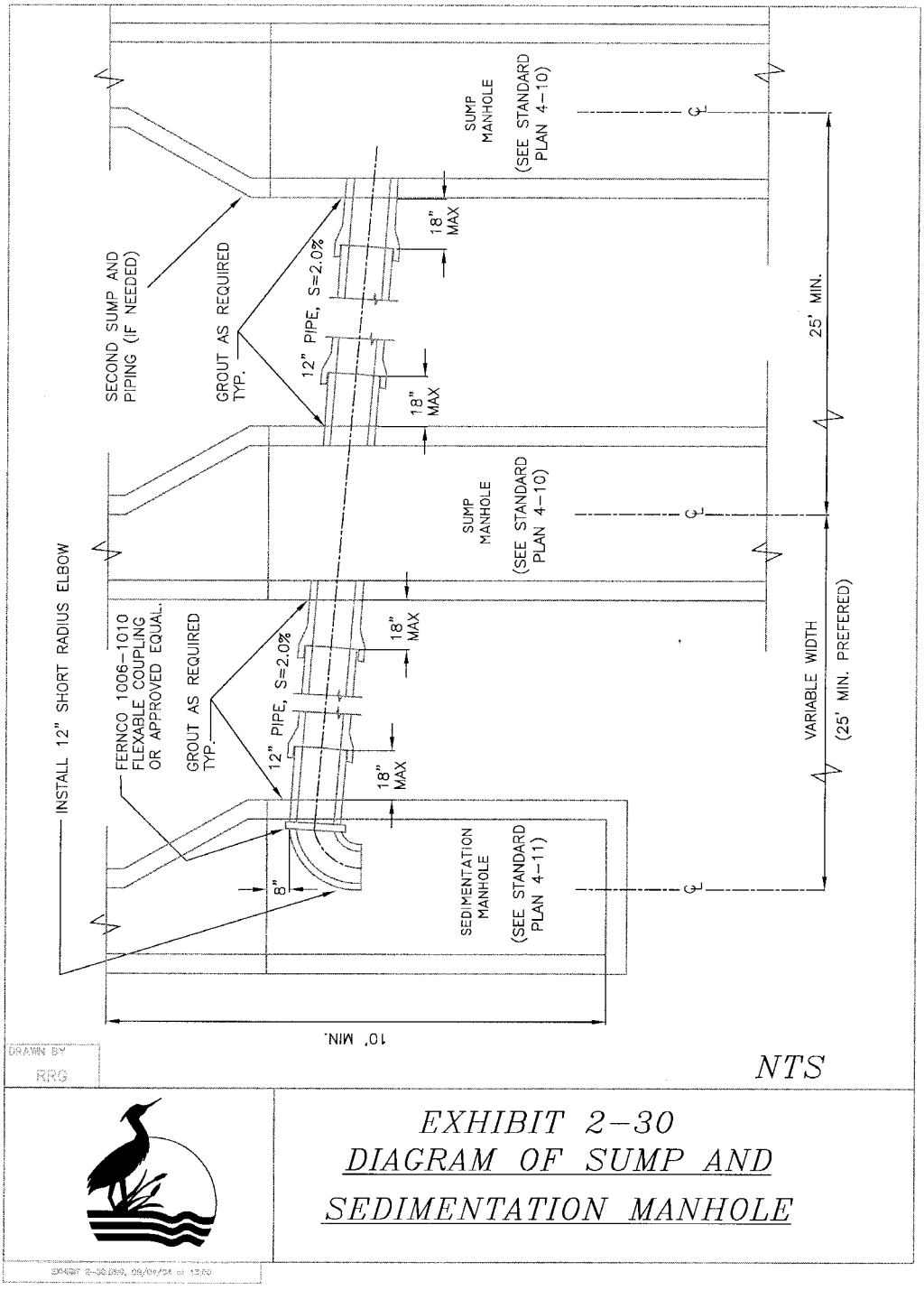
- Hydraulic calculations for public sumps shall be performed using the Rational Method. Information on the use and application of the Rational Method is found in BES's *Sewer Design Manual.*

- Sumps shall be designed for a 10-year design storm, with a safety factor of 2.

- The time of concentration for sump design shall be 5 minutes.

Example:	What is the design percolation rate that a sump system must achieve to adequately dispose of runoff from 10,000 square-feet of paved street area?
Rational Formula:	Q=C*I*A
Assume:	Time of concentration = 5 minutes for the street area
Where:	Q= Flow in cubic feet per second C= Runoff Coefficient (0.9 for paved surfaces) I= Intensity (2.86 inches per hour for a 10-year storm event and a time of concentration of 5 minutes) A= Area in acres (10,000 square-feet = 0.23 acres)
	Q= (0.9) * (2.86) * (0.23) = 0.59 cfs
Apply safety factor of 2:	Q= 2 * 0.59 cfs = **1.18 cfs or 530 gallons per minute**

Public Infiltration Sump System



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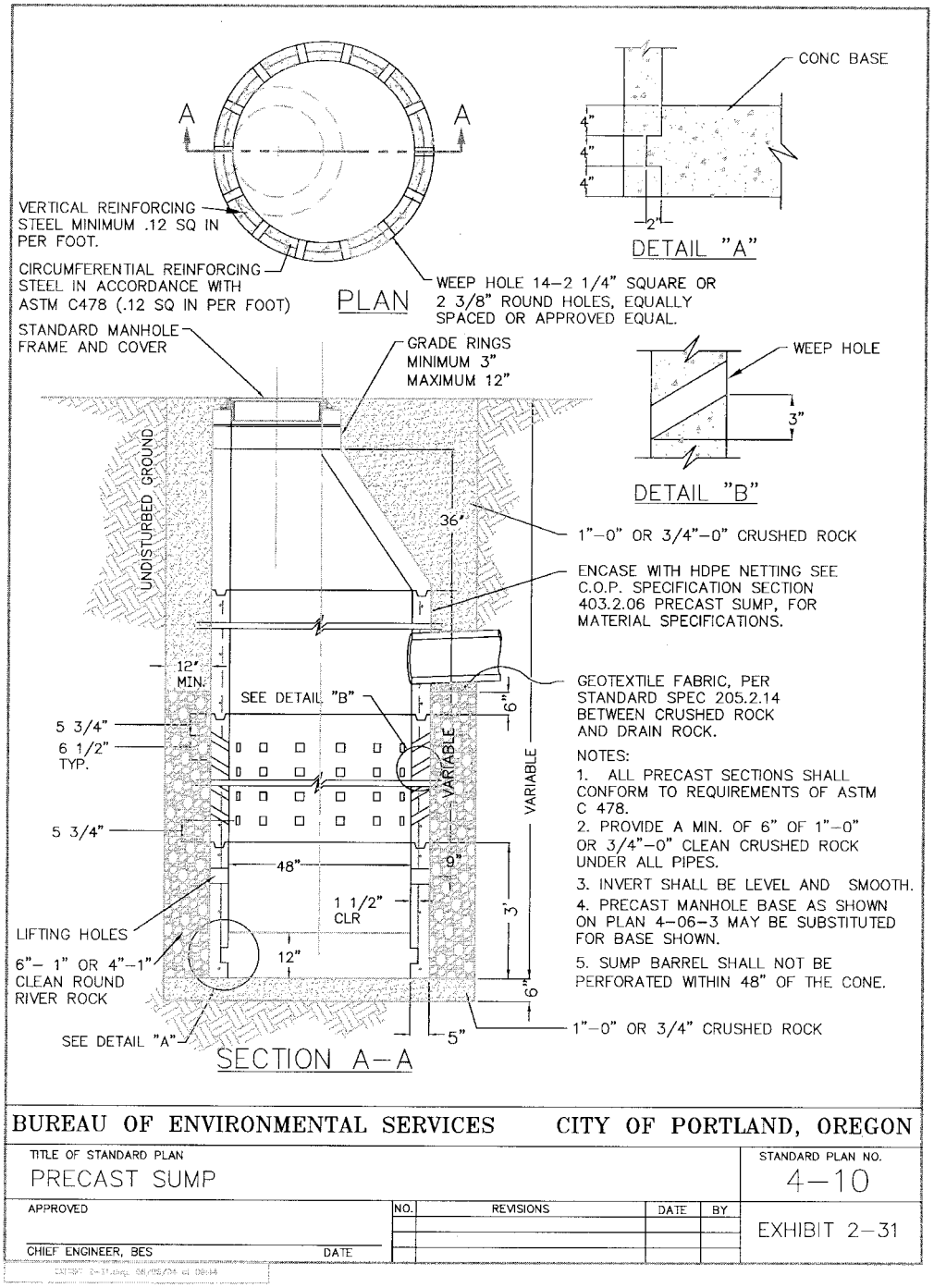
Public Infiltration Sump System



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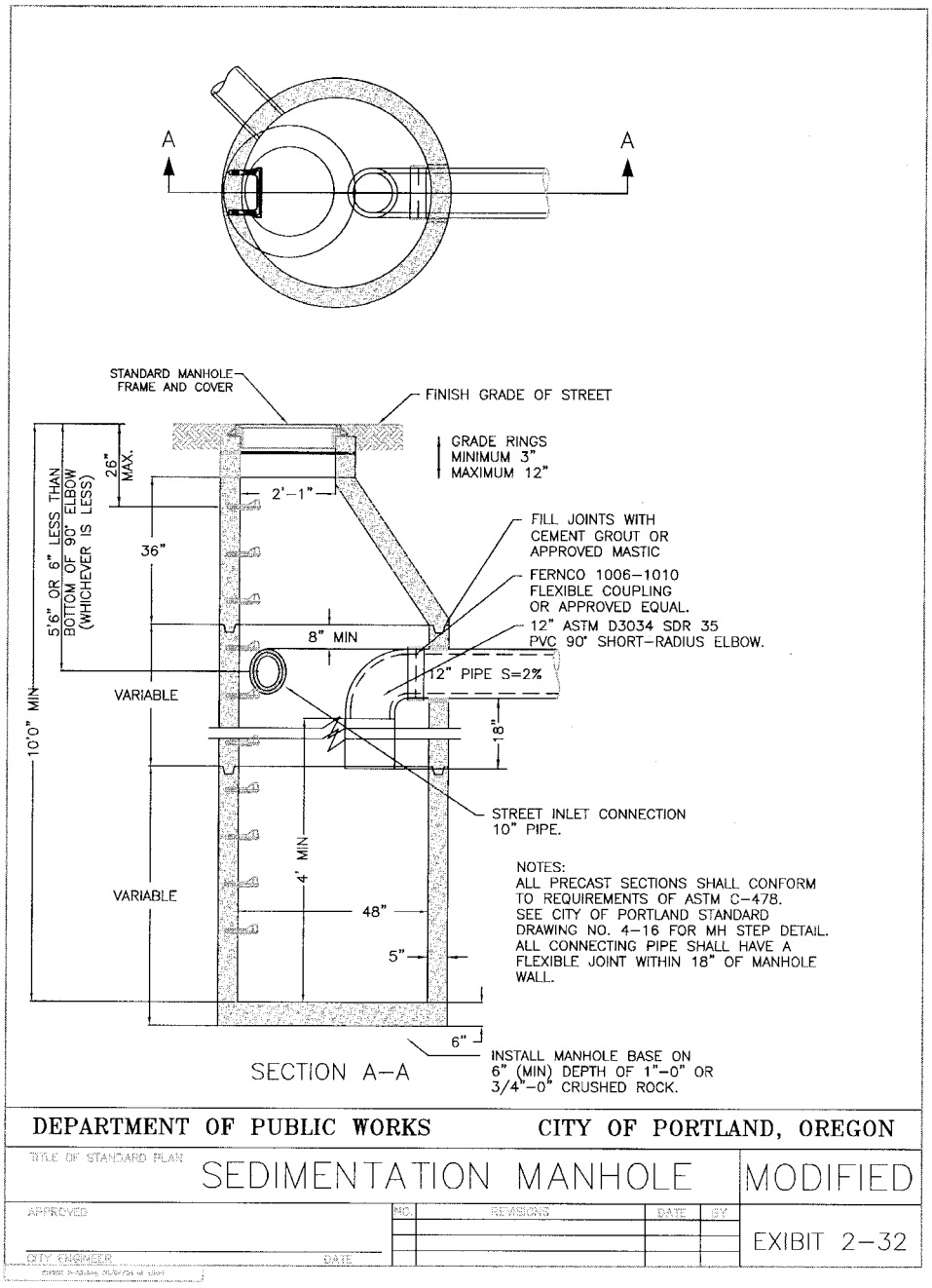
Public Infiltration Sump System



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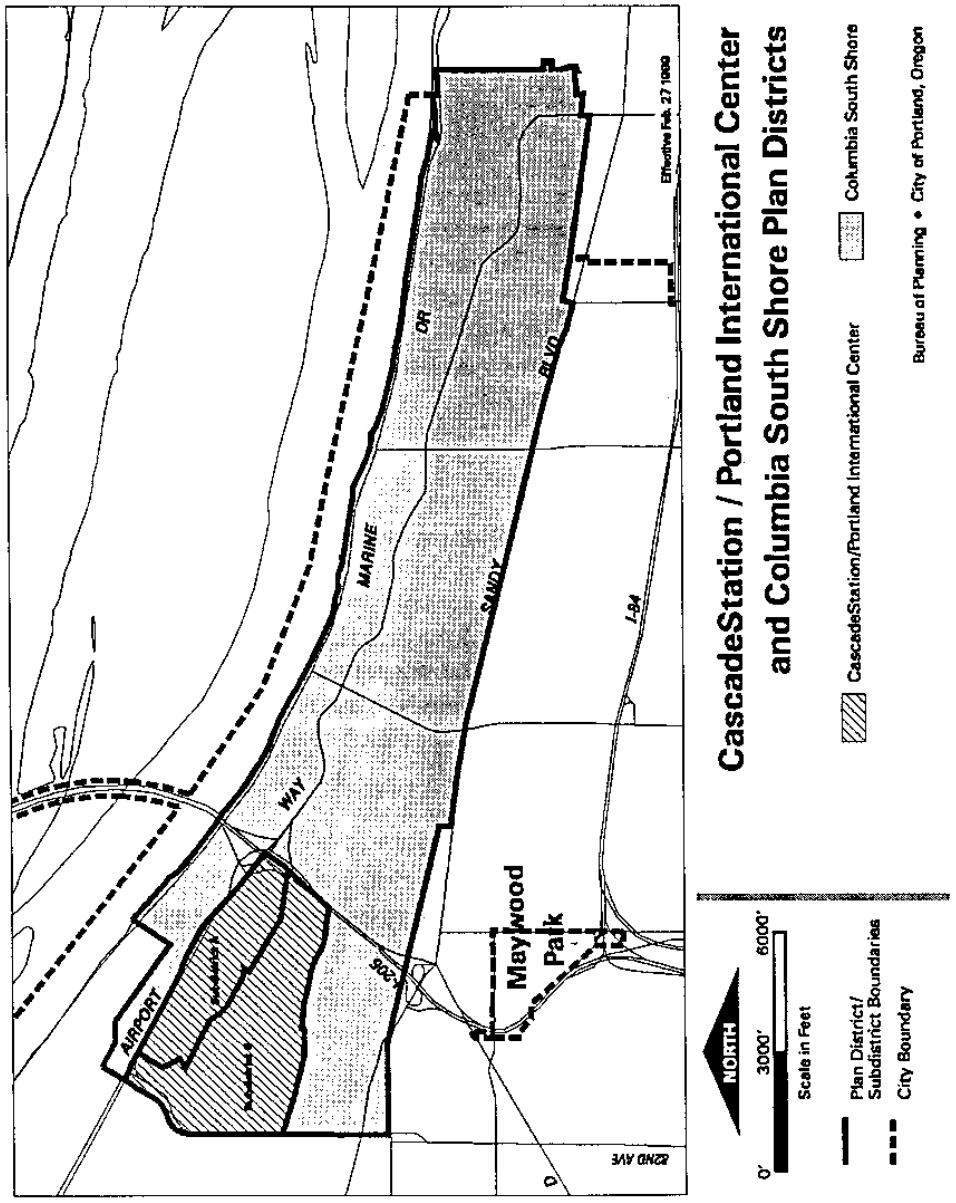
Public Infiltration Sump System

EXHIBIT 2-33
CASCADE STATION/ PORTLAND INTERNATIONAL CENTER AND COLUMBIA SOUTH SHORE PLAN DISTRICTS



SARB_007956

Public Infiltration Sump System

Public Sump System Design Requirements

- Public sump systems shall be designed to handle **twice** the flow from the calculated design storm.
- A maximum of two sumps shall be used in series, unless approved by BES.
- The minimum distance between sumps shall be 25 feet.
- The desired distance between the sump and sedimentation manhole is 25 feet. This figure is a guideline and depends on site conditions.
- Sumps shall not be located within 200 feet from the tops of slopes more than 10 feet high and steeper than 2h: 1v.
- The sump depth shall be 30 feet, unless otherwise approved by BES.
- The sedimentation manhole depth shall be 10 feet.
- The diameter of pipe between the sump and sedimentation manhole shall be 12 inches. (Note: The pipe leaving the sedimentation manhole is fitted with a 90-degree short-radius elbow; see **Exhibit 2-32.**)
- See the City of Portland's *Sewer Design Manual* for acceptable pipe material types between the sump and sedimentation manhole.
- Sumps shall not be located in areas with a constant or seasonally high groundwater table, or shallow bedrock. The bottom of the sump shall be at least 10 feet above the seasonal high water table, and at least 3 feet above bedrock.

SUMP TESTING

Soil conditions are critical to the success of sump systems. The use of sumps will not be approved without supporting geotechnical evidence and a documented sump test to demonstrate they will work in the particular area of interest. The geotechnical evidence shall include test sump data to provide information about local underground soil conditions and the potential infiltration capacity of the surrounding soil. Before being accepted by the City, all public sumps shall be tested after construction to ensure they meet or exceed the design capacity. The following sump testing procedure shall be used and must be shown on the construction plans of all public works sump projects:

Public Infiltration Sump System

SUMP NOTES
Design flows reflect a factor of safety of 2.
All sumps shall be tested by the contractor as directed and approved by the city inspector.
Sump testing shall take place after sump construction is complete and before the construction of the sedimentation manhole. Should a sump test fail to verify adequate capacity, an additional sump, constructed in series with the first sump (a maximum of two sumps per system) shall be required, as approved by BES. Should a test of two sumps in series fail to verify adequate capacity, an alternative public stormwater destination shall be required, as approved by BES.
Notify BES inspector, or BES construction office at (503) 823-5728, at least 48 hours before beginning sump testing. A BES representative must be present during all sump capacity tests.
Contractor shall contact the City Water Bureau, or applicable water district, to arrange for sump test water supply. Contractor shall be responsible for obtaining necessary permits, authorization, and any fees.
Contractor may lease sump testing equipment from BES Materials Testing Laboratory, subject to leasing conditions and fees. Contact the laboratory, located at 1405 N River, at (503) 823-2340. Similar testing equipment from any vendor may be used, as approved by BES.
Provide water flow from fire hydrants to sump being tested using 8-inch nominal diameter pipe. Deliver clean potable water to sump. Introduction of sediment is not acceptable and may result in failure of sump capacity test and reconstruction of sump.
Fill sump with water at an initial rate of 300 gallons per minute (gpm) and record water elevation below sump manhole lid, every five minutes. When water surface reaches a constant elevation, increase flow rate to sump to 600 gpm. Record water surface elevations every five minutes. Continue to increase flow rate 300 gpm each time water surface elevation stabilizes, until maximum capacity is reached.
Immediately upon completion of the sump test, provide BES inspector with recorded test data. Contractor shall sign the results and submit to the BES inspector.
The closest fire hydrant for sump testing is located at the intersection of _____ & _____. Contact the Water Bureau to apply for a hydrant use permit.

Public Infiltration Sump System

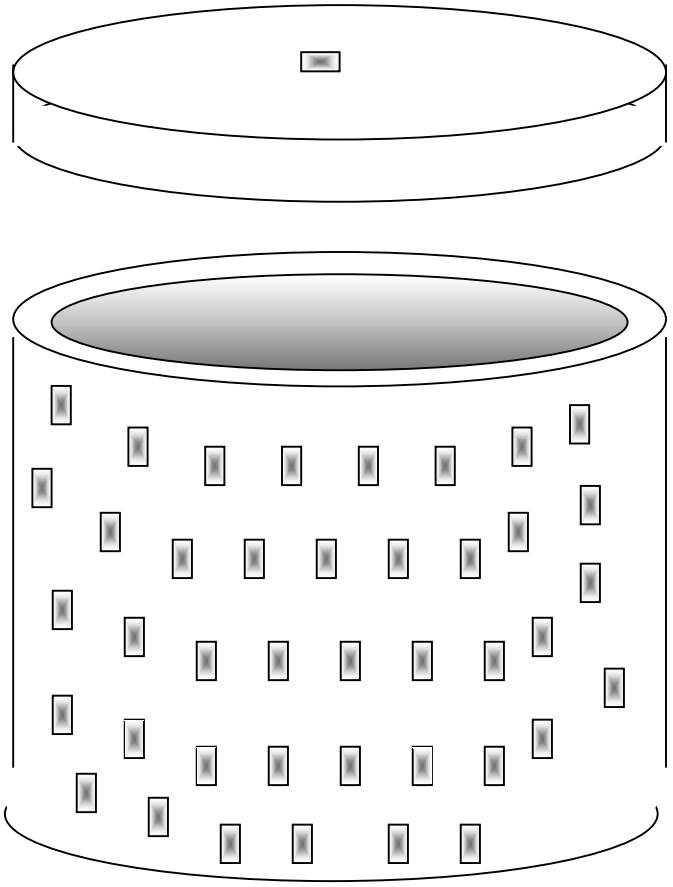
Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Sump and sedimentation manhole location with setbacks to curb, right-of-way lines, and other existing and proposed utilities.
2) Rim and bottom elevation.
3) The sump and sedimentation manhole shall reference the City of Portland standard plan numbers.
4) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection.

Operations and Maintenance requirements: The applicant or contractor is required to maintain the public infiltration sump system for two years after construction is complete and signed-off by BES. Turbid runoff from construction sites shall not be allowed to enter the system at any time. The sedimentation manhole shall be cleaned prior to BES acceptance of ownership and maintenance.

Private Drywell



Stormwater Management Goals Achieved		Acceptable Sizing Methodologies
	Pollution Reduction…….……..	NA
√	Flow Control……	PRES
√	Destination/ Disposal……	PRES

This facility is classified as an Underground Injection Control structure (UIC).

SIM=Simplified Approach, PRES= Presumptive Approach, PERF= Performance Approach

Notes: 1) Private drywells can be used to manage stormwater from private property.

Private Drywell

Description: Private drywells can be used as stormwater disposal points by collecting and recharging stormwater runoff into the ground. The use of drywells is highly dependent on soil type and elevation of the groundwater table.

Note: DEQ identifies drywells as "Class V Injection Wells" under the federal Underground Injection Control (UIC) Program. These facilities must be classified as exempt, authorized by rule, or authorized by permit by DEQ. Since the UIC Program states that these types of wells can have a direct impact on groundwater, pollution reduction is required before disposing stormwater into them, with the exception of drywells that serve rooftops only. All drywells, with the exception of those that drain residential rooftops only, must be registered with DEQ prior to City permit issuance.

More information about the UIC Program can be found in **Section 1.4.4** or at DEQ's website at: **Http://www.deq.state.or.us/wq/groundwa/uichome.htm**

For technical questions call the DEQ UIC Program at 503-229-5886. For copies of applications or forms call 503-229-5189.

Drywells are recognized as a stormwater disposal point, but they are not intended to be used to meet pollution reduction requirements. Unless a drywell used exclusively for roof runoff, pollution reduction facilities must be used to receive runoff before it enters the drywell. If used for residential streets with less than 1,000 average daily trips, or non-vehicular access areas such as pedestrian plazas, a spill control manhole per **Exhibit 2-26** may be used to meet pollution reduction requirements.

Drywell systems are prohibited from use within the Columbia South Shore and Cascade Station/ Portland International Center Plan Districts (see **Exhibit 2-33**). Drywells are also prohibited where permanent or seasonally shallow groundwater will exist within 10 feet of the bottom of the drywell.

Private Drywell Design and Sizing Method

Soil conditions are critical to the success of drywells. Because of this, the use of drywells must be pre-approved by the Environmental Soils section of BDS. Supporting geotechnical evidence and a documented drywell test may be required to demonstrate that drywells will work in the project area. Drywells shall not be located in areas with a constant or seasonally high groundwater table.

Private Drywell

Exhibit 2-34 shall be used to design private drywells, after BDS approval has been given. To use this chart, the impervious surface area flowing to the proposed drywell must be known. The gray boxes corresponding to combinations of drywell diameter and depth may be used. Any other combinations of drywell diameter and depth will need to be pre-approved by BDS, and drywell testing may be required in accordance with the drywell testing procedure below.

Note: Developers should refer to OAR 340, Division 44, "Construction and Use of Waste Disposal Wells or Other Underground Injection Activities" for additional design and regulatory requirements.

Drywell Testing Procedure

Equipment Needed:

- Water supply capable of filling drywell
- 25-foot tape measure
- Stopwatch
- Flashlight

Procedure: In the presence of a City Building Inspector:

1) Place the measuring tape against drywell wall, measuring to the bottom of drywell. Secure in place for the duration of the test.

2) Fill the drywell with clean potable water. Document water level before starting stopwatch.

3) Shut off water supply and start stopwatch.

4) Stop stopwatch when water level has dropped by 5 feet. Document this elapsed time.

5) Compare this time to the "Maximum Time in Minutes for Water to Drop by 5 feet in Drywell" from **Table B of Exhibit 2-35**. The diameter of the drywell and square footage of impervious site area that will flow into the drywell must be known to determine drawdown time.

   If the elapsed time is less than the time shown on the chart, one (1) drywell is sufficient. If the elapsed time is greater than the time shown on the chart, divide the elapsed time by the chart time and round to the nearest whole number. This is the number of drywells that will be required.

Private Drywell

Exhibit 2-34: Drywell Sizing

Once approval has been given by BDS for on-site infiltration of stormwater, the following chart shall be used to select the number and size of drywells.

Impervious Area (sq-ft)	28" Diameter Drywell Depth				48" Diameter Drywell Depth				60" Diameter Drywell Depth			
	5'	10'	15'	20'	5'	10'	15'	20'	5'	10'	15'	20'
1000												
2000												
3000												
4000												
5000												
6000												
7000												
8000												
9000												
10000												
11000												
12000												
13000												
14000												
15000												
16000												
17000												
18000												
19000												
20000												

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Private Drywell

Exhibit 2-35: Drywell Testing

Table A: Minimum Infiltration Rate Required in Gallons per Minute

Impervious Area (sq-ft)	28" Diameter Drywell Depth				48" Diameter Drywell Depth				60" Diameter Drywell Depth			
	5'	10'	15'	20'	5'	10'	15'	20'	5'	10'	15'	20'
1000	53	53	53	53	53	53	53	53	53	53	53	53
2000	106	106	106	106	106	106	106	106	106	106	106	106
3000	159	159	159	159	159	159	159	159	159	159	159	159
4000	212	212	212	212	212	212	212	212	212	212	212	212
5000	265	265	265	265	265	265	265	265	265	265	265	265
6000	318	318	318	318	318	318	318	318	318	318	318	318
7000	371	371	371	371	371	371	371	371	371	371	371	371
8000	424	424	424	424	424	424	424	424	424	424	424	424
9000	477	477	477	477	477	477	477	477	477	477	477	477
10000	530	530	530	530	530	530	530	530	530	530	530	530
11000	583	583	583	583	583	583	583	583	583	583	583	583
12000	636	636	636	636	636	636	636	636	636	636	636	636
13000	689	689	689	689	689	689	689	689	689	689	689	689
14000	742	742	742	742	742	742	742	742	742	742	742	742
15000	795	795	795	795	795	795	795	795	795	795	795	795
16000	848	848	848	848	848	848	848	848	848	848	848	848
17000	901	901	901	901	901	901	901	901	901	901	901	901
18000	954	954	954	954	954	954	954	954	954	954	954	954
19000	1007	1007	1007	1007	1007	1007	1007	1007	1007	1007	1007	1007
20000	1060	1060	1060	1060	1060	1060	1060	1060	1060	1060	1060	1060

Table B: Maximum Time in Seconds for Water to Drop by 5 feet in Drywell

Impervious Area (sq-ft)	28" Diameter Drywell Depth				48" Diameter Drywell Depth				60" Diameter Drywell Depth			
	5'	10'	15'	20'	5'	10'	15'	20'	5'	10'	15'	20'
1000	180	180	180	180	534	534	534	534	828	828	828	828
2000	90	90	90	90	270	270	270	270	414	414	414	414
3000	60	60	60	60	180	180	180	180	276	276	276	276
4000	48	48	48	48	132	132	132	132	210	210	210	210
5000	36	36	36	36	108	108	108	108	168	168	168	168
6000	30	30	30	30	90	90	90	90	138	138	138	138
7000	24	24	24	24	78	78	78	78	120	120	120	120
8000	24	24	24	24	66	66	66	66	102	102	102	102
9000	18	18	18	18	60	60	60	60	90	90	90	90
10000	18	18	18	18	54	54	54	54	84	84	84	84
11000	18	18	18	18	48	48	48	48	78	78	78	78
12000	18	18	18	18	42	42	42	42	72	72	72	72
13000	12	12	12	12	42	42	42	42	66	66	66	66
14000	12	12	12	12	36	36	36	36	60	60	60	60
15000	12	12	12	12	36	36	36	36	54	54	54	54
16000	12	12	12	12	36	36	36	36	54	54	54	54
17000	12	12	12	12	30	30	30	30	48	48	48	48
18000	12	12	12	12	30	30	30	30	48	48	48	48
19000	12	12	12	12	30	30	30	30	42	42	42	42
20000	12	12	12	12	24	24	24	24	42	42	42	42

(Rational Method, Safety Factor of 2)

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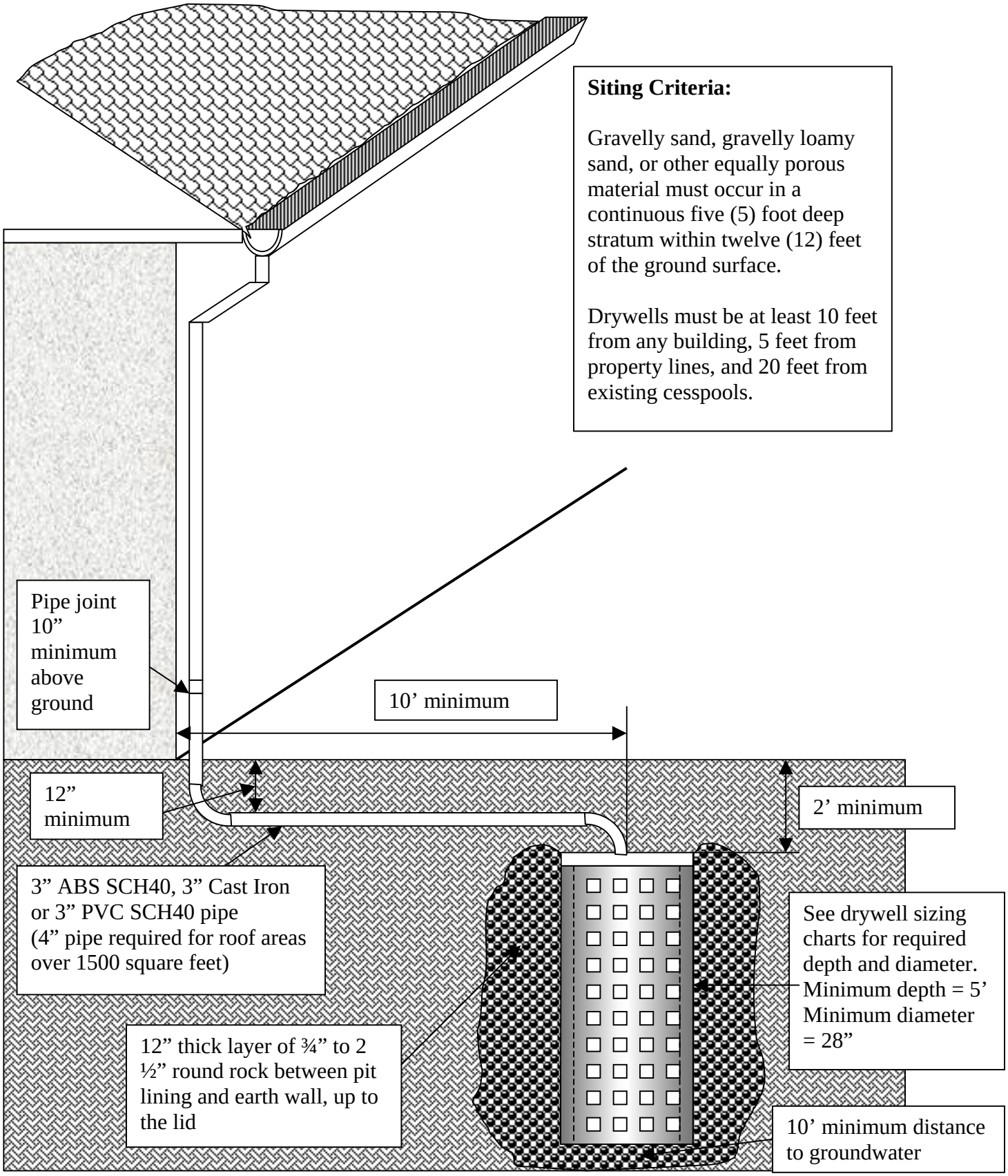
Private Drywell

Exhibit 2-36: Private Reinforced Concrete Drywell Typical Configuration



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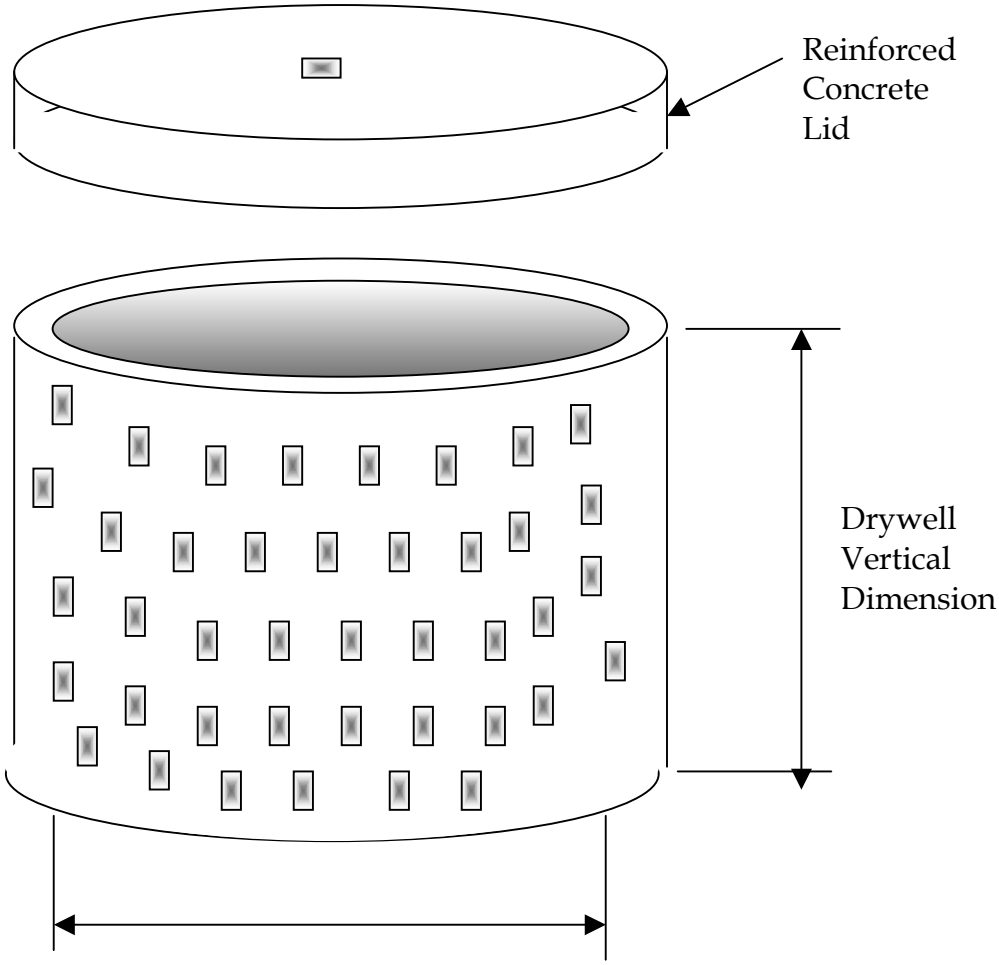
Private Drywell

Exhibit 2-37: Typical Private Drywell:



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Private Drywell

Checklist of minimal information to be shown on the permit drawings:

(Additional information may be required on the drawings during permit review, depending on individual site conditions.)

1) Facility location with setbacks from property lines and structures.
2) Depth and diameter of drywell.
3) All stormwater piping associated with the facility, including pipe materials, sizes, slopes, and invert elevations at every bend or connection.

Inspection requirements and schedule: The following table shall be used to determine which stormwater facility components require City inspection, and when the inspection shall be requested:

Facility Component	Inspection Requirement
Drywell excavation	
Piping	Call for inspection
Drywell installation & backfill	Cal for inspection

Operations and Maintenance requirements: See **Chapter 3.0**.

*** Link to drywell O&M form**

Chapter 3.0
OPERATIONS & MAINTENANCE

Summary of Chapter 3.0

This chapter presents operation and maintenance (O&M) requirements for the stormwater management facilities in this manual. It includes:

3.1 Applicability of O&M requirements
3.2 O&M submittal requirements
3.2.1 for private facilities
3.2.2 for public facilities
3.3 O&M Plan Enforcement
- **Form O&M**
- **Example of Form O&M**
- **Inspection Log Sample**
- **Facility-specific O&M plans**

To Use This Chapter:

1) After using **Chapters 1.0** and **2.0** to complete a stormwater management design for the project, fill out **Form O&M**.
2) Form O&M includes a blank section to insert a **site plan**, or attach a separate site plan sheet showing the location of the stormwater management facilities on the site, sources of stormwater runoff, and ultimate stormwater disposal point.
3) For **private** facilities: Record a copy of **Form O&M** and the **site plan** with the applicable county Department of Assessment and Taxation.
4) Submit a recorded copy of these sheets, along with the **facility-specific O&M plan** for each stormwater management facility used on-site, with the permit application. The O&M activities listed on the facility-specific O&M forms, which will be on file with BES, may later be revised with BES approval.
5) For **public** facilities: Submit a copy of an O&M plan with the public works permit application. County recording of this plan is not necessary.

Note: Enforcement rules regarding the inspection, operations, and maintenance of stormwater management facilities can be found in the *BES Enforcement Administrative Rules*, not included in this manual. Contact Dawn Hottenroth at 503-823-7767 for a copy of this document.

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3.1 APPLICABILITY

The operations and maintenance (O&M) requirements in this chapter apply to:

- All stormwater management facilities and related facility components identified in **Chapter 2.0**.

  Exceptions: 1) Developments treating less than 1,000 square-feet of impervious surface with new trees do not need to submit or record O&M plans for the new trees used as simplified approaches.

  2) O&M plans do not need to be submitted for existing tree canopy.

- City personnel are responsible for the operations and maintenance of capital improvement projects. These CIP projects may or may not include requirements for maintenance in the contract specifications when contractors are hired to perform work.

This chapter provides a **facility-specific O&M plan** that identifies the O&M requirements for each type of facility included in this manual. If a stormwater facility that is not included in this manual is used (such as a manufactured stormwater treatment technology) it is still necessary to prepare and submit an O&M plan, along with facility-specific O&M activities that complies with the requirements of this chapter.

3.2 O&M SUBMITTAL REQUIREMENTS

3.2.1 Requirements for Privately Maintained Facilities

Form O&M: Operations & Maintenance Plan (see page 3-6) identifies the owner's name, address, and phone number, the site address, financial method used to cover future operation and maintenance, and parties responsible for inspecting and maintaining the facility. It also provides a space to insert a site plan to identify the location of the facility on the site, sources of runoff entering the facility, and ultimate stormwater disposal point. This form must be included with every private stormwater management facility permit application, and must be recorded with the applicable county before permit issuance.

Facility-specific O&M plans (see page 3-9 through 3-32) identify the specific O&M activities that are required for each type of stormwater management facility. The appropriate plans must be attached to **Form O&M** and submitted as part of the stormwater management facility permit application. The facility-

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specific O&M plans do not have to be recorded with the county. This allows the future stormwater management facility owner to revise O&M activities, with BES approval, without the need to re-record the O&M plan with the county.

The facility-specific O&M activities for private facilities may be modified any time after permit issuance. This is optional, and is intended to give the owner an opportunity to adjust maintenance needs according to site-specific history and conditions. Proposed modifications to the O&M plan must be submitted to BES for review and approval.

City Code requires an **Inspection and Maintenance Log** to be kept by facility owners. In general, the log should note all inspection dates, the facility components that were inspected, and any maintenance or repairs made. The facility-specific O&M plans can serve as a checklist for what should be included in the log (e.g. the facility elements that need to be inspected, frequency of inspection, conditions that indicate maintenance is needed, etc.). See page 3-8 for an **inspection and maintenance log sample**.

3.2.2 Requirements for City-Maintained Facilities

A stormwater management facility that receives stormwater runoff from a public right-of-way shall become a public (City-maintained) facility unless the right-of-way is not part of the City's road maintenance system. Facilities that will become City-maintained must be constructed under a public works permit.

For facilities built under a public works permit a preliminary O&M plan shall be submitted before construction, as part of the applicant's public works permit application package. **Form O&M** and **facility-specific O&M plans** may be used to serve as the O&M plan. In addition, the applicant shall demonstrate on the public works plans that the City can achieve the specified O&M activities. This may involve the construction of maintenance access roads and the dedication of public access easements.

Contractors building facilities under a public works permit are responsible for maintaining all site stormwater management features, including their associated vegetative components, during a 2-year maintenance warranty period.

At the end of this period, BES requires a modified O&M plan for all site features, based on experience with the site over the 2 years**.** Final facility sign-off will not be given until the modified O&M plan has been submitted. Contractors working directly for the City shall follow the specifications in their contracts.

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3.3 O&M PLAN ENFORCEMENT

City code Chapter 17.38 requires that all stormwater management facilities, constructed to comply with the requirements of this manual, must be properly operated and maintained for the life of the facility. City staff has the right and responsibility to inspect facilities to assure they are being properly operated and maintained. It is the intent of BES to use education and technical assistance to ensure the proper O&M of private facilities. Administrative rules and procedures regarding BES inspection and enforcement activities for assurance of proper O&M can be found in the BES Enforcement Administrative Rules package, not included in this manual. For a copy of this document, contact Dawn Hottenroth at 503-823-7767.

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FORM O&M: OPERATIONS & MAINTENANCE PLAN INSTRUCTIONS

The following are instructions to prepare and file Form O&M: Operations & Maintenance Plan for a stormwater management facility.

City of Portland Code Section 17.38.040 states that "All new development, redevelopment, plats, site plans, building permits or public works projects, as a condition of approval, shall be required to submit an operation and maintenance plan for the required stormwater quality and quantity control facilities for review and approval by the Bureau of Environmental Services."

Failure to properly operate or maintain the water quality or quantity control facility according to the operation and maintenance plan may result in a civil penalty, as specified in 17.38.045: Enforcement.

A copy of the operation and maintenance plan shall be filed with the Bureau of Environmental Services. Completed O&M Plans shall be submitted to:

Document Services
1900 SW Fourth Ave., Suite 5000
Portland, OR 97201

The operation and maintenance plan shall be recorded and filed with the appropriate county Department of Assessment and Taxation. The O&M plan must be recorded in the county where the property site is located. Form O&M with a site plan must be recorded. Additional plans of the facility and facility-specific O&M activities will be retained at the Portland Building – 1200 SW 5th Avenue, Room 1000.

Before recording the O&M plan, the applicant shall sign the form, and the signature shall be notarized. When completed accurately, this form meets the recording requirements in Multnomah, Clackamas, and Washington Counties. The notarized O&M plan may be submitted in person or mailed, along with payment of the applicable fees, to the appropriate county. Each county provides a web site and telephone number with recorded information to answer commonly asked questions about the recording procedures.

County Recorder's Office Addresses and Fees
(as of June 2001)

Multnomah
Multnomah County Recorder
Room 158
501 SE Hawthorne St.
Portland, OR 97214
Http://www.co.multnomah.or.us/at/services.html
Phone: 503-988-3326
$19 first page, $5 each additional page

Washington
Washington County Recording Office
155 N. First Ave.
Suite 130, MS 9
Hillsboro, OR 97124
Http://www.co.washington.or.us/deptmts/at/recordng/record.htm
Phone: 503-846-8751
$22 first page, $5 each additional page

Clackamas
Clackamas County Recording Division
104 11th St.
Oregon City, OR 97045
Http://www.co.clackamas.or.us/recording/legible.htm
Phone: 503-655-8661
$26 first page, $5 each additional page

FORM O&M: OPERATIONS & MAINTENANCE PLAN

INSTRUCTIONS (PAGE 2)

1: Fill out Form O&M (Page 3-6)

Project building application number: City staff will insert this number.

Owner: Print the name of the property owner.

Phone no.: Print the area code and 7-digit phone number of the property owner.

Mailing address: Print the property owner's mailing address, including zip code. After the plan is recorded with the county recorder's office, a copy of the recorded O&M Plan will be mailed to this address. The City will also use this address if further correspondence is required.

Site address: Print the address of the property where the stormwater management facility is located.

Site legal description: Print the property's legal description. Property legal descriptions may be obtained from the county assessor's office.

Signature: Sign the O&M plan form under "filer" in the presence of a notary.

Site plan: Include a site plan showing the facility location (in relation to building structures or other permanent monuments on the site), the sources of runoff entering the stormwater facility, and where stormwater will be discharged to after leaving the facility. The site plan can be inserted on Form O&M or included as a separate sheet.

Description of the financial method used to cover future operations and maintenance:
Check the appropriate box.

Party (ies) responsible for maintenance:
Provide the name, address, and phone number (both daytime and after-hours numbers) for the person or company who shall be responsible for maintaining or directly supervising the maintenance of the stormwater facilities described in the O&M Plan.

Maintenance practices and schedule for the stormwater management facility:
Provide the date the O&M Plan was prepared, the date the plan was revised (if applicable), and the month and year of the stormwater management facility installation. Provide the name, firm (if applicable), and address of the person who prepared the O&M Plan.

FORM O&M: OPERATIONS & MAINTENANCE PLAN

REQUIRED IN ACCORDANCE WITH CITY CODE CHAPTER 17.38

Project Building Application No.	*For official county use only*
Owner's Name	
Phone No. (area code required) **(**_____**)** _____ **-** _____	
Mailing Address (RETURN ADDRESS FOR RECORDER**)**	
Site Address	
Site Legal Description	

BY SIGNING BELOW, filer accepts and agrees to the terms and conditions contained in this operations & maintenance plan and in any document executed by filer and recorded with it.

_____

Filer

NOTARIZATION: GIVEN under my hand and official seal

this _____ day of _____ , _____.

Notary Public in and for the State of Oregon:

My Appointment Expires on:

O&M PLAN REQUIRED INFORMATION:

1) Site Plan. Include a site plan showing the facility location (in relation to building structures or other permanent monuments on the site), sources of runoff entering the facility, and where stormwater will be discharged to after leaving the facility. **The stormwater management facility located on this site plan is a required condition of building permit approval for the identified property. The owner of the identified property is required to operate and maintain this facility in accordance with the O&M plan on file with the City of Portland, Bureau of Environmental Services. The requirement to operate and maintain this facility in accordance with the on-file O&M plan is binding on all current and future owners of the property. The O&M plan may be modified under written consent of new owners with written approval by and re-filing with the Bureau of Environmental Services. The O&M plan for this facility is available at the Bureau of Environmental Services, located at 1120 SW 5th Avenue, Room 1000, Portland, Oregon, between the hours of 8 a.m. and 5 p.m., Monday through Friday. Call (503) 823-7761 for assistance.**	**Site Plan (insert here or include separate sheet):**

2) Description of the financial method used to cover future operations and maintenance. ***Check One:***

❑ Homeowner Association ❑ Property Owner Account ❑ Other (*describe)*_____

3) Party (ies) responsible for maintenance (only if other than owner).

Daytime Phone No. (area code required)(_____) _____ - _____	Emergency/After-Hours Contact Phone No. (_____) _____ - _____
Maintenance Contact & Address	

4) Maintenance practices and schedule for the stormwater facility is included in the facility-specific O&M plan filed with the Bureau of Environmental Services, City of Portland. The operation and maintenance practices are based on the publication date of the City of Portland's Stormwater Management Manual.

Preparation Date _____ / ____ / _____	Revision Date _____ / ____ / _____	Estimated Date of Installation *(month/year)* ___ / ___
Prepared By_____		

FORM O&M: OPERATIONS & MAINTENANCE PLAN (Example)

REQUIRED IN ACCORDANCE WITH CITY CODE CHAPTER 17.38

Project Building Application No.

For official county use only

Owner's Name John Doe

Phone No. (area code required) (_503_) _555_ - _5555__

Mailing Address (RETURN ADDRESS FOR RECORDER)
XXX NW XXX Street, Portland, OR XXXXX

Site Address
XXX NW XXX Street, Portland, OR XXXXX

Site Legal Description
Section XX, Township XX, Range XX, Tax Lot XX

BY SIGNING BELOW, filer accepts and agrees to the terms and conditions contained in this operations & maintenance plan and in any document executed by filer and recorded with it.

John Doe

Filer

NOTARIZATION: GIVEN under my hand and official seal

this _____ day of _____ , _____.

Notary Public in and for the State of Oregon:

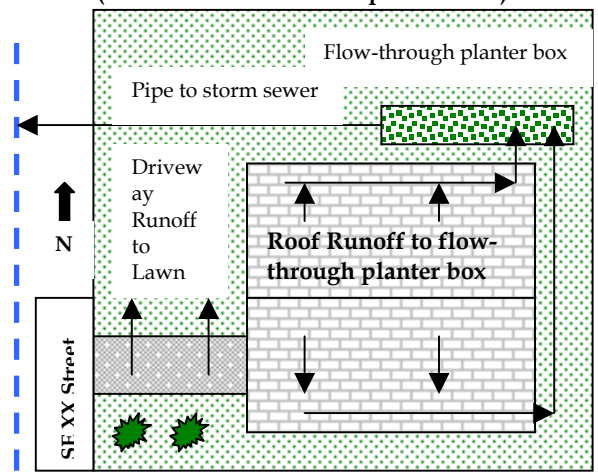
My Appointment Expires on:

O&M PLAN REQUIRED INFORMATION:

1) Site Plan. Include a site plan showing the facility location (in relation to building structures or other permanent monuments on the site), sources of runoff entering the facility, and where stormwater will be discharged to after leaving the facility.

The stormwater management facility located on this site plan is a required condition of building permit approval for the identified property. The owner of the identified property is required to operate and maintain this facility in accordance with the O&M plan on file with the City of Portland, Bureau of Environmental Services. The requirement to operate and maintain this facility in accordance with the on-file O&M plan is binding on all current and future owners of the property. The O&M plan may be modified under written consent of new owners with written approval by and re-filing with the Bureau of Environmental Services. The O&M plan for this facility is available at the Bureau of Environmental Services, located at 1120 SW 5th Avenue, Room 1000, Portland, Oregon, between the hours of 8 a.m. and 5 p.m., Monday through Friday. Call (503) 823-7761 for assistance.

Site Plan (insert here or include separate sheet):



2) Description of the financial method used to cover future operations and maintenance. *Check One:*

❑ Homeowner Association X Property Owner Account ❑ Other *(describe)*_____

3) Party (ies) responsible for maintenance (only if other than owner). Owner Responsible

Daytime Phone No. (area code required) (503) xxx--xxxx | Emergency/After-Hours Contact Phone No. (503) xxx-xxxx

Maintenance Contact & Address Garden Guy Landscaping XXX NE XX Street Portland, OR 97XXX

4) Maintenance practices and schedule for the stormwater facility is included in the facility-specific O&M plan filed with the Bureau of Environmental Services, City of Portland. The operation and maintenance practices are based on the publication date of the City of Portland's Stormwater Management Manual.

Preparation Date XX/ XX /200X | Revision Date _____ / ____ / _____ | Estimated Date of Installation *(month/year)* XX /XXXX

Prepared By John Doe

STORMWATER MANAGEMENT FACILITY
INSPECTION & MAINTENANCE LOG (SAMPLE)

Property Address:

Inspection Date:

Inspection Time:

Inspected By:

Approximate Date/Time of Last Rainfall:

Type of Stormwater Management Facility:

Location of Facility on Site (In relation to buildings or other permanent structures):

Water levels and observations (Oil sheen, smell, turbidity, etc.):

Sediment accumulation & record of sediment removal:

Condition of vegetation (Height, survival rates, invasive species present, etc.) & record of replacement and management (mowing, weeding, etc.):

Condition of physical properties such as inlets, outlets, piping, fences, irrigation facilities, and side slopes. Record damaged items and replacement activities:

Presence of insects or vectors. Record control activities:

Identify safety hazards present. Record resolution activities:

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FACILITY-SPECIFIC OPERATIONS AND MAINTENANCE PLANS

FACILITY **PAGE**

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Ecoroofs and Roof Gardens

Operations & Maintenance Plan

Ecoroofs and Roof Gardens are vegetated roof systems that retain and filter stormwater and provide aesthetic and energy conservation benefits. All facility components, including soil substrate or growth medium, vegetation, drains, irrigation systems (if applicable), membranes, and roof structure shall be inspected for proper operations, integrity of the waterproofing, and structural stability throughout the life of the ecoroof or roof garden. All elements shall be inspected once a month from April through September. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Soil Substrate/ Growing Medium shall be inspected for evidence of erosion from wind or water.

- If erosion channels are evident, they shall be stabilized with additional soil substrate/growth medium and covered with additional plants.

Ecoroof System Structural Components shall be operated and maintained in accordance with manufacturer's requirements. Drain Inlets shall be kept unrestricted.

- Inlet pipe shall be cleared when soil substrate, vegetation, debris or other materials clog the drain inlet. Sources of sediment and debris shall be identified and corrected.
- Determine if drain inlet pipe is in good condition and correct as needed.

Debris and Litter shall be removed to prevent clogging of inlet drains and interference with plant growth.

Vegetation shall be maintained to provide 90% plant cover.

- During the Establishment Period, plants shall be replaced once per month as needed. During the long-term period, dead plants shall generally be replaced once per year in the fall months.
- Fallen leaves and debris from deciduous plant foliage shall be removed.
- Nuisance and prohibited vegetation from the Portland Plant List shall be removed when discovered.
- Dead vegetation shall be removed and replaced with new plants.
- Weeding shall be manual with no herbicides or pesticides used. Weeds shall be removed regularly and not allowed to accumulate.
- Fertilization is not necessary and fertilizers shall not be applied.
- During drought conditions, mulch or shade cloth may be applied to prevent excess solar damage and water loss.
- Mowing of grasses shall occur as needed. Clippings shall be removed.

Irrigation can be accomplished either through hand watering or automatic sprinkler systems. If automatic sprinklers are used, manufacturers' instructions for operations and maintenance shall be followed.

- During the Establishment Period (1-3 years), water sufficient to assure plant establishment and not to exceed ¼ inch of water once every 3 days shall be applied.
- During the long-term period (3+ years), water sufficient to maintain plant cover and not to exceed ¼ inch of water once every 14 days shall be applied.

Spill Prevention measures from mechanical systems located on roofs shall be exercised when handling substances that can contaminate stormwater.

- Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining ecoroofs shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access and Safety to the ecoroof shall be safe and efficient.

- Egress and ingress routes shall be maintained to design standards. Walkways shall be clear of obstructions and maintained to design standards.

Aesthetics of the ecoroof shall be maintained as an asset to the property owner and community.

- Evidence of damage or vandalism shall be repaired and accumulation of trash or debris shall be removed upon discovery.

Insects shall not be harbored at the ecoroof.

- Standing water creating an environment for development of insect larvae shall be eliminated by manual means. Chemical sprays shall not be used.

Contained Planters

Operations & Maintenance Plan

Contained planters are designed to intercept rainfall that would normally fall on impervious surfaces. In this respect contained planters convert impervious surfaces to pervious ones, decreasing the amount of stormwater runoff from a site. Water should drain through the planter within 3-4 hours after a storm event. All facility components and vegetation shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation and 2 times per year thereafter. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Filter Media consisting of sand or topsoil shall allow stormwater to percolate uniformly through the planter.

- The planter shall be excavated and cleaned, and gravel or soil shall be replaced to correct low infiltration rates.
- Holes that are not consistent with the design and allow water to flow directly through the planter to the ground shall be plugged.
- Litter and debris shall be removed routinely (e.g., no less than quarterly) and upon discovery.

Planter shall contain filter media and vegetation.

- Structural deficiencies in the planter including rot, cracks, and failure shall be repaired.

Planter Reservoir receives and detains storm water prior to infiltration. If water does not drain from reservoir within 3-4 hours of storm event, sources of clogging shall be identified and corrected. Topsoil may need to be amended with sand or replaced all together.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion.

- Mulch shall be replenished at least annually.
- Planter vegetation shall be irrigated to ensure survival.
- Vegetation, large shrubs or trees that limit access or interfere with planter operation shall be pruned or removed.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance and prohibited vegetation from the Portland Plant List shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species (measured in a 10 x 10 foot plot) shall be removed and replaced.
- Dead vegetation shall be removed to maintain less than 10% of area coverage or when planter function is impaired. Vegetation shall be replaced within a specific timeframe, e.g., 3 months, or immediately if required to maintain cover density and control erosion where soils are exposed.

Training and/or written guidance information for operating and maintaining planters shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the stormwater planter shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.

- Obstacles preventing maintenance personnel and/or equipment access to the stormwater planter shall be removed.
- Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored at the stormwater planter. Pest control measures shall be taken when insects/rodents are found to be present.

- Standing water creating an environment for development of insect larvae shall be eliminated.
- If sprays are considered, then a mosquito larvicide, such as Bacillus thurengensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the stormwater planter shall be filled and compacted.

Pervious Pavement
Operations & Maintenance Plan

Pervious pavement is a permeable pavement surface with an underlying stone reservoir that temporarily stores surface runoff before infiltrating into the subsoil or being collected in underlying drain pipes and being discharged off-site. There are many types of pervious pavement including plastic rings planted with grass, stone or concrete blocks with pore spaces backfilled with gravel or sand, porous asphalt, and porous concrete. Pervious pavement accepts only precipitation, not stormwater runoff. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability, at a minimum, quarterly for the first 2 years from the date of installation, 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Surface: In most pervious pavement design, the pavement itself acts as pretreatment to the stone reservoir below. The surface shall be kept clean and free of leaves, debris, and sediment. The surface shall not be overlaid with an impermeable paving surface

- Regular sweeping shall be implemented for porous asphalt or concrete systems.

Overflows or Emergency Spillways are used in the event that the facility's infiltration capacity is exceeded. Overflow devices shall be inspected for obstructions or debris, which shall be removed upon discovery Overflow or emergency spillways shall be capable of transporting high flows of stormwater to an approved stormwater receiving system.

- Sources of erosion damage shall be identified and controlled when native soil is exposed near the overflow structure.

Vegetation (where applicable) shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion. Vegetation, such as trees and shrubs, should not be located in or around the pervious pavement because roots from trees can penetrate the pavement, and leaves from deciduous trees and shrubs can increase the risk of clogging the surface.

- Vegetation and large shrubs/trees that limit access or interfere with porous pavement operation shall be pruned.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Poisonous, nuisance, dead or odor producing vegetation shall be removed immediately.
- Grass shall be mowed to less than four inches and grass clippings shall be bagged and removed.
- Irrigation shall be provided as needed.

Source Control measures prevent pollutants from mixing with stormwater. Typical non-structural control measures include raking and removing leaves, street sweeping, vacuum sweeping, limited and controlled application of pesticides and fertilizers, and other good house keeping practices.

Spill Prevention measures shall be exercised when handling substances that can contaminate stormwater. A spill prevention plan shall be implemented at all non-residential sites and in areas where there is likelihood of spills from hazardous materials. However, virtually all sites, including residential and commercial, present potential danger from spills. All homes contain a wide variety of toxic materials including gasoline for lawn mowers, antifreeze for cars, solvents, pesticides, and cleaning aids that can adversely affect storm water if spilled. It is important to exercise caution when handling substances that can contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining pervious pavement shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the pervious pavement shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.
Obstacles preventing maintenance personnel and/or equipment access to the porous pavement shall be removed.
Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored at the pervious pavement. Pest control measures shall be taken when insects/rodents are found to be present.

- Standing water creating an environment for development of insect larvae shall be eliminated.
- If sprays are considered, then a mosquito larvicide, such as Bacillus thurengensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the pervious pavement shall be filled and compacted.

If used at this site, the following will be applicable:

Signage may serve to educate people about the importance or function of the site's stormwater protection measures. It may also discourage behaviors that adversely affect stormwater protection measures. For example, if debris is a problem, a sign reminding people not to litter may partially solve the problem. Broken or defaced signs shall be replaced/repaired.

Vegetated, Grassy, and Street Swales
Operations & Maintenance Plan

Swales are planted or grassed open channels that trap pollutants by filtering and slowing flows, allowing particles to settle out. The swale should drain within 48 hours of a storm event. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability, at a minimum, quarterly for the first 2 years from the date of installation, 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Swale Inlet (such as curb cuts or pipes) shall maintain a calm flow of water entering the swale.

- Source of erosion shall be identified and controlled when native soil is exposed or erosion channels are forming.
- Sediment accumulation shall be hand-removed with minimum damage to vegetation using proper erosion control measures. Sediment shall be removed if it is more than 4" thick or so thick as to damage or kill vegetation.
- Inlet shall be cleared when conveyance capacity is plugged. Sources of sediment and debris shall be identified and corrected.
- Rock splash pads shall be replenished to prevent erosion.

Side Slopes shall be maintained to prevent erosion that introduces sediment into the swale.

- Slopes shall be stabilized and planted using appropriate erosion control measures when native soil is exposed or erosion channels are forming.

Swale Media shall allow stormwater to percolate uniformly through the landscape swale. If the swale does not drain within 48 hours, it shall be tilled and replanted according to design specifications.

- Annual or semi-annual tilling shall be implemented if compaction or clogging continues.
- Debris in quantities that inhibit operation shall be removed routinely (e.g., no less than quarterly), or upon discovery.

Swale Outlet shall maintain sheet flow of water exiting swale unless a collection drain is used. Source of erosion damage shall be identified and controlled when native soil is exposed or erosion channels are forming.

- Outlets such as drains and overland flow paths shall be cleared when 50% of the conveyance capacity is plugged.
- Sources of sediment and debris shall be identified and corrected.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion. Mulch shall be replenished as needed to ensure survival of vegetation.

- Vegetation, large shrubs or trees that interfere with landscape swale operation shall be pruned.
- Fallen leaves and debris from deciduous plant foliage shall be removed.
- Grassy swales shall be mowed to keep grass 4” to 9” in height.
- Nuisance and prohibited vegetation from the Portland Plant List (such as blackberries and English Ivy) shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed and replaced.
- Dead vegetation and woody material shall be removed to maintain less than 10% of area coverage or when swale function is impaired. Vegetation shall be replaced within 3 months, or immediately if required to maintain cover density and control erosion where soils are exposed.

Spill Prevention measures shall be exercised when handling substances that contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining swales shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the swale shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.

- Obstacles preventing maintenance personnel and/or equipment access to the swale shall be removed.
- Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored in the swale. Pest control measures shall be taken when insects/rodents are found to be present.

- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the swale shall be filled.

If used at this site, the following will be applicable:

Check Dams shall control and distribute flow.

- Causes for altered water flow shall be identified, and obstructions cleared upon discovery.
- Causes for channelization shall be identified and repaired.

Vegetated Filters

Operations & Maintenance Plan

Vegetated filters are gently sloped vegetated areas that stormwater runoff is directed to flow and filter through. Stormwater enters the filter as sheet flow from an impervious surface or is converted to sheet flow using a flow spreader. Flow control is achieved using the relatively large surface area and check dams. Pollutants are removed through infiltration and sedimentation. The vegetative filter should drain within 48 hours of storm event. All facility components and vegetation shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation, 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Flow Spreader shall allow runoff to enter the vegetative filter as predominantly sheet flow.

- Source of erosion damage shall be identified and controlled when native soil is exposed or erosion channels are forming.
- Sediment build-up near or exceeding 2" in depth shall be removed.

Filter Inlet shall assure unrestricted stormwater flow to the vegetative filter.

- Sources of erosion shall be identified and controlled when native soil is exposed or erosion channels are present.
- Sediment accumulation shall be hand-removed with minimum damage to vegetation using proper erosion control measures. Sediment shall be removed if it is more than 4 inches thick or so thick as to damage or kill vegetation.
- Inlet shall be cleared when conveyance capacity is plugged.
- Rock splash pads shall be replenished to prevent erosion.

Filter Media shall allow stormwater to percolate uniformly through the vegetative filter.

- If the vegetative filter does not drain within 48 hours, it shall be regraded and replanted according to design specifications. Established trees shall not be removed or harmed in this process.
- Debris in quantities more than 2" deep or sufficient to inhibit operation shall be removed routinely (e.g., no less than quarterly), or upon discovery.

Check Dams shall direct and control flow.

- Causes for altered water flow and channelization shall be identified, and obstructions cleared upon discovery.
- Cracks, rot, and structural damage shall be repaired.

Filter Outlet shall allow water to exit the vegetative filter as sheet flow, unless a collection drainpipe is used.

- Sources of erosion damage shall be identified and controlled when native soil is exposed or erosion channels are deeper than 2 inches.
- Outlet shall be cleared when 50% of the conveyance capacity is plugged. Sources of sediment and debris shall be identified and corrected.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion.

- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance and prohibited vegetation from the Portland Plant List (such as blackberries and English Ivy) shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed and replaced.
- Dead vegetation shall be removed to maintain less than 10% of area coverage or when vegetative filter function is impaired. Vegetation shall be replaced immediately to control erosion where soils are exposed and within 3 months to maintain cover density.

Spill Prevention measures shall be exercised when handling substances that contaminate stormwater.
Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining vegetated filters shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the vegetative filter shall be safe and efficient. Egress and ingress routes shall be maintained to design standards.
Obstacles preventing maintenance personnel and/or equipment access to the facility shall be removed.
Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored in the vegetated filter. Pest control measures shall be taken when insects/rodents are found to be present.

- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the vegetated filter shall be filled.

Infiltration and Flow-Through Planters

Operations & Maintenance Plan

Planters are designed to allow runoff to filter through layers of topsoil (thus capturing pollutants) and then either infiltrate into the native soils (infiltration planter) or be collected in a pipe to be discharged off-site (flow-through planter). The planter is sized to accept runoff and temporarily store the water in a reservoir on top of the soil. The flow-through planter is designed with an impervious bottom or is placed on an impervious surface. Water should drain through the planter within 3-4 hours after a storm event. All facility components and vegetation shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation, 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Downspout from rooftop or sheet flow from paving allows unimpeded stormwater flow to the planter.

- Debris shall be removed routinely (e.g., no less than every 6 months) and upon discovery.
- Damaged pipe shall be repaired upon discovery.

Splash Blocks prevent splashing against adjacent structures and convey water without disrupting media.

- Any deficiencies in structure such as cracking, rotting, and failure shall be repaired.

Planter Reservoir receives and detains storm water prior to infiltration. Water should drain from reservoir within 3-4 hours of storm event.

- Sources of clogging shall be identified and corrected.
- Topsoil may need to be amended with sand or replaced all together.

Filter Media consisting of sand, gravel, and topsoil shall allow stormwater to percolate uniformly through the planter. The planter shall be excavated and cleaned, and gravel or soil shall be replaced to correct low infiltration rates.

- Holes that are not consistent with the design and allow water to flow directly through the planter to the ground shall be plugged.
- Sediment accumulation shall be hand removed with minimum damage to vegetation using proper erosion control measures. Sediment shall be removed if it is more than 4 inches thick or so thick as to damage or kill vegetation.
- Litter and debris shall be removed routinely (e.g., no less than quarterly) and upon discovery.

Planter shall contain filter media and vegetation.

- Structural deficiencies in the planter including rot, cracks, and failure shall be repaired.

Overflow Pipe safely conveys flow exceeding reservoir capacity to an approved stormwater receiving system.

- Overflow pipe shall be cleared of sediment and debris when 50% of the conveyance capacity is plugged.
- Damaged pipe shall be repaired or replaced upon discovery.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion.

- Mulch shall be replenished at least annually.
- Vegetation, large shrubs or trees that limit access or interfere with planter operation shall be pruned or removed.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance or prohibited vegetation from the Portland Plant List shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed and replaced.
- Dead vegetation shall be removed to maintain less than 10% of area coverage or when planter function is impaired. Vegetation shall be replaced within a specific timeframe, e.g., 3 months, or immediately if required to maintain cover density and control erosion where soils are exposed.

Spill Prevention measures shall be exercised when handling substances that contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining stormwater planters shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the stormwater planter shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.

- Obstacles preventing maintenance personnel and/or equipment access to the stormwater planter shall be removed.
- Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored in the stormwater planter.
Pest control measures shall be taken when insects/rodents are found to be present.
If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
Holes in the ground located in and around the stormwater planter shall be filled and compacted.

Vegetated Infiltration Basins
Operations & Maintenance Plan

A **vegetated Infiltration Basin** is a vegetated depression created by excavation, berms, or small dams to provide for short-term ponding of surface water until it percolates into the soil. The basin shall infiltrate stormwater within 24 hours. All facility components and vegetation shall be inspected for proper operations and structural stability, at a minimum, quarterly for the first 2 years from the date of installation, 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Basin Inlet shall assure unrestricted stormwater flow to the vegetated basin.

- Sources of erosion shall be identified and controlled when native soil is exposed or erosion channels are present.
- Inlet shall be cleared when conveyance capacity is plugged.
- Rock splash pads shall be replenished to prevent erosion.

Embankment, Dikes, Berms & Side Slopes retain water in the infiltration basin.

- Structural deficiencies shall be corrected upon discovery:
- Slopes shall be stabilized using appropriate erosion control measures when soil is exposed/ flow channels are forming.
- Sources of erosion damage shall be identified and controlled.

Overflow or Emergency Spillway conveys flow exceeding reservoir capacity to an approved stormwater receiving system.

- Overflow shall be cleared when 25% of the conveyance capacity is plugged.
- Sources of erosion damage shall be identified and controlled when soil is exposed.
- Rocks or other armament shall be replaced when only one layer of rock exists.

Filter Media shall allow stormwater to percolate uniformly through the infiltration basin. If water remains 36-48 hours after storm, sources of possible clogging shall be identified and corrected.

- Basin shall be raked and, if necessary, soil shall be excavated, and cleaned or replaced.

Sediment/ Debris Management shall prevent loss of infiltration basin volume caused by sedimentation. Gauges located at the opposite ends of the basin shall be maintained to monitor sedimentation.

- Sediment and debris exceeding 4" in depth shall be removed every 2-5 years or sooner if performance is affected.
- Restricted sources of sediment and debris, such as discarded lawn clippings, shall be identified and prevented.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion.

- Mulch shall be replenished as needed to ensure healthy plant growth.
- Vegetation, large shrubs or trees that limit access or interfere with basin operation shall be pruned or removed.
- Grass shall be mowed to 4"-9" high and grass clippings shall be removed no less than 2 times per year.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance or prohibited vegetation from the Portland Plant List (such as blackberries or English Ivy) shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed.
- Dead vegetation shall be removed to maintain less than 10% of area coverage or when infiltration basin function is impaired. Vegetation shall be replaced within 3 months, or immediately if required to control erosion.

Spill Prevention measures shall be exercised when handling substances that contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining vegetated infiltration basins shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the infiltration basin shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.

- Obstacles preventing maintenance personnel and/or equipment access to the infiltration basin shall be removed.
- Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored in the infiltration basin. Pest control measures shall be taken when insects/rodents are found to be present.

- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the infiltration basin shall be filled.

If used at this site, the following will be applicable:

Fences shall be maintained to preserve their functionality and appearance.

- Collapsed fences shall be restored to an upright position, jdamaged fences shall be repaired or replaced.

Sand Filters

Operations & Maintenance Plan

Sand filters consist of a layer of sand in a structural box used to trap pollutants. The water filters through the sand and then flows into the surrounding soils or an underdrain system that conveys the filtered stormwater to a discharge point. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation, and 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Filter Inlet shall allow water to uniformly enter the sand filter as calm flow, in a manner that prevents erosion.

- Inlet shall be cleared of sediment and debris when 40% of the conveyance capacity is plugged.
- Source of erosion shall be identified and controlled when native soil is exposed or erosion channels are forming.
- Sediment accumulation shall be hand-removed with minimum damage to vegetation using proper erosion control measures. Sediment shall be removed if it is more than 4 inches thick or so thick as to damage or kill vegetation.
- Rock splash pads shall be replenished to prevent erosion.

Reservoir receives and detains stormwater prior to infiltration. If water does not drain within 2-3 hours of storm event, sources of clogging shall be identified and correction action taken.

- Debris in quantities more than 1 cu ft or sufficient to inhibit operation shall be removed routinely (e.g., no less than quarterly), or upon discovery.
- Structural deficiencies in the sand filter box including rot, cracks, and failure shall be repaired upon discovery.

Filter Media shall allow to stormwater to percolate uniformly through the sand filter. If water remains 36-48 hours after storm, sources of possible clogging shall be identified and corrected.

- Sand filter shall be raked and if necessary, the sand/gravel shall be excavated, and cleaned or replaced.
- Sources of restricted sediment or debris (such as discarded lawn clippings) shall be identified and prevented.
- Debris in quantities sufficient to inhibit operation shall be removed no less than quarterly, or upon discovery.
- Holes that are not consistent with the design structure and allow water to flow directly through the sand filter to the ground shall be filled.

Underdrain Piping (where applicable) shall provide drainage from the sand filter, and **Cleanouts** (where applicable) located on laterals and manifolds shall be free of obstruction, and accessible from the surface.

- Underdrain piping shall be cleared of sediment and debris when conveyance capacity is plugged. Cleanouts may have been constructed for this purpose.
- Obstructions shall be removed from cleanouts without disturbing the filter media.

Overflow or Emergency Spillway conveys flow exceeding reservoir capacity to an approved stormwater receiving system.

- Overflow spillway shall be cleared of sediment and debris when 50% of the conveyance capacity is plugged.
- Source of erosion damage shall be identified and controlled when erosion channels are forming.
- Rocks or other armament shall be replaced when sand is exposed and eroding from wind or rain.

Vegetation

- Vegetation, large shrubs or trees that limit access or interfere with sand filter operation shall be pruned.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance or prohibited vegetation from the Portland Plant List (such as blackberries or English Ivy) shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed.

Spill Prevention measures shall be exercised when handling substances that contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

Training and/or written guidance information for operating and maintaining sand filters shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the sand filter shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable.

- Obstacles preventing maintenance personnel and/or equipment access to the facility shall be removed.
- Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.

Insects & Rodents shall not be harbored in the sand filter. Pest control measures shall be taken when insects/rodents are found to be present.

- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the sand filter shall be filled.

Soakage Trenches

Operations & Maintenance Plan

Soakage Trenches consist of drain rock and sand, and receive stormwater from roof downspouts and/or area drains. There are various components within the system - piping, silt basin and the trench itself. The **Conveyance Piping** consists of an inlet pipe (downspout or area drain), an outlet pipe located between the silt basin and the soakage trench, and a perforated pipe, located on top of the aggregate bed of the soakage trench. The **Silt Basin** is a structure receiving runoff from an inlet pipe and conveying it to the soakage trench. The silt basin serves as the pre-treatment system for the soakage trench, removing sediments and other debris that can impact its proper functioning. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first two years from the date of installation, then two times per year afterwards, or within 48 hours after each major storm. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Soakage trench infiltration: If water is noticed on top of the trench within 48 hours of a major storm, the soakage trench may be clogged.

- Check for debris/sediment accumulation, rake and remove and evaluate upland causes (erosion, surface or roof debris, etc
- Assess the condition of the aggregate and the filter fabric in the trench. If there is sediment in the aggregate, excavate and replace.
- If there is a tear in the filter fabric, repair or replace.

Conveyance Piping: If water ponds over the trench for more than 48 hours after a major storm and no other cause if identified, it may be necessary to remove the filter fabric to determine if the perforated pipe is clogged with sediment or debris.

- Any debris or algae growth located on top of the soakage trench should be removed and disposed of properly.
- If the piping has settled more than 1-inch, add fill material. If there are cracks or releases, replace or repair the pipe. If there are signs of erosion around the pipe, this may be an indication of water seeping due to a crack or break.

Silt Basin: If water remains in the soakage trench for 36-48 hours after storm, check for sediment accumulation in the silt basin

- If less than 50% capacity remains in the basin or 6" of sediment has accumulated, remove and dispose the sediment.

Spill Prevention*:* Virtually all sites, including residential and commercial, present dangers from spills. All homes contain a wide variety of toxic materials including gasoline for lawn mowers, antifreeze for cars, nail polish remover, pesticides, and cleaning aids that can adversely affect groundwater if spilled. It is important to exercise caution when handling substances that can contaminate stormwater.

- Activities that pose the chance of hazardous material spills shall not take place near soakage trenches.

A **Shut-Off Valve or Flow-Blocking Mechanism** may have been required with the construction of the soakage trench to temporarily prevent stormwater from flowing into it, in the event of an accidental toxic material spill. This may also involve mats kept on-site that can be used to cover inlet drains in parking lots. The shut-off valve shall remain in good working order, or if mats or other flow-blocking mechanisms are used, they shall be kept in stock on-site.

Training and/or written guidance information for operating and maintaining soakage trenches shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the soakage trench is required for efficient maintenance. Egress and ingress routes will be maintained to design standards at inspections.

Insects & Rodents shall not be harbored in the soakage trench. Pest control measures shall be taken when insects/rodents are found to be present.

- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the soakage trench shall be filled.

Wet, Extended Wet Detention, and Dry Detention Ponds

Operations & Maintenance Plan

Wet Ponds are constructed ponds with a permanent pool of water. Pollutants are removed from stormwater through gravitational settling and biologic processes. **Extended Wet Ponds** are constructed ponds with a permanent pool of water and open storage space above for short-term detention of large storm events. Pollutants are removed from stormwater through gravitational settling and biologic processes. **Dry Detention Ponds** are constructed ponds with temporary storage for the detention of large storm events. The stormwater is stored and released slowly over a matter of hours. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation, and 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Pond Inlet shall assure unrestricted stormwater flow to the wet pond.

- Inlet pipe shall be cleared when conveyance capacity is plugged. Sources of sediment and debris shall be identified and corrected.
- Determine if pipe is in good condition:
  - If more than 1 inch of settlement, add fill material and compact soils.
  - If alignment is faulty, correct alignment.
  - If cracks or openings exist indicated by evidence of erosion at leaks, repair or replace pipe as needed.

Forebay traps coarse sediments, reduces incoming velocity, and distributes runoff evenly over the wet pond. A minimum 1-foot freeboard shall be maintained.

- Sediment buildup exceeding 50% of the facility capacity shall be removed every 2-5 years, or sooner if performance is being affected.

Embankment, Dikes, Berms & Side Slopes retain water in the wet pond.

- Slopes shall be stabilized using appropriate erosion control measures when native soil is exposed or erosion channels are forming.
- Structural deficiencies shall be corrected upon discovery:
  - If cracks exist, repair or replace structure.
  - If erosion channels deeper than 2 inches exist, stabilize surface. Sources of erosion damage shall be identified and controlled.

Control Devices (e.g., weirs, baffles, etc.) shall direct and reduce flow velocity. Structural deficiencies shall be corrected upon discovery:

- If cracks exist, repair or replace structure.

Overflow Structure conveys flow exceeding reservoir capacity to an approved stormwater receiving system.

- Overflow structure shall be cleared when 50% of the conveyance capacity is plugged. Sources of sediment and debris shall be identified and corrected.
- Sources of erosion damage shall be identified and controlled when native soil is exposed at the top of overflow structure or erosion channels are forming.
- Rocks or other armoring shall be replaced when only one layer of rock exists above native soil.

Sediment & Debris Management shall prevent loss of wet pond volume caused by sedimentation.

- Wet ponds shall be dredged when 1 foot of sediment accumulates in the pond.
- Gauges located at the opposite ends of the wet pond shall be maintained to monitor sedimentation. Gauges shall be checked 2 times per year.
- Sources of restricted sediment or debris, such as discarded lawn clippings, shall be identified and prevented.
- Debris in quantities sufficient to inhibit operation shall be removed routinely, e.g. no less than quarterly, or upon discovery.

Wet, Extended Wet Detention, and Dry Detention Ponds Operations & Maintenance Plan
Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion and minimizing solar exposure of open water areas. • Mulch shall be replenished at least annually. • Vegetation, large shrubs or trees that limit access or interfere with wet pond operation shall be pruned or removed. • Grass (where applicable) shall be mowed to 4"-9" high and grass clippings shall be removed. • Fallen leaves and debris from deciduous plant foliage shall be raked and removed. • Nuisance or prohibited vegetation from the Portland Plant List (such as blackberries or English Ivy) shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed and replaced. • Dead vegetation shall be removed to maintain less than 10% of area coverage or when wet pond function is impaired. Vegetation shall be replaced within 3 months, or immediately if required to maintain cover density and control erosion where soils are exposed. • Vegetation producing foul odors shall be eliminated.
Spill Prevention measures shall be exercised when handling substances that can contaminate stormwater Releases of pollutants shall be corrected as soon as identified.
Training and/or written guidance information for operating and maintaining ponds shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.
Access to the wet pond shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable. • Obstacles preventing maintenance personnel and/or equipment access to the wet pond shall be removed. • Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.
Insects & Rodents shall not be harbored in the pond. Pest control measures shall be taken when insects/rodents are found to be present. • If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor. • Holes in the ground located in and around the pond shall be filled.
If used at this site, the following will be applicable:
Signage shall clearly convey information. • Broken or defaced signs shall be replaced or repaired.
Fences shall be maintained to preserve their functionality and appearance. • Collapsed fences shall be restored to an upright position. • Jagged edges and damaged fences and shall be repaired or replaced.

Constructed Treatment Wetlands

Operations & Maintenance Plan

Constructed Treatment Wetlands remove pollutants through several processes: sedimentation, filtration, and biological processes. All facility components, vegetation, and source controls shall be inspected for proper operations and structural stability. These inspections shall occur, at a minimum, quarterly for the first 2 years from the date of installation, and 2 times per year thereafter, and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Wetland Inlet shall assure unrestricted stormwater flow to the wetland.

- Inlet pipe shall be cleared when conveyance capacity is plugged. Sources of sediment and debris shall be identified and corrected.
- Determine if pipe is in good condition:
  - If more than 1 inch of settlement, add fill material and compact soils.
  - If alignment is faulty, correct alignment.
  - If cracks or openings exist indicated by evidence of erosion at leaks, repair or replace pipe as needed.

Forebay traps coarse sediments, reduces incoming velocity, and distributes runoff evenly over the wetland. A minimum 1-foot freeboard shall be maintained.

- Sediment buildup exceeding 50% of the facility capacity shall be removed every 2-5 years, or sooner if performance is being affected.

Embankment, Dikes, Berms & Side Slopes retain water in the wetland.

- Slopes shall be stabilized using appropriate erosion control measures when native soil is exposed or erosion channels are forming.
- Structural deficiencies shall be corrected upon discovery:
  - If cracks exist, repair or replace structure.
  - If erosion channels deeper than 2 inches exist, stabilize surface. Sources of erosion damage shall be identified and controlled.

Control Devices (e.g., weirs, baffles, etc.) shall direct and reduce flow velocity.

- Structural deficiencies shall be corrected upon discovery:
- If cracks exist, repair or replace structure.

Overflow Structure conveys flow exceeding reservoir capacity to an approved stormwater receiving system.

- Overflow structure shall be cleared when 50% of the conveyance capacity is plugged. Sources of sediment and debris shall be identified and corrected.
- Sources of erosion damage shall be identified and controlled when native soil is exposed at the top of overflow structure or erosion channels are forming.
- Rocks or other armament shall be replaced when only one layer of rock exists above native soil.

Sediment & Debris Management shall prevent loss of wetland volume caused by sedimentation.

- Wetlands shall be dredged when 1 foot of sediment accumulates.
- Gauges located at the opposite ends of the wetland shall be maintained to monitor sedimentation. Gauges shall be checked 2 times per year.
- Sources of restricted sediment or debris, such as discarded lawn clippings, shall be identified and prevented.
- Debris in quantities sufficient to inhibit operation shall be removed routinely, e.g. no less than quarterly, or upon discovery.

Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion and minimizing solar exposure of open water areas.

- Mulch shall be replenished when needed.
- Vegetation, large shrubs or trees that limit access or interfere with wetland operation shall be pruned.
- Fallen leaves and debris from deciduous plant foliage shall be raked and removed.
- Nuisance or prohibited vegetation from the Portland Plant List (such as blackberries or English Ivy) shall be removed when discovered. Invasive vegetation contributing up to 25% of vegetation of all species shall be removed and replaced.
- Dead vegetation shall be removed to maintain less than 10% of area coverage or when wetland function is impaired. Vegetation shall be replaced within 3 months, or immediately if required to maintain cover density and control erosion where soils are exposed.
- Vegetation producing foul odors shall be eliminated.

Constructed Treatment Wetlands Operations & Maintenance Plan
Spill Prevention measures shall be exercised when handling substances that can contaminate stormwater Releases of pollutants shall be corrected as soon as identified.
Training and/or written guidance information for operating and maintaining treatment wetlands shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.
Access to the wetland shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles, if applicable. • Obstacles preventing maintenance personnel and/or equipment access to the wetland shall be removed. • Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic.
Insects & Rodents shall not be harbored in the constructed treatment wetland. Pest control measures shall be taken when insects/rodents are found to be present. • If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor. • Holes in the ground located in and around the constructed treatment wetland shall be filled.
If used at this site, the following will be applicable:
Signage shall clearly convey information. • Broken or defaced signs shall be replaced or repaired.
Fences shall be maintained to preserve their functionality and appearance. • Collapsed fences shall be restored to an upright position. • Jagged edges and damaged fences and shall be repaired or replaced.

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Underground Detention Tanks, Vaults, and Pipes

Operations & Maintenance Plan

Underground detention tanks, vaults, and pipes are designed to fill with stormwater during large storm events, slowly releasing it over a number of hours. There are numerous components to each system. **Drain Inlet Pipes** convey stormwater into the detention facility. The **detention Chamber** is the structure in which stormwater accumulates during a storm event. **Orifice Structure/ Outlet Drain Pipe** restricts the flow out of the detention chamber, allowing it to fill up and slowly drain out. The orifice structure is located at the downstream end of the detention chamber. Underground facilities shall be inspected quarterly and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Drain Inlet Pipes shall be inspected for clogging or leaks where it enters the vault or basin during every inspection and cleanout.

- Debris/sediment that is found to clog the inlet shall be removed, tested, and disposed of in accordance with applicable federal and state requirements.

Detention Chamber shall be inspected for cracks or damage during each inspection.

- The detention chamber shall be cleaned out yearly or after an inch of sediment has accumulated. If there is a valve on the outlet pipe it shall be closed otherwise the outlet shall be plugged prior to cleanout. Grit and sediment that has settled to the bottom of the chamber shall be removed during each cleaning.
- Water and sediment in the detention chamber shall be removed, tested, and disposed of in accordance with regulations.
- Cleaning shall be done without use of detergents or surfactants. A pressure washer may be used if necessary.

Orifice Structure/ Outlet Drain Pipe shall be inspected for clogging during unit inspections/cleanouts.

- Debris/sediment that is found to clog the inlet shall be removed, tested, and disposed of in accordance with applicable federal and state requirements.

Vegetation such as trees should not be located in or around the detention facility because roots from trees can penetrate the unit body, and leaves from deciduous trees and shrubs can increase the risk of clogging the intake pipe.

- Large shrubs or trees that are likely to interfere with detention facility operation shall be identified at each inspection then removed.

Source Control measures typically include structural and non-structural controls. Non-structural controls can include street sweeping and other good house keeping practices. It is often easier to prevent pollutants from entering stormwater than to remove them.

- Source control measures shall be inspected and maintained (where applicable).

Spill Prevention procedures require high-risk site users to reduce the risk of spills. However, virtually all sites, including residential and commercial, present dangers from spills. Homes contain a wide variety of toxic materials including gasoline for lawn mowers, antifreeze for cars, nail polish remover, pesticides, and cleaning aids that can adversely affect storm water if spilled. It is important for everyone to exercise caution when handling substances that can contaminate stormwater. Spill prevention procedures shall be implemented in areas where there is likelihood of spills from hazardous materials.

Training and/or written guidance information for operating and maintaining detention facilities shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the detention facility is required for efficient maintenance.
Egress and ingress routes shall be open and maintained to design standards.

Signage may serve to educate people about the importance or function of the site's stormwater protection measures. Signs may also discourage behavior that adversely impacts the stormwater protection measures and encourages behavior that enhances or preserves stormwater quality. If debris is a problem, a sign reminding people not to litter may partially solve the problem.
Signage (where applicable) will be maintained and repaired as needed during or shortly after inspections.

Insects & Rodents shall not be harbored in the detention facility. Pest control measures shall be taken when insects/rodents are found to be present.

- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the detention facility shall be filled.

Drywells

Operations & Maintenance Plan

Drywells are designed to infiltrate stormwater into the ground. Stormwater is piped to drywells from roof downspouts or pollution control facilities such as swales or planters. The pollution control facility is designed to settle out sediments and separate oils and greases from the water before releasing it through a pipe to the drywell. This prolongs the life of the drywell and helps to prevent the contamination of soils and groundwater. The drywell is a concrete or plastic manhole section with many small holes in the sides to allow stormwater to infiltrate into the surrounding soil. The drywell system shall be inspected and cleaned quarterly and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

Stormwater Drain Pipe shall be inspected for clogging or leaks where it enters the drywell.

- Debris/sediment that is found to clog the pipe shall be removed and disposed of in accordance with applicable federal and state requirements.

Drywell shall be inspected during each cleanout. Ponding around the catch basins or sedimentation manhole or drywell lids may indicate that the drywell is failing due to siltation, or the clogging of the sediment pores surrounding the drywell. Clogged drywells must be replaced.

Vegetation such as trees should not be located in or around the drywell because roots from trees can penetrate the unit body, and leaves from deciduous trees and shrubs can increase the risk of clogging the intake pipe.

- Large shrubs or trees that are likely to interfere with operation will be identified at each inspection and removed.

Source Control measures typically include structural and non-structural controls. Non-structural controls can include parking lot or street sweeping and other good house keeping practices. It is often easier to prevent pollutants from entering stormwater than to remove them.

- Source control measures shall be inspected and maintained (where applicable).

Spill Prevention procedures require high-risk site users to reduce the risk of spills. However, virtually all sites, including residential and commercial, present dangers from spills. Homes contain a wide variety of toxic materials including gasoline for lawn mowers, antifreeze for cars, solvents, pesticides, and cleaning aids that can adversely affect storm water if spilled. It is important to exercise caution when handling substances that can contaminate stormwater.
Spill prevention procedures shall be implemented in areas where there is likelihood of spills from hazardous materials.

A **Shut-Off Valve or Flow-Blocking Mechanism** may have been required with the construction of the drywell to temporarily prevent stormwater from flowing into it, in the event of an accidental toxic material spill. This may also involve mats kept on-site that can be used to cover inlet drains in parking lots. The shut-off valve shall remain in good working order, or if mats or other flow-blocking mechanisms are used, they shall be kept in stock on-site.

Training and/or written guidance information for operating and maintaining drywell systems shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the drywell is required for efficient maintenance. Egress and ingress routes shall be open and maintained to design standards.

Insects & Rodents shall not be harbored in the drywell. Pest control measures shall be taken when insects/rodents are found to be present.

- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the drywell shall be filled.

Signage may serve to educate people about the importance or function of the site's stormwater protection measures. Signs may also discourage behavior that adversely impacts the stormwater protection measures and encourages behavior that enhances or preserves stormwater quality. If debris is a problem, a sign reminding people not to litter may partially solve the problem.
Signage (where applicable) shall be maintained and repaired as needed during or shortly after inspections.

Spill Control Manholes

Operations & Maintenance Plan

Spill Control Manholes operate using the principal that oil and water are immiscible (do not mix) and have different densities. Oil, being less dense than water, floats to the surface. The spill control manhole shall be inspected and cleaned quarterly. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:

- **Stormwater Drain Inlet Pipe** shall be inspected for clogging or leaks where it enters the manhole during every inspection and cleanout. Debris/sediment that is found to clog the inlet shall be removed, tested, and disposed of in accordance with applicable federal and state requirements.

Manhole Chamber shall be inspected for cracks or damage during each inspection.

- The manhole shall be cleaned out quarterly. Cleanout shall be done in a manner to minimize the amount of trapped oil entering the outlet pipe. If there is a valve on the outlet pipe it shall be closed otherwise the outlet will be plugged prior to cleanout.
- Water and oil shall be removed, tested, and disposed of in accordance with regulations. Grit and sediment that has settled to the bottom of the chamber shall be removed during each cleaning
- Cleaning shall be done without use of detergents or surfactants. A pressure washer may be used if necessary.

Absorbent Pillows and Pads (where applicable) absorb oil from the separation chamber.

- Replacement shall occur at least twice a year, in the spring and fall, or as necessary to retain oil-absorbing function.

Stormwater Drain Outlet Pipe shall be inspected for clogging or leaks where it exits the manhole. Particular attention shall be paid to ensure that the joint where the tee joins the outlet pipe is watertight.

- Debris/sediment that is found to clog the outlet shall be removed, tested, and disposed of in accordance with applicable federal and state requirements.

Vegetation such as trees should not be located in or around the spill control manhole because roots can penetrate the unit body, and leaves from deciduous trees and shrubs can increase the risk of clogging.

- Large shrubs or trees that are likely to interfere with manhole operation shall be identified at each inspection and removed.

Source Control measures typically include structural and non-structural controls. Non-structural controls can include street sweeping and other good house keeping practices.

- Source control measures shall be inspected and maintained.

Spill Prevention procedures require high-risk site users to reduce the risk of spills. However, virtually all sites, including residential and commercial, present dangers from spills. Homes contain a wide variety of toxic materials including gasoline for lawn mowers, antifreeze for cars, nail polish remover, pesticides, and cleaning aids that can adversely affect storm water if spilled. It is important to exercise caution when handling substances that can contaminate stormwater.
Spill prevention procedures shall be implemented in areas where there is likelihood of spills from hazardous materials.

Training and/or written guidance information for operating and maintaining spill control manholes shall be provided to all property owners and tenants. A copy of the O&M Plan shall be provided to all property owners and tenants.

Access to the spill control manhole is required for efficient maintenance. Egress and ingress routes shall be open and maintained to design standards.

Insects & Rodents shall not be harbored in the spill control manhole. Pest control measures shall be taken when insects/rodents are found to be present.

- If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor.
- Holes in the ground located in and around the manhole shall be filled.

Signage may serve to educate people about the importance or function of the site's stormwater protection measures. Signage (where applicable) shall be maintained and repaired as needed during or shortly after inspections.

New Evergreen and Deciduous Trees Operations & Maintenance Plan
Trees intercept rainfall and therefore provide a level of pollution reduction and flow control. They also provide shade, helping to cool stormwater runoff. Trees used to meet stormwater management requirements shall be kept on a site and maintained properly to ensure continued stormwater benefits. Trees shall be inspected 2 times a year and within 48 hours of a major wind or storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items shall be inspected and maintained as stated:
Leaves and Debris from the tree shall be regularly raked and disposed of. • Fallen leaves and debris from deciduous plant foliage shall be raked and removed. • Poisonous and nuisance vegetation around the tree shall be removed when discovered. • Dead vegetation shall be pruned from the tree on a regular basis.
Irrigation shall be implemented during the establishment period to ensure tree survival. Hand watering is preferred, but a drip-irrigation system may be used.
Protection of the tree trunk and roots shall ensure tree survival. Care should be taken when digging near tree roots.
Replacement of dead trees shall be with a comparable species if it dies or must be removed for any another reason. The replacement tree shall be a minimum of 6' tall.
Insects & Rodents shall not be harbored in or around the trees. Pest control measures shall be taken when insects/rodents are found to be present. • If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor. • Holes in the ground located in and around the trees shall be filled.

Chapter 4.0
SOURCE CONTROLS

Summary of Chapter 4.0

This chapter presents storm and sanitary source controls required for site uses and characteristics that generate, or have the potential to generate, specific pollutants of concern.

4.1 Introduction and Applicability
4.2 Fuel Dispensing Facilities and Surrounding Traffic Areas
4.3 Above-Ground Storage of Liquid Materials
4.4 Solid Waste Storage Areas, Containers, and Trash Compactors
4.5 Exterior Storage of Bulk Materials
4.6 Material Transfer Areas/ Loading Docks
4.7 Equipment and/or Vehicle Washing Facilities
4.8 Stormwater and Groundwater Management For Development On Land With Suspected or Known Contamination
4.9 Covered Vehicle Parking Areas
4.10 Forms and Reference Materials:

Signage Examples
Source Control Installations Form
Special Requests Form

To Use This Chapter:

1) Determine if the project has any of the characteristics or site uses listed in **Section 4.1.1**.
2) If so, go to the applicable section for that characteristic or site use and follow the requirements to design source controls for the project.
3) The site use may require a **Source Control Installations and/or a Special Requests form** to be submitted with the permit application.

4.1 INTRODUCTION AND APPLICABILITY

Some site characteristics and uses may generate specific pollutants of concern or levels of pollution that are not addressed solely through implementation of the pollution reduction measures identified in Chapter 2.0. The site characteristics and uses in this chapter have been identified as potential sources for chronic loadings or acute releases of pollutants such as oil and grease, toxic hydrocarbons, heavy metals, toxic compounds, solvents, abnormal pH levels, nutrients, organics, bacteria, chemicals, and

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suspended solids. This chapter presents source controls for managing these pollutants at their source.

Stormwater discharge benchmarks for pollutants exist in NPDES industrial stormwater general permits issued by the State of Oregon for facilities with industrial activities that are exposed to rainfall and stormwater runoff. The state also has water quality standards listed in Oregon Administrative Rules (OAR) 340 Division 041 for discharges to surface waters.

City Code 17.39 lists prohibited discharges to the City's storm sewer system. The City used the state standards and industrial stormwater NPDES benchmarks in developing the manual's listed source controls so stormwater discharges can better meet those criteria. Section 4.1.1 lists the site uses and characteristics that are subject to the requirements of this chapter and will therefore be subject to BES Source Control review. Sections 4.2 through 4.9 then provide detailed information about the required source controls.

These source controls apply to all projects with the defined uses or characteristics listed in Section 4.1.1 including: new development, redevelopment, tenant improvements or those existing sites proposing new off-site discharges. With tenant improvements, only those areas of a structure or activity area that are being disturbed under the permit are required to make the structural changes identified in this chapter. With new off-site discharges only those proposed areas draining off-site will be subject to these regulations.

The requirements of this chapter are in addition to the applicable destination/disposal, pollution reduction, and flow control requirements identified in Chapter 1.0. Development sites discharging to combined sewers are required to provide pollution reduction and flow control for stormwater in accordance with the standards outlined in **Chapter 1.0**, and on-site storm and sanitary flows shall remain separated until the connection point off-site.

For all structural source controls, a **Source Control Installations Form**, located at the end of this chapter, shall be submitted as part of the building permit application packet. Applicants may propose alternatives to the source controls identified in this chapter. In that case, the applicant shall complete the **Special Requests Form**, located at the end of this chapter. Proposal of an alternative source control or alternative design element will require an additional review process and may delay issuance of related building or public works permits.

Note: Developments citing special circumstances (see **Chapter 1.0, Section 1.11**) are not exempt from the source control requirements of this chapter.

4.1.1 Site Uses and Characteristics That Trigger Source Controls

Projects with the following site uses and characteristics are subject to the requirements of this chapter:

- Fuel Dispensing Facilities and Surrounding Traffic Areas (**Section 4.2**)
- Above-Ground Storage of Liquid Materials (**Section 4.3**)
- Solid Waste Storage Areas, Containers, and Trash Compactors (**Section 4.4**)
- Exterior Storage of Bulk Materials (**Section 4.5**)
- Material Transfer Areas/Loading Docks (**Section 4.6**)
- Equipment and/or Vehicle Washing Facilities (**Section 4.7**)
- Stormwater and Groundwater Management For Development On Land With Suspected or Known Contamination (**Section 4.8**)
- Covered Vehicle Parking Areas (**Section 4.9**)

Detailed descriptions of these site uses and characteristics can be found in each applicable section. Definitions of terms used in Sections 4.2 through 4.9 are provided in **Section 1.3**.

Applicants are required to address all of the site characteristics and uses listed in Sections 4.2 through 4.9. For example, if a development includes both a fuel dispensing area and a vehicle washing facility, the source controls in both Sections 4.2 and 4.7 will apply.

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4.1.2 Goals and Objectives for Source Control

The specific source control requirements are based on the following goals and objectives:

1) Prevent stormwater pollution by eliminating pathways that may introduce pollutants into stormwater.

2) Protect soil, groundwater, and surface water by capturing acute releases and reducing chronic contamination of the environment.

3) Segregate stormwater and wastewater flows to minimize additions to the sanitary and combined sewer systems.

4) Direct wastewater discharges and areas with the potential for relatively consistent wastewater discharges (such as vehicle washing facilities) to the sanitary or combined sewer system.

5) Direct areas that have the potential for acute releases or accidental spills, and are not expected to regularly receive flow or require water use (such as covered fuel islands or covered containment areas) to an approved method of containment or disposal.

6) Safely contain spills on-site, avoiding preventable discharges to sanitary or combined sewers, surface water bodies, or underground injection control structures (UICs).

7) Emphasize structural controls over operational procedures. Structural controls are not operator dependent and are considered to provide more permanent and reliable source control. Any proposals for operation-based source controls need to describe the long-term viability of the maintenance program.

4.1.3 Signage Requirements

Informational signage is required for some site uses and activities that have the potential to contaminate stormwater. Signage addresses good housekeeping rules and provides emergency response measures in case of an accidental spill.

All signage shall conform to the requirements described in the following box. Signage requirements for specific activities are noted in applicable sections, and spill signage examples can be found at the end of this chapter.

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Signs shall be located and plainly visible from all activity areas. More than one sign may be needed to accommodate larger activity areas. Signs shall be water-resistant. They shall include the following information:

- Safety precautions
- Immediate spill response procedures—for example: "Turn the valve located at..." or "Use absorbent materials"
- Emergency contact(s) and telephone number(s)—for example: "Call 911" and "City of Portland (BES) Spill Response Number 503-823-7180"

Signs may need to be in more than one language if required to effectively communicate with employees and delivery personnel.

Any applicable spill response supplies need to be clearly marked and located where the signage is posted and near the high-risk activity area. More than one spill response kit may be necessary to accommodate larger activity areas.

4.1.4 Request for Alternative Method of Source Control

Applicants may request an alternative method of source control by notifying BES's Source Control Division in writing, specifying the reason for the request and supporting it with technical and factual data. The **Special Requests Form**, located at the end of this chapter, shall be used to request the alternative. All requests shall be given directly to the BES Source Control plans examiner reviewing the plans.

The BES Source Control plans examiner will check the submitted form and supporting information for completeness and forward the request to his or her supervisor for review and decision. The applicant should expect to be contacted within five (5) working days, unless additional documentation is needed.

If the request cannot be satisfied with this process, the tier one appeal process as described in **Appendix A** may be implemented by the applicant.

4.1.5 Additional Requirements

Conformance with this chapter's requirements does not relieve the applicant of other applicable local, state, or federal regulatory or permit requirements. This chapter is intended to complement any additional requirements, and is not expected to conflict with, exclude, or replace those requirements. In case of a conflict, the most stringent local, state, or federal regulations generally apply. Any conflict will be resolved by a

City review representative in consultation with appropriate agencies. Some of the more common additional requirements that may apply are summarized below.

SPILL RESPONSE SUPPLIES

The City expects spill response supplies, such as absorbent material and protective clothing, to be available at all potential spill areas. Employees should be familiar with the site's operations and maintenance plan and/or proper spill cleanup procedures.

STORMWATER AND WASTEWATER DISCHARGE PERMITS

Some facilities may be required to obtain a State of Oregon NPDES industrial stormwater permit before discharging to the City's separated storm sewer system or to waters of the state. Applicants may also be required to obtain an industrial wastewater permit for discharges to the sanitary sewer system. Facilities subject to these requirements are generally commercial or industrial. Typical discharges include process wastewater, cooling water, or other discharges generated by some of the sources in this chapter that drain to a City sewer system (storm, sanitary, or combined). (Contact BES's Industrial Source Control Division at 503-823-7122 for a list of current sanitary sewer discharge limits.)

An evaluation will be done during the building permit review process to determine if an industrial discharge permit is required. If a permit is required, the industrial permit application process will be independent of the building permit review/issuance process. However, building permit applications may have to be revised to accommodate industrial permitting compliance requirements (e.g., sampling points, pretreatment facilities). Please note that if industrial permitting is not applicable at the time of building permit submittal, changes in regulations could trigger industrial permitting requirements in the future.

OREGON DEQ UNDERGROUND INJECTION CONTROL (UIC) REGULATIONS

The Oregon Department of Environmental Quality (DEQ) identifies drywells, sumps, and piped soakage trenches as "Class V Injection Wells" under the federal Underground Injection Control (UIC) Program. Because the UIC Program states that these types of wells may have a direct impact on groundwater, registration or permitting with DEQ is required. Site uses that are classified as high risk under this chapter are generally not allowed to use UICs for stormwater disposal. See **Section 1.4.4** for additional information.

Additional City of Portland and DEQ permit requirements may apply. Contact BES's Industrial Source Control Division at 503-823-7122 for additional information about

stormwater or wastewater discharges to City-owned sanitary, stormwater, or combined sewer systems.

COLUMBIA SOUTH SHORE WELLHEAD PROTECTION PROGRAM

Storage, use, and transportation of hazardous/toxic materials in designated groundwater resource protection areas are regulated under the Water Bureau's *Columbia South Shore Well Field Wellhead Protection Area Reference Manual* (June 25, 2003).

OTHER LOCAL, STATE, AND FEDERAL REGULATIONS

The requirements presented in this chapter do not exclude or replace the requirements of other applicable codes or regulations, such as the hazardous substances storage requirements of articles 79 and 80 of the Oregon State Fire Code; the spill prevention control and containment (SPCC) regulations of 40 CFR 112 (EPA); the Resource Conservation and Recovery Act (RCRA); or any other applicable local, state, or federal regulations or permit requirements.

4.2 FUEL DISPENSING FACILITIES AND SURROUNDING TRAFFIC AREAS

4.2.1 Applicability

The requirements in this section apply to all development where vehicles, equipment, or tanks are refueled on the premises; whether a large-sized gas station, a single-pump maintenance yard, or a small-sized fuel tank. A fuel dispensing facility is defined as the area where fuel is transferred from bulk storage tanks to vehicles, equipment, and/or mobile containers (including fuel islands, above- or below-ground fuel tanks, fuel pumps, and the surrounding pad). Propane tanks are exempt from these requirements.

4.2.2 Requirements

1) COVER

The fuel dispensing area shall be covered with a permanent canopy, roof, or awning so precipitation cannot come in contact with the fueling activity area. Rainfall shall be directed from the cover to a stormwater disposal point that meets all applicable code requirements.

- **Covers 10 feet high or less** shall have a minimum overhang of 3 feet on each side. The overhang shall be measured relative to the perimeter of the hydraulically isolated fueling activity area it is to cover.

- **Covers higher than 10 feet** shall have a minimum overhang of 5 feet on each side. The overhang shall be measured relative to the perimeter of the hydraulically isolated fueling activity area it is to cover.

2) PAVEMENT

A paved fueling pad of asphalt or concrete shall be placed under and around the fueling activity area and shall meet all applicable building code requirements. Sizing of the paved area shall be adequate to cover the activity area, including placement and number of the vehicles or pieces of equipment to be fueled by each pump. Fuel pumps shall be located a minimum of 7 feet from the edge of the fueling pad.

3) DRAINAGE

The paved area beneath the cover shall be hydraulically isolated through grading, berms, or drains. This will prevent uncontaminated stormwater from running onto the area and carrying pollutants away. Drainage from the hydraulically isolated area shall be directed to an approved City sanitary sewer or authorized pretreatment facility.

Surrounding runoff shall be directed away from the hydraulically isolated fueling pad to a stormwater disposal point that meets all stormwater management requirements of this manual and other applicable code requirements.

4) SIGNAGE

Signage shall be provided at the fuel dispensing area and shall be plainly visible from all fueling activity areas. Detailed signage information is located in **Section 4.1.3**.

5) SPILL CONTROL MANHOLE

A spill control manhole shall be installed on the discharge line of the fueling pad (before the domestic waste line tie-in). The tee section shall extend 18 inches below the outlet elevation, and 60 cubic feet of dead storage volume shall be provided below the outlet elevation for storage of oil, grease, and solids. The manhole shall be located on private property. For more information about spill control manholes, see **Exhibit 2-26**.

6) SHUT-OFF VALVES

Shut off valves are required to protect City sewer systems or onsite infiltration facilities from spill risks from chemicals and other constituents that provide a danger for widespread contamination, system damages, or risk to the public health.

A) **Shut-off valves** are required for any of the following situations:

- Site or activity areas are exposed to corrosives or oxidizers that can harm conveyance system components (such as, but not limited to, battery acid).
- Substances (such as, but not limited to, oil and grease) that do not settle or remain in one location, and are capable of being dissolved in or float on water. These substances can spread rapidly into downstream conveyance and disposal systems, causing widespread impacts and difficult cleanup situations.
- Substances that are known to infiltrate through soils and contaminate groundwater.

B) **Traffic pathways that surround fueling pads are considered high-use/high-risk areas and will require a valve on the storm drainage system.** Valves installed on storm drainage systems shall be installed downstream of all applicable private stormwater quality facilities to accommodate spill containment. These valves shall be left open to facilitate stormwater flows during normal conditions, and immediately closed in the event of a spill.

C) **Fueling pads require a valve downstream of the spill control manhole.** Valves installed on sanitary sewer systems shall be installed before the domestic waste line tie-in. These valves shall be kept closed, and opened only to allow incidental drainage activities that do not pose a threat or risk to the disposal point system. The valve shall be closed immediately after drainage activities are completed.

Shut-off valves shall be located on private property and downstream of the exposed area's collection system. All valves shall be installed and maintained as per manufacturers recommendations. For more information about shut-off valves and associated valve boxes, contact the City's Commercial Plumbing Department at 503-823-7302.

7) ADDITIONAL REQUIREMENTS

A) A **Source Control Installations Form**, located in Section 4.10, shall be submitted as part of the building permit application to facilitate tracking of spill control manhole and shut-off valve installations.

B) **Installation, alterations, or removal of above-ground fuel tanks larger than 55 gallons, and any related equipment,** are subject to additional permitting requirements by the Portland Fire Marshall's Office. For technical questions and permitting, call the Fire Marshall's Office Permit Center at 503-823-3712, or visit the center at 1300 SE Gideon, Portland, Oregon 97202.

C) **Bulk fuel terminals, also known as tank farms,** require the following:

- Secondary containment equal to 110 percent of the product's largest container or 10 percent of the total volume of product stored, whichever is larger.

- A separate containment area for all valves, pumps, and coupling areas, with sub-bermed areas either in front of or inside the main containment areas. These sub-bermed areas shall have rain shields and be directed to a City sanitary sewer system for disposal. If no City sanitary sewer is available, drainage shall be directed to a temporary holding facility for proper disposal and may require a water pollution control facility (WPCF) permit from the Water Quality Division of DEQ.

- An impervious floor within all containment areas. Floors shall be sealed to prevent spills from contaminating the groundwater.

- Truck loading and off-loading areas. These areas shall follow cover, pavement, drainage, spill control, and shut-off valve requirements identified for fuel dispensing facilities.

- Shut-off valves installed for the drainage of the tank yard. The valves shall be installed downstream of the drainage system of the primary containment area and kept closed. Valves installed for the drainage of the truck pad and sub-bermed containment areas shall be installed on the sanitary waste line downstream of the spill control manhole.

- A batch discharge authorization before draining a containment area. This authorization will determine appropriate disposal methods, identify pretreatment requirements (if applicable), and authorize the discharge. Pretreatment may be required for oil and grease removal, and testing may be required to establish the specific characteristics of the discharge.

D) **Underground fuel tanks** less than 4,000 gallons in size are subject to additional permitting requirements by DEQ, and tanks larger than 4,000 gallons are referred to the federal Environmental Protection Agency (EPA). For technical questions and permitting, call DEQ's Northwest Region main office at 503-229-5263 and ask for the Underground Storage Tank Permitting Department.

8) EXCEPTIONS

A) **The requirement to cover the fuel dispensing area** can be appealed if the fuel dispensing area is generally used to service oversized equipment (e.g., cranes) that cannot maneuver under a roof or canopy. A **Special Requests form**, located in Section 4.10, shall be submitted as part of the building permit application to evaluate exception qualifications.

B) **Propane tanks** are exempt from the requirements of this section.

C) **Existing fueling areas** are not required to install source controls identified in this section if the scope of work is limited to the following:

1. A new canopy installation over an existing fuel pad that is not being upgraded.
2. An underground tank replacement for compliance with state regulations.
3. The replacement of a fuel pump on an existing fuel pad that is not being upgraded.

If any improvements are made to the fueling activity area and/or pad, such as regrading or surface replacement, retrofits are required to comply with all fueling activity source controls identified in this chapter.

4.3 ABOVE-GROUND STORAGE OF LIQUID MATERIALS

4.3.1 Applicability

The requirements in this section apply to all development where there is any exterior storage of liquid chemicals, food products, waste oils, solvents, process wastewaters, or petroleum products in above-ground containers, in quantities of 50 gallons or more. This includes both permanent storage and temporary storage areas. Underground storage tanks or installations requiring a water pollution control facility (WPCF) permit are exempt from these requirements, but must go through DEQ's WPCF permit process.

4.3.2 Requirements

1) CONTAINMENT

Liquid materials shall be stored and contained in such a manner that if the container(s) is ruptured, the contents will not discharge, flow, or be washed into a receiving system. A containment device and/or structure for accidental spills shall have enough capacity to capture a minimum of 110 percent of the product's largest container or 10 percent of the total volume of product stored, whichever is larger.

Double-walled containers are generally exempt from these spill containment requirements.

Quantity thresholds of products that are generally exempt from these spill containment measures are:

- Janitorial and cleaning supplies of less than 100 pounds net weight or 15 gallons net volume. These supplies shall be packaged for consumer use in containers of five gallons or less or having a net weight of less than 30 pounds per container. This does not include cleaners or solvents used for cleaning machinery or motor vehicle and machine parts.

- Office and stationary supplies less than 100 pounds net weight. These supplies shall be packaged for consumer use in containers sized less than 5 gallons in size or 30 pounds in weight.

2) COVER

Storage containers (other than tanks) shall be completely covered so rainfall cannot come in contact with them. Runoff shall be directed from the cover to a stormwater disposal point that meets all applicable code requirements.

- **Covers 10 feet high or less** shall have a minimum overhang of 3 feet on each side. The overhang shall be measured relative to the perimeter of the hydraulically isolated activity area.

- **Covers higher than 10 feet** shall have a minimum overhang of 5 feet on each side. The overhang shall be measured relative to the perimeter of the hydraulically isolated activity area.

3) PAVEMENT

A paved storage area is required unless otherwise approved by BES's Industrial Source Control Division staff. The storage area shall be paved with asphalt or concrete and shall meet all applicable building code requirements. Sizing of the paved areas shall be adequate to cover the area intended for storage. The applicant shall clearly identify any requested alternative method by submitting a **Special Requests Form**, located at the end of this chapter.

4) DRAINAGE

All paved storage areas shall be hydraulically isolated through grading, berms, or drains to prevent uncontaminated stormwater run-on to a storage area.

Covered storage areas: Significant amounts of precipitation are not expected to accumulate in covered storage areas, and drainage facilities are not required for the contained area beneath the cover. If the applicant elects to install drainage facilities, the drainage from the hydraulically isolated area shall be directed to an approved City sanitary sewer or authorized pretreatment facility.

Uncovered storage areas with containment: Water will accumulate in uncovered storage areas during and after rain. Any *contaminated* water cannot simply be drained from the area. It must be collected, inspected, and possibly tested at the expense of the property owner before proper disposal can be determined. Frequent draining may be required during the wet season, which may prove costly. Some type of monitoring may also be needed to determine the characteristics and level of contamination of the stormwater.

All discharges to the sanitary sewer shall be considered batch discharges and shall require approval and pretreatment prior to discharge. Pretreatment requirements shall be set as part of the discharge approval process, based on the types and quantities of material to be discharged. A discharge evaluation shall be performed before connection to a sanitary sewer. Testing may be required to establish characteristics of the wastewater or contaminated stormwater and to verify that local discharge limits are not exceeded. For batch discharge applications, call BES's Industrial Source Control Division at 503-823-5320.

5) SIGNAGE

Signage shall be provided at the liquid storage area and shall be plainly visible from all surrounding activity areas. Detailed information is located in **Section 4.1.3.**

6) ADDITIONAL REQUIREMENTS

A) A **Source Control Installations Form**, located in Section 4.10, shall be submitted as part of the building permit application to facilitate tracking of containment and shut-off valve installations.

B) **Covered storage areas:** A shut-off valve may be required for the covered storage area if the applicant elects to install drainage facilities to an approved City sanitary sewer. BES will make this determination based on the type of material stored and the proposed system receiving the discharge.

Uncovered storage areas: A shut-off valve shall be installed in the storage area so excess stormwater can be drained out of the activity area and directed either to the storm drainage facilities (*if clean*) or into the City sanitary sewer or authorized pretreatment facility (*if contaminated*). Except when excess stormwater is being discharged, the valve shall always be kept closed so any spills within the activity area can be effectively contained.

C) **Storage of hazardous materials** located in designated groundwater resource protection areas is subject to additional requirements, as identified in the Water Bureau's *Columbia South Shore Well Field Wellhead Protection Area Reference Manual* (June 25, 2003).

D) **Tank farms** shall follow the criteria established for bulk fuel terminals in **Section 4.2**. Exceptions may be granted, based on the product being stored. Requests for an exception will require an additional review process and may delay issuance of related building permits.

E) **Storage of reactive, ignitable, or flammable liquids** shall comply with the Uniform Fire Code as adopted by the State of Oregon. Source controls presented in this section are intended to complement, not conflict with, current fire code requirements. None of these requirements shall exclude or supersede any other requirements in this manual, other City permit requirements, or state and federal laws pertaining to water quality. Contact the Portland Fire Bureau (503-823-7366) and/or BES's Industrial Source Control Division (503-823-7122) for further information and requirements.

4.4 SOLID WASTE STORAGE AREAS, CONTAINERS, AND TRASH COMPACTORS

4.4.1 Applicability

The requirements in this section apply to all commercial and industrial development with facilities that store solid wastes (both food and non-food wastes). A solid waste storage area is a place where solid waste containers are collectively stored. Solid waste containers include compactors, dumpsters, and garbage cans. Requirements of this section also apply to activity areas used to collect and store refuse or recyclable materials, such as can or bottle return stations and debris collection areas.

This section applies to multi-family residential sites of three or more units if a shared trash collection area is proposed. However, the requirements of this section do not apply to single-family homes or debris collection areas used for the temporary storage of wood pallets or cardboard.

4.4.2 Requirements

The following design requirements apply for approval of solid waste storage and handling activity areas in the City of Portland. The text below clarifies each requirement.

ACTIVITY/ USE	REQUIREMENTS			
	(1) Cover	(2) Pavement	(3) Isolation	(4) Drainage
Multi-family (with shared trash areas)	X	X	X	X*
Commercial	X	X	X	X
Industrial	X	X	X	X
Compactors (regardless of use)		X	X	X
Can and bottle return stations	X	X	X	X

* If gravity service to the sanitary sewer lines cannot be obtained, a special request can be made to direct the drainage from the hydraulically isolated activity area to the development's stormwater pollution reduction facility. This applies only to multi-family uses. For more information, refer to **Additional Requirements** below.

1) COVER

A permanent canopy, roof, or awning shall be provided to cover the solid waste storage activity area and shall be constructed to cover the activity area so rainfall cannot come in contact with the waste materials being stored. The cover shall be sized relative to the

perimeter of the hydraulically isolated activity area it is to cover. Runoff shall be directed from the cover to a stormwater disposal point that meets all applicable code requirements.

2) PAVEMENT

A paved waste storage area is required when a structural cover or trash compactor is used. The area shall be paved with asphalt or concrete and meet all applicable building code requirements. Sizing of the paved area shall adequately cover the activity area intended for refuse storage, or the trash compactor(s) and associated equipment.

3) ISOLATION

Hydraulic isolation shall be provided for the solid waste storage activity area and shall be designed to prevent uncontaminated stormwater runoff from entering the area and carrying pollutants away. Runoff occurring outside the hydraulically isolated area shall be directed to a stormwater disposal point that meets all applicable code requirements. This can be achieved by reverse grading at the perimeter of an activity area, perimeter curbing or berming, or the use of area drains to collect and divert runoff.

4) DRAINAGE

Drainage shall be provided for the hydraulically isolated solid waste storage area and directed to an approved city sanitary sewer or authorized pretreatment facility. A sanitary sewer drain is required for those areas that may be subject to refuse or suspected pollutants that pose a risk if the structural integrity of the trash receptacle is damaged or if its contents are exposed to rainfall.

Non-gravity Option
Activity areas that do not have gravity sanitary sewer service may be allowed to install a pressurized system. With these types of installations, the following items shall e provided at the time of building permit application:

1) Verification or evidence that gravity service cannot be obtained.
2) Details of an electronic sump pump system equipped with a float switch.
3) A completed Discharge Authorization (DAR) form.

Pressurized system installations are considered "permanent equipment" and deemed the property owner's liability in the event of system failure or if the property becomes vacated.

The Bureau of Development Services (BDS) Commercial Plumbing Division will review all sump pump or sewage ejector installations for compliance with the Uniform Plumbing Code and Oregon State Plumbing Specialty Code. The BES Source Control Division will review for compliance with this chapter of the *Stormwater Management Manual.*

5) ADDITIONAL REQUIREMENTS

Multi-family developments with shared trash areas may be allowed an alternative to the sanitary drain for the hydraulically isolated solid waste storage area. This activity area may be allowed to drain to the site's privately owned and operated stormwater pollution reduction facility if gravity service to the sanitary sewer pipe of the development cannot be obtained. For the alternative to be considered, information showing that gravity service cannot be obtained and a completed **Special Requests Form** shall be submitted. All other requirements previously outlined for multi-family uses shall apply.

4.5 EXTERIOR STORAGE OF BULK MATERIALS

4.5.1 Applicability

The requirements of this section apply to developments that stockpile or store materials in outdoor containers that may erode or have negative stormwater impacts. The materials are separated into three categories, based on risk assessments for each material stored: high-risk, low-risk, and exempt. These include, but are not limited to, the following general types of materials:

High-Risk Materials	Low-Risk Materials	Exempt Materials
• Recycling materials with potential effluent • Corrosive materials (e.g., lead-acid batteries) • Storage and processing of food items • Chalk/gypsum products • Feedstock/grain • Material by-products with potential effluent • Fertilizer • Pesticides • Lime/lye/soda ash • Animal/human wastes	• Recycling materials without potential effluent • Scrap or salvage goods • Metal • Sawdust/bark chips • Sand/dirt/soil (including contaminated soil piles) • Material by-products without potential effluent • Unwashed gravel/rock • Compost • Asphalt	• Washed gravel/rock • Finished lumber • Rubber and plastic products (hoses, gaskets, pipe, etc.) • Clean concrete products (blocks, pipe, etc.) • Glass products (new, non-recycled) • Inert products

Materials with any of the following characteristics are exempt from the requirements of this section:

- Have no measurable solubility or mobility in water and no hazardous, toxic, or flammable properties.

- Exist in a gaseous form at ambient temperature.

- Are contained in a manner that prevents contact with stormwater (excluding pesticides and fertilizers).

4.5.2 Requirements

1) COVER

Low-risk materials shall be covered with a temporary plastic film or sheeting at a minimum.

High-risk materials shall be permanently covered with a canopy or roof to prevent stormwater contact and minimize the quantity of rainfall entering the storage area. Runoff shall be directed from the cover to a stormwater disposal point that meets all applicable code requirements.

- **Covers 10 feet high or less** shall have a minimum overhang of 3 feet on each side. The overhang shall be measured relative to the perimeter of the hydraulically isolated activity area.

- **Covers higher than 10 feet** shall have a minimum overhang of 5 feet on each side. The overhang shall be measured relative to the perimeter of the hydraulically isolated activity area.

2) PAVEMENT

Low-risk material storage areas are not required to be paved.

High-risk material storage areas shall be paved beneath the structural cover. Sizing of the paved area shall adequately cover the activity area intended for storage.

3) DRAINAGE

Low-risk material storage areas are typically allowed in areas served by standard stormwater management systems. However, all erodible materials being stored must be protected from rainfall.

If materials are erodible, a structural containment barrier shall be placed on at least three sides of every stockpile. The barrier shall be tall enough to prevent run-on of uncontaminated stormwater into the storage area and migration of the stored materials as a result of being blown or washed away. If the area under the stockpile is paved, the barrier can be constructed of asphalt berms, concrete curbing, or retaining walls. If the area under the stockpile is unpaved, sunken retaining walls or ecology blocks can be used. The applicant shall clearly identify the method of containment on the building plans.

For **high-risk** material storage areas, the paved area beneath the structural cover shall be hydraulically isolated through grading, structural containment berms or walls, or perimeter drains to prevent uncontaminated stormwater from running onto the area and carrying pollutants away. Significant amounts of precipitation are not expected to accumulate in covered storage areas, and drainage facilities <u>are not required</u> for the

contained area beneath the cover. If the applicant elects to install drainage facilities, the drainage from the hydraulically isolated area shall be directed to an approved City sanitary sewer or authorized pretreatment facility.

4) ADDITIONAL REQUIREMENTS

A) A **Source Control Installations Form**, located in Section 4.10, shall be submitted as part of the building permit application to facilitate tracking of containment, sampling manholes, and shut-off valve installations.

B) **Storage of pesticides and fertilizers** may need to comply with specific regulations outlined by DEQ. For answers to technical questions, call DEQ's Northwest Region main office at 503-229-5263.

C) **A sampling manhole** or other suitable stormwater monitoring access point may be required to monitor stormwater runoff from the storage area. This may apply to certain types of storage activities and materials or if an alternative source control is proposed. This requirement complies with City Code Chapter 17.39.080, which requires appropriate stormwater disposal. BES Source Control staff will review for applicability of this requirement.

D) **Signage** shall be provided at the storage area if hazardous materials or other materials of concern are stored. Signage shall be located so it is plainly visible from all storage activity areas. More than one sign may be needed to accommodate large storage areas. Detailed information and examples are provided in Section 4.1.3.

E) **A shut-off valve** may be required for the structurally covered storage area if the applicant elects to install drainage facilities to an approved City sanitary sewer. BES will make this determination based on the type of material stored and the proposed system receiving the discharge.

F) **Storage of hazardous materials** that are toxic, carcinogenic, or halogenated solvents (within designated groundwater protection areas) are subject to additional requirements, as identified in the Water Bureau's *Columbia South Shore Well Field Wellhead Protection Area Reference Manual* (June 25, 2003).

4.6 MATERIAL TRANSFER AREAS/LOADING DOCKS

4.6.1 Applicability

The requirements in this section apply to all developments proposing the installation of new material transfer areas, or structural alterations to existing material transfer areas (e.g., access ramp regrading, leveler installations).

Two standard types of material transfer areas associated with buildings are:

1) Loading/unloading facilities with docks
2) Large bay doors without docks

The requirements apply to all material transfer areas, including loading/unloading docks, bay doors, and any other building access point(s) with the following characteristics:

- The area is designed (size, width, etc.) to accommodate a truck or trailer being backed up to or into it, and

- The area is expected to be used specifically to receive or distribute materials to and from trucks or trailers.

The requirements may not apply to areas that are used only for mid-sized to small-sized passenger vehicles and that are restricted (by lease agreements or other regulatory requirements) to storing, transporting, or using materials that are classified as domestic use. Examples of domestic uses include primary educational facilities (elementary, middle, or high school), buildings used for temporary storage (a lease agreement will need to be provided), and churches. Contact BES's Industrial Source Control Division at 503-823-7122 for help in determining if requirements apply.

4.6.2 Requirements

1) PAVEMENT

A paved material transfer area of asphalt or concrete shall be placed underneath and around the loading and unloading activity area and shall meet all applicable building code requirements. This will reduce the potential for soil contamination with potential impacts on groundwater, and will help control any acute or chronic release of materials present in these areas.

3) ISOLATION

Loading Docks

The first 3 feet of the paved area, measured from the building or dock face, shall be hydraulically isolated through grading, berms, or drains to prevent uncontaminated stormwater from running onto the area and carrying pollutants away.

Bay Doors and Other Interior Transfer Areas

Bay doors and other interior transfer areas shall be designed so that stormwater runoff does not enter the building. This can be accomplished by grading or drains.

3) DRAINAGE

Loading Docks

Drainage from the hydraulically isolated area shall be directed to an approved City sanitary sewer or authorized pretreatment facility. Surrounding runoff and drainage from the access ramp shall be directed away from the hydraulically isolated area to a stormwater disposal point that meets all applicable requirements of this manual.

Non-Gravity Option

Activity areas that cannot achieve gravity sanitary sewer service may be allowed to install a pressurized system. With these types of installations, the following items shall be provided at the time of building permit application:

1) Proof that gravity sanitary sewer service cannot be obtained.
2) Details of an electronic sump pump system equipped with a float switch.
3) A completed **Source Control Installations Form.**

Pressurized system installations are considered "permanent equipment" and deemed the property owner's liability in the event of system failure or if the property becomes vacated.

The Bureau of Development Services (BDS) Commercial Plumbing Division will review all sump pump or sewage ejector installations for compliance with the Uniform Plumbing Code and Oregon State Plumbing Specialty Code. The BES Source Control Division will review for compliance with this chapter of the *Stormwater Management Manual*.

Bay Doors and Other Interior Transfer Areas

Because interior material transfer areas are not expected to accumulate precipitation, installation of floor drains is not required or recommended. It is preferable to handle these areas with a dry mop or absorbent material. If interior floor drains are installed,

they shall be plumbed to an approved City sanitary sewer or authorized pretreatment facility.

4) SIGNAGE

Signage shall be provided at the material transfer area and shall be plainly visible from all surrounding activity areas. Detailed information and examples are located in **Section 4.1.3.**

5) ADDITIONAL REQUIREMENTS

A) A **Source Control Installations Form**, located at the end of this chapter, shall be submitted as part of the building permit application to facilitate tracking of shut-off valve installations.

B) **Bay doors and other interior transfer areas** shall provide a 10-foot "no obstruction zone" beyond the entrance within the building. This will allow the transfer of materials to occur with the truck or trailer end placed at least 5 feet inside the building, with an additional staging area of 5 feet beyond that. The "no obstruction" zone shall be clearly identified on the building plan at the time of the building permit application, and shall be painted at the facility with a bright or fluorescent floor paint.

C) A **shut-off valve** may be required for the sanitary drainage facilities of the material transfer area. BES will make this determination, based on the type of material being transferred and the proposed system receiving the discharge.

Shut-off valves are required to protect the City sewer system or on-site infiltration facilities from spills of chemicals and other constituents that may provide a danger of widespread contamination, system damage, or risk to public health.

Shut-off valves are required for any of the following situations:

1) Site activity areas that are exposed to corrosives or oxidizers that can harm conveyance system components (such as battery acid).

2) Substances (such as oil and grease) that do not settle or remain in one location, and are capable of being dissolved in or float on top of water. These substances can spread rapidly into downstream systems, causing widespread impacts and difficult clean-up situations.

3) Substances that are known to infiltrate through soils and contaminate groundwater.

Valves located in material transfer areas are typically left open to facilitate drainage during normal conditions, and immediately closed in the event of a spill.

Prior to transfer activities of harmful substances, the valves shall be closed and reopened only after the transfer is complete. The shut-off valves must be located on private property and downstream of the exposed area's collection system.

All valves shall be installed and maintained in accordance with manufacturer specifications. For more information about shut-off valves and associated valve boxes, contact the Bureau of Development Services (BDS) Commercial Plumbing Department at 503-823-7302.

C) **Transport and handling of hazardous materials** that are toxic, carcinogenic, or halogenated solvents (located in designated groundwater protection areas) are subject to additional requirements, as identified in the Water Bureau's *Columbia South Shore Well Field Wellhead Protection Area Reference Manual* (June 25, 2003).

5) EXCEPTIONS

Drainage: The requirement for drainage from the hydraulically isolated area of the loading dock to be directed to an approved City sanitary sewer or authorized pretreatment facility may be waived if BES determines there is no gravity sanitary service available and an appropriately sized, underground temporary storage structure (such as a catch basin with no outlet or dead-end sump) is provided. For the exception and alternative to be considered, information showing that gravity service cannot be obtained and a completed **Special Requests Form** shall be submitted.

4.7 EQUIPMENT AND/OR VEHICLE WASHING FACILITIES

4.7.1 Applicability

The requirements in this section apply to all development with a designated equipment and/or vehicle washing or steam cleaning area. This includes smaller activity areas, such as wheel-washing stations. Single-family and duplex residential sites are exempt.

4.7.2 Requirements

1) COVER

The washing area shall be covered with a permanent canopy or roof so precipitation cannot come in contact with the washing activity area. Precipitation shall be directed from the cover to a stormwater disposal point that meets all applicable code requirements.

- **Covers 10 feet high or less** shall have a minimum overhang of 3 feet on each side. The overhang shall be measured relative to the perimeter of the hydraulically isolated washing activity area it is to cover.

- **Covers higher than 10 feet** shall have a minimum overhang of 5 feet on each side. The overhang shall be measured relative to the perimeter of the hydraulically isolated washing activity area it is to cover.

2) PAVEMENT

A paved wash pad of asphalt or concrete shall be placed under and around the washing activity area and shall meet all applicable building code requirements. Sizing of the paved area shall adequately cover the activity area, including the placement of the vehicle or piece of equipment to be cleaned.

3) DRAINAGE

The paved area beneath the cover shall be hydraulically isolated through grading, berms, or drains to prevent uncontaminated stormwater from running onto the area and carrying pollutants away. Drainage from the hydraulically isolated area shall be directed to an approved City sanitary sewer or authorized pretreatment facility. Surrounding runoff shall be directed away from the hydraulically isolated washing pad to a stormwater disposal point that meets all applicable requirements of this manual.

4) OIL CONTROLS

All vehicle and equipment washing activities will be reviewed for needed oil controls to comply with the City's sanitary sewer discharge limits. The following design criteria are established for oil/water separators discharging to a sanitary sewer:

A) Washing Areas Protected with a Cover or Located Inside a Structure

1) Baffled oil/water separators and spill control (SC-type) separators shall not be allowed for use with equipment and/or vehicle washing applications. *Note: Activities and processes of a washing facility change over time, and the introduction of heat and surfactants may occur.*

2. Coalescing plate separators shall be designed to achieve 100-ppm non-polar oil and grease in the effluent from the peak flow generated by the washing activity. Testing information must be submitted by the manufacturer of the unit that supports the 100-ppm effluent standard at the calculated flow rate.

   a. Standard flow from a 5/8" hose is estimated to be 10 gpm.
   b. For specially designed washing units, check the vendor specifications for maximum flow rates.

2) Any pumping devices shall be installed downstream of the separator to prevent oil emulsification.

3) Separator details must be shown on the building plans submitted at the time of building permit application and shall match manufacturer specifications and details, including the unit flow rate, effluent water quality, and maximum process flow rate.

B) Washing Areas Exposed to Rainfall (by exception only)

1) Washing areas exposed to rainfall will be accepted by exception only. Stormwater volume charges will be applicable because the City will charge the owner stormwater volume charges for the stormwater discharged to separated sanitary sewer systems. The stormwater volume charges will be based on the impervious area and average rainfall, or by the installation of a discharge meter. The discharge will be charged at sanitary sewer volume rates (City Code Chapter 17.36.010 (A)(2)).

2) Oil/water separators shall be installed with a high-flow bypass to route flows greater than the operational rate around the unit, unless the operational rate exceeds the flow rate generated by a 10-year storm, as calculated with the Rational Method (Q=C*I*A, I=2.86"/hr for 10-year storm).

C) On-site Wash Recycling Systems

Wash recycling systems may be used for oil control as long as they can meet effluent discharge limits for the City's sanitary sewer system. A detail of the wash recycling system and vendor specifications identifying effluent efficiencies shall be submitted as part of the building plans at the time of building permit application.

5) EXCEPTIONS

A) **Permanent Cover**: If a washing activity area is generally used to service oversized equipment that cannot maneuver under a roof or canopy (cranes, sail boats, etc.) an exception to the roof or canopy requirement will be granted. A **Special Requests form**, located in Section 4.10, shall be submitted as part of the building permit application to evaluate exception qualifications.

B) **Sanitary Sewer Connection**: If an evaporation unit is installed as part of a wash recycling system, an exception to the sanitary sewer connection will be granted. NOTE: The cover requirement cannot be waived for evaporation units because of the sizing and capacity limitations of the individual units. A **Special Requests form**, located in Section 4.10, shall be submitted as part of the building permit application to evaluate exception qualifications.

4.8 STORMWATER AND GROUNDWATER MANAGEMENT FOR DEVELOPMENT ON LAND WITH SUSPECTED OR KNOWN CONTAMINATION

4.8.1 Applicability

The requirements in this section apply to all development projects that disturb property at risk, suspected, or known to contain pollutants in the soil or groundwater. This includes development that is surrounded by properties found to have trace pollutants. These requirements will also be applied to any property that is seeking to make a new connection to a Public storm system (whether a public separated storm sewer or a public underground injection structure, such as a sump) from a property that is at risk, suspected, or known to contain pollutants in the soil or groundwater. To avoid confusion with references to water quality pollutant throughout this manual, this section refers to pollutants as **contaminants** and/or **contamination**.

Because of local, state, and federal regulations, special handling and management of site soils, groundwater, and surface drainage may be necessary. As a result of these regulations, sites with suspected or known contamination require a more detailed review process and may delay issuance of related building permits. Applicants are advised to contact source control staff early on in the plan design process (before plan submittal) if they are aware or suspect the site has contaminants or is adjacent to a contaminated site.

To research contaminant information, refer to DEQ's facility profiler database, which can be found at: **http://deq12.deq.state.or.us**

If records indicate that a No Further Action (NFA) or Record of Decision (ROD) exists for your site, you must contact DEQ prior to pre- and post-construction activities to ensure conditions of record are not violated. For technical questions related to site contamination and clean-up, contact the Land Quality Division of DEQ.

All regulatory divisions or departments of DEQ referenced in this section can be reached by calling DEQ's Northwest Region Office at 503-229-5263.

Even if a site is not included in DEQ's tracking database, this does not mean that contamination may not be present. At a minimum, if a site has a history of commercial or industrial use, a Phase I site assessment should be performed prior to design.

Contaminants have the potential to become entrained and transported through exposure to construction activities and post-construction design elements of a development. The requirements in this section apply to:

- Excavation and stockpiling of contaminated soils (soil management)
- Disposal or re-use facilities related to groundwater, foundation or footing drains, interior floor drains in basements or sub-grade structures, construction dewatering, and surface stormwater treatment and conveyance systems

4.8.2 Requirements

Stormwater and groundwater discharges from sites suspected of contamination, whether proposed as a temporary construction connection or as permanent connection to any public system, will require a special authorization from BES. After reviewing the proposal and a characterization of the contaminants from the site, BES Source Control Division may make one of the following decisions:

- Approve discharges with restrictions such as described in these pages or as is necessary given the nature of the discharge.
- Require the applicant to obtain an NPDES permit from DEQ for the anticipated discharge prior to connection.
- Require that the applicant become part of BES' Industrial Pre-treatment Program.
- Deny the request to use the City storm or sump system.
- Allow unrestricted connection to the city storm sewers, with a testing point for future monitoring.

Contaminants, media, and site conditions are unique to each parcel of land. Sites at risk for contamination shall therefore be reviewed on a case-by-case basis.

1) SOIL MANAGEMENT

Stockpiles of contaminated soils shall be covered with temporary plastic film or sheeting to prevent stormwater from coming into contact with them.

Stockpile perimeters shall have a containment barrier on all four sides of every stockpile to prevent stormwater run-on and material run-off. Barriers can consist of concrete curbing, silt fencing, or other berming material, depending on the activity, size, and resources available.

Areas under stockpiles of contaminated soils are not required to be paved. However, an impervious layer shall be placed beneath the stockpile to protect uncontaminated areas from potential leachate.

2) CONSTRUCTION DEWATERING

All construction dewatering discharges resulting from groundwater or precipitation (rainfall) will be evaluated for contamination before disposal methods can be approved.

Laboratory analysis reports will be required, as defined in this chapter.

A temporary sampling point may be necessary. The temporary sampling point will be agreed upon between the City staff member processing the batch discharge authorization and the applicant.

Source control requirements will be identified as part of the review process of the laboratory analysis reports and the building permit application. Source controls, sampling points, and the disposal point shall be identified on the erosion control plan of the building permit application.

If on-site infiltration is the proposed method for disposal, authorizations are required from the Bureau of Development Services (BDS) and the Land Quality Division of DEQ. Infiltration systems for construction dewatering shall be located and maintained on private property, outside the public rights-of-way.

If on-site (proposed as a privately owned and maintained facility) underground injection control structure (UIC) is the proposed method for disposal, authorizations are required from BDS and the Water Quality Division of DEQ. All UICs shall be located and maintained on private property, outside the public rights-of-way.

If a public sanitary system is the proposed method of disposal, authorizations are required from BES and will be allowed only if extensive pretreatment is implemented and the discharge is approved through the BES appeal process. All groundwater and surface water discharges to a sanitary sewer system shall meet local discharge limits and will be subject to discharge volume charges. Discharges will be charged at sanitary sewer volume rates, as stated in City Code, Chapter 17.36.010(A)(2).

If a public stormwater system (such as a public sump system or storm sewer) is the proposed method of disposal, evaluations of discharge to the City's storm or sump system will be based on whether discharges meet, or can be pretreated to meet, requirements of the City's NPDES or other state and federal regulations for the receiving system, either groundwater or surfacewater.

Discharges to a combined sewer system may be flow restricted and shall meet local discharge limits, as stated in City Code, Chapter 17.34, Administrative Rules. Water Quality rules will also be applicable.

If a receiving stream is the proposed method for disposal, authorizations are required from BDS, the U.S. Army Corp of Engineers, and both the Land Quality and Water Quality Divisions of DEQ.

For technical assistance on obtaining a batch discharge authorization for construction dewatering activities, contact the BES Industrial Source Control Division at 503-823-7122.

3) POST-CONSTRUCTION SURFACE DRAINAGE SYSTEMS

If on-site infiltration is the proposed method for disposal, authorizations are required from the Bureau of Development Services (BDS) and the Land Quality Division of DEQ. Private infiltration systems shall be located and maintained on private property, outside the public rights-of-way. If crossings of public rights-of-way are necessary, authorizations and permits are required from BES and Portland's Office of Transportation (PDOT).

If on-site underground injection control structure (UIC) is the proposed method for disposal, authorizations are required from BDS and the Water Quality Division of DEQ. Private UICs shall be located and maintained on private property, outside the public rights-of-way. If crossings of public rights-of-way are necessary, authorizations and permits are required from BES and PDOT.

If a receiving stream is the proposed method for disposal, authorizations are required from BDS, the Army Corp of Engineers, and both the Land Quality and Water Quality Divisions of DEQ.
If crossings of public rights-of-way are necessary, authorizations and permits are required from BES and PDOT.

If an off-site Public sewer system is the proposed method for disposal, authorization is required from BES. Evaluations for discharges from sites with suspected contamination will be based on the following:

a) Surface drainage systems that are not exposed to industrial activities, contaminated soils, or subsurface discharges are not expected to contain contaminants and do not pose a threat to Public infrastructure. All discharges to a public sewer system will need an additional sewer connection permit.

b) A permanent monitoring point may be required to ensure compliance with local discharge regulations. If monitoring is necessary, a permanent structure

(such as a sampling manhole or flow-through vault) shall be installed on the discharge line of the subsurface drainage system.

4) POST-CONSTRUCTION WATER RECLAIM OR RE-USE SYSTEMS

Water reclamation or re-use systems provide innovative ways to use natural resources and save money. However, using groundwater as a resource from sites at risk of contamination may require additional source controls and environmental compliance regulations, depending on the nature of the contaminants and the extent of the remediation that has been completed.

Authorizations for re-use systems are required from the Bureau of Development Services (BDS), BES, the Oregon Water Resources Department, and DEQ.

If surface drainage systems are the proposed resource, discharges are not expected to contain contaminants and do not pose a threat to City infrastructure. Review will verify that there is no interaction between groundwater and the surface.

Non-potable uses for plumbing fixtures and industrial equipment (e.g., cooling towers or boilers) will require the following:

a) A discharge meter shall be installed on the outlet of the re-use system for sewer billing purposes.

b) Industrial equipment bleed-offs or drain valves shall have discharges routed to the sanitary waste line of the facility.

c) Overflows from the re-use system, prior to use, are not considered a wastewater and shall have discharges routed to the storm disposal system of the facility.

Irrigation systems may encourage transportation of contaminants and require authorization from the Land Quality Division of DEQ prior to installation.

If subsurface drainage systems are the proposed resource, discharges may contain contaminants and will be evaluated for contamination before disposal methods can be approved.

Non- potable uses for plumbing fixtures and industrial equipment (e.g., cooling towers or boilers) will require the following:

a) A discharge meter shall be installed on the outlet of the re-use system for sewer billing purposes.

b) Industrial equipment bleed-offs or drain valves shall have discharges routed to the sanitary waste line of the facility. Discharges shall meet local discharge limits, as stated in City Code, Chapter 17.34, Administrative Rules.

c) Because overflows from the re-use system, prior to use, may contain contaminants, the requirements stated under **Post-Construction Subsurface Drainage Systems** apply.

d) A permanent monitoring point may be required to ensure compliance with local discharge regulations. If monitoring is necessary, a permanent structure (such as a sampling manhole or flow-through vault) shall be installed on the discharge line of the subsurface drainage system.

Irrigation systems may encourage transportation of contaminants and require authorization from the Land Quality Division of DEQ prior to installation.

If groundwater is proposed for commercial or industrial uses of a development (e.g., non-potable uses or irrigation) authorization or a permit is required from the Oregon Water Resources Department (WRD) prior to use.

Minimum requirements that warrant a permit for industrial and commercial groundwater wells include, but are not limited to, irrigation of areas greater than ½ acre and use of more than 5,000 gallons per day of water. Unique groundwater reuse systems (anything other than a standard supply well installation) will be reviewed on a case-by-case basis to determine permitting requirements (if applicable).

For assistance in obtaining authorization for the use of groundwater, contact WRD's Multnomah County Water Master at 503-722-1410. For more information on water rights and groundwater regulations, see the WRD website at**: www.wrd.state.or.us**

5) POST CONSTRUCTION SUBSURFACE DRAINAGE SYSTEMS

In an area at risk for contamination, structures proposed below grade can greatly impact and add unexpected costs to the surface drainage systems, water reclaim or re-use systems, and subsurface drainage systems of a project.

All surface, subsurface and re-use systems will be evaluated for contamination risks before disposal and re-use methods can be approved.

If on-site infiltration is the proposed method for disposal, authorizations are required from the Bureau of Development Services (BDS) and the Land Quality Division of DEQ.

Private infiltration systems shall be located and maintained on private property, outside the public rights-of-way. If crossings of public rights-of-way are necessary, authorizations and permits are required from BES and Portland's Office of Transportation (PDOT).

If on-site subsurface injection is the proposed method for disposal, authorizations are required from BDS and the Water Quality Division of DEQ.

Private subsurface injection systems (Underground injection controls) shall be located and maintained on private property, outside the public rights-of-way. If crossings of public rights-of-way are necessary, authorizations and permits are required from BES and PDOT.

If a receiving stream is the proposed method for disposal, authorizations are required from BDS, the U.S. Army Corp of Engineers, and both the Land Quality and Water Quality Divisions of DEQ. If crossings of public rights-of-way are necessary to obtain access to an approved discharge point of a receiving stream, authorizations and permits are required from BES and PDOT.

If a Public sewer system is the proposed method for disposal, authorization is still required from BES. A permanent monitoring point may also be required to ensure compliance with local discharge regulations.

6) LABORATORY ANALYSIS REPORTS

Laboratory analysis reports are required to identify the characteristics and levels of contamination in the soils and groundwater of a site.

An additional review process will be applied to these laboratory reports to determine regulatory authority and requirements. Testing and analysis are highly recommended prior to submitting building permit applications. DEQ permitting and/or review may be required if contaminants are found and the levels of contamination appear to exceed the City's local discharge regulations. This may delay issuance of related building permits.

Laboratory analysis reports shall include the following information:

a) Analysis reports shall identify the elevation of the seasonal water table and identify the depth of any perched water aquifers.

b) Analysis reports shall identify the method of laboratory testing, the detection level and analytical method for detection, and the depth of any found contaminants in the soils.

c) Minimum test parameters for baseline contaminants shall include metals (arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, silver, and zinc), TPH (total petroleum hydrocarbons), and BTEX (benzene, toluene, ethyl benzene and xylene).

d) Test parameters may be required to include other contaminants identified through historical data, research, and environmental assessments (as recommended under Section 4.8.1).

e) If post-construction subsurface drainage or dewatering systems are proposed to discharge to a City sump system, test parameters will be required to include parameters identified in the federal Safe Drinking Water Act. Discharges to any public UIC must meet the standards listed for each parameter. The parameters and standards regulated by the federal Safe Drinking Water Act can be found on the internet at: **www.epa.gov/safewater/mcl.html#mcls**

7) ADDITIONAL REQUIREMENTS

All structural controls in this section require a Source Control Installations form, located at the end of this chapter. Typical controls that would need a DAR form include containment areas, shut-off valves, and oil/water separators. If an applicant requests an alternative or exception to any of the source controls identified in this section, the applicant shall complete the **Special Requests form**, located at the end of this Chapter. These types of requests require an additional review process and may delay issuance of related building or public works permits.

4.9 COVERED VEHICLE PARKING AREAS

4.9.1 Applicability

The requirements in this section apply to all development with a covered vehicle parking area, except single-family and duplex residential sites. Existing parking structures are not required to retrofit unless the structure is being redeveloped. New parking structures are required to meet these requirements.

4.9.2 Requirements

1) DRAINAGE

Top Floor Drainage of a Multi-Level Parking Structure

Stormwater runoff from the top floor shall be directed to a stormwater disposal point that meets all water quality requirements of this manual and any other applicable code requirements.

Lower Floor Drainage of a Multi-Level Parking Structure

Significant amounts of precipitation are not expected to accumulate in covered vehicle parking areas, and drainage facilities are not required for the lower floors. If the applicant elects to install drainage facilities, the drainage from the lower floors shall be directed to an approved City sanitary sewer.

Adjacent, Uncovered Portions of the Site

The surrounding uncovered portions of the site shall be designed so stormwater does not enter the covered parking areas. This can be accomplished through grading or drains.

EXCEPTIONS

Single-level covers (canopies, overhangs, and carports) are exempt from the requirements of this section.

4.10 FORMS AND REFERENCE MATERIALS

Signage Examples:





Spill sign samples
recommend
PMS 185 red and black
on white

SOURCE CONTROL INSTALLATIONS

This form is required for structural source controls that address site characteristics and facility uses at risk for source point pollutant releases that are regulated or prohibited by local, state, and federal regulations. This form will be utilized for tracking and inspection purposes.

Existing facilities proposing a new connection to a Public Storm or Sanitary system, with the characteristics and uses identified in Chapter 4 of the City's Stormwater Management Manual, will be subject to the same structural source controls as new development, redevelopment, and tenant improvements.

(Please Print)

FACILITY INFORMATION

Facility Name (if applicable): _____

Facility Address or Location: _____

Type of business/facility: _____

Facility Contact or Owner: _____ Phone No.: _____

APPLICANT INFORMATION

Applicant's Name: _____ Phone No.: _____

Applicant's Mailing Address: _____

STRUCTURAL SOURCE CONTROLS (*check all that apply*)

Building Permit No. (if applicable): _____

- ☐ Oil/Water Separator
- ☐ Shut-off Valve on Storm Drainage Line
- ☐ Shut-off Valve on Sanitary Waste Line
- ☐ Collection Device w/ No Outlet
- ☐ Discharge Meter
- ☐ Containment Area
- ☐ Wall Valve for Containment Area
- ☐ Spill Control Manhole
- ☐ Sampling Structure
- ☐ Other: _____

The following items need to accompany this form:

- A detail or vendor specification for each proposed source control, and
- A site plan of the facility/property clearly identifying the location of each structural source control in reference to a permanent structure, to help assist the Source Control Division in field verification. (*A hand-drawn sketch, not to scale, is acceptable as long as it is legible*.)

City Comments:

SPECIAL REQUESTS
for
Source Controls

This form is required if you are requesting alternatives to standard structural source controls, removal or abandonment of existing source controls, exception qualifications per Chapter 4 of the City's Stormwater Management Manual, or other special requests you would like reviewed by the Source Control Division.

Special requests will require an additional review process and may delay issuance of related building permits. If this request cannot be satisfied by the Special Requests process through the Source Control Division, the tier one appeal process, as described in **Appendix A** of the Stormwater Management Manual, may be implemented by the applicant.

(Please Print)

FACILITY INFORMATION

Facility Name (if applicable): _____

Facility Address or Location: _____

Type of business/facility: _____

Facility Contact or Owner: _____ Phone No.: _____

APPLICANT INFORMATION

Applicant's Name: _____ Phone No.: _____

Applicant's Mailing Address: _____

SPECIAL REQUEST

Building Permit No. (if applicable): _____

☐ Request for an alternative source control method

☐ Request to remove or abandon existing structural source control(s)

☐ Request for review of EXCEPTION qualifications.

☐ Other: _____

The following items need to accompany this form:

- A detail or vendor specification for each alternative source control, and
- A site plan of the facility/property clearly identifying the location on the site that will be impacted by this special request. Existing and proposed utilities may need to be shown to ensure regulatory compliance with local, state and federal regulations. (*A hand-drawn sketch, not to scale, is acceptable as long as it is legible*.)

(SPECIAL REQUESTS FORM CONT.)

Provide a brief explanation for your request (*Use additional pages if necessary*.):

TO BE COMPLETED BY SOURCE CONTROL DIVISION Date Received:

☐ Approved ☐ Denied ☐ Other (*see comments below*)

Date: _____ Signature: _____

City Comments:

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City of Portland
Stormwater Management Manual

September 1, 2004

Appendices:

Appendix A: City Code Chapter 17.38, Policy Framework, Appeals & Update Process

Appendix B: Vendor Submission Guidance for Stormwater Treatment Technologies

Appendix C: Santa Barbara Urban Hydrograph Method

Appendix D: Simplified Approach Sizing Calculations

Appendix E: Pollution Reduction Storm Report

Appendix F: Facility Planting & Soil Recommendations

Appendix G: Supplemental Drawings

Appendix H: Stormwater Facility Photos

Reference & Resources

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Appendix A
CITY CODE CHAPTER 17.38,
POLICY FRAMEWORK, APPEALS AND UPDATE PROCESS

A.1 CITY CODE CHAPTER 17.38

17.38.015

B. Adoption of Rules.

1. During the public review, a designee of the Director shall hear testimony and receive written comments concerning the proposed rules. The Director shall review the recommendation of his or her designee, taking into consideration the comments received during the public review process and shall either adopt the proposal, modify or reject it.

2. If a substantial modification is made to the rules submitted for public review, the Director may adopt the modification as Interim Rules or shall provide an additional public review prior to adoption.

3. Unless otherwise stated, all rules shall be effective upon adoption by the Director and shall be filed in the Office of the Director.

C. Interim Rules.

1. Notwithstanding paragraphs 17.38.015 A. and B., an interim rule may be adopted without prior notice upon a finding that failure to act promptly will result in serious prejudice to the public interest or the interest of the affected parties. The rule should include the specific reasons for such prejudice.

2. Any rule adopted pursuant to this paragraph shall be effective for a period of not longer than 180 days.

3. After adoption, public notice of interim rules shall be given by publication in a newspaper of general circulation and notice sent to the Office of Neighborhood Involvement. Such notice shall include the location at which copies of the full set of the interim rules may be obtained.

D. Initial Rules. Notwithstanding sections 17.38.015 A-C. above, the rules contained in the Stormwater Management Manual filed with the Council in conjunction with Ordinance No. 173330 may be adopted by the Director without further public review.

17.38.020 Purpose.

The purpose of this Chapter is to provide for the effective management of stormwater and drainage, and to maintain and improve water quality in the Watercourses and Water Bodies within the City of Portland as described in 17.38.025.

17.38.025 Stormwater Management Policies and Standards.

A. Stormwater shall be managed as close as is practicable to development sites, and stormwater management shall avoid a net negative impact on nearby streams, wetlands, groundwater, and other waterbodies. All local, state and federal permit requirements related to implementation of stormwater management facilities must be met by the owner/operator prior to facility use. Surface water discharges from on-site facilities shall be conveyed via an approved drainage facility.

B. The quality of stormwater leaving the site after development shall be equal to or better than the quality of stormwater leaving the site before development, as much as is practicable, based on the following criteria:

1. Water quality control facilities required for development shall be designed, installed and maintained in accordance with the Stormwater Management Manual, which is based on achieving at least 70% removal of the Total Suspended Solids (TSS) from the flow entering the facility for the design storm specified in the Stormwater Management Manual or Administrative Rules.

2. Land use activities of particular concern as pollution sources shall be required to implement additional pollution controls, including, but not limited to, those management practices specified in the Stormwater Management Manual.

3. Development in a watershed that drains to streams with established Total Maximum Daily Load limitations, as provided under the Federal Clean Water Act, Oregon Law, Administrative Rules and other legal mechanisms shall assure that water quality control facilities meet the requirements for pollutants of concern, as stated in the Stormwater Management Manual.

4. Stormwater discharge, which is not practicable to fully treat as defined in sections 17.38.025 B.1-3. and the Stormwater Management Manual, shall either: be treated in an off-site facility or be given the option of paying a stormwater off-site management fee. The Bureau will employ a methodology for calculating the fee that is based upon an average unit cost of on-site facilities where such facilities would be effective. The stormwater off-site management fee collected will be placed in a mitigation account to be used to mitigate the impacts that arise from off-site discharge of stormwater runoff. Information relating to sites that are paying fees will be evaluated in planning for capital improvement projects.

5. Not withstanding section 17.38.025 B.4., for any parcel created after the effective date of this Chapter, stormwater shall be fully treated on-site or within the original parcel from which the new parcel was created, or in a privately developed off-site facility with sufficient capacity, as determined by the Bureau.

C. The quantity of stormwater leaving the site after development shall be equal to or less than the quantity of stormwater leaving the site before development, as much as is practicable, based on the following criteria:

1. Development shall mitigate all project impervious surfaces through retention and onsite infiltration to the maximum extent practicable. Where onsite retention is not possible, development shall detain stormwater through a combination of provisions that prevent an increased rate of flow leaving a site during a range of storm frequencies as specified in the Stormwater Management Manual.

2. The Director may exempt areas of the city from the requirement of 17.38.025 C.1. if flow control is not needed or desirable and if:

a. Stormwater is discharged to a large waterbody directly through a private outfall, or
b. Stormwater is discharged to a waterbody directly through a separated public storm sewer having adequate capacity to convey the additional flow.

3. Any development that contributes discharge to a tributary to the Willamette River, other than the Columbia Slough, shall design facilities such that the rate of flow discharging from water quantity control facilities for up to a two-year storm does not lengthen the period of time the channel sustains erosion-causing flows, as determined by the Bureau. .

4. Facilities shall be designed to safely convey the less frequent, higher flows through or around facilities without damage.

5. Stormwater quantity discharge which is not practicable to be managed as defined in 17.38.025 C.1. through 17.38.025 C.4. and the Stormwater Management Manual shall either: be managed in an off-site facility or be given the option of paying a stormwater off-site management fee. The Bureau will employ a methodology for calculating the fee that is based upon an average unit cost of on-site facilities where such facilities would be effective. The stormwater off-site management fee collected will be placed in a mitigation account to be used to mitigate the impacts that arise from off-site discharge of stormwater runoff. Information relating to sites that are paying fees will be evaluated in planning for capital improvement projects.

6. Not withstanding section 17.38.025 C.5., for any parcel created after the effective date of this chapter shall fully manage stormwater on-site or within the original parcel from which the new parcel was created, or in a privately developed off-site facility with sufficient capacity, as determined by the Bureau.

17.38.030 Definitions.

A. Approved Drainage System**.** A system approved by BES which, in general, shall adequately collect, convey, treat and or dispose of stormwater runoff or other site discharge. Approved systems shall meet all requirements and specifications laid out in this code or in any BES design guidance document plus any applicable plumbing code provisions relating to the piped portions of any system.

B. "Capacity". The capacity of a stormwater system shall mean the flow volume or rate that a facility (e.g., pipe, pond, vault, swale, ditch, drywell, etc.) is designed to safely contain, receive, convey, treat or infiltrate stormwater that meets a specific performance standard. There are different performance standards for treatment, detention, conveyance, and disposal. Example: Public storm sewer pipes are required to convey the 10-year storm without surcharge, and the 25-year storm without damage to property or endangering human life or public health. Public infiltration sumps are required to infiltrate the 10-year storm with a safety factor of two. Combined sewers that overflow during a 25-year storm are not considered to have adequate capacity.

C. "Combination Facilities". Systems that are designed to meet two or more of the multiple objectives of stormwater management.

D. "Director". The Director of the Bureau of Environmental Services, or the Director's designee.

E. "Disposal". The ultimate discharge point for the stormwater from a site. Disposal points can include drywells and sumps, soakage trenches, ditches, drainageways, rivers and streams, off-site storm pipes, and off-site combination sewers.

F. "Drainageway". An open linear depression, whether constructed or natural, which functions for the collection and drainage of surface water. It may be permanently or temporarily inundated.

G. "Impervious Surface". Any constructed surface that has a runoff coefficient greater than 0.8 (as defined in the Sewer Design Manual, Chart 10 "Runoff Coefficients"). Note: Decks which do not retain water are considered pervious.

H. "Off-Site Stormwater Facility". Any stormwater management facility located outside the property boundaries of a specific development, but designed to reduce pollutants from and/ or control stormwater flows from that development.

I. "On-Site Stormwater Facility". Any stormwater management facility necessary to control stormwater within an individual development project and located within the project property boundaries.

J. "Pollutants of Concern". Watershed-specific parameters identified by the Oregon Department of Environmental Quality (DEQ) as having a negative impact on the receiving water body.

K. "Practicable". Available and capable of being done as determined by the Director, after taking into consideration cost, existing technology, and logistics in light of overall project purpose.

L. "Public Works Project". Public works project means any development conducted or financed by a local, state, or federal governmental body and includes local improvements and public improvements, as defined in Title 17, PUBLIC IMPROVEMENTS.

M. "Redevelopment". Development that requires demolition or complete removal of existing structures or impervious surfaces at a site and replacement with new development. Maintenance activities such as top-layer grinding and repavement are not considered redevelopment.

Interior remodeling projects are also not considered to be redevelopment. Utility trenches in streets are not considered redevelopment unless more than 50% of the street width is removed and re-paved.

N. "Site Map". For purposes of this code section, a site map shall show the stormwater management facility location in relation to building structures or other permanent monuments on the site. The site map shall depict location of sources of runoff entering the facility and the discharge point and type of receiving system for runoff leaving the facility.

O. "Stormwater Management". The overall culmination of techniques used to reduce pollutants from, detain, and/ or retain, and dispose of stormwater to best preserve or mimic the natural hydrologic cycle, to accomplish goals of reducing combined sewer overflows, or to incorporate sustainable building practices by reusing stormwater, on a development site. Public health and safety, aesthetics, maintainability, capacity of the existing infrastructure and sustainability are important characteristics of a site's stormwater management plan.

P. "Stormwater Management Facility". A single technique used to treat, detain, and/or retain stormwater to best preserve or mimic the natural hydrologic cycle, or to fit within the capacity of existing infrastructure, on a development site.

Q. "Tract". A tract is a section of land set aside from development during the Land Division phase of development. Tract as used in this code section shall be the definition of tract as described in Title 33 of the City Code.

R. "Water Body". Rivers, streams, sloughs, drainages including intermittent streams and seeps, and ponds, lakes, aquifers, wetlands, and coastal waters.

S. "Watercourse". Watercourse means a channel in which a flow of water occurs, either continuously or intermittently, and if the latter with some degree of regularity. Watercourses may be either natural of artificial.

T. "Water Quality Control/Pollution Reduction Facility". Refers to any structure or drainageway or drainage device that is designed, constructed, and maintained to collect and filter, retain, or detain surface water runoff during and after a storm event for the purpose of maintaining or improving surface and/or groundwater quality. These facilities may include, but are not limited to, constructed wetlands, water quality swales, and ponds that are maintained as stormwater quality control facilities.

U. "Water Quantity Control Facility". Refers to any structure or drainage device that is designed, constructed, and maintained to collect, retain, infiltrate, or detain surface water runoff during and after a storm event for the purpose of controlling post-development quantity leaving the development site. These facilities may include, but are not limited to, constructed wetlands, infiltration basins, and wet ponds that are maintained as stormwater quantity or quality control facilities.

V. "Wetland". An area that is inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands include swamps, marshes, bogs, and similar areas except those constructed as water quality or quantity control facilities. Specific wetland designations shall be made by the Corps of Engineers and the Division of State Lands.

17.38.040 Stormwater Quality and Quantity Control Facilities Required.

No plat, site plan, building permit or public works project shall be approved unless the conditions of the plat, permit or plan approval require installation of permanent stormwater quality and quantity control facilities designed according to standards or guidelines established by the Director of the Bureau of Environmental Services and as specified in the City of Portland's Stormwater Management Manual.

A. Exemptions. The requirements of this Chapter for stormwater management do not apply to:

1. Development for which an application for development approval is accepted by the permitting agency prior to July 1, 1999 shall be subject to the requirements in place at the time of application.

2. Development, whether public or private, that does not result in impervious surface coverage or results in coverage that is de minimus, such as fences, environmental enhancement projects, buried pipelines or cables, and utility lines.

3. Transportation improvements which will not directly increase non-point source pollution or quantity of stormwater runoff once construction has been completed (i.e., pavement overlays).

4. Impervious surface created by a water quality or water quantity control facility. Paved or compacted gravel facility access and maintenance roads that extend beyond the facility itself are not exempted from treatment requirements.

B. Appeals. Any permit applicant aggrieved by a decision, interpretation, or determination made pursuant to the administration of the Stormwater Management Manual may appeal such action in accordance with 17.38.040 B.1. and B.2.

1. In order to provide for reasonable interpretation of the provisions of the Stormwater Management Manual, the Director shall establish an internal Administrative Appeals Committee and an External Appeals Board. The Commissioner in charge of the Bureau of Environmental Services shall appoint members of the External Appeals Board.

2. Applicants shall file appeals in accordance with the appeals process procedures specified in the Stormwater Management Manual.

C. Maintenance of Water Quality and Quantity Control Facilities.

1. All new development, redevelopment, plats, site plans, building permits or public works projects, as a condition of approval, shall be required to submit an operation and maintenance plan for the required stormwater quality and quantity control facilities for review and approval by the Bureau of Environmental Services. A water quality or quantity control facility that receives stormwater runoff from a public right-of-way shall be a public facility, unless the right-of-way is not part of the city road maintenance system.

a. The information required in the operation and maintenance plan shall satisfy the requirements of the Stormwater Management Manual (SWMM). Applicants are encouraged to use the O & M Plan template provided in the SWMM. The Plan shall include and not be limited to:

(1) Design plans of the specific facility and related parts, including design assumptions.

(2) A schedule for routine inspection, including post storm related inspections.

(3) A description of the various facility components, the observable trigger for maintenance, and the method of maintenance, including appropriate method of disposal of materials.

(4) The intended method of providing financing to cover future operations and maintenance.

(5) The party or parties responsible for the maintenance of the facility including the means of effecting contact, including contact means for emergency situations. The party may be an individual or an organization.

b. A maintenance log is required. The log shall provide a record of all site maintenance related activities. The log shall include the time and dates of facility inspections and specific maintenance activities. The log shall be available to City inspection staff upon request.

2. Failure to properly operate or maintain the water quality or quantity control facility according to the operation and maintenance plan may result in a civil penalty as specified in 17.38.045, Enforcement.

3. A copy of the operation and maintenance plan shall be filed with the Bureau of Environmental Services. Staff may require a site map to be recorded and filed with the appropriate county Department of Assessment and Taxation.

A.2 POLICY FRAMEWORK

The Stormwater Policy Advisory Committee (SPAC) was established in April 1996 at the direction of the City Commissioner of Public Works. SPAC members included representatives of City bureaus, the Homebuilders Association, Metro, the Oregon Department of Environmental Quality, watershed advocates, and the development community. The SPAC was charged with recommending stormwater management policies to the Bureau of Environmental Services (BES). In addressing stormwater issues, the SPAC also considered other City goals and policies for environmental protection, density, transportation, and economic development.

In July 1997, the SPAC submitted and City Council accepted policy recommendations for new development (*Final Recommendations: Stormwater Management Requirements for New Development*). Council directed BES to develop this *Stormwater Management Manual* to implement policy recommendations for development. The *Stormwater Management Manual* was adopted on July 1, 1999. The *Stormwater Management Manual* is part of BES's Administrative Rules, authorized by Portland City Code Chapter 17.38, adopted by the Director of BES following a public review process, and filed with the City Auditor as required by Portland City Code Chapter 1.07.

In spring 1999, the City Council established the Stormwater Advisory Committee (SAC), whose members represent environmental, development, engineering, business, and community interests. One of the SAC's tasks was to review and make recommendations regarding changes to the manual. The SAC presented its recommendations to Council in April 2000 and again in August 2002. In addition, a public review process was conducted to obtain public comment on the manual. The SAC recommendations, public comments where appropriate, and BES staff changes are incorporated into this revised manual.

The policies that form the basis for this manual are codified in City Code Chapter 17.38, which is restated above.

A.3 APPEALS PROCESS

BES's appeals process allows development applicants to appeal staff interpretation of the City Code and adopted policies and procedures that guide the review of development proposals. City Council has adopted the appeals process. Applicants may appeal any issue related to interpretation of the stormwater management policy. For example, an applicant may appeal staff assessment of a site's stormwater management level or a permit denial. Applicants may not appeal the content or requirements of the policy, or technical parameters such as design storms, coefficients, and other technical criteria through this appeals process.

This process is not intended to address requested changes to technical specifications as adopted in the *Portland Standard Construction Specifications* or the *Bureau of Environmental Services Sewer Design Manual*. In these cases, applicants should contact BES's Development Assistance (503-823-7761) to request consideration by the BES Standards and Practices Committee. The committee has a separate process to consider changes to technical standards, such as the use of new stormwater management technologies.

Note: "Special circumstances," as described in **Section 1.11**, are part of the standard application process and are not considered an appeal, unless the applicant is appealing denial of a special circumstance designation.

A.3.1 Tier One Appeal

Tier one is an appeal to BES's Administrative Appeals Committee, comprising the Chief Engineer, Development Services Manager, and Pollution Prevention Services Manager (or their designees). Applicants must notify BES of their appeal in writing, specifying the reason for the request and supporting their position with technical and factual data.

The Development Services Manager reviews all appeals applications for completeness. Once an application is complete, the process operates on a turnaround of 10 working days. The Development Services Manager schedules a meeting of the Administrative Appeals Committee and notifies the applicant of the meeting date, place, and time. The applicant may, but is not required to, attend the meeting. At the meeting, the Development Services Manager (or designee) presents a brief, cohesive overview of the questions and issues raised in the appeal. The applicant may briefly speak in support of the request. The committee reaches decisions by a majority opinion of the members. All decisions are recorded and mailed to the applicant.

A.3.2 Tier Two Appeal

Applicants not satisfied with the actions of the Administrative Appeals Committee may submit a written request for a hearing by BES's External Appeals Board. This five-member board is appointed by the Commissioner of Public Works to serve two-year terms. It also serves as the appeal board for the City's *Erosion Control Manual*, and may be convened for other appeals to BES staff decisions, as determined by BES's Director. The Development Services Manager performs administrative duties.

The Development Services Manager schedules a board meeting to occur within 14 days of receipt of the written request and notifies the applicant of the meeting date, place, and time. Public notice of the appeal request is given. A board meeting may not take place unless at least three members are present. The Development Services Manager presents a cohesive overview of the questions and issues raised in the appeal. The applicant, if present, may briefly address the board. Decisions are reached by a majority opinion of the board. All decisions are recorded and mailed to the applicant. Decisions of the board are binding.

A.4 UPDATE AND AMENDMENT PROCESS

This *Stormwater Management Manual* will be reviewed a minimum of every 3 years and updated as necessary. The review process will include:

- Consideration of changed and new technologies
- Review of appeals made during the preceding interval
- Review of requests for variances to standard design criteria for public and private facilities
- Review of all performance-based approaches approved since the last manual revision
- Review of recommendations from the Stormwater Advisory Committee
- Review of community comments and concerns
- Adjustment of internal review processes and submittal requirements
- Incorporation of new sections and issues

The amendment process will also include a mailing to interested persons to solicit suggestions for amendments or procedural changes; a public meeting to review amendments and solicit input; and documentation and explanation of any changes made.

Suggestions for changes and improvements can be made at any time and should be sent to:

Attn: Steve Fancher
City of Portland, BES
1120 SW 5th Ave., Room 1100
Portland, OR 97204

Any changes to the current stormwater management policies will require the approval of City Council. If changes to the manual are proposed, the Chief Engineer will distribute any proposed manual improvements to interested parties and internal staff no later than May 1 of the year the manual is to be revised. The amended manual will be approved by the Chief Engineer and Bureau Director no later than September 1 of the year the amendments will occur.

Appendix B

CITY OF PORTLAND, OREGON
BUREAU OF ENVIRONMENTAL SERVICES

VENDOR SUBMISSION GUIDANCE

FOR

EVALUATING STORMWATER TREATMENT TECHNOLOGIES

February 2001, Updated September 1, 2004

SARB_008050

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VENDOR SUBMISSION GUIDANCE FOR EVALUATING STORMWATER TREATMENT TECHNOLOGIES

February 20, 2001, Updated September 1, 2004

I. Introduction

The City of Portland's Stormwater Management Manual provides stormwater pollution reduction requirements and guidance. BES specifies design criteria, such as pollution reduction storm intensity and volume, and facility performance goals. Facilities need to be designed to satisfy those criteria as stand-alone systems or as part of a treatment train approach.

Chapter 2.0 presents stormwater pollution reduction facility designs and includes a section on manufactured stormwater treatment technologies. Stormwater treatment technologies and the knowledge base around them are rapidly evolving, and as such no proprietary facility names are included in the Stormwater Management Manual. Rather, BES will keep an updated list of technologies that have been approved for stand-alone and pretreatment uses.

This guidance is designed to provide a process of designating approval levels for manufactured treatment technologies. To be approved for use as a stand-alone stormwater pollution reduction facility, the protocols of this document must be followed. Results must indicate that the facility performs to Portland's design standards (see Performance Criteria section below, and Data Evaluation section, Page B-14).

This guidance will also define "TSS (Total Suspended Solids) removal", and provide the equations necessary to calculate it. Portland's method for evaluating test results, which includes provisions for influent concentration, is also included (See Data Evaluation section, Page B-14).

II. Performance Criteria

DESIGN STORM

Flow rate-based pollution reduction facilities shall be sized to treat 90% of the average annual Portland runoff. When used with the Rational Method, the following rainfall intensities will result in flow rates that achieve this goal (see Appendix E of the Stormwater Management Manual).

Site's Time of Concentration (Minutes)	Rainfall Intensity (Inches per Hour)
5	0.19
10	0.16
20	0.13

REQUIRED POLLUTION REDUCITON PERFORMANCE GOALS

Basic Pollution Reduction Performance Goal

The basic pollution reduction performance goal for the entire city is 70% TSS (Total Suspended Solids) removal from 90% of the average annual runoff. TSS is defined as "matter suspended in stormwater excluding litter, debris, and other gross solids exceeding 1 millimeter in diameter (larger than coarse sand, also see Distribution of Sediment Sizes Table, Page B-9).

Influent concentration of TSS is known to greatly impact the ability of a facility to remove 70% TSS, so it is important to specify limits to be used in performance tests. BES will use the "Line of Comparative

Performance©" method, developed by Dr. Gary Minton of Resource Planning Associates (See Charts 1 through 3 in the Data Evaluation section, Pages B-14 and 14) to determine whether or not a facility meets this requirement. These lines were generated from test data on the TSS removal efficiencies of grassy swales and sand filters and modified to account for Portland's 70% TSS removal standard. The premise behind using these lines of performance is that grassy swales and sand filters have been widely accepted as adequate-performing treatment facilities. These, as well as other treatment BMPs, remove a higher percentage of TSS with higher TSS influent concentrations. It is not fair or practical to require 70% TSS removal from clean stormwater. This method of evaluation, however, accounts for this dilemma. Manufactured technologies will not be expected to outperform grassy swales and sand filters, but data points must be comparable, with a certain percentage falling above the "Line of Comparative Performance©" for the facility to be accepted as a "Presumptive Approach" in the Stormwater Manual. As a low-level baseline, a facility must also achieve an effluent goal of no more than 20 mg/l TSS for low influent concentrations (< 70 mg/l).

TMDL Enhanced Performance Goal

Certain watersheds within the City of Portland have established TMDLs (Total Maximum Daily Loads). The TMDLs apply specific pollution control requirements to designated pollutants of concern. To ensure that new development does not contribute pollutants of concern to a TMDL watershed, pollution reduction facilities are required to demonstrate specific removal rates for those specific pollutants.

To be considered for use as a stand-alone facility in a TMDL watershed, a manufactured technology must demonstrate removal efficiencies for specific pollutants of concern, as well as TSS. See Section 1.5.2 of the Stormwater Management Manual for a current list of TMDL watersheds with corresponding pollutant parameters.

Oil and Grease Performance Goal

Certain site uses within the City of Portland, such as high-use or high-risk parking lots, require additional treatment for oil and grease. The Stormwater Manual currently only recognizes oil/water separators for the pretreatment of oil and grease. To be considered for use as an oil/water separator, a manufactured technology must demonstrate adequate performance. Adequate performance needs to include: the removal of oil droplets from 50 to 60 microns in size, and the ability to achieve effluent efficiencies of 10 ppm or mg/L for influent concentrations exceeding 50 ppm or mg/L.

Pretreatment Performance Goal

A facility may be approved for pretreatment use only. In this case, the facility would be constructed in conjunction with another pollution reduction facility as a "treatment train" to accomplish the basic or enhanced performance goal. To be approved as a pretreatment facility only, data pertaining to the assessment protocol should be submitted. However, the level of performance will not need to meet basic pollution reduction performance goals. The facility will need to demonstrate the ability to remove large debris and the larger range of TSS particle sizes (see Distribution of Sediment Sizes Chart on page B-9), as approved by BES.

REQUIRED PERFORMANCE

Manufactured technologies claiming effectiveness for the listed pollutants must demonstrate (based on data provided per the Technology Assessment Protocol described below) that the above treatment performance goals will be generally achieved. Facilities shall be designed to perform without maintenance for one full year. In addition, factors other than treatment performance are important and will be evaluated to determine appropriate use of the emerging technology. Technologies may be approved as "Presumptive Approaches", which are then presumed to comply with the City's basic pollution reduction performance goal, or as pre-treatment facilities, only accepted in combination with other facilities. Facilities demonstrating compliance with enhanced or oil and grease performance goals may be added to applicable

Stormwater Manual sections in future revisions. Facilities that don't demonstrate adequate maintainability (See Section E, Page B-11) will not be included in the Stormwater Management Manual and will not be accepted for use within the City.

III. Technology Assessment Protocol

This testing protocol is based on protocols developed by other jurisdictions in the northwest. The Washington Chapter of the American Public Works Association (APWA), the Washington Department of Ecology, the City of Olympia, and the City of Sacramento/ Sacramento County have all developed very similar protocols, and were all instrumental in the development of this one. In this document, BES has tailored various sections of these protocols to fit Portland's design standards. BES reserves the right to change or update this document at any time. As design standards change, compliance with this protocol does not "grandfather" any manufactured facilities into the Stormwater Manual. BES reserves the right to request additional information at any time, and may remove technologies from accepted status after gaining further experience with them, or as new data becomes available. If a vendor wishes to use a different protocol, it is highly recommended to submit protocol details to BES for review prior to initiating tests.

REQUIRED NUMBER AND TYPES OF STUDIES

For BES to adequately evaluate the performance of a facility, a sufficient number of data points, or tests, must be submitted by the manufacturer. The submission of at least 30 tests will be deemed adequate for review. A "test" is defined as a controlled study that meets the requirements set forth in this protocol and results in a single data point which can be plotted on an Influent TSS (mg/L) vs. Removal Efficiency (%) curve (see Chart 3, Page B-15). Removal efficiency shall be calculated using methods specified on page B-10 of this report. At least half of the tests must come from field installations; either field performance studies with real storms or field performance studies with artificial storms.

Testing by "Independent Entities"

Testing of technologies may be conducted by qualified "independent entities" such as consultants, universities, local, state, or federal agencies. Testing may also be sponsored by the manufacturers themselves, but actual sampling, testing, and laboratory reporting must come from a qualified laboratory.

A. FIELD PERFORMANCE STUDIES WITH REAL STORMS

For inclusion in the Stormwater Manual as a stand-alone "Presumptive Approach", at least 15 data points must be obtained from actual field installations. These can come from field studies with real or artificial storms. At least two different land-uses must be represented, including medium density residential, retail commercial, non-retail commercial, or industrial. Testing within transportation corridors, including public or private streets within these land-uses, is encouraged. The purpose of this is to obtain a range of influent concentrations representative of typical storm water runoff. While it is acknowledged to be more difficult and expensive than laboratory testing, field testing will ensure that situations existing in "real-life" will be mimicked to the maximum extent practicable.

The following storm characteristic requirements must be met for field tests with real storm events, and must be documented and submitted to BES for acceptance.

NUMBER AND CHARACTERISTICS OF SAMPLED STORMS

Minimum Number of Sampled Storms

For acceptance as a stand-alone "Presumptive Approach", 5 storm events from three different sites must be submitted for a total of 15 storms. Real or artificial storm events can be used. At least two different land-uses must be represented, from either medium density residential, retail commercial, non-retail commercial, or industrial. Testing within transportation corridors, including public or private streets within these land-uses, is encouraged. The purpose of this is to obtain a range of influent concentrations representative of typical storm water runoff. For possible acceptance as a pretreatment device, at least 5 storm events must be submitted. To represent seasonal differences if only real storms are used, the tests shall occur throughout the calendar year. No more than 70% of the real storms may be sampled during the dry season (May through September) or during the wet season (October through April).

Minimum Storm Depth

The minimum total storm depth shall be 0.12 inches. As a guideline, at least 50% of the sampled storms should exceed 0.42 inches, and at least 10% of the sampled storms should exceed 0.83 inches.

Minimum Facility Flow Rate

Obtain data for a range of flows, from 10 to 100% of the design flow for off-line facilities, and from 10 to 125% for facilities designed to be flow-through, on-line facilities. Exceeding the design flow will demonstrate the facility's ability to retain previously trapped pollutants during high-flow periods. This requirement will most likely be accomplished through field testing with artificial storms.

Start/ End of Storm Event: A storm event is preceded and followed by at least six hours of dry weather.

Minimum Runoff Duration: 6 Hours.

Minimum Average Rainfall Intensity

Minimum average rainfall intensity shall be 0.02 inches/ hour. As a guideline, at least 50% of the storms should exceed 0.03 inches/ hour, and at least 10% should exceed 0.05 inches/ hour.

Maximum Average Rainfall Intensity: Maximum average rainfall intensity shall be 0.1 inches/ hour.

SAMPLING SPECIFICATIONS

Type of Samples

Flow-weighted composite samples (Event Mean Concentration or EMC), except pollutants or technologies for which grab sampling is mandated by sampling protocols. Document all sample types for BES review.

Sampling Procedure

To the maximum extent practicable, sample the entire runoff period. As a guideline, sample at least 75% of the total volume of each storm. The final composite sample shall comprise at least 10 influent and 10 effluent sub-samples collected throughout the storm. Plot sampling times on a copy of the runoff hydrograph.

Sampling Locations

If Method #1, 2, or 3 (Page B-10) is used to calculate Removal Efficiency: Collect influent samples and measurements of flow rates and volumes at a point upstream of the treatment system, before any flow

bypasses. Collect effluent samples and measurements of flow rates and volumes at a point downstream of the treatment system after bypassed and treated flows are rejoined.

If Method #4 (Page 10) is used to calculate Removal Efficiency: Ensure that the unit has been thoroughly cleaned and all sediment removed prior to start of test. Collect influent samples and measurements of flow rates and volumes at a point upstream of the treatment system. Immediately after test, block incoming flows and remove collected pollution for analysis.

Document all sampling locations for BES review.

Parameters of Interest

Parameters of interest include: total suspended solids (TSS), total dissolved solids, BOD, temperature, pH, hardness, total recoverable and dissolved metals including zinc, copper, lead, and cadmium, total and ortho-phosphate, total nitrogen, total petroleum hydrocarbons (NWTPH-Dx and –Gx, silica gel), visible sheen, bacteria (E. coli), nitrate-N, and ammonia-N. The vendor may submit any additional parameters that are deemed to be relevant to facility performance.

The vendor should tailor its sampling procedure to support the treatment goal. To be included in the Stormwater Manual as a general "Presumptive Approach", TSS needs to be sampled. To be considered as an oil/ water separator, Total petroleum hydrocarbons (NWTPH-Dx and –Gx, silica gel) and visible sheen needs to be tested. To be considered for use in TMDL watersheds, other pollutants of concern must be addressed. Because pollution removal parameter requirements tend to change over time, it is in the vendor's best interest to evaluate as many pollutants as possible. Testing methods and procedures are not included in this document for all pollutants of interest, and therefore must be submitted to BES with any testing data.

Sample Handling and Reporting

The methods of sample preservation and analysis are to be documented and submitted with test results. A qualified laboratory shall analyze samples. Results shall be analyzed and reported by entities independent of the vendor. The report shall discuss any discarded samples, QA/QC, duplicates, and ignored data. Analyzation techniques should not employ very minute samples, such as the "10 ml technique".

ACCUMULATED SEDIMENT TESTING

At the end of the test period, remove, weigh, and analyze accumulated sediment. Evaluate the sediment for the following: total dry weight, moisture content, particle size distribution, organic content, TPH, total phosphorus, and total zinc, copper, cadmium, and lead. Analyze particle size distribution using both wet and dry sieve test procedures following ASTM methods. Analyzing particle size distribution is very important in determining a facility's ability to remove the full range of sediment sizes (see table on page B-9). Quantify or otherwise document gross solids (debris, litter, and other particles exceeding 1 mm in diameter) and oil accumulations.

GROSS SOLIDS TESTING

At the end of the test period, remove, weigh, and describe accumulated gross solids. Compare gross solids collected in the facility with gross solids bypassed downstream, measured through collection in mesh bags with one-millimeter openings.

RAINFALL MONITORING

Rainfall shall be measured at a representative site. Document site location and distance from facility.

GEOGRAPHIC SETTING

Sites in the Pacific Northwest (SCS Type 1A Rainfall Distribution) are preferred, but not required, as long as rainfall and runoff measurements are within tolerances specified on page B-7.

B. FIELD PERFORMANCE STUDIES WITH ARTIFICIAL STORMS

Field performance studies with artificial storms may be submitted by vendors. The procedures described above for "real" storms must be followed, and additional data on the methods used to calculate and field-distribute the artificial storms must be documented and submitted. An artificial hydrograph or series of constant flow rates must be formulated and followed during the field test. It is highly recommended that the vendor submit this artificial hydrograph to BES for review prior to field testing.

C. LABORATORY PERFORMANCE STUDIES

BES recognizes that laboratory testing provides useful information under controlled conditions. Vendors may submit laboratory performance studies for consideration. Up to one-half (15) of the performance studies may be performed in the laboratory.

Removal rates for tests using potable water, spiked with pollutants, have generally been shown to be higher than tests using “real” storm water. Real storm water is therefore preferred when laboratory testing is employed, and should be used for at least half of the tests. When real storm water is used, one performance study shall be comprised of at least 10 influent and 10 effluent samples collected throughout the testing period (treatment efficiency calculation method #1, Page B-10), or 10 influent samples collected throughout the testing period and one final captured load mass (treatment efficiency calculation method #4, Page B-10). Documentation of the method of acquisition of test water must be submitted to BES for approval.

Spiked test water may be used for up to seven studies. When spiked test water is used, one study shall consist of either; 1) a test performed on water loaded with the full range of particle sizes, or 2) a series of tests on each separate particle size. Treatment efficiency calculation method #4 on page B-10 shall be used in either case. TSS added to laboratory water shall conform to the particle size distribution shown in the table below. Documentation of the composition of test water must be submitted to BES for approval.

TABLE: DISTRIBUTION OF SEDIMENT SIZES (STANDARD SIEVE)

PARTICLE DIAMETER	% LESS THAN (WEIGHT)
< 1,000 micron	100%
< 707 micron (coarse sand)	95 to 100%
< 595 micron	90 to 95%
< 420 micron (medium sand)	85 to 90%
< 297 micron	80 to 85%
< 177 micron (fine sand)	75 to 80%
< 88 micron (very fine sand)	50 to 75%
< 44 micron (coarse silt)	25 to 50%
< 16 micron (medium silt)	0 to 25%
<8 micron (fine silt)	0%

D. TREATMENT EFFICIENCY

There are many different methods used to calculate treatment efficiency, four of which are shown below. Method #1 and #4 calculate efficiencies for individual storms, while method #2 and #3 calculate average

efficiencies over a number of storms. While any of these described methods are acceptable for use, methods 1 and 4 require fewer storm events to be sampled and are therefore easier to perform. Describe which treatment efficiency methods below were used and include calculations. All are expressed as percentages. Any samples analyzed below detection limits may either be included at the detection limit, or be excluded (with a notation to that effect).

Method #1: Removal in each storm calculated as:

100(flow-weighted influent concentration – flow-weighted effluent concentration) / flow-weighted influent concentration

Where: All concentrations are averages of the 10 flow-weighted sub-samples.

Method #2: Aggregate removal of the storms sampled as:

100(A-B) / A

Where: A = (influent concentration Storm 1)(flow of Storm 1) + (influent concentration of Storm 2)(flow of Storm 2) +…(influent concentration of Storm N)(flow of Storm N)

B = (effluent concentration of Storm 1)(flow of Storm 1) + (effluent concentration of Storm 2)(flow of Storm 2) +…(effluent concentration of Storm N)(flow of Storm N)

Where concentrations are flow-weighted, and flow = average storm flow or total storm volume (vendor's choice).

Method #3: Efficiency based on geometric mean:

100(A-B) / A

Where: A = Geometric mean of all products of flow-weighted influent concentration times average storm flow or total storm volume.

B = Geometric mean of all products of flow-weighted effluent concentration times average storm flow or total storm volume.

Method #4: Removal in each storm calculated as:

Efficiency = 100(Captured load mass) / (Influent load mass over entire storm)

Where: Captured load mass = Mass of accumulated TSS in the treatment facility during testing period

Influent load mass over entire storm = Flow-weighted influent concentration times total storm volume through facility, or for laboratory tests with spiked water, total mass of added TSS. Note: TSS gradation must comply with table on page B-9.

E. FACTORS OTHER THAN TREATMENT PERFORMANCE

BES staff must make reasoned decisions about storm water treatment technologies. To do so, all relevant factors need to be evaluated, while recognizing the critical importance of the technology's verified treatment performance for a target group of pollutants. Given the limited experience with emerging technologies, this is an arena where "best professional judgement" based on the weight of evidence is appropriate. To be accepted as a publicly owned and maintained facility, the vendor must present the following data to BES's *Standards and Practices Committee*, and receive their official consent. To be accepted for use as private facilities, the vendor must submit the following data to the BES address on page B-13.

Applications

1) How does the facility work? How does it remove pollutants?
2) For which applications (e.g. land uses, pollutants) does the vendor recommend this technology? Why?
3) How many systems are installed in the United States? Provide at least three references with names and telephone numbers. Provide specific model numbers.
4) Provide information on at least three units owned and maintained by public municipalities and information on the oldest units installed to date. Provide specific model numbers.

Site Characteristics

5) Do any of these site characteristics or safety considerations favor or limit the technology's use: steep slopes, high groundwater, baseflows, soils, proximity to wells, septic systems and buildings, facility depth limits for access and safety, risk of hazardous materials spills, and driving head requirements? How?

Design Criteria

6) Pollutant removal at design flow and for representative storm water characteristics (e.g. TSS particle size distribution)
7) Stormwater constituent limitations, pollutants and other constituents, including fouling factors
8) Design hydraulics (treatment and hydraulic design flows, by-pass flow, hydraulic grade line, scour velocities, etc.)
9) Design residence time, vertical/ horizontal velocities, etc.
10) Specific flow rate for media
11) Head loss curves for media
12) Minimum contact time and minimum thickness for media
13) Design life of system or components of the system before major overhaul is projected; describe fully
14) Media specifications to ensure that adequate quality of each medium is supplied to the user at all times. A list of all the physical/ chemical and impurity specifications should be provided
15) Structural, water tightness, buoyancy, and constructability
16) Design sizing and cost information for units designed to perform without maintenance for one full-year, and over-designed to last three years before the first cleaning.
17) Pretreatment requirements if any
18) Materials used to construct facility

Construction

19) What role does the vendor take in design and construction? Will a vendor representative be available to the contractor in the field? A letter from the vendor is required with every facility accepted to be publicly owned and maintained. This letter must confirm that the facility is being designed per manufacturer specifications to meet City of Portland requirements.
20) List the steps taken to install the technology. How long does it take?
21) How are factors such as structural integrity, water tightness, and buoyancy addressed?
22) What types of problems can occur in designing and installing the technology?

23) How are potential problems diagnosed and corrected, and by whom?
24) If problems go uncorrected, how does this affect the technology's effectiveness? What will cause complete facility failure?
25) How available is the technology (e.g. where do the major components come from and how much lead-time is needed?)

Costs

26) Provide materials (capital) and installation costs for complete system(s), indicating total costs and costs per cfs treated (not per cfs hydraulic capacity)
27) What is estimated useful facility life before replacement is needed?

Operation and Maintenance: For a typical installation with typical stormwater, discuss each of the following:

28) How are inspections performed and how often?
29) How do you tell or forecast when maintenance will be needed, i.e., what is the "trigger" for determining when maintenance is needed and why?
30) How is maintenance performed? Specify equipment, materials, and man-hours necessary
31) Are all maintenance areas accessible by people and equipment? Are special equipment or methods needed for access? Any confined space entry areas?
32) What is the estimated maintenance frequency and on what information/ tests do you base this estimate?
33) What role does the vendor take in maintenance/ How much does the vendor charge for maintenance service?
34) Can the technology be damaged due to delayed maintenance, and if so, how is it restored?
35) How many years have you been in business? If vendor goes out of business or product model changes, how/ where will facility owner find needed parts, materials, and service?
36) Provide information on how other public jurisdictions clean and maintain their units.
37) Is there a standardized Operations and Maintenance plan available? If so, please provide a copy.

Reliability

38) Assuming the technology is designed and installed correctly, what factors can cause it not to perform as designed?
39) Can the technology add, transform, or release accumulated pollutants?
40) Does the filter medium decompose or is it subject to slime/ bacteria growth/
41) Is the technology sensitive to heavy or fine sediment loadings- is pretreatment required?
42) How is under-performance diagnosed and treated?
43) What is the warranty?
44) What initial/ ongoing user support is provided? Does the vendor charge for support?

Other Factors

45) Does the technology provide benefits or present challenges in other potentially relevant areas, such as groundwater recharge, thermal effects on surface waters, habitat creation, aesthetics, vectors, safety, community acceptance, and recreational use?

IV. REPORTING

Vendors seeking BES approval of manufactured stormwater treatment facilities must submit the specified test data in report format, and must include answers to the "Factors Other than Treatment Performance" section above. While treatment performance is the most obvious factor in determining facility acceptance, others such as maintainability and reliability are equally important.

All relevant data should be included in the report, including but not limited to: test site locations with maps, dates and times of sampling, topography maps outlining drainage basins, system plans showing all relevant stormwater piping and pollution reduction facilities, expected flow calculations for various storm events, beginning and end times of all storm events and samplings, rainfall data from specified rain gage, measured flows through the system at various times (submit calculated hydrographs), and history of the facility (when constructed, when last maintenance/ cleaning occurred, etc.). All data pertaining to characteristics of storms and sampling procedures must be submitted to show conformance with previous specifications.

All reports should be submitted to ATTN: Steve Fancher, PE
Bureau of Environmental Services, C.O.P.
1120 SW 5th Ave. Room 1100
Portland, OR 97204-1972

BES will evaluate the data and report findings to the vendor within 60 days of the submittal.

V. DATA EVALUATION

BES will evaluate the data submitted by the vendors, and group each technology into one or more of the following classifications:

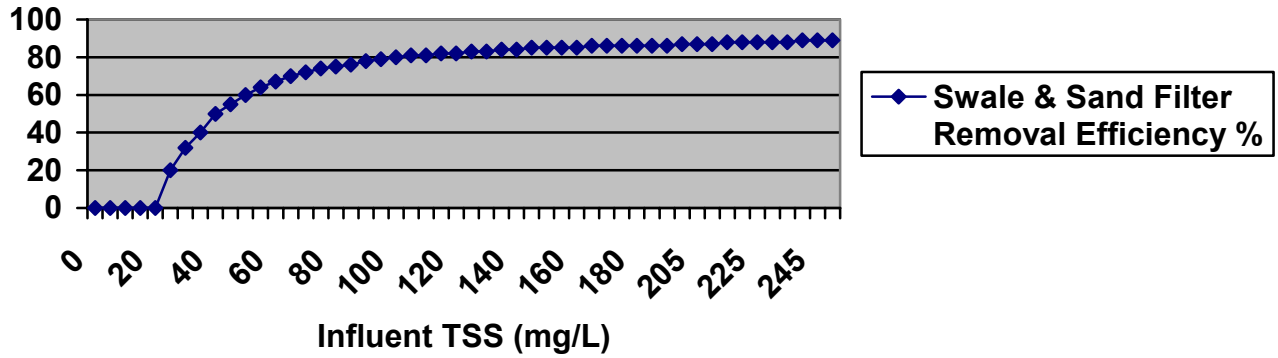
- Presumptive Approach (TSS)
- Pretreatment Only
- Oil/ Water Separation
- Specific Pollutants of Concern (TMDL pollutants)
- Acceptable as Public Facility
- Private Facility Only
- Not Approved for Any Application
- Insufficient Information, Provide Additional Data

LINES OF COMPARABLE PERFORMANCE

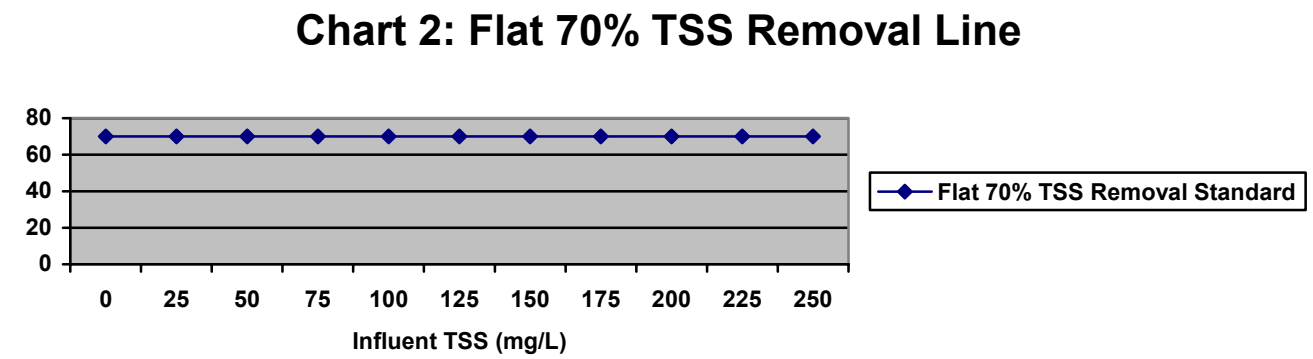
As mentioned earlier, BES will use the "Line of Comparative Performance©" method to evaluate a treatment technology's ability to remove TSS. The following table describes the data points that form the approximate grassy swale/ sand filter comparison line:

INFLUENT TSS (mg/L)	REMOVAL EFFICIENCY
20	0 %
25	20 %
50	60 %
75	74 %
100	80 %
125	83 %
150	85 %
175	87 %
200	88 %
250	89 %

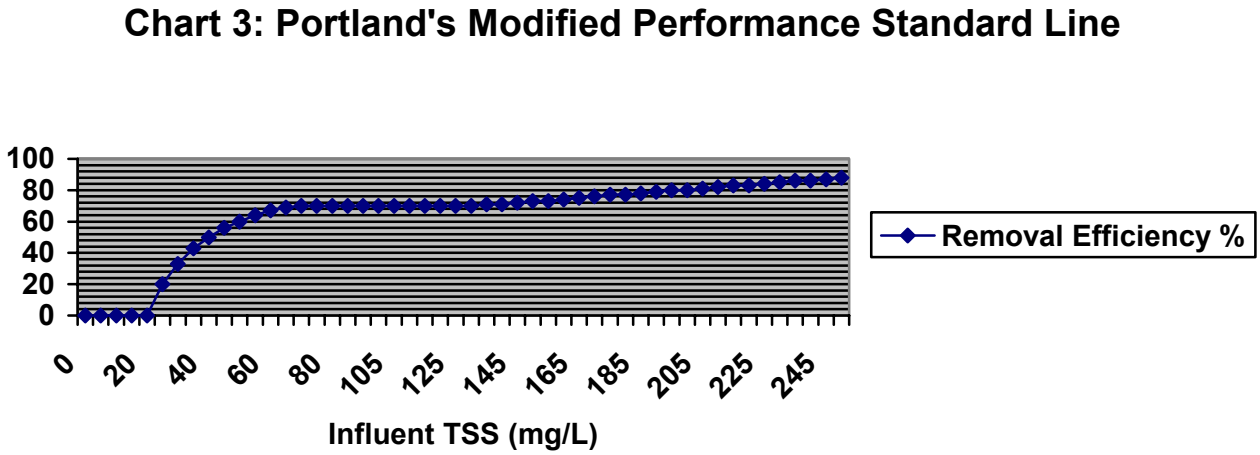
Chart 1: Grassy Swale/ Sand Filter Line of Performance



The following chart represents a flat "70% TSS Removal" standard:



The following performance line is consistent with the City of Portland's 70% TSS removal standard and takes into account influent TSS concentrations:



According to Section 403 Report to Congress, U.S. EPA, 1995, "Typical" stormwater contains about 100 mg/L TSS. This line specifies 70% TSS removal for a range 30% below and 30% above 100 mg/L. For every point with less than 70 mg/L influent TSS, it is assumed that the effluent will be the minimum allowed 20 mg/L. For influent concentrations greater than 130 mg/L, the points rise linearly to 88% removal at 250 mg/L, which is a point shared with the swale/ sand filter comparison line.

To meet the City of Portland's basic pollution reduction standard, at least 50% of a technology's data points should fall above this line of performance, as approved by BES. Efficiency calculation methods on page B-9 and 10 shall be used to plot points on the chart. Facilities will be required to remove more than 70% for high (<130 mg/L) influent concentrations, while being allowed to remove less than 70% for low (<70 mg/L) influent concentrations. This will result in facilities being evaluated as they actually perform in the field, with those that average 70% TSS removal during the design storm of 0.83 inches over 24 hours receiving acceptable performance evaluations.

SAMPLE DATA COLLECTION SHEET

FIELD SITE #1

TEST 1= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 2= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 3= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 4= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 5= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____

FIELD SITE #2

TEST 1= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 2= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 3= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 4= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 5= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____

FIELD SITE #3

TEST 1= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 2= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 3= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 4= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 5= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____

LABORATORY STUDIES WITH "REAL" STORMWATER

TEST 1= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 2= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 3= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 4= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 5= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 6= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 7= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____
TEST 8= 10 sub-samples: ave. influent conc.=_____; ave. effluent conc.=_____; efficiency=_____

LABORATORY STUDIES WITH SPIKED WATER

TEST 1: influent load mass over entire storm=_____; captured load mass=_____; efficiency=_____
TEST 2: influent load mass over entire storm=_____; captured load mass=_____; efficiency=_____
TEST 3: influent load mass over entire storm=_____; captured load mass=_____; efficiency=_____
TEST 4: influent load mass over entire storm=_____; captured load mass=_____; efficiency=_____
TEST 5: influent load mass over entire storm=_____; captured load mass=_____; efficiency=_____
TEST 6: influent load mass over entire storm=_____; captured load mass=_____; efficiency=_____
TEST 7: influent load mass over entire storm=_____; captured load mass=_____; efficiency=_____

VI. REFERENCES

Washington Department of Ecology, "Draft 4: Vendor Submission Guidance for Evaluating Emerging Stormwater Treatment Technologies", October 2000

Puget Sound Watershed, "Final Draft: Protocol for the Acceptance of Unapproved Stormwater Treatment Technologies for Use in the Puget Sound Watershed", APWA Task Committee, November 1999

The County of Sacramento and Cities of Citrus Heights, Folsom, Galt, and Sacramento, "Investigation of Structural Control Measures for New Development", November 1999

Boyd, Gail, URS Corporation, personal communication

SARB_008066

Technical Update #1

Subject: **Vendor Submission Guidance for Evaluating Stormwater Treatment Technologies: Clarification Regarding "TSS" versus "SSC" Testing Methods**

Date: **July 5, 2001**

The recently released USGS policy regarding the collection and use of total suspended solids data in determining the suspended sediment load in stormwater runoff was recently brought to our attention. We have been reviewing the USGS "Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data" document dated August of 2000, and would like to clarify our sampling specifications, as listed in the above mentioned "Vendor Submission Guidance for Evaluating Stormwater Treatment Technologies".

By using "Total Suspended Solids" or "TSS" terminology, we may have implied that the *Total Suspended Solids Analytical Method*, as described by the American Public Health Association, American Water Works Association, and Water Pollution Control Federation should be used to analyze test samples. According to the USGS study (Water-Resources Investigations Report 00-4191 by John R. Gray, G. Douglas Glysson, Lisa M. Turcios, and Gregory E. Schwarz) this method, which uses predetermined sub-sample volumes from an original water sample obtained while the sample is being mixed, is fundamentally unreliable for the analysis of natural-water samples. Methods used in the withdrawal of an aliquot of the original sample are inconsistent and often non-representative of the sample.

The *Suspended-Sediment Concentration Analytical Method*, however, measures all sediment and the mass of the entire water-sediment mixture. ASTM Standard Test Method D 3977-97 lists three methods that result in a determination of SSC values in water and wastewater samples: Test Method A- Evaporation, Test Method B- Filtration, and Test Method C- Wet-sieving filtration. The percentage of sand-size and finer material can be determined as part of the SSC method, but not as part of the TSS method. Overall, the SSC method "produces relatively reliable results for samples of natural water, regardless of the amount or percentage of sand-size material in the samples".

We would like to see the *Suspended-Sediment Concentration Analytical Method* used, as described in ASTM D 3977-97 for analysis of suspended sediment load in stormwater runoff.

Appendix C
SANTA BARBARA URBAN HYDROGRAPH METHOD

INTRODUCTION

The Santa Barbara Urban Hydrograph (SBUH) method was developed by the Santa Barbara County Flood Control and Water Conservation District to determine a runoff hydrograph for an urbanized area. It is a simpler method than some other approaches, as it computes a hydrograph directly without going through intermediate steps (i.e., a unit hydrograph) to determine the runoff hydrograph.

The SBUH method is a popular method for calculating runoff, since it can be done with a spreadsheet or by hand relatively easily. The SBUH method is the method approved by the Bureau of Environmental Services (BES) for determining runoff when doing flow control calculations.

ELEMENTS OF THE SBUH METHOD

The SBUH method depends on several variables:

- Pervious (A_p) and impervious (A_{imp}) land areas
- Time of concentration (T_c) calculations
- Runoff curve numbers (CN) applicable to the site
- Design storm

These elements shall all be presented as part of the submittal process for review by BES staff. In addition, maps showing the pre-development and post-development conditions shall be presented to BES to help in the review.

Land Area

The total area, including the pervious and impervious areas within a drainage basin, shall be quantified in order to evaluate critical contributing areas and the resulting site runoff. Each area within a basin shall be analyzed separately and their hydrographs combined to determine the total basin hydrograph. Areas shall be selected to represent homogenous land use/development units.

Time of Concentration

Time of concentration, T_c, is the time for a theoretical drop of water to travel from the furthest point in the drainage basin to the facility being designed. (In this case, T_c is derived by calculating the overland flow time of concentration and the channelized flow time of concentration.) T_c depends on several factors, including ground slope, ground roughness, and distance of flow. The following formula for determining T_c is found in BES's *Sewer Design Manual*.

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Formulas

$T_c = T_{t1} + T_{c2} + T_{c3} + \ldots + T_{cn}$

$T_t = L/60V$ (Conversion of velocity to travel time)

$T_t = \frac{0.42\,(nL)^{0.8}}{1.58(s)^{0.4}}$ (Manning's kinematic solution for sheet flow less than 300 feet)

(Shallow concentrated flow for slopes less than 0.005 ft/ft. For steeper slopes, consult BES's Sewer Design Manual):

$V = 16.1345(s)^{0.5}$ (Unpaved surfaces)

$V = 20.3282(s)^{0.5}$ (Paved surfaces)

Where,

- T_t = travel time, minutes
- T_c = total time of concentration, minutes (minimum T_c = 5 minutes)
- L = flow length, feet
- V = average velocity of flow, feet per second
- n = Manning's roughness coefficient for various surfaces (see Chart 10 of the 1991 Sewer Design Manual)
- s = slope of the hydraulic grade line (land or watercourse slope), feet per foot

When calculating T_c, the following limitations apply:

- Overland sheet flow (flow across flat areas that does not form into channels or rivulets) shall not extend for more than 300 feet.

- For flow paths through closed conveyance facilities such as pipes and culverts, standard hydraulic formulas shall be used for establishing velocity and travel time. (See the *Sewer Design Manual* for more data on pipe flow rates and velocities.)

- Flow paths through lakes or wetlands may be assumed to be zero (i.e. $T_c = 0$).

Runoff Curve Numbers

Runoff curve numbers were developed by the Natural Resources Conservation Service (NRCS) after studying the runoff characteristics of various types of land. Curve numbers (CN) were developed to reduce diverse characteristics such as soil type, land usage, and vegetation into a single variable for doing runoff calculations. The runoff curve numbers approved by BES for water quantity/quality calculations are included as Table C-2 of this appendix.

The curve numbers presented in Table C-2 are for *wet* antecedent moisture conditions. Wet conditions assume previous rainstorms have reduced the capacity of soil to absorb water. Given the frequency of rainstorms in the Portland area, wet conditions are most likely, and give conservative hydrographic values.

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Design Storm

The SBUH method also requires a design storm to perform the runoff calculations. For flow control calculations, BES uses a NRCS Type 1A 24-hour storm distribution. This storm is shown in Figure C-1 and Table C-4. The depth of rainfall for the 2 through 100-year storm events is shown below in Table C-1.

Table C-1
24-HOUR RAINFALL DEPTHS AT PORTLAND AIRPORT

Recurrence Interval, Years	2	5	10	25	100
24-Hour Depths, Inches	2.4	2.9	3.4	3.9	4.4

Table C-2
RUNOFF CURVE NUMBERS

Runoff curve numbers for urban areas*

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area	A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.):					
Poor condition (grass cover <50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82

Runoff curve numbers for other agricultural lands*

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing					
<50% ground cover or heavily grazed with no mulch	Poor	68	79	86	89
50 to 75% ground cover and not heavily grazed	Fair	49	69	79	84
>75% ground cover and lightly or only occasionally grazed	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay	-	30	58	71	78
Brush--weed-grass mixture with brush as the major element					
<50% ground cover	Poor	48	67	77	83
50 to 75% ground cover	Fair	35	56	70	77
>75% ground cover	Good	30	48	65	73
Woods-grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79

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Runoff curve numbers for other agricultural lands*

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Woods					
Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.	Poor	45	66	77	83
Woods are grazed but not burned, and some forest litter covers the soil.	Fair	36	60	73	79
Woods are protected from grazing, and litter and brush adequately cover the soil.	Good	30	55	70	77

Runoff curve numbers for Simplified Approaches**

Cover description		Curve numbers for hydrologic soil group			
Simplified Approaches	Hydrologic condition	A	B	C	D
Eco-roof	Good	n/a	61	n/a	n/a
Roof Garden	Good	n/a	48	n/a	n/a
Contained Planter Box	Good	n/a	48	n/a	n/a
Infiltration & Flow-Through Planter Box	Good	n/a	48	n/a	n/a
Pervious Pavement	-	76	85	89	n/a
Trees					
New and/or Existing Evergreen	-	36	60	73	79
New and/or Existing Deciduous	-	36	60	73	79

n/a - Does not apply, as design criteria for the relevant mitigation measures do not include the use of this soil type.
*Soil Conservation Service, *Urban Hydrology for Small Watersheds*, Technical Release 55, pp. 2.5-2.8, June 1986.
**CNs of various cover types were assigned to the Proposed Simplified Approaches with similar cover types as follows:

Eco-roof – assumed grass in good condition with soil type B.
Roof Garden – assumed brush-weed-grass mixture with >75% ground cover and soil type B.
Contained Planter Box – assumed brush-weed-grass mixture with >75% ground cover and soil type B.
Infiltration & Flow-Through Planter Box – assumed brush-weed-grass mixture with >75% ground cover and soil type B.
Pervious Pavement – assumed gravel.
Trees – assumed woods with fair hydrologic conditions.

Note: To determine hydrologic soil type, consult local USDA Soil Conservation Service Soil Survey.

TABLE C-3
NRCS HYDROLOGIC SOIL GROUP DESCRIPTIONS

NRCS Hydrologic Soil Group	Description
Group A	Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist chiefly of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water transmission.
Group B	Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
Group C	Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils that have a layer that impedes the downward movement of water or soils that have moderately fine texture or fine texture. These soils have a slow rate of water transmission.
Group D	Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clay soils that have a high shrink-swell potential, soils that have a permanent high water table, soils that have a fragipan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

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Figure C-1 - NRCS 24-Hour Type 1A Hyetograph

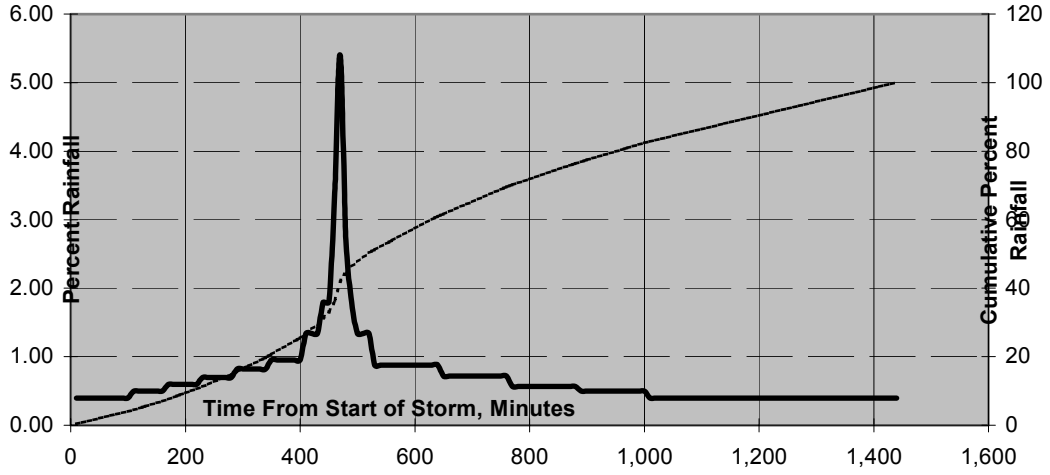

Table C-3 - NRCS Type 1A Hyetographic Distrubution - For Use In Water Quality/Quantity Design

Time From Start of Storm, Minutes		% Rainfall	Cumu-lative % Rainfall	Time From Start of Storm, Minutes		% Rainfall	Cumu-lative % Rainfall	Time From Start of Storm, Minutes		% Rainfall	Cumu-lative % Rainfall	Time From Start of Storm, Minutes		% Rainfall	Cumu-lative % Rainfall
0 -	10	0.40	0.40	360 -	370	0.95	22.57	720 -	730	0.72	67.40	1080 -	1090	0.40	86.00
10 -	20	0.40	0.80	370 -	380	0.95	23.52	730 -	740	0.72	68.12	1090 -	1100	0.40	86.40
20 -	30	0.40	1.20	380 -	390	0.95	24.47	740 -	750	0.72	68.84	1100 -	1110	0.40	86.80
30 -	40	0.40	1.60	390 -	400	0.95	25.42	750 -	760	0.72	69.56	1110 -	1120	0.40	87.20
40 -	50	0.40	2.00	400 -	410	1.34	26.76	760 -	770	0.57	70.13	1120 -	1130	0.40	87.60
50 -	60	0.40	2.40	410 -	420	1.34	28.10	770 -	780	0.57	70.70	1130 -	1140	0.40	88.00
60 -	70	0.40	2.80	420 -	430	1.34	29.44	780 -	790	0.57	71.27	1140 -	1150	0.40	88.40
70 -	80	0.40	3.20	430 -	440	1.80	31.24	790 -	800	0.57	71.84	1150 -	1160	0.40	88.80
80 -	90	0.40	3.60	440 -	450	1.80	33.04	800 -	810	0.57	72.41	1160 -	1170	0.40	89.20
90 -	100	0.40	4.00	450 -	460	3.40	36.44	810 -	820	0.57	72.98	1170 -	1180	0.40	89.60
100 -	110	0.50	4.50	460 -	470	5.40	41.84	820 -	830	0.57	73.55	1180 -	1190	0.40	90.00
110 -	120	0.50	5.00	470 -	480	2.70	44.54	830 -	840	0.57	74.12	1190 -	1200	0.40	90.40
120 -	130	0.50	5.50	480 -	490	1.80	46.34	840 -	850	0.57	74.69	1200 -	1210	0.40	90.80
130 -	140	0.50	6.00	490 -	500	1.34	47.68	850 -	860	0.57	75.26	1210 -	1220	0.40	91.20
140 -	150	0.50	6.50	500 -	510	1.34	49.02	860 -	870	0.57	75.83	1220 -	1230	0.40	91.60
150 -	160	0.50	7.00	510 -	520	1.34	50.36	870 -	880	0.57	76.40	1230 -	1240	0.40	92.00
160 -	170	0.60	7.60	520 -	530	0.88	51.24	880 -	890	0.50	76.90	1240 -	1250	0.40	92.40
170 -	180	0.60	8.20	530 -	540	0.88	52.12	890 -	900	0.50	77.40	1250 -	1260	0.40	92.80
180 -	190	0.60	8.80	540 -	550	0.88	53.00	900 -	910	0.50	77.90	1260 -	1270	0.40	93.20
190 -	200	0.60	9.40	550 -	560	0.88	53.88	910 -	920	0.50	78.40	1270 -	1280	0.40	93.60
200 -	210	0.60	10.00	560 -	570	0.88	54.76	920 -	930	0.50	78.90	1280 -	1290	0.40	94.00
210 -	220	0.60	10.60	570 -	580	0.88	55.64	930 -	940	0.50	79.40	1290 -	1300	0.40	94.40
220 -	230	0.70	11.30	580 -	590	0.88	56.52	940 -	950	0.50	79.90	1300 -	1310	0.40	94.80
230 -	240	0.70	12.00	590 -	600	0.88	57.40	950 -	960	0.50	80.40	1310 -	1320	0.40	95.20
240 -	250	0.70	12.70	600 -	610	0.88	58.28	960 -	970	0.50	80.90	1320 -	1330	0.40	95.60
250 -	260	0.70	13.40	610 -	620	0.88	59.16	970 -	980	0.50	81.40	1330 -	1340	0.40	96.00
260 -	270	0.70	14.10	620 -	630	0.88	60.04	980 -	990	0.50	81.90	1340 -	1350	0.40	96.40
270 -	280	0.70	14.80	630 -	640	0.88	60.92	990 -	1000	0.50	82.40	1350 -	1360	0.40	96.80
280 -	290	0.82	15.62	640 -	650	0.72	61.64	1000 -	1010	0.40	82.80	1360 -	1370	0.40	97.20
290 -	300	0.82	16.44	650 -	660	0.72	62.36	1010 -	1020	0.40	83.20	1370 -	1380	0.40	97.60
300 -	310	0.82	17.26	660 -	670	0.72	63.08	1020 -	1030	0.40	83.60	1380 -	1390	0.40	98.00
310 -	320	0.82	18.08	670 -	680	0.72	63.80	1030 -	1040	0.40	84.00	1390 -	1400	0.40	98.40
320 -	330	0.82	18.90	680 -	690	0.72	64.52	1040 -	1050	0.40	84.40	1400 -	1410	0.40	98.80
330 -	340	0.82	19.72	690 -	700	0.72	65.24	1050 -	1060	0.40	84.80	1410 -	1420	0.40	99.20
340 -	350	0.95	20.67	700 -	710	0.72	65.96	1060 -	1070	0.40	85.20	1420 -	1430	0.40	99.60
350 -	360	0.95	21.62	710 -	720	0.72	66.68	1070 -	1080	0.40	85.60	1430 -	1440	0.40	100.00

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Appendix D
SIMPLIFIED APPROACH SIZING CALCULATIONS

The spreadsheet columns are described below:

Column (1)	Time in Minutes
Column (2)	Inflow for Storm Event (25-Year Detention Storm 3.9"/24 hours) and Contributing Impervious Area (1 acre)
Column (3)	Inflow (cf) = Inflow (cfs) x 60 x 10
Column (4)	Inflow (in) = Inflow (cf) x 12 / 43,560
Column (5)	Cumulative Inflow (in) = inflow (in) + Cumulative inflow (in) of previous step
Column (6)	Max Outflow (cfs) = Facility Area (sf) x Infiltration Rate (ft/s) **Note: Infiltration rate is assumed to be 2.5"/hr in this case. Also, for simplicity head is not taken into account.**
Column (7)	Cumulative Outflow (cf) = outflow (cfs) x 10 x 60 + cumulative outflow (cf) of previous step
Column (8)	Inflow – Outflow (cfs) = Column 2 inflow (cfs) – Column 6 outflow (cfs)
Column (9)	Incremental inflow – outflow (cf) = inflow – outflow (cfs) x 10 x 60
Column (10)	Cumulative inflow – outflow (cf) = If incremental inflow – outflow (cf) + cumulative inflow – outflow (cf) of previous step is less than 0, 0; else = incremental inflow – outflow (cf) + cumulative inflow – outflow (cf) of previous time step
Column (11)	Cumulative depth (in) = cumulative inflow – outflow (cf) x 12 / Facility Area (sf) **Note that cumulative depth does not exceed 6 inches in this case, which would result in an overflow condition. When modeling for detention purposes, overflow is allowed, but only at pre-developed peak rates. When modeling for pollution reduction, the entire post-developed runoff rate from the pollution reduction storm must be infiltrated without overflow.** **Resulting swale square-footage is 3,940, which when divided by the 43,560 square-foot impervious surface equals the 0.09 sizing factor.**

Spreadsheet Illustrating Vegetated Swale Sizing: 43,560 sq-ft imp. 25 yr storm **Swale Square Footage= 3940**

B Soil Infiltration Rate=2.5"/hr= .21 ft/hr= 0.00006 ft/s

(1) Time (min)	(2) Inflow (cfs)	(3) Inflow Volume (cf)	(4) Inflow Volume (in)	(5) Cumulative Inflow (in)	(6) Max Outflow (cfs)	(7) Cumulative Outflow Vol. (cf)	(8) Inflow - Outflow (cfs)	(9) Incremental Inflow - Outflow (cf)	(10) Cumulative Inflow - Outflow (cf)	(11) Cumulative Depth (in)
0	0	0	0.00	0.00	0.2364	0	-0.2364	-141.84	0	0
10	0	0	0.00	0.00	0.2364	141.84	-0.2364	-141.84	0	0
20	0	0	0.00	0.00	0.2364	283.68	-0.2364	-141.84	0	0
30	0	0	0.00	0.00	0.2364	425.52	-0.2364	-141.84	0	0
40	0.01	6	0.00	0.00	0.2364	567.36	-0.2264	-135.84	0	0
50	0.02	12	0.00	0.00	0.2364	709.2	-0.2164	-129.84	0	0
60	0.03	18	0.00	0.01	0.2364	851.04	-0.2064	-123.84	0	0
70	0.03	18	0.00	0.01	0.2364	992.88	-0.2064	-123.84	0	0
80	0.04	24	0.01	0.02	0.2364	1134.72	-0.1964	-117.84	0	0
90	0.05	30	0.01	0.03	0.2364	1276.56	-0.1864	-111.84	0	0
100	0.05	30	0.01	0.04	0.2364	1418.4	-0.1864	-111.84	0	0
110	0.06	36	0.01	0.05	0.2364	1560.24	-0.1764	-105.84	0	0
120	0.08	48	0.01	0.06	0.2364	1702.08	-0.1564	-93.84	0	0
130	0.08	48	0.01	0.07	0.2364	1843.92	-0.1564	-93.84	0	0
140	0.08	48	0.01	0.09	0.2364	1985.76	-0.1564	-93.84	0	0

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150	0.09	54	0.01	0.10	0.2364	2127.6	-0.1464	-87.84	0	0
160	0.09	54	0.01	0.12	0.2364	2269.44	-0.1464	-87.84	0	0
170	0.1	60	0.02	0.13	0.2364	2411.28	-0.1364	-81.84	0	0
180	0.11	66	0.02	0.15	0.2364	2553.12	-0.1264	-75.84	0	0
190	0.12	72	0.02	0.17	0.2364	2694.96	-0.1164	-69.84	0	0
200	0.12	72	0.02	0.19	0.2364	2836.8	-0.1164	-69.84	0	0
210	0.12	72	0.02	0.21	0.2364	2978.64	-0.1164	-69.84	0	0
220	0.12	72	0.02	0.23	0.2364	3120.48	-0.1164	-69.84	0	0
230	0.13	78	0.02	0.25	0.2364	3262.32	-0.1064	-63.84	0	0
240	0.15	90	0.02	0.28	0.2364	3404.16	-0.0864	-51.84	0	0
250	0.15	90	0.02	0.30	0.2364	3546	-0.0864	-51.84	0	0
260	0.15	90	0.02	0.33	0.2364	3687.84	-0.0864	-51.84	0	0
270	0.15	90	0.02	0.35	0.2364	3829.68	-0.0864	-51.84	0	0
280	0.15	90	0.02	0.38	0.2364	3971.52	-0.0864	-51.84	0	0
290	0.17	102	0.03	0.40	0.2364	4113.36	-0.0664	-39.84	0	0
300	0.18	108	0.03	0.43	0.2364	4255.2	-0.0564	-33.84	0	0
310	0.18	108	0.03	0.46	0.2364	4397.04	-0.0564	-33.84	0	0
320	0.18	108	0.03	0.49	0.2364	4538.88	-0.0564	-33.84	0	0
330	0.18	108	0.03	0.52	0.2364	4680.72	-0.0564	-33.84	0	0
340	0.18	108	0.03	0.55	0.2364	4822.56	-0.0564	-33.84	0	0
350	0.2	120	0.03	0.59	0.2364	4964.4	-0.0364	-21.84	0	0
360	0.21	126	0.03	0.62	0.2364	5106.24	-0.0264	-15.84	0	0
370	0.21	126	0.03	0.66	0.2364	5248.08	-0.0264	-15.84	0	0
380	0.22	132	0.04	0.69	0.2364	5389.92	-0.0164	-9.84	0	0
390	0.22	132	0.04	0.73	0.2364	5531.76	-0.0164	-9.84	0	0
400	0.22	132	0.04	0.77	0.2364	5673.6	-0.0164	-9.84	0	0
410	0.26	156	0.04	0.81	0.2364	5815.44	0.0236	14.16	14.16	0.04830213
420	0.31	186	0.05	0.86	0.2364	5957.28	0.0736	44.16	58.32	0.19893928
430	0.31	186	0.05	0.91	0.2364	6099.12	0.0736	44.16	102.48	0.34957644
440	0.36	216	0.06	0.97	0.2364	6240.96	0.1236	74.16	176.64	0.60254862
450	0.42	252	0.07	1.04	0.2364	6382.8	0.1836	110.16	286.8	0.97832284
460	0.6	360	0.10	1.14	0.2364	6524.64	0.3636	218.16	504.96	1.72250314
470	1.02	612	0.17	1.31	0.2364	6666.48	0.7836	470.16	975.12	3.32629766
480	0.94	564	0.16	1.46	0.2364	6808.32	0.7036	422.16	1397.28	4.76635614
490	0.52	312	0.09	1.55	0.2364	6950.16	0.2836	170.16	1567.44	5.34680040
500	0.37	222	0.06	1.61	0.2364	7092	0.1336	80.16	1647.6	5.62023959
510	0.31	186	0.05	1.66	0.2364	7233.84	0.0736	44.16	1691.76	5.77087675
520	0.31	186	0.05	1.71	0.2364	7375.68	0.0736	44.16	1735.92	5.92151390
530	0.26	156	0.04	1.76	0.2364	7517.52	0.0236	14.16	1750.08	5.96981604
540	0.21	126	0.03	1.79	0.2364	7659.36	-0.0264	-15.84	1734.24	5.91578314
550	0.21	126	0.03	1.82	0.2364	7801.2	-0.0264	-15.84	1718.4	5.86175025
560	0.21	126	0.03	1.86	0.2364	7943.04	-0.0264	-15.84	1702.56	5.80771736
570	0.21	126	0.03	1.89	0.2364	8084.88	-0.0264	-15.84	1686.72	5.75368446
580	0.21	126	0.03	1.93	0.2364	8226.72	-0.0264	-15.84	1670.88	5.69965157
590	0.21	126	0.03	1.96	0.2364	8368.56	-0.0264	-15.84	1655.04	5.64561868
600	0.21	126	0.03	2.00	0.2364	8510.4	-0.0264	-15.84	1639.2	5.59158578
610	0.21	126	0.03	2.03	0.2364	8652.24	-0.0264	-15.84	1623.36	5.53755289
620	0.21	126	0.03	2.07	0.2364	8794.08	-0.0264	-15.84	1607.52	5.48352
630	0.21	126	0.03	2.10	0.2364	8935.92	-0.0264	-15.84	1591.68	5.42948710
640	0.21	126	0.03	2.14	0.2364	9077.76	-0.0264	-15.84	1575.84	5.37545421
650	0.19	114	0.03	2.17	0.2364	9219.6	-0.0464	-27.84	1548	5.28048731
660	0.17	102	0.03	2.20	0.2364	9361.44	-0.0664	-39.84	1508.16	5.14458639
670	0.17	102	0.03	2.22	0.2364	9503.28	-0.0664	-39.84	1468.32	5.00868548
680	0.17	102	0.03	2.25	0.2364	9645.12	-0.0664	-39.84	1428.48	4.87278456
690	0.17	102	0.03	2.28	0.2364	9786.96	-0.0664	-39.84	1388.64	4.73688365
700	0.17	102	0.03	2.31	0.2364	9928.8	-0.0664	-39.84	1348.8	4.60098274
710	0.17	102	0.03	2.34	0.2364	10070.64	-0.0664	-39.84	1308.96	4.46508182
720	0.17	102	0.03	2.37	0.2364	10212.48	-0.0664	-39.84	1269.12	4.32918091
730	0.17	102	0.03	2.39	0.2364	10354.32	-0.0664	-39.84	1229.28	4.19328
740	0.17	102	0.03	2.42	0.2364	10496.16	-0.0664	-39.84	1189.44	4.05737908
750	0.17	102	0.03	2.45	0.2364	10638	-0.0664	-39.84	1149.6	3.92147817
760	0.17	102	0.03	2.48	0.2364	10779.84	-0.0664	-39.84	1109.76	3.78557725
770	0.15	90	0.02	2.50	0.2364	10921.68	-0.0864	-51.84	1057.92	3.60874233
780	0.13	78	0.02	2.52	0.2364	11063.52	-0.1064	-63.84	994.08	3.39097340
790	0.13	78	0.02	2.55	0.2364	11205.36	-0.1064	-63.84	930.24	3.17320446
800	0.13	78	0.02	2.57	0.2364	11347.2	-0.1064	-63.84	866.4	2.95543553
810	0.13	78	0.02	2.59	0.2364	11489.04	-0.1064	-63.84	802.56	2.73766659
820	0.13	78	0.02	2.61	0.2364	11630.88	-0.1064	-63.84	738.72	2.51989766
830	0.13	78	0.02	2.63	0.2364	11772.72	-0.1064	-63.84	674.88	2.30212873
840	0.13	78	0.02	2.65	0.2364	11914.56	-0.1064	-63.84	611.04	2.08435979

850	0.13	78	0.02	2.67	0.2364	12056.4	-0.1064	-63.84	547.2	1.86659086
860	0.13	78	0.02	2.70	0.2364	12198.24	-0.1064	-63.84	483.36	1.64882192
870	0.13	78	0.02	2.72	0.2364	12340.08	-0.1064	-63.84	419.52	1.43105299
880	0.13	78	0.02	2.74	0.2364	12481.92	-0.1064	-63.84	355.68	1.21328406
890	0.13	78	0.02	2.76	0.2364	12623.76	-0.1064	-63.84	291.84	0.99551512
900	0.12	72	0.02	2.78	0.2364	12765.6	-0.1164	-69.84	222	0.75727918
910	0.12	72	0.02	2.80	0.2364	12907.44	-0.1164	-69.84	152.16	0.51904324
920	0.12	72	0.02	2.82	0.2364	13049.28	-0.1164	-69.84	82.32	0.28080731
930	0.12	72	0.02	2.84	0.2364	13191.12	-0.1164	-69.84	12.48	0.04257137
940	0.12	72	0.02	2.86	0.2364	13332.96	-0.1164	-69.84	0	0
950	0.12	72	0.02	2.88	0.2364	13474.8	-0.1164	-69.84	0	0
960	0.12	72	0.02	2.90	0.2364	13616.64	-0.1164	-69.84	0	0
970	0.12	72	0.02	2.92	0.2364	13758.48	-0.1164	-69.84	0	0
980	0.12	72	0.02	2.94	0.2364	13900.32	-0.1164	-69.84	0	0
990	0.12	72	0.02	2.96	0.2364	14042.16	-0.1164	-69.84	0	0
1000	0.12	72	0.02	2.98	0.2364	14184	-0.1164	-69.84	0	0
1010	0.11	66	0.02	3.00	0.2364	14325.84	-0.1264	-75.84	0	0
1020	0.09	54	0.01	3.01	0.2364	14467.68	-0.1464	-87.84	0	0
1030	0.09	54	0.01	3.03	0.2364	14609.52	-0.1464	-87.84	0	0
1040	0.09	54	0.01	3.04	0.2364	14751.36	-0.1464	-87.84	0	0
1050	0.09	54	0.01	3.06	0.2364	14893.2	-0.1464	-87.84	0	0
1060	0.09	54	0.01	3.07	0.2364	15035.04	-0.1464	-87.84	0	0
1070	0.09	54	0.01	3.09	0.2364	15176.88	-0.1464	-87.84	0	0
1080	0.09	54	0.01	3.10	0.2364	15318.72	-0.1464	-87.84	0	0
1090	0.09	54	0.01	3.12	0.2364	15460.56	-0.1464	-87.84	0	0
1100	0.09	54	0.01	3.13	0.2364	15602.4	-0.1464	-87.84	0	0
1110	0.09	54	0.01	3.15	0.2364	15744.24	-0.1464	-87.84	0	0
1120	0.09	54	0.01	3.16	0.2364	15886.08	-0.1464	-87.84	0	0
1130	0.09	54	0.01	3.18	0.2364	16027.92	-0.1464	-87.84	0	0
1140	0.09	54	0.01	3.19	0.2364	16169.76	-0.1464	-87.84	0	0
1150	0.09	54	0.01	3.20	0.2364	16311.6	-0.1464	-87.84	0	0
1160	0.09	54	0.01	3.22	0.2364	16453.44	-0.1464	-87.84	0	0
1170	0.09	54	0.01	3.23	0.2364	16595.28	-0.1464	-87.84	0	0
1180	0.09	54	0.01	3.25	0.2364	16737.12	-0.1464	-87.84	0	0
1190	0.09	54	0.01	3.26	0.2364	16878.96	-0.1464	-87.84	0	0
1200	0.09	54	0.01	3.28	0.2364	17020.8	-0.1464	-87.84	0	0
1210	0.09	54	0.01	3.29	0.2364	17162.64	-0.1464	-87.84	0	0
1220	0.09	54	0.01	3.31	0.2364	17304.48	-0.1464	-87.84	0	0
1230	0.09	54	0.01	3.32	0.2364	17446.32	-0.1464	-87.84	0	0
1240	0.09	54	0.01	3.34	0.2364	17588.16	-0.1464	-87.84	0	0
1250	0.09	54	0.01	3.35	0.2364	17730	-0.1464	-87.84	0	0
1260	0.09	54	0.01	3.37	0.2364	17871.84	-0.1464	-87.84	0	0
1270	0.09	54	0.01	3.38	0.2364	18013.68	-0.1464	-87.84	0	0
1280	0.09	54	0.01	3.40	0.2364	18155.52	-0.1464	-87.84	0	0
1290	0.09	54	0.01	3.41	0.2364	18297.36	-0.1464	-87.84	0	0
1300	0.09	54	0.01	3.43	0.2364	18439.2	-0.1464	-87.84	0	0
1310	0.09	54	0.01	3.44	0.2364	18581.04	-0.1464	-87.84	0	0
1320	0.09	54	0.01	3.46	0.2364	18722.88	-0.1464	-87.84	0	0
1330	0.09	54	0.01	3.47	0.2364	18864.72	-0.1464	-87.84	0	0
1340	0.09	54	0.01	3.49	0.2364	19006.56	-0.1464	-87.84	0	0
1350	0.09	54	0.01	3.50	0.2364	19148.4	-0.1464	-87.84	0	0
1360	0.09	54	0.01	3.52	0.2364	19290.24	-0.1464	-87.84	0	0
1370	0.09	54	0.01	3.53	0.2364	19432.08	-0.1464	-87.84	0	0
1380	0.09	54	0.01	3.55	0.2364	19573.92	-0.1464	-87.84	0	0
1390	0.09	54	0.01	3.56	0.2364	19715.76	-0.1464	-87.84	0	0
1400	0.09	54	0.01	3.58	0.2364	19857.6	-0.1464	-87.84	0	0
1410	0.09	54	0.01	3.59	0.2364	19999.44	-0.1464	-87.84	0	0
1420	0.09	54	0.01	3.61	0.2364	20141.28	-0.1464	-87.84	0	0
1430	0.09	54	0.01	3.62	0.2364	20283.12	-0.1464	-87.84	0	0
1440	0.09	54	0.01	3.64	0.2364	20424.96	-0.1464	-87.84	0	0
1450	0.05	30	0.01	3.64	0.2364	20566.8	-0.1864	-111.84	0	0
1460	0	0	0.00	3.64	0.2364	20566.8	-0.2364	-141.84	0	0

Appendix E

STORMWATER POLLUTION REDUCTION STORM DEVELOPMENT METHODOLOGY

May 20, 2004 (Updated for September 1, 2004 Stormwater Management Manual Revision)

INTRODUCTION

The development of design storms for the sizing of stormwater pollution reduction (treatment) facilities generally involves a statistical analysis of local rainfall data, whereas a certain storm volume, duration, and peak intensity (or rainfall distribution) is identified to achieve a predetermined treatment volume goal. This treatment volume goal will vary from jurisdiction to jurisdiction, but is generally 80 to 95% of the average annual runoff. It can be linked to each jurisdiction's municipal stormwater discharge permit (MS4 permit) definition of MEP (maximum extent practicable) as it relates to the removal of pollutants from stormwater. This definition is rarely clear, but justification for the treatment volume goal generally involves social/political, economic, and environmental considerations. Without a firm grasp on the environmental consideration at this time (i.e. what percentage of average annual runoff volume needs to be treated such that the effluent water quality isn't harmful to fish or aquatic systems or groundwater resources?), the economic and social/political considerations are most widely used. An optimization model can be developed to determine a treatment volume that will result in the "biggest bang for the buck", or the point at which additional percentage points of annual treatment volume begin to require a disproportionately large increase in treatment facility size (see attached Figure 4). However the treatment volume goal is justified, the link to how treatment facilities are actually sized, and whether they end up achieving the intended goal, can be lost in translation.

TREATMENT VOLUME GOAL

Before the adoption of the September 2004 Stormwater Management Manual revision, Portland relied on a single treatment storm methodology, using a storm of 0.83 inches over 24 hours (NRCS Type 1A rainfall distribution). Used since 1994, the original intent of this design storm was to: 1) treat the "first-flush" or first 0.5 inches of runoff from all storm events and 2) pass 100% of 95% of all storm events through the treatment facility. There did not seem to be a direct environmental or economic justification for choosing 95% of storm events at the time. The justification was mainly social/political in that it sounded like a reasonable standard.

The City of Eugene uses a treatment goal of 80% of the average annual runoff, and the justification seems to be both social/political and economic, as an attempt was made to choose a treatment intensity at the "knee" of an intensity versus percentage of annual runoff volume treated curve. Gresham also uses 80% of the average annual runoff, with a similar justification (URS performed both studies). The Washington State Department of Ecology (and thus many other jurisdictions in Washington) uses 91%, and claims that an economic analysis was performed to justify the goal.

Rather than stating a treatment volume goal without a link to environmental or economic considerations, Portland has chosen to consider economic factors to provide the most "bank for the buck". From a social/political and environmental perspective it is also desirable to set a

minimum value to this goal. A continuous simulation analysis, summarized as Figure 4, has been performed on multiple years of rainfall data to determine the percentage of average annual rainfall that should be treated to maximize treatment efficiency. This analysis indicates a knee in the curve somewhere between 80 and 85 percent of the average annual volume. It may not be desirable to set the treatment goal directly at the economically optimal point, as stormwater treatment facilities do not always operate at their optimal design flow rates. Filters blind over time, or swales accumulate sediments that decrease the effective treatment flow rate through them. A margin of safety should be incorporated into the treatment volume goal. For these reasons, the City of Portland has chosen to set its treatment volume goal at 90% of the average annual rainfall volume.

TREATMENT STORM ANALYSIS

Over the past several years, Portland's 0.83" storm and justification have been questioned by other northwest jurisdictions. Agencies such as NOAA Fisheries are unsure which stormwater management regulations to use in the Pacific Northwest, as from an outside perspective the water quality storms and overall treatment goals used by various jurisdictions seem to vary dramatically. On the surface, Washington State DOE appears to use a treatment volume roughly double that of Portland's, although with the incorporation of the Vb/Vr (volume of basin / volume of runoff) factor they are basically equal (both result in the use of 2/3rd of the 2-year, 24-hour storm volume). The City of Eugene uses 1.4"/ 24 hours, and the City of Gresham uses 1.2"/12 hours. Their treatment storm volumes appear greater than Portland's (1.4" and 1.2" compared with 0.83"), but with the incorporation of the Vb/Vr ratio, are actually less (1.4" and 1.2" compared with 1.66").

While the City of Eugene uses 1.4"/ 24 hours for volume based treatment facilities, they use the intensities of 0.13"/hr and 0.22"/hr (for off-line and on-line facilities, respectively) for flow rate based facilities. These dual sizing standards result in treatment of 80% of the average annual runoff for rate based facilities, and 100% treatment of the 80th percentile storm for volume based facilities. At this time it is unclear how the treatment of X% of the average annual runoff with rate based systems is comparable to treating the Xth percentile storm with volume based facilities. Rather than sizing to the Xth percentile storm for volume based facilities, it is recommended to use a different methodology (see discussion under Volume Based Treatment Systems). In either case, the need for separate rate and volume based facility sizing standards is clear if the treatment volume goal is to remain consistent.

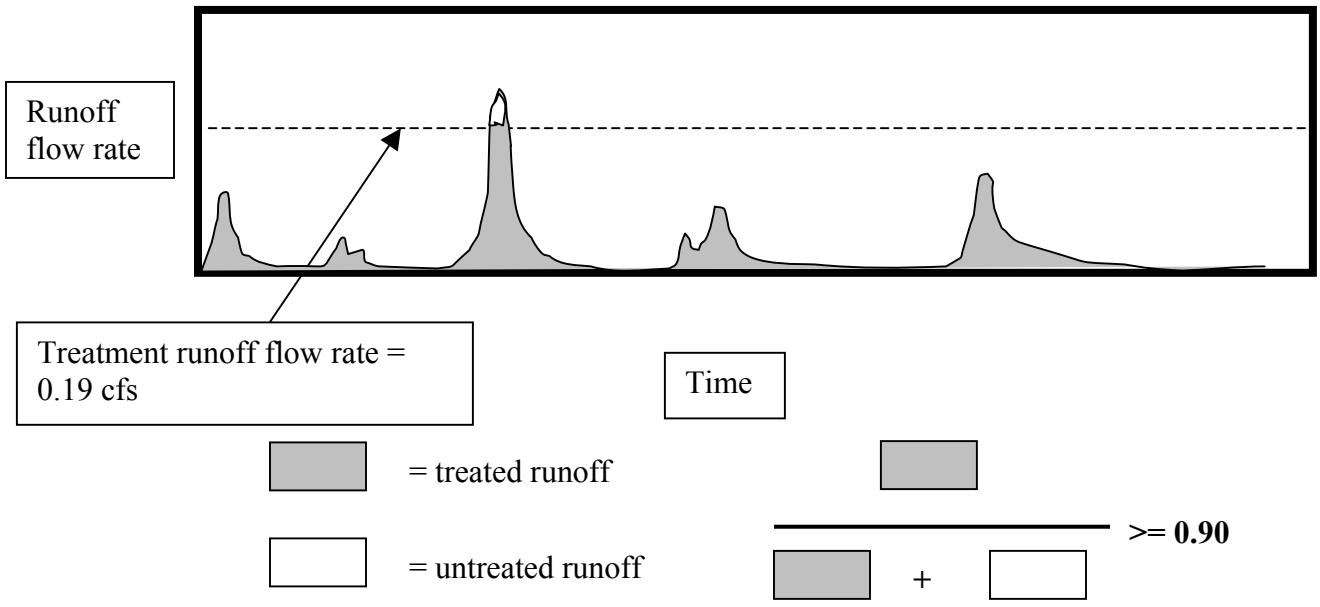
RATE BASED TREATMENT SYSTEMS

Stormwater treatment systems can be divided into two categories based on the methods used to size them: rate (or flow) and volume (or detention) based systems. Rate based systems used in Portland include swales, sand filters, and Stormfilter cartridge systems. Rate based systems remove pollutants with physical processes that settle or filter particulates as the flow passes through the system. The actual volume of the facility doesn't play a major role in the pollutant removal process, as there isn't a significant detention period for the water to remain in the system for any length of time.

A continuous simulation model can easily be used to determine the average annual runoff volume percentage treated by a rate based system. An assumption is that 100% of the runoff less than or equal to the peak treatment flow rate is fully treated, while the flows that exceed the peak treatment flow rate receive no treatment. Different assumptions can be made for on and off-line treatment systems. Likewise, an analysis of continuous rainfall intensity data can determine the average annual rainfall volume that is associated with a particular range of rainfall intensities. This type of analysis was completed for four different rain gages representing the different quadrants of Portland, and is summarized in Exhibit 5. 5, 10 and 20-minute intensities were analyzed to determine the intensities associated with the 90% rainfall volume goal. For 5-minute intensities, rainfall intensities of 0.19 inches per hour or less were determined to account for 90% of the average annual rainfall volume.

Eugene performed an analysis on 50 years of Eugene Airport rainfall data and also concluded that a rainfall intensity of 0.19"/hr would be needed to treat 90% of the average annual runoff volume.

Figure 1: Continuous simulation determination of 90% treatment flow rate



VOLUME BASED TREATMENT SYSTEMS

Unlike rate based systems, volume (or detention) based systems provide a significant storage volume for water to accumulate and be detained for a period of time. Pollutants are removed through physical (settlement) and/or biological processes. Volume based facilities used in Portland include wet ponds and wetlands. Unlike rate based systems, it is not easy to model volume based systems with continuous simulation models or rainfall analysis. Storm detention time needs to be factored into the model, and the mixing of water within the facility from one storm to the next creates a complex process that cannot be simulated accurately at this time. The currently accepted methodology used to size volume based treatment facilities (in Portland's SWMM, Gary Minton's *Stormwater Treatment* textbook, and many other jurisdictions) is to set the wet portion of the pond or wetland (permanent pool) equal to the full volume of runoff generated by the predetermined water quality storm, and apply a safety factor (Vb/Vr ratio).

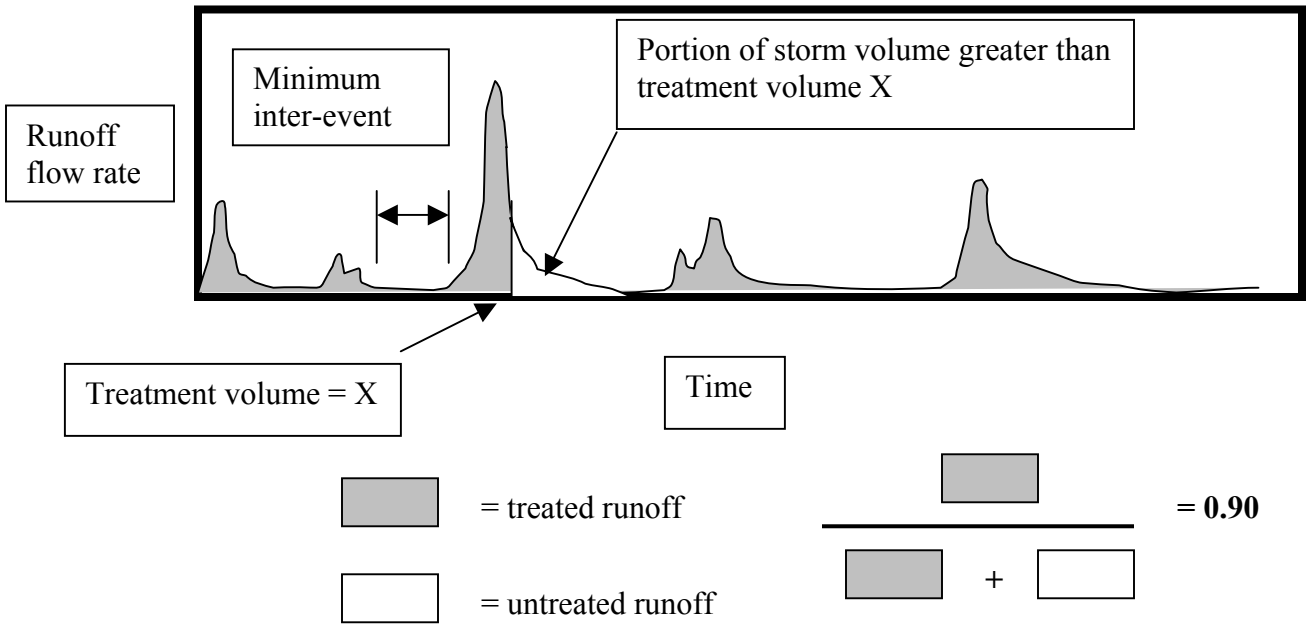
The volumes of most jurisdictions' water quality storms are set at their average annual treatment volume goal. For example, if the goal is to treat 80% of the average annual flow volume, the treatment storm depth is set to the 80% percentile storm. Eugene's goal is to treat 80% of the average annual volume. Their water quality storm is 1.4"/24 hours, which is equal to the 80th percentile storm. 80% of their storm events have a depth of 1.4 inches or less. In Portland's case, the 0.83" storm is not equal to the 90th percentile storm. An estimate would put it somewhere between the 60th and 65th percentile storm. This had been compensated for in the September 2002 Stormwater Management Manual by requiring volume-based facilities to use twice the volume of runoff generated by the 0.83" storm, or a Vb/Vr ratio of 2, but this factor should most likely be a function of soil type. In a recent version of *Stormwater Treatment Northwest* (Vol 9, No 4), Gary Minton and Roger Sutherland suggest that Pacific Northwest monitoring data indicates that a Vb/Vr ration of 1 may be adequate to achieve a TSS removal of 80%.

The City of Eugene has performed an analysis on 50 years of Eugene Airport rainfall data, and concluded that 90% of rainfall events are less than 2.4 inches in depth. Hourly rainfall intensity data was used in the analysis, storm depths of 0.01 inches or less were eliminated from the analysis, and a minimum inter-event time of 6 hours was used. A slight change in the modeling assumptions has a significant impact on the outcome. In the December 2003 issue of *Stormwater Treatment Northwest*, Gary Minton stated that an analysis he did of 24-hour rainfall data from the Seattle-Tacoma International Airport indicated that with a storm depth of about 1.35 inches, 90% of the runoff would be treated over time. The specific assumptions that were used in Dr. Minton's analysis are not known, but he was not using the 90th percentile Seattle-Tacoma storm. The Washington State Department of Ecology's Western Washington Stormwater Manual targets the capture of 91% of the average annual runoff for water quality, which they equate to two-thirds of a 2-year storm event (roughly 1.65 inches). Again, this storm event is not equivalent to the 91st percentile Western Washington storm.

A way of modeling the rainfall that could result in a clearer link to the treatment goal may be to determine the volume of a wet basin that will result in an average storm detention time of 24, 36, or 48 hours, depending on the anticipated TSS settling velocity in the vicinity of the site. The assumed inter-event time could be adjusted to ensure that enough detention time is provided between each storm event. An assumption could be made that storms with total volumes less than the "90% treatment storm" would receive 100% treatment. Storms with total volumes greater than the "90% treatment storm" would receive partial treatment- 100% treatment for the volume equal to the 90% storm volume, and 0 treatment for the volume greater than the 90%

storm volume. This may be overly conservative, as some very long, drawn-out storms (>24 hours) with total volumes greater than the designated treatment volume, may in fact receive greater than 24 hours of detention time for the entire storm, or 100% effective treatment.

Figure 2: Continuous simulation determination of 90% treatment volume



CONCLUSION AND RECOMMENDATION

The Portland water quality design storm shall be stated as a volume treatment goal- e.g. "90% of the average annual runoff shall be treated", and will be clarified by stating the peak rainfall intensity, and total volume components. This achieves two things:

1) Volume based facilities and rate based facilities will be theoretically sized to achieve treatment of the same percentage of average annual runoff volume.
2) With the treatment rainfall intensity already given, the SBUH or other hydrograph based hydrologic analysis method won't be needed to size rate based treatment facilities, simplifying the design process. Rather, the Rational Method can be used to calculate the runoff treatment flow rate, based on the site's time of concentration.

To achieve the treatment of 90% of the average annual rainfall volume, rate based facilities must be sized to treat rainfall at 0.19 inches per hour for sites with 5-minute time of concentration or less, 0.16 inches per hour for sites with a 10-minute time of concentration, and 0.13 inches per hour for sites with a 20-minute time of concentration.

For volume based facilities, Portland shall continue to size wet basins using 0.83 inches of rainfall over 24 hours (NRCS Type 1A rainfall distribution), with a Vb/Vr ratio of 2. Further analysis will be completed during the September 2007 Stormwater Management Manual revision process.

There should no longer be the perception of extreme water quality design storm discrepancies between Portland's Stormwater Management Manual and the Department of Ecology's Stormwater Management Manual for Western Washington, answering questions raised by NOAA Fisheries during review of Portland's manual.

In the long term, as more is learned about the capabilities of stormwater treatment facilities and their relationship to environmental, economic, and social considerations, Portland's treatment storm characteristics shall be re-analyzed and compared with those of other local jurisdictions periodically to determine if changes are necessary.

Figure 3: Water Quality Design Storm Pacific Northwest Comparison

Jurisdiction	Average Annual Rainfall (inches)	Treatment Goal (average annual runoff %)	WQ Storm Volume (inches) Vr	Volume Based Facility Sizing Factor	WQ Storm Duration (hours)	WQ Storm Intensity for Off-Line Facilities (in/hr)	WQ Storm Intensity for On-Line Facilities (in/hr)
City Of Gresham	37.4	80	1.2	1	12	0.11	0.20
City Of Eugene	46.6	80	1.4	1	24	0.13	0.22
City Of Corvallis	43.2	90	0.90, 0.3 mean ann. storm for wet ponds	3	24	Not Specified: 0.90" storm peak 10 min intensity (per NRCS 1A dist.) = 0.29 in/hr	
Clean Water Services-Oregon	36	85	0.36	1	4	WQ Volume / 4 hours = 0.09 in/hr	
DOE Western Washington SWMM	Varies 36-46	91	"6-month storm volume"-Varies	1	24	91% treatment: varies by jurisdiction, HSPF continuous simulation, different on & off-line	
City Of Tacoma	37.6	91	"6-month storm volume"	1	24	91% treatment, HSPF continuous simulation, different on & off-line	
City Of Seattle	38.6	Not Clear	"Mean annual storm" = 0.47	1	24	6-month storm (64% of 2-year storm or 1.08 inches) peak 10-min intensity using SBUH = 0.35 in/hr	
King County-Washington	38.6	95	"Mean annual storm" = 0.47- 0.65	3	24	60% of 2-yr storm flow rate using KCRTS continuous simulation, or 64% of 2-yr storm flow rate using SBUH	
Oregon State DEQ	Varies 37 approx. average	Not Clear	2-year storm: 2.4" in Portland	1	24	Not Specified: 2.4" storm peak 10 min intensity (per NRCS 1A dist.) = 0.78 in/hr	
City Of Portland (1996-Sept. 2004)	36	Not Clear: 95% Claim	0.83	2	24	Not Specified: 0.83" storm peak 10 min intensity (per NRCS 1A dist.) = 0.27 in/hr	
City Of Portland (Recom-mended for Sept. 2004)	36	90	90% Ave. annual treatment volume*	1 if Vr = 1.7, 2 if Vr = 0.83	24	90% treatment as shown by continuous simulation (see Figure 5) = 0.19 to 0.13 in/hr, depending on site's TofC	

* As defined by the recommended analysis of 24 years of Portland rainfall data, assuming a minimum inter-event time of 12 hours and minimum rainfall amount of 0.01 inches (see Figure 6). Portion of storm volume below specified treatment volume receives 100% treatment, portion of storm volume above specified treatment volume receives 0% treatment.

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Figure 4: Rainfall Intensity Versus Percentage of Annual Rainfall Volume 8/12/2004
Rainfall data taken from each of four Portland quadrants, then averaged. Fancher

5-minute intensity in/hr	% Annual Rainfall Volume
0	0
0.01	7
0.02	14
0.03	21
0.04	28
0.05	35
0.06	42
0.07	48.5
0.08	55.5
0.09	62.5
0.1	69.5
0.11	76.5
0.12	83.5
0.13	84.5
0.14	85.5
0.15	86
0.16	87
0.17	88
0.18	89
0.19	90
0.2	90.5
0.21	91.5
0.22	92.5
0.23	93
0.24	94
0.25	95
0.3	96
0.4	98
0.5	98

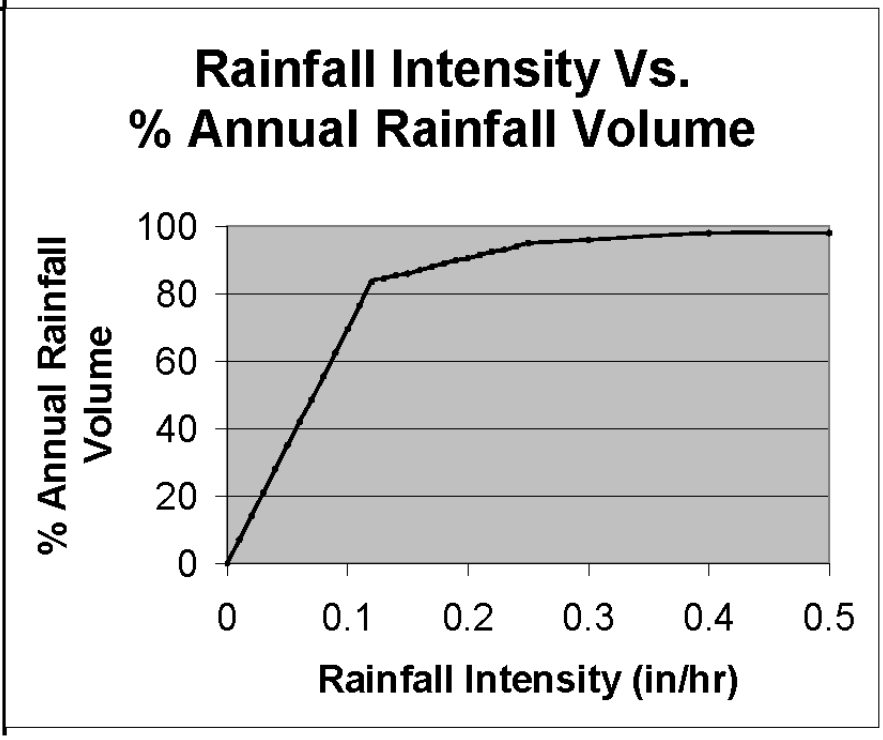

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Figure 5: BES Stormwater Pollution Reduction Storm Analysis April 30, 2004

Intensities Resulting in Treatment of 90% of Rainfall Volume (in/hr)
Assumption: Percentage of rainfall less intense than specified intensity receives 100% treatment, percentage of rainfall more intense than specified intensity receives 0 treatment.

5 minute intensity NW	0.19	Average = 0.19 in/hr
5 minute intensity SW	0.19	
5 minute intensity SE	0.20	
5 minute intensity NE	0.19	
10 minute intensity NW	0.15	Average = 0.16 in/hr
10 minute intensity SW	0.15	
10 minute intensity SE	0.165	
10 minute intensity NE	0.16	
20 minute intensity NW	0.13	Average = 0.13 in/hr
20 minute intensity SW	0.12	
20 minute intensity SE	0.14	
20 minute intensity NE	0.135	

Figure 6: BES Stormwater Pollution Reduction Storm Analysis April 30, 2004

Volumes Resulting in Treatment of 90% of Rainfall Volume (in/hr)
Assumptions: Percentage of storm volume less than specified volume receives 100% treatment, percentage of storm volume greater than specified volume receives 0 treatment. Storm event is defined by a minimum of 0.01 inches of rainfall with a minimum inter-event period of 12 hours.

Place & Time	Total Rainfall (in)	Number of 12-hr Storms	Average Storm Size (in)	90% Treatment Storm Size (in)	Average 90% Treatment Storm Size (in)
NW 97-98	80.15	169	0.47	1.6	Average = 1.7 in
NW 90-91	65.5	163	0.40	1.3	
NW 83-84	83.9	202	0.42	1.9	
NW 80-81	95.37	247	0.39	2.1	
SW 97-98	73.85	176	0.42	1.4	Average = 1.7 in
SW 90-91	61.83	180	0.34	1.25	
SW 83-84	82.37	201	0.41	1.9	
SW 80-81	67.45	160	0.42	2.1	
SE 97-98	74.41	185	0.40	1.6	Average = 1.8 in
SE 90-91	63.71	184	0.35	1.3	
SE 83-84	82.75	192	0.43	2.0	
SE 80-81	65.41	163	0.40	2.3	
NE 97-98	74.00	180	0.41	1.4	Average = 1.7 in
NE 90-91	64.62	176	0.37	1.2	
NE 83-84	72.27	217	0.33	1.7	
NE 80-81	65.37	188	0.35	2.3	

Appendix: Local Pollution Reduction Storm Specifications

MEMORANDUM

TO: Greg Gescher, CP&P Supervisor

FROM: Bruce Moser, Project Manager

DATE: December 15, 2003

SUBJECT: **Stormwater Quality Facility Design Storm**

This memo reviews the stormwater quality design storm event for the City of Corvallis, and recommends using a NRCS Type 1A storm event of 0.9 inch in 24 hours.

Background

NPDES Phase 1 and 2 Stormwater regulations require agencies to implement stormwater quality treatment by the use of best management practices. NPDES Phase 1 and 2 Permits do not include a specific requirement for meeting a design storm and treatment level. The State of Oregon DEQ has not established stormwater quality criteria for NPDES Phase 1 for receiving streams that are not water quality limited (TMDLs have not been established).

The Corvallis SWMP includes the requirement to retrofit all existing stormwater outfalls with water quality facilities, and to require new development to install stormwater quality facilities. The SWMP includes Technical Memorandum No. 3, dated Nov. 10, 1999, in which Brown&Caldwell staff recommended that the City of Corvallis use 2/3's of the 2 year, 24 hour rainfall event, or 1.67 inches for 24 hours for the stormwater treatment design storm event. This level of treatment exceeds the level other agencies in Oregon are currently using.

Discussion

Agencies in Oregon that have NPDES stormwater permits have established differing criteria for the stormwater quality design storm event to capture and treat. Agencies have reviewed local rainfall data to determine the level of storm event to capture that represents a percentage of the total rainfall. This methodology is based on the assumption that the majority of pollutants are mobilized and transported prior to the peak of a large rainfall event. Several stormwater quality studies have substantiated this assumption.

The process for review of rainfall data involves review of historical rainfall events to establish a level of 24 hour precipitation that represents a given percentage of the total volume of rainfall. The City of Portland has established design criteria of 95% of total stormwater runoff is to be treated to remove 70% of Total Suspended Solids (TSS). The design storm to capture has been established as 0.83 inches in 24 hours, using NRCS Type 1A curve. The City of Eugene has established the design criteria of 90% of total stormwater runoff to be treated, but the TSS removal criteria is not mentioned. City of Eugene staff assume that a properly designed stormwater quality BMP will remove 80% of TSS. City of Eugene has established the design storm as 0.21 inches in one hour for on-line facilities, and 0.12 inches in one hour for off-line facilities. This is based on using 1.0 inch

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in 24 hour as the design storm, using the NRCS Type 1A curve. The on-line facilities have a greater design storm based on the assumption that the effectiveness of an on-line facility will be impacted by flow when compared to an off-line facility.

Establishing Stormwater Quality Treatment Design Storm Event for Corvallis

The design rainfall event and treatment level is not currently identified under existing or anticipated regulatory requirements for the City of Corvallis. The SWMP does not specify treatment levels, but community input frequently referenced the water quality requirements that larger Oregon cities were meeting. A reasonable expectation for the implementation of stormwater quality facilities in Corvallis would be meeting community standards established in other Oregon cities that require stormwater treatment.

The stormwater receiving streams in Corvallis do not have established TMDL's, and none are anticipated to be implemented in the foreseeable future. In addition, the EPA Implementation Plan for Corvallis has not established a water quality treatment requirement with the exception of water temperature.

The methodology for developing the storm event for design treatment levels for the City of Corvallis uses review of historical daily rainfall over the last 42 years from the Hyslop rainfall gage (located 4 miles north of Corvallis) to determine the 24 hour event that would provide 90% capture for treatment. The 42 year historical data was tabulated to establish the average yearly rainfall of 43.20 inches. The amount of yearly rainfall that equals 90% of this yearly rainfall is 38.87 inches. The next step of the methodology was to establish a daily rainfall amount that collectively meets the 38.88 inches over the 42 years of data. The historical rainfall data was input to a spreadsheet "if, then" command to record all daily rainfall less than or equal to 0.9 inches. Rainfall greater than 0.9 inches was converted to 0.9 inches for the 24 hour period. The data was again tabulated and averaged to determine the yearly average rainfall amount, which was calculated to be 38.99 inches. This level nearly matches the target the yearly average for 90% rainfall of 38.88 inches.

The following table compares the annual average rainfall and design storm events for Portland, Corvallis, and Eugene.

City	Portland	Corvallis	Eugene
Annual Ave. Rainfall (inches)	37.07	43.20	50.90
24 Hr. Design Storm (inch/24 hour)	0.83	0.90	1.00

Recommendation

Based on review of other agency design storm methodology and review of local rainfall data, the stormwater quality design storm event for the City of Corvallis is recommended to be 0.9 inches in 24 hours, using the NRCS Type 1A distribution curve.

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Design & Construction Standards

Clean Water Services Design and Construction Standards c the administrative and technical requirements for the design of sanitary and surface water management systems which a of residential or commercial development. The new Design a Standards Resolution and Order 04-9 (R&O 04-9) became e March 1, 2004 and replaces the previous version of the stan 11.

Unless otherwise specifically identified in the land use condit new development submittals within the District's boundaries- development within cities--should comply with R&O 04-9.

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APPENDIX B:
WATER QUALITY & QUANTITY
FACILITY DESIGN

1.0 GENERAL REQUIREMENTS FOR WATER QUALITY AND QUANTITY FACILITIES

1.1 Erosion Protection

a. Inlets to water quality and quantity facilities shall be protected from erosive flows through the use of an energy dissipater or rip rap stilling basin of appropriate size based on flow velocities. Flow shall be evenly distributed across the treatment area.

b. All exposed areas of water quality and quantity facilities shall be protected using coconut or jute matting. Coconut matting or high density jute matting (Geojute Plus or approved equal) shall be used in the treatment area of swales and below the WQV levels of ponds. Low density jute matting (Econojute or approved equal) may be used on all other zones.

1.2 Vegetation

a. Vegetation shall be in accordance with the Appendix D: Landscape Requirements.

b. No invasive species shall be planted or permitted to remain within the facility which may affect its function, including, but not limited to the following:

1. Himalayan blackberry (Rubus discolor)
2. Reed canarygrass (Phalaris arundinacea)
3. Teasel (Dipsacus fullonum)
4. English Ivy (Hedra helix)
5. Nightshade (Solanum sp.)
6. Clematis (Clematis ligusticifolia and C. vitabla)
7. Cattail (Typhus latifolia)
8. Thistle (Cirsium arvense and C. vulgare)
9. Scotch Broom (Cytisus scoparius)

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8) A vehicle turnaround shall be provided when the access road exceed 40' in length.

2.0 WATER QUALITY FACILITY DESIGN

This section presents methodology for designing water quality facilities.

2.1 Water Quality Volumes and Flows

(Reproduced from Appendix A: Hydrology and Hydraulics; Section 1)

The water quality storm is the storm required by regulations to be treated. The storm defines both the volume and rate of runoff.

a. Water Quality Storm: Total precipitation of 0.36 inches falling in 4 hours with a storm return period of 96 hours.

b. Water quality volume (WQV) is the volume of water that is produced by the water quality storm.

c. Water Quality Volume (WQV): 0.36-inches over 100-percent of the new impervious area.

$$\textit{Water Quality Volume (cf)} = \frac{\textit{0.36(in) x Area (sf)}}{\textit{12 (in/ft)}}$$

d. Water Quality Flow (WQF): The average design flow anticipated from the water quality storm.

$$\textit{Water Quality Flow (cfs)} = \frac{\textit{Water Quality Volume (cf)}}{\textit{14,400 Sec}}$$

Or

$$\textit{Water Quality Flow (cfs)} = \frac{\textit{0.36(in) x Area (sf)}}{\textit{12(in/ft)(4 hr)(60 min/hr)(60 sec/min)}}$$

2.2 Pretreatment

a. Pretreatment Required

Sheet flow of impervious surfaces into water quality facilities will not be allowed without pretreatment. Incoming flows to the water quality facility must be pretreated using a water quality manhole in accordance with section 2.3 or other pre-treatment method as approved by the District/City. Other methods of pretreatment may include proprietary devices, filter

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Stormwater Management Manual for Western Washington

Volume I - Minimum Technical Requirements and Site Planning
Volume II - Construction Stormwater Pollution Prevention
Volume III - Hydrologic Analysis and Flow Control Design/BMPs
Volume IV - Source Control BMPs
Volume V - Runoff Treatment BMPs

Prepared by:

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Water Quality Program

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Chapter 4 - General Requirements for Stormwater Facilities

Note: All Figures in Chapter 4 are courtesy of King County

This chapter addresses general requirements for treatment facilities. Requirements discussed in this chapter include design volumes and flows, sequencing of facilities, liners, and hydraulic structures for splitting or dispersing flows.

4.1 Design Volume and Flow

4.1.1 Water Quality Design Storm Volume

The volume of runoff predicted from a 24-hour storm with a 6-month return frequency (a.k.a., 6-month, 24-hour storm).

Wetpool facilities are sized based upon use of the NRCS (formerly known as SCS) curve number equations in Chapter 2 of Volume III, for the 6-month, 24-hour storm. Treatment facilities sized by this simple runoff volume-based approach are the same size whether they precede detention, follow detention, or are integral with the detention facility (i.e., a combined detention and wetpool facility).

Unless amended to reflect local precipitation statistics, the 6-month, 24-hour precipitation amount may be assumed to be 72 percent of the 2-year, 24-hour amount. Precipitation estimates of the 6-month and 2-year, 24-hour storms for certain towns and cities are listed in Appendix I-B of Volume I. For other areas, interpolating between isopluvials for the 2-year, 24-hour precipitation and multiplying by 72% yields the appropriate storm size. Isopluvials for 2-year, 24-hour amounts for Western Washington are reprinted in Volume III.

4.1.2 Water Quality Design Flow Rate

***Downstream of Detention Facilities*: The full 2-year release rate from the detention facility.**

An approved continuous runoff model should identify the 2-year return frequency flow rate discharged by a detention facility that is designed to meet the flow duration standard.

***Preceding Detention Facilities or when Detention Facilities are not required*: The flow rate at or below which 91% of the runoff volume, as estimated by an approved continuous runoff model, will be treated.** Design criteria for treatment facilities are assigned to achieve the applicable performance goal at the water quality design flow rate (e.g., 80 percent TSS removal).

- *Off-line facilities*: For treatment facilities not preceded by an equalization or storage basin, and when runoff flow rates exceed the water quality design flow rate, the treatment facility should continue to receive and treat the water quality design flow rate to the applicable treatment performance goal. Only the higher incremental portion of flow rates are bypassed around a treatment facility. Ecology encourages design of systems that engage a bypass at higher flow rates provided the reduction in pollutant loading exceeds that achieved with bypass at the water quality design flow rate.

  Treatment facilities preceded by an equalization or storage basin may identify a lower water quality design flow rate provided that at least 91 percent of the estimated runoff volume in the time series of a continuous runoff model is treated to the applicable performance goals (e.g., 80 percent TSS removal at the water quality design flow rate and 80 percent TSS removal on an annual average basis).

- *On-line facilities*: Runoff flow rates in excess of the water quality design flow rate can be routed through the facility provided a net pollutant reduction is maintained, and the applicable annual average performance goal is likely to be met.

Estimation of Water Quality Design Flow Rate for Facilities Preceding Detention or when Detention Facilities are not required:

Until a continuous runoff model is available that identifies the water quality design flow rate directly, that flow rate shall be estimated using Table 4.1, and its following directions for use:

Step 1 Determine whether to use the 15-minute time series or the 1-hour time series. At the time of publication, all BMPs except wetpool-types should use the 15-minute time series.

Step 2 Determine the ratio corresponding with the effective impervious surface associated with the project. For effective impervious areas between two 5 percent increments displayed in the table, a straight line interpolation may be used, or use the higher 5 percent increment value.

Step 3 Multiply the 2-year return frequency flow for the post-developed site, as predicted by an approved continuous runoff model, by the ratio determined above.

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related natural resources. Based upon gross level applications of continuous runoff modeling and assumptions concerning minimum flows needed to maintain beneficial uses, watersheds must retain the majority of their natural vegetation cover and soils, and developments must meet the Flow Control Minimum Requirement of this chapter, in order to avoid significant natural resource degradation in lowland streams.

The Roof Downspout Control BMPs described in Chapter 3 of Volume III, and the Dispersion and Soil Quality BMPs in Chapter 5 of Volume V are insufficient to prevent significant hydrologic disruptions and impacts to streams and their natural resources. Therefore, Ecology has suggested that the City and other local governments should look for opportunities to encourage and require additional BMPs such as those in Sections 5.2 through 5.4 of Volume V through updates to their site development standards and land use plans.

3.5.6 Minimum Requirement #6: Runoff Treatment

Thresholds

The following require construction of stormwater treatment facilities (see Table 3.1):

- **Projects in which the total of effective pollution-generating impervious surface (PGIS) is 5,000 square feet or more in a threshold discharge area of the project, or**
- **Projects in which the total of pollution-generating pervious surfaces (PGPS) is three-quarters (3/4) of an acre or more in a threshold discharge area, and from which there is a surface discharge in a natural or man-made conveyance system from the site.**

Treatment Facility Sizing

Water Quality Design Storm Volume: The volume of runoff predicted from a 24-hour storm with a 6-month return frequency (a.k.a., 6-month, 24-hour storm). Wetpool facilities are sized based upon the volume of runoff predicted through use of the Natural Resource Conservation Service curve number equations in Chapter 2 of Volume III, for the 6-month, 24-hour storm.

Water Quality Design Flow Rate:

- ***Preceding Detention Facilities or when Detention Facilities are not required*: The flow rate at or below which 91% of the runoff volume will be treated, as estimated by an approved continuous runoff model. Design criteria for treatment facilities are assigned to achieve the applicable performance goal at the water quality design flow rate.**
- **Volume V includes performance goals for Basic, Enhanced, Phosphorus, and Oil Control treatment, and a menu of facility options for each treatment type. Treatment facilities that are**

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Volume 1: Source Control Technical Requirements Manual
Volume 2: Construction Stormwater Control Technical Requirements Manual
Volume 3: Flow Control Technical Requirements Manual
Volume 4: Stormwater Treatment Technical Requirements Manual

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concentration. TC depends on several factors, including ground slope, ground roughness, and distance of flow.

The Soil Conservation Service (SCS) runoff curve number to be used with the SBUH method shall be 98 for impervious surfaces, and 85 or greater for pervious surfaces unless one of the following conditions is met:

- A lower SCS curve number is justified for an area incorporating one or more site design options (see City of Seattle Directors' Rule for Flow Control), or
- A soil report by an experiences geotechnical/civil engineer indicates site soils are sufficiently pervious to allow a smaller SCS curve number to be used.

In the City of Seattle, the design storm used by the SBUH method *for design of treatment facilities* is based on a *standard* SCS Type 1A storm event hyetograph where, during the peak 10-minute period, 5.40% of the total rainfall occurs. Note that *for design of flow control facilities*, a *modified* SBUH method is used where 9.92% of the rainfall occurs during the ten-minute period at the peak of the storm event (see Appendix A).

Water Quality Design Flow

Flow-through treatment structures, such as biofiltration facilities, media filtration facilities, and oil control facilities, must be sized based on runoff from the 6-month, 24-hour storm event, which has a rainfall runoff volume of 1.08 inches. This value is based on the assumption that the 6-month, 24-hour storm volume is 64% of the volume of the 2-year, 24-hour storm event.[4] For these types of facilities, water quality design flow, Q_{wq}, is equal to the peak flow (measured in cfs). Using the SBUH method, this peak occurs during the ten-minute interval between 470 and 480 minutes, when 5.40% of the total rainfall volume occurs. Additional information on the SBUH method is provided in Appendix A. For *storage* treatment facilities, such as wetponds, wetvaults, and stormwater wetlands, sizing is based on the volume of runoff from the *mean annual storm event*, which for Seattle is 0.47 inches. Additional information on determining water quality design flows for storage treatment facilities is contained in Chapter 4.

2.2 SEQUENCE OF FACILITIES

As specified in the water quality menus, where more than one water quality facility is used, the order is often prescribed. This is because the specific pollutant removal role of the second or third facility in a treatment train often assumes that significant solids settling has already occurred. For example, phosphorus removal using a two-facility treatment train relies on the second facility (sand filter) to remove a finer fraction of solids than those removed by the first facility.

There is a larger question, however, of whether water quality facilities should be placed upstream or downstream of detention facilities. In general, all water quality facilities may be installed upstream of detention facilities, although presettling basins are needed for sand filters and infiltration basins. Not all water quality facilities, however, can be located

[4] Ref: Stormwater Management Manual for the Puget Sound Basin; The Technical Manual (1992). Publication 91-75, Washington State Department of Ecology, Olympia. Washington.

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CHAPTER 6
WATER QUALITY DESIGN



KING COUNTY, WASHINGTON
SURFACE WATER DESIGN MANUAL

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*9/1/98

6.2 GENERAL REQUIREMENTS FOR WQ FACILITIES

This section presents the general requirements for water quality (WQ) facilities. When detail in the WQ designs is lacking, refer to Chapter 5 for guidance. In cases where requirements are extremely costly, a less expensive alternative that is functionally equivalent in terms of performance, environmental effects, health and safety, and maintenance can be sought through the adjustment process (see Section 1.4).

Use of Metal Materials

Galvanized metals leach zinc into the environment, especially in standing water situations. High zinc concentrations, sometimes in the range that can be toxic to aquatic life, have been observed in the region.[12] Therefore, use of galvanized materials in stormwater facilities and conveyance systems is discouraged. Where other metals, such as aluminum or stainless steel, or plastics are available, they should be used.

6.2.1 WATER QUALITY DESIGN FLOWS

Water Quality Design Flow

The water quality design flow is defined as follows:

- *Preceding detention*: **60% of the developed two-year peak flow rate, as determined using the KCRTS model** with 15-minute time steps calibrated to site conditions (see Chapter 3). *Note: If KCRTS is not being used on a project, the WQ design flow may also be estimated using 64% of the 2-year 24-hour precipitation in the SBUH model.*[13]
- *Downstream of detention*: The full **2-year release rate from the detention facility**.

The KCRTS model will typically be used to compute the WQ design flow. When examining the peak flow rates associated with various runoff volumes, it was found that detained flows and undetained flows must be described differently. However, unlike peak flows, the KCRTS model computation of volume of runoff is unaffected by whether or not the runoff is detained. Therefore, facilities such as wetponds, which are sized by a simple volume-based approach that does not route flows through a detention ~~pond~~facility, are the same size whether they precede or follow detention.

Note that facilities which are sized based on volume and which include routing of flows through a detention ~~pond~~facility, such as the detailed sand filter method, are significantly smaller when located downstream of detention, even though the same volume of water is treated in either situation. This is because the detention ~~pond~~facility routing sequence stores peaks within the pond and releases them at a slow rate, reducing the size of the sand filter pond subsequently needed (the volume needed to store the peaks need not be provided again in the sand filter pond).

Flow Volume to be Treated

When water quality treatment is required pursuant to the core and special requirements of this manual, it is intended that a minimum of **95% of the annual average runoff volume** in the (8 year) time series, as determined with the KCRTS model, be treated. Designs using the WQ design flow (as discussed above) will treat this minimum volume.

Treatable Flows

As stated in Chapter 1, only runoff from target pollution-generating surfaces must be treated using the water quality facility options indicated in the applicable water quality menu. These surfaces include both

[12] Finlayson, 1990. Unpublished data from reconnaissance of Metro Park and Ride lot stormwater characteristics.

[13] The Department of Ecology WQ design flow is based on the flow predicted by the SBUH model for 64% of the 2-year 24-hour precipitation. This is roughly equivalent to the WQ design flows given here for the KCRTS model.

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6.4.1.1 METHODS OF ANALYSIS

This section describes methods of analysis for the following two wetpond sizes:

- **Basic wetpond** (see below)
- **Large wetpond** (see page 6-73).

❑ BASIC WETPOND

The primary design factor that determines a wetpond's **particulate removal efficiency** is the volume of the wetpool in relation to the volume of stormwater runoff from the *mean annual storm*.[25] The larger the wetpond volume in relation to the volume of runoff, the greater the potential for pollutant removal. Also important are the avoidance of short-circuiting and the promotion of plug flow. *Plug flow* describes the hypothetical condition of stormwater moving through the pond as a unit, displacing the "old" water in the pond with incoming flows. To prevent short-circuiting, water is forced to flow, to the extent practical, to all potentially available flow routes, avoiding "dead zones" and maximizing the time water stays in the pond during the active part of a storm.

Design features that encourage plug flow and avoid dead zones are as follows:

- Dissipating energy at the inlet
- Providing a large length-to-width ratio
- Providing a broad surface for water exchange across cells rather than a constricted area.

Maximizing the flowpath between inlet and outlet, including the vertical path, also enhances treatment by increasing residence time.

Wetponds designed using the method below (with the volume = $3V_r$) and the required design criteria in Section 6.6.2.2 are expected to meet the Basic WQ menu goal of 80% TSS removal. The actual performance of a wetpond may vary, however, due to a number of factors, including design features, maintenance frequency, storm characteristics, pond algae dynamics, and waterfowl use.

Procedures for determining a wetpond's dimensions and volume are outlined below.

Step 1: Identify required wetpool volume factor (*f*). A basic wetpond requires a volume factor of **3**. This means that the required wetpond volume is 3 times the volume of runoff V_r from the mean annual storm (see Steps 2 and 3).

Step 2: Determine rainfall (*R*) for the mean annual storm. The rainfall for the mean annual storm R is obtained by locating the project site on Figure 6.4.1.A (p. 6-71) and interpolating between isopluvials. Convert to feet for use in Equation (6-13).

Step 3: Calculate runoff from the mean annual storm (V_r) for the developed site. The runoff volume V_r is the amount of rainfall that runs off a particular set of land covers. To determine V_r, each portion of the wetpond tributary area is assigned to one of four cover types, each having a different runoff coefficient: impervious surface, till grass, till forest, or outwash.

- **Impervious surface** is a compacted surface, such as pavement, gravel, soil, or other hard surfaces, as well as open water bodies. *Note: The effective impervious computations given in Chapter 3, Table 3.2.2.~~D~~ E may be used, unless more detailed information is available ~~if desired~~.*
- **Till grass** is post-development grass or landscaped area and onsite forested land on till soil that are not permanently in sensitive area buffers or covenants. *Till* is soil that does not drain readily and, as a

[25] The *mean annual storm* is a statistically derived rainfall event defined by the U.S. Environmental Protection Agency in "Results of the Nationwide Urban Runoff Program", 1986. It is defined as the annual rainfall divided by the number of storm events in the year. The NURP studies refer to pond sizing using a V_s/V_r ratio: the ratio of the pond volume V_s to the volume of runoff from the mean annual storm V_r. This is equivalent to using a volume factor f times V_r.

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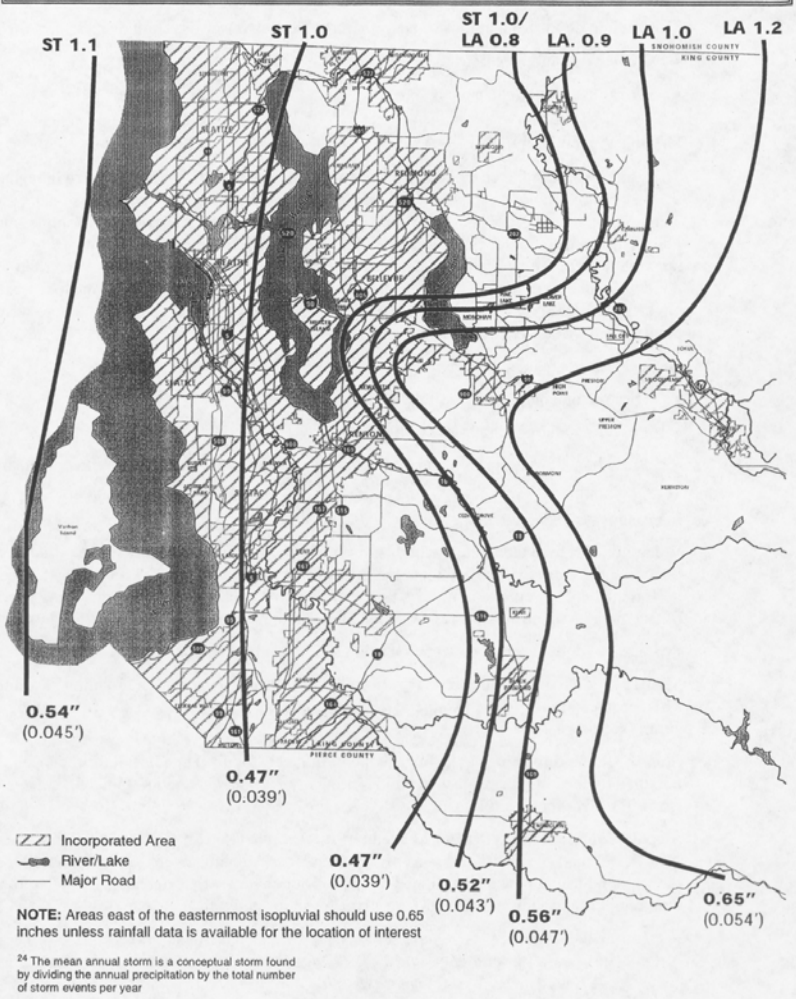
FIGURE 6.4.1.A PRECIPITATION FOR MEAN ANNUAL STORM IN INCHES (FEET)



[24] The mean annual storm is a conceptual storm found by dividing the annual precipitation by the total number of storm events per year

result, generates large amounts of runoff. For this application, till soil types include Buckley and bedrock soils, and alluvial and outwash soils that have a seasonally high water table or are underlain at a shallow depth (less than 5 feet) by glacial till. U.S. Soil Conservation Service (SCS) hydrologic soil groups that are classified as till soils include a few B, most C, and all D soils. See Chapter 3 for classification of specific SCS soil types.

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Appendix F
FACILITY PLANTING & SOIL RECOMMENDATIONS

F.1 RECOMMENDED PLANT LISTS

Ecoroof Recommended Plants:

Note: For additional descriptions of these plants visit the Bureau of Environmental Services website, www.cleanrivers-pdx.org. For Roof Garden plants, BES recommends using drought tolerant, self-sustaining native trees, shrubs and ecoroof plants.

Sedums and Succulents

Delosperma cooperi,	Ice plant
Delosperma nubegenum,	Ice plant
Sedum acre	Stonecrop
**Sedum album*	White Stonecrop
**Sedum telephium* varieties including 'Autumn Joy' and 'Variegatum'	Stonecrop
Sedum divergens	Stonecrop
Sedum hispanicum	Stonecrop
Sedum kamtschaticum	Stonecrop
**Sedum oreganum*	Oregon Stonecrop
Sedum sexangular	Stonecrop
**Sedum spathilifolium*	Stonecrop
**Sedum spurium* varieties	Stonecrop
**Sempervivum tectorum*,	Hens and Chicks

Herbaceous

Achillea millefolium,	Common Yarrow
Achillea ageratifolia,	Greek Yarrow
Achillea tomentosum,	Wooly Yarrow
Arenaria montana,	Sandwort
Artemesia 'Silver mound',	Artemesia
Aurinia saxatilis,	Alyssum saxatile
**Cerastium*,	Snow-in-Summer
Dianthus alwoodii,	Pink
Dianthus deltoides,	Maiden Pink
Erigeron discoideus,	Fleabane
Festuca glauca,	Blue Fescue
Fragaria vesca,	Woodland Strawberry
Gazania linearis var. 'CO gold',	Gazania
**Gilia capitata*,	Globe gilia

Lobularia maritima,	Sweet alyssum
Nierembergia repens,	Cup Flower
**Polypodium glycrrhiza*,	Licorice Fern
**Polystichum munitum*,	Sword Fern
Potentilla nepalensis,	Nepal Cinquefoil
Potentilla nuemaniana,	Cinquefoil
Thymus serphyllum,	Mother of Thyme
Thymus vulgaris,	Common Thyme
Veronica liwanensis,	Speedwell

* Indicates that BES has observed these plants surviving in ecoroof areas that do not receive summer irrigation. Most of these locations have moderate to deep shade. To date these plants appear very stressed by the end of summer, but they have comeback each year. It is likely that many of the other plants listed above could survive in such conditions without irrigation.

Contained Planter Box, Infiltration Planter Box, and Flow-Through Planter Box Recommended Plants:

Note: Generally, plants requiring **moist-wet** conditions are preferred for flow-through facilities; plants requiring **moist to dry** conditions are preferred for infiltration facilities.

Shrubs

Ceanothus velutinus,	Snowbrush- moist-dry
Cornus sericea,	Redtwig Dogwood- moist-wet
Gaultheria shallon,	Salal- moist-dry
Mahonia (or Berberis) aquifolium,	Tall Oregon Grape-moist-dry
Mahonia nervosa,	Dull Oregon Grape– moist-dry
Physocarpus capitatus,	Pacific Ninebark- moist-wet
Ribes sanguineum,	Red-flowering Current- moist-dry
Rosa gymnocarpa,	Baldhip Rose– moist-dry
Rosa nutkana,	Nootka Rose– moist-dry
Rosa pisocarpa,	Swamp Rose– moist-dry
Rubus parviflorus,	Thimbleberry– moist-dry
Symphoricarpos alba,	Common Snowberry- moist-dry
Viburnum edule,	Highbush Cranberry; Squashberry- moist

Large Shrubs/ Small Trees

Acer circinatum,	Vine Maple– moist-wet
Amelanchier alnifolia,	Western Saskatoon Serviceberry-dry
Crataegus douglasii (or *C. suksdorfii*),	Douglas' Black Hawthorn– moist-wet
Malus fusca,	Pacific Crab Apple– moist-wet
Oemleria cerasiformis,	Indian Plum– moist-dry
Philadelphus lewisii,	Mock Orange– moist-dry
Prunus emarginata (or *P. virginiana*),	Bitter Cherry- moist
Rhamnus purshiana,	Cascara– dry-wet
Salix hookeriana,	Piper's Willow– moist-wet
Salix scouleriana,	Scoulers Willow- moist-wet
Salix sessilifolia,	Soft leafed Willow– moist-wet
Salix sitchensis,	Sitka Willow– moist-wet
Spiraea douglasii,	Douglas Spiraea– moist-wet

Grass and Grass-Like Plants

Beckmannia syzigachne,	American Slough Grass– moist-wet
Bromus carinatus,	California Brome Grass- moist-dry
Bromus sitchensis,	Alaska Brome– moist-dry
Bromus vulgaris,	Columbia Brome Grass– moist-dry

Camassia quamash,	Common Camas-moist
Carex aperta,	Columbia Sedge– moist-wet
Carex deweyanna,	Dewey Sedge– moist-wet
Carex obnupta,	Slough Sedge- moist-wet
Carex stipata,	Sawbeak Sedge– moist-wet
Deschampsia cespitosa,	Tufted Hairgrass- moist-dry
Eleocharis acicularis,	Needle Spike-Rush- moist-wet
Eleocharis ovata,	Ovate Spike-Rush- moist-wet
Eleocharis palustris,	Creeping Spike-Rush- moist-wet
Elymus glaucus,	Blue Wildrye– moist-dry
Festuca occidentalis,	Western Fescue Grass– moist-dry
Festuca rubra var. commutata,	Western Red Fescue– moist-dry
Glycera occidentalis,	Western Mannagrass– moist-wet
Iris douglasiana,	Douglas Iris– moist-dry
Iris tenax,	Oregon Iris– moist-dry
Juncus effusus var. pacificus	Common Rush– moist-wet
Juncus effufus var. gracilis	Common Rush– moist-wet
Juncus ensifolius,	Dagger-leaf Rush- moist-wet
Juncus patens,	Grooved Rush, Spreading Rush, - moist-wet
Juncus tenuis,	Slender Rush– moist-wet
Scirpus acutus,	Hardstem Bulrush- moist-wet
Scirpus microcarpus,	Small Fruited Bulrush- moist-wet
Sedum oreganum,	Oregon Sedum- dry
Sisyrinchium idahoense (or *S.angustifolium; S. bellum*),	Blue-eyed Grass– moist
Sisyrinchium douglasii,	Purple-Eyed Grass-moist

Ferns: Moist Shade

Athyrium felix-femina,	Lady Fern
Blechnum spicant,	Deer Fern
Polypodium glycrrhiza,	Licorice Fern
Polystichum munitum,	Sword Fern
Pteridium aquilinum,	Bracken Fern

Vegetated Swale and Vegetated Filter Strip Recommended Plants:

Planting zones
Swale bottom to 1.5 ft. up the side slope = wet to moist
Side slopes from 1.5 – 3 ft. = moist to dry
Side slopes above 3 ft. and upland = dry

Grasses and Groundcovers - Wet to Moist

Carex aperta,	Columbia Sedge
Carex obnupta,	Slough Sedge
Scirpus microcarpus,	Small flowered (or fruited) Bulrush
Hordeum brachyantherum,	Meadow Barley
Juncus effusus var. pacificus	Common Rush– moist-wet
Juncus effufus var. gracilis	Common Rush– moist-wet
Juncus ensifolius,	Dagger-leaf Rush
Juncus oxymeris,	Pointed Rush
Juncus tenuis,	Slender Rush
Juncus patens,	Grooved Rush; Spreading Rush
Glyceria occidentalis,	Manna Grass

Ferns: Moist shade

Blechnum spicant,	Deer Fern
Polypodium gycrrhiza,	Licorice Fern
Polystichum munitum,	Sword Fern

Moist to dry

Arctostaphyllos uva-ursi,	Kinnick-innick Aster
Aster suspicatus,	Douglas' Aster
Bromus carinatus,	California Brome Grass
Bromus sitchensis,	Alaska Brome
Bromus vulgaris,	Columbia Brome Grass
Lupinus micranthus,	Small Flowered Lupine
Sisyrinchium idahoense,	Blue-eyed Grass
Camassia quamash,	Common Camas
Festuca occidentalis,	Western Fescue Grass
Deschampsia caespitosa,	Tufted Hairgrass
Elymus glaucus,	Blue Wildrye
Fragaria vesca or *F. virginiana*,	Woodland strawberry or Wild strawberry
Sisyrinchium idahoense,	Blue-eyed Grass

Shrubs- varying zones

Cornus sericea,	Redtwig Dogwood- moist-wet
Gaultheria shallon,	Salal- dry

Mahonia aquifolium,	Tall Oregon Grape- moist -dry
Mahonia nervosa,	Dull Oregon Grape- moist-dry
Physocarpus capitatus,	Pacific Ninebark- moist-wet
Ribes sanguineum,	Red-flowering Current-dry
Rosa gymnocarpa,	Baldhip Rose– moist -dry
Rosa nutkana,	Nootka Rose– moist-dry
Rosa pisocarpa,	Swamp Rose– moist-dry
Spiraea betulifolia,	Shiny-leaf Spiraea - dry
Symphoricarpos alba,	Common Snowberry- moist-dry
Viburnum edule,	Highbush Cranberry; Squashberry- moist -dry

Large Shrub/Small Tree– varying zones

Acer circinatum,	Vine Maple- moist-wet
Amelanchier alnifolia,	Western Saskatoon Serviceberry- dry
Ceanothus sanguineus,	Oregon Redstem Ceanothus- moist-dry
Corylus cornuta,	Western Beaked Hazelnut- moist-dry
Crataegus douglasii,	Douglas' Black Hawthorn- moist
Holodiscus discolor,	Oceanspray- moist-dry
Malus fusca,	Pacific Crab Apple- moist-wet
Oemleria cerasiformis,	Indian Plum; Osoberry- moist-wet
Philadelphis lewesii,	Mock Orange- moist-dry
Prunus emarginata or *P.Virginiana*	Bitter or Choke Cherry- moist
Rhamnus purshiana,	Cascara- dry-wet
Rosa nutkana,	Nootka Rose- moist-dry
Rubus parviflorus,	Thimbleberry- moist-dry
Salix fluviatalis,	Columbia Willow- moist-wet
Salix hookeriana,	Piper's Willow- moist-wet
Salix lucida (or S. *lasiandra*),	Pacific Willow- moist-wet
Salix scouleriana,	Scoulers Willow-moist-wet
Salix sessilifolia,	Soft leafed Willow- moist-wet
Salix sitchensis,	Sitka Willow- moist-wet
Sambucus cerulea,	Blue Elderberry- moist- dry
Sambucus racemosa,	Red Elderberry- moist- dry

Conifer and Evergreen Trees- varying zones

Abies grandis,	Grand Fir- moist-dry
Arbutus menziesii,	Madrone- dry
Pinus monticola,	Western White Pine- moist-dry
Pinus ponderaosa,	Ponderosa Pine- dry
Pseudotsuga menziesii,	Douglas Fir- moist-dry
Thuja plicata,	Western Red Cedar- moist-wet
Tsuga heterophylla,	Western hemlock-moist

Deciduous Trees- varying zones

Acer macrophyllum,	Big leaf Maple- moist-dry
Alnus rubra,	Red Alder - moist-wet
Amelanchier alnifolia,	Serviceberry - dry
Cornus nuttallii,	Western Flowering Dogwood– moist-dry
Fraxinus latifolia,	Oregon Ash - moist-wet
Populus balsamifera,	Black Cottonwood – moist-wet
Quercus chrysolopsis,	Canyon Live Oak - dry
Quercus garryana,	Oregon White Oak – moist-dry

Grassy Swale Recommended Seed Mixes:

See **Exhibit F-1** for grass seed recommendations and specifications.

Vegetated Infiltration Basin and Dry Detention Pond Recommended Plants:

Planting zones
Basin bottom to 1.5 ft. up the side slope = moist
Side slopes from 1.5 – 3 ft. = moist to dry
Side slopes above 3 ft. and upland = dry

Note: These plants are recommended based on experience and/or literature review. For soils with slow infiltration rates (< 2 inches per hour) moist to wet plants are preferable; for soils with higher infiltration rates moist to dry plants are preferable.

Grasses and groundcovers: See **Exhibit F-1** for grass seed recommendations and specifications.

Moist –

Beckmannia syzigachne,	American Slough Grass
Carex aperta,	Columbia Sedge
Carex densa,	Dense Sedge
Carex deweyana,	Dewey Sedge
Carex hendersonii,	Henderson Sedge
Carex obnupta,	Slough Sedge
Carex stipata,	Sawbeak Sedge
Carex vesicaria,	Inflated Sedge
Eleocharis acicularis,	Needle Spike-rush
Eleocharis ovata,	Ovate Spike-rush
Eleocharis palustris,	Creeping Spike-rush
Juncus effusus,	Common/Soft Rush
Juncus ensifolius,	Dagger-leaf Rush
Juncus patens,	Grooved Rush; Spreading Rush
Juncus tenuis,	Slender Rush
Scirpus acutus,	Hardstem Bulrush
Scirpus americanus,	Three-square or American Bulrush
Scirpus microcarpus,	Small Fruited Bulrush

Moist to Dry

Aster suspicatus,	Douglas' Aster
Bromus carinatus,	California Brome Grass
Bromus sitchensis,	Alaska Brome

Bromus vulgaris,	Columbia Brome Grass
Camassia quamash,	Common Camas
Festuca occidentalis,	Western Fescue Grass
Deschampsia caespitosa,	Tufted Hairgrass
Elymus glaucus,	Blue Wildrye
Fragaria vesca or F. virginiana,	Woodland strawberry or Wild strawberry
Hordeum brachyantherum,	Meadow Barley
Iris tenax,	Oregon Iris
Lupinus micranthus,	Small Flowered Lupine
Sisyrinchium idahoense,	Blue-eyed Grass

Ferns: Moist shade

Blechnum spicant,	Deer Fern
Polypodium gycrrhiza,	Licorice Fern
Polystichum munitum,	Sword Fern
Athyrium felix-femina,	Lady Fern

Shrubs: moist

Cornus sericea,	Red-stemmed or Red-osier Dogwood
Salix hookeriana,	Hookers Willow
Salix lucida var. 'lasiandra',	Pacific Willow
Salix sitchensis,	Sitka Willow
Salix scouleriana,	Scouler's Willow
Salix fluviatalis,	Columbia Willow
Sambucus racemosa,	Red Elderberry
Physocarpis capitatus,	Pacific Ninebark
Spiraea douglasii,	Douglas Spirea
Crataegus douglasii,	Black Hawthorn
Rhamnus purshiana,	Cascara
Rubus spectabilis,	Salmonberry
Rosa pisocarpa,	Swamp Rose

Shrubs: (moist-dry)

Acer circinatum,	Vine maple
Ceanothus sanguineous,	Oregon Redstem Ceanothus
Ceanothus velutinus,	Snowbrush
Corylus cornuta,	Western Beaked Hazelnut
Gautheria shallon,	Salal
Holodiscus discolor,	Oceanspray
Mahonia aquifolium,	Tall Oregon Grape
Mahonia nervosa,	Dull Oregon Grape
Philadelphus lewisii,	Mock Orange
Ribes sanguineum,	Red Flowering Currant

Rosa gymnocarpa,	Baldhip Rose
Rosa nutkana,	Nootka Rose
Rubus parviflorus,	Thimbleberry
Spiraea betulifolia,	Shiny-leaf Spiraea
Symphoricarpus albus,	Snowberry
Viburnum edule,	Highbush Cranberry

Trees

Conifer and Evergreen Trees- varying zones

Abies Grandis,	Grand Fir- moist-dry
Arbutus menziesii,	Madrone- dry
Castanopsis chrysopylla,	Chinquapin- dry
Pinus monticola,	Western White Pine- moist-dry
Pinus Ponderaosa,	Ponderosa Pine- dry
Pseudotsuga menziesii,	Douglas Fir- moist-dry
Thuja plicata,	Western Red Cedar- moist-wet (prefers shade)
Tsuga heterophylla,	Western hemlock- moist

Deciduous Trees- varying zones

Acer macrophyllum,	Big leaf Maple – moist-dry
Alnus rubra,	Red Alder - moist-wet
Amelanchier alnifolia,	Serviceberry - dry
Cornus nuttalii,	Western Flowering Dogwood – moist-dry
Fraxinus latifolia,	Oregon Ash - moist-wet
Malus fusca,	Pacific crabapple - moist-wet
Oemleria cerasiformis,	Indian Plum - moist-dry
Populus balsamifera,	Black Cottonwood – moist-wet
Quercus garryana,	Oregon White Oak – moist-dry

Wet and Extended Wet Pond Recommended Plants:

Planting zones
Shallow water to 1 ft. up the side slope = wet to saturated
Side slopes from 1 – 3 ft. = moist to dry
Side slopes above 3 ft. and upland = dry

Wetland herbaceous plants (aquatic and emergent)
Emergent wet to saturated zone

Alisma plantago-aquatica,	Water Plantain
Carex obnupta,	Slough Sedge
Eleocharis ovata,	Ovate Spike rush
Eleocharis palustris,	Creeping Spike rush
**Lemna minor*,	Common Lesser Duckweed*
Myosotis laxa,	Small-flowered Forget-me-not
**Potamogeton natans*,	Floating-leafed Pondweed
**Sagittaria latifolia*,	Broadleaf Arrowhead; Wapato
Scirpus acutus,	Hardstem Bulrush
Sparganium emersum,	Narrowleaf Bureed

Moist to wet zone

Alopecurus geniculatus,	Water foxtail
Beckmannia syzigachne,	American Slough Grass
Carex aperta,	Columbia Sedge
Carex deweyana,	Dewey Sedge
Juncus effusus,	Common/Soft Rush
Juncus ensifolius,	Dagger-leaf Rush
Juncus oxymeris,	Pointed Rush
Juncus tenuis,	Slender Rush
Juncus patens,	Grooved Rush; Spreading Rush
Lupinus polyphyllus,	Large-leaved Lupine
Scirpus microcarpus,	Small flowered (or fruited) Bulrush

Grasses and Groundcovers: varying zones, see **Exhibit F-1** for grass seed recommendations and specifications.

Aster suspicatus,	Douglas' Aster- moist
Bidens cernua,	Nodding Beggarticks- moist -wet
Bromus sitchensis,	Alaska Brome- moist-dry
Camassia quamash,	Common Camas- moist
Deschampsia caespitosa,	Tufted Hairgrass- moist-dry
Elymus glaucus,	Blue Wildrye- moist-dry
Fragaria vesca or *F. virginiana*,	Woodland strawberry or wild strawberry- moist-dry

Glyceria occidentalis,	Western Mannagrass- moist-wet
Hordeum brachyantherum,	Meadow Barley- moist
Sisyrinchium idahoense,	Blue-eyed Grass- moist
Viola palustris,	Marsh Violet- moist- wet
Veronica americana,	Speedwell- moist-wet

Shrub: moist to saturated zones

Acer circinatum,	Vine Maple
Blechnum spicant,	Deer Fern
Cornus sericea,	Red-stemmed dogwood
Crateagus douglasii,	Black Hawthorn
Rhamnus purshiana,	Cascara
Rubus spectabilis,	Salmonberry
Rosa gymnocarpa,	Baldhip Rose
Rosa pisocarpa,	Swamp Rose
Oemlaria cerasiformis,	Indian Plum
Physocarpis capitatus,	Pacific Ninebark
Polystichum munitum,	Sword fern
Prunus emarginata,	Bitter Cherry
Salix fluviatalis,	Columbia Willow
Salix hookeriana,	Hookers Willow
Salix sitchensis,	Sitka Willow

Shrub: moist to dry zones

Mahonia aquifolium,	Tall Oregon Grape
Mahonia nervosa,	Dull Oregon Grape
Rosa nutkana,	Nootka Rose
Rubus parviflorus,	Thimbleberry
Spiraea betulifolia,	Shiny-leaf Spiraea
Symphoricarpus alba,	Snowberry
Sambucus racemosa,	Red Elderberry
Spiraea douglasii,	Douglas Spiraea
Viburnum edule,	Highbush Cranberry; Squashberry

Shrub dry zones

Corylus cornuta,	Western Beaked Hazelnut
Holodiscus discolor,	Oceanspray
Lonicera involucrata,	Black twinberry (moist-dry)
Mahonia aquifolium,	Tall Oregon Grape
Philadelphis lewesii,	Mock Orange
Ribes sanguineum,	Red Flowering Currant
Salix scouleriana,	Scouler's Willow

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Conifer and Evergreen Trees - varying zones

Abies grandis,	Grand Fir- moist-dry
Arbutus menziesii,	Madrone- dry
Castinopsis chrysophylla,	Chinquapin- dry
Pinus ponderosa,	Ponderosa Pine- dry
Pinus monticola,	Western White Pine- dry-moist
Pseudotsuga menziesii,	Douglas Fir- moist-dry
Sequoia sempervirons,	Coast Redwood- moist
Thuja plicata,	Western Red Cedar- moist-wet
Tsuga heterophylla,	Western Hemlock- moist

Deciduous Trees - varying zones

Acer macrophyllum,	Big leaf Maple- moist- dry
Alnus rubra,	Red Alder- moist-wet
Amelanchier alnifolia,	Serviceberry- dry
Cornus nuttalii,	Western Flowering Dogwood- moist-dry
Fraxinus latifolia,	Oregon Ash- moist-wet
Malus fusca,	Pacific crabapple- moist-wet
Oemleria cerasiformis,	Indian Plum- moist-dry
Populus balsamifera,	Black Cottonwood- moist-wet
Salix lucida var.' lasiandra',	Pacific Willow- moist-wet
Quercus cyrsolepsis,	Canyon Live Oak- dry
Quercus garryana,	Oregon White Oak- moist-dry

SEED SPECIFICATIONS FOR STORMWATER MANAGEMENT MANUAL

Species listed below should only be used in the listed moisture regime for optimal success. *Sow rates for **small seeded mixes** shall contain a **minimum of 20 lbs/per acre in combination** for stormwater management facilities and **30 lbs/acre for erosion control** purposes. **Sow rates for large/medium seeded** mixes should contain a **minimum of 25 lbs per acre** in combination for stormwater management facilities and 40 pounds per acre **for erosion control** purposes.*

Common name	Scientific Name	Optimal Sow Season	Matrix or to add diversity?	Swale or Pond Sow Rate (Hand)	Erosion Control Sow Rate	Moisture	Exposure	Seed size	Commercial accessibility of local eco-type
Grasses									
American sloughgrass	Beckmannia syzigachne	fall/spring	D	2 lbs/ac	NR	inundated to wet	sun	medium	easy to medium, Willamette Valley
Blue wildrye	Elymus glaucus	early fall/spring	**M**	**25 lbs/ac**	40 lbs/acre	xeric to mesic	sun to shade	large	easy, Portland Metro
California brome	Bromus carinatus	early fall/spring	**M**	**25 lbs/ac**	40 lbs/acre	xeric to mesic	sun	large	easy, Portland Metro
California oatgrass	Danthonia californica	fall/spring	**M**	**30 lbs/ac**	NR		sun	large	easy to medium, Willamette Valley
Columbia brome	Bromus vulgaris	fall/spring	D	5 lbs/ac	NR	xeric to mesic	shade	large	medium, Portland Metro
Junegrass	Koeleria macrantha	fall/spring	**M**	**20 lbs/ac**	NR	xeric to mesic	sun	small	easy to medium, PDX or Willamette Valley
Meadowbarley	Hordeum brachyantheru	early fall/spring	**M**	**25 lbs/ac**	40 lbs/acre	wet to mesic	sun	large	easy to medium, Willamette Valley
Pine bluegrass	Poa secunda								
Rice cutgrass	Leersia oryzoides	fall/spring	D	5 lbs/ac	NR	inundated to wet	sun	medium	medium to difficult, Portland Metro
Roemer's fescue	Festuca roemeri	fall/spring	D	2 lbs/ac	NR	xeric to mesic	sun	small	difficult, Willamette Valley
Sitka brome	Bromus sitchensis	early fall/spring	**M**	**25 lbs/ac**	40 lbs/acre	wet to mesic	sun/shade	large	easy, Willamette Valley
Slender hairgrass	Deschampsia elongata	early fall/spring	**M**	**20 lbs/ac**	30 lbs/acre	wet to xeric	sun	small	easy, Portland Metro
Slender wheatgrass	Elymus trachycaulus	early fall/spring	**M**	**25 lbs/ac**	40 lbs/acre	xeric to mesic	sun	large	medium to difficult, Willamette Valley
Spike bentgrass	Agrostis exarata	early fall/spring	D	5 lbs/ac	30 lbs/acre	saturated to wet	sun	small	easy to medium, Portland Metro
Tall mannagrass	Glyceria elata	fall/spring	D	2 lbs/ac	NR	saturated to mesic	shade	small	medium to difficult, Portland Metro
Tufted hairgrass	Deschampsia cespitosa	fall/spring	D	2 lbs/ac	NR	saturated to wet	sun	small	easy, Willamette Valley
Water foxtail	Alopecuris geniculatus	fall/spring	**M**	**25 lbs/ac**	NR	inundated to wet	sun	medium	easy, PDX or Willamette Valley
Western fescue	Festuca occidentalis	fall/spring	**M**	**20 lbs/ac**	NR	xeric to mesic	sun	small	medium to difficult, Willamette Valley
Western mannagrass	Glyceria occidentalis	fall/spring	**M**	**25 lbs/ac**	NR	saturated to wet	sun	medium	easy to medium, Willamette Valley
Sedges, Rushes - soil moisture as indicated into summer months									
Carex obnupta	Slough sedge	fall/spring	D	2 lbs/ac	NR	inundated to mesic	sun/shade	medium	medium to difficult, PDX
Carex scoparia	Pointed broom sedge	fall/spring	D	2 lbs/ac	NR	wet to mesic	sun	medium	medium to difficult, PDX
Carex stipata	Sawbeak sedge	fall/spring	D	2 lbs/ac	NR	inundated to mesic	sun	medium	medium, Willamette Valley
Eleocharis ovata	Ovate spikerush	fall/spring	D	1 lb/ac	NR	inundated to wet	sun	small	easy, PDX or Willamette Valley
Eleocharis palustris	Creeping spikerush	fall/spring	D	2 lbs/ac	NR	inundated to wet	sun	small	easy to medium, Willamette Valley
Juncus acuminatus	Tapertip rush	fall/spring	D	0.25 lbs/ac	NR	inundated to wet	sun	small	medium, Willamette Valley, PDX
Juncus bufonius	Toad rush	fall/spring	D	0.25 lbs/ac	NR	wet to mesic	sun	small	medium, Willamette Valley
Juncus patens	Spreading rush	fall/spring	D	0.50 lb/ac	NR	wet to mesic	sun/shade	small	easy, PDX
Forbs									
Achillea millefolium	Western Yarrow	fall	D	0.25 lbs/ac	NR	wet to mesic	sun	medium	easy, PDX or Willamette Valley
Aquilegia formosa	Western Columbine	fall	D	1.0 lb/ac	NR	wet to mesic	sun	medium	easy to medium, Willamette Valley
Alisma media	Water plantain	fall/spring	D	1.0 lb/ac	NR	inundated to wet	sun	medium	easy to medium, Willamette Valley
Collomia grandiflora	Large flowered collomia	fall/spring	D	.50 lbs/ac	NR	xeric to mesic	sun	small	medium to difficult, Willamette Valley
Collinsia rattanii	Blue eyed mary	fall/spring	D	.25 lbs/ac	NR	xeric to mesic	sun	small	medium to difficult, Willamette Valley
Epilobium densiflora	Dense spike primrose	fall	D	1.0 lb/ac	NR	wet to mesic	sun	small	medium, Willamette Valley
Eriophyllum lanatum	Wooly sunshine	fall	D	1.0 lb/ac	NR	wet to mesic	sun	medium	easy to medium, Willamette Valley
Gilia capitata	Blue gilia	fall/spring	D	2 lbs/acre	1 lb/ac (w/	xeric to mesic	sun	medium	medium, Willamette Valley
Lotus purshianus	Spanish clover	fall	D	2 lbs/acre	1 lb/ac (w/	xeric to mesic	sun	medium	medium, Willamette Valley
Lupinus albicaulis	Sickle keel lupine	fall	D	1 lb/ac	1 lb/ac (w/	xeric to mesic	sun	large	medium, Willamette Valley
Iris tenax	Oregon Iris	fall	D	2 lbs/ac	NR	xeric to mesic	sun	large	easy to medium, Willamette Valley
Camassia quamash	Common camas	fall	D	1 lb/ac	NR	wet to mesic	sun	medium	easy to medium, Willamette Valley
Camassia quamash va	Great camas	fall	D	1 lb/ac	NR	wet to mesic	sun	medium	easy to medium, Willamette Valley
Lupinus micranthus	Small flowered lupine	fall	D	1 lb/ac	NR	xeric to mesic	sun	medium	medium to difficult, Willamette Valley
Ranunculus occidental	Western buttercup	fall	D	1 lb/ac	NR	xeric to mesic	sun	medium	medium to difficult, Willamette Valley
Sidalcea campestris	Checker mallow	fall	D	1 lb/ac	NR	xeric to mesic	sun	large	medium to difficult, Willamette Valley
Lupinus rivularis	Stream lupine	fall	D	1 lb/ac	1 lb/ac (w/	xeric to mesic	sun	large	medium, Willamette Valley
Plagiobothrys figuratus	Popcorn flower	fall/spring	D	1.0 lb/ac	NR	inundated to wet	sun	small	medium to difficult, Willamette Valley
Prunella vulgaris var. la	Self heal	fall/spring	D	2 lbs/ac	1 lb/ac (w/	wet to mesic	sun/shade	medium	easy to medium, PDX or Willamette Valley
Solidago canadensis	Goldenrod	fall	D	0.50 lbs/ac	NR	xeric to mesic	sun	small	easy to medium, PDX or Willamette Valley
Recommended Non-Native Cover Crop Species									
Festuca rubra var. com	Chewings fescue	year round	M	20 lbs/ac	30-40				n/a
Triticum spp.	Wheat	year round	M	50 lbs/ac	60				n/a
Avena spp.	Oats	year round	M	50 lbs/ac	60				n/a
Regreen	Sterile wheat hybrid	year round	M	40 lbs/ac	50				n/a
Agropyron spp.	Wheatgrass	year round	M	30 lbs/acre	40				A. trachycaulus (W.V. source)

Nuisance Grass Species not recommended for use on Erosion Control or Stormwater Projects

Species	*Common name*		*State Listed Noxious Weed?*			*City*		
Agropyron repens	Quackgrass		yes (B-list)			Nuisance List Portland Plant List		
Alopecuris pratensis	Meadow foxtail		no			Nuisance List Portland Plant List		
Anthoxanthum odoratu	Sweet vernal grass		no			Nuisance List Portland Plant List		
Arrhenatherum elatius	Tall oatgrass		no			Nuisance List Portland Plant List		
Brachypodium sylvatic	False brome		yes (B-list)			Nuisance List Portland Plant List		
Bromus diandrus	Ripgut		no			Nuisance List Portland Plant List		
Bromus hordaceus	Smooth brome		no			Nuisance List Portland Plant List		
Bromus inermis	Smooth brome		no			Nuisance List Portland Plant List		
Bromus japonicus	Japanese brome		no			Nuisance List Portland Plant List		
Bromus sterilis	Poverty grass		no			Nuisance List Portland Plant List		
Bromus tectorum	Cheatgrass		no			Nuisance List Portland Plant List		
Festuca arundinacea	Tall fescue		no			Nuisance List Portland Plant List		
Holcus lanatus	Velvet grass		no			Nuisance List Portland Plant List		
Lolium multiflorum	Annual ryegrass		no			Nuisance List Portland Plant List		
Phalaris arundinacea	Reed canary grass		no			Nuisance List Portland Plant List		
Phalaris aquatica	Harding grass		no			Nuisance List Portland Plant List		
Phleum pratensis	Timothy		no			Nuisance List Portland Plant List		
Phragmites australis	Common reed		no			Nuisance List Portland Plant List		
Vulpia myoros	Rat-tailed fescue		no			Nuisance List Portland Plant List		

F.2 DESIGN CONCEPTS AND PRINCIPLES

The Bureau of Environmental Services (BES) requires developers to design stormwater facilities in project landscape areas, using surface retention facilities such as those shown in the simplified approach. The resulting integrated stormwater landscape can meet many, if not all, of Title 33 landscape requirements, applicable plan district requirements, and Title 17 requirements. The benefits of integrated designs include construction cost savings, combined maintenance, aesthetic benefits, and the greater likelihood of maintaining long-term functionality. A well-designed and established landscape will also prevent post-construction soil erosion. These approaches can also help reduce urban heat island effects and contribute to other sustainable principles.

An integrated design may require changing the size of some site elements. For example, Title 33.266 parking code allows parking layout and dimensions to be designed to allow more space for simplified approach facilities. Also see Parking lot Design Tips in Chapter 2 of this document.

In order to integrate stormwater management with the project landscape areas, it is essential that impervious surface grading be directed toward the stormwater facility areas. Surface stormwater facilities also must be depressed to allow sheet flow into the area. Since these design approaches are still new to many construction contractors it is advisable to clearly show these details in cross section and plan view drawings.

Pollution Prevention

Stormwater pollution prevention practices related to landscaping can be categorized into two broad categories:

- Toxic Substance Use Reduction
- Pollutant Source Reduction

Toxic Substance Use Reduction

Projects shall be designed to minimize the need for toxic or potentially polluting materials such as herbicides, pesticides, fertilizers, or petroleum based fuels within the facility area before, during, and after construction. Use of these materials creates the risk of spills, misuse, and future draining or leaching of pollutants into facilities or the surrounding area. (*For information about alternatives, contact Metro's Alternatives to Pesticides Program at 503-797-1811.*)

Pollutant Source Reduction

Materials that could leach pollutants or pose a hazard to people and wildlife shall not be used as components of a stormwater facility. Some examples of these materials are chemically treated railroad ties and lumber and galvanized metals. Many alternatives to these materials are available.

Soils

Soil analysis shall be conducted **within the stormwater facility area** to determine the viability of soils to assure healthy tree and vegetation growth and to provide adequate infiltration rates through the topsoil, or soil in these areas shall be amended. These tests can help the designer specify appropriate levels and types of soil amendments.

Projects should stockpile existing topsoil for re-use on the site to minimize the need to import topsoil. Appropriate erosion control measures, as required by the City's *Erosion Control Manual*, shall be used. Soil analysis tests shall be performed on stockpiled soil if it will be used within the facility area.

Topsoil is not required to be placed in the bottom of wet ponds or constructed wetland areas having a permanent pool depth of 6" or more. At the time of final inspection all surface area soils shall be covered with plants and/or mulch sufficient to prevent erosion.

Site Preparation and Grading

Unwanted vegetation in the facility area shall be removed during site preparation with equipment appropriate for the type of material encountered and site conditions. It is recommended that the maximum amount of pre-existing native vegetation be retained and protected.

No material storage or heavy equipment is allowed within the stormwater facility area after site clearing and grading has been completed, except to excavate and grade as needed to build the facility.

After the facility area is cleared and graded, all disturbed subsoil shall be tilled before capping with 18 inches of topsoil. If existing areas surrounding the stormwater facility are disturbed by construction, the top 18 inches of soil shall be tilled. No tilling shall occur within the drip line of existing trees. After tilling is completed, no other construction traffic shall be allowed in the area, except for planting and related work.

All construction and other debris shall be removed before topsoil is placed. Unless otherwise specified, the City will expect the landscape contractor to be responsible for final grading and for ensuring that surface and stormwater runoff flows are functioning as designed.

Mulch

Approved mulching materials and practices include organic materials such as compost, bark mulch, leaves, sawdust, straw, or wood shavings, as well as small river gravel, pumice, or other inert materials, applied in a 1-foot radius (measured from the center of the plant) around specific trees or shrubs. For ground cover plantings, the mulch shall be applied to cover all soil between plants. Care should be exercised to use the appropriate amount of mulch. Over-use can cause excessive nutrients to leach into the facility. Mulch shall be weed-free. Manure mulching and high-fertilizer hydroseeding are prohibited in a facility area during and after construction.

Irrigation

Permanent irrigation systems are not allowed for BES maintained facilities, unless approved by BES. Temporary irrigation systems or alternative methods of irrigation for landscape establishment shall be specified. Permanent irrigation systems are allowed for private facilities, but designers are encouraged to minimize the need for permanent irrigation. Innovative methods for watering vegetation are encouraged, such as the use of cisterns and air conditioning condensate.

Facility Screening

Facility elements such as chain link fences, concrete bulkheads, outfalls, rip-rap, gabions, large steel grates, steep side slopes, manhole covers/vault lids, berm embankments planted only with grasses, exposed pipe, blank retaining walls greater than 2 feet high, and access roads are generally not aesthetic. When these elements are part of City-maintained facilities or private facilities that face public right-of-way or other private property, BES requires them to be screened with plant materials. The quantities of landscape materials that are required by this chapter have been estimated to provide sufficient screening in most of the stormwater facilities. Attention will need to be paid to site conditions that may require adjustments in planting layout and/or the need for additional trees and shrubs. It is not the intent of this screening requirement to dictate a specific solution such as a linear hedge. Designers are encouraged to integrate the facility landscaping with the screening objective. Designers can also use more decorative materials providing they are attractive and meet the intent of city code requirements such as L2, L3, or L4 standards as specified in City Code Title 33.248.

Commercial Sources for Native Plant Material

Bareroot (Seedling) Trees/ Shrubs

Balance Restoration Nursery	541-942-5530 (fax & phone)
Wallace Hansen Nursery	503-581-2638, fax 503-581-9957
D.L. Phipps State Forest Nursery	541-584-2214, fax 541-584-2326
Brooks Tree Farm	503-393-6300, fax 503-393-0827
Mineral Springs Ornamentals	503-852-6129, fax 503-852-6553
Mt. Jefferson Farms	503-363-0467, fax 503-362-5248
Northwest Native Plants	503-632-7079, fax 503-632-7087
Seven Oaks Native Nursery	541-757-6620 (fax & phone)
Bosky Dell Natives	503-638-5945, fax 503-638-8047

Container Material

Northwest Native Plants	503-632-7079, fax 503-632-7087
Seven Oaks Native Nursery	541-757-6620 (fax & phone)
Bosky Dell Natives	503-638-5945, fax 503-638-8047
Watershed Gardenworks	360-423-6456

Emergent Plugs

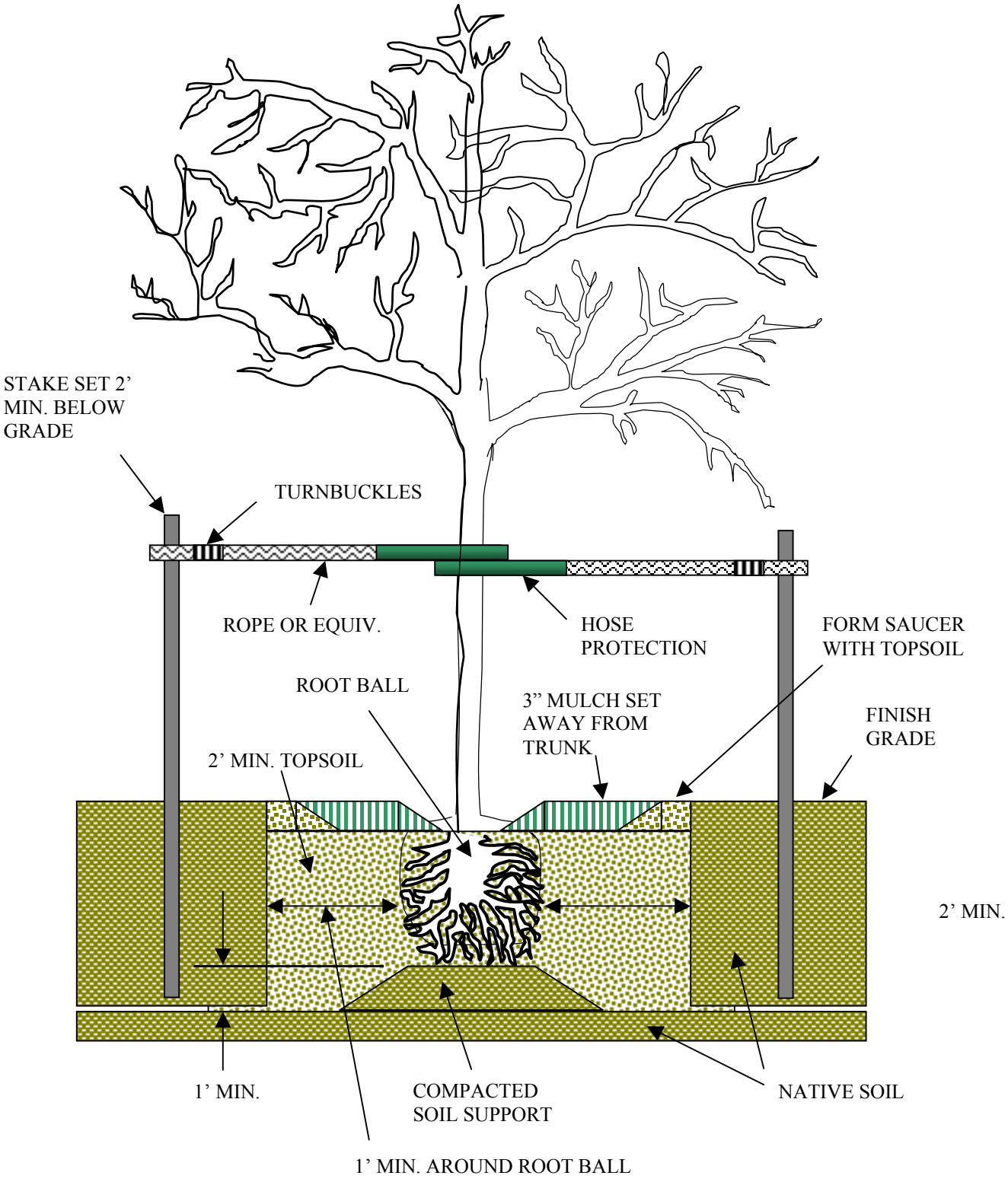
Balance Restoration Nursery	541-942-5530 (fax & phone)
Seven Oaks Native Nursery	541-757-6620 (fax & phone)
Watershed Gardenworks	360-423-6456

Native Seed

Pacific Northwest Natives	541-928-8239
Mid-Valley Farms	541-936-6061
North American Revegetation	541-928-9095
Triangle Farms	503-873-5190
Oregon Heritage Farms	503-628-2775

Note: This list is not all-inclusive and is only up-to-date at the time of this manual's release. If you are interested in being added to this list notify Steve Fancher at stevef@bes.ci.portland.or.us. For a more inclusive list of nurseries that supply native plants, contact: www.tardigrade.org/natives/nurseries.html. For an updated database of commercial native seed availability in the Pacific Northwest, contact: www.nativeseednetwork.org.

Tree Planting Detail for Trees of 3" Caliper or Larger, usually used for street trees applications. This detail is not required for smaller trees. However, all trees must be secured sufficiently at the time of planting and throughout the warranty period to assure that the tree is well established.



SARB_008123

Portland Plant List

A detailed plant list, including habitat types (i.e. wetland, riparian, forested slopes, thicket, grass and rocky) can be found at:

http://www.portlandonline.com/planning/index.cfm?c=35517

Parking Lot Trees

BES has included the parking lot tree list to assist designers in selection of trees most appropriate for the potentially numerous micro-climates that might exist in parking lots and often associated proximity to building walls. It is likely that most parking lots will be hot in summer months until the trees become established. BES has attempted to point out native species in the list and provide their suitability to various conditions.

Trees are listed by the scientific name of the species first, then the common name. Where applicable, names of cultivars are presented in single quote marks with the common name.

The recommended minimum clearance from the pavement provides guidance on the amount of planting space each tree needs. It is expressed as the distance from the center of the planted tree trunk to the nearest paved surface. Comments provide guidance as to best applications of the different trees and additional information that may help in tree selection. For example, some trees are well suited to landscaped areas that will receive stormwater runoff, while others may not tolerate the additional moisture from runoff, largely depending on the soil.

There are two tables. The first consists of trees that are not native to the Portland area and the second consists of native trees listed on the Portland Plant List.

Non-native trees

Species name	Common Name	Minimum Distance from Pavement	Comments
Abies amabilis	Silver Fir	4 feet	Conifer, evergreen. Native to Oregon Cascades.
Acer campestre	Hedge maple	2 feet	Broadleaf, deciduous.
Acer rubrum	Red maple 'Embers Red,' 'October Glory,' 'Red Sunset,' 'Gerling,' 'Autumn Flame'	3 feet	Broadleaf, deciduous. Good for stormwater facilities

Species name	Common Name	Minimum Distance from Pavement	Comments
Acer saccharum	Sugar Maple (Except 'Legacy')	3 feet	Broadleaf, deciduous.
Calocedrus decurrens	Incense Cedar	3 feet	Conifer, evergreen Drought tolerant
Carpinus betulus	European Hornbeam	2 feet	Broadleaf, deciduous. Shade tolerant.
Celtis occidentalis	Hackberry	3 feet	Broadleaf, deciduous.
Cercidiphyllum japonicum	Katsura Tree	3 feet	Broadleaf, deciduous. Prefers well-drained soils Needs summer irrigation
Cladrastis kentuckea	Yellowwood	3 feet	Broadleaf, deciduous. Prefers summer irrigation and well-drained soil.
Cornus kousa var. *chinensis*	Chinese Dogwood	3 feet	Broadleaf, deciduous. Small tree. Fruits, but is not messy. Needs summer water.
Crataegus x *lavallei*	Lavalle Hawthorn	2 feet	Broadleaf, deciduous. Fruit can be messy.
Fagus grandifolia	American Beech	4 feet	Broadleaf, deciduous.
Fagus sylvatica	European Beech	4 feet	Broadleaf, deciduous.
Fagus sylvatica	European Beech 'Roseo-marginata,' 'Tricolor'	3 feet	Broadleaf, deciduous.
Fraxinus americana	White Ash	3 feet	Broadleaf, deciduous. Needs plenty of water until established
Fraxinus excelsior	European Ash	3 feet	Broadleaf, deciduous. Needs plenty of water until established
Fraxinus pennsylvanica	Green Ash 'Marshall,' 'Patmore,' 'Summit,' 'Urbanite'	3 feet	Broadleaf, deciduous. Needs plenty of water until established
Ginkgo biloba	Ginkgo 'Shangri-la,' 'Saratoga'	3 feet	Measured as a broadleaf; deciduous. Use the male only. Female produces messy, smelly fruit.
Liquidambar styraciflua	Sweetgum	4 feet	Broadleaf, deciduous.
Liriodendron tulipifera	Tulip Tree or Tulip Poplar	4 feet	Broadleaf, deciduous.
Magnolia grandiflora	Southern Magnolia	4 feet	Broadleaf, evergreen.
Magnolia kobus	Kobus Magnolia	2 feet	Broadleaf, deciduous.
Metasequoia	Dawn Redwood	4 feet	Conifer, deciduous.

Species name	Common Name	Minimum Distance from Pavement	Comments
glyptostroboides			
Nothofagus dombeyi	South American Beech or Southern Beech	3 feet	Broadleaf, evergreen.
Nothofagus obliqua	Roble Beech	3 feet	Broadleaf, deciduous.
Nyssa sylvatica	Black Gum or Black Tupelo	3 feet	Broadleaf, deciduous. Good for stormwater facilities.
Ostrya virginiana	American Hornbeam	2 feet	Broadleaf, deciduous.
Pinus contorta	Shore Pine	3 feet	Conifer, evergreen. A smaller tree.
Pinus monticola	Western White Pine	3 feet	Conifer, evergreen.
Quercus bicolor	Swamp White Oak	3 feet	Broadleaf, deciduous. Tolerates wet soil.
Quercus coccinea	Scarlet Oak	3 feet	Broadleaf, deciduous. Intolerant of wet soil.
Quercus frainetto	Hungarian Oak 'Forest Green'	3 feet	Broadleaf, deciduous.
Quercus nigra	Water Oak	3 feet	Broadleaf, evergreen. Tolerates wet conditions.
Quercus phellos	Willow Oak	3 feet	Broadleaf, deciduous.
Quercus robur	English Oak	3 feet	Broadleaf, deciduous.
Quercus rubra	Northern Red Oak	4 feet	Broadleaf, deciduous.
Quercus velutina	Black Oak	4 feet	Broadleaf, deciduous.
Sequoia sempervirens	Coast Redwood	6 feet	Conifer, evergreen. Grows very tall.
Sequoiadendron giganteum	Giant Sequoia	8 feet	Conifer, evergreen. Trunk quickly becomes massive, needs ample space.
Sophora japonica	Japanese Pagoda Tree	3 feet	Broadleaf, deciduous.
Taxodium distichum	Bald Cypress	4 feet	Conifer, deciduous. Tolerates extremely wet conditions, but does not require it.
Umbellularia californica	California Laurel, Oregon Myrtle, Bay	4 feet	Broadleaf, evergreen. Drought tolerant.
Zelkova serrata	Sawleaf Zelkova 'Green Vase,' 'Halka,' 'Village Green'	3 feet	Broadleaf, deciduous.

Native Parking Lot Trees from the Portland Plant List

Species Name	Common Name	Minimum Distance from Pavement	Comments
Abies grandis	Grand Fir	4 feet	Conifer, evergreen. Can grow very tall.
Acer macrophyllum	Big Leaf Maple	4 feet	Broadleaf, deciduous.
Alnus rubra	Red Alder	3 feet	Broadleaf, deciduous. Moisture loving. ***Short live species.*** *
Crataegus douglasii, var. douglasii	Black Hawthorn, wetland form	3 feet	Broadleaf, deciduous. A smaller tree. Wetland form tolerates wet areas.
Fraxinus latifolia	Oregon Ash	3 feet	Broadleaf, deciduous. Tolerates wet conditions.
Pinus ponderosa, ssp. Valley	Ponderosa Pine, Valley subspecies	4 feet	Conifer, evergreen. Prefers drier conditions, but Valley subspecies is adapted to Willamette Valley climate.
Pseudotsuga menziesii	Douglas Fir	4 feet	Conifer, evergreen. Can grow very tall.
Quercus garryana	Oregon White Oak	4 feet	Broadleaf, deciduous. Drought tolerant.
Rhamnus purshiana	Cascara	3 feet	Broadleaf, deciduous. A smaller tree.
Thuja plicata	Western Red Cedar	4 feet	Conifer, evergreen. Prefers moist conditions and some shade. **Does not do well in direct sunlight, Shade tolerant**
Thuja plicata	Western Red Cedar 'Hogan'	4 feet	Conifer, evergreen. Prefers moist conditions and some shade. 'Hogan' is a narrow-growing variety.

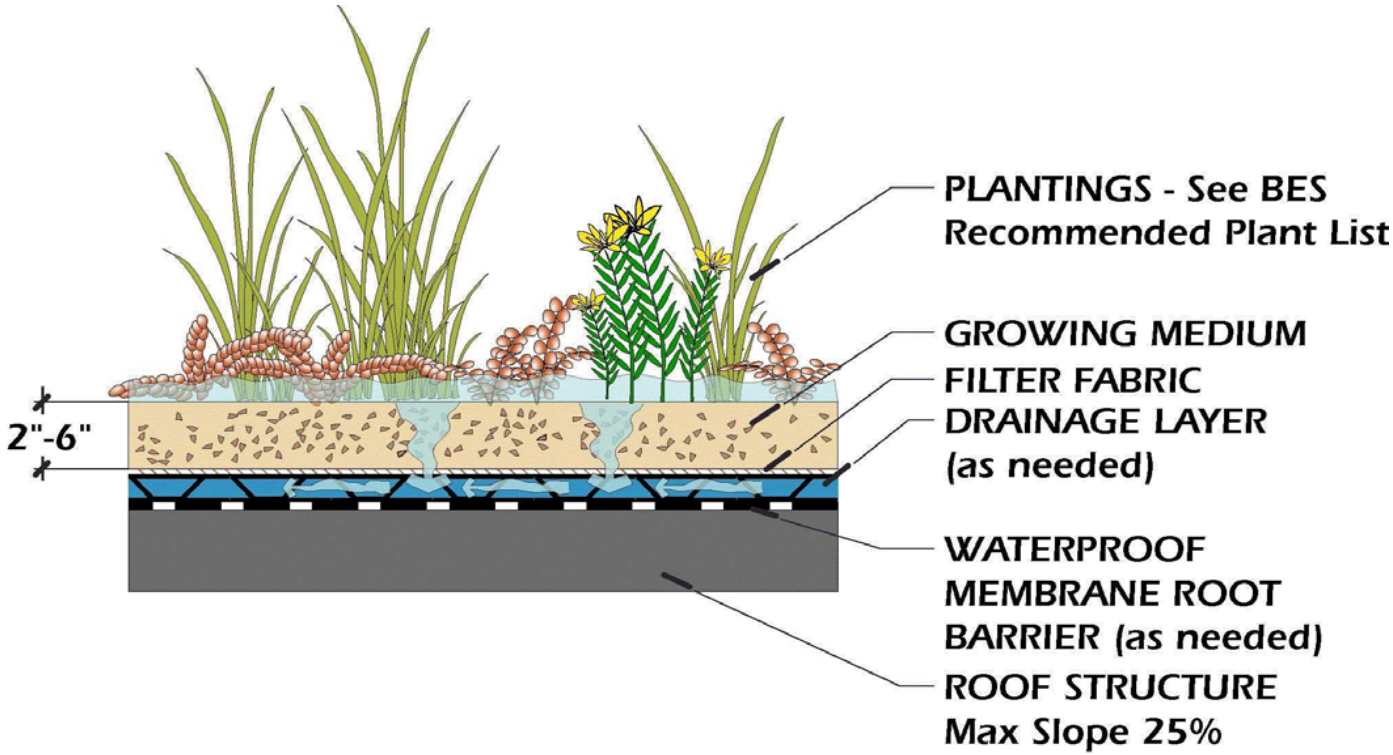
* According to the "Western Tree Book" maximum age of a Red Alder is thought to be 100 years. Relatively speaking these trees have a life span sufficient for urban parking lot swales. A report by the Portland Planning Bureau in 1997 indicated that the life expectancy of most trees in non-residential areas was 20-40 years.

SARB_008127

Appendix G

Supplemental Drawings and
Example Landscaping Plans

September 2004 Stormwater
Management Manual



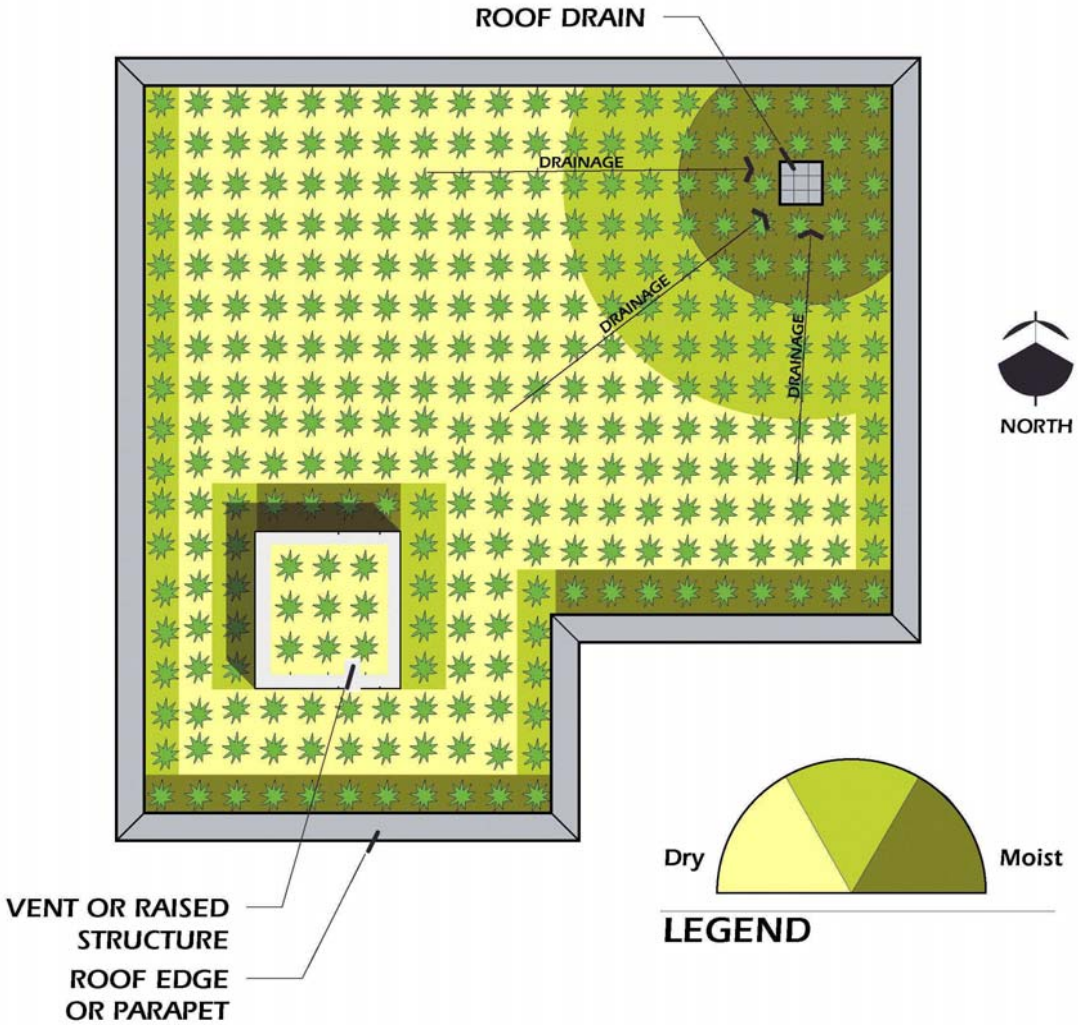
SIMPLIFIED APPROACH DESIGN CRITERIA

Eco-roof

SARB_008130

7/26v/02

PLANTINGS:
See BES Recommended
Plant List



Ecoroof Evaporation Diagram

7/26/02

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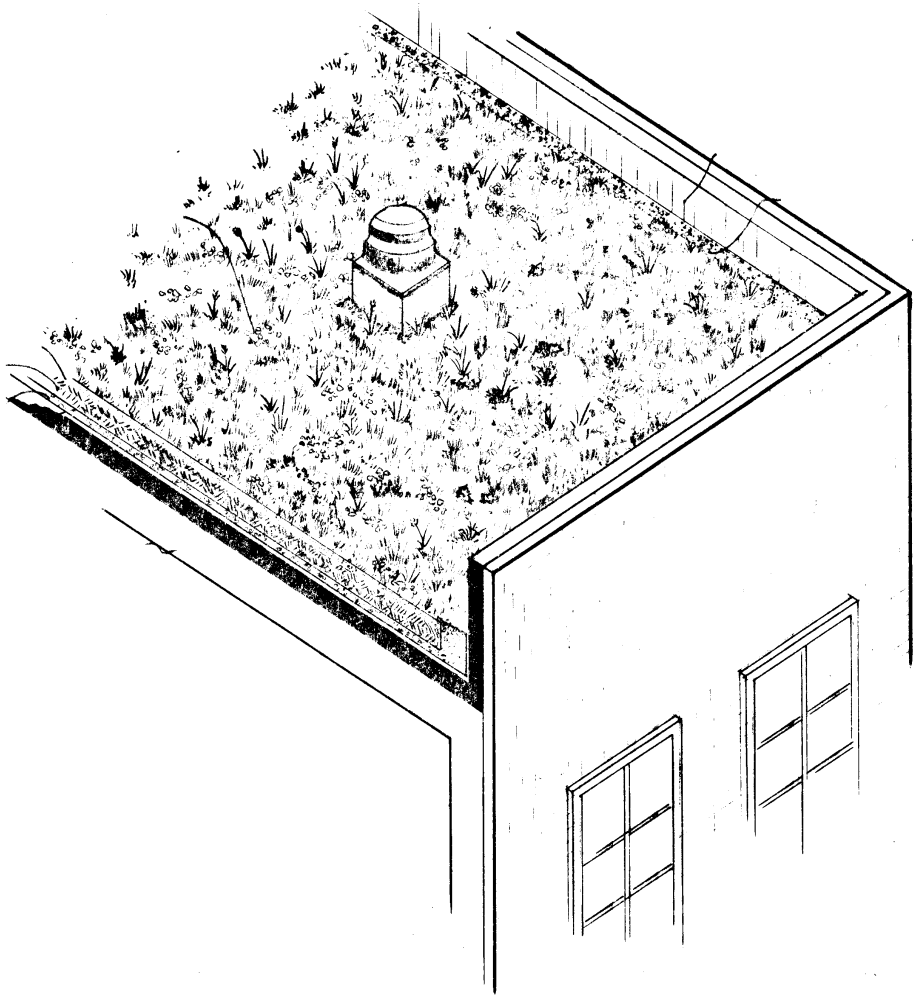
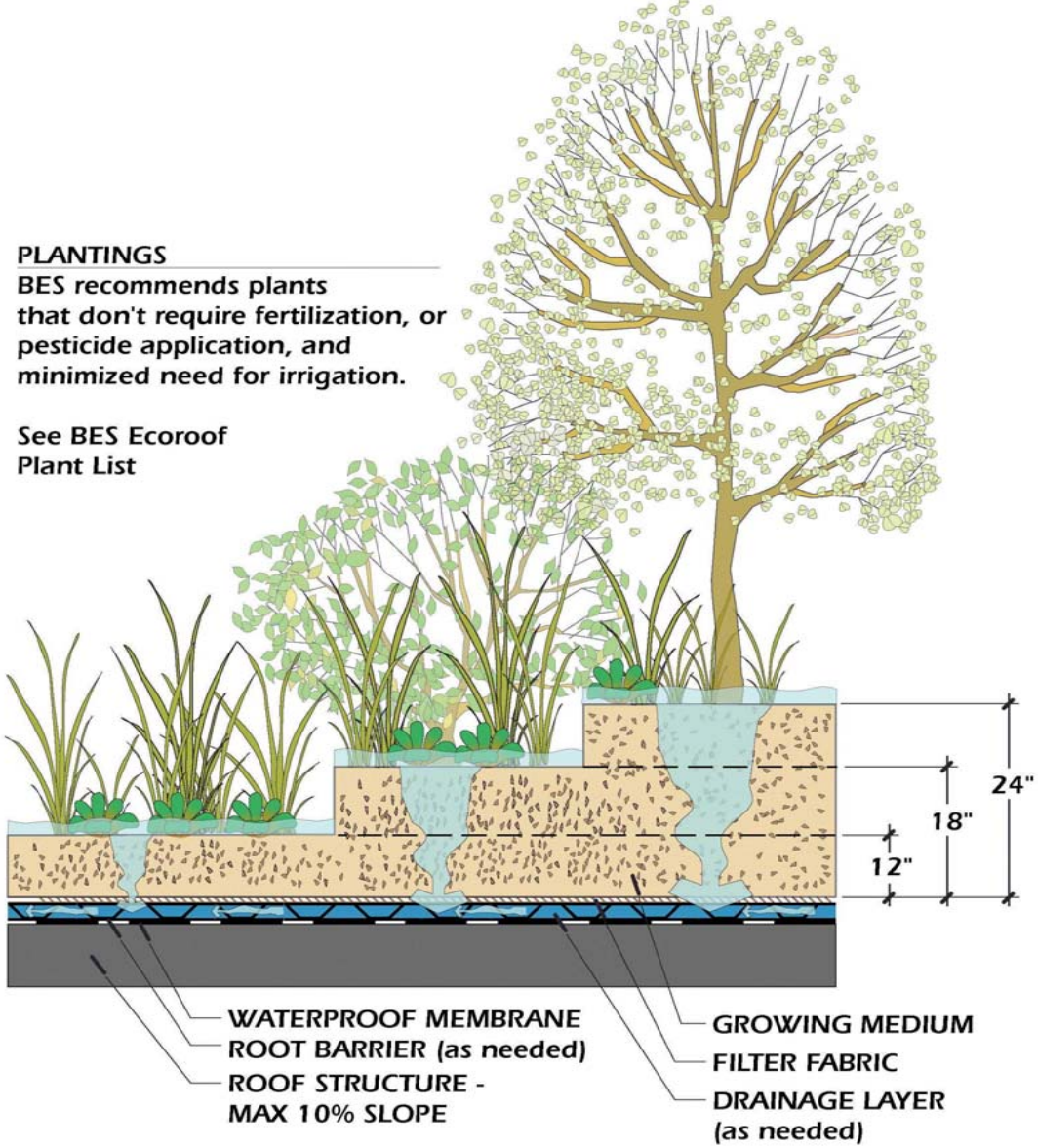
Eco-Roof





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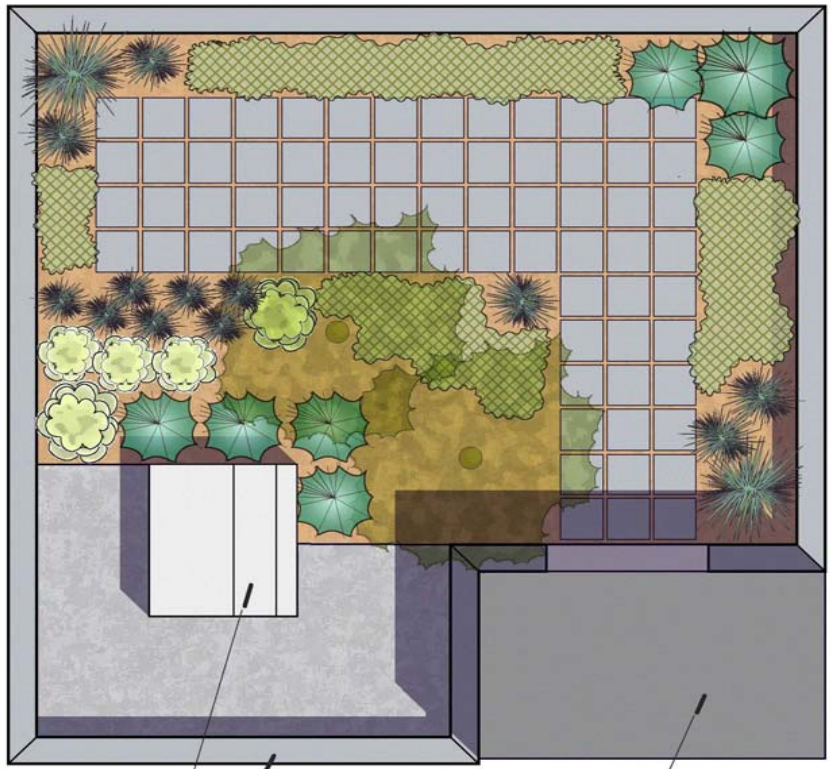
Roof Garden

7/26/02



LEGEND PLANTINGS: See BES Recommended Plant List

DECIDUOUS TREE

SHRUBS

EVERGREEN TREE

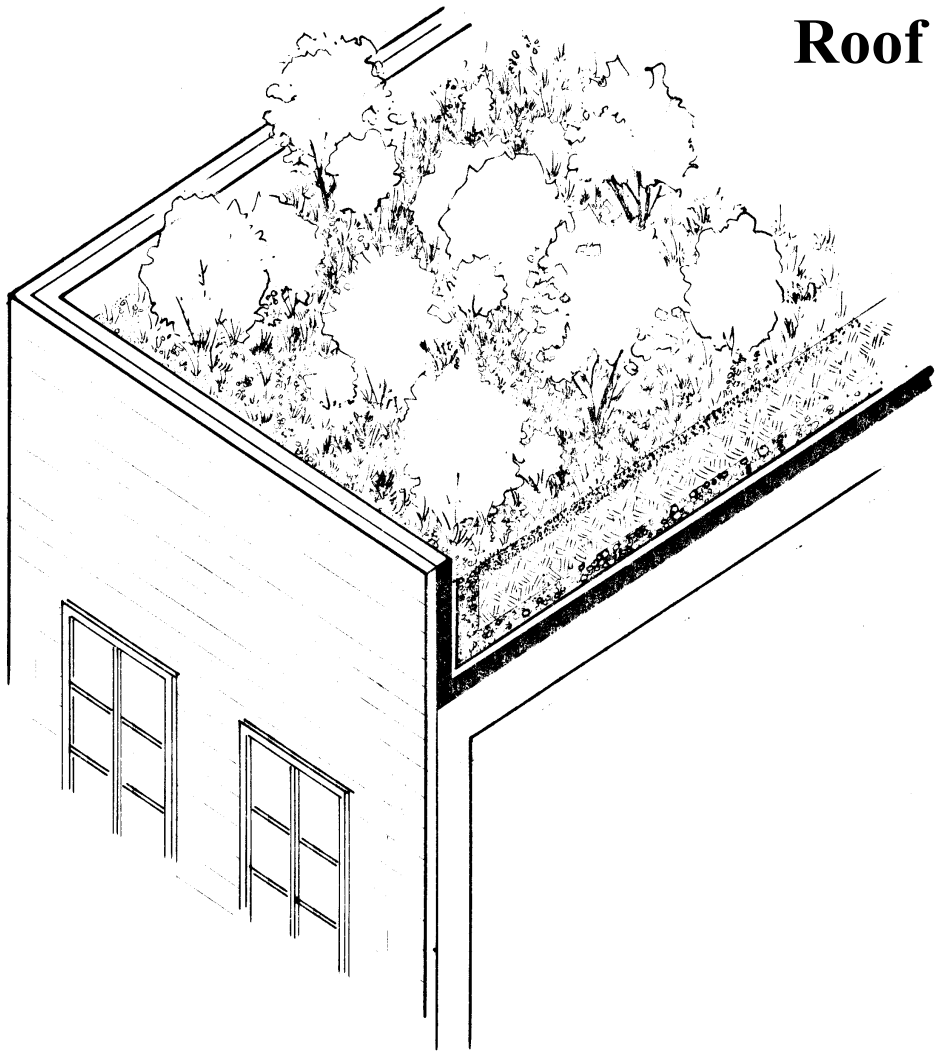
GROUNDCOVER

SARB_008134

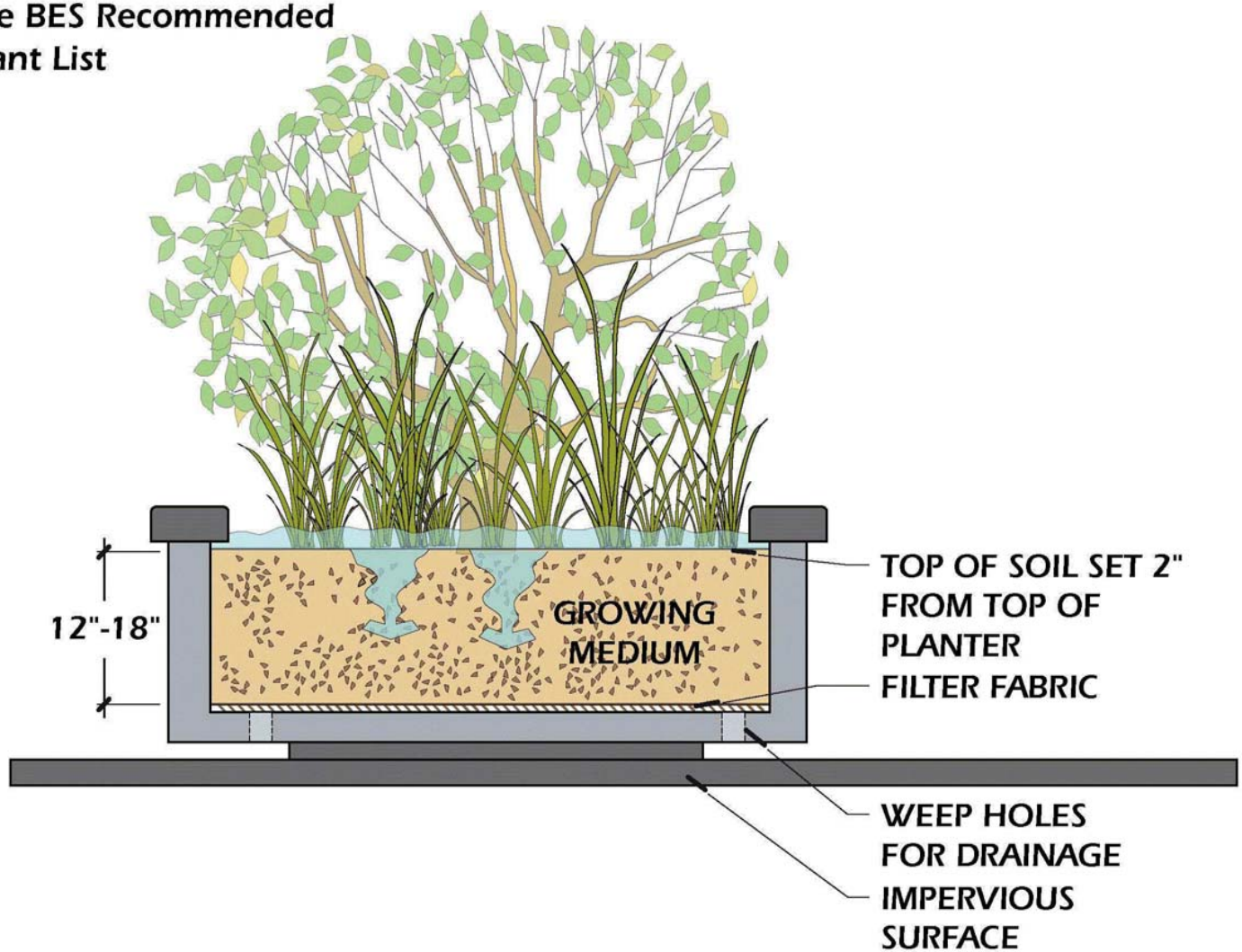
Roof Garden Plan

7/26/02

Roof Garden



PLANTINGS:
See BES Recommended
Plant List



Contained Planter Box

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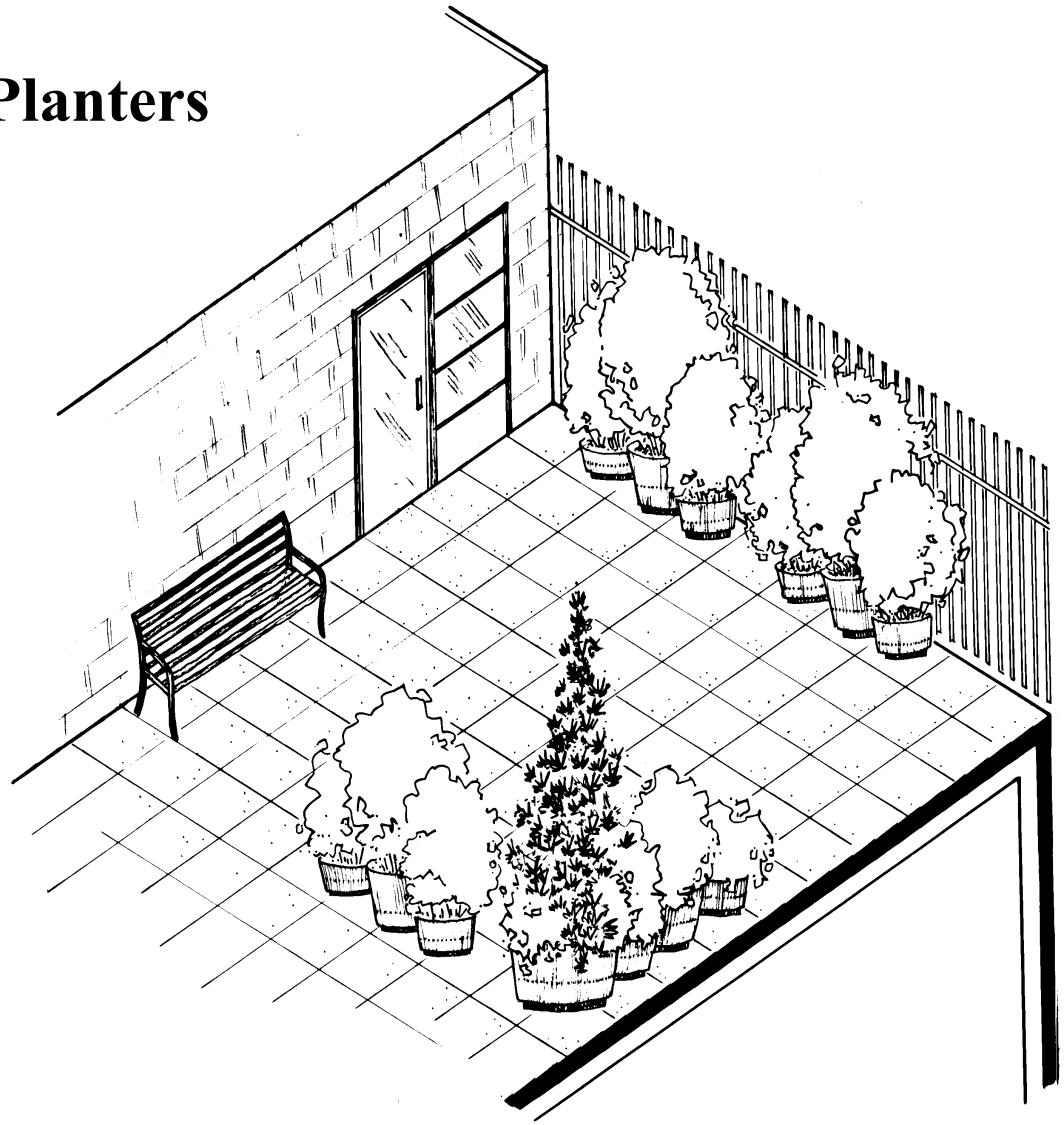
7/26/02

Contained Planters



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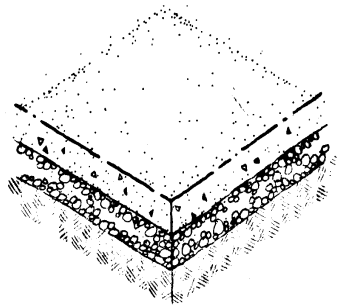
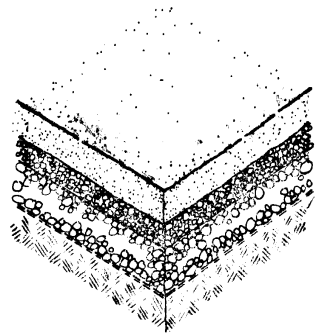
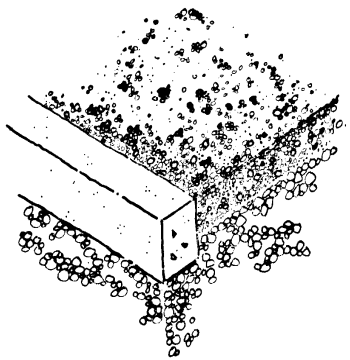
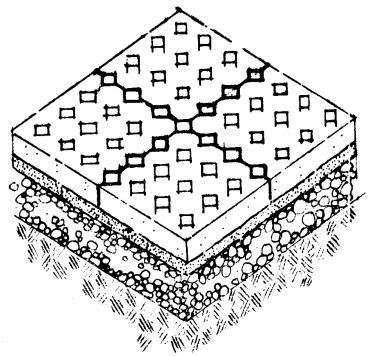
Porous Pavement

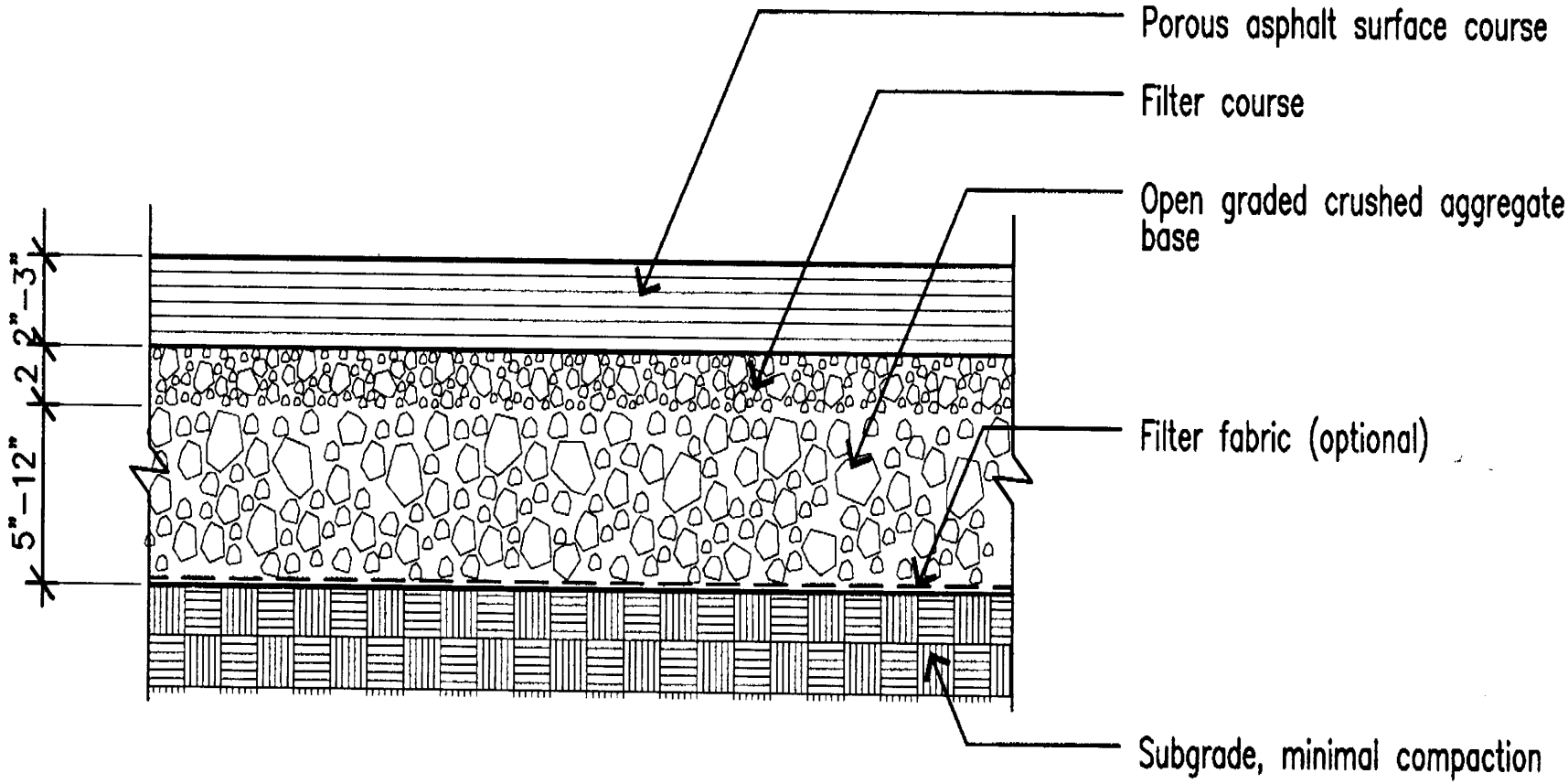








porous asphalt



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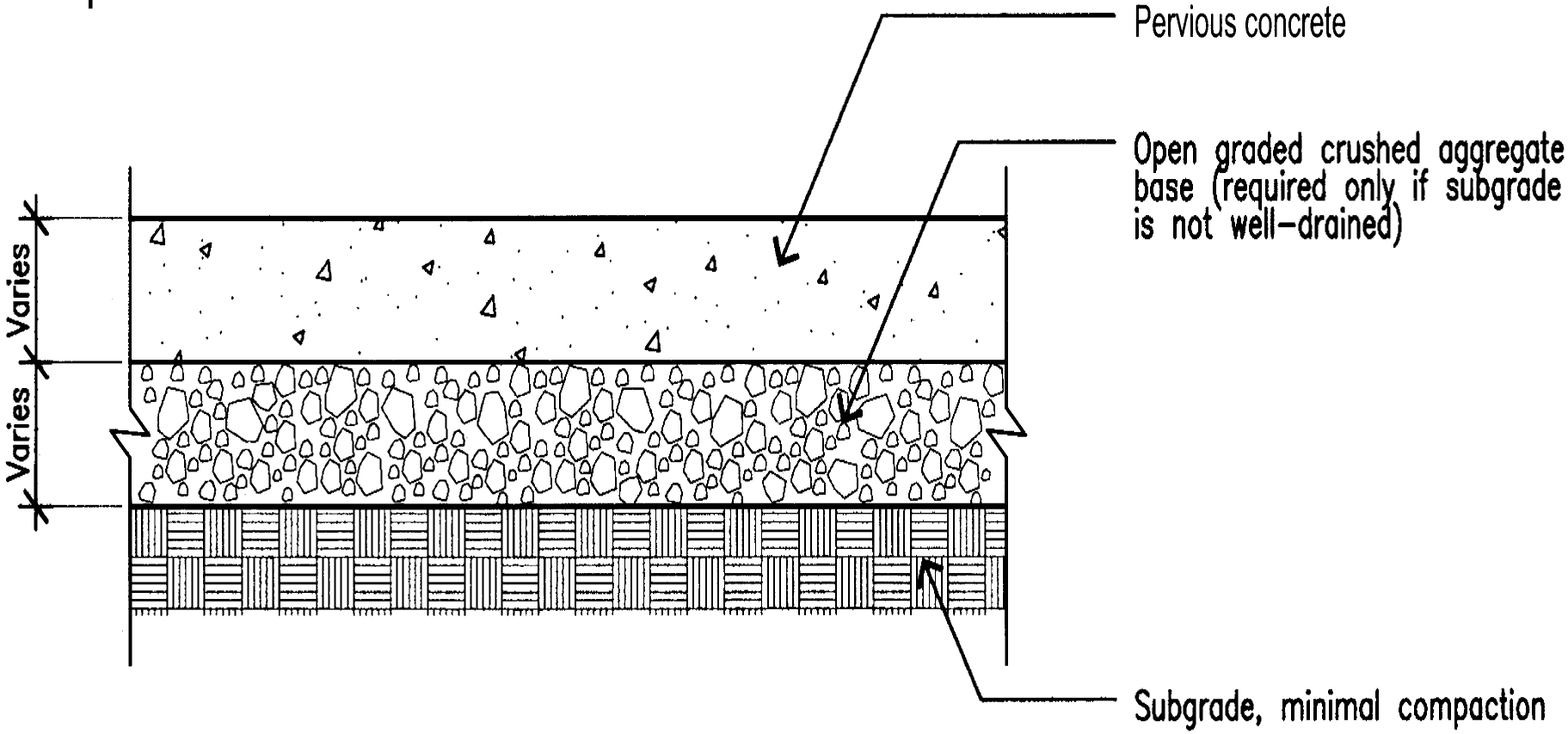
pervious concrete



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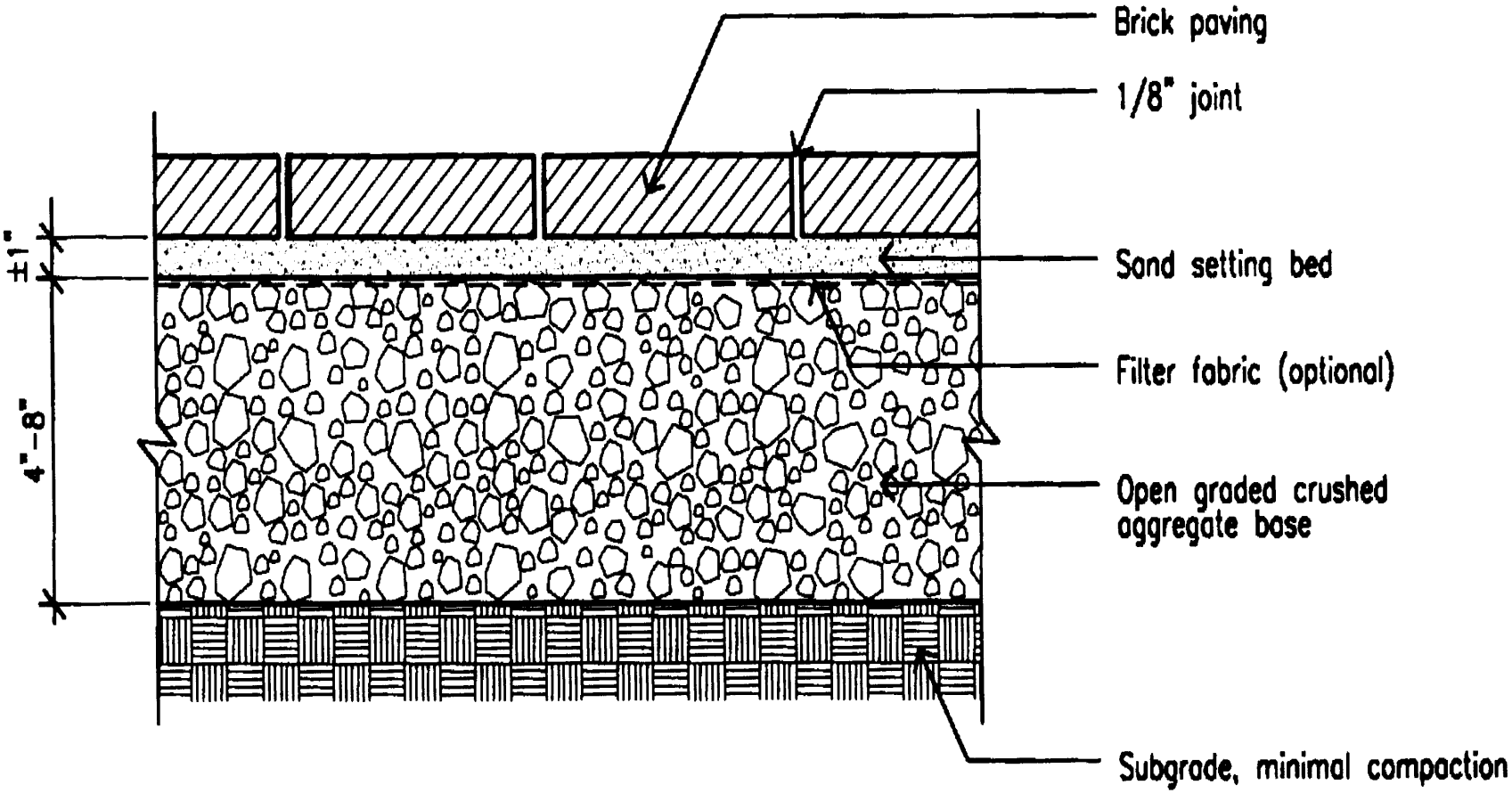
brick



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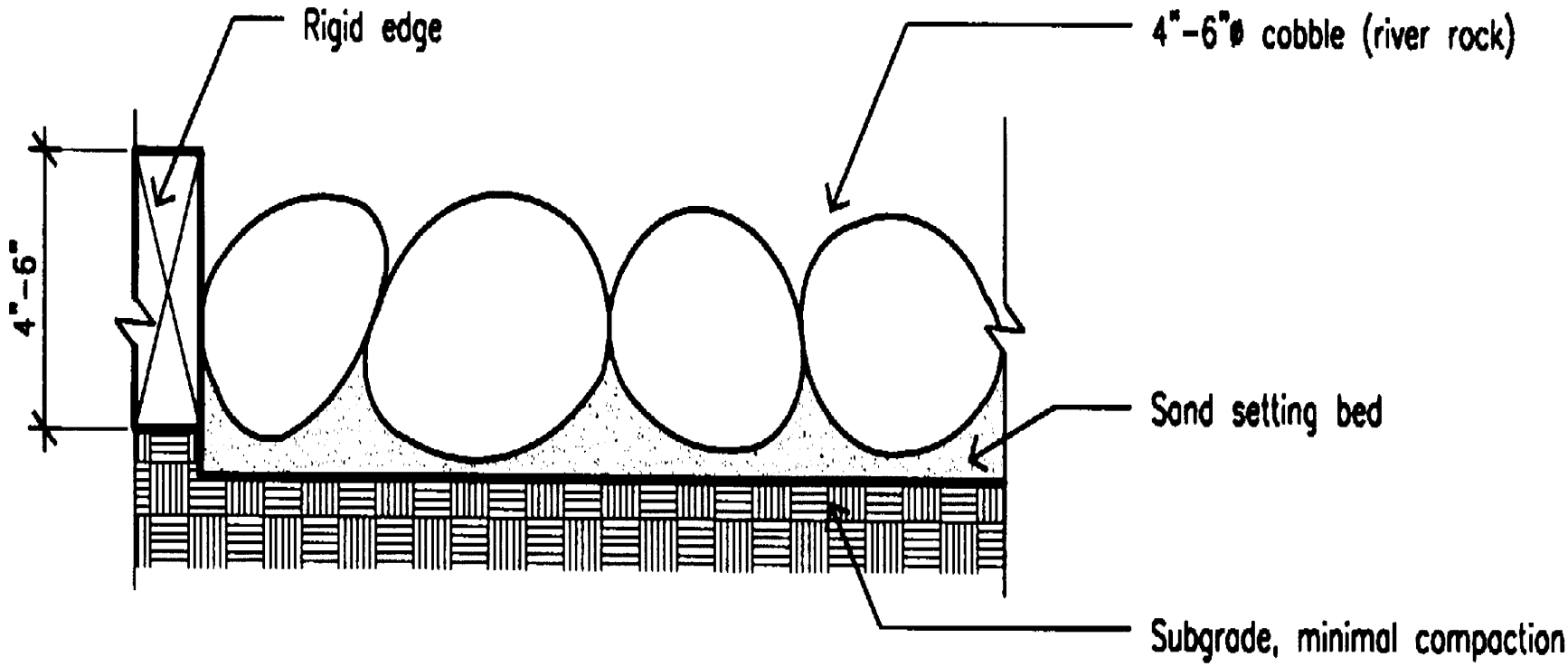
cobbles



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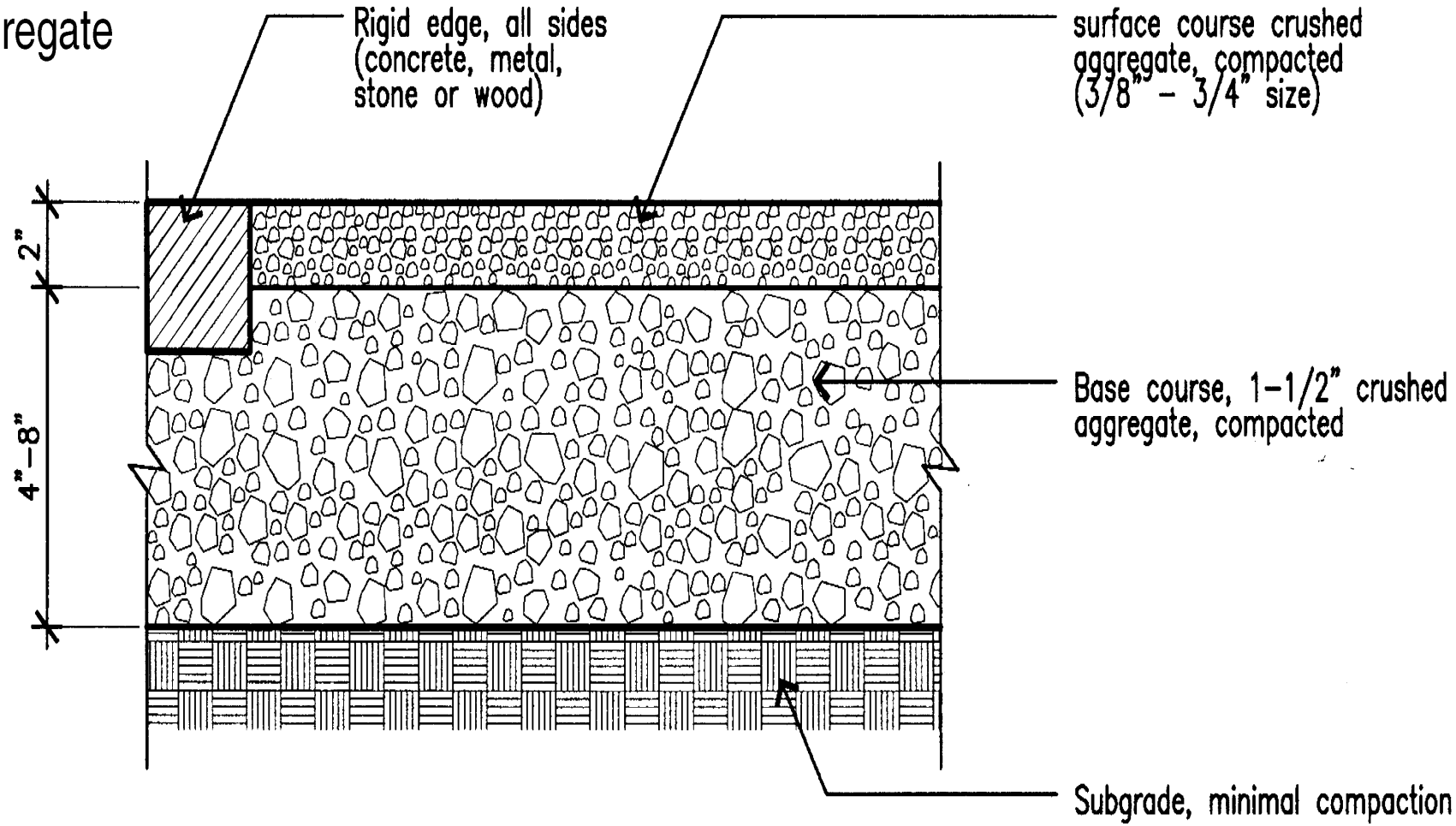
crushed aggregate



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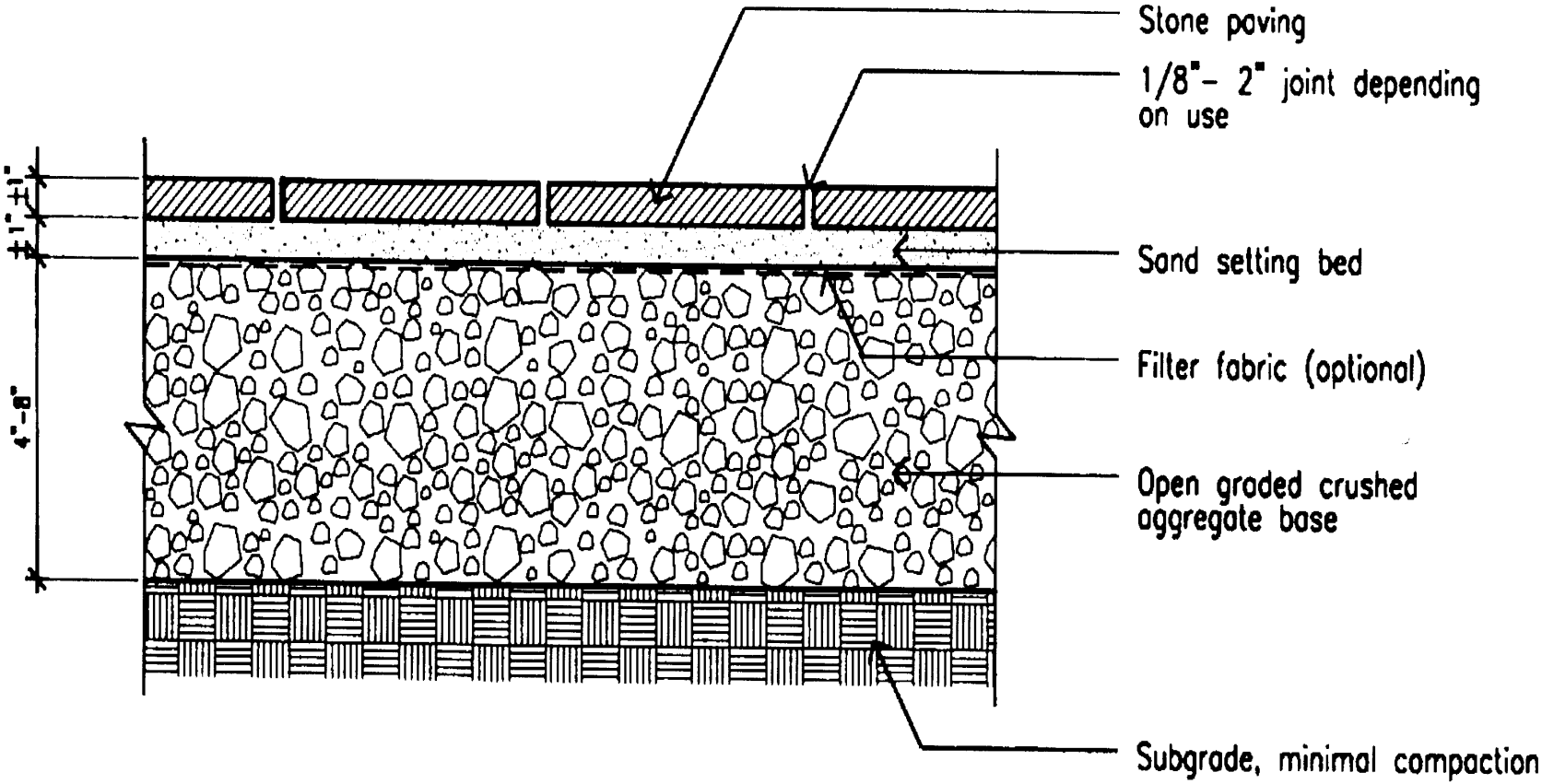
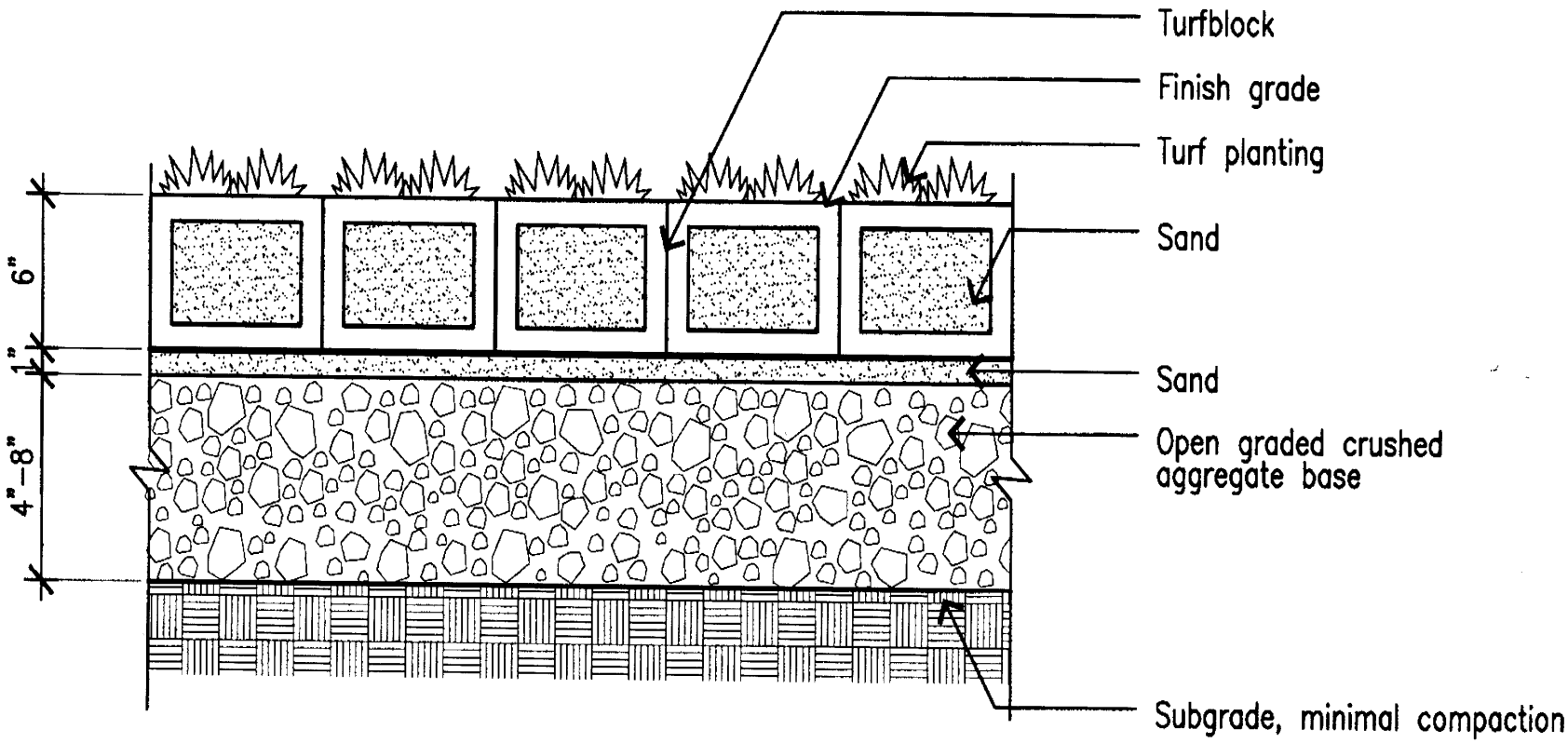
natural stone



Turf block



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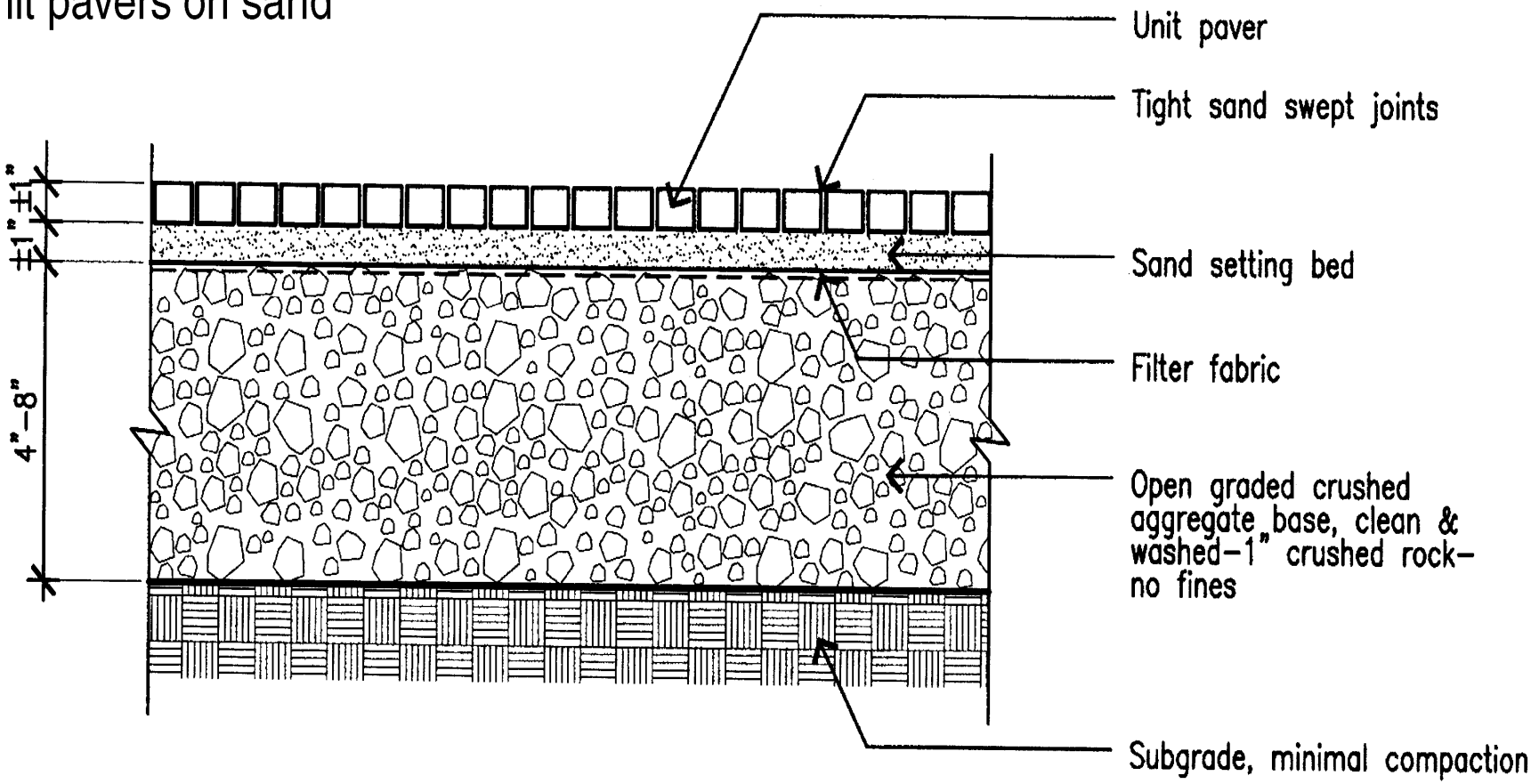
unit pavers on sand



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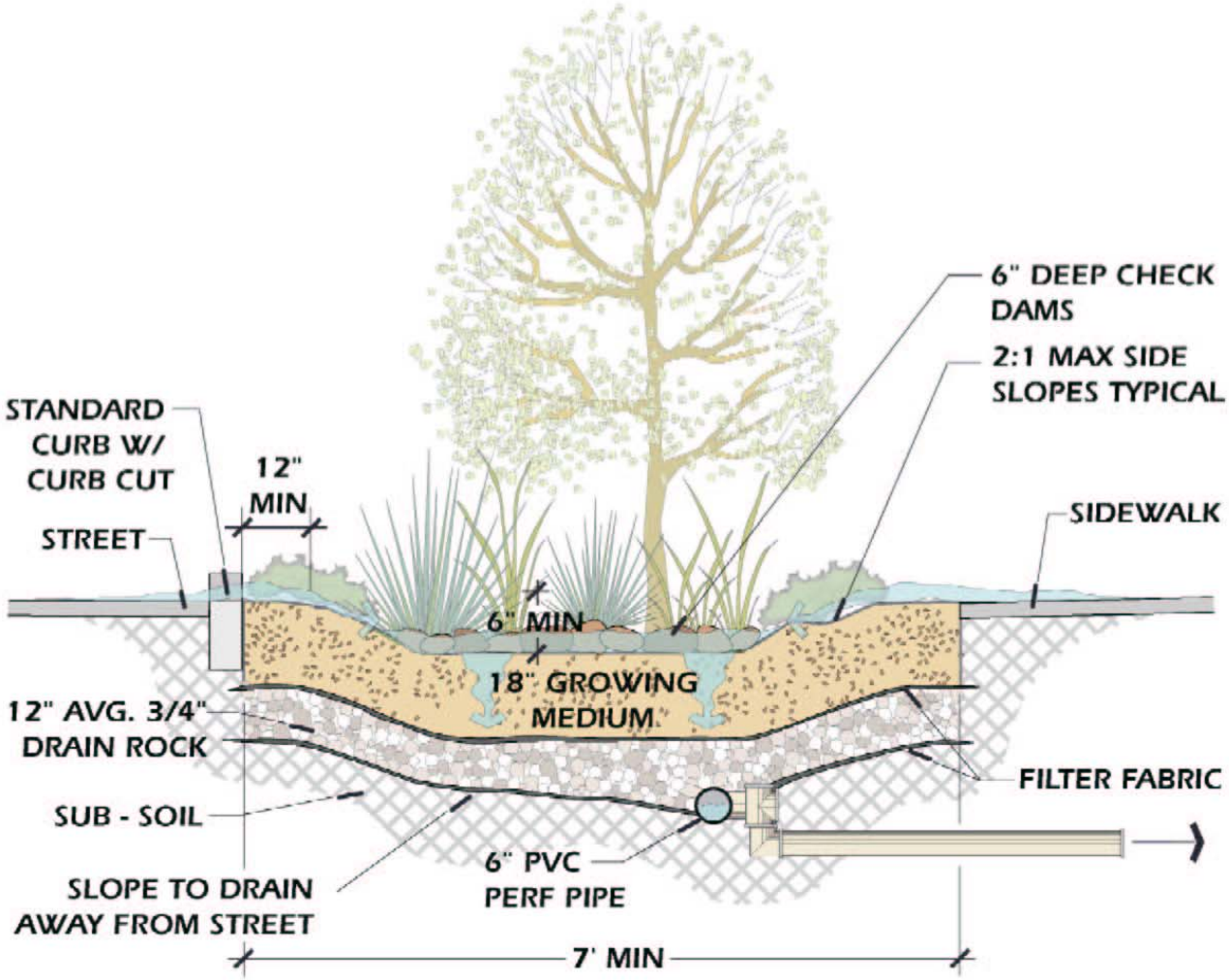
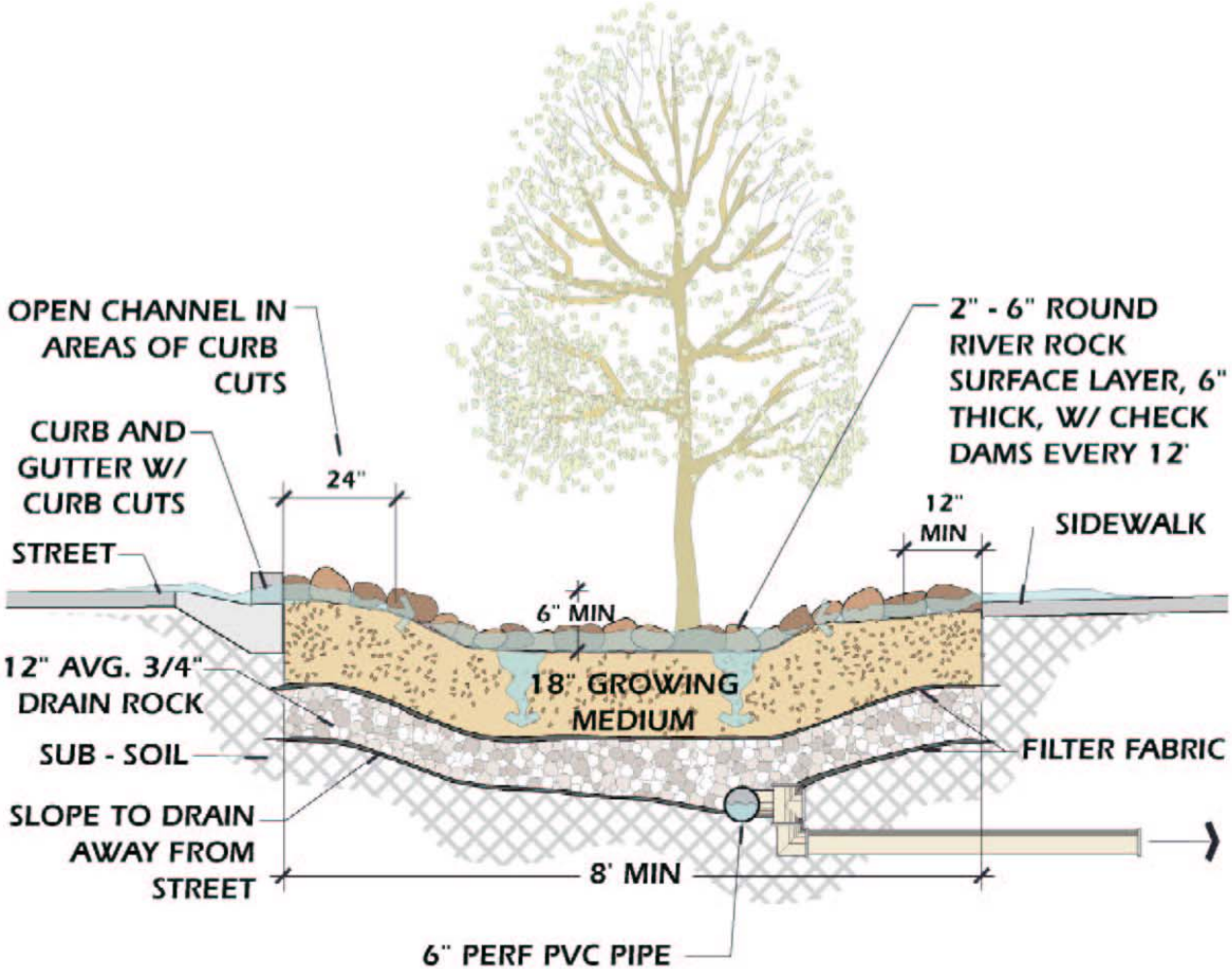


SIMPLIFIED APPROACH DESIGN CRITERIA

Lowered Planter Strip - Private Street Design

7/8/02

SARB_008147

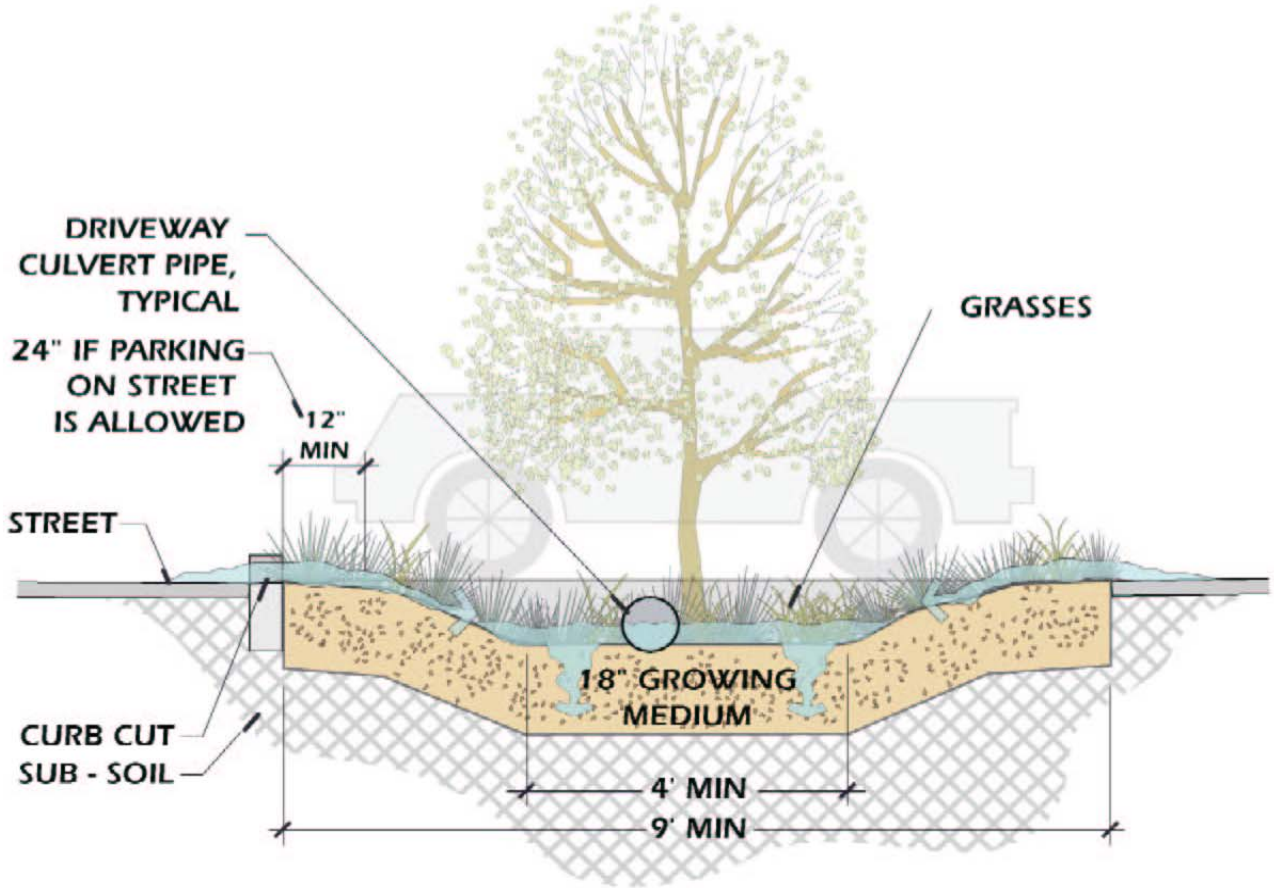


SIMPLIFIED APPROACH DESIGN CRITERIA

Lowered Planter Strip - Parking Allowed

7/8/02

SARB_008148



SIMPLIFIED APPROACH DESIGN CRITERIA

Side Swale - Cross Section

7/8/02

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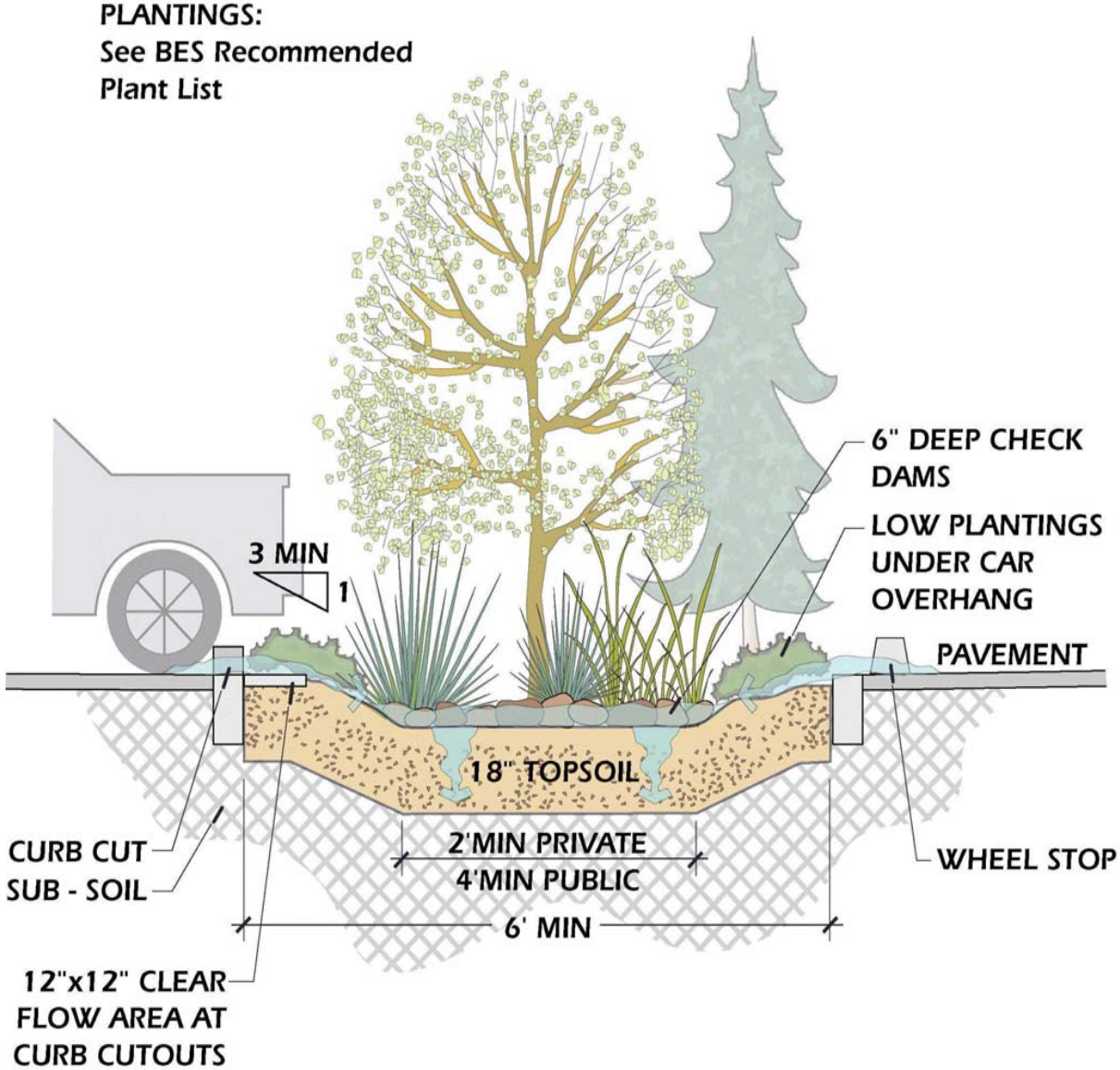


Vegetated Swale

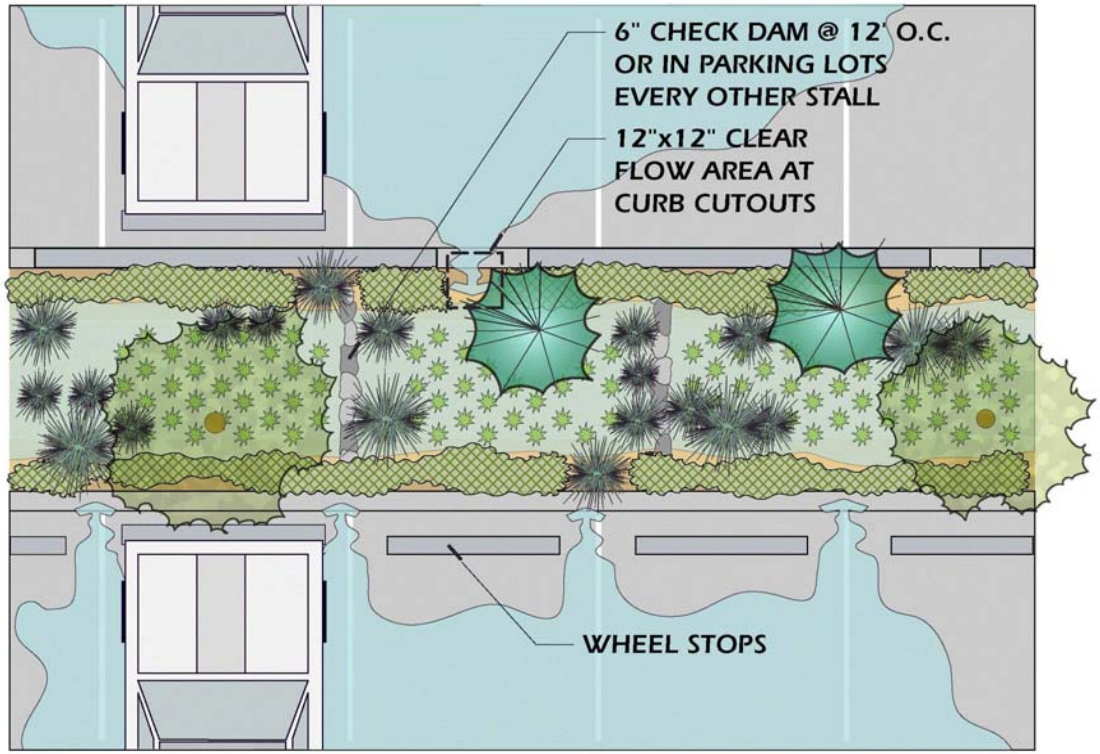
Parking Lot Application

7/26/02

SARB_008150

LEGEND





Swale Area = Approx. 400 sq. ft.
(Not to Scale)

Notes:

1. At least 50% of the facility shall be planted with grasses or grass-like plants, primarily in the flow path.
2. Large grass like plants can be considered as shrubs.
   See BES recommended plant list and parking lot tree list and plant quantity requirements.

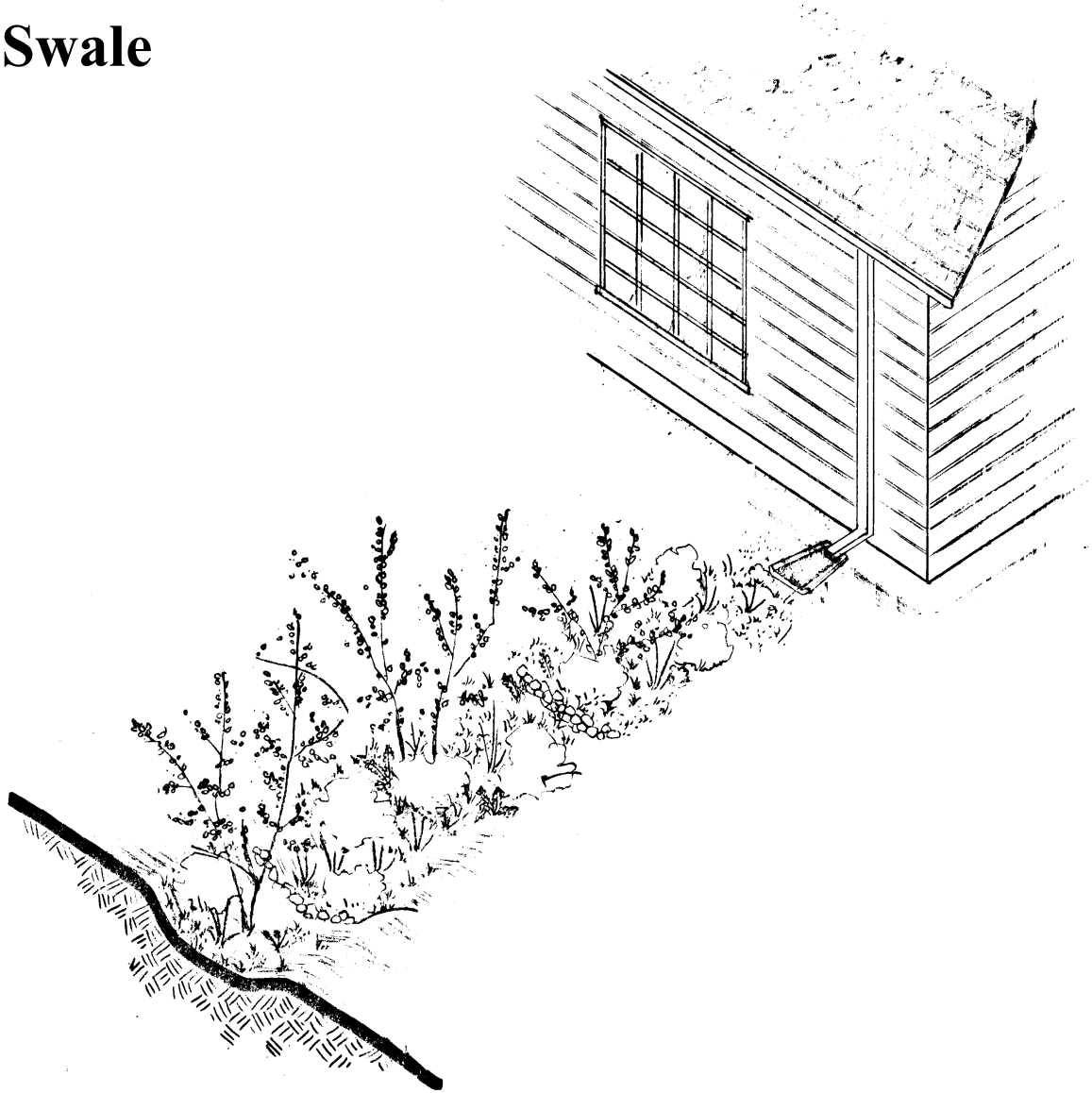
SARB_008151

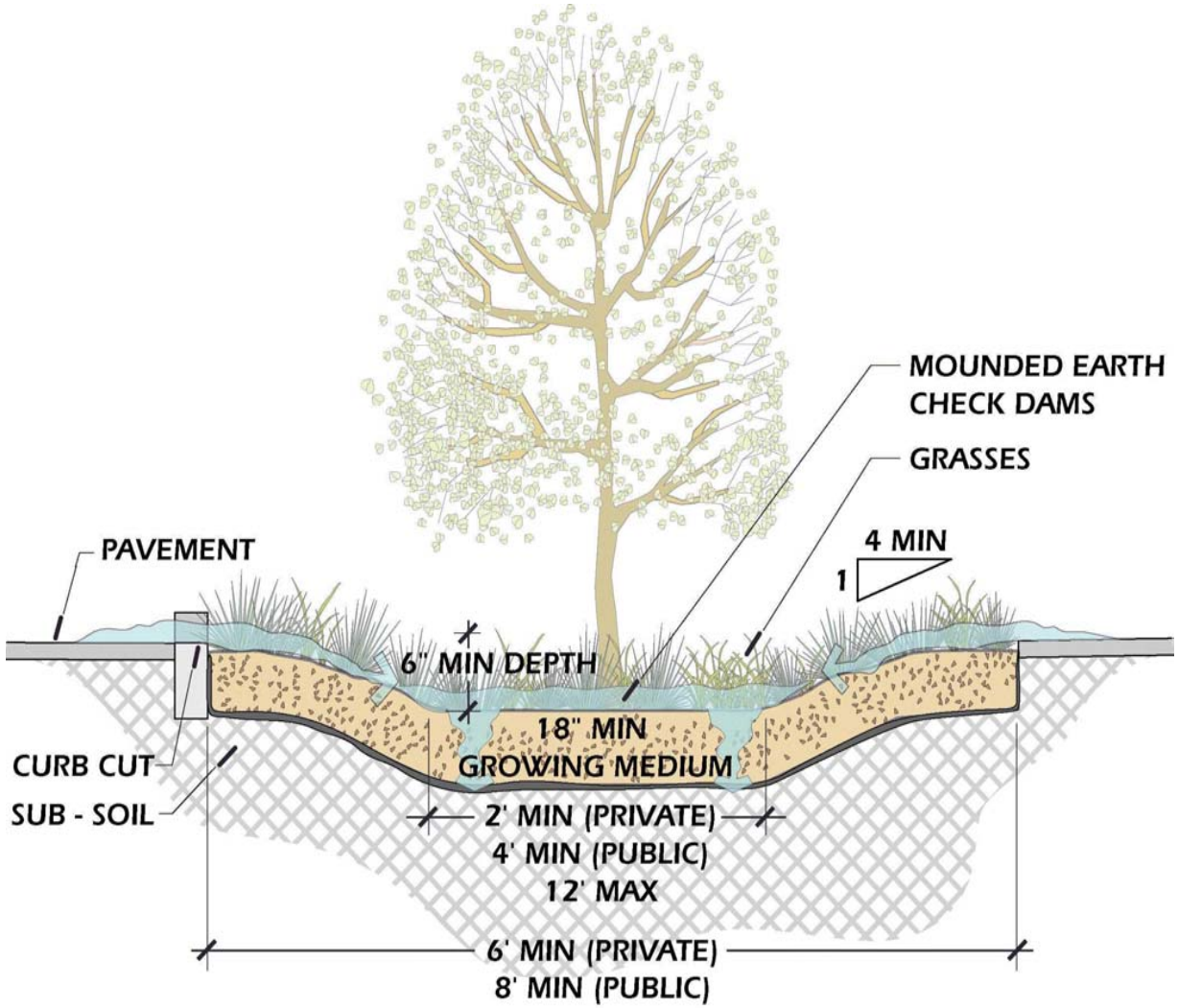
Vegetated Swale - Plan

Parking Lot Application

7/26/02

Vegetated Swale

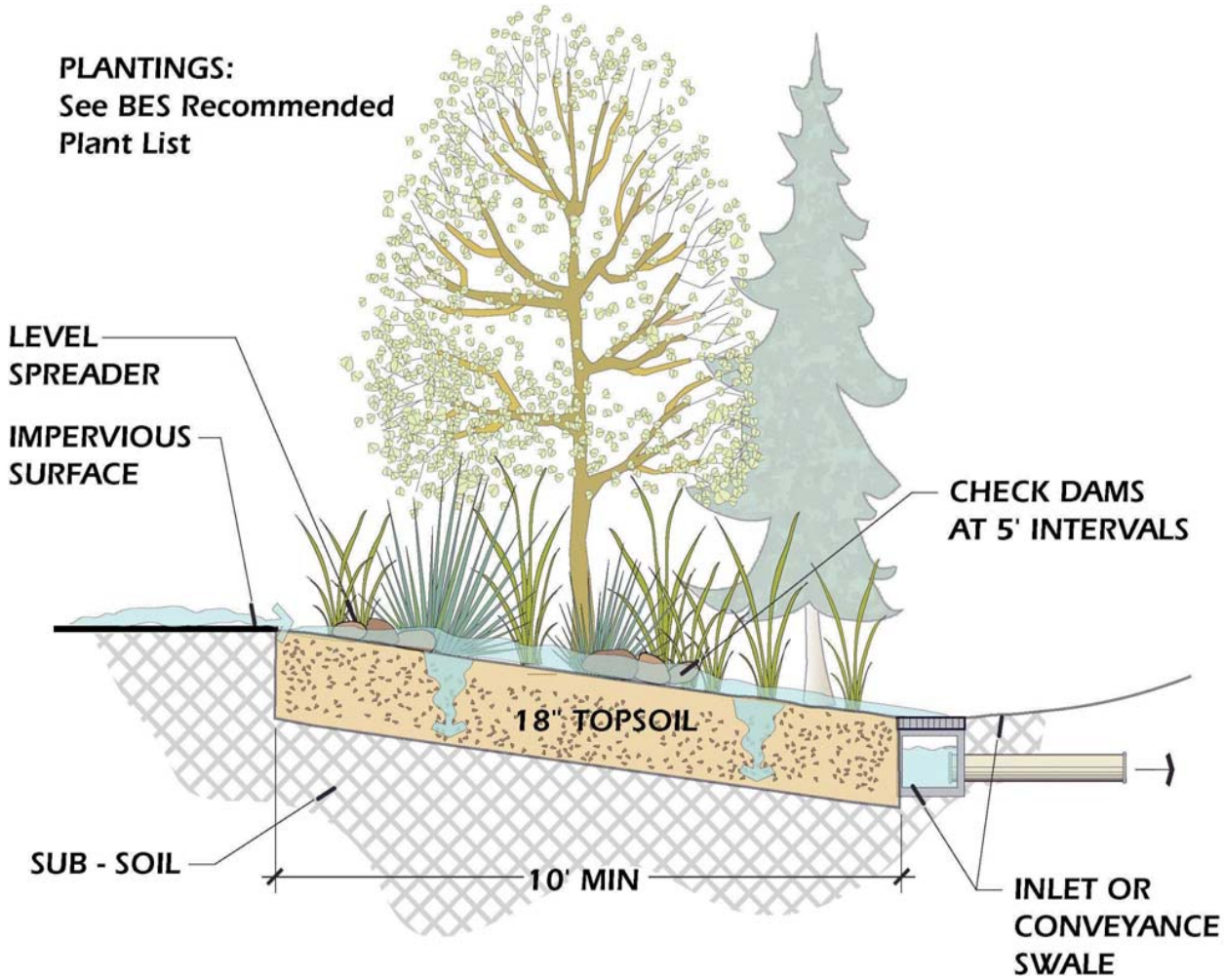




Grassy Swale

7/26/02

SARB_008153

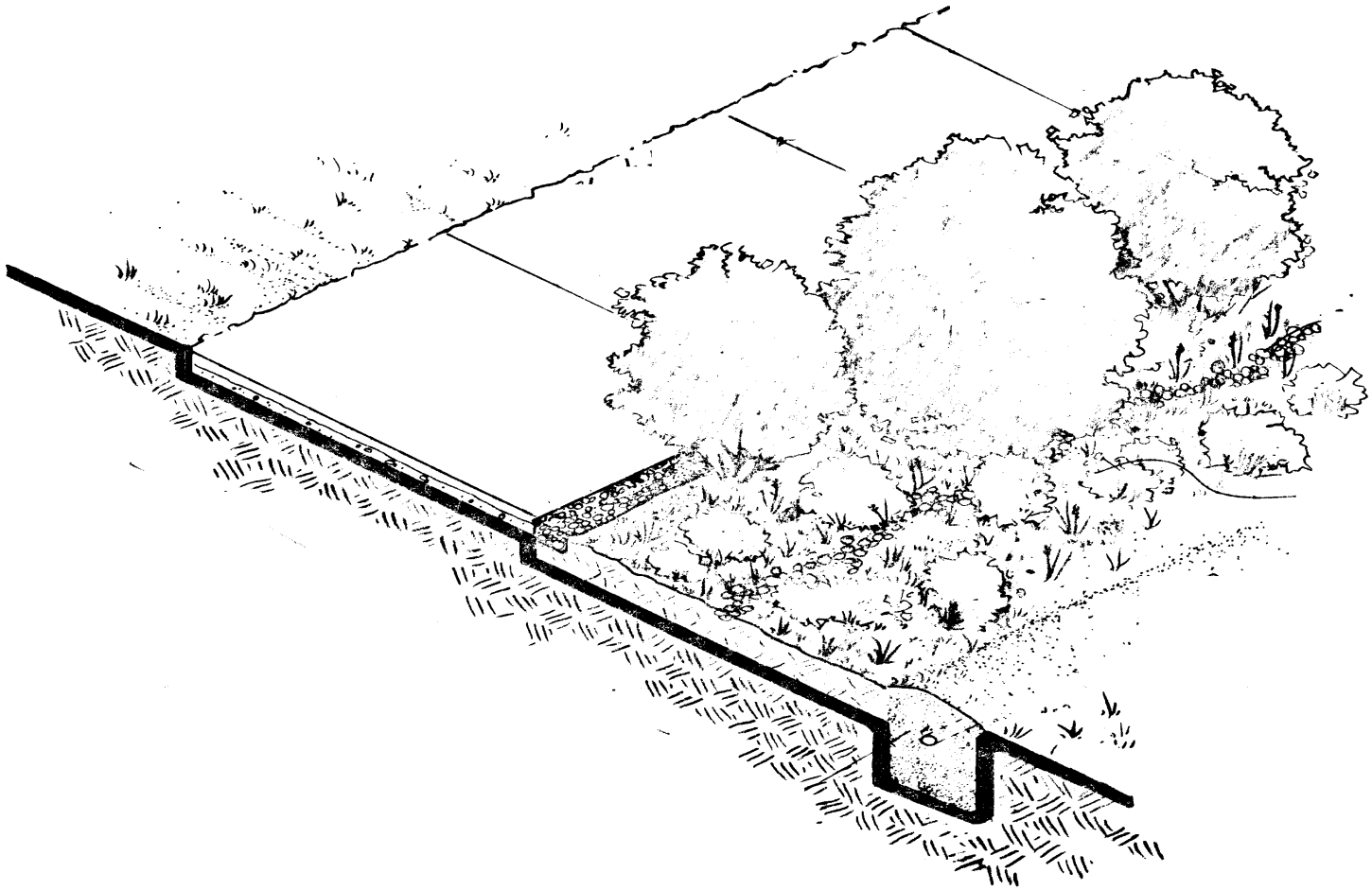


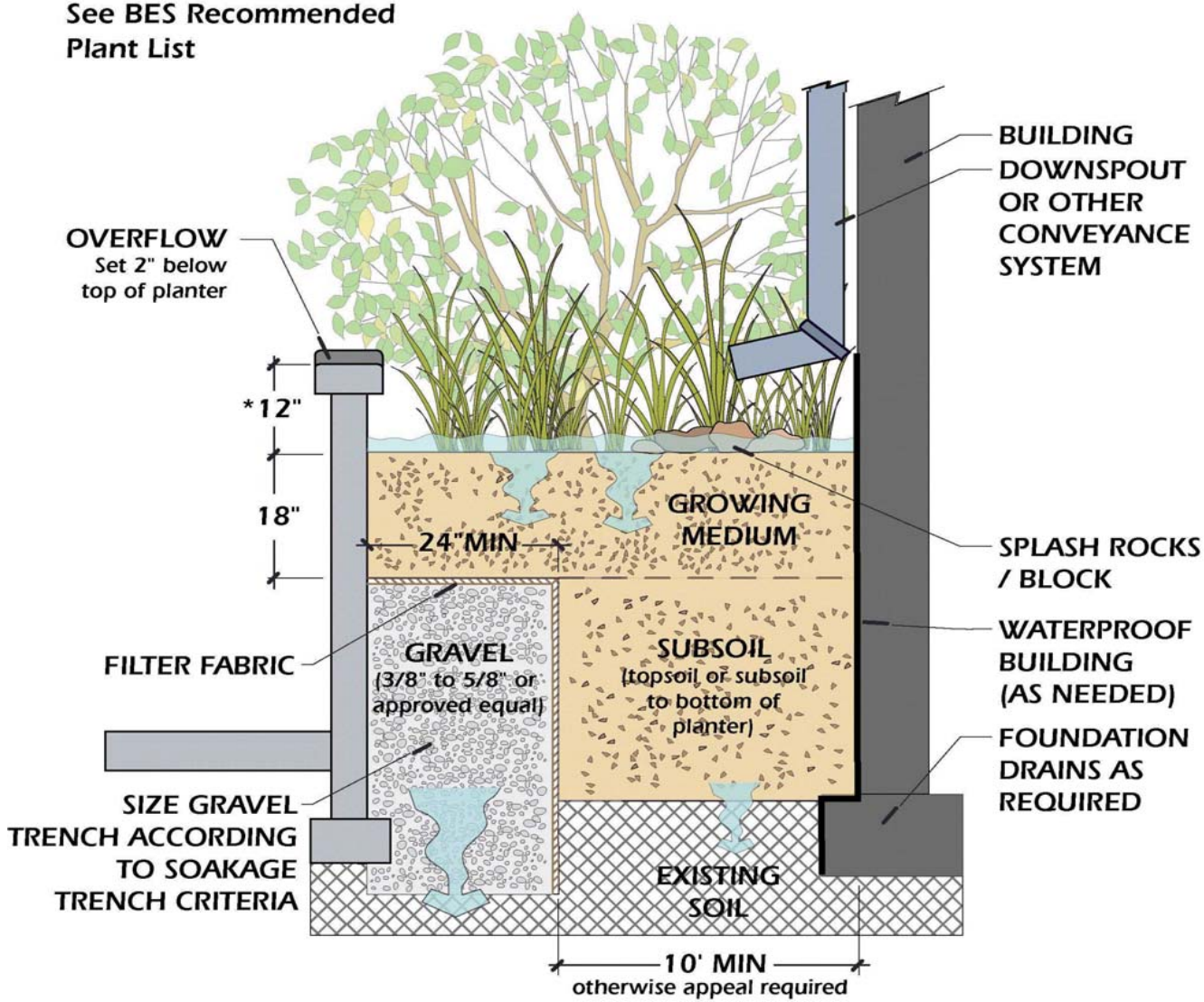
Vegetated Filter

7/26/02

SARB_008154

Vegetated Filter





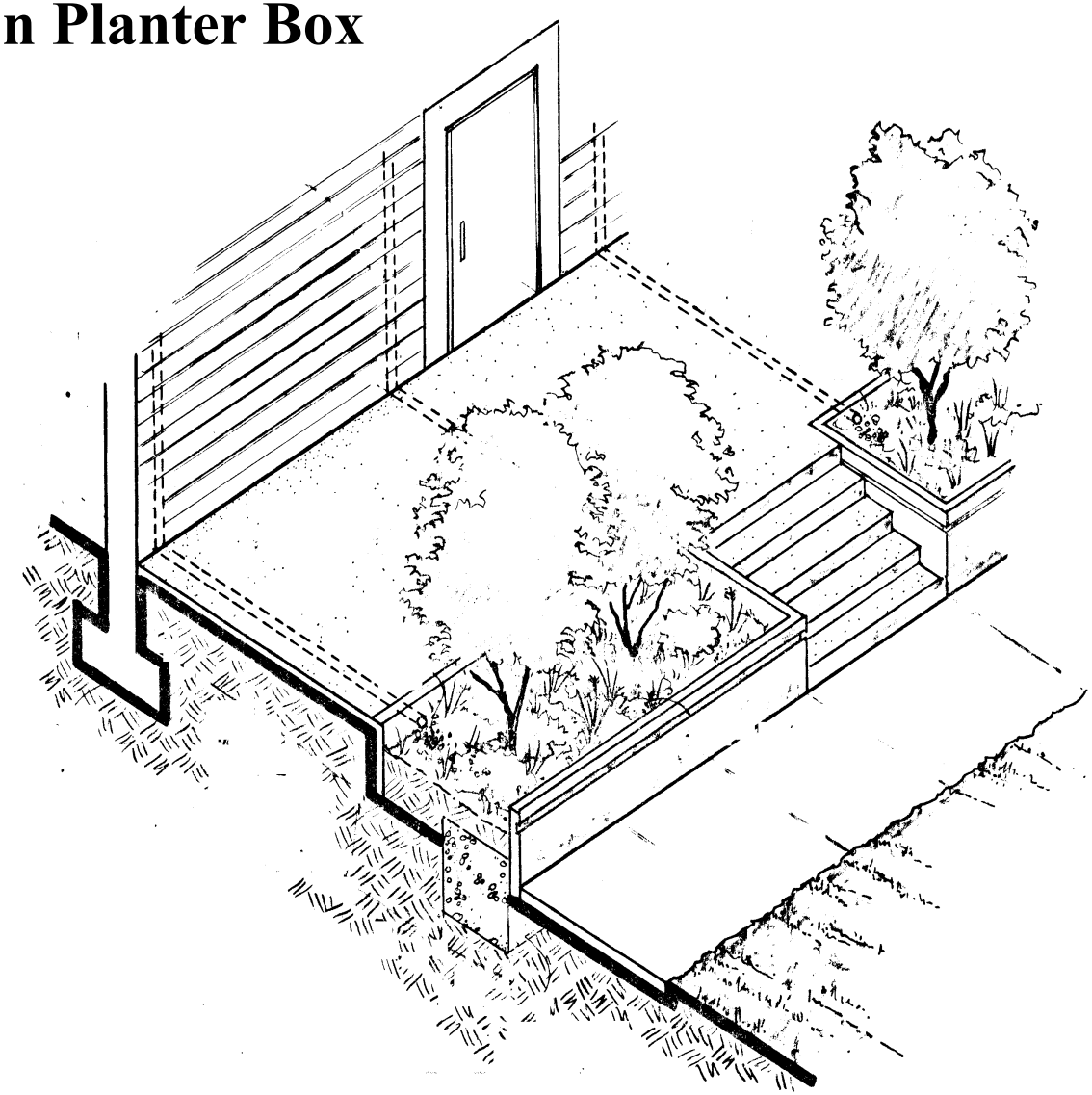
*Water reservoir depth may be reduced
if planter surface area is increased.

SARB_008156

Infiltration Planter

7/26/02

Infiltration Planter Box



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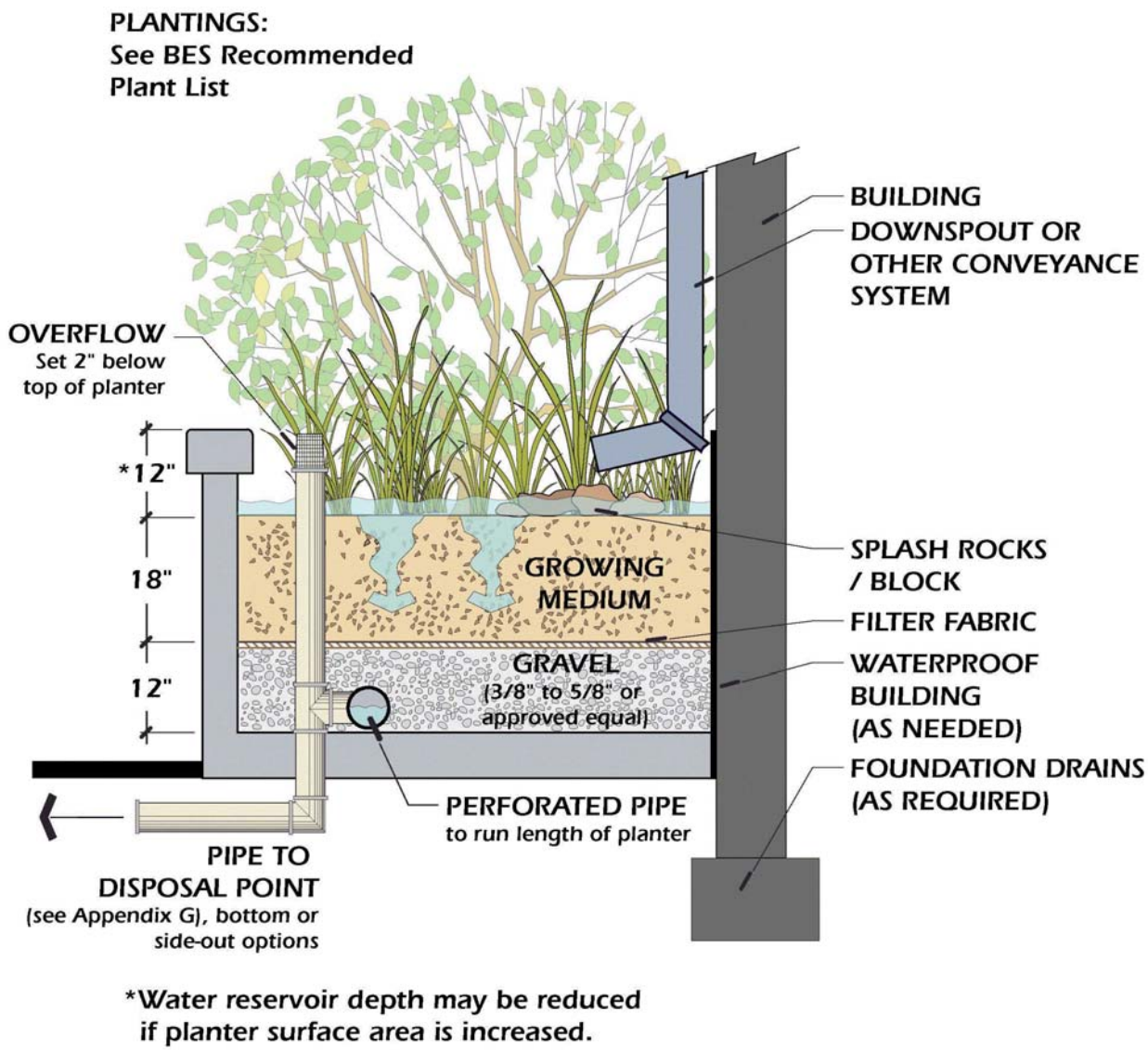


*Water reservoir depth may be reduced if planter surface area is increased.

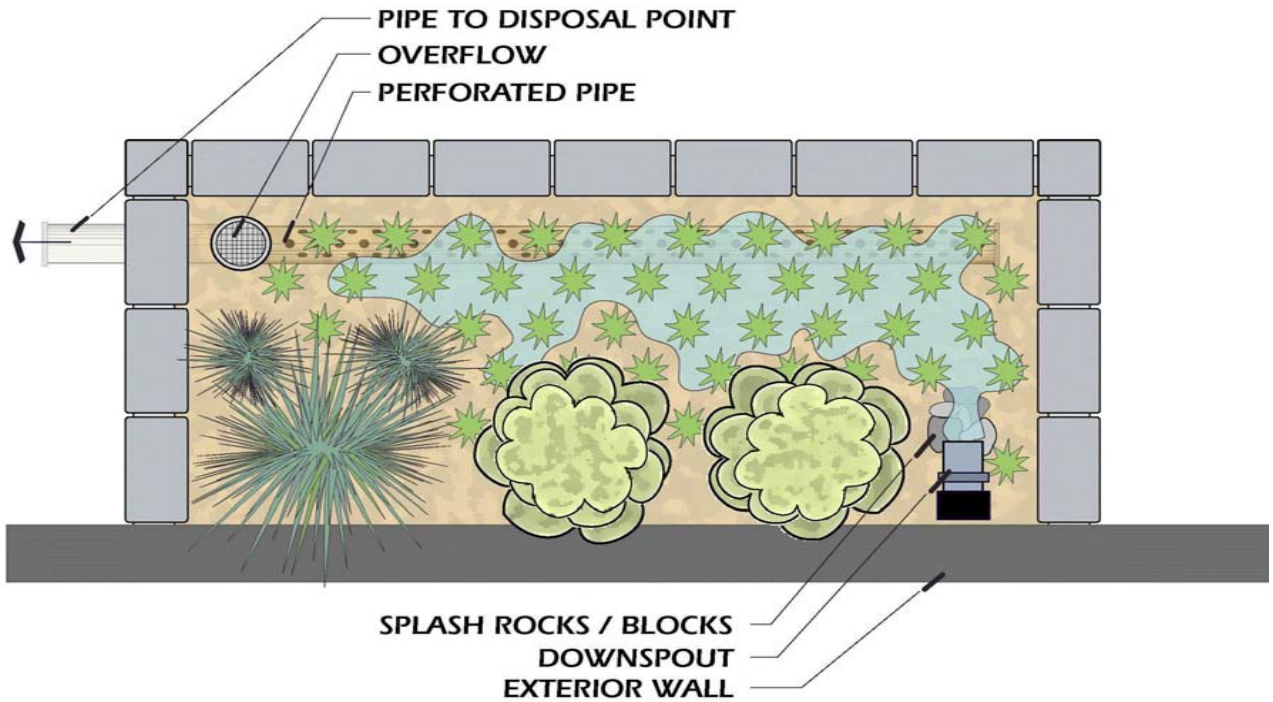
Flow-Through Planter Box

SARB_008158

7/26/02

LEGEND





Planter Area = Approx. 50 sq. ft.

Not to Scale

Notes:

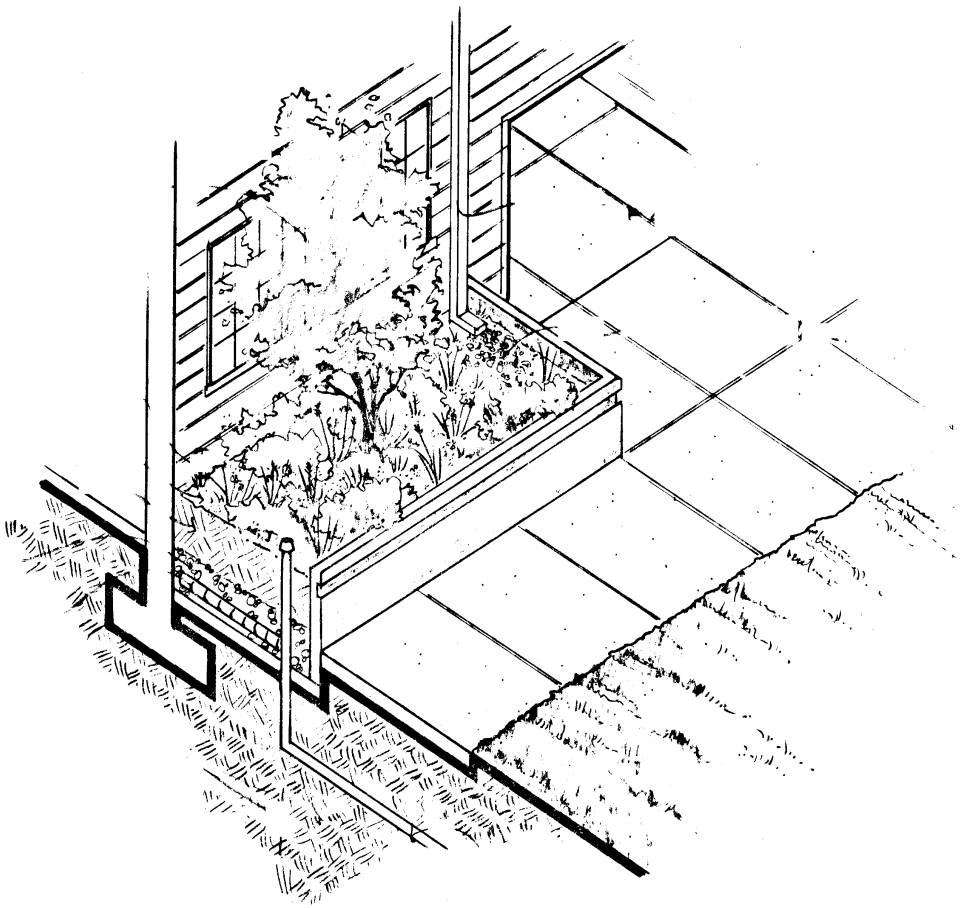
1. At least 50% of the facility shall be planted with grasses or grass-like plants, primarily in the flow path. Large grass like plants can be considered as shrubs.
2. See BES recommended plant list, and quantity requirements.

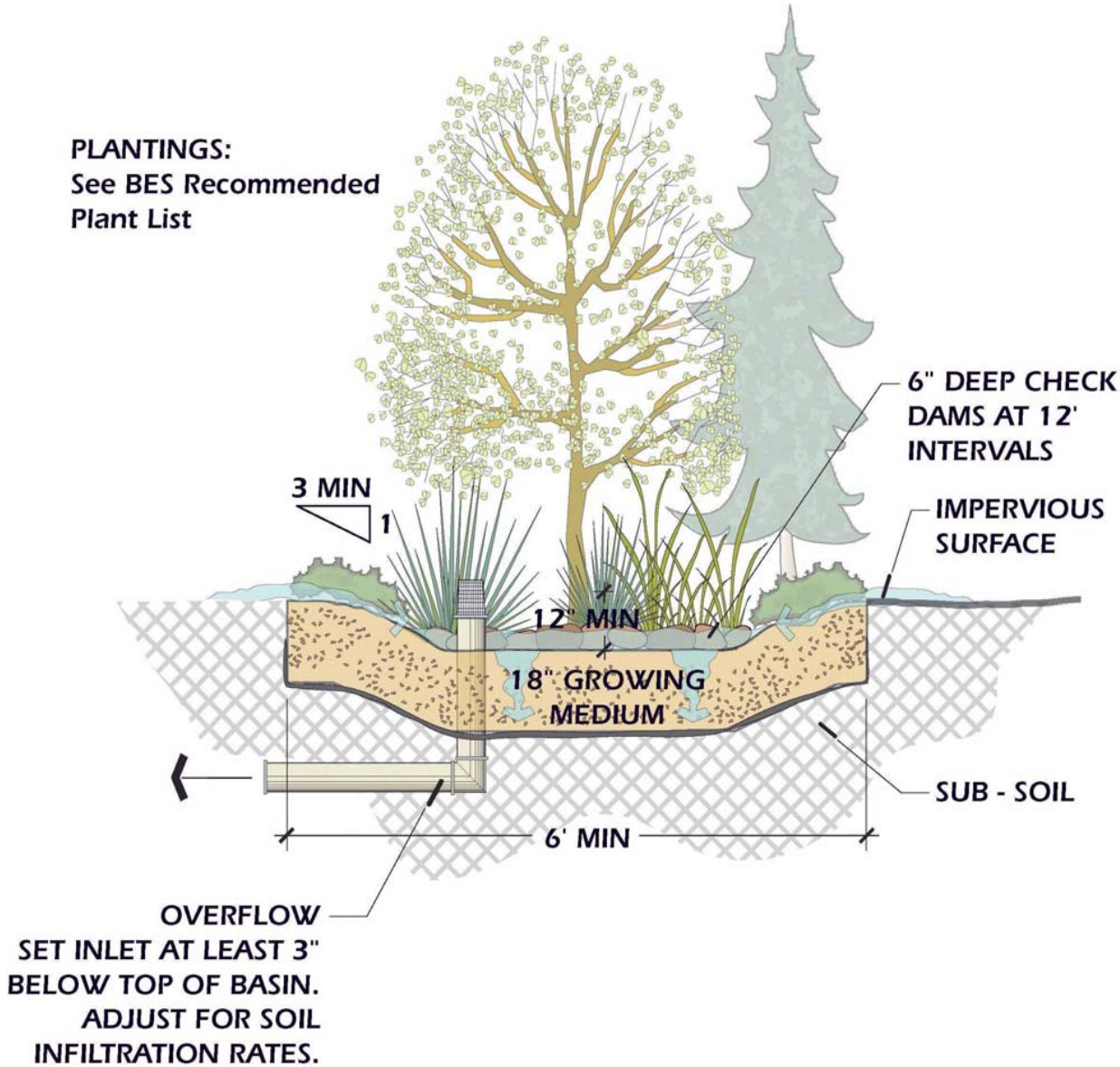
SARB_008159

Flow-Through Planter - Plan

7/26/02

Flow-Through Planter Box

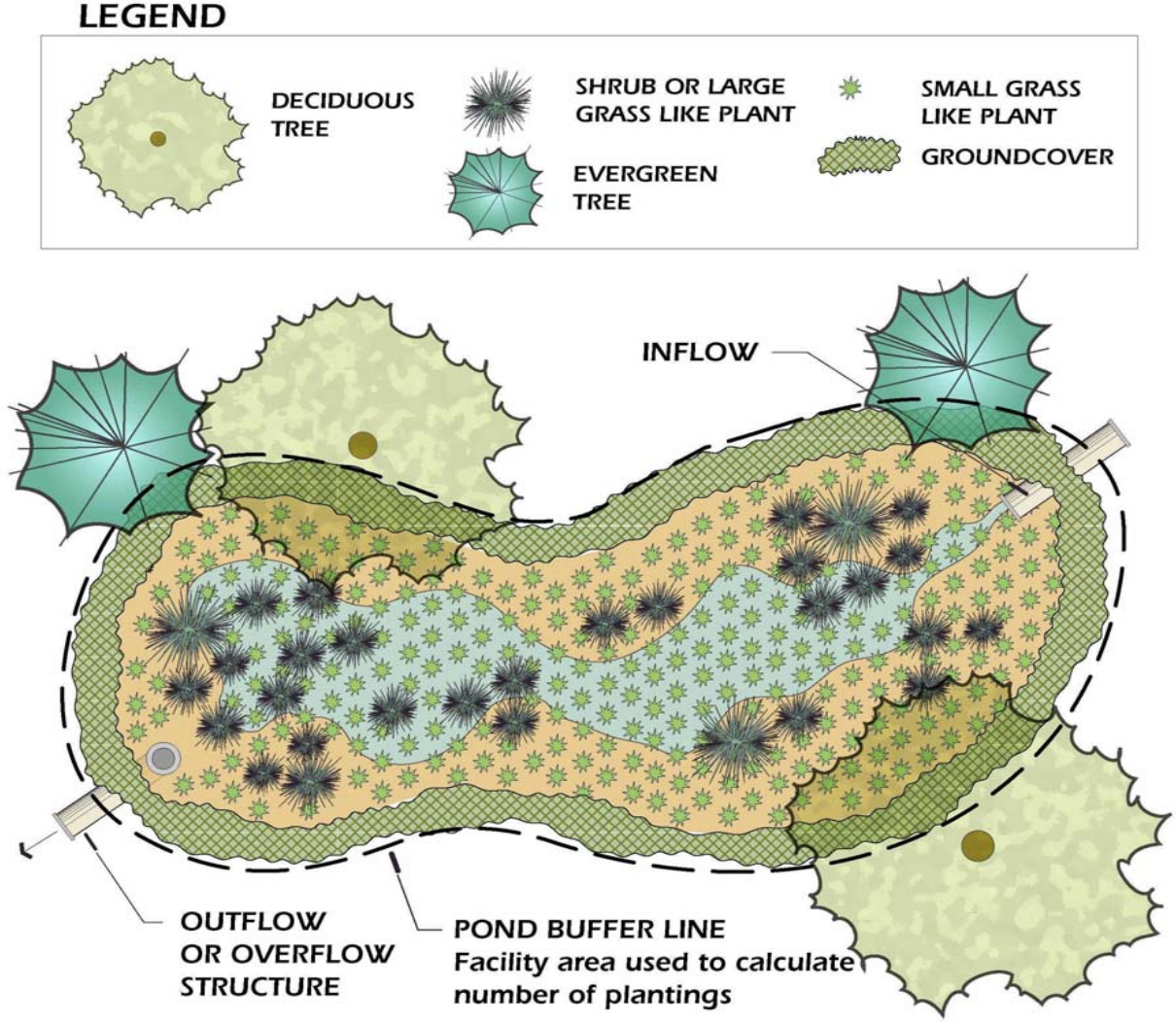




Vegetated Infiltration Basin

7/26/02

SARB_008161



Swale Area = Approx. 1000 sq. ft.
(Not to Scale)

Notes:

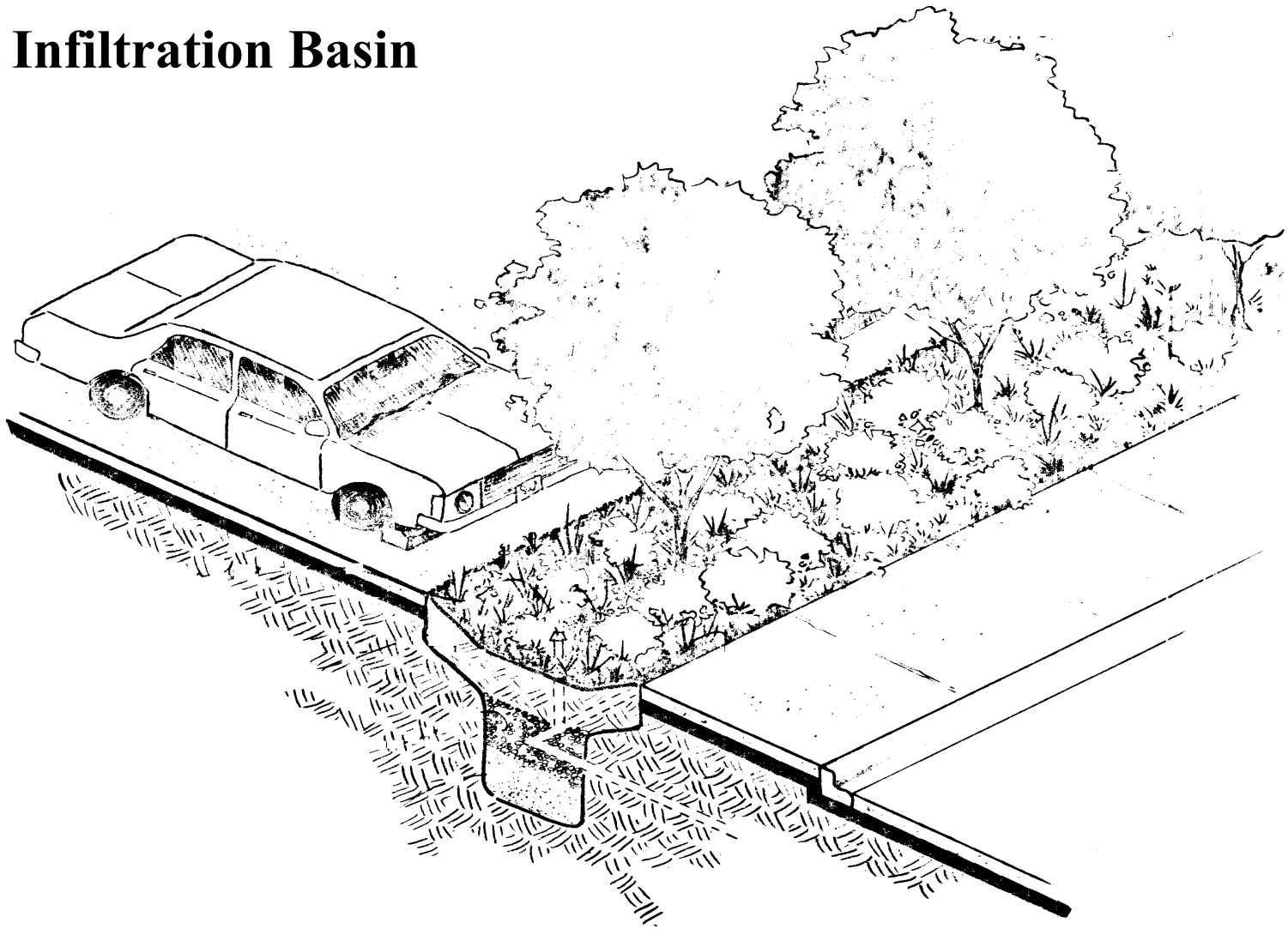
1. At least 50% of the facility shall be planted with grasses or grass-like plants, primarily in the flow path, or basin bottom.
2. Large grass like plants can be considered as shrubs. See BES recommended plant list and parking lot tree list.

Vegetated Infiltration Basin or Detention Pond - Plan

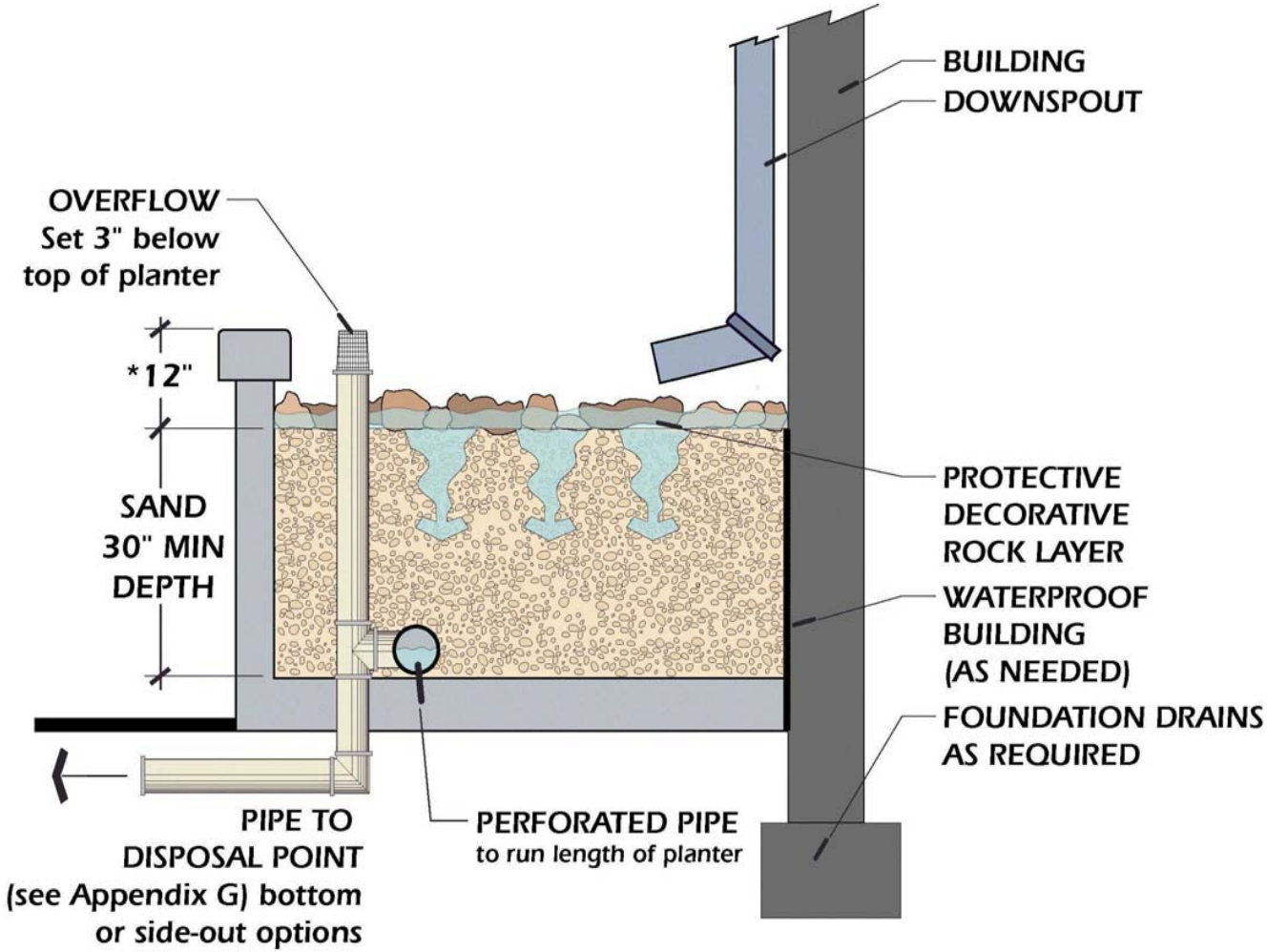
7/26/02

SARB_008162

Vegetated Infiltration Basin



SARB_008163



*Water reservoir depth may be reduced
if planter surface area is increased.

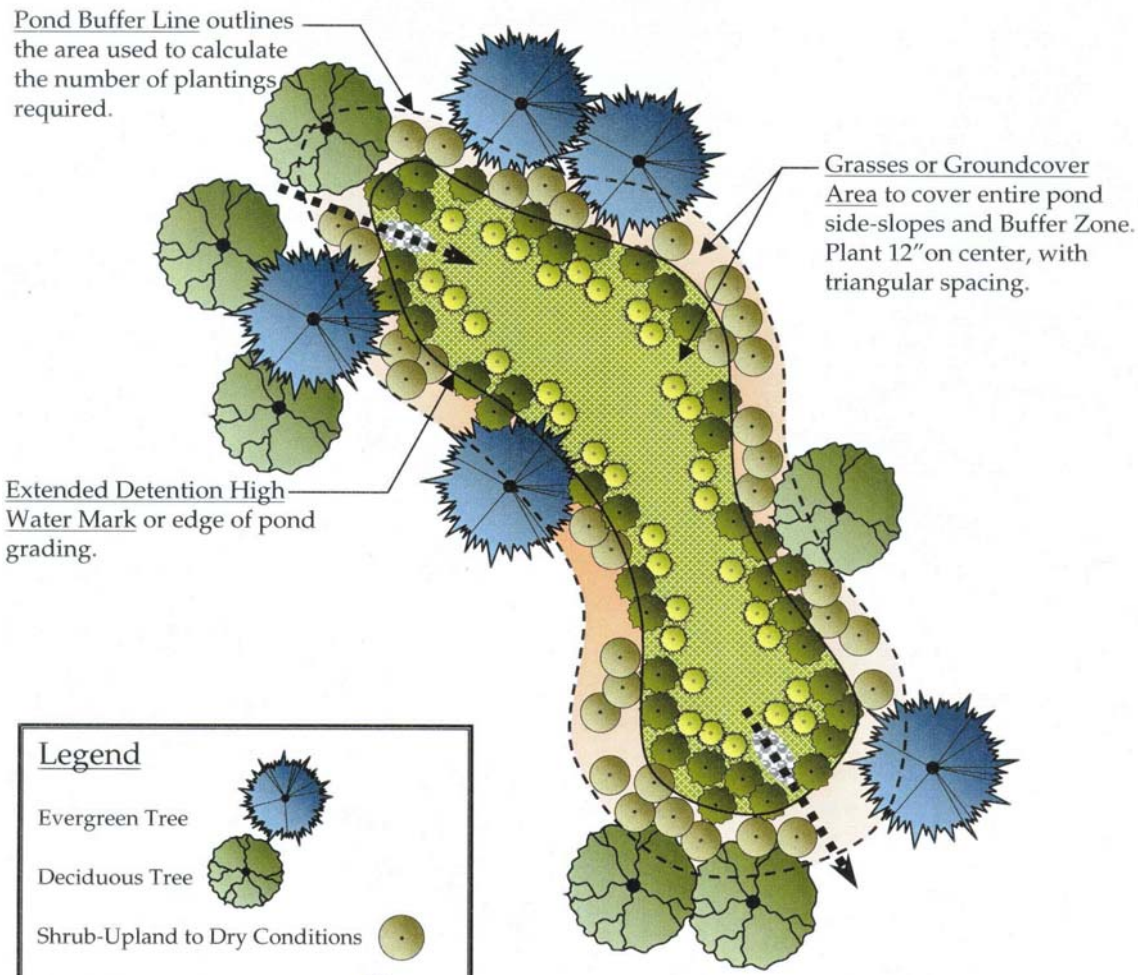
SARB_008164

Sand Filter Planter

7/26/02

Dry Detention Ponds

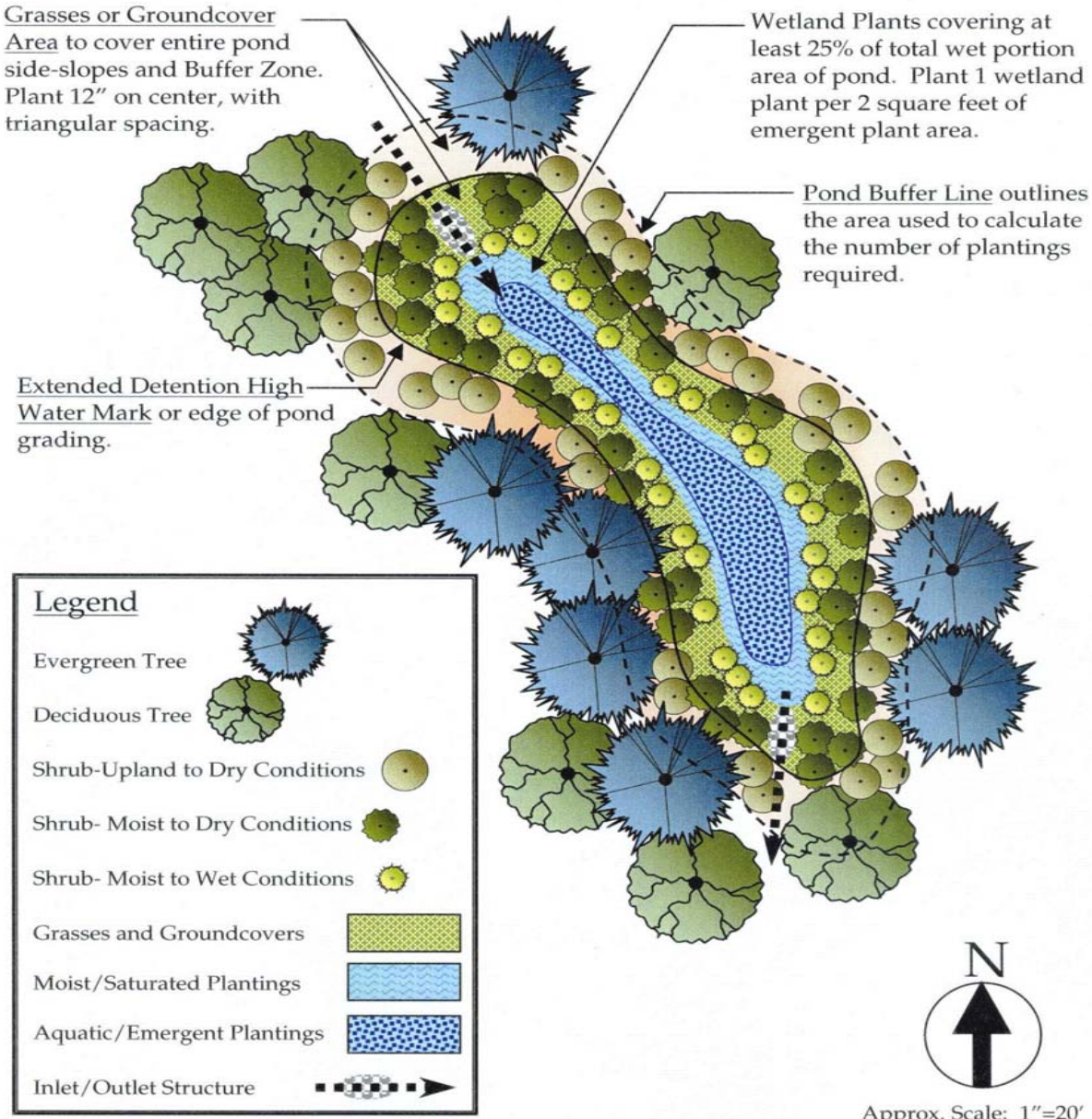
The plan below illustrates a typical planting plan for an approximately 3,500 square foot dry detention pond. This plan is diagrammatic use only. The actual project site condition may require designers to consider numerous other pond configurations and planting layouts.



SARB_008165

Wet and Extended Wet Ponds

The plan below illustrates a typical planting plan for an approximately 3,500 square foot wet or extended wet pond. This plan is diagrammatic use only. The actual project site condition may require designers to consider numerous other pond configurations and planting layouts.



SARB_008166

Appendix H

Stormwater Management Facility Photos

September 2004 Stormwater Management Manual

Parking Lot Examples

Site Location	Page/ Slide
Glencoe Elementary School Parking Lot (825 SE 51st)	3-6
PCC Annex (SE Water Ave.)	7
OMSI, 1992 (1945 SE Water Ave.)	8
Troutdale Arata Creek School Site	9



Glencoe Elementary School Parking Lot (825 SE 51st)

SARB_008169



SARB_008170

Glencoe Elementary School Parking Lot (825 SE 51st)



SARB_008171

Glencoe Elementary School Parking Lot (825 SE 51st)



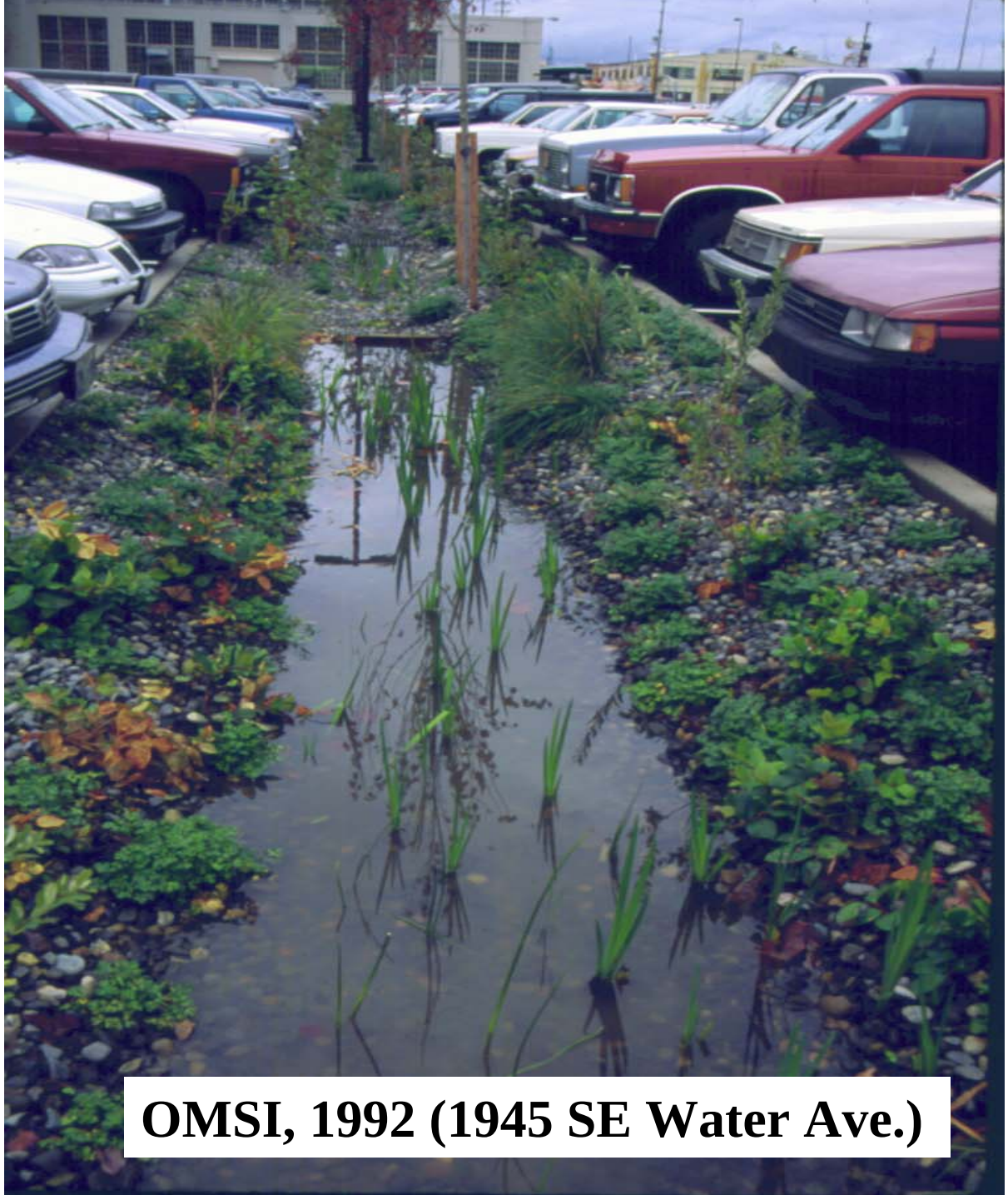
Glencoe Elementary School Parking Lot (825 SE 51st)

SARB_008172



PCC Annex (SE Water Ave.)

SARB_008173



OMSI, 1992 (1945 SE Water Ave.)

SARB_008174



Troutdale Arata Creek School Site

SARB_008175

Street Examples

Site Location	Page/ Slide
NE 35th Pl. & Siskiyou	11-16
SE 56th & Ankeny	17-19
N Leadbetter Road	20,21
SW Lodi Lane (& Shattuck) Subdivision	22
Seattle Street Edge Alternative Project	23-25
Seattle- Cascade & Broadview	26



NE 35th Pl & Siskiyou St.



NE 35th Pl & Siskiyou St.



NE 35th Pl & Siskiyou St.


NE 35th Pl & Siskiyou St.
SARB_008180


NE 35th Pl & Siskiyou St.



NE 35th Pl & Siskiyou St.

SARB_008182



SARB_008183

SE 56th Ave. & Ankeny St.



SE 56th Ave. & Ankeny St.



SE 56th Ave. & Ankeny St.



SARB_008186

N Leadbetter Road street swale w/ overflow catch basin & curb slots

N Leadbetter Road street swale w/ overflow catch basin & curb spillway



SARB_008187



SARB_008188

North side of SW Lodi Lane (& Shattuck), sand filter/ street swale

Seattle’s Street Edge Alternatives Program



SARB_008189

After Completion - January 2001

Seattle's Street Edge Alternatives Program



SARB_008190



Seattle's Street Edge Alternatives Program



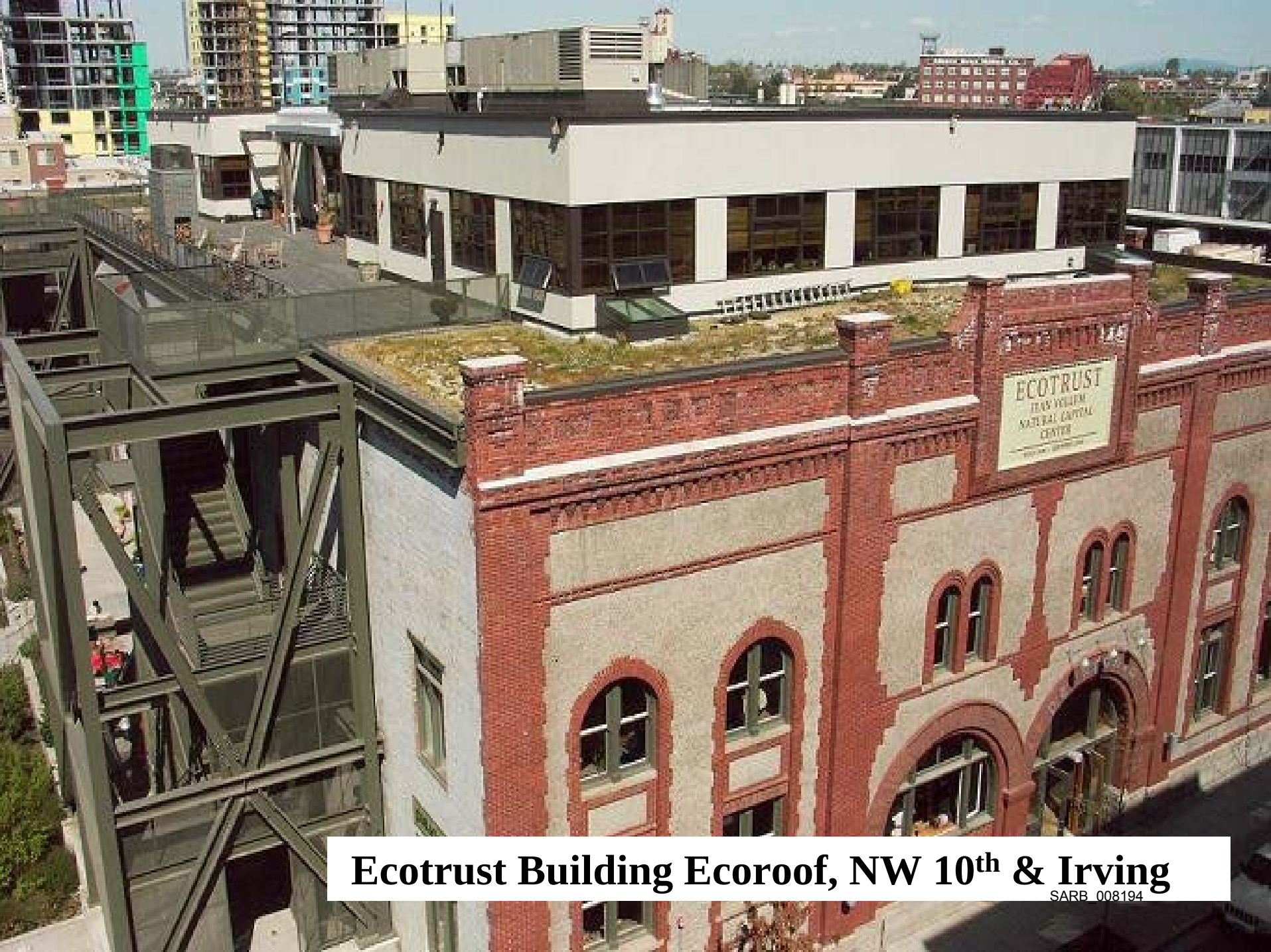
Seattle's Street Edge Alternatives Program, Cascade & Broadview

SARB_008192

Ecoroofs and Roof Gardens

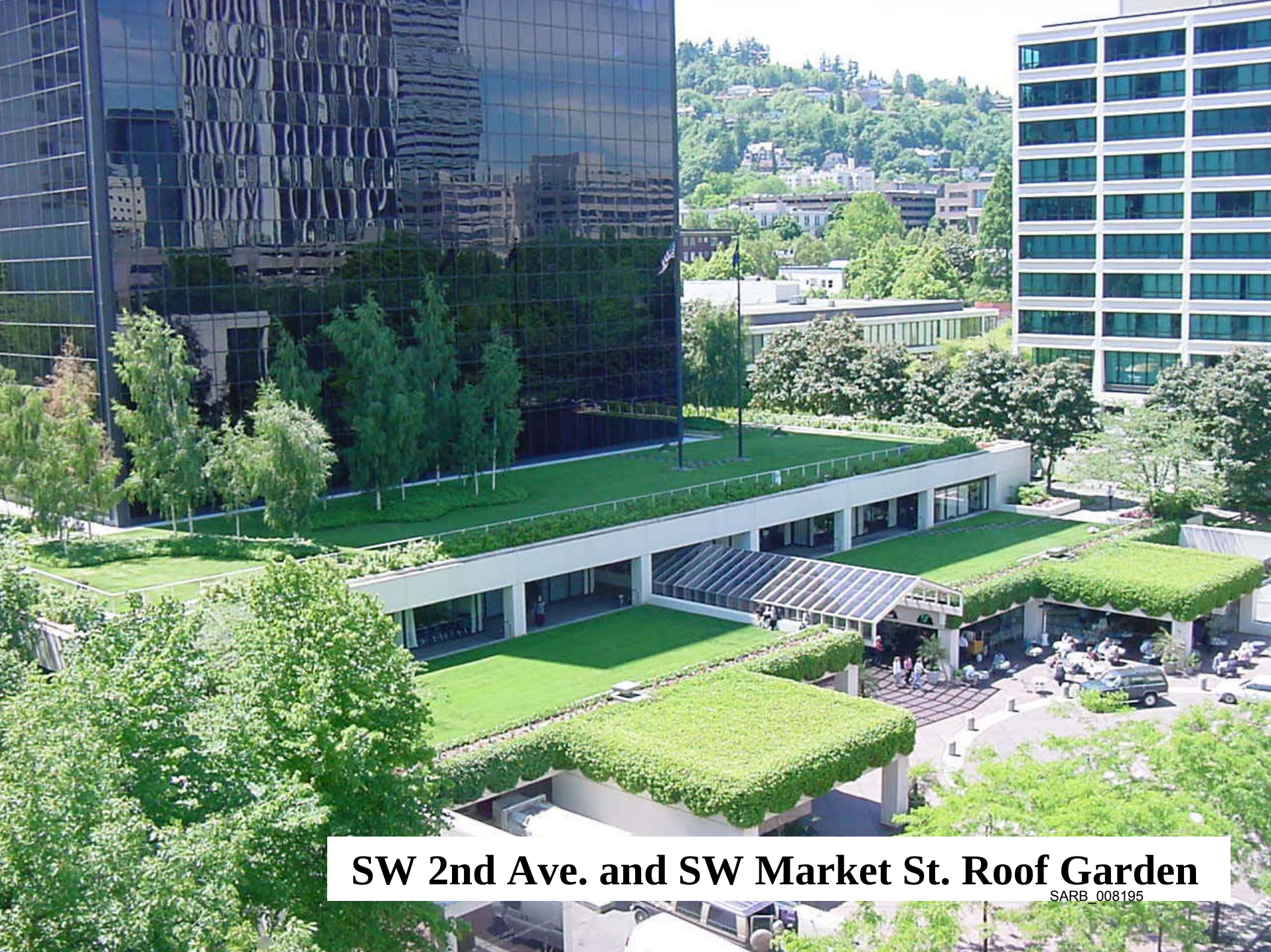
Site Location	Page/ Slide
Ecotrust Building (NW 10th & Irving)	28
SW 2nd Ave. & Market St.	29, 30
Hamilton Apartments (1212 SW Clay St.)	31, 32
Multnomah County (501 SE Hawthorne)	33
2021 SE Clinton St.	34
Buckman Terrace Apartments (303 NE 16th Ave.)	35, 36

SARB_008193



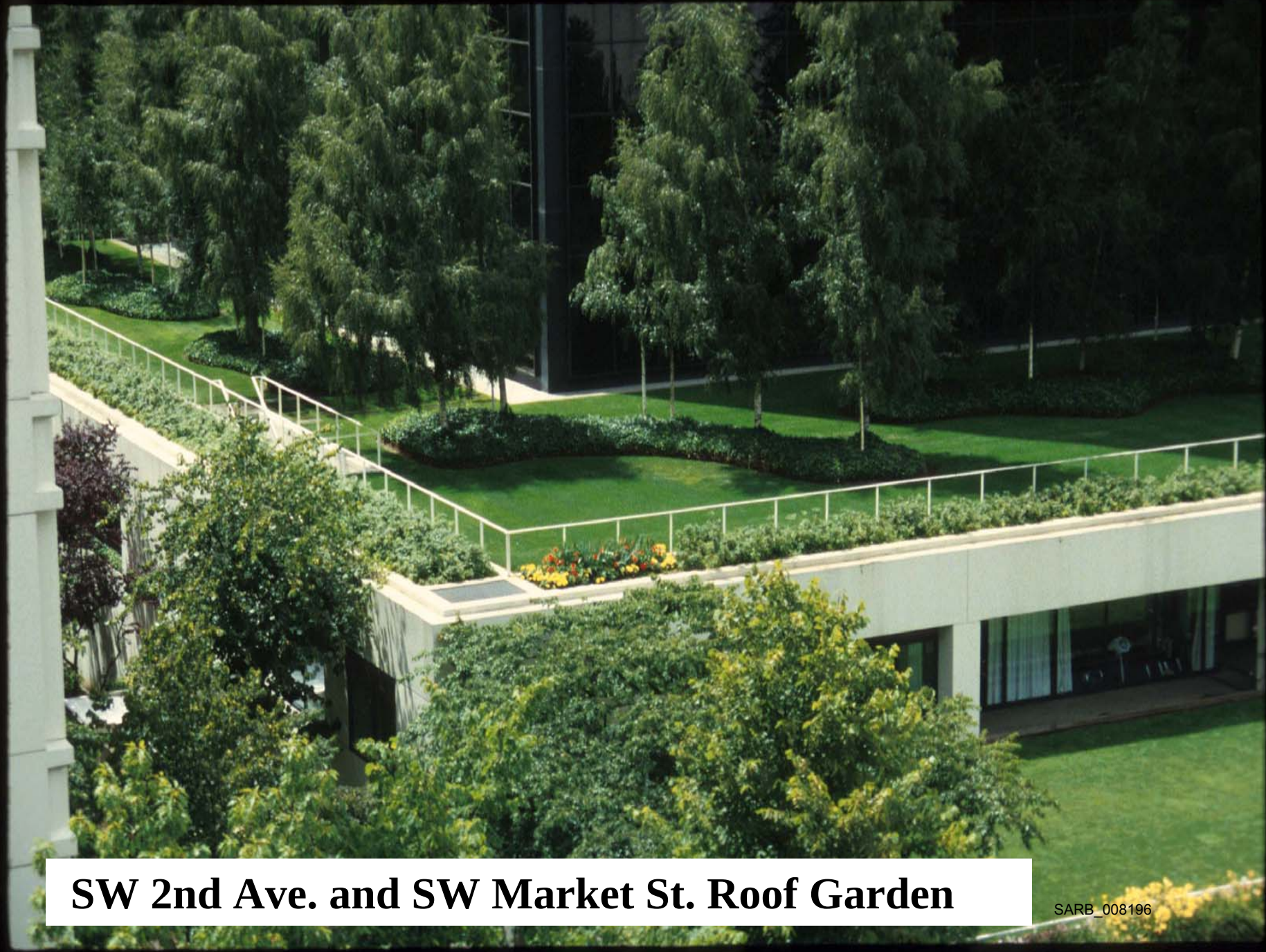
Ecotrust Building Ecoroof, NW 10th & Irving

SARB_008194



SW 2nd Ave. and SW Market St. Roof Garden

SARB_008195



SW 2nd Ave. and SW Market St. Roof Garden

SARB_008196



Hamilton Apartments Ecoroof (1212 SW Clay St.)

SARB_008797



Hamilton Apartments Ecoroof (1212 SW Clay St.)

SARB_008198

Multnomah County Ecoroof (501 SE Hawthorne)



SARB_008199



2021 SE Clinton St. Ecoroof



Buckman Terrace Ecoroof (303 NE 16th Ave.)

SARB_00620



Buckman Terrace Ecoroof (303 NE 16th Ave.)

SARB_008202

Pervious Pavement

Site Location	Page/ Slide
Multnomah Arts Center Eco-Stone	38, 39
Eco-Lock Pavers in Lacey, Washington	40, 41
ONRC (5825 N Greeley)	42, 43
Pervious Concrete Core Sample	44
NE 94th & Broadway Pump Station	45
Clean Water Services Pervious Concrete	46, 47
SE 162nd & Foster Pervious Asphalt	48
Unknown Location	49



Multnomah Arts Center Eco-Stone Parking Lot



SARB_008205

Multnomah Arts Center Eco-Stone Parking Lot



SARB_008206

Installation of Eco-Loc Paver Parking Lot in Washington

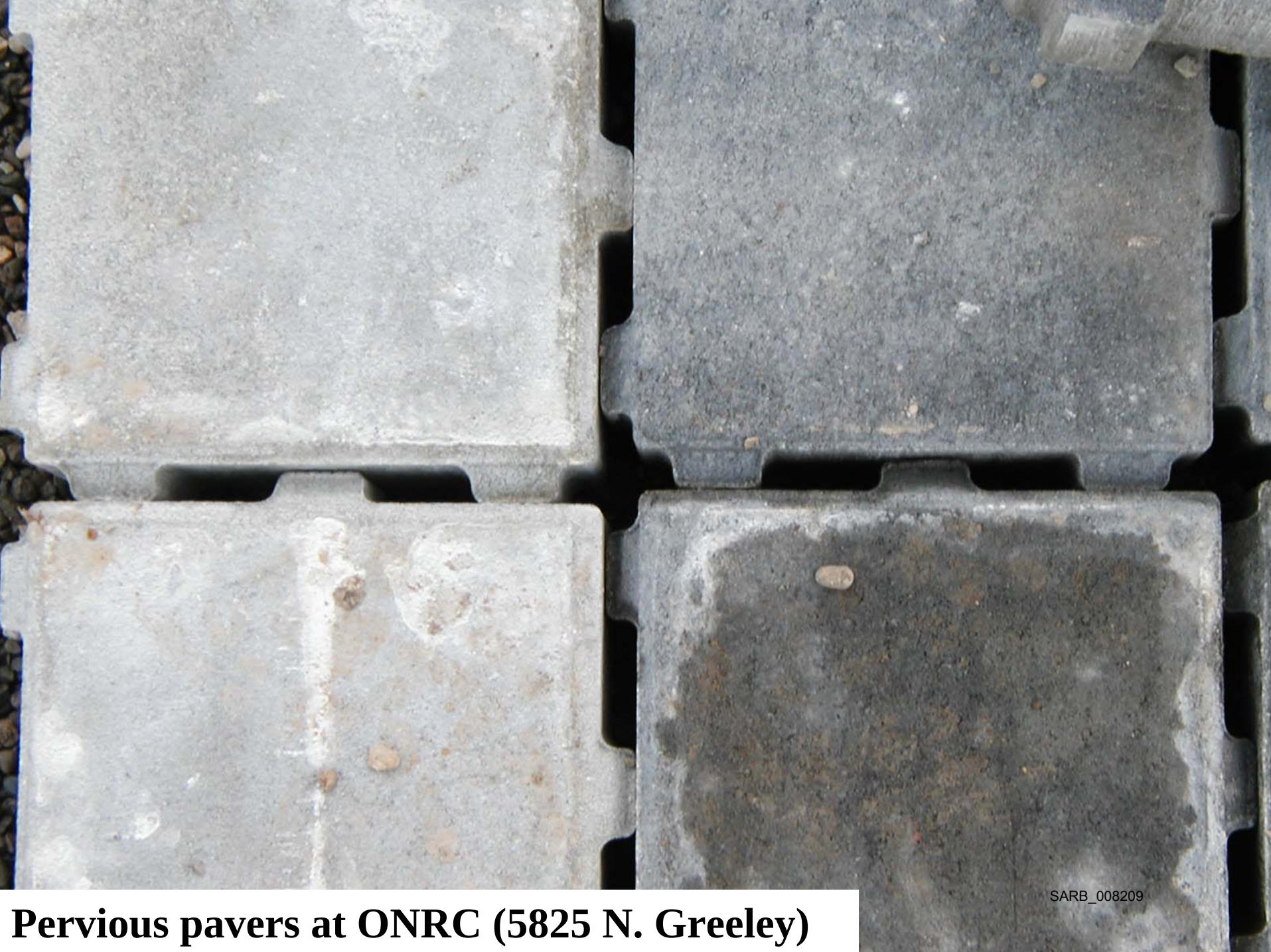


SARB_008207

Installation of Eco-Loc Paver Parking Lot in Washington



Pervious pavers at ONRC (5825 N. Greeley)



Pervious pavers at ONRC (5825 N. Greeley)



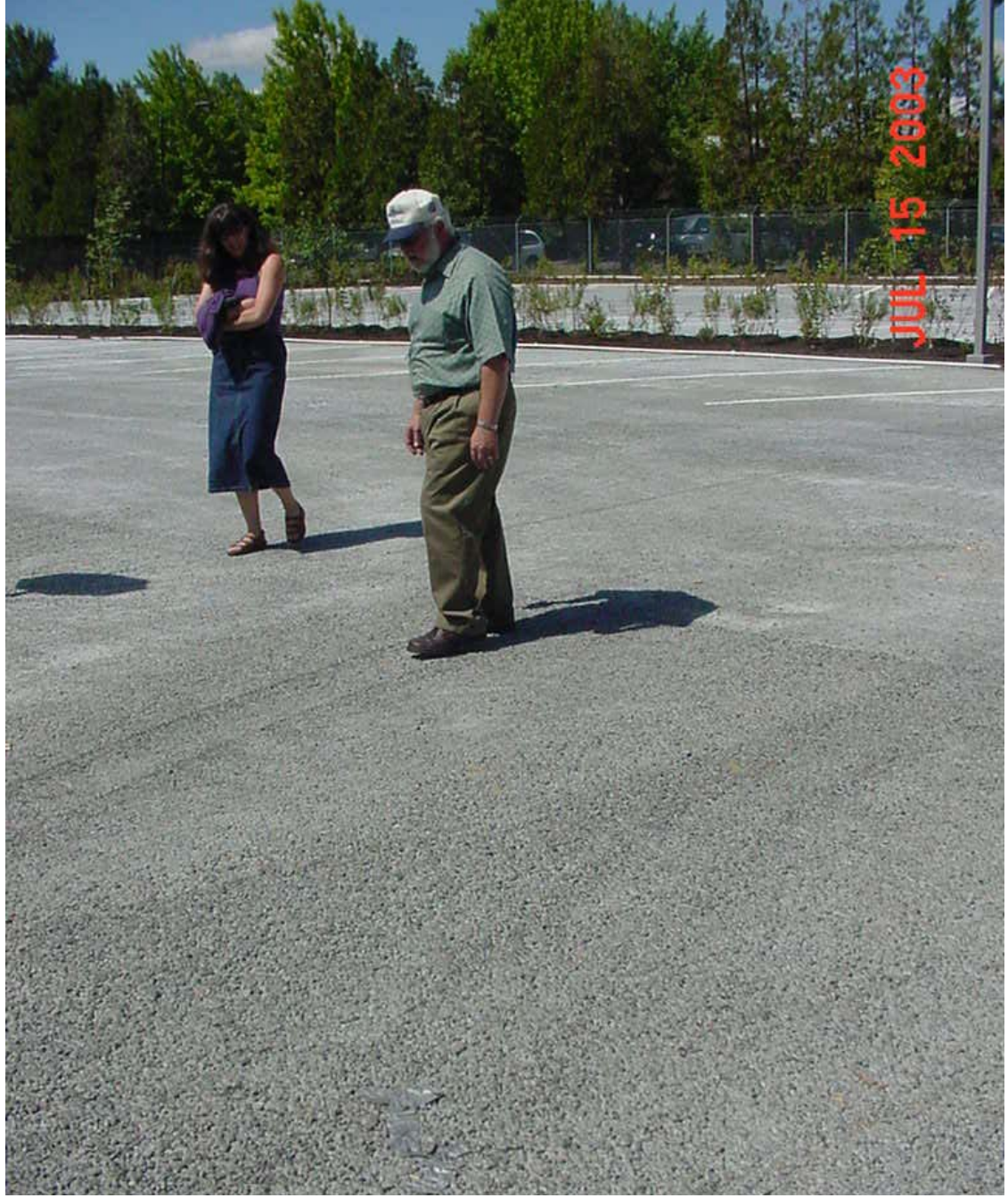
SARB_008210

Core-Sample of Pervious Concrete, Dyed Brown



Pervious concrete installation at NE 94th & Broadway pump station site

SARB_008211



SARB_008212

Clean Water Services' pervious concrete parking lot in Beaverton

Clean Water Services
Pervious Concrete
Parking Lot





SARB_008214

Pervious Asphalt installation near SE 162nd & Foster



SARB_008215

Pervious pavement parking lot at unknown location

Vegetated Swales

Site Location	Page/ Slide
Hawthorne Ridge Subdivision (SE 162 S. of Foster)	51
OMSI (1945 SE Water Ave.)	52
BES Water Pollution Control Lab (6543 N. Burlington)	53



SARB_008217

Hawthorne Ridge Subdivision (SE 162nd, South of Foster)



OMSI Vegetated Swale (1945 SE Water Ave.)

SARB_008218



BES Water Pollution Control Lab (6543 N. Burlington)

SARB_008219

Grassy Swales

Site Location	Page/ Slide
Reed College (SE 28th Ave.)	55
Russell Pond Site (NE 88th Ave. & Freemont Dr.)	56
SW Scholls Ferry Road	57



Reed College (SE 28th Ave.)

SARB_008221



SARB_008222

Russell Pond Site (NE 88th Ave. and Freemont Dr.)


SW Scholls Ferry Road
SARB_008223

Vegetated Filters

Site Location	Page/ Slide
SW Community Center (6820 SW 45th Ave.)	59



SARB_008225

SW Community Center (6820 SW 45th Ave.)

Contained Planters

Site Location	Page/ Slide
1100 block of bus mall, downtown Portland	61
Federal Building (1200 block of SW 3rd Ave.)	62



1100 block of bus mall, downtown Portland

SARB_008227



Federal Building (1200 block of SW 3rd Ave.)

SARB_008228

Infiltration Planters

Site Location	Page/ Slide
Wattles Boys and Girls Club (9330 SE Harold	64
Portland State University	65-67



SARB_008230

Wattles Boys and Girls Club (9330 SE Harold)


Portland State University
SARB_008231



Portland State University

SARB_008232


Portland State University
SARB_008233

Flow-Through Planters

Site Location	Page/ Slide
Buckman Terrace Apartments (303 NE 16th Ave.)	69, 70
Ritzdorf Apartments (SE 12th Ave. & Belmont)	71
Liberty Center Parking Garage (650 NE Holladay)	72-74
Flow-Through Planter Test in New Zealand	75, 76



Buckman Terrace Apartments (303 NE 16th Ave.)

SARB_008235



Buckman Terrace Apartments (303 NE 16th Ave.)

SARB_008236



Ritzdorf Apartments (SE 12th Ave. & SE Belmont St.)

SARB_008237



SARB_008238

Liberty Center Parking Garage (650 NE Holladay)



Liberty Center Parking Garage (650 NE Holladay)



Liberty Center Parking Garage (650 NE Holladay)



SARB_008241

Flow-through planter test in New Zealand

Flow-through planter test in New Zealand



SARB_008242

Vegetated Infiltration Basins

Site Location	Page/ Slide
Buckman Heights Apartments (430 NE 16th Ave.)	78-80
Glencoe Elementary School (825 SE 51st)	81, 82
Macintyre Estates Subdivision (SE 139th & Steele)	83, 84
Wattles Boys and Girls Club (9330 SE Harold)	85



Buckman Heights courtyard infiltration basins (430 NE 16th Ave.)

SARB_008244



Buckman Heights courtyard infiltration basin (430 NE 16th Ave.)



Buckman Heights courtyard planter overflow (430 NE 16th Ave.)

SARB_008246

Glencoe Elementary School (825 SE 51st)



SARB_008247

Glencoe Elementary School (825 SE 51st)



SARB_008248



SARB_008249

Macintyre Estates Subdivision (SE 139th & Steele)

Macintyre Estates Subdivision (SE 139th & Steele)



SARB_008250



Wattles Boys and Girls Club (9330 SE Harold)

Sand Filters

Site Location	Page/ Slide
Cascade Station (NE Airport Way & I-205)	87, 88



SARB_008253

Cascade Station (NE Airport Way & I-205)



SARB_008254

Cascade Station (NE Airport Way & I-205)

Soakage Trenches

Site Location	Page/ Slide
7123 SE Powell	90, 91
Unknown location	92



7123 SE Powell

SARB_008256



SARB_008257

7123 SE Powell



SARB_008258

Unknown location

Wet & Extended Wet Detention Ponds

Site Location	Page/ Slide
BES Water Pollution Control Lab (6543 N. Burlington)	94, 95
DaVinci Middle School (2508 NE Everett)	96, 97
Mill Pond (NW Mill Pond Road, Forest Heights)	98
Arata Creek School Site in Troutdale	99
Hawthorne Ridge Subdivision (SE 162nd, S. of Foster)	100

BES Water Pollution Control Lab (6543 N. Burlington)



SARB_008260



BES Water Pollution Control Lab (6543 N. Burlington)

SARB_008261



SARB_008262

DaVinci Middle School (2508 NE Everett)



SARB_008263

DaVinci Middle School (2508 NE Everett)



Mill Pond (NW Mill Pond Rd., Forest Heights Subdivision)

SARB_008264


Troutdale Arata Creek School Site



SARB_008266

Hawthorne Ridge Subdivision (SE 162nd, S. of Foster)

Constructed Treatment Wetlands

Site Location	Page/ Slide
Russell Pond Site (NE 88th & Freemont)	102



Russell Pond Site (NE 88th Ave. and Freemont)

SARB_008268

Tree Credit Examples

Site Location	Page/ Slide
Miscellaneous	104
Buckman Terrace Apartments (303 NE 16th Ave.)	105


SEP 16 2000


JAN 4 2001


STOP
SEP 27 2000


SARB_008270
DEC 17 2000



Buckman Terrace tree preservation and at grade infiltration planter
(303 NE 16th Ave.)

SARB_008271

Rainwater Harvesting

Site Location	Page/ Slide
Oregon Natural Resources Council Office	107



Cistern at ONRC (5825 N. Greeley)

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SARB_008276

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CHAPTER 33.248
LANDSCAPING AND SCREENING

(Amended by: Ord. No. 165594, effective 7/8/92; Ord No. 166572, effective 6/25/93; Ord. No. 173533, effective 8/2/99; Ord. No. 174263, effective 4/15/00; Ord. Nos. 175341 and 175358, effective 3/16/01; Ord. No. 175837, effective 9/7/01; Ord. No. 176469, effective 7/1/02; Ord. No. 177701, effective 8/30/03; Ord. No. 178657, effective 9/3/04; Ord. No. 179316, effective 7/8/05; Ord. No. 179980, effective 4/22/06.)

Sections:

33.248 010 Purpose
33.248.020 Landscaping and Screening Standards
33.248.030 Plant Materials
33.248.040 Installation and Maintenance
33.248.050 Landscaped Areas on Corner Lots
33.248.060 Landscape Plans
33.248.065 Tree Preservation Plans
33.248.068 Tree Protection Requirements
33.248.070 Completion of Landscaping
33.248.080 Street Trees
33.248.090 Mitigation and Restoration Plantings

33.248.010 Purpose

The City recognizes the aesthetic, ecological, and economic value of landscaping and requires its use to:

- Preserve and enhance Portland's urban forest;
- Promote the reestablishment of vegetation in urban areas for aesthetic, health, and urban wildlife reasons;
- Reduce stormwater runoff pollution, temperature, and rate and volume of flow;
- Establish and enhance a pleasant visual character which recognizes aesthetics and safety issues;
- Promote compatibility between land uses by reducing the visual, noise, and lighting impacts of specific development on users of the site and abutting uses;
- Unify development, and enhance and define public and private spaces;
- Promote the retention and use of existing vegetation;
- Aid in energy conservation by providing shade from the sun and shelter from the wind;
- Restore natural communities through re-establishment of native plants; and
- Mitigate for loss of natural resource values.

This chapter consists of a set of landscaping and screening standards and regulations for use throughout the City. The regulations address materials, placement, layout, and timing of installation. Specific requirements for mitigation plantings are in 33.248.090.

The *Portland Tree and Landscaping Manual* contains additional information about ways to meet the regulations of this chapter.

33.248.020 Landscaping and Screening Standards

Subsections A. through H. state the different levels of landscaping and screening standards to be applied throughout the City. The locations where the landscaping or screening is required and the depth of the landscaping or screening are stated in various places throughout the Code. **All** landscaping and screening required by this Title must comply with all of the provisions of this chapter, unless specifically superseded. The landscaping standards are generally in a hierarchical order. The landscaping standards are minimums;

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higher standards can be substituted as long as all fence or vegetation height limitations are met. Crime prevention and safety should be remembered when exceeding the landscaping standards (height and amount of vegetation may be an issue).

A. L1, general landscaping.

1. Intent. The L1 standard is a landscape treatment for open areas. It is intended to be applied in situations where distance is used as the principal means of separating uses or development, and landscaping is required to enhance the area in-between. While primarily consisting of ground cover plants, it also includes a mixture of trees, high shrubs, and low shrubs.

2. Required materials. The L1 standard has two different requirements for trees and shrubs. Ground cover plants must fully cover the remainder of the landscaped area.

    a. Where the area to be landscaped is less than 30 feet deep, the standard is one large tree per 30 linear feet, one medium tree per 22 linear feet, or one small tree per 15 linear feet. Trees of different sizes may be combined to meet the standard. Trees may be grouped.

    b. Where the area is 30 feet deep or greater, the requirement is either two high shrubs or three low shrubs per 400 square feet of landscaped area in addition to the trees required in 2.a, above. The shrubs and trees may be grouped.

B. L2, low screen.

1. Intent. The L2 standard is a landscape treatment which uses a combination of distance and low level screening to separate uses or development. The standard is applied where a low level of screening is adequate to soften the impact of the use or development, or where visibility between areas is more important than a total visual screen. It is usually applied along street lot lines.

2. Required materials. The L2 standard requires enough low shrubs to form a continuous screen 3 feet high. The shrubs must be evergreen. In addition, one large tree is required per 30 linear feet of landscaped area, one medium tree per 22 linear feet of landscaped area, or one small tree per 15 linear feet of landscaped area. Trees of different sizes may be combined to meet the standard. Ground cover plants must fully cover the remainder of the landscaped area. A 3-foot-high masonry wall or a berm may be substituted for the shrubs, but the trees and ground cover plants are still required. When applied along street lot lines, any required or nonrequired screen, wall, or fence is to be placed along the interior side of the landscaped area.

C. L3, high screen.

1. Intent. The L3 standard is a landscape treatment which uses screening to provide the physical and visual separation between uses or development. It is used in those instances where visual separation is required.

2. Required materials. The L3 standard requires enough high shrubs to form a screen 6 feet high. The shrubs must be evergreen. In addition, one large tree is required per 30 linear feet of landscaped area, one medium tree per 22 linear feet of landscaped area, or one small tree per 15 linear feet of landscaped area. Trees of different sizes may be combined to meet the

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standard. Ground cover plants must fully cover the remainder of the landscaped area. A 6-foot-high masonry wall may be substituted for the shrubs, but the trees and ground cover plants are still required. When applied along street lot lines, any required or nonrequired screen, wall, or fence is to be placed along the interior side of the landscaped area.

D. L4, high wall.

1. Intent. The L4 standard is intended to be used in special instances where extensive screening of both visual and noise impacts is needed to protect abutting sensitive uses in areas and where there is little space for separation.

2. Required materials. The L4 standard requires a 6 foot high masonry wall along the interior side of the landscaped area. One large tree is required per 30 linear feet of wall, one medium tree per 22 linear feet of wall, or one small tree per 15 linear feet of wall. Trees of different sizes may be combined to meet the standard. In addition, four high shrubs are required per 30 linear feet of wall. Ground cover plants must fully cover the remainder of the landscaped area.

E. L5, high berm.

1. Intent. The L5 standard is intended to be used in special instances where extensive screening of both visual and noise impacts is needed to protect abutting sensitive uses, and where it is desirable and practical to separate a use by distance as well as sight-obscuring materials.

2. Required materials. The L5 standard requires a berm between 4 and 6 feet high. If the berm is less than 6 feet high, low shrubs that meet the L2 standard must be planted on top of the berm to assure that the overall screen height is 6 feet. In addition, one large tree is required per 30 linear feet of berm, one medium tree per 22 linear feet of berm, or one small tree per 15 linear feet of berm. Trees of different sizes may be combined to meet the standard. Ground cover plants must fully cover the remainder of the landscaped area.

F. F1, partially sight-obscuring fence.

1. Intent. The F1 fence standard provides a tall, but not totally blocked visual separation. The standard is applied where a low level of screening is adequate to soften the impact of the use or development, or where visibility between areas is more important than a total visual screen. It is applied in instances where landscaping is not necessary and where nonresidential uses are involved.

2. Required materials. Fences must be 6 feet high and at least 50 percent sight-obscuring. Fences may be made of wood, metal, bricks, masonry or other permanent materials. See Figure 248-1.

G. F2, fully sight-obscuring fence.

1. Intent. The F2 fence standard provides a tall and complete visual separation, and is intended to be used in special instances where complete screening is needed to protect abutting uses, and landscaping is not practical. It is usually applied in nonresidential situations.

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2. Required materials. Fences must be 6 feet high and 100 percent sight-obscuring. Fences may be made of wood, metal, bricks, masonry or other permanent materials. See Figure 248-2.

Figure 248-1
F1 – Partially Sight-Obscuring

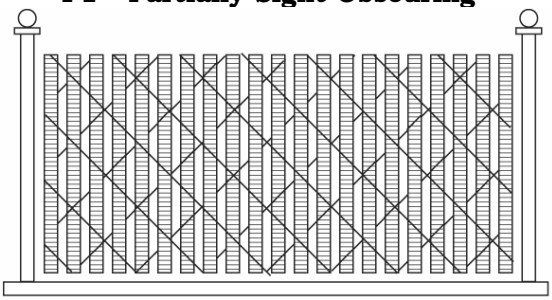
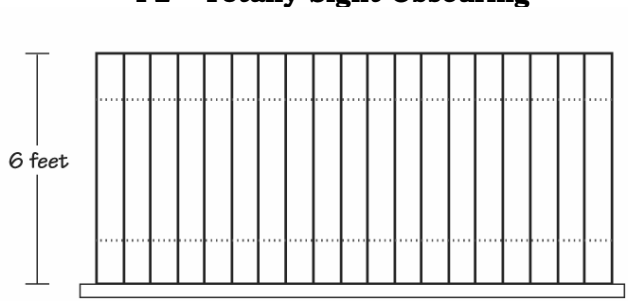


Figure 248-2
F2 – Totally Sight-Obscuring



H. T1, trees.

1. Intent. The T1 standard is a tree requirement for new residential development. It encourages the retention of trees, minimizes the impact of tree loss during development, and ensures a sustained tree canopy in Portland.

2. Tree requirement. This requirement may be met using any of the three options below. The applicant may choose to meet one or more of these options. Adjustments to this Subsection are prohibited. The options are:

   a. Tree preservation. At least 2 inches of existing tree diameter per 1,000 square feet of site area must be preserved. On lots that are 3,000 square feet or smaller, at least 3 inches of existing tree diameter must be preserved per lot. This standard may be met using trees on the lot and within 5 feet of the edges of the lot. Trees within public and private rights-of-way may not be used to meet this standard. When this option is used, a tree preservation plan is required.

   b. Tree planting. At least 2 inches of tree diameter per 1,000 square feet of site area must be planted. On lots that are 3,000 square feet or smaller, at least 3 inches of tree diameter must be planted per lot.

   c. Tree Fund. This option may be used where site characteristics or construction preferences do not support the preservation or planting options.

      (1) Fund use and administration. The Tree Fund fee is collected by the Bureau of Development Services and is administered by the Urban Forestry Division of the Bureau of Parks and Recreation. The funds collected will be used to plant trees on public or private property in the same watershed as the site.

      (2) Calculation of required fund contributions. Applicants must contribute the cost to purchase and plant trees, as set out in (3), below. The cost to purchase and plant trees will be adjusted annually as determined by the Urban Forester based on current market prices per inch for materials, labor, and maintenance.

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(3) Required fund contribution. The applicant must contribute the following to the Tree Fund before a building permit will be issued:

- For lots with 3,000 square feet or more of area, the cost to purchase and plant at least 2 inches of tree diameter per 1,000 square feet of site area; or
- For lots with less that 3,000 square feet of area, the cost to purchase and plant at least 3 inches of tree diameter per lot.

I. P1, parking lot interior landscaping.

1. Intent. The P1 standard is a landscape treatment which uses a combination of trees, shrubs, and ground cover to provide shade, stormwater management, aesthetic benefits, and screening to soften the impacts of large expanses of pavement and vehicle movement. It is applied to landscaped areas within parking lots and associated vehicle areas.

2. Required materials.

   a. Trees. The P1 standard requires one large tree per 4 parking spaces, one medium tree per 3 parking spaces, or one small tree per 2 parking spaces. At least 20 percent of trees must be evergreen. Trees of different sizes may be combined to meet the standard.

   b. Shrubs. The P1 standard requires 1.5 shrubs per space. For spaces where the front two feet of parking spaces have been landscaped instead of paved, the P1 standard requires one shrub per space. Shrubs may be evergreen or deciduous.

   c. Ground cover plants. The P1 standard requires that the remainder of the area must be planted in ground cover plants. The plants must be spaced to cover the area within 3 years. Mulch does not count as ground cover.

33.248.030 Plant Materials

A. Ground cover.

1. Ground cover required. All of the landscaped area that is not planted with trees and shrubs must be planted in ground cover plants, which may include grasses. Mulch (as a ground cover) must be confined to areas underneath plants and is not a substitute for ground cover plants.

2. Size and spacing. Ground cover plants other than grasses must be at least the four-inch pot size. Area planted in ground cover plants other than grass seed or sod must be planted in triangular spacing (see Figure 248-3) at distances appropriate for the plant species. Ground cover plants must be planted at a density that will cover the entire area within three years.

   To use a ground cover plant not listed in the *Portland Tree and Landscaping Manual*, the applicant must provide the Bureau of Development Services with an objective source of information about the plant's requirements for spacing. Applicants are encouraged to provide information about the plant's watering needs, sun or shade preference, and climate zone hardiness. This information can come from published sources, Internet sources, or nursery information, for example, cut sheets.

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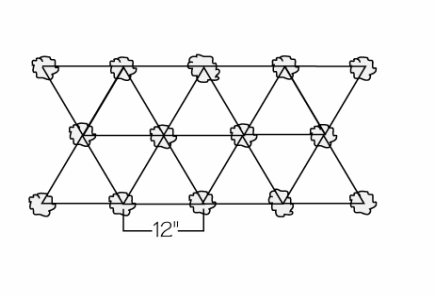
Figure 248-3
Example of Ground Cover Planting on Twelve-Inch Centers



B. Shrubs. All shrubs must be of sufficient size and number to meet the required standards within 3 years of planting. Shrubs must be at least the one-gallon container size at planting.

C. Trees.

1. Planting size. Trees may be broadleaf or conifers. Broadleaf trees at the time of planting must be fully branched. Broadleaf trees planted in residential zones must be a minimum of 1.5 inches in diameter. Broadleaf trees planted in all other zones must be a minimum of 2 inches in diameter. Conifer trees at the time of planting must be fully branched and a minimum of 5 feet in height. Specific planting size requirements related to the mitigation, remediation, or restoration of landscaped areas in overlay zones and plan districts supercede the minimums of this paragraph. These minimum requirements do not apply to trees approved through an Environmental Review, or Pleasant Valley Resource Review to be used for mitigation, remediation, or restoration.

2. Size category.

   a. Trees are categorized as small, medium, or large using the formulas in C.2.c. The *Portland Tree and Landscaping Manual*'s suggested plant lists include the size categories recognized by BDS for many trees.

   b. To determine the size category of a tree not listed in the *Portland Tree and Landscaping Manual*, the applicant must provide BDS with an objective source of information about the tree's mature height, crown spread, and growth rate. This information can come from published sources, Internet sources, or nursery information such as cut sheets. BDS will assign the tree to one of the size categories using the formulas in C.2.c, and will periodically update the suggested tree list to include newly categorized trees.

   c. The size of a tree is calculated according to the following formulas, which incorporate the estimated height and crown spread of a mature specimen and on the species' growth rate:

      (1) Small trees have a canopy factor of less than 40, medium trees have a canopy factor from 40 to 90, and large trees have a canopy factor greater than 90;

      (2) Mature height of tree x Mature canopy spread x Growth rate factor x 0.01 = Canopy factor;

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(3) The growth rate factor is 3 for fast-growing trees, 2 for medium-growing trees, and 1 for slow-growing trees.

3. Existing trees may be used to meet the standards of this chapter. If existing trees are used, each tree 6 inches or less in diameter counts as one medium tree. Each tree more than 6 inches and up to 9 inches in diameter counts as two medium trees. Each additional 3-inch diameter increment above 9 inches counts as an additional medium tree.

D. Plant material choices.

1. Existing vegetation. Existing landscaping or natural vegetation may be used to meet the standards, if protected and maintained during the construction phase of the development as specified in Section 33.248.065, and if the plants are not listed as prohibited on the *Portland Plant List*. When an existing tree is 3 to 12 inches in diameter, each 1 inch diameter counts as 1 inch toward meeting the tree requirements of a landscaping or tree standard. When an existing tree is more than 12 inches in diameter each 1 inch counts as 3 inches toward meeting the tree requirement of a landscaping or tree standard.

2. Selection of materials. Landscape materials should be selected and sited to produce a hardy and drought-resistant landscape area. Selection should include consideration of soil type and depth, the amount of maintenance required, spacing, exposure to sun and wind, the slope and contours of the site, and compatibility with existing native vegetation preserved on the site. Arborescent shrubs from the *Portland Plant List* may not be used to meet the tree requirement.

3. Plant diversity.

   a. Trees. If there are more than 8 required trees, no more than 40 percent of them can be of one species. If there are more than 24 required trees, no more than 24 percent of them can be of one species. This standard applies only to trees being planted to meet the regulations of this Title, not to existing trees.

   b. Shrubs. If there are more than 25 required shrubs, no more than 75 percent of them can be of one species.

   c. Plants may be selected from the *Portland Tree and Landscaping Manual*'s suggested plant lists or other sources.

4. Prohibited materials. Plants listed as nuisance or prohibited in the *Portland Plant List* are prohibited in required landscaped areas. Prohibited plants include plants identified by the Director of BDS or the City Forester as invasive and alien or as potentially damaging to sidewalks, roads, underground utilities, drainage improvements, foundations, etc.

E. Exceeding standards. Landscaping materials that exceed the standards may be substituted for the minimums so long as all fence or vegetation height limitations are met, including the vision clearance standards of Title 16, Vehicles and Traffic.

F. Complying with the standards. It is the applicant's responsibility to show that the landscaping materials proposed will comply with the regulations of this chapter.

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33.248.040 Installation and Maintenance

A. Installation. All required landscaping must be in-ground, except when in raised planters that are used to meet minimum Bureau of Environmental Services stormwater management requirements. Plant materials must be installed to current nursery industry standards. Plant materials must be properly supported to ensure survival. Support devices such as guy wires or stakes must not interfere with vehicular or pedestrian movement.

B. Maintenance. Maintenance of landscaped areas is the ongoing responsibility of the property owner. Required landscaping must be continuously maintained in a healthy manner. Plants that die must be replaced in kind. A fine may be levied if the landscaping has not been maintained, and new plants required to be planted.

C. Irrigation. The intent of this standard is to ensure that plants will survive the critical establishment period when they are most vulnerable due to lack of watering. All landscaped areas must provide an irrigation system, as stated in option 1, 2, or 3.

1. Option 1. A permanent built-in irrigation system with an automatic controller.

2. Option 2. An irrigation system designed and certified by a licensed landscape architect as part of the landscape plan, which provides sufficient water to ensure that the plants will become established. The system does not have to be permanent if the plants chosen can survive adequately on their own once established.

3. Option 3. Irrigation by hand. If the applicant chooses this option, an inspection will be required one year after final inspection to ensure that the landscaping has become established. An inspection fee, paid at the time of permit application, will be required.

D. Protection. All required landscaped areas, particularly trees and shrubs, must be protected from potential damage by adjacent uses and development, including parking and storage areas.

E. Topping prohibited. Topping, an extreme form of crown reduction, of trees that are required by this Title is prohibited; required trees must be allowed to grow in their natural form. This prohibition does not apply to pruning performed to remove a safety hazard, to remove dead or diseased material, or to avoid overhead power lines.

If a tree smaller than 8 inches in diameter is topped, it must be replaced in kind. If a tree 8 inches or larger in diameter is topped, the owner must have an arborist develop and carry out a 5-year pruning schedule.

33.248.050 Landscaped Areas on Corner Lots

All landscaped areas on corner lots must meet the vision clearance standards of Section 16.70.800 of Title 16, Vehicles and Traffic. If high shrubs or other sight-obscuring screening is required by this Title, low screening must be substituted within vision clearance areas.

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33.248.060 Landscape Plans

Landscape plans must be submitted showing all landscaped areas. Plans must be drawn to scale and show type, size, number, and placement of materials. Materials must be identified with both their scientific and common names. Any required irrigation system must also be shown.

33.248.065 Tree Preservation Plans

A. When a tree preservation plan is required. A tree preservation plan must be submitted and approved when existing trees are used to meet a landscape or tree standard.

B. Elements of a tree preservation plan. A tree preservation plan includes both a site plan and a written statement. All of the following elements must be included:

1. A written statement that the trees to be preserved are healthy; and

2. A site plan that is drawn to scale and shows:

   a. All trees to be preserved on the site, their species and diameter;

   b. The location of water, sewer, and other utility easements;

   c. The location of dry wells and soakage trenches; and

   d. How the requirements of Section 33.248.068, Tree Protection Requirements, are met.

C. Alternative tree preservation plans. If the requirements of Section 33.248.068, below, cannot be met, an alternative tree preservation plan may be submitted by an arborist or landscape architect. The alternative tree preservation plan must show alternative means for tree protection and preservation, and include a statement by the arborist or architect that the plan provides the same level of protection as the requirements of Section 33.248.068.

33.248.068 Tree Protection Requirements

A. Where these requirements apply. These requirements apply to all trees shown on a tree preservation plan.

B. Construction fencing. A construction fence must be placed around each tree at the edge of the root protection zone. The fence must be placed before construction starts and remain in place until construction is complete. The fence must meet one of the following:

1. The fence must be 6-foot high orange plastic and be secured to the ground with 8-foot metal posts, or

2. The fence must be 6-foot high steel on concrete blocks.

C. Development limitations. Within the root protection zone of each tree, the following development is not allowed:

1. New buildings;

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2. Grade change or cut and fill during or after construction;

3. New impervious surfaces;

4. Utility or drainage field placement;

5. Staging or storage of materials and equipment during construction; and

6. Vehicle maneuvering areas during construction.

33.248.070 Completion of Landscaping
The installation of any required landscaping may be deferred during the summer or winter months to the next planting season, but never for more than 6 months. All required landscaping must be installed prior to final inspection.

33.248.080 Street Trees
Street trees are not subject to the regulations of this chapter and are not counted toward any landscaping required by this chapter. Street trees are regulated by the City Forester. See Chapter 20.40, Street Trees and Other Public Tree Regulations.

33.248.090 Mitigation and Restoration Plantings
Plantings intended to mitigate for the loss of natural resource values are subject to the following requirements. Where these requirements conflict with other requirements of this chapter, these requirements take precedence.

A. Plant Source. Plant materials must be native and selected from the Portland Plant List. They must be non-clonal in origin, seed source must be as local as possible, and plants must be nursery propagated unless transplanted from on-site areas approved for disturbance. These requirements must be included in the Mitigation Plan specifications.

B. Plant Materials. The Mitigation Plan must specify that plant materials are to be used for restoration purposes. Generally, this means that standard nursery practices for growing landscape plants, such as use of pesticides, fungicides or fertilizers, and the staking of trees must not be employed.

C. Installation. Plant materials must be supported only when necessary due to extreme winds at the planting site. Where support is necessary, stakes, guy wires or other measures must be removed as soon as the plant can support itself.

D. Irrigation. The intent of this standard is to ensure that plants will survive the critical establishment period when they are most vulnerable due to lack of watering. New plantings must be manually watered regularly during the first growing season. During later seasons, watering must be done as needed to ensure survival of the plants.

E. Monitoring and Reporting. Monitoring of landscape areas is the ongoing responsibility of the property owner. Plants that die must be replaced in kind. Written proof that all specifications of this section have been met must be provided one year after the planting is completed. The property owner must provide this documentation to BDS.

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Chapter 21.5 STORMWATER MANAGEMENT*

***Editor's note:** Ord. No. 003-12, adopted March 18, 2003, amended ch. 21.5 in its entirety and enacted similar provisions as set out herein. The former ch. 21.5 derived from Ord. No. 093-55, §§ 1--14, adopted Dec. 14, 1993; Ord. No. 097-61, adopted Nov. 18, 1997; Ord. No. 097-80, adopted Dec. 16, 1997; and Ord. No. 000-88, adopted Oct. 17, 2000.

Cross references: Stormwater management facilities in CRPA, § 11-19; stormwater management plan for Chesapeake Bay preservation area overlay district, § 22-94; discharge of stormwater, etc., § 25-122.

Art. I. In General, §§ 21.5-1--25.1-15
Art. II. Stormwater Pollution and Illicit Discharge, §§ 21.5-16--21.5-22

ARTICLE I. IN GENERAL

Sec. 21.5-1. Introduction.

(a) *Purpose.*

(1) The board of supervisors desires to protect the safety, welfare, and property of Stafford County residents and businesses, and the quality of waters within Stafford County. The board recognizes that development tends to degrade these waters through increased flooding, stream channel erosion, and the transport and deposition of waterborne pollutants. This degradation is due, in part, to increased stormwater runoff as property is developed. The regulation of stormwater runoff from developments can control thenegative impacts of generating increased flooding, erosion, and nonpoint source pollutant runoff. Hence, the board has determined that it is in the public interest to establish requirements, which regulate the discharge of stormwater runoff from developments.

(2) The purpose of this chapter is to establish minimum stormwater management requirements which: Protect the safety and welfare of Stafford County residents and businesses; reduce flood damage to property; minimize the impacts of increased stormwater runoff from new land development; maintain the adequacy of existing and proposed culverts, bridges, dams, and other structures; prevent, to the greatest extent feasible, an increase in nonpoint source pollution; maintain the integrity of stream channels for theirbiological functions and drainage; minimize the impact of development upon stream erosion; and preserve and protect water supply facilities from increased flood discharges, stream erosion, and nonpoint source pollution.

(b) *Statutory authority.* This chapter is enacted in accordance with the Stormwater Management Act (section 10.1-603 et seq., Code of Virginia, (1950), as amended).

(c) *Conflict of provisions.* In any case where the requirements of this chapter conflict with any other provisions of the Stafford County Code, whichever imposes the more stringent restrictions shall apply. Approvals issued pursuant to this chapter do not relieve the applicant of the responsibility to secure applicable federal, state, or local permits or approvals for regulated activities. When any referenced code citation is amended, the amended code shall be the applied standard.

(d) *Severability.* If any part of this chapter, or application thereof of this chapter to any person, property, or circumstance is held invalid by a court of the competent jurisdiction, the remainder of this chapter and its application to other persons, property or circumstances shall not be affected.

(e) *Administration.* This chapter shall be administered and enforced by the program administrator. The program administrator or designee, upon proper identification, shall have the right to enter upon any land for the purpose of making an inspection or acquiring information to determine whether or not the property conforms to the requirements of this chapter.

(f) *Applicability.*

(1) Except as provided for in subsection (f)(2), all land development projects within Stafford County shall comply with the requirements of this chapter.

(2) The following activities shall be exempt from this chapter:

a. Permitted surface or deep mining operations and projects, or oil and gas operations and projects conducted under the provisions of title 45.1, Code of

Virginia.

b. Tilling, planting, or harvesting of agricultural, horticultural, or forest crops.

c. Linear development projects, provided that (i) less than one acre of land will be disturbed per outfall or watershed, (ii) there will be insignificant increases in peak flow rates, and (iii) there are no existing or anticipated flooding or erosion problems downstream of the discharge points.

d. Single-family detached residences separately built and not part of a subdivision, including additions or modifications to existing single-family detached residential structures, provided that all applicable requirements of section 28-62 (Chesapeake Bay preservation area overlay districts) of the Code are met.

e. Structures considered ancillary to single-family detached and semidetached residences, duplexes, and townhouses, including, but not limited to, garages, decks, patios, and barns provided that all applicable requirements of section 28-62 (Chesapeake Bay preservation area overlay districts) of the Code are met.

f. Land development projects that disturb less than two thousand five hundred (2,500) square feet of land.

(g) *Incorporation by reference.* For the purpose of this chapter, the following documents are incorporated by reference:

(1) Stafford County Stormwater Management Design Manual prepared by Stafford County, Virginia, dated March 2003 and subsequent modifications and updates thereof.

(2) Virginia Stormwater Management Handbook, Volumes I and II, prepared by the Virginia Department of Conservation and Recreation dated 1999 and subsequent modifications and updates thereof.

(3) Low-Impact Development Design Strategies: An Integrated Design Approach, United States Environmental Protection Agency, Office of Water, EPA 841-B-00-003 dated June 1999 and subsequent modifications and updates thereof.

(4) Low-Impact Development Hydrologic Analysis, United States Environmental Protection Agency, Office of Water, EPA 841-B-00-002 dated June 1999 and subsequent modifications and updates thereof.

(h) *Definitions.*

Adequate channel means a natural or manmade channel which is capable of conveying runoff from a ten-year storm without overtopping its banks and from a two-year storm without eroding. A pipe or storm sewer system is adequate if runoff from a ten-year storm is contained within the system.

Applicant means any person submitting a stormwater management plan for approval.

As-built plan means a set of engineering or site drawings that adequately depict stormwater management facilities and stormwater drainage systems as they were actually constructed.

Best management practice (BMP) means a structural or nonstructural practice, which is designed to minimize the impacts of development on surface or groundwater systems.

Channel means a natural stream or artificial watercourse with a definite bed and banks that conducts continuously or periodically flowing water.

Development means a tract of land developed or to be developed as a unit under single ownership or unified control that is to be used for any business or industrial purpose or is to contain three (3) or more residential dwelling units.

Flooding means a volume of water that is too great to be confined within the banks or walls of

the stream, water body, or conveyance system, and that overflows onto adjacent lands, causing or threatening damage.

Floodplain means the floodplain districts defined in chapter 28 (zoning ordinance) of this Code as being areas subject to inundation by waters of the hundred-year flood.

Hotspot means an area where the land use or activities are considered to generate runoff with concentrations of pollutants in excess of those typically found in stormwater.

Integrated management practice means low-impact development microscale and distributed management techniques used to maintain predevelopment site hydrology. Integrated management practices shall include bioretention facilities, dry wells, filter/buffer strips, grassed swales, rain barrels, cisterns, infiltration trenches and amended soils as specified in the low-impact development design manuals.

Land development or *land development project* means a manmade change to the land surface that potentially changes its runoff characteristics.

Linear development project means a land development project that is linear in nature such as, but not limited to, (i) the construction of electric and telephone utility lines and natural gas pipelines; (ii) construction of tracks, rights-of-way, bridges, communication facilities and other related structures of a railroad company; and (iii) highway construction projects.

Low-impact development means a hydrologically functional site design with pollution-prevention measures to reduce impacts and compensate for development impacts on hydrology and water quality.

Low-impact development design manuals refers to the Low-Impact Development Design Strategies: An Integrated Design Approach Manual and the Low-Impact Development Hydrologic Analysis Manual as incorporated by reference in this chapter.

Maintenance agreement means a legally binding agreement between the landowner of a stormwater management structure and Stafford County outlining each party's responsibility towards the operation, maintenance and general upkeep of said structure.

Maintenance plan means a component of the stormwater management design plan describing the stormwater management structures at the land development project and identifying maintenance items that will be performed by the landowner to ensure proper functioning of said structures.

Nonpoint source pollution means pollution consisting of constituents such as sediment, nutrients, and organic and toxic substances from diffuse sources, such as runoff from urban land development and use.

Nonstructural stormwater practice means a stormwater runoff treatment technique which uses natural measures to reduce pollutant levels, does not require extensive construction efforts and/or promotes pollution reduction by eliminating the pollutant source.

Off-site stormwater management facility means a stormwater management facility located outside the subject property boundary described in the stormwater management design plan for the land development activity.

On-site stormwater management facility means a stormwater management facility located within the subject property boundary described in the stormwater management design plan for the land development activity.

Overcompensation means the extra water quantity or quality control provided at one site discharge point in order to allow another discharge point(s) to go uncontrolled.

Person means any firm, association, organization, partnership, trust, company, or corporation, as well as an individual.

Postdevelopment refers to the conditions that reasonably may be expected or anticipated to exist after completion of the land development activity on a specific site or tract of land.

Predevelopment refers to the land condition that exists at the time that plans for the land development are submitted to the locality. Where phased development or plan approval occurs (preliminary grading, roads, and utilities, etc.), the existing land use at the time the first item is submitted shall establish predevelopment conditions.

Pretreatment means the techniques employed in a stormwater management plan to provide storage or filtering to help trap course materials before they enter the stormwater BMP. Pretreatment is required on some BMPs to help avoid costly maintenance.

Program administrator means the county administrator or his designee.

Redevelopment means the process of developing land that is or has been previously developed.

Regional stormwater management facility (regional facility) means a facility or series of facilities designed to control stormwater runoff from a specific watershed and for one or more developments.

Runoff means that portion of precipitation that is discharged across the land surface or through conveyances to one or more waterways.

Stormwater drainage means the collection and conveyance of storm and other surface flows through the land development project in a manner to prevent flooding of structures and associated properties and erosion of channels. Stormwater drainage systems shall include stormwater conveyance channels, storm sewers and culverts.

Stormwater management means the collection, conveyance, storage, treatment, and disposal of stormwater runoff in a manner to prevent accelerated channel erosion, increased flood damage, and degradation of water quality.

Stormwater management concept plan means a generalized plan provided with the preliminary plan of subdivision or preliminary site development plan describing how stormwater runoff through and from a land development project will be conveyed and controlled.

Stormwater management design manuals refers to the Stafford County Stormwater Management Design Manual and the Virginia Stormwater Management Handbook as incorporated by reference in this chapter.

Stormwater management design plan means a set of drawings and supporting documents that comprises all of the information and specifications for the systems and structures that will be used to convey and control stormwater runoff in accordance with the requirements of this chapter.

Stormwater management extended detention basin (extended detention basin) means a stormwater management facility that temporarily impounds runoff and discharges it through a hydraulic outlet structure over a specified period of time to a downstream conveyance system for the purpose of water quality enhancement or stream channel erosion control. Since an extended detention facility impounds runoff only temporarily, it is normally dry during nonrainfall periods.

Stormwater management facility means a device that controls stormwater runoff and changes the characteristics of that runoff including, but not limited to, the quantity and quality, the period of release, or the velocity of flow.

Stormwater management filtering system means a stormwater treatment practice that utilizes an artificial media [medium] to filter out pollutants. Filtering systems shall include bioretention facilities and sand filters, as specified in the Virginia Stormwater Management Design Manuals.

Stormwater management infiltration facility means a stormwater management facility that temporarily impounds runoff and discharges it via infiltration through the surrounding soil. Infiltration facilities shall include infiltration basins, infiltration trenches, dry wells and porous pavement as specified in the stormwater management design manuals.

Stormwater management open channel system means a vegetated open channel designed to

remove pollutants from stormwater runoff by filtration through grass and infiltration into the soil.

Stormwater management retention basin (retention basin) means a stormwater management facility that temporarily impounds runoff and discharges it through a hydraulic outlet structure to a downstream conveyance system, and also includes a permanent impoundment. Therefore, it is normally wet, even during nonrainfall periods.

Stormwater management wetland means an area intentionally designed and created to emulate the water quality improvement function of wetlands for the primary purpose of removing pollutants from stormwater.

Watershed means a defined land area drained by a river, stream or drainage way, or system of connecting rivers, streams or drainage ways such that all surface water within the area flows through a single outlet.

(Ord. 003-12, 3-18-03)

Sec. 21.5-2. Stormwater management technical criteria.

(a) *General.*

(1) Site designs shall minimize the generation of stormwater and maximize pervious areas for stormwater treatment. Structural and nonstructural infiltration BMPs shall be encouraged to provide stormwater quality and quantity control and groundwater recharge.

(2) Natural channel characteristics shall be preserved to the maximum extent practicable.

(3) Residential, commercial or industrial developments shall apply these stormwater management criteria to land development as a whole. Individual residential lots in new subdivisions shall not be considered separate land development projects, but rather the entire subdivision shall be considered a single land development project. Hydrologic parameters shall reflect the ultimate land development and shall be used in all engineering calculations.

(4) The design criteria, methodologies and construction specifications for all stormwater management facilities, and structural and nonstructural BMPs shall be those of the stormwater management design manuals. The design shall be certified by a professional licensed in Virginia to perform such work.

(5) Predevelopment and postdevelopment runoff rates shall be verified by calculations that are consistent with good engineering practices and methodologies found in the stormwater management design manuals.

(6) Outflows from a stormwater management facility shall be discharged to an adequate channel, and velocity dissipaters shall be placed at the outfall of all stormwater management facilities and along the length of any outfall channel as necessary to provide a nonerosive velocity of flow from the facility to a channel.

(7) Safety measures shall be incorporated into the design of all stormwater management facilities in accordance with the stormwater management design manuals.

(8) Stormwater management facilities shall be designed to minimize the propagation of insects, particularly mosquitoes, provided that design features proposed will not negatively impact the functions of the facility.

(9) Impounding structures that are not covered by the Virginia Impounding Structures Regulations (4VAC50-20-10, et seq.) shall be engineered for structural integrity during the 100-year storm event in accordance with the stormwater management design

manuals.

(10) All stormwater management facilities shall have a maintenance plan and agreement, which identifies the owner and responsible party for carrying out the maintenance plan in accordance with section 21.5-5.

(11) Storm drainage easements shall be required on lots or parcels where the conveyance, storage or treatment of stormwater is proposed or can reasonably be expected to occur. These drainage easements shall be located in accordance with the provisions of section 22-152 (Lots for stormwater management facilities) of the Code and shall be computed and identified on the plat of record prior to recordation in accordance with the stormwater management design manuals.

(12) Notwithstanding any other provisions of this chapter or waivers or exemptions thereto, land development projects shall comply with chapter 11 (Erosion and Sediment Control) and section 28-62 (Chesapeake Bay preservation area overlay districts) of the Code.

(13) Construction of stormwater management facilities or modifications to channels shall comply with all applicable laws and regulations. Evidence of all applicable federal and state permits required for construction of the facility shall be presented to the program administrator prior to issuance of a grading permit.

(14) If stormwater management facilities are provided through which water passes at times other than rainfall, the program administrator shall be consulted to ensure the appropriateness of design prior to submission of the stormwater management design plan. This applies to all onstream or online stormwater management facilities.

(15) Construction of stormwater management impoundment structures within a Federal Emergency Management Agency (FEMA) designated floodplain shall be avoided to the extent possible. When this is unavoidable, all stormwater management facility construction shall be in compliance with all applicable requirements of the flood hazard overlay district as defined in chapter 28 (zoning ordinance) of this Code.

(b) *Water quality.*

(1) For land development, the postdeveloped stormwater runoff shall be treated by an appropriate technology-based water quality BMP(s) based on the imperviousness of the drainage area as specified in the stormwater management design manuals.

(2) The selected water quality BMP(s) shall be located, designed and maintained to perform at or higher than the target pollutant removal efficiency identified in the stormwater management design manuals.

(3) The following water quality BMPs shall be used to satisfy the applicable water quality control requirements in this subsection:

a. Stormwater management retention and extended detention basins;

b. Stormwater management wetlands;

c. Stormwater management infiltration facilities;

d. Stormwater management filtering systems;

e Stormwater management open channel systems;

f. Low-impact development site planning and integrated management practices in accordance with subsection (e); and

g. Regional stormwater management facilities in accordance with subsection (f).

(4) Innovative and alternative water quality BMPs may be allowed for land development

at the discretion of the program administrator subject to pollutant removal efficiencies recognized by the Virginia Department of Conservation and Recreation.

(5) When a land development project contains or is divided by multiple drainage areas, water quality BMPs shall be evaluated for each drainage area. If a portion of the site is left uncontrolled or a portion of the site is treated with a lower than target pollutant removal efficiency BMP, the program administrator may require performance-based water quality calculations to verify total site water quality compliance in accordance with methodologies in the stormwater management design manuals. Overcompensation ofwater quality shall be in accordance with requirements outlined in the stormwater management design manuals.

(6) Water quality BMPs shall have an acceptable form of water quality pretreatment in accordance with pretreatment requirements found in the stormwater management design manuals.

(7) Stormwater discharges from stormwater hotspots may require the use of specific structural BMPs and pollution prevention practices. Stormwater from a hotspot shall not be infiltrated without proper pretreatment.

(8) All redevelopment projects not served by an existing water quality BMP shall reduce post-development pollutant loads to ninety (90) percent of predevelopment levels through the reduction of site impervious areas or the application of water quality BMPs in accordance with performance-based criteria in the stormwater management design manuals. For redevelopment of any property that is currently and adequately served by one or more water quality BMPs, the postdevelopment pollution load shall not exceed the predevelopment pollution load.

(c) *Stream channel erosion.*

(1) Properties and receiving waterways downstream of any land development project shall be protected from erosion and damage due to increases in volume, velocity and frequency of peak flow rate of stormwater runoff in accordance with the minimum design standards set out in this subsection.

(2) The land development project shall provide twenty-four-hour extended detention of runoff generated by the one-year, twenty-four-hour-duration storm.

(3) The extended detention storage volume, release rate and orifice size shall be determined using the design methods in the stormwater management design manuals.

(4) Stream channel erosion impacts to receiving streams due to land development projects shall be addressed for each point of discharge from the development project.

(5) In lieu of extended detention of the one-year storm, land development may provide channel improvements, nonstructural practices, low impact development site design or other measures satisfactory to the program administrator to prevent channel erosion.

(d) *Flooding.*

(1) Downstream properties and waterways shall be protected from localized flooding due to increases in volume, velocity and peak flow rate of stormwater runoff in accordance with the minimum design standards set out in this subsection.

(2) The ten-year storm post-developed peak rate of runoff from the development site shall not exceed the ten-year predeveloped rate.

(3) The design storm shall be defined as either a twenty-four-hour storm using the rainfall distribution recommended by the U.S. Natural Resources Conservation Service (i.e., Soil Conservation Service) when using Soil Conservation Service methods or as the storm of critical duration that produces the greatest required storage volume at the

site when using a design method such as the rational method.

Selection of appropriate hydrology method and corresponding calculations shall be in accordance with requirements of the stormwater management design manuals.

(4) For the purposes of computing runoff, all pervious lands in the site shall be assumed prior to development to be in good condition (if lands are pastures, lawns or parks), with good cover (if lands are woods), or with conservation treatment (if lands are cultivated), regardless of conditions existing at time of computation.

(5) Determination of flooding impacts to receiving streams due to land development projects shall be measured at each point of discharge from the development project and such determination shall include any runoff from the balance of the watershed, which also contributes to that point of discharge. Overcompensation of ten-year peak controls shall be in accordance with requirements of the stormwater management design manuals.

(6) Linear development projects shall not be required to control postdeveloped stormwater runoff for flooding, except in accordance with watershed or regional stormwater management plan.

(e) *Low-impact development sites.*

(1) The use of low-impact development site planning and integrated management practices shall be encouraged to control stormwater runoff at the source and more closely approximate predevelopment runoff conditions.

(2) Low-impact development stormwater management design plans developed consistent with the requirements of this subsection shall satisfy the water quality and quantity performance criteria of subsections (b), (c) and (d).

(3) The design criteria, hydrologic analysis and computational procedures for low-impact development stormwater management design plans shall be those of the low-impact development design manuals.

(4) Low-impact development stormwater management design plans shall not conflict with existing state or Stafford County laws, ordinances, regulations or policies.

(5) Storm drainage easements shall be recorded to identify the locations of integrated management practices on lots or parcels. The property owner shall not remove or structurally alter integrated management practices without prior written approval from the program administrator.

(6) Stormwater runoff from parking lots shall utilize stormwater management infiltration facilities and/or stormwater management filtering systems. These shall be placed within or near the parking lot islands.

(f) *Regional stormwater management facilities.*

(1) Land development projects shall implement regional stormwater management facilities identified in adopted stormwater management plans in accordance with requirements in the stormwater management design manuals and regulations adopted by the board of supervisors.

(2) When a land development project desires to install a regional stormwater management facility at a location not identified in an adopted stormwater management plan, the program administrator shall require submission of a comprehensive watershed study. The watershed study shall include sufficient information to evaluate impacts of the proposed facility on runoff rates, volumes and velocities, and environmental characteristics of the affected areas.

(3) Land development projects served by an existing or planned regional stormwater

management facility shall pay a pro-rata share of the cost of implementing the facility in accordance with regulations adopted by the board of supervisors.

(Ord. 003-12, 3-18-03; Ord. No. O04-32, 6-15-04)

Sec. 21.5-3. Stormwater drainage technical criteria.

(a) All land development projects shall provide for a system of adequate stormwater drainage. The system shall be based on sound engineering practices and shall be certified as adequate to provide for the necessary stormwater drainage by a professional licensed in Virginia to perform such work.

(b) Stormwater drainage systems shall be designed and constructed in accordance with the stormwater management design manuals. Design details for stormwater drainage systems shall be identified on the stormwater management design plan.

(c) Stormwater drainage systems shall be designed such that properties over which surface waters are conveyed, from the development site to discharge point(s), are not adversely affected. The increase in runoff volume caused by the development shall not aggravate an existing drainage problem or cause a drainage problem. A downstream drainage system may be created, expanded or improved in combination with or in lieu of on-site stormwater detention if approved by the program administrator.

(d) Stormwater drainage systems and stormwater management facilities shall be designed to honor natural drainage divides to the maximum extent practicable.

(e) Concentrated surface waters, including outflows from stormwater management facilities, shall not be discharged onto an adjoining developed property (such as any developed nonresidential property, a residential lot less than three (3) acres or the improved portion of a residential lot three (3) acres or greater), unless a storm drainage easement has been recorded on the affected property or unless the discharge is into a well defined natural stream (i.e., incised channel with bed and banks) or an existing drainage system of adequate capacity. Such drainage easement(s) shall be obtained prior to approval of the stormwater management design plan and shall extend to the nearest recorded storm drainage easement, well-defined natural stream, or manmade stormwater facility, channel or pipe of adequate capacity.

(f) Stormwater drainage easements shall be extended where necessary to upstream property lines to permit future development reasonable access to on-site drainageways or drainage systems for connections.

(g) Surface runoff greater than three (3) cubic feet per second for the ten-year storm event that flows through lots shall be piped when average lot size is less than thirty thousand (30,000) square feet except that the program administrator may approve an open-channel system where the preservation of a natural drainageway is desirable or the use of an open channel will not interfere with the use of the property. This requirement shall not apply to low-impact development sites designed in accordance with the requirements of subsection (e) of section 21.5-2.

(h) Residential lots in which lot size is less than thirty thousand (30,000) square feet shall be graded in such a manner that surface runoff does not cross more than three (3) lots before it is collected in a storm sewer system or designed stormwater conveyance channel.

(Ord. 003-12, 3-18-03)

Sec. 21.5-4. Stormwater management plans.

(a) *Stormwater management concept plans.*

(1) All preliminary plans of subdivision and major site development plans shall provide a stormwater management concept plan describing, in general, how stormwater runoff through and from the development will be conveyed and controlled.

(2) The stormwater management concept plan must be approved prior to submission of a stormwater management design plan (as part of the construction or final site plan) for the entire development, or portions thereof.

(3) A copy of the approved stormwater management concept plan shall be submitted with the stormwater management design plan. The program administrator shall check the design plan for consistency with the concept plan and may require a revised stormwater management concept plan if changes in the site development proposal have been made.

(4) The stormwater management concept plan shall provide all appropriate information as identified in the stormwater management design manuals.

(5) The stormwater management concept plan shall include a hydrologic/hydraulic analysis of the downstream watercourse for all concentrated surface waters that will be discharged onto a developed property. The program administrator may request relocation of a stormwater outfall if other alternative discharge locations are practical.

(6) Prior to approval of the stormwater management concept plan, the program administrator, or his designee, shall meet on site with the applicant or his representative to field-verify the hydraulic conditions of all receiving channels.

(7) The stormwater management concept plan shall utilize to the maximum extent practicable low-impact development site planning in accordance with the low-impact development design manuals.

(b) *Stormwater management design plans.*

(1) Except as provided for in subsection 21.5-1(f)(2), no grading or building permit shall be issued for land development without approval of a stormwater management design plan unless the applicant can demonstrate compliance with section 21.5-2.

(2) The applicant shall demonstrate that the project meets the criteria set forth in this chapter through submission of a stormwater management design plan. Failure of the applicant to demonstrate that the project meets these criteria, as determined by the program administrator, shall be reason to deny approval of the plan.

(3) A stormwater management design plan containing all appropriate information as specified in this chapter shall be submitted to the department of planning and community development in conjunction with the construction plan or final site plan.

(c) *Stormwater management design plan contents.* The stormwater management design plan shall contain maps, charts, graphs, tables, photographs, narrative descriptions, explanations, and citations to supporting references as appropriate to communicate the information required by this chapter and the stormwater management design manuals and the low-impact development design manuals. At a minimum, the stormwater management design plan shall contain the following:

(1) *General.*

a. Description of the project, and proposed design, including how water quality, quantity and stormwater drainage requirements will be addressed.

b. Proposed erosion and sediment controls, and proposed temporary and permanent stormwater management facilities.

c. Project schedule, including a sequence of construction.

d. Maps depicting all pertinent stormwater management information necessary for review of the plan as identified in the stormwater management design manuals, including, but not limited to maps of the drainage area, soils and plan view of the development project.

(2) *Stormwater management facilities.*

a. Stormwater management facilities identified on a map, including details, plan, profile, cross sections, and other pertinent data necessary for review as identified in the stormwater management design manuals.

b. Comprehensive hydrologic and hydraulic design calculations, including all assumptions and criteria, for the pre-development and post-development conditions for the design storms specified in this chapter or the stormwater management design manuals.

c. If infiltration facilities are proposed, the location of existing and proposed wells and septic system drain fields shall be shown along with an analysis that supports the location of the infiltration facility in the soil type identified.

d. A geotechnical report with recommendations and earthwork specifications in accordance with requirements in the stormwater management design manuals. The geotechnical engineer shall acknowledge on the design plan that the geotechnical recommendations have been incorporated into the design of stormwater management facilities.

e. A landscaping plan describing the woody and herbaceous vegetative stabilization and management techniques to be used within and adjacent to the stormwater management facility in accordance with standards in the stormwater management design manuals.

f. Identification of all easements needed for inspection and maintenance of stormwater management facilities in accordance with specifications in the stormwater management design manuals.

g. A maintenance plan identifying the parts or components of the stormwater management facility that need to be maintained to ensure continued proper functioning of the facility. If the designated maintenance responsibility is with a party other than Stafford County, then a maintenance agreement shall be executed between the responsible party and Stafford County.

(3) *Low-impact development sites.*

a. Integrated management practices identified on a map and corresponding design details in accordance with the low-impact development design manuals.

b. Hydrologic computations to determine low-impact development stormwater requirements in accordance with the low-impact development design manuals.

c. Hydrologic evaluation and design details for supplemental conventional stormwater management facilities in the event that integrated management practices alone cannot meet site stormwater management requirements.

d. Identification of all storm drainage easements needed to establish locations of integrated management practices.

(4) *Stormwater drainage systems.*

a. Hydrologic and hydraulic design calculations, including calculations for overlot drainage systems.

b. Design specifications in accordance with the stormwater management design

manuals.

c. Identification of all easements needed for inspection and maintenance of drainage systems in accordance with specifications in the stormwater management design manuals.

d. All existing and proposed drainage systems, natural or manmade, shall be analyzed for the one-hundred-year storm impact as required in subsection 11-12 (b)(3) a., b. and c.

(d) *Stormwater management design plan approval.*

(1) A maximum of thirty (30) calendar days from the receipt of an application will be allowed for preliminary review of the application to determine if the application is complete. During this period, the application will be accepted for review, which will begin the sixty-day review period, or rejected for incompleteness. The applicant will be informed in writing of the information necessary to complete the application.

(2) The sixty-day review period begins on the day the complete stormwater management design plan is accepted for review. At this time an acknowledgment letter will be sent to the applicant. During the sixty-day review period, the program administrator shall either approve or disapprove the plan and communicate the decision to the applicant in writing. Approval or denial shall be based on the plan's compliance with this chapter and the stormwater management design manuals. In cases where modifications are required to approve the plan, the county shall have an additional sixty (60) days to review the revised plan from the initial and any subsequent resubmission dates. If the plan is approved, one copy bearing certification of such approval shall be returned to the applicant. If the plan is disapproved, the applicant shall be notified in writing of the reasons.

(3) All plans, profiles, and specifications shall be distributed to the appropriate county departments and/or state agencies for review and recommendation. Comments and recommendations shall be coordinated at the meeting of the technical review committee. The technical review committee shall review the plan for compliance with this chapter.

(4) The applicant or any aggrieved party authorized by law may appeal the program administrator's decision of approval or disapproval of a stormwater management design plan application within thirty (30) days after rendering of such decision by the program administrator, to the board of supervisors.

(e) Conditions of approval.

(1) The applicant shall comply with all applicable requirements of the approved plan.

(2) No substantive changes shall be made to an approved plan without review and written approval by the program administrator.

(3) No transfer, assignment, or sale of the rights granted by virtue of an approved plan shall be made unless a written notice of transfer is filed with the program administrator and the transferee certifies agreement to comply with all obligations and conditions of the approved plan.

(4) The stormwater management design plan's approval expires in one year from the date of approval unless a final plat is recorded or unless work has actually begun on the site. The recordation of a final plat for a section of a subdivision (or initiation of construction in a section) does not vest the approval of the stormwater management design plan for the remainder of the subdivision. If the stormwater management design plan expires, the applicant shall file with the program administrator for reapproval ofthe stormwater management design plan.

(5) Three (3) sets of certified as-built plans, meeting the specifications documented in

the stormwater management design manuals, shall be submitted to the program administrator upon completion of the project. Each as-built plan shall have a certification statement by a professional licensed in Virginia to perform such work.

(6) The applicant shall be responsible for implementing the approved plan, and may be required to conduct a monitoring program, if deemed necessary by the program administrator.

(Ord. 003-12, 3-18-03; Ord. No. O04-32, 6-15-04)

Sec. 21.5-5. Inspection and maintenance.

(a) *Inspections.*

(1) A preconstruction conference between the county, the applicant, and the person(s) performing the work shall be required.

(2) On-site inspections will be conducted by the county and the applicant in accordance with the stormwater management design manuals. Essential elements of such inspection shall include:

a. Inspection immediately following preliminary site preparation, including stripping of vegetation, stockpiling of soil, and construction of temporary stormwater management facilities.

b. Inspections during construction of the permanent stormwater management facilities.

c. Final inspection of the project to ensure that stormwater management facilities have been constructed in accordance with the approved stormwater management design plan and the stormwater management design manuals.

(3) All inspections pursuant to this section shall be documented by a written report or log containing dates and times of inspections and comments concerning verbal communications relating to the project.

(4) If, at any stage of the development, the county determines that the soil or other physical conditions on the site are not as stated or shown on the approved stormwater management plan, or the county determines that the storm drainage system or stormwater management facility is inadequate or not constructed as shown on the approved stormwater management design plan, the county may refuse to approve further work and the county may revoke existing permits or approvals until a revised stormwater management design plan has been submitted and approved.

(5) Final certification of compliance with the construction specifications and integrity of all storm drainage and stormwater management facilities and their appurtenant structures shall be provided on the as-built plan by a professional licensed in Virginia to perform such work.

(b) *Maintenance.*

(1) Responsibility for the operation and maintenance of the stormwater management facilities and storm drainage system, unless assumed by Stafford County, shall remain with the property owner or an owner's association. All maintenance activities shall be in accordance with standard maintenance practices for stormwater management facilities and the stormwater management design manuals.

(2) If the designated maintenance responsibility is with a party other than Stafford County, then a maintenance agreement and plan shall be executed between the responsible party and Stafford County. The maintenance agreement shall be recorded

with the Clerk of the Circuit Court of Stafford County prior to or in conjunction with recordation of a plat or approval of the site plan.

(3) To ensure proper performance of the stormwater facility, the property owner or owner's association is responsible for inspecting and performing all necessary maintenance and repairs to the stormwater management facility in accordance with the approved maintenance plan and the stormwater management design manuals. The responsible party shall keep written records of inspections and maintenance/repairs and make them available to the county upon request.

(4) The county shall notify the property owner or owner's association in writing when a determination has been made that the stormwater management facility is in disrepair or is not functioning as intended. The notice shall specify the measures needed to comply with the plan and shall specify the time within which such measures shall be completed. If the responsible party fails to perform such maintenance and repair, the county shall have the authority to perform the work and recover the costs from the responsible party.

(Ord. 003-12, 3-18-03)

Sec. 21.5-6. Performance guarantee.

(a) No permits shall be issued unless the applicant furnishes a performance guarantee, in accordance with the current county security policy. This is to ensure that action can be taken by the county, at the applicant's expense, should the applicant fail, after proper notice and within the time specified, to initiate or maintain those measures identified in the approved stormwater management design plan. If the county takes such action upon such failure by the applicant, the county shall collect from the applicant the difference should the amount of reasonable cost of such action exceed the amount of the security held.

(b) A certified estimate of costs by the design engineer or land surveyor shall be used to verify costs for the purpose of determining the amount of the performance guarantee required by this section.

(c) The performance guarantee furnished pursuant to this section, or the unexpended or unobligated portion thereof, shall be returned to the applicant within sixty (60) days of the final acceptance of completion of the stormwater management facility by the program administrator. Final acceptance shall be defined as the time at which all clearing and grading on the land development site for roads, lots, and other ancillary activities such as recreational or institutional uses, as defined by the preliminary subdivision, construction, or site plan, on land which drains to the stormwater management facility has been completed and stabilized, and construction certification and as-built plans have been received.

(Ord. 003-12, 3-18-03)

Sec. 21.5-7. Exceptions.

(a) Exceptions to the provisions of this chapter may be granted by the program administrator, upon receipt of request for such exception in writing from the applicant or property owner. The request shall include descriptions, drawings, calculations and other information that is necessary to evaluate the waiver of stormwater management requirements.

(b) An exception may be granted provided that: (i) exceptions to the criteria are the minimum necessary to afford relief, (ii) economic hardship is not sufficient reason to grant an exception, (iii) reasonable and appropriate conditions shall be imposed as necessary upon an exception granted so the intent of the chapter is preserved.

(c) The minimum requirements for stormwater management may be waived in whole or part provided at least one of the following conditions applies:

(1) It can be demonstrated that the proposed development is not likely to impair attainment of the objectives of this chapter.

(2) The program administrator finds that meeting the minimum on-site requirements is not feasible due to the natural or existing physical characteristics of the site.

(3) The location of the land development project in the watershed is such that on-site stormwater management will result in increased flows on the main stream. The applicant or property owner must provide supporting hydrologic analysis in accordance with the stormwater management design manuals.

(4) The proposed land development project will not generate more than a ten-percent increase in the two-year and ten-year predevelopment peak discharge rates and the off-site receiving channel is adequate.

(5) An existing off-site stormwater management facility provides the required controls.

(6) An existing regional stormwater management facility provides the required controls, and the property owner agrees to a pro-rata share contribution in accordance with section 21.5-2.

(7) A regional stormwater management facility has been identified for construction in the Stafford County Land Use Plan. The regional stormwater management facility will provide the required controls for the land development project, the property owner agrees to construct all necessary interim stormwater management controls deemed necessary by the program administrator, and the property owner agrees to a pro-rata share contribution in accordance with section 21.5-2.

(Ord. 003-12, 3-18-03)

Sec. 21.5-8. Fees.

Fees shall be paid to the county in accordance with the Stafford County Fee Schedule to defray the cost of plan review, permit administration, and necessary inspections.

(Ord. 003-12, 3-18-03)

Sec. 21.5-9. Penalties; enforcement.

(a) If the program administrator determines that there is a failure to comply with the approved plan, notice of such failure shall be served upon the applicant or person responsible for implementing the plan by registered or certified mail or by delivery to the land development site. The notice shall specify the measures needed to comply with the plan and shall specify the time within which such measures shall be completed.

(b) Upon failure to comply within the time specified, the permit or approval may be revoked and the applicant or person responsible for implementing the plan shall be deemed to be in violation of this chapter.

(c) Any person who violates any provision of this chapter shall be guilty of a misdemeanor and shall be subject to a fine or imprisonment for each violation, or both, as provided for in § 10.1-603.14, Code of Virginia (1950), as amended.

(d) The program administrator may apply to the circuit court to enjoin a violation or a threatened violation of this chapter as provided for in § 10.1-603.14, Code of Virginia (1950), as

amended, without the necessity of showing that an adequate remedy of law does not exist.

(e) Without limiting the remedies which may be obtained in this section, the program administrator may bring a civil action against any person or violation of this chapter, or any condition of the permit or approval. The action may seek to impose a civil penalty of not more than two thousand dollars ($2,000.00) for each violation as provided for in § 10.1-603.14 of the Code of Virginia 1950, as amended.

(f) With the consent of the person who has violated or failed, neglected, or refused to obey this chapter or any condition of the permit or approval, the program administrator may issue an order against or to such person for the payment of civil charges for violations in specific sums, not to exceed the limit specified in subsection (e) of this section as provided for in § 10.1-603.14, Code of Virginia 1950, as amended. Such civil charges shall be instead of any appropriate civil penalty, which could be imposedunder subsection (e) of this section.

(Ord. 003-12, 3-18-03)

Sec. 21.5-10. Effective date.

This chapter shall be effective for all new development applications submitted after the effective date of this chapter.

(Ord. 003-12, 3-18-03)

Secs. 21.5-11--21.5-15. Reserved.

ARTICLE II. STORMWATER POLLUTION AND ILLICIT DISCHARGE

Sec. 21.5-16. Title.

This article shall be known as the Stafford County Stormwater Pollution and Illicit Discharge Ordinance.

(Ord. No. O05-61, 12-13-05)

Sec. 21.5-17. Findings.

(a) Stafford County is subject to the requirements of the Federal Clean Water Act's National Pollution Discharge Elimination System (NPDES) phase II permit program for stormwater discharges from a municipal separate storm sewer system (MS4).

(b) The NPDES regulations for stormwater discharges require certain municipalities including Stafford County to effectively prohibit through ordinance nonstormwater discharges into the storm drain system and to develop a plan to detect and address nonstormwater discharges, including illegal dumping, to the system.

(Ord. No. O05-61, 12-13-05)

Sec. 21.5-18. Definitions.

Director : The county administrator or his designee or his/her designee.

Discharge : Dispose, deposit, pour, inject, dump, leak or place by any means, or that which is disposed, deposited, spilled, poured, injected, dumped, leaked, or placed by any means.

Illicit discharge : Any discharge to the stormwater system that is not composed entirely of stormwater, except discharges pursuant to a VPDES permit or discharges resulting from fire fighting activities. This definition shall not include the discharges listed in subsection 21.5-19(b) unless such discharges are identified by the county as sources of pollutants to waters of the United States.

Industrial wastes : Liquid or other wastes resulting from any process of industry, manufacture, trade, or business, or from the development of any natural resources.

NPDES : Means National Pollution Discharge Elimination System (also known as municipal separate storm sewer system or MS4).

Other wastes : Decayed wood, sawdust, shavings, bark, leaves, lawn clippings, lime, garbage, refuse, ashes, offal, oil, tar, paint, solvents, petroleum products, antifreeze, chemicals and all other substances, except industrial wastes and sewage, which may cause pollution.

Person : Any individual, firm, corporation, partnership, association, organization, or other entity, including governmental entities, or any combination thereof.

Pollution : Such alteration of the physical, chemical or biological properties of any state waters as will or is likely to create a nuisance or render such waters:

(a) Harmful or detrimental or injurious to the public health, safety or welfare, or to the health of animals, fish or aquatic life;

(b) Unsuitable with reasonable treatment for use as present or possible future sources

of public water supply; or

(c) Unsuitable for recreational, commercial, industrial, agricultural, or other reasonable uses, provided that:

(i) An alteration of the physical, chemical, or biological property of state waters, or a discharge or deposit of sewage, industrial wastes or other wastes to state waters by any owner which by itself is not sufficient to cause pollution, but which, in combination with such alteration of or discharge or deposit to state waters by other owners, is sufficient to cause pollution;

(ii) The discharge of untreated sewage by any owner into state waters; and

(iii) Contributing to the contravention of standards of water quality duly established by the state water control board.

Sanitary sewer : A system of underground conduits that collect and deliver sanitary wastewater to a wastewater treatment plant.

Sanitary wastewater : Wastewater from toilets, sinks, and other plumbing fixtures.

Sewage : The water-carried human wastes from residences buildings, industrial establishments, or other places, together with such industrial wastes, stormwater or other water as may be present.

Stormwater system : All natural watercourses, man-made facilities, and structures used for collecting and conveying stormwater to, through, and from drainage areas to the points of final outlet including, but not limited to, the following: streets, roads, curbs and gutters, inlets, conduits, canals, creeks, channels, catch basins, ditches, drains, sewers, streams, gulches, gullies, flumes, culverts, retention or detention basins, dams, pumping stations, and wetlands.

VPDES : Virginia Pollution Discharge Elimination System (also known as the Virginia Stormwater Management Permit), in accordance with the provisions of the Clean Water Act.

Waters of the United States : All waters, whether on the surface or underground, the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce, including, but not limited to, intrastate lakes, rivers, streams (including intermittent and ephemeral streams), mudflats, sand flats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes and natural ponds, except that waste treatment systems, treatment ponds and lagoons designed to meet the requirements of the Federal Clean Water Act shallnot be waters of the United States.

(Ord. No. O05-61, 12-13-05)

Sec. 21.5-19. Prohibitions.

(a) It shall be unlawful to:

(1) Cause or allow illicit discharges into the county's stormwater system;

(2) Discharge materials other than stormwater into the stormwater system by spills, dumping, or disposal without a VPDES permit;

(3) Cause or allow industrial discharges into the stormwater system without a VPDES permit; or

(4) Violate any condition or provision of this article or any permit granted for stormwater discharges.

(b) Subject to the provisions of subsection (c) below, the following activities shall not be unlawful discharges:

(1) Discharges pursuant to a VPDES or NPDES permit;

(2) Discharges resulting from firefighting activities;

(3) Water line flushing;

(4) Landscape irrigation;

(5) Diverted stream flows or rising groundwater;

(6) Infiltration of uncontaminated groundwater;

(7) Pumping of uncontaminated groundwater;

(8) Discharges from potable water sources, foundation drains, irrigation water, springs, water from crawl spaces or footing drains;

(9) Air conditioning condensation;

(10) Lawn watering;

(11) Residential car washing;

(12) Public street washing;

(13) Swimming pool discharges.

(c) In the event that any of the activities listed in subsection (b) above are found to cause sewage, industrial wastes or other wastes to be discharged into the system, the director shall so notify the person performing such activities, and shall order that such activities be stopped or conducted in a manner to avoid the discharge or sewage, industrial wastes or other wastes into a storm sewer system. The failure to comply with any such order shall constitute a violation of the provisions of this article.

(Ord. No. O05-61, 12-13-05)

Sec. 21.5-20. Inspections and monitoring.

The director shall have authority to make such lawful inspections and conduct such monitoring of stormwater outfalls or other components of the storm sewer system as may be necessary or appropriate in the administration and enforcement of this article. The director shall also have authority to initiate enforcement actions in accordance under section 21.5-21.

(Ord. No. O05-61, 12-13-05)

Sec. 21.5-21. Notice to correct violation.

If any activity listed in section 21.5-19 is found by the director to be a source of pollutants to waters of the United States, the director shall serve a written notice on the party responsible for the activity which orders that the activity be ceased or conducted in a manner that will avoid the discharge of pollutants to the stormwater system. The notice shall state the date by which the activity shall cease or be conducted without pollution. Failure to comply with any such order within the time stated inthe notice shall constitute a violation.

For any violations of this article, the owner must comply with the director's orders within the time specified in the notice. Failure to comply with such order shall constitute a violation of this article. In addition to any penalty imposed for each violation, a judge hearing the case may direct the person responsible to remediate or correct violation, and each day's default in such remediation or correction shall constitute a violation of and a separate offense under this section.

(Ord. No. O05-61, 12-13-05)

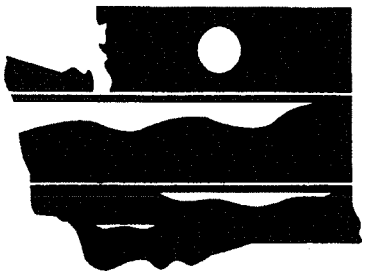
Sec. 21.5-22. Penalties for violations.

(a) Any person who knowingly violates any provision of this article shall be guilty of a class 1 misdemeanor. Each day that such violation is committed, and each day that such violation is permitted to remain uncorrected shall constitute a separate offense.

(b) Any person who otherwise violates any provision of this article shall be subject to civil penalty between two hundred and fifty dollars ($250) and one thousand dollars ($1,000) for each day that the violation continues. The court assessing such civil penalty may order the penalty to be paid into the treasury of the county and designated for the purpose of minimizing, preventing, managing or mitigating pollution of the waters of the United States.

(c) Any person who violates any provision of this article shall be responsible for testing, containing, cleaning up, abating, removing and disposing of any substance unlawfully discharged into the stormwater system or into waters of the county, or, if the director determines that correction of the violation can best be accomplished by the county, shall be liable to the county for all costs of testing, containment, cleanup, abatement, removal and disposal of any substance unlawfully discharged into the storm sewer system or into waters of the United States.

(Ord. No. O05-61, 12-13-05)



Stormwater Management in Washington State

Volume I
Minimum Technical Requirements

August 1999
(Draft)

Publication No. 99-11
(A revised portion of Publication No. 91-75)

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Prepared by:

Washington State Department of Ecology
Water Quality Program

August 1999
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How to Get Printed Copies of the Stormwater Manual

The manual, which is close to 700 pages, is now divided into five volumes. Three volumes are now available for review, the remaining two volumes will be done by the end of September, 1999.

To order printed copies of the first three available volumes of the stormwater manual, send check or money order for $25.50 (delivery in the state of Washington) or $26.50 (delivery outside the state of Washington) payable to "Department of Printing" at the following address:

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P.O. Box 798
Olympia, WA 98507-0798

Make sure you include your name, address (no P.O. Boxes), phone number, and the name of the publication (Stormwater Manual, Volumes I, II an IV). Allow about two weeks for delivery.

How to Find the Stormwater Manual on the Internet

The first three volumes of the Stormwater Manual are also available on Ecology's Home Page. The internet address for Water Quality Program publications is:

http://www.wa.gov/ecology/biblio/wq.html

Contact Information

If you have any questions on the proposed schedule or public review process, please e-mail Tony Barrett at tbar461@ecy.wa.gov or call him at (360) 407-6467. If you have technical questions or comments, you can contact the technical leads directly. The technical leads for each volume are:

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Objective of the Manual

The objective of this manual is to provide guidance on the measures necessary to control the quantity and quality of stormwater produced by new development and redevelopment, such that they comply with water quality standards and protect beneficial uses of the receiving waters.

Development and Geographic Scope of This Manual

The Ecology stormwater manual was originally developed for the Puget Sound Basin in response to a directive of the Puget Sound Water Quality Management Plan. The technical manual was intended to provide technical guidance and to define minimum requirements for implementing local stormwater management programs.

The original 1992 manual was prepared by Ecology staff, with significant contributions from advisory committee members from local government public works and planning officials, representatives from other state agencies, and other affected parties including industry and tribes. This update was prepared in much the same manner. There were five separate advisory committees, with over 70 members representing a broad range of expertise and interests. Their insights and practical knowledge gained from years of experience in the field have been particularly valuable.

What is Driving the Revisions to the Manual?

There are several drivers behind the revisions to the manual. First, the manual was written in 1990-1991, drawing from research done in the 1980's and from existing manuals prepared by King County and by communities in other states. Even as the manual was published, deficiencies and shortcomings were evident. In addition, lessons learned from applying the manual and information from current research all point out additional deficiencies and errors in the manual. Second, funding has been provided under the Puget Sound Plan for the past two biennia to update the manual. Third, actual and proposed listing under the Endangered Species Act (ESA) call for significant changes in the way we manage urban runoff. Updating the technical manual to include new information and standards that are more protective will likely be an essential element in managing urban runoff under the ESA.

With this update of the manual, Ecology is seeking to broaden the applicability of the manual to the entire state. In that effort,

we have found that the concepts developed originally for the Puget Sound Basin are applicable throughout western Washington. In addition, most of the minimum requirements and the BMPs are equally applicable in eastern Washington. It will probably be necessary to make adjustments in the minimum requirements for flow control and treatment, in some BMP design criteria, and in specifying which BMPs are applicable in some eastern Washington environments.

Organization of This Manual

The manual is organized into five volumes. The volumes will be published as separate documents to make it easier for the user to find needed information and to make it easier to publish future revisions. However, most users will find it necessary to have a complete set of all five volumes. We have tried to strike a balance between bouncing the user back and forth between volumes and unnecessary replication of material.

Unfinished Business (The Text Boxes – a Call for Action)

Although we are inviting comments and recommendations on the manual as a whole, there are some specific issues or questions where we want public comment, information or assistance. We have elected to use "Text Boxes" to highlight these issues. To comment, contact technical leads listed earlier.

The Process and Schedule for Completing the Revisions

Ecology will conduct public workshops, from early October to about mid-November, at both eastside and westside locations. We anticipate separate workshops on Volume I (Minimum Requirements and overall policy issues), Volume II (Construction Stormwater Pollution Prevention), and Volumes III – IV (Hydrologic Analysis, Source Control BMPs, and Runoff Treatment BMPs).

The comment period on the Public Review Draft will end December 15, 1999 and we anticipate publishing a Final Draft by mid-February 2000. We will conduct public meetings on the Final Draft during March and expect to publish a revised manual by the end of April 2000.

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CHAPTER 1 - Introduction

1.1 Effects of Urbanization

1.1.1 Background Conditions

Prior to the Euro-American settlement, western Washington primarily was forested in alder, maple, fir, hemlock and cedar. The area's bountiful rainfall supported the forest and the many creeks, springs, ponds, lakes and wetlands. The forest system provided protection by intercepting rainfall in the canopy, reducing the possibility of erosion and the deposition of sediment in waterways. The trees and other vegetative cover evapotranspirated at least 40% of the rainfall. The forest duff layer absorbed large amounts of runoff releasing it slowly to the streams through shallow ground water flow. Forest ecosystems in eastern Washington provided similar hydrologic functions though not always to the same extent. The shrub-steppe and grasslands of eastern Washington also had their own natural hydrologic rhythms.

1.1.2 Hydrologic Changes

As settlement occurs and the population grows, trees are logged and land is cleared for the addition of impervious surfaces such as rooftops, roads, parking lots, and sidewalks. Maintained landscapes that have much higher runoff characteristics typically replace the natural vegetation. The natural soil structure is also lost due to grading and compaction during construction. Roads are cut through slopes and low spots are filled. Drainage patterns are irrevocably altered. All of this results in drastic changes in the natural hydrology, including:

- Increased peak surface runoff volumetric flow rates;
- Increased volume of surface runoff;
- Decreased time for runoff to reach a natural receiving water;
- Reduced ground water recharge;
- Increased frequency and duration of high stream flows and reduced stream flows during dry weather;
- Greater stream velocities; and
- Increased frequency and duration of wetlands inundation and reduced water elevations during the dry season.

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As a consequence of these hydrology changes, stream channels are eroded by high flows and can lose summertime base flows. Increased flooding occurs. Habitat is degraded and receiving water species composition is altered as explained below.

Figure 1.1 (Booth and Jackson, 1997)[1] illustrates the relationship between the level of development in a basin, the changes in the recurrence of high stream flows, and the resultant streambank instability and channel erosion.

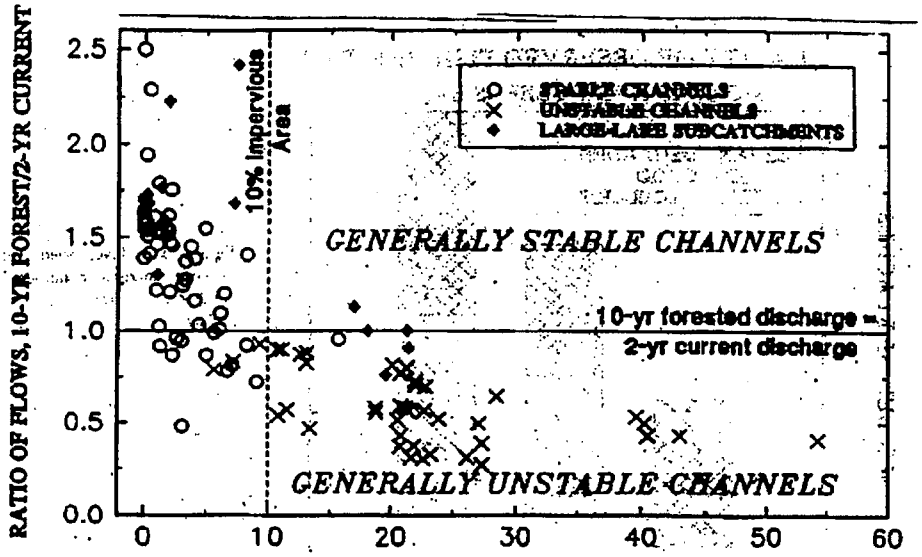

Figure 1.1: Channel Stability and Land Use:
Hylebos, East Lake Sammamish, Issaquah Basins

1.1.3 Water Quality Changes

Urbanization also causes an increase in the types and quantities of pollutants in surface and ground waters. Runoff from urban areas has been shown to contain many different types of pollutants, depending on the nature of the activities in those areas. Table 1.1 from an Analysis of Oregon Urban Runoff Water Quality Monitoring Data Collected From 1990 to 1996 (1997)[2] shows mean concentrations for a limited number of pollutants from different land uses.

The runoff from roads and highways is contaminated with pollutants from our vehicles. Oil and grease, polynuclear aromatic hydrocarbons (PAH's), lead, zinc, copper, cadmium, as well as sediments (soil particles) and road salts are typical pollutants in road runoff. Runoff from industrial areas typically contains even more types of heavy metals, sediments, and a broad range of man-made organic pollutants, including

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phthalates, PAH's, and other petroleum hydrocarbons. Residential areas contribute the same road-based pollutants as well as herbicides, pesticides, nutrients (from

fertilizers), bacteria and viruses (from animal waste) to runoff. All of these contaminants can seriously impair beneficial uses of receiving waters.

Regardless of the eventual land use conversion, the sediment load produced by a construction site can turn the receiving waters turbid and be deposited over the natural sediments of the receiving water.

The pollutants added by urbanization can be dissolved in the water column or can be attached to particulates that settle in streambeds, lakes, wetlands, or marine estuaries. A number of urban bays in Puget Sound have contaminated sediments due to pollutants associated with particulates in stormwater runoff.

Urbanization also tends to cause an increase in water temperature. Heated stormwater from impervious surfaces and exposed treatment and detention ponds discharges to streams with less riparian vegetation for shade.

Table 1.1: Land Uses Mean Concentrations for Selected Pollutants[2]

Land Use	TSS mg/l	Total Cu mg/l	Total Zn mg/l	Dissolved Cu mg/l	Total P mg/l
In-pipe Indus.	194	0.053	0.629	0.009	0.633
Instream Indus.	102	0.024	0.274	0.007	0.509
Transportation	169	0.035	0.236	0.008	0.376
Commercial	92	0.032	0.168	0.009	0.391
Residential	64	0.014	0.108	0.006	0.365
Open	58	0.004	0.025	0.004	0.166

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1.1.4 Biological Changes

The hydrologic and water quality changes result in changes to the biological systems that were supported by the natural hydrologic system. In particular, aquatic life is greatly affected by urbanization. Habitats are drastically altered when a stream changes its physical configuration and substrate due to increased flows. Natural riffles, pools, gravel bars and other areas are altered or destroyed. These and other alterations produce a habitat structure that is very different from the one in which the resident aquatic life evolved. For example, spawning areas, particularly those of salmonids, are lost. Fine sediments imbed stream gravels and suffocate salmon redds. The complex food web is destroyed and is replaced by a biological system that can tolerate the changes. However, that biological community is typically not as complex, is less desirable, and is unstable due to the ongoing rapid changes in the new hydrologic regime.

Significant and detectable changes in the biological community of Puget Sound lowland streams begins early in the urbanization process. May et al (1997)[3] reported changes in the 5-10% total impervious area range of a watershed. Figure 1.2 from May et al (1997) shows the relationship observed between the Benthic Index of Biotic Integrity (B-IBI) developed by Kleindl (1995)[4] and Karr (1991)[5], and the extent of watershed urbanization as estimated by the percentage of total impervious area (% TIA). Also shown in the figure is the correlation between the abundance ratio of juvenile coho salmon to cutthroat trout (Lucchetti and Fuerstenberg 1993)[6] and the extent of urbanization.

The biological communities in wetlands are also severely impacted and altered by the hydrological changes. Relatively small changes in the natural water elevation fluctuations can cause dramatic shifts in vegetative and animal species composition.

If the hydrological changes don't knock out a species, the toxic pollutants in the water column such as pesticides, soaps, and metals can have immediate and long-term lethal impacts. Toxic pollutants in sediments can yield similar impacts with the lesions and cancers in bottom fish of urban bays serving as a prime example.

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A rise in water temperature can have direct lethal effects. It reduces the maximum available dissolved oxygen and may cause algae blooms that further reduce the amount of dissolved oxygen in the water.

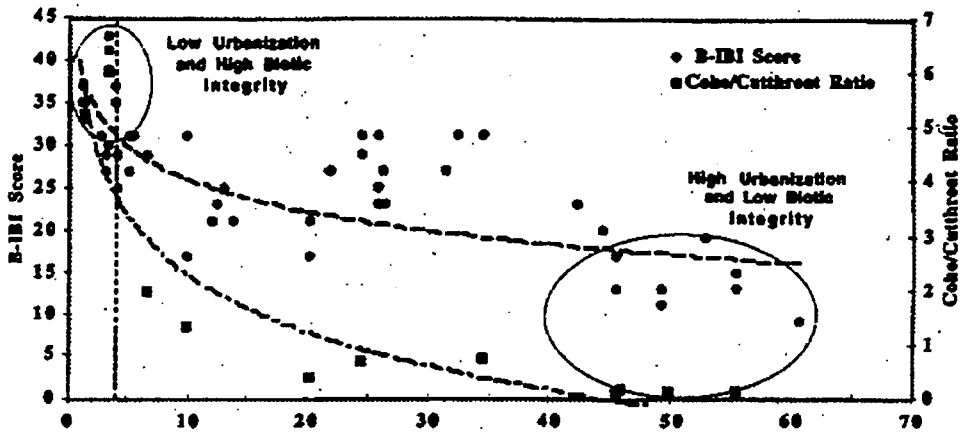

Figure 1.2: Relationship Between Basin Development and Biotic Integrity in Puget Sound Lowland Streams

1.1.5 The Role of Land Use and Our Lifestyles

The engineered stormwater conveyance, treatment, and detention systems advocated by this and other stormwater manuals can reduce the impacts of development to water quality and hydrology. But they cannot replicate the natural hydrologic functions of the natural watershed that existed before development, nor can they remove sufficient pollutants to replicate the water quality of pre-development conditions. Ecology understands that despite the application of appropriate Best Management Practices identified in this manual, we will continue to degrade our urban and suburban receiving waters and continue to lose some beneficial uses due to development. This is because land development, as we practice it today, is incompatible with the achievement of sustainable ecosystems. Unless we adopt development methods that cause significantly less disruption of the hydrologic cycle, we will inevitably degrade and lose more beneficial uses of our waters as we develop more areas.

In recent years, researchers (May et al, 1997)[3] and regulators (e.g., Issaquah Creek Basin and Nonpoint Action Plan, 1996)[7] have speculated on the amount of natural land cover and soils that would have to be maintained in a watershed in order to retain sufficient hydrologic conditions to prevent stream channel degradation and maintain base flows. There is some agreement that preserving a high percentage (50%? 65%?) of the land cover

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and soils in an undisturbed state is necessary to preserve hydrology.

It is not clear what other combinations of measures are also necessary to preserve beneficial uses. Clearly, we must improve our stormwater detention, treatment, and source control technologies. This manual is the Department of Ecology's latest effort to apply updated knowledge in these areas. We must also improve the operation and maintenance of our engineered systems so that they function as well as possible. Changing public attitudes toward chemicals use, preferred housing, and transportation modes are also necessary.

A dramatic reduction is necessary in the amount of impervious surfaces and artificially landscaped areas we create to accommodate our preferred housing, play, and work environments, and most significantly, our transportation choices. It is estimated that 65% of the impervious surfaces are created to provide "car habitat." Therefore to make appreciable progress in reducing impervious surfaces in a watershed, we must reduce the density of our road systems, alter our road construction standards, reduce surface parking, and rely more on transportation systems that do not require such extensive impervious surfaces (rail, bicycles, walking).

In short, we must implement drastic changes in where and how we develop land and how we live and move across the land if we are to achieve the goals we set for ourselves in the federal Clean Water Act - to preserve, maintain, and restore the beneficial uses of our nation's waters.

1.2 Objective

The objective of this manual is to control the quantity and quality of stormwater produced by new development and redevelopment such that they comply with water quality standards and protect beneficial uses of the receiving waters. Application of appropriate minimum requirements and BMP's identified in this manual are necessary but sometimes insufficient measures to achieve those goals.

To accomplish the objective, the manual establishes minimum requirements for projects of all sizes and provides guidance concerning how to prepare and implement stormwater site plans. These plans are required for new development and redevelopment on both large and small parcels, and must meet the applicable minimum requirements contained in Chapter 2. These requirements are, in turn, satisfied by the application of

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BMPs from Volumes II through V. Projects that follow this approach will apply reasonable, technology-based BMPs to reduce the adverse impacts of stormwater.

It is important to understand that compliance with this manual does not ensure compliance with water quality standards. State and local permitting authorities with jurisdiction can require more stringent measures that are deemed necessary to meet locally established goals, state water quality standards, or other established natural resource or drainage objectives.

The manual can also be helpful in identifying options for retrofitting BMPs to existing development. Retrofitting stormwater BMPs into existing developed areas will be necessary in many cases to meet federal Clean Water Act and state Water Pollution Control Act (Chapter 90.48 RCW) requirements.

Ecology does not have guidance specifically for retrofit situations (not including redevelopment situations). We encourage application of BMPs from this manual when it is feasible to do so. However, there are typically site constraints that make the application infeasible.

Application to Retrofit Situations

Ecology is inviting comment on how and under what circumstances to modify these BMPs for retrofit situations.

Ecology is also inviting comment on the use of BMPs not included in the manual for retrofit situations.

1.3 Development and Geographic Scope of This Manual

The Ecology stormwater manual was originally developed in response to a directive of the Puget Sound Water Quality Management Plan (Plan).[8] The Puget Sound Water Quality Authority (since replaced by the Puget Sound Water Quality Action Team, PSWQAT) recognized the need for overall guidance for stormwater quality improvement. It incorporated requirements in its Plan to implement a cohesive, integrated stormwater management approach through the development and implementation of programs by local jurisdictions, and the development of rules, permits, and guidance by Ecology.

One of the plan's stormwater elements (SW-3.1) requires Ecology to develop a stormwater technical manual for use by

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local jurisdictions. The Plan specifies aspects that the manual is to include.

With this update of the manual, Ecology is seeking to broaden the applicability of the manual to the entire state. In that effort, we have found that the concepts developed originally for the Puget Sound Basin are applicable throughout western Washington. In addition, most of the concepts, minimum requirements and BMPs are equally applicable in eastern Washington. Adjustment in the minimum requirements for flow control and treatment, adjustment of some BMP design criteria, and specification of the types of BMPs applicable in some eastern Washington environments seem appropriate.

1.4 Development of Best Management Practices to Improve Water Quality

1.4.1 Best Management Practices (BMPs)

The primary method by which the manual controls the adverse impacts of development and redevelopment is through the application of Best Management Practices

Best Management Practices are defined as schedules of activities, prohibitions of practices, maintenance procedures, and structural and/or managerial practices, that when used singly or in combination, prevent or reduce the release of pollutants to waters of Washington State. The types of BMPs are source control, runoff treatment, and flow control.

The primary purpose of using BMPs is to protect beneficial uses of water resources through the reduction of pollutant loads and concentrations, and through reduction of discharges (volumetric flow rates) causing stream channel erosion. If it is found that, after the implementation of BMPs advocated in this manual, beneficial uses are still threatened or impaired, then additional controls may be required.

1.4.2 Source Control BMPs

Stormwater management programs should keep in mind that it is generally more cost effective to **prevent** impacts using source control than using runoff treatment to remove pollutants. However, since source controls cannot prevent all impacts, some combination of measures will always be needed.

Source control BMPs, as the term implies, aim to **prevent** pollution, or other adverse effects of stormwater, from occurring. Ecology further classifies source control BMPs as operational or structural. Examples of source control BMPs include methods as various as using mulches and covers on disturbed soil, putting roofs over outside storage areas, berming areas to prevent stormwater run-on and pollutant runoff.

1.4.3 Treatment BMPs

Runoff treatment BMPs include facilities that remove pollutants by simple gravity settling of particulate pollutants, filtration, biological uptake, and soil adsorption. Runoff treatment BMPs can accomplish significant levels of pollutant load reductions if properly designed and maintained.

1.4.4 Flow Control BMPs

Flow control BMPs typically control the rate, frequency, and flow duration of stormwater surface runoff releases. The need to provide flow control BMPs depends on whether a development site discharges to a stream system or wetland, either directly or indirectly. Stream channel erosion control can be accomplished by BMPs that detain runoff flows and also by those which physically stabilize eroding streambanks. Both types of measures may be necessary in urban watersheds. Only the former is covered in this manual.

Construction of a detention pond is the most common means of meeting flow control requirements. The concept of detention is to collect runoff from a developed area and release it at a slower rate than it enters the collection system. The reduced release rate requires temporary storage of the excess amounts in a pond with release occurring over a few hours or days. The volume of storage needed is dependent on 1) the size of the drainage area; 2) the extent of disturbance of the natural vegetation, topography, and soils and creation of effective impervious surfaces (surfaces that drain to a stormwater collection system); and 3) how rapidly the water is allowed to leave the detention pond, i.e., the target release rates.

The 1992 Ecology manual focused primarily on controlling the peak flow release rates for recurrence intervals of concern – the 2, 10, and 100-year rates. This level of control did not adequately address the increased duration at which those high flows occur because of the increased volume of water from the developed condition as compared to the pre-developed conditions. To protect stream channels from increased erosion, it is necessary to control the durations over which a stream channel experiences geomorphically significant flows such that the energy imparted to the stream channel does not increase

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significantly. Geomorphically significant flows are those that are capable of moving sediments. This target will translate into lower release rates and significantly larger detention ponds than the previous Ecology standard. The size of such a facility can be reduced by changing the extent to which a site is disturbed.

In regard to wetlands, it is necessary to not alter the natural hydroperiod . This means control of flows from a development such that the wetland is within certain elevations at different times of the year. If the amount of surface water runoff draining to a wetland is increased because of land conversion from forested to impervious areas, it may be necessary to bypass some water around the wetland in the wet season. If however, the wetland was fed by local ground water elevations during the dry season, the impervious surface additions and the bypassing practice may cause variations from the dry season elevations. Estimations of what should be done to maintain the natural hydroperiod requires the use of a continuous runoff model. It remains to be seen whether the continuous runoff models we have available are sufficiently accurate to determine successful flow management strategies. And even if the modeling approaches are sufficient, it will be a challenge to simulate pre-development hydrology once you have significant development around and draining to or through a wetland.

1.5 Organization of This Manual

The manual is organized into five volumes

Volume I provides an introduction and overview, establishes thresholds for determining whether to apply small or large parcel minimum requirements, establishes the minimum requirements for large and small parcels, and provides guidance on preparation of a stormwater site plan. A glossary is included at the back of Volume I.

Volume II covers stormwater pollution prevention at construction sites with a primary focus on erosion and sediment control. The volume provides an overview of erosion and sedimentation, summarizes various regulatory requirements, describes how to prepare a Construction Stormwater Pollution Prevention Plan, and details the standards and specifications for BMPs.

Volume III covers hydrologic analysis methods for estimating pre- and post-developed runoff quantities and flow rates, and details of detention facility design, construction, and maintenance. It provides general information in regard to

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infiltration and constructed wetlands with references to Volume V for further details. It provides reference to the use of natural wetlands for stormwater. We have deleted the chapter on conveyance design, and encourage the use of other references.

Volume IV addresses control of runoff pollution produced by urban land uses with a primary emphasis on source control BMPs. Source control BMPs for specific types of activities are described in detail. Extensive appendices provide guidance on BMPs applicable to business types and helpful information concerning other related regulatory requirements and recycling, disposal, and treatment options for waste materials.

Volume V provides the details of treatment BMP design, construction, and maintenance. It is organized by treatment BMP types and details how to select BMPs according to the requirements and the needs of the site.

1.6 Users of This Manual

The users of this manual will be engineers, planners, environmental scientists, plan reviewers, and inspectors from local government and private industry. Local government officials may adopt and apply the requirements of this manual directly or adopt and apply the requirements of an equivalent manual. Local government staff will use this manual, or their own manual, as a reference for reviewing stormwater site plans, checking BMP designs, and for providing technical advice in general. Private industry will use the manual for information on how to develop and implement stormwater site plans, and as a reference for technical specifications of BMPS.

Where permits, such as the Baseline General Permit for Industrial Activities, references BMPs in this manual, affected industries shall use the manual for specifics concerning how to comply with their permits.

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1.7 How to Use This Manual

Development project proponents will want to take the following steps:

- Read Chapter 2 in Volume I to determine the minimum requirements that apply to the project;
- Use Chapter 4 of Volume I to help select permanent BMPs for the project;
- Reference Volumes III through V for BMP design criteria;
- Use Chapter 3 of Volume I to help develop your stormwater site plan; and
- Use Volume II to plan your construction activities, including:

  check your regulatory responsibilities in chapter 2;

  use chapter 3 to develop your Construction Stormwater Pollution Prevention Plan; and

  use chapter 4 to select and specify BMPs.

Businesses which need to comply with their industrial stormwater permit or a local requirement to apply source control BMPs should reference Volume IV.

1.8 Regulatory Status of the Manual

This manual has been developed by Ecology to represent the latest developments in technology-based management of urban stormwater. The manual itself has no independent regulatory authority. Its requirements and BMPs only become required through:

- ordinances and rules established by local governments; and,
- permits and other authorizations issued by local, state, and federal authorities.

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1.9 Relationship of this Manual to Federal, State, and Local Regulatory Requirements

The Ecology manual is one cog in the efforts to manage and reduce the impacts of urban stormwater discharges. This section will explain the relationship of the manual to each of the various programs, permits, and planning efforts described below.

1.9.1 The Puget Sound Water Quality Management Plan

The Puget Sound Water Quality Management Plan (The Plan) requires all cities and counties in the Puget Sound Basin to implement stormwater management programs. Element SW-1.1 states that those programs are to include:

Ordinances for all new development and redevelopment which address control of off-site water quality and quantity effects; the use of source control BMPs; the effective treatment of the water quality design storm; the use of infiltration where appropriate; the protection of stream channels, fish and shellfish habitat, and wetlands; erosion and sediment control at construction project, and local enforcement of these stormwater controls.

Element SW-1.3 states that:

> "In conjunction with the runoff control ordinances for new development and redevelopment, each jurisdiction shall adopt a stormwater management manual containing best management practices. A local government may adopt the manual prepared by Ecology under element SW-3 or prepare its own manual as long as it has substantially equivalent technical standards to those in Ecology's manual. Ecology shall review alternative manuals of local governments for substantial consistency with the Plan and Ecology's manual and guidance."

Element SW-2.4 of the Plan requires that:

> "Each urban stormwater program shall seek to control the quality and quantity of runoff from public facilities and industrial, commercial and residential areas, including streets and roads, consistent with manuals and guidance provided by Ecology..."

Element SW-3.1 requires Ecology to:

> "...maintain a technical manual that implements the requirements in elements SW-1 and SW-2 for use by local jurisdictions in stormwater planning."

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Ecology publishes this manual to fulfill its responsibilities under the Plan. Cities and counties are to adopt ordinances and manuals that are substantially equivalent. Ecology published guidance ("Guidance for Local Governments When Submitting Manuals and Associated Ordinances for Equivalency Review," 3/94, Publication #94-45) that listed the following criteria that Ecology uses to determine equivalency:

1. The Minimum Requirements *(in Chapter 2 of Volume I)* for new development and redevelopment now in the model ordinance *(also published by Ecology)* and the technical manual or their equivalents must be included in the ordinance adopted by the local government. More stringent requirements may be used, and/or the Minimum Requirements may be tailored to local circumstances through the use of basin plans.
2. The thresholds for and definitions of new development, redevelopment, land disturbing activities, and existing conditions should provide equivalent protection of receiving waters or equivalent levels of pollution treatment as those provided by Ecology's criteria.
3. The substantially equivalent manual must include BMP selection and site planning processes that have outcomes that provide equivalent or greater protection to those in Ecology's technical manual.
4. BMPs equivalent to those contained in Volumes II through IV *(corresponding to proposed Volumes II through V of this update)* of Ecology's manual must be included in the local government's version of the manual.
5. An exceptions or variance process similar in content to Section I-2.16 *(Section 2.8 of Volume I in this update)*, Exceptions, must be included.

Manual Equivalency Criteria

As part of this manual update, Ecology will update the equivalency criteria. Ecology invites comments on this section.

The text in Chapter 2 of Volume 1 that is in **bold print** are those concepts that Ecology will require local governments to incorporate or to have equivalent concepts that provide an equal or greater level of protection or treatment.

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1.9.2 Phase I NPDES and State Waste Discharge Stormwater Permits for Municipalities

Ecology has issued joint NPDES and State Waste Discharge permits to regulate the discharges of stormwater from the municipal separate storm sewer systems operated by the following cities and counties:

Clark County, King County, Pierce County,

Snohomish County, Seattle, and Tacoma.

The Washington Department of Transportation is also a Phase I municipal stormwater permittee for its stormwater discharges within the jurisdictions of the above cities and counties.

As a condition (Special Condition S7.b.8.a.) of the permits issued in July, 1995, these entities are required to implement stormwater programs that must include:

> "... ordinances (except WSDOT's program), minimum requirements and best management practices (BMPs) equivalent to those found in Volumes I-IV of Ecology's *Stormwater Management Manual for the Puget Sound Basin* (1992 edition, and as amended by its replacement)...."

These entities have until the end of the permit terms, July, 2000 to comply with this requirement.

Ecology will reissue the Phase I permits in July, 2000. At that time we will add whatever additional municipalities are required by federal law to have an NPDES Phase I municipal stormwater permit. We also intend to continue to retain the above special condition with a reference to the year 2000 edition of the Ecology stormwater manual. Ecology may also add a deadline or deadlines within the term of the permit for compliance with the condition.

1.9.3 Phase II NPDES and State Waste Discharge Stormwater Permits for Municipalities

The U.S. Environmental Protection Agency (EPA) intends to promulgate its Phase II stormwater regulations in October, 1999. Those rules will identify additional municipalities as subject to NPDES municipal stormwater permitting requirements. An initial estimate is that 76 municipalities will be subject to the requirements, and 13 additional municipalities may be subject to the requirements depending upon an analysis that Ecology must perform. Unless the dates change in the final rule, the Phase II permits must be issued by November 2002. The Phase II communities must submit their stormwater programs to comply with permit requirements by January 2003.

The proposed regulations specify minimum requirements for the stormwater programs developed to comply the Phase II permits.

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One of those requirements is the adoption of a program for "post-construction stormwater management in new development and redevelopment." Another is a program for "construction site stormwater runoff control."

To at least partially fulfill these requirements, Ecology intends to require the Phase II municipalities to adopt ordinances, minimum requirements, and BMPs equivalent to those in this updated manual. Essentially, this would be the same permit condition as required of the Phase I municipalities. However, a different schedule for compliance may be necessary for some municipalities. Municipalities within the Puget Sound Basin should have already completed these tasks as required by the Puget Sound Water Quality Management Plan, and as encouraged by the State's strategy for salmon recovery.

1.9.4 Municipalities Not Subject to the Puget Sound Water Quality Management Plan nor NPDES Stormwater Permits for Municipalities

Municipalities not subject to the Puget Sound Plan nor NPDES stormwater permits for municipalities are encouraged to adopt stormwater programs at least equivalent to the Puget Sound Basic Stormwater Program. This would include adoption of ordinances, minimum requirements, and BMPs equivalent to those in Ecology's manual. Any municipalities in areas where urban stormwater has been identified as a limiting factor to salmon recovery are expected to have an equivalent stormwater manual as part of a Comprehensive Stormwater Program as defined by the Puget Sound Water Quality Management Plan.

1.9.5 The NPDES and State Waste Discharge Baseline General Permit for Stormwater Discharges Associated With Industrial Activities (a.k.a., industrial stormwater permit)

Businesses subject to the Baseline General Permit for Stormwater Discharges Associated With Industrial Activities have to prepare and implement a Stormwater Pollution Prevention Plan in accordance with the terms of that permit. The permit issued in November 1995 requires a description and implementation of generic "operational BMPs" (the same category of BMPs referred to as operational source control BMPs in this manual), and "source control BMPs" (the same category of BMPs referred to as "structural source control" BMPs in this manual) from Volume IV of the 1992 Puget Sound Stormwater Manual. Additionally, application of erosion and sediment control BMPs, flow control BMPs and treatment BMPs from the 1992 manual and other published guidance is required if necessary to address an erosion, flow, or pollution problem.

The existing industrial stormwater permit expires in November 2000. Ecology intends to redraft the permit conditions and reissue the permit by that date. As a condition of the reissued permit, Ecology anticipates that it will require industrial stormwater permittees to implement the BMPs in this updated stormwater manual. Ecology will consider retaining the

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statement in the existing permit that allows businesses to implement alternative BMPs as long as they can demonstrate that it will result in equal or better quality of stormwater discharge.

1.9.6 The NPDES and State Waste Discharge General Permit for Stormwater Discharges Associated With Construction Activity (a.k.a., construction stormwater permit)

Projects covered by the construction stormwater permit must select BMPs from Volume II of this manual if the date of the BMP selection process for the project is 120 days or more after the issue date of the manual.

Construction sites that will disturb five acres or more and will have a discharge of stormwater from the project site to a surface water must apply for Ecology's construction stormwater permit. The permit requires application of stabilization and structural practices to reduce the potential for erosion and the discharge of sediments from the site. The stabilization and structural practices cited in the permit are very similar to the 15 minimum requirements for sedimentation and erosion control in Volume I of the 1992 Puget Sound stormwater manual. The permit also requires construction sites within the Puget Sound basin to select BMPs from Volume II of **the most recent version of the Ecology stormwater manual that has been available at least 120 days prior to the BMP selection.** Sites outside the basin are required to select BMPs from the manual, from the Erosion and Sediment Control Handbook, by Goldman et al, or to select other appropriate BMPs. The permit also states that where Ecology has determined the local government requirements for construction sites to be at least as stringent as Ecology's, Ecology will accept compliance with the local requirements.

The construction stormwater permit issued in November 1995 expires in November 2000. Ecology intends to reissue a new permit by the latter date. We anticipate that the reissued permit will require compliance with the construction stormwater pollution prevention elements cited in Large Parcel Minimum Requirement #1, and listed in Chapter 3 of Volume II. We also anticipate that the permit will require selection of BMPs from Volume II of this manual, and that it will allow use of BMPs from local government manuals where they have been determined to be equivalent.

The proposed EPA Phase II stormwater regulations would require construction sites of 1 acre and larger to apply for an NPDES stormwater permit. If that regulation is adopted as proposed, Ecology will likely require all such sites to apply for coverage under its reissued construction stormwater permit.

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1.9.7 The Endangered Species Act: Section 4(d) Rules, Section 7 Consultations, Section 10 Habitat Conservation Plans

With the listing of multiple species of salmon as threatened or endangered across much of Washington State, and the probability of more listings in the future, implementation of the requirements of the Endangered Species Act will have a dramatic effect on urban stormwater management. The manner in which that will occur is still evolving.

Under Section 4(d) of the statute, the federal government issues regulations to provide for the conservation of the species. A 4(d) rule may require new development and redevelopment to comply with specific requirements. It remains to be seen whether the federal government will cite the requirements of this manual in a 4(d) rule.

Under Section 7 of the statute, all federal agencies must insure that any action they authorize, fund, or carry out is not likely to jeopardize the continued existence of any endangered or threatened species (or a species proposed for listing), nor result in the destruction or adverse modification of designated critical habitat. The responsibility for determining whether jeopardy is likely to occur rests with the "action" agency. If an action "may affect" a listed species, the "action" agency must consult with the National Marine Fisheries Service (NMFS), or the U.S. Fish and Wildlife Service (F &WS) depending on the species involved, to determine whether jeopardy is likely to occur. Where NMFS or F&WS believes that jeopardy would result, it must specify reasonable and prudent alternatives to the action that would avoid jeopardy if any such alternatives are available. If the "action" agency rejects these, the action cannot proceed. This manual may play a role in these jeopardy decisions and the alternatives cited to avoid jeopardy.

Under Section 10 of the ESA, through voluntary agreements with the federal government that provide protections to an endangered species, a non-federal applicant may commit an "incidental take" of individuals of that species as long as it is incidental to an otherwise lawful activity (such as developing land or building a road). This new provision of the ESA is designed to resolve conflicts between development pressures and endangered species protection. A "Habitat Conservation Plan" (HCP) is an example of this type of agreement. Under an HCP, the applicant's plan must:

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- ξ outline the impact that will likely result from the taking;
- ξ list steps the applicant will take to minimize and mitigate such impacts, and funding available to implement such steps; and
- ξ include alternative actions the applicant considered and reasons alternative acts are not being used.

The federal government may grant a permit if it finds that the taking will be incidental; the applicant will minimize and mitigate impacts of taking; and the applicant will ensure that adequate funding for the conservation plan will be provided. This manual may play a key role in any proposed Habitat Conservation Plans.

1.9.8 Section 401 Water Quality Certifications

For projects that require a fill or dredge permit under Section 404 of the Clean Water Act, Ecology must certify to the permitting agency, the U.S. Army Corps of Engineers, that the proposed project will not violate water quality standards. In order to make such a determination, Ecology may do a more specific review of the potential impacts of a stormwater discharge from the construction phase of the project and from the completed project. As a result of that review, Ecology may condition its certification to require:

- ξ application of the minimum requirements and BMPs in this manual; or
- ξ application of more stringent requirements.

1.9.9 Hydraulic Project Applications (HPAs)

Under Chapter 75.20 RCW, the Hydraulics Act, the Washington State Department of Fish and Wildlife has the authority to require actions of projects whose stormwater discharges would change the natural flow or bed of state waters. The implementing mechanism is the issuance of an Hydraulics Project Approval (HPA) permit. In exercising this authority, Fish and Wildlife may require:

- ξ compliance with the provisions of this manual; or
- ξ application of more stringent requirements that they determine are necessary to meet their statutory obligations to protect fish and wildlife.

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1.9.10 Aquatic Lands Use Authorizations

The Department of Natural Resources (DNR), as the steward of public aquatic lands, may require a stormwater outfall to have a valid use authorization, and to avoid or mitigate resource impacts. Through its use authorizations, which are issued under authority of Chapter 79.90 through 96, and in accordance with Chapter 332-30 WAC, DNR may require:

- compliance with the provisions of this manual; or
- application of more stringent requirements that they determine are necessary to meet their statutory obligations to protect the quality of the state's aquatic lands.

1.9.11 Requirements Identified through Watershed/Basin Planning or Total Maximum Daily Loads (TMDL's, a.k.a., Water Clean-up Plans)

A number of the requirements of this manual can be superseded by the adoption of ordinances and rules to implement the recommendations of watershed plans or basin plans. Local governments may initiate their own watershed or basin planning processes to identify more stringent or alternative requirements. They may also choose to develop a watershed plan in accordance with the Watershed Management Act (ESHB 2514) that includes the optional elements of water quality and habitat. They may also choose to develop a basin plan in accordance with Chapter 400-12 WAC. As long as the actions or requirements identified in those plans and implemented through local or state ordinances or rules comply with the intent of applicable state and federal statutes (e.g., The federal Clean Water Act and the Endangered Species Act), they can supersede the requirements in this manual. The decisions concerning whether such locally derived requirements comply with the intent of federal and state statutes rest with the regulatory agencies responsible for implementing those statutes.

The requirements of this manual can also be superseded through the adoption of actions and requirements identified in a Total Maximum Daily Load that is approved by the EPA.

1.9.12 Other Local Government Requirements

Local governments have the option of applying more stringent requirements than those in this manual. They are not required to base those more stringent requirements on a watershed/basin plan or their obligations under a TMDL. Project proponents should always check with the local governmental agency with jurisdiction to determine the stormwater requirements that apply to their project.

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CHAPTER 2 - Minimum Requirements For All New Development and Re-Development

2.1 Introduction

This manual, now expanded to be applicable on a statewide basis, was originally developed to comply the 1991 Puget Sound Water Quality Management Plan. That plan (as amended) requires all counties and cities within the Puget Sound drainage basin to adopt stormwater programs which include minimum requirements for new development and redevelopment set by the Plan and in guidance developed by Ecology. The programs are to include ordinances that address:

> *"... at a minimum: (1) the control of off-site water quality and quantity effects; (2) the use of best management practices for source control and treatment; (3) the effective treatment, using best management practices, of the storm size and frequency (design storm) as specified in the manual for proposed development; (4) the use of infiltration, with appropriate precautions, as the first consideration in stormwater management; (5) the protection of stream channels, fish, shellfish habitat, other aquatic habitat, and wetlands; (6) erosion and sedimentation control for new construction and redevelopment projects; and (7) local enforcement of these stormwater controls."*

Ecology considers the above description to be generic to proper stormwater management in any region within the State of Washington. There are judgements that must be made concerning appropriate technical standards for each region of the state based on differences in hydrology, soils, and underlying geology. For this edition of the manual, Ecology has identified flow control standards and water quality treatment design storms as the only requirements that justify different standards for eastern and western Washington. Ecology has also identified different Best Management Practices (BMPs) that will aid eastern Washington development sites to achieve the intent of the minimum requirements.

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There are several sets of requirements for proposed new development and redevelopment that are applied depending on the type and size of the proposed development. In general, small sites are required to control erosion and sedimentation from construction activities and to apply simpler approaches to treatment and flow control of stormwater runoff from the developed site. Controlling flows from small sites is important because the cumulative effect of uncontrolled flows from many small sites can be as damaging as those from a single large site.

Large sites must provide erosion and sedimentation control during construction, permanent control of stormwater runoff from the developed site through selection of appropriate BMPs, and other measures to reduce and control the onsite and offsite impacts of the project. Sites being redeveloped must generally meet the same minimum requirements as new development for the portion of the site being redeveloped. In addition, if the redevelopment meets certain cost thresholds, updated stormwater management for the entire site must be provided. There may also be situations in which additional controls are required for sites, regardless of type or size, as a result of basin plans or special water quality concerns.

Development sites are to demonstrate compliance with these requirements through the preparation of Stormwater Site Plans (SSP). The plans are described in detail in Chapter I-3. Two major components of these plans are a Construction Stormwater Pollution Prevention Plan (SWPPP) and a Permanent Stormwater Quality Control (PSQC) Plan. The Construction SWPPP shall identify how the project intends to control pollution generated during the construction phase only, primarily erosion and sediment. The PSQC shall identify how the project intends to provide permanent BMPs for the control of pollution from stormwater runoff after construction has been completed. Small sites must submit these plans for review by the local government only if they add or replace 5,000 square feet or more of impervious surface.

A flow chart demonstrating how to determine which set of requirements applies to a particular project is shown in Figure 2.2.

Throughout this Chapter, guidance to meet the requirements of the Puget Sound Water Quality Management Plan is written in bold and supplemental guidelines that serve as advice and other materials are <u>not</u> in bold.

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2.2 Definitions

A full listing and definition of stormwater-related words and phrases that are used in this manual is given in the glossary. A few of the key definitions are listed here for ease in understanding the requirements that follow.

Land disturbing activity — Any activity that results in a change in the existing soil cover (both vegetative and nonvegetative) and/or the existing soil topography. Land disturbing activities include, but are not limited to demolition, construction, clearing, grading, filling and excavation.

New development — Land disturbing activities, including Class IV -general forest practices that are conversions from timber land to other uses; structural development, including construction or installation of a building or other structure; creation of impervious surfaces; subdivision, short subdivision and binding site plans, as defined and applied in Chapter 58.17 RCW. All other forest practices and commercial agriculture are not considered new development.

Impervious surface — A hard surface area that either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development. A hard surface area which causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development. Common impervious surfaces include, but are not limited to, roof tops, walkways, patios, driveways, parking lots or storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled, macadam or other surfaces which similarly impede the natural infiltration of stormwater. Open, uncovered retention/detention facilities shall not be considered as impervious surfaces.

Pollution-generating impervious surface (PGIS) — Those impervious surfaces considered to be a significant source of pollutants in stormwater runoff. Such surfaces include those which are subject to: vehicular use; industrial activities; or storage of erodible or leachable materials, wastes, or chemicals, and which receive direct rainfall or the run-on or blow-in of rainfall. Erodible or leachable materials, wastes, or chemicals are those substances which, when exposed to rainfall, measurably alter the physical or chemical characteristics of the rainfall runoff. Examples include erodible soils, uncovered process wastes, manure, fertilizers, oily substances, ashes, kiln dust, and garbage dumpster leakage. Metal roofs are also considered to be PGIS unless they are treated to prevent leaching.

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	A surface, whether paved or not, shall be considered subject to vehicular use if it is regularly used by motor vehicles. The following are considered regularly-used surfaces: roads, unvegetated road shoulders, bike lanes within the traveled lane of a roadway, driveways, parking lots, unfenced firelanes, diesel equipment storage yards, and airport runways. The following are not considered regularly-used surfaces: road shoulders primarily used for emergency parking, paved bicycle pathways, bicycle lanes adjacent to unpaved or paved road shoulders primarily used for emergency parking, fenced firelanes, and infrequently used maintenance access roads.
Pollution-generating pervious surfaces (PGPS)	Any non-impervious surface subject to use of pesticides and fertilizers or loss of soil.
Project site	That portion of a property or properties subject to proposed project improvements including those required by this manual.
Redevelopment	On an already developed site, the creation or addition of impervious surfaces; the expansion of a building footprint or addition or replacement of a structure; structural development including an increase in gross floor area and/or exterior construction or remodeling; replacement of impervious surface that is not part of a routine maintenance activity; land disturbing activities associated with structural or impervious redevelopment; and any change in use that has the potential to release new pollutants from the site. New pollutants means a pollutant that was not discharged at that location immediately prior to the change in use, as well as a pollutant that was discharged in less quantities immediately prior to the change in use.
Replaced impervious surface	For structures, the removal and replacement of any exterior surfaces or foundation. For other impervious surfaces, the removal down to bare soil or base course and replacement, excluding impervious surfaces removed for the sole purpose of installing underground utilities.
Site	The legal boundaries of a parcel or parcels of land that is (are) subject to new or redevelopment.
Small Parcel	A site with less than one acre of land disturbing activity, AND

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- ξ is a single family residential site, or a small subdivision project, that adds or replaces less than 10,000 square feet of impervious surface; or
- ξ is another type of development project that adds less than 5,000 square feet of impervious surface.

Source control BMP A BMP that is intended to prevent pollutants from entering stormwater. This manual separates source control BMPs into two types. *Structural Source Control BMPs* are physical, structural, or mechanical devices that are intended to prevent pollutants from entering stormwater. *Operational BMPs* are schedules of activities, prohibition of practices, and other managerial practices to prevent or reduce pollutants from entering stormwater. See Volume IV for details.

Threshold Discharge Area An onsite area draining to a single natural discharge location or multiple natural discharge locations that combine within one-quarter mile downstream (as determined by the shortest flowpath). The examples in Figure 2.1 below illustrate this definition.

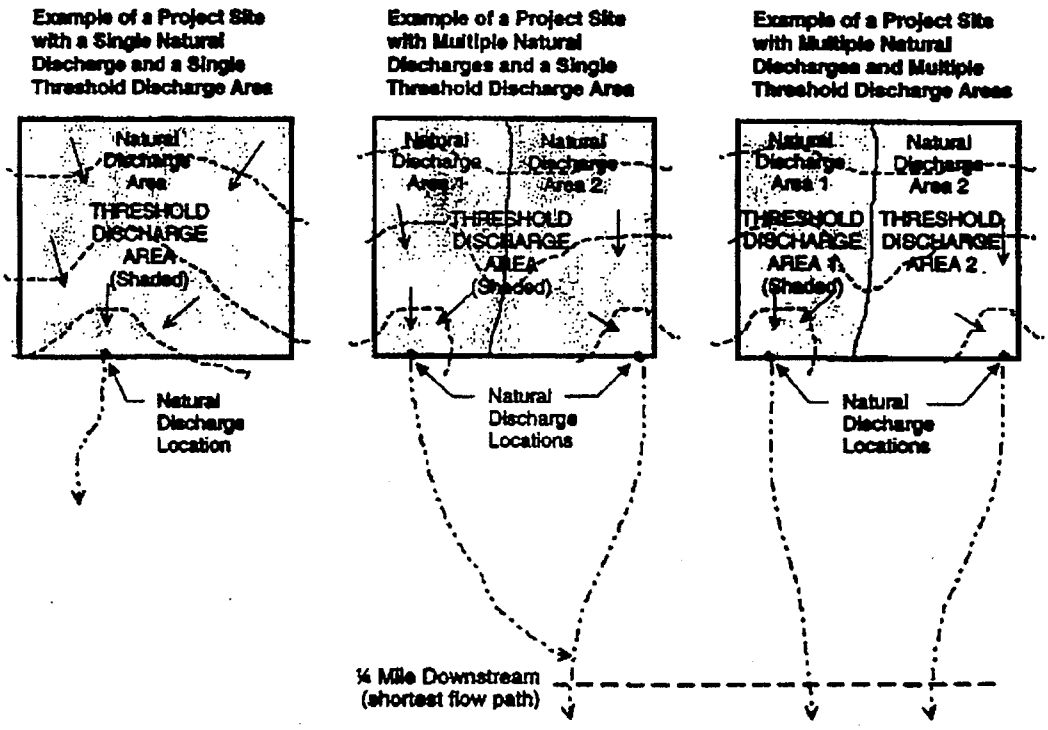

Figure 2.1. Threshold Discharge Areas

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2.3 Exemptions

Commercial agriculture, and forest practices regulated under Title 222 WAC, except for Class IV General forest practices that are conversions from timber land to other uses, are exempt from the provisions of the minimum requirements. All other new development is subject to the minimum requirements.

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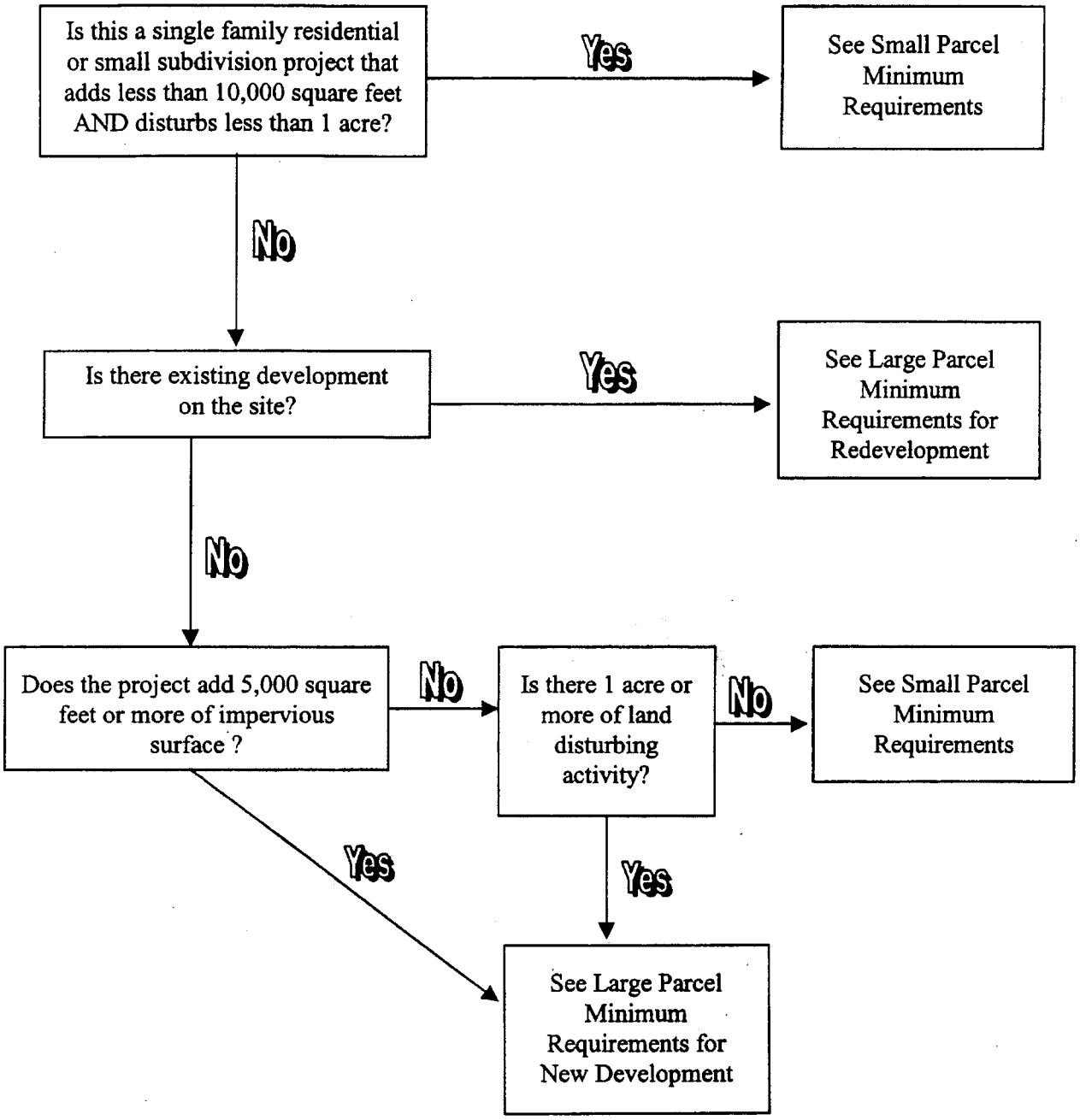

Figure 2.2: Flow Chart for Determining Applicable Requirements

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2.4 Small Parcel Requirements

A project site of a single family residence, or a small subdivision, that meets the small parcel definition is required to comply with the applicable provisions of Large Parcel Minimum Requirement #1 – Construction Stormwater Pollution Prevention (Construction SWPP) and to apply Small Site Requirements for water quality treatment and flow control. Other types of development projects that meet the definition must comply with the applicable provisions of Large Parcel Minimum Requirement #1 – Construction SWPP, Large Parcel Minimum Requirement #3 – Source Control, and apply Small Site Requirements for water quality treatment and flow control.

Small Parcels that add or replace 5,000 square feet or more of impervious surface must prepare a stormwater site plan for local government review.

Small Site Flow Control and Treatment

Ecology intends to propose small site flow control and treatment BMPs for addition to the appropriate Volumes III and V of this manual.

2.5 Large Parcel Thresholds

2.5.1 New Development

All new development, other than small parcels, that includes the creation or addition of 5,000 square feet, or greater, of new impervious surface area, and/or land disturbing activity of one acre or greater, shall comply with Large Parcel Minimum Requirements #1 through #9 and prepare a Stormwater Site Plan.

Supplemental Guidelines:

Basin planning is encouraged and may be used to tailor certain of the Large Parcel Minimum Requirements to a specific basin (see Large Parcel Minimum Requirement #8).

2.5.2 Redevelopment

All redevelopment projects in which the total of *new plus replaced* impervious surfaces is 5,000 square feet or more must comply with Large Parcel Minimum Requirements #1 and #3 for the project site.

Redevelopment projects that add 5,000 square feet or more of *new* impervious surface must comply with all the Large

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Parcel Minimum Requirements for the new impervious surfaces. If the runoff quantity from the new surfaces is not separated from runoff from other surfaces prior to treatment or flow control, the stormwater facilities must be sized for the entire flow. Alternatively, the local government may allow the Large Parcel Minimum Requirements to be met for an equivalent (flow and pollution characteristics) area within the same site.

All redevelopment projects in which the total of new plus replaced impervious surfaces is 5,000 square feet or more, and whose valuation of proposed improvements – including interior improvements - exceeds 50% of the assessed value of the existing site improvements shall comply with all the Large Parcel Minimum Requirements for the entire site.

Local governments may exempt redevelopment projects from compliance with Large Parcel Minimum Requirements #4, #5, and/or #6 if they have adopted a plan that fulfills those requirements in regional facilities that will discharge to the same receiving water, AND if they have an implementation plan and a schedule for construction of those facilities. Redevelopment projects for public roads may be exempted from meeting Large Parcel Minimum Requirements #4, #5, and/or #6 for the entire site (i.e., the exemption does not extend to new surfaces that add impervious area) if there is an adopted Capital Improvement Program for retrofitting existing road surfaces.

Application of the Exemptions

Ecology is interested in advice on the application of the exemptions listed above. Should exemptions be granted for redevelopment projects if the local government has a plan and a schedule for future construction of regional facilities, or should the exemption only apply if the regional facilities have been constructed?

Also, who determines the adequacy of plans and schedules for regional facilities or of Capital Improvement Programs? Currently, there isn't a review entity identified to ensure the quality and legal adequacy of those plans, nor if they are properly implemented and on schedule.

Supplemental Guidelines:

Local governments can establish criteria for allowing redevelopment projects to pay a fee in lieu of constructing water quality or flow control facilities on a redeveloped site. At a minimum, the fee should be the equivalent of an engineering estimate of the cost of meeting all applicable stormwater requirements for the project. For

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purposes of cost estimation, the local government may allow the applicant to presume the site does not have unusual physical constraints that would escalate stormwater costs. The local government must use such funds for the implementation of stormwater control projects that would have similar benefits to the same receiving water as if the project had constructed its required improvements. Expenditure of such funds is subject to other state statutory requirements.

Underground utility projects that replace the ground surface with in-kind material or materials with similar runoff characteristics should not be subject to redevelopment requirements.

Local governments are also encouraged to review all road projects for changes in elevations or drainage flowpath that could cause flooding, upland or stream erosion, or changes to discharges to wetlands.

2.6 Large Parcel Minimum Requirements

2.6.1 Minimum Requirement #1: Construction Stormwater Pollution Prevention (SWPP)

All new development and redevelopment shall comply with Construction SWPP Elements #1 through #12 below, and shall develop and implement a Construction Stormwater Pollution Prevention Plan (SWPPP). Each of the following twelve required elements must be included in the Construction SWPPP unless exemptions are justified in the narrative.

The following Construction Stormwater Pollution Prevention (SWPP) elements shall be met:

Element #1: Mark Clearing Limits

- **Prior to beginning earth disturbing activities, including clearing and grading, all clearing limits, easements, setbacks, sensitive areas and their buffers, trees, and drainage courses should be clearly marked to prevent damage and offsite impacts.**

Element #2: Establish Construction Access

- **Construction vehicle access and exit shall be limited to one route if possible.**
- **Access points shall be stabilized with quarry spall or crushed rock to minimize the tracking of sediment onto public roads.**
- **Wheel wash or tire baths should be located on-site.**

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- **If sediment is transported onto a road surface, the roads shall be cleaned thoroughly at the end of each day. Sediment shall be removed from roads by shoveling or sweeping and be transported to a controlled sediment disposal area. Street washing will be allowed only after sediment is removed in this manner.**
- **Street wash wastewater shall be controlled by pumping back on-site, or otherwise be prevented from discharging into systems tributary to state surface waters without prior and adequate treatment.**

Element #3: Detain Flows

- **Properties and waterways downstream from development sites shall be protected from erosion due to increases in the volume, velocity, and peak flow rate of stormwater runoff from the project site, as required by local plan approval authority.**
- **Downstream analysis is necessary if changes in offsite flows could impair or alter conveyance systems, streambanks, bed sediment or aquatic habitat. See Volume 1, Minimum Requirement #8, for downstream analysis requirements.**
- **Stormwater detention facilities shall be constructed as one of the first steps in grading. Detention facilities shall be functional before other land disturbing activities take place.**

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Flow Control for Sediment Ponds

We would like to receive comment on whether the flow control achieved (as estimated by the analysis below) by the flow control release structure specified for sediment ponds in Chapter 4 is adequate for construction sites which are by their nature, temporary. Also, should flow control release structures be required for sediment traps?

The flow release structure detailed in Volume II, Chapter 4 for sediment ponds and traps will not achieve the same level of flow control as required by Minimum Requirement # 5 of Volume I. The flow control specified by Minimum Requirement # 5 is intended to protect stream channels from accelerated erosion due to increases in the duration and frequency of high stream flows.

Using a continuous runoff simulation model (King County Runoff Time Series) King County staff did a brief evaluation of the level of control achieved by the release structure specified in Chapter 4. The analysis assumed a typical sediment retention facility sized using the 2-year developed flow for a 10-acre urban residential subdivision (4 acres effective impervious area and 6 acres of grass on till soils). The performance of the facility was evaluated assuming the construction site was fully disturbed, but with no improvements (modeled as 10 acres of grass on till soils). The analysis concluded that pre-developed peak flows were at least matched up to a 5-year event. Flow durations were controlled to pre-developed rates for peak flows ranging between 70% of the 2-year and roughly a 15-year event.

Element #4: Install Sediment Controls

- **Prior to leaving a construction site, stormwater runoff shall pass through a sediment pond, sediment trap, or other appropriate sediment removal BMP.**
- **Sediment ponds and traps, vegetated buffer strips, sediment barriers or filters, dikes, and other BMPs intended to trap sediment on-site shall be constructed as one of the first steps in grading. These BMPs shall be functional before other land disturbing activities take place.**
- **Earthen structures such as dams, dikes, and diversions shall be seeded and mulched according to the timing indicated in Element #5.**

Element #5: Stabilize Soils

- **All exposed and unworked soils shall be stabilized by application of effective BMPs, which protect the soil from the erosive forces of raindrop impact and flowing water.**

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- **From October 1 through April 30, no soils shall remain exposed and unworked for more than 2 days. From May 1 to September 30, no soils shall remain exposed and unworked for more than 7 days. This condition applies to all soils on site, whether at final grade or not.**
- **Applicable practices include, but are not limited to, sod and other established vegetative cover, mulching, plastic covering, and the early application of gravel base on areas to be paved.**
- **Soil stabilization measures selected should be appropriate for the time of year, site conditions, estimated duration of use, and potential water quality impacts that stabilization agents may have on downstream waters.**
- **Soil stockpiles must be stabilized and protected with sediment trapping measures.**
- **Work on linear construction sites and activities, including right-of-way and easement clearing, roadway development, pipelines, and trenching for utilities, shall not exceed the capability of the individual contractor for his portion of the project to install the bedding materials, roadbeds, structures, pipelines, and/or utilities, and to re-stabilize the disturbed soils, meeting the timing conditions specified above in Element #5.**

Element #6: Protect Slopes

- **Cut and fill slopes shall be designed and constructed in a manner that will minimize erosion.**
- **Consider soil type and its potential for erosion.**
- **Reduce slope runoff velocities by reducing continuous length of slope with terracing and diversions, reduce slope steepness, and roughen slope surface.**
- **Divert upslope drainage and run-on waters from off-site with interceptors at top of slope. Off-site stormwater should be handled separately from stormwater generated on the site. Diversion of off-site stormwater around the site may be a viable option.**
- **Contain downslope collected flows in pipes, slope drains, or protected channels.**

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- ξ **Provide drainage to remove ground water intersecting the slope surface.**
- ξ **Excavated material shall be placed on the uphill side of trenches, consistent with safety and space considerations.**
- ξ **Flow retention barriers shall be placed at regular intervals within trenches, which are cut down a slope.**
- ξ **Stabilize soils on slopes, as specified in Element #5.**

Element #7: Protect Drain Inlets

- ξ **All storm drain inlets made operable during construction shall be protected so that stormwater runoff shall not enter the conveyance system without first being filtered or treated to remove sediment.**
- ξ **All approach roads shall be kept clean, and all sediment and street wash water shall not be allowed to enter storm drains without prior and adequate treatment.**
- ξ **Suggested BMPs**

BMP 220: Storm Drain Inlet Protection

Element #8: Stabilize Channels and Outlets

- ξ **All temporary on-site conveyance channels shall be designed, constructed and stabilized to prevent erosion from the expected velocity of flow from a 2 year, 24-hour frequency storm for the developed condition.**
- ξ **Stabilization, including armoring material, adequate to prevent erosion of outlets, adjacent streambanks, slopes and downstream reaches shall be provided at the outlets of all conveyance systems.**

Element #9: Control Pollutants

- ξ **All pollutants, including waste materials and demolition debris, that occur on-site during construction shall be handled and disposed of in a manner that does not cause contamination of stormwater.**
- ξ **Cover, containment, and protection from vandalism shall be provided for all chemicals, liquid products, petroleum products, and wastes present on the site.**

- **Maintenance and repair of heavy equipment and vehicles involving oil changes, hydraulic system drain down, solvent and de-greasing cleaning operations, fuel tank drain down and removal, and other activities which may result in discharge or spillage of pollutants to the ground or into stormwater runoff must be conducted under cover and on impervious surfaces. These surfaces shall be cleaned immediately following any discharge or spill incident.**
- **Wheel wash, or tire bath wastewater, shall not be discharged to the storm drain, or the on-site stormwater treatment system.**
- **Application of agricultural chemicals, including fertilizers and pesticides, shall be conducted in a manner and at application rates that will not result in loss of chemical to stormwater runoff. Manufacturers' recommendations shall be followed for application rates and procedures.**
- **Management of pH-modifying sources shall prevent contamination of runoff and stormwater collected on the site. These sources include, but are not limited to, bulk cement, cement kiln dust, fly ash, new concrete washing and curing waters, waste streams generated from concrete grinding and sawing, exposed aggregate processes, and concrete pumping and mixer washout waters.**

Element #10: Control De-Watering

- **All foundation, vault, and trench de-watering water, which has similar characteristics to stormwater runoff at the site, shall be discharged into a controlled conveyance system, prior to discharge to a sediment trap or sediment pond. Channels must be stabilized, as specified in Element #8.**
- **Clean, non-turbid de-watering water, such as well-point ground water, can be discharged to systems tributary to state surface waters, as specified in Element #8, provided the de-watering flow is less than 20 percent of the receiving water flow. These clean waters should not be routed through sediment traps or sediment ponds with stormwater.**
- **Highly turbid or otherwise contaminated dewatering water, such as from construction equipment**

operation, clamshell digging, concrete tremie pour, or work inside a cofferdam, shall be handled separately from stormwater at the site.

- Other disposal options, depending on site constraints, may include: 1) sanitary sewer discharge with local sewer district approval, 2) overland infiltration, 3) transport off-site in vehicle, such as a vacuum flush truck, for legal disposal in a manner that does not pollute state waters.

Element #11: Maintain BMPs

- All temporary and permanent erosion and sediment control BMPs shall be maintained and repaired as needed to assure continued performance of their intended function. All maintenance and repair shall be conducted in accordance with BMPs.
- All temporary erosion and sediment control BMPs shall be removed within 30 days after final site stabilization is achieved or after the temporary BMPs are no longer needed. Trapped sediment shall be removed or stabilized on site. Disturbed soil areas resulting from removal of BMPs or vegetation shall be permanently stabilized.

Element #12: Manage The Project

- Phasing of construction
- Seasonal work
- Employee training
- Pre-construction conference
- Coordination with utilities and other contractors
- Sub-contractor oversight
- Linear site special considerations
- Monitoring / reporting
- Keeping Construction SWPPP up to date

Managing the Project

Ecology intends to add more detail to Element #12. We encourage comments concerning the completeness of the above list of sub-elements, and concerning the appropriate text for each of the sub-elements.

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Objective:	To control erosion and prevent sediment and other pollutants from leaving the site during the construction phase of a project.
Supplemental Guidelines:	If a Construction SWPPP is found to be inadequate (with respect to erosion and sediment control requirements), then the Plan Approval Authority[1] within the Local Government should require that other BMPs be implemented, as appropriate.
2.6.2 Minimum Requirement #2: Preservation of Natural Drainage Systems	**Natural drainage patterns shall be maintained, and discharges from the site shall occur at the natural location, to the maximum extent practicable. The manner by which runoff is discharged from the project site must not cause a significant adverse impact to downgradient receiving waters.**
Objective:	To preserve and utilize natural drainage systems to the fullest extent because of the multiple stormwater benefits these systems provide.
Supplemental Guidelines:	Creating new discharge points can create significant stream channel erosion problems as the receiving water body typically must adjust to the new flows. Diversions can cause greater impacts than would otherwise occur by discharging runoff at the natural location. Where no conveyance system exists at the adjacent downstream property line and the discharge was previously unconcentrated flow or significantly lower concentrated flow, then measures must be taken to prevent downstream impacts. Local governments are encouraged to broaden this requirement to include protection against adverse impacts to downgradient properties and drainage systems. Drainage easements from downstream property owners may be needed and should be obtained prior to approval of engineering plans.
2.6.3 Minimum Requirement #3: Source Control Of Pollution	**All known, available and reasonable source control BMPs shall be applied to all projects. Source control BMPs shall be selected, designed, and maintained according to this manual.** **An adopted and implemented basin plan (Minimum Requirement #8) or a Total Maximum Daily Load (TMDL, also known as a Water Clean-up Plan) may be used to develop more stringent source control requirements that are tailored to a specific basin.**

[1]The Plan Approval Authority is defined as that department within a local government that has been delegated authority to approve erosion and sediment control plans.

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Objective:

The intention of source control BMPs is to prevent stormwater from coming in contact with pollutants. They are a cost effective means of reducing pollutants in stormwater, and, therefore, should be a first consideration in all projects.

Supplemental Guidelines:

A list of many source control BMPs is provided in the BMP selection chapter of this volume. Source Control BMPs include Operational BMPs and Structural Source Control BMPs. See Volume IV for design details of these BMPs. For construction sites, see Volume II, Chapter 4.

2.6.4 Minimum Requirement #4: Runoff Treatment

Thresholds

The following require construction of stormwater treatment BMPs that are sized to treat runoff from the water quality design storm:

- **Single family or multi-family residential or subdivision projects in which the total of new plus replaced pollution-generating impervious surfaces (PGIS) is 10,000 square feet or more in a threshold discharge area of the project, or**
- **Other development projects in which the total of new plus replaced PGIS is 5,000 square feet or more in a threshold discharge area of the project, or**
- **Projects in which the total of new plus modified pollution-generating pervious surfaces (PGPS) is one acre or more in a threshold discharge area, and from which there is a surface discharge in a natural or man-made conveyance system from the site. Modified PGPS means any existing PGPS that is re-graded or re-contoured by the proposed project.**

Standard Requirement

Treatment BMPs shall be sized to treat runoff from the water quality design storm, defined as the 24-hour rainfall amount with a 6-month return frequency. Approved single event hydrograph methods identified in Volume III shall be used to identify runoff volumes and peak flow rates for design purposes. Alternative methods can be used if they identify volumes and flow rates that are at least equivalent.

That portion of any development project in which the above PGIS or PGPS thresholds are not exceeded in a threshold discharge area shall apply Small Site Requirements for water quality treatment.

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Table 2.1. Treatment Requirements for PGIS by Threshold Discharge Area

	SFR or MFR < 10,000 sf PGIS	SFR or MFR, ≥ 10,000 sf PGIS	Other type of development <5,000 sf PGIS	Other type of development, ≥ 5,000 sf
Large Site Treatment BMPs		✔		✔
Small Site Treatment BMPs	✔		✔	

PGIS = pollution-generating impervious surfaces
SFR = single family residence
MFR = multiple family residence
sf = square feet

Performance Criteria

A discussion on performance criteria will be included in Volume V.

Water Quality Design Storm Event

Ecology encourages discussion of options for establishing a water quality design storm event. The options currently under consideration include the following. These are discussed in more detail in Appendix B:

1) An estimation of a 6-month, 24-hour rainfall amount.

2) Selected percentages of the 2-year, 24-hour rainfall amount, as an estimate of the 6-month, 24-hour rainfall amount.

3) Using 24-hour rainfall data, selection of a precipitation amount for which the cumulative sum of rainfall amounts of that size and smaller account for a certain percentage (e.g., 90%) of the total rainfall inches.

4) Using 24-hour rainfall data, establish a rainfall amount for the knee of the curve for a graph of increasing 24-hour rainfall amounts (y-axis) versus cumulative number of rainfall events (x-axis).

5) Use a multiple of the mean annual storm.

6) Use of continuous runoff modeling to establish: a) a runoff flow rate that is exceeded only X % of the time using the appropriate time increment for a BMP sized based on a peak flow rate, and b) a 24-hour runoff amount that is exceeded only X% of the time for BMP's based on runoff volume.

A more detailed description of each of these options and the rainfall amounts they represent for various locations around the state are found in Appendix 2 to this chapter.

Additional Requirements

Direct discharge of untreated stormwater from pollution-generating impervious surfaces to ground water is prohibited, except for that achieved by infiltration or dispersion of runoff as allowed under the Small Site Requirements. All treatment BMPs shall be selected, designed, and maintained according to a local government manual deemed equivalent to this manual.

An adopted and implemented basin plan (Minimum Requirement #8), or a Total Maximum Daily Load (TMDL, also known as a Water Clean-up Plan) may be used to develop more stringent runoff treatment requirements that are tailored to a specific basin.

Treatment BMPs applied consistent with this manual are presumed to meet the requirement of state law to provide all

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known available and reasonable methods of treatment (RCW 90.52.040, RCW 90.48.010). This technology-based treatment requirement does not excuse any discharge from the obligation to apply whatever technology is necessary to comply with state water quality standards, Chapter 173-201A WAC, state ground water quality standards, Chapter 173-200 WAC, and state sediment management standards, Chapter 173-204 WAC. Additional treatment to meet those standards may be required by federal, state, or local governments.

Objective:

The purpose of runoff treatment is to reduce pollutant loads and concentrations in stormwater runoff using physical, biological, and chemical removal mechanisms. When site conditions are appropriate infiltration can potentially be the most effective BMP for runoff treatment.

Supplemental Guidelines:

See Volume V. The water quality design storm is intended to capture and effectively treat about 90-93% of the annual runoff in western and eastern Washington, and about 80-85% of the annual runoff in Central Washington (an area east of the Cascade crest and west of the Columbia River).

Infiltration can provide both treatment of stormwater, through the ability of certain soils to remove pollutants, and volume control of stormwater, by decreasing the amount of water that runs off to surface water. Infiltration can be very effective at treating stormwater runoff but soil conditions must be appropriate to achieve effective treatment while not impacting ground water resources. Methods currently in use such as direct discharge into dry wells do not achieve adequate water quality treatment and are therefore not permitted.

2.6.5 Minimum Requirement #5: Flow Control for Discharges to Streams

Applicability

The requirement below applies only to situations where stormwater runoff is discharged directly or indirectly to a stream, and must be met in addition to meeting the requirements in Minimum Requirement #4, Runoff Treatment BMPs.

Thresholds

The following require construction of detention ponds with discharge orifices that are sized to meet the applicable standard requirement for western or eastern Washington:

- **Any projects in which the total of new plus replaced impervious surfaces is 10,000 square feet or more in a threshold discharge area of the project, or**

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- ξ **Projects in which the total of land disturbing activity is one acre or more in a threshold discharge area, and from which there is a surface discharge in a natural or man-made conveyance system from the site.**

That portion of any development project in which the above thresholds are not exceeded in a threshold discharge area shall apply Small Site Requirements for flow control.

Western Washington Standard Requirement:
Applies to the geographic areas designated as regions 3 and 4 in NOAA Atlas #2 (Miller et al, 1973)[9].

Stormwater discharges to streams shall match developed discharge durations to predeveloped durations for the range of predeveloped discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. In addition, the developed peak discharge rates shall not exceed the pre-developed peak discharge rates for 2- and 10-year return periods. The applicant shall use best available information to determine whether to assume that the pre-developed condition was forested or pasture.

Western Washington Alternative Requirement
An alternative requirement may be established through application of watershed-scale hydrological modeling and supporting field observations. Possible reasons for an alternative flow control requirement include:

1) **Establishment of a stream –specific threshold of significant bedload movement other than the assumed 50% of the 2-year peak flow;**

2) **Zoning and Land Clearing Ordinance restrictions that, in combination with an alternative flow control standard, maintain or reduce the naturally occurring erosive forces on the stream channel; or**

3) **A duration control standard is not necessary for protection, maintenance, or restoration of designated beneficial uses or Clean Water Act compliance.**

Additional Requirement
As the first priority, flow control BMPs shall utilize infiltration to the fullest extent practicable if site conditions

are appropriate and ground water quality is protected. Flow Control BMPs shall be selected, designed, and maintained according to a local government manual deemed equivalent to this manual.

Flow Control Exemption

Ecology is considering an exemption from the flow control requirement for projects that discharge directly to major receiving waters and that are within a certain flowpath distance of those receiving waters. We encourage suggestions for a definition for major receiving waters and of a flowpath distance as well as other conditions for applying such an exemption.

Submerged and Intertidal Bedlands

Ecology has received comments concerning the physical impacts of stormwater discharges to lakes and marine intertidal and subtidal areas. The comments are primarily in regard to the erosive effects of the discharges. Ecology is interested in hearing suggestions regarding the wording of a generic minimum requirement to discharge flows in a manner that does not cause significant impacts to submerged and intertidal bedlands.

Objective: To prevent increases in stream channel erosion rates or stream channel instability by maintaining existing erosion rates. The standard intends to maintain the total amount of time that a receiving stream exceeds an erosion-causing threshold. That threshold is assumed to be 50% of the 2-year peak flow. Maintaining existing erosion rates within streams is vital to protect fish habitat and production.

Supplemental Guidelines: Reduction of flows through infiltration decreases stream channel erosion and helps to maintain base flow throughout the summer months. However, infiltration should only be used where ground water quality is not threatened by such discharges

Interim Guideline: Local governments have a choice to make concerning a flow control standard to use until a flow duration standard is adopted and a continuous rainfall/runoff model is available for use. They can continue to use the peak flow standard of the 1992 Puget Sound manual, or use a peak flow standard that approximates the results that the proposed flow duration standard would achieve. By adjusting the target peak flow standard, restricting use of variables in the SBUH hydrologic analysis, and applying a volume correction factor, you can estimate the orifice sizes and detention volumes that the proposed flow duration standard

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would indicate. The following example is a result of adjusting the SBUH approach to obtain similar results as the output from the King County Runoff Time Series (An application of the Hydrologic Simulation Program – Fortran) with the proposed flow duration standard as the target.

Adjusted target peak flow standard:
Limit the peak rate of runoff from individual development sites to 50 percent of the pre-developed condition 2-year, 24-hour design storm. Limit the peak rate from the 10-year, 24-hour design storm to the pre-developed condition peak rate from the 2-year, 24-hour design storm. Limit the peak rate from the 100-year, 24-hour design storm to the pre-developed condition peak rate from the 10-year, 24 hour design storm.

Restricted variable assumptions:
The flow path length assumed for sheet flow runoff in the pre-developed condition calculations must not be less than 300 feet.

The Manning's effective roughness coefficient for pre-developed forested conditions should be 0.80. For pasture conditions, the coefficient should be 0.15.

In the table of curve numbers in Volume III, Chapter 1 of the 1999 manual, the curve numbers for pre-developed forest and pasture conditions must be selected from the "fair" category.

Volume correction factor:
In addition to the above, the pond volume correction factor identified in Volume III, Chapter I should be used where the pre-developed condition is modeled as pasture.

Eastern Washington Standard Requirement:
Applies to geographic areas designated as regions 1 and 2 in NOAA Atlas 2 (Miller et al, 1973)[10].

Stormwater discharges to streams shall control streambank erosion by limiting the peak rate of runoff from individual development sites to 50 percent of the pre-developed condition 2-year, 24-hour design storm while maintaining the pre-developed condition peak runoff rate for the 10-year, 24-hour and 100-year, 24-hour design storms. As the first priority, flow control BMP's shall utilize infiltration to the fullest extent practicable, if site condtions are appropriate and ground water quality is protected. Flow control BMP's shall be selected, designed, and maintained according to a

local government manual that is deemed equivalent to this manual.

Eastern Washington Alternative Requirement:
An alternative requirement may be established through application of watershed-scale hydrological modeling and supporting field observations. Possible reasons for an alternative flow control requirement include:

1) **Establishment of a stream –specific threshold of significant bedload movement other than the assumed 50% of the 2-year peak flow;**

2) **Zoning and Land Clearing Ordinance restrictions that, in combination with an alternative flow control standard, maintain or reduce the naturally occurring erosive forces on the stream channel; or**

3) **A duration control standard is necessary for protection, maintenance, or restoration of designated beneficial uses or Clean Water Act compliance.**

Objective:

To prevent increases in stream channel erosion rates or stream channel instability by maintaining existing erosion rates. The standard intends to maintain the total amount of time that a receiving stream exceeds an erosion-causing threshold. That threshold is assumed to be 50% of the 2-year peak flow. Maintaining existing erosion rates within streams is vital to protect fish habitat and production. Because of the different precipitation patterns prevalent in eastern Washington, use of a continuous runoff model to support a flow duration standard may not be necessary. Ecology has insufficient information to propose a flow duration standard for most of eastern Washington

Rainfall Regions

Figure 2.3 Rainfall Regions for Washington State from NOAA Atlas #2 to be added

2.6.6 Minimum Requirement #6: Wetlands Protection

The requirements below apply only to situations where stormwater discharges directly or indirectly through a conveyance system into a wetland, and must be met in addition to meeting the requirements in Minimum Standard #4, Runoff Treatment BMPs.

Thresholds

The thresholds identified in Minimum Requirement #4 – Runoff Treatment, and Minimum Requirement #5 – Flow Control for Discharges to Streams shall also be applied for discharges to wetlands.

Standard Requirement

Discharges to wetlands shall maintain the hydrologic conditions, hydrophytic vegetation, and substrate characteristics necessary to support existing and designated uses.

The publication, "Wetlands and Urbanization, Implications for the Future", the final report of the Puget Sound Wetland and Stormwater Management Research Program, 1997, shall be used as guidance for discharges to natural and constructed wetlands.

Additional Requirements

The standard requirement does not excuse any discharge from the obligation to apply whatever technology is necessary to comply with state water quality standards, Chapter 173-201A WAC, or state ground water standards, Chapter 173-200 WAC. Additional treatment requirements to meet those standards may be required by federal, state, or local governments.

An adopted and implemented basin plan (Minimum Requirement #8), or a Total Maximum Daily Load (TMDL, also known as a Water Clean-up Plan) may be used to develop requirements for wetlands that are tailored to a specific basin.

Objective:

To ensure that wetlands receive the same level of protection as any other waters of the state. Wetlands are extremely important natural resources which provide multiple stormwater benefits, including ground water recharge, flood control, and stream channel erosion protection. They are easily impacted by development unless careful planning and management are conducted. Wetlands can be severely degraded by stormwater

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discharges from urban development due to pollutants in the runoff and also due to disruption of natural hydrologic functioning of the wetland system. Changes in water levels and the frequency and duration of inundations are of particular concern.

Supplemental Guidelines:

See Volume V for a summary of the "Wetlands and Stormwater Management Guidelines: Managing Wetland Hydroperiod While Managing Stormwater" (draft, 1999). These management guidelines are considered the best available science to assist in meeting the state water quality standards. The guidelines were developed in part, and include, the findings of the Puget Sound Wetlands and Stormwater Management Research Program.[10]

While it is always necessary to pre-treat stormwater prior to discharge to a wetland, there are limited circumstances where wetlands may be used for additional treatment and detention of stormwater. These situations are considered in the guidelines as well.

2.6.7 Minimum Requirement #7: Off Site Analysis and Mitigation

All development projects shall submit an offsite analysis report that assesses the potential off-site water quality, erosion, and drainage impacts associated with the project and that proposes appropriate mitigation of those impacts. An initial qualitative analysis shall extend downstream for the entire flow path from the project site to the receiving water or up to 1 mile, whichever is less. If a receiving water is within one-quarter mile, the analysis shall extend within the receiving water to one-quarter mile from the project site. The analysis shall extend one-quarter mile beyond any improvements proposed as mitigation. The analysis must extend upstream to a point where any backwater effects created by the project cease. Upon review of the qualitative analysis, the local administrator may require that a quantitative analysis be performed.

The existing or potential impacts to be evaluated and mitigated shall include:

- **Upland erosion impacts**
- **stream channel erosion**
- **loss of stream channel base flow**
- **Violations of surface water quality standards as identified in a Basin Plan or a TMDL (Water Clean-up Plan); or violations of ground water standards in a wellhead protection area.**

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Local governments are encouraged to expand the offsite analysis to include an assessment of the existing and potential impacts due to flooding and conveyance capacity.

Objective: To identify and evaluate offsite water quality, erosion and drainage impacts that may be caused or aggravated by a proposed project, and to determine measures for preventing impacts and for not aggravating existing impacts. Aggravated shall mean increasing the frequency of occurrence and/or severity of a problem.

Supplemental Guidelines:

Guidance for performing an initial qualitative analysis, a subsequent quantitative analysis, and for developing mitigation options is being developed. Ecology intends to include those in the next draft of the manual.

2.6.8 Minimum Requirement #8: Basin/Watershed Planning

Adopted and implemented watershed-based basin plans may be used to require equivalent or more stringent minimum requirements for source control, treatment, and wetlands protection, and alternative requirements for flow control. Basin/Watershed plans shall evaluate and include, as necessary, retrofitting of urban stormwater BMPs for existing development and/or redevelopment in order to achieve watershed-wide pollutant reduction and flow control goals that are consistent with requirements of the federal Clean Water Act. Standards developed from basin plans shall not modify any of the above minimum requirements until the basin plan is formally adopted and implemented by the local governments within the basin, and approved or concurred with by the Department of Ecology.

Objective: To promote watershed-based planning as a means to develop and implement comprehensive water quality protection measures. Primary objectives of basin planning are to reduce pollutant loads and hydrologic impacts to surface and ground waters in order to protect beneficial uses.

Supplemental Guidelines: While Minimum Requirements #3 through #6 establish general standards for individual sites, they do not evaluate the overall pollution impacts and protection opportunities which could exist at the watershed level. In order for a basin plan to serve as a means of modifying the minimum requirements it must be formally adopted by all jurisdictions that have responsibilities

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under the basin plan, and ordinances or regulations called for by the plan must be in effect. This is what is meant by an adopted and implemented basin plan.

Basin planning provides a mechanism by which the on-site standards can be evaluated and refined based on an analysis of an entire watershed. Basin plans are especially well-suited to develop control strategies to address impacts from future development and to correct specific problems whose sources are known or suspected. Basin plans can be effective at addressing both long-term cumulative impacts of pollutant loads and short-term acute impacts of pollutant concentrations, as well as hydrologic impacts to streams, wetlands, and ground water resources.

Examples of how Basin Planning can alter the minimum requirements of this manual is given in Appendix A.

2.6.9 Minimum Requirement #9: Operation and Maintenance

An operation and maintenance schedule that is consistent with the local government standards shall be provided for all proposed stormwater facilities and BMPs, and the party (or parties) responsible for maintenance and operation shall be identified.

Objective:

To ensure that stormwater control facilities are adequately maintained and operated properly.

Supplemental Guidelines:

Inadequate maintenance is likely the leading cause of failure for stormwater control facilities. The description of each BMP in Volumes II, III, and V includes a section on maintenance. The Guidance Manual also includes a section on developing an operation and maintenance program and a model operation and maintenance ordinance.

2.7 Optional Guidance #1: Financial Liability

Performance bonding or other appropriate financial guarantees shall be required for all projects to ensure construction of drainage facilities in compliance with these standards. In addition, a project applicant shall post a two year financial guarantee of the satisfactory performance and maintenance of any drainage facilities that are scheduled to be assumed by the local government for operation and maintenance.

Objective:

To ensure that development projects have adequate financial resources to fully implement stormwater management plan requirements and that liability is not unduly incurred upon local governments.

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Supplemental Guidelines:

The type of financial instrument required is less important than ensuring that there are adequate funds available in the event that non-compliance occurs.

2.8 Exceptions

Exceptions to the Small Parcel Requirements and Large Parcel Minimum Requirements #1 through #9 may be granted prior to permit approval and construction. An exception may be granted following a public hearing, provided that a written finding of fact is prepared, that addresses the following:

- **The exception provides equivalent environmental protection and is in the overriding public interest; and that the objectives of safety, function, environmental protection and facility maintenance, based upon sound engineering, are fully met; AND**
- **There are special physical circumstances or conditions affecting the property such that the strict application of these provisions would deprive the applicant of all reasonable use of the parcel of land in question, and every effort to find creative ways to meet the intent of the Minimum Requirements has been made; AND**
- **That the granting of the exception will not be detrimental to the public health and welfare, nor injurious to other properties in the vicinity and/or downstream, and to the quality of waters of the state; AND**
- **The exception is the least possible exception that could be granted to comply with the intent of the Minimum Requirements.**

Public Hearing Alternatives

The above exception provision includes a requirement to hold a public hearing on the proposed exception. Ecology is interested in suggestions of an alternative to a public hearing which would give local governments more flexibility and less onerous administrative procedures in granting an exception while still protecting the interests of, and alerting interested and potentially impacted parties to the exception under consideration.

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Supplemental Guidelines:

Ecology encourages the Plan Approval Authority to impose additional or more stringent criteria as appropriate for their area. Additionally, criteria which may be inappropriate or too restrictive for an area may be modified through basin planning (Minimum Requirement #8). Modification of any of the minimum requirements which are deemed inappropriate for the site may be done by granting an exception.

The exception procedure is an important element of the plan review and enforcement programs. It is intended to maintain a necessary flexible working relationship between local officials and applicants. Plan Approval Authorities should consider these requests judiciously, keeping in mind both the need of the applicant to maximize cost-effectiveness and the need to protect off-site properties and resources from damage.

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CHAPTER 3 - Preparation of Stormwater Site Plans

3.1 Introduction

The purpose of this chapter is to provide summarized guidelines on how Construction Stormwater Pollution Prevention Plan Plan (Construction SWPPP) and Permanent Stormwater Quality Control (PSQC) Plans, the plans that make up a Stormwater Site Plan (SSP) can be prepared. The thresholds and Minimum Requirements for these plans are described in detail in Chapter 2

The goal of this chapter is to provide a framework for uniformity in plan preparation. Such uniformity will promote predictability throughout the region and help secure prompt governmental review and approval. Properly drafted engineering plans and supporting documents will also facilitate the operation and maintenance of the proposed system long after its review and approval.

Please note that this chapter describes how to prepare a Stormwater Site Plan - the specific BMPs and design methods and standards to be used are contained in Volumes II-V. Construction SWPPPs are covered in detail in Chapter 3 of Volume II. Guidelines for selecting BMPs are given in Chapter 3 of this Volume. Note also that all plans, except small parcel plans, shall be stamped a professional engineer licensed in the State of Washington. All land boundary surveys used, and any legal descriptions prepared, except those for small parcels, must be stamped by a professional land surveyor licensed in the State of Washington.

Chapter 3 of Volume I

The text for this chapter was not completed in time for this preliminary draft of the manual. Ecology will discuss its intent for this chapter in public meetings to discuss this preliminary draft. Public comments and criticisms of this chapter in the existing manual would be helpful.

After receiving public comment, Ecology will develop this chapter with the assistance of an advisory committee for Volume 1. A draft will be included in the second draft of the manual that is scheduled for release early in 2000.

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CHAPTER 4 - BMP Selection Process For Permanent Stormwater Quality Control Plans

Chapter 4 of Volume I

We are considering combining Chapter III and IV of Volume I of the 1992 manual and moving the details of the BMP selection process to the appropriate volume in the current manual.

APPENDIX A - Guidance for Altering the Minimum Requirements Through Basin Planning

Basin Planning Applied to Source Control

(Minimum Requirement #3)

Basin plans can identify potential sources of pollution and develop strategies to eliminate or control these sources to the fullest extent possible. A basin plan can include the following source control strategies:

1. Detection and correction of illicit discharges to storm sewer systems, including the use of dry weather sampling and dye-tracing techniques;

2. Identification of existing businesses, industries, utilities, and other activities which may store materials susceptible to spillage or leakage of pollutants into the storm sewer system;

3. Elimination or control of pollutant sources identified in (2);

4. Identification and control of future businesses, industries, utilities, and other activities which may store materials susceptible to spillage or leakage of pollutants into the storm sewer system; and

5. Training and public education

Basin Planning Applied to Runoff Treatment

(Minimum Requirement #4)

Basin plans can develop more stringent runoff treatment requirements and performance standards to reduce pollutant concentrations or loads based on an evaluation of the beneficial uses to be protected within or downstream of a watershed. Consideration must be given to the antidegradation provisions of the Clean Water Act and implementing state water quality standards. The evaluation should include an analysis of existing and future conditions. Additional levels of control beyond Minimum Requirement #4 may be justified in order to control the impacts of future development. Requirements/performance

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standards can be developed based on an evaluation of pollutant loads and modeling of receiving water conditions.

Runoff treatment requirements/performance standards developed from a basin plan should apply to individual development sites. Regional treatment BMPs can be considered an acceptable substitute for on-site treatment BMPs if they can meet the identified treatment requirements/performance standards. A limitation to the use of regional treatment systems is that the conveyances used to transport the stormwater to the BMP must not include waters of the state that have (or had as of November, 1975) beneficial uses other than drainage.

Basin plans shall evaluate retrofitting opportunities, such as installation of extended detention outlets for existing stormwater detention facilities.

Basin Planning Applied to Flow Control

(Minimum Requirement #5)

Basin planning is well-suited to control stream channel erosion for both existing and future conditions. Flow control standards developed from a basin plan may include a combination of on-site, regional, and stream protection/rehabilitation measures. On-site standards shall be the primary mechanism to protect streams from the impacts of future conditions. Regional flow control BMPs are to used primarily to correct existing stream erosion problems. Stream protection/rehabilitation measures may be applied where stream channel erosion problems currently exist which will not be corrected by on-site or regional BMPs. However, caution is urged in the application of such measures. If the causes of the stream channel erosion problems still exist, repairs to the physical expression of those problems will be short-lived.

Basin Planning Applied to Wetlands and other Sensitive Areas

(Minimum Requirement #6)

Basin planning can be used to develop additional protection standards for wetlands and other sensitive areas, such as landslide hazard areas, wellhead protection areas, and ground water quality management areas. . These standards can include source control, runoff treatment, flow control, and stage levels, and frequency and duration of inundations.

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APPENDIX B - Water Quality Treatment Design Storm Options

Ecology encourages discussion of options for establishing a water quality design storm event. The options currently under consideration include:

1. **An estimation of a 6-month, 24-hour rainfall amount.**

   This is the current water quality design storm in the Stormwater Management Manual for the Puget Sound Basin. It was originally chosen when developing the Puget Sound manual based upon a judgement of when the incremental costs of additional treatment capacity exceed the incremental benefits. In particular, the cost of providing the increased detention volume for a wet pond was not seen as cost-effective when compared with the incremental amount of annual stormwater volume that would be effectively treated. Rainfall data from Sea-Tac was used in the original analysis.

   There are at least two ways to estimate the rainfall amount of a 6-month, 24-hour storm. One way is to analyze the 24-hour rainfall records for each rainfall station. The more extensive your record, the more confidence you may have in your estimate. The rainfall amount which has a probability of being equaled or exceeded twice a year is the 6-month, 24-hour storm. The 6-month, 24-hour rainfall amounts shown for 58 stations in Table B.1 have been estimated by analyzing the daily rain gauge data obtained from CD-ROM Hydrodata, USGS Daily and Peak Values, published by Hydrosphere Data Products, Inc.[11]

   The way in which the 6-month, 24-hour estimates in table 2 are calculated is as follows. A data set containing the annual maxima series for 24-hour durations for rainfall stations throughout the state was used.to determine the 2-year, 24-hour return frequency in the first column of Table B.2. The data set was collected by Dr. Schaefer of the Washington Dept. of Ecology and is more fully described in "Regional Analyses of Precipitation Annual Maxima in Washington State,"[12] Then an algorithm was applied to convert the series to a partial duration series. Dr. Schaefer describes the conversion as follows: "A return period of 1.16 years (annual exceedance probability of 0.862) in the annual maxima data series is equivalent to a 6-month return period in the partial duration data series. The 6-month values were computed using at-site 24-hour station mean

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values, regional coefficients of variation (Cv) and L-skewness (tau3), and a frequency factor (K) of –0.94 which corresponds to a return period of 1.16 years. This K value of –0.94 yields 6-month estimates that are correct within 3% +/- for various Kappa distribution parameter sets for climates from arid to rainforest in Washington State." (The reader is referred to references #13 and #14.) Note that the 2-year storm values in Table B.2 differ slightly from those in Table B.1 because they are a different data set and have undergone additional statistical analysis.

A disadavantage to using a 6-month, 24-hour storm as the design storm is that we do not have isopluvials identifying 6-month, 24-hour storms statewide. We would have to produce such a map, or develop a method to estimate the volume for projects at sites not listed in a reference table of 6-month, 24-hour storms. One method to do that is listed as the second option below.

2. **72% of the 2-year, 24-hour rainfall amount for areas in western Washington and in Ferry, Stevens, Pend Oreille, Spokane, Whitman, Garfield, Walla, Walla, Columbia, and Asotin Counties of eastern Washington. Other areas of eastern Washington shall use 65% of the 2-year, 24-hour rainfall amount.**

Based upon an analysis of the rainfall record of 58 stations across the state, the 6-month, and 2-year, 24-hour rainfall amounts were calculated and compared. Those results are shown in Table B.1. Based on those results, there seemed to be a justification for establishing two different percentages for ease in estimating 6-month, 24-hour rainfall amounts across the state.

The arithmetic average of the ratio of the 6-month to the 2-year totals for 35 stations in western Washington (expressed as a percentage) was 71%. With the exception of a few stations, the percentages vary within a range of 67% to 76%. Using only four stations for the mountainous northeastern area and the far eastern areas of the state , the computed ratios were 71% to 73% with an average of 72%. A ratio of 72% is suggested for both of these areas.

Using 16 stations for an area generally described as eastern Cascades and the Columbia Basin, the ratios varied from 61.6% to 68.4% with an average of 65%.

An advantage of this approach is that updated statewide isopluvial maps for the 2-year, 24-hour design storm are expected

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to be available soon. By interpolation, the 2-year rainfall amount for a project site can be easily identified. Application of the percentage assigned to that area yields the estimate of the 6-month, 24-hour rainfall amount. Citing a particular percentage of the 2-year, 24-hour rainfall amount (or a 6-month, 24-hour event) means that different areas of the state will be effectively sizing treatment facilities for the runoff from storms of vastly different sizes. However, those size differences are based upon actual differences in rainfall among the sites.

Also, as mentioned above in Option 1, the original basis for 6-month, 24-hour rainfall amount was a comparison of costs to benefits based upon how much annual runoff would be effectively treated. (The assumption in these comparisons is that storm sizes crudely track relative runoff quantities). The 6-month, 24-hour storm and smaller storms constituted about 91% of the total rainfall of record at SEA-TAC. Because the % of the 24-hour rainfall volumes that the 6-month, 24-hour storm and smaller 24-hour rainfall amounts represent changes across the state (See Table B.1, column entitled, "6 month, % Rainfall Volume") the cost analysis isn't exactly the same for other areas. However, for the 58 stations computed, the 6-month storm and smaller storms represent from 93% to 82% of the total rainfall volume. Therefore, for most areas of the state, the relative cost to % of runoff effectively treated is lower than was assumed in the original analysis.

3) **Using 24-hour rainfall data, identification of a precipitation amount for which the cumulative sum of rainfall amounts of that size and smaller account for a certain percentage of the total rainfall inches.**

For example, we could choose to size a treatment BMP to effectively treat the runoff from all the 24-hour precipitation amounts that made up 90% of the total rainfall. To do that, you order all the recorded 24-hour precipitation amounts by increasing size, and sum the total precipitation as you move up the list from smaller to larger 24-hour amounts. The last 24-hour total that you have to include to bring your cumulative total to approximately 90% of the total historical rainfall amount is your water quality design storm. The rainfall amount from this storm would be used as input to your runoff calculations to estimate total runoff volume for sizing volume-sensitive BMP's, and as input to your hyetograph/hydrograph analysis to determine the estimated peak flow rates for sizing water quality treatment BMPs. Note that for BMP's designed based on runoff volumes,

we can estimate that 24-hour rainfall amounts of lesser amount will meet the detention time design criteria. However, for treatment BMP's whose design is based on volumetric runoff rates or velocity, i.e., cubic feet per second or feet per second, we do not know how frequently, nor how much of the actual runoff occurs at flow rates below the design flow rate. This is because the design flow rate is based upon an idealized hyetograph.

The relative sizes of water quality design storms defiined in this manner are shown in Table B.1 for 90% and 95% of the total rainfall inches for 58 rainfall stations. Note that a different set of rainfall data was used in this table than in Table B.2. Also the data was managed differently. However, based upon a close correlation of computed 2-year, 24-hour return frequency storms, we would expect insignificant differences in the percentages if computed for the other data set.

The water quality design storm identified in this approach would vary across the state. Assuming a 90% goal, rainfall amounts vary from 0.54 inches at Moses Lake to 3.18 inches at Cushman Dam. Runoff amounts from these storms will also vary depending upon natural soil conditions, vegetative cover, and the % effective imperviousness of a site. Maryland has recently adopted a statewide standard of capturing and treating 90% of the annual runoff volume. Rainfall in Maryland does not vary to the extent it does in Washington.

To implement this approach, Ecology would have to publish the water quality design storm for as many rainfall stations as possible. Then we would have to identify an adjustment factor to use for the project site. The factor could be based on a ratio of 2-year, 24-hour rain amounts between the nearest or most appropriate rainfall station and the project site, or upon a ratio of mean annual precipitation for the same two sites. The 2-year, 24-hour amount or the mean annual precipitation for the project site would have to be based upon interpolation of isopluvials.

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An example estimation would be as follows: 1) calculate the 2-year, 24-hour or the mean annual precipitation for a site by interpolating between the two nearest isopluvials. 2) calculate ratios of the mean annual rainfall amounts or 2-year, 24-hour amounts for the site to the nearest or most appropriate gauge for which a 90% value is published; 2) multiply the 90% rainfall amount for the gauge by the ratio.

4. **Using 24-hour rainfall data, establish the knee of the curve for a graph of increasing 24-hour rainfall amounts (y-axis) versus cumulative rainfall depth (x-axis).**

   Please refer to Figures B.1 and B.2. Figure B.1 shows examples of graphing the record of 24-hour rainfall amounts versus the cumulative percent of rainfall depth for the record. So each point on the curve shows the percent of rainfall depth that is represented by the corresponding 24-hour amount and lesser amounts. Figure B.2 depicts how the knee of the curve was determined for four rain gauge sites. Note that the graphs in Figures B.1 and B.2 have the same units for the x- and y-axes, but the scales are different. The curves start out fairly straight with a gentle rise, and then begin to rise sharply for the largest rainfall amounts. In order to perform the knee of the curve analysis, two tangent lines, or asymptotes were drawn, one through the horizontal portion of the curve and the other through the rising part of the curve. The two tangent lines were then bisected and the point where the bisect line intersected the curve was considered to be the knee of the curve. The rainfall depth and percent of total rainfall represented by the knee of the curve can then be determined.

   The tangent lines were drawn by choosing points that included as much of the flat horizontal portion of the curve as possible and as many points as possible to represent the sharply rising portion of the curve. Then a best-fit approach on the points was used to generate the tangent lines. Only a portion of the curves are shown in Figure B.2.

   The intent of this analysis is to relate the size of the storm (and by direct relationship, treatment cost) to the percent of total runoff (by assuming runoff tracks approximately with rainfall amount) that would receive treatment within the design parameters for the selected BMP (benefit).

   The results of using this approach for a number of rainfall stations are shown in Table B.2. For most stations, the rainfall

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amounts are substantially greater than the amounts identified in options #1 or #2 above, or the amount identified in option #3 assuming a 90% total rainfall criterion.

5. **Use a multiple of the mean annual storm.**

   The mean annual storm is defined as the total annual average precipitation amount divided by the average annual number of precipitation events. Mean annual storm values for various sites were computed based on data in The National Precipitation Databook, 1992[15], and are displayed in Table B.2.

   Other areas of the country have identified multiples of the mean annual storm as the basis for sizing water quality treatment BMPs. King Co. recently adopted a multiplier of 3x the runoff of the mean annual storm as the design basis for the volume of their "basic wetpond." The factor of three was arrived at as an estimate of the volume needed to achieve the County's design goal of 80% removal of total suspended solids.

   For BMPs sized based on volumetric flow rate or velocity, a characteristic hyetograph would be used in combination with the selected multiple of the mean annual storm to compute the peak flow rate for the time increment of interest.

6. **Use continuous runoff modeling to establish: a runoff flow rate that is exceeded only X % of the time using the appropriate time increment for a BMP sized based on a peak flow rate, and a runoff amount that is exceeded only X% of the time for BMP's based on runoff volume.**

   Using continuous runoff models allows you to obtain estimates of the probability of exceedence for flow rates and runoff volumes for the available rainfall record. This approach has probably the best statistical basis for deciding upon what your goal should be for technology-based water quality treatment volumes and flow rates. In weighing the cost reasonableness of selecting any particular percentage, we could compare the flow rates and volumes to those for which we have conducted cost analyses in the past, i.e., the current standards. The only method by which we could pursue this approach within the alloted timeframe for reissuance of this manual is to use results from King Co.'s application of HSPF, i.e., KCRTS .

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Table B.1. Rainfall Amounts and Comparisons for Selected USGS Stations as Published by Hydrosphere Data Products, Inc.

Station Name	6 Month Storm Inches	6 Month % Rainfall Volume	2 Year Storm Inches	6 Month/ 2 year %	90% Rainfall Inches	95% Rainfall Inches	Mean Annual Precip.Inches
1 Aberdeen	2.47	92.58%	3.43	72.0%	2.25	2.81	83.12
2 Anacortes	0.93	90.45%	1.37	67.9%	0.91	1.22	25.92
3 Appleton	1.39	89.04%	1.96	70.9%	1.45	1.80	32.71
4 Arlington	1.28	93.42%	1.74	73.6%	1.11	1.40	46.46
5 Bellingham	1.27	90.78%	1.79	70.9%	1.23	1.63	35.82
6 Bremerton	1.87	90.75%	2.61	71.6%	1.83	2.22	49.97
7 Cathlamet	2.13	92.52%	3.47	61.4%	1.89	2.59	78.97
8 Centralia	1.49	91.81%	2.09	71.3%	1.40	1.78	45.94
9 Chelan	0.62	84.50%	0.96	64.6%	0.76	1.00	10.44
10 Chimacum	1.20	89.63%	1.73	69.4%	1.22	1.52	29.45
11 Clearwater	3.46	92.88%	4.75	72.8%	3.04	3.94	125.25
12 CleElum	1.06	86.85%	1.66	63.9%	1.20	1.64	22.17
13 Colfax	0.80	90.52%	1.07	74.8%	0.80	0.99	19.78
14 Colville	0.71	90.46%	0.97	73.2%	0.69	0.86	18.31
15 Cushman Dam	3.31	91.26%	5.29	62.6%	3.18	4.25	100.82
16 Cushman PwrH	3.17	90.81%	4.42	71.7%	3.08	4.00	85.71
17 Darrington	2.90	91.19%	4.01	72.3%	2.73	3.42	82.90
18 Ellensburg	0.50	84.63%	0.79	63.3%	0.62	0.81	8.75
19 Elwha RS	2.14	90.49%	2.80	76.4%	2.11	2.53	55.87
20 Everett	1.10	93.14%	1.46	75.3%	1.00	1.22	36.80
21 Forks	3.47	92.50%	5.07	68.4%	3.13	4.00	117.83
22 Goldendale	0.84	86.92%	1.29	65.1%	0.98	1.25	17.57
23 Hartline	0.61	84.85%	0.96	63.5%	0.77	0.97	10.67
24 Kennewick	0.46	84.10%	0.71	64.8%	0.55	0.72	7.57
25 Lk. Wenatchee	2.20	85.87%	3.16	69.6%	2.58	3.16	42.72
26 Long Beach	2.32	93.09%	3.08	75.3%	2.04	2.55	80.89
27 Longview	1.41	92.02%	1.97	71.6%	1.29	1.67	45.62
28 Mc Millin	1.31	92.24%	1.82	72.0%	1.21	1.49	40.66
29 Monroe	1.38	92.90%	1.86	74.2%	1.26	1.53	48.16
30 Moses Lake	0.47	85.32%	0.70	67.1%	0.54	0.68	7.89
31 Oakville	1.81	92.86%	2.28	79.4%	1.62	1.98	57.35
32 Odessa	0.52	87.23%	0.76	68.4%	0.56	0.72	10.09
33 Olga	1.02	90.82%	1.52	67.1%	0.99	1.30	28.96
34 Olympia	1.74	91.13%	2.51	69.3%	1.65	2.19	50.68
35 Omak	0.66	85.89%	0.98	67.3%	0.79	0.98	11.97
36 Packwood	2.41	88.70%	3.52	68.5%	2.51	3.20	55.20

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Station Name	6 Month Storm Inches	6 Month % Rainfall Volume	2 Year Storm Inches	6 Month/ 2 year %	90% Rainfall Inches	95% Rainfall Inches	Mean Annual Precip.Inches
37 Pomeroy	0.75	89.29%	1.02	73.5%	0.78	0.98	16.04
38 Port Angeles	1.12	88.39%	1.66	67.5%	1.19	1.56	25.46
39 Port Townsend	0.77	90.56%	1.14	67.5%	0.76	0.95	19.13
40 Prosser	0.48	83.82%	0.74	64.9%	0.61	0.78	7.90
41 Quilcene	2.53	88.81%	3.40	74.4%	2.61	3.15	54.88
42 Quincy	0.53	82.12%	0.81	65.4%	0.68	0.90	8.07
43 Sea-Tac	1.32	91.13%	1.83	72.1%	1.27	1.63	38.10
44 Seattle JP	1.30	92.05%	1.74	74.7%	1.20	1.49	38.60
45 Sedro Woolley	1.50	92.07%	2.01	74.6%	1.41	1.80	46.97
46 Shelton	2.15	91.49%	3.13	68.7%	2.05	2.55	64.63
47 Smyrna	0.52	83.16%	0.76	68.4%	0.63	0.75	7.96
48 Spokane	0.68	89.54%	0.96	70.8%	0.70	0.88	16.04
49 Sunnyside	0.45	82.22%	0.73	61.6%	0.63	0.76	6.80
50 Tacoma	1.21	92.18%	1.61	75.2%	1.12	1.37	36.92
51 Toledo	1.36	92.73%	2.10	64.8%	1.25	1.68	50.18
52 Vancouver	1.35	91.32%	1.93	69.9%	1.28	1.62	38.87
53 Walla Walla	0.90	88.60%	1.23	73.2%	0.94	1.18	19.50
54 Waterville	0.67	84.43%	1.04	64.4%	0.81	1.05	11.47
55 Wauna	1.82	91.37%	2.50	72.8%	1.72	2.18	51.61
56 Wenatchee	0.58	81.97%	0.92	63.0%	0.80	1.04	8.93
57 Winthrop	0.75	85.36%	1.13	66.4%	0.94	1.13	14.28
58 Yakima	0.53	81.44%	0.85	62.4%	0.72	1.03	8.16

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Table B.2. Rainfall Amounts and Statistics Using Data from References #12 and #15

Station Name	Return Freq 2-yr.	Return Freq 6-month	Knee-of-curve 24 hr. (in)	Mean Annual Storm (in)	Mean Annual Precip (in)
ABERDEEN	3.32	2.53	2.81		83.1
ANACORTES	1.33	0.99	1.20		25.9
APPLETON	1.97	1.47	1.80		32.7
ARLINGTON	1.79	1.35	1.40		46.5
AUBURN	2.00	1.51		0.54	44.9
BATTLE GROUND	2.12	1.60			52.0
BELLINGHAM 3SSW -- F	1.70	1.27			35.0
BELLINGHAM CAA AP	1.56	1.17	1.63		35.8
BENTON CITY 2NW	0.79	0.53			8.0
BLAINE 1ENE	1.89	1.42		0.46	39.9
BREMERTON	2.31	1.74	2.22		50.0
BUCKLEY 1NE	2.09	1.58			49.0
BURLINGTON	1.75	1.31		0.40	35.0
CARNATION 4NW	1.91	1.44		0.49	47.5
CATHLAMET 6NE	3.84	2.93	2.59		79.0
CENTRALIA 1W	2.10	1.59	1.78	0.44	47.6
CHELAN	0.94	0.65	1.00		10.4
COLFAX 1NW	1.18	0.86	0.99		19.8
COLVILLE	1.02	0.74	0.86		18.3
COLVILLE WB AP	1.01	0.73		0.35	17.4
COUPVILLE 1S	1.08	0.79			21.0
CUSHMAN DAM	4.61	3.52	4.25	1.23	99.7
DARRINGTON RS	3.32	2.53	3.42	0.84	79.8
DUVALL 3NE	1.99	1.50			50.0
ELLENSBURG	0.70	0.48	0.80	0.25	9.2
ELLENSBURG WB AP	0.72	0.51			12.0
ELWHA RS	2.74	2.07	2.53		55.9
EVERETT JR. COL.	1.48	1.11	1.22	0.41	34.4
FORKS 1E	4.90	3.76	3.99		117.8
GOLDENDALE	1.12	0.81	1.25		17.6
GOLDENDALE 2E	1.31	0.95			18.0
HARTLINE	0.89	0.62	0.98		10.7
HOQUIAM AP	2.85	2.17			71.0
KENNEWICK	0.71	0.48	0.71		7.6
KENT	1.87	1.40			36.0

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Station Name	Return Freq 2-yr.	Return Freq 6-month	Knee-of-curve 24 hr. (in)	Mean Annual Storm (in)	Mean Annual Precip (in)
LEAVENWORTH	1.64	1.21			26.0
LONG BEACH EXP	2.99	2.28	2.54		80.0
LONGVIEW	2.20	1.66	1.67	0.48	48.1
MAZAMA 2W	1.59	1.17		0.41	22.7
MC MILLIN RESERVOIR	1.81	1.36	1.49	0.46	40.0
MILL CREEK	2.04	1.53			35.0
MONROE	1.91	1.44	1.52		48.2
MONTESANO 3NW	3.30	2.52		0.81	81.5
MOSES LAKE DEVIL FAR	0.74	0.50	0.68		7.9
MOUNT VERNON 3WNW	1.60	1.20			32.0
NEWPORT	1.41	1.05			29.0
OAKVILLE	2.46	1.86	1.99		57.4
ODESSA	0.80	0.55	0.72		10.1
OKANOGAN	0.90	0.63			12.0
OLGA 2SE	1.52	1.13	1.29		29.0
OLYMPIA WB AP	2.62	1.98	2.18	0.62	51.1
OMAK 2NW	0.99	0.70	0.98		12.0
OTHELLO 5E	0.70	0.47			8.0
PACKWOOD	2.92	2.21	3.16		55.2
POMEROY	1.10	0.79	0.97		16.0
PORT ANGELES	1.69	1.26	1.56	0.42	24.2
PORT TOWNSEND	1.11	0.81	0.95	0.35	17.6
PROSSER	0.74	0.49	0.78		7.9
PROSSER 4NE	0.72	0.48			8.0
PULLMAN 2NW	1.17	0.86		0.41	22.3
PUYALLUP 2W EXP STN	1.85	1.40			41.0
QUILCENE 2SW	3.42	2.59	3.14		54.9
QUILCENE DAM 5SW	3.84	2.92		0.77	69.4
QUINCY 1S	0.77	0.52	0.90		8.1
REPUBLIC	1.04	0.76			17.0
SEATTLE JACKSON PARK	1.49	1.12	1.49		38.6
SEATTLE TAC WB AP	1.90	1.42	1.62	0.49	37.4
SEATTLE U. OF W.	1.72	1.29			36.0
SEDRO WOLLEY 1E	2.05	1.55	1.80		47.0
SEQUIM	1.11	0.80			16.0
SHELTON	3.15	2.39	2.54		64.6
SMYRNA	0.79	0.53	0.75		8.0

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Station Name	Return Freq 2-yr.	Return Freq 6-month	Knee-of-curve 24 hr. (in)	Mean Annual Storm (in)	Mean Annual Precip (In)
SPOKANE	1.11	0.80	0.88		16.0
SPOKANE WB AP	0.97	0.70		0.35	17.0
SUNNYSIDE	0.76	0.50	0.76	0.30	7.4
TACOMA CITY HALL	1.70	1.28	1.37		36.9
TOLEDO	1.99	1.51	1.68		50.2
VANCOUVER 4NNE	2.01	1.51	1.62		38.9
WALLA WALLA CAA AP	1.19	0.87	1.17		19.5
WATERVILLE	1.00	0.70	1.05		11.5
WAUNA	2.15	1.63	2.18		51.6
WENATCHEE	0.95	0.65	1.04		8.9
WINTHROP 1WSW	1.19	0.85	1.13		14.3
YAKIMA WB AP	0.81	0.54	1.03	0.33	8.2

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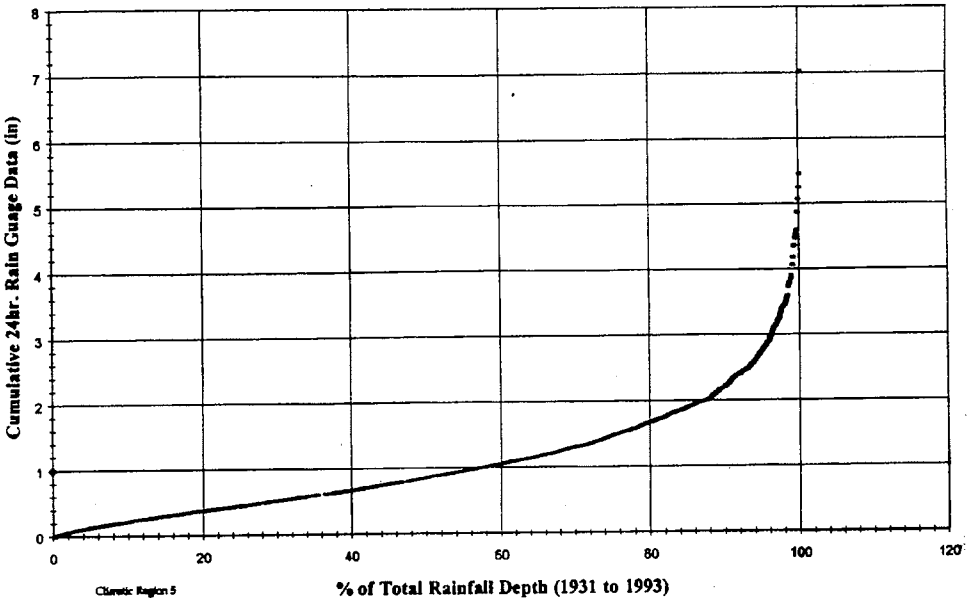
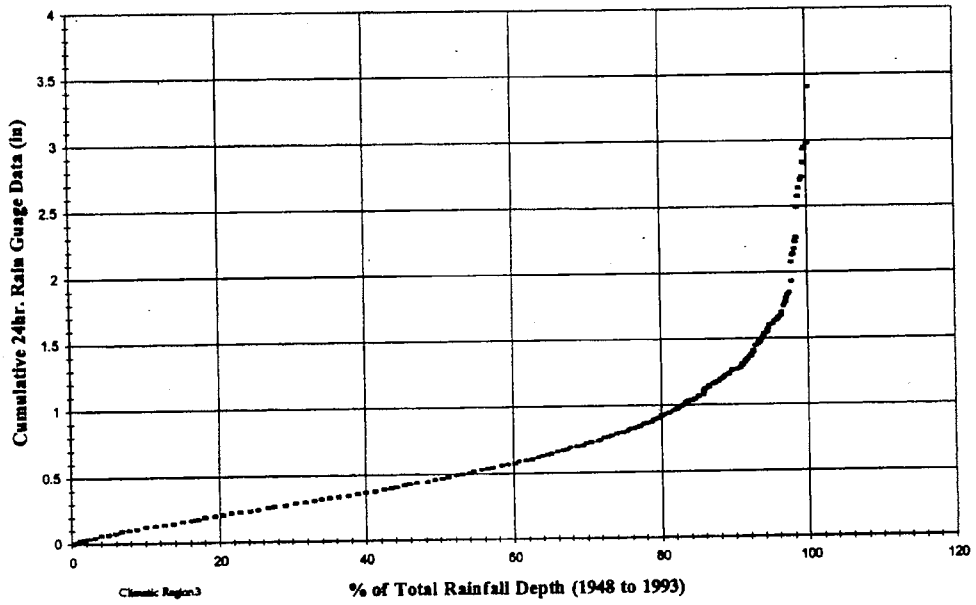
Aberdeen Stormwater Quality Design Storm



Sea-Tac Stormwater Quality Design Storm



Figures B.1 and B.2: 24-hour Rainfall Amounts vs. Total Rainfall Depth

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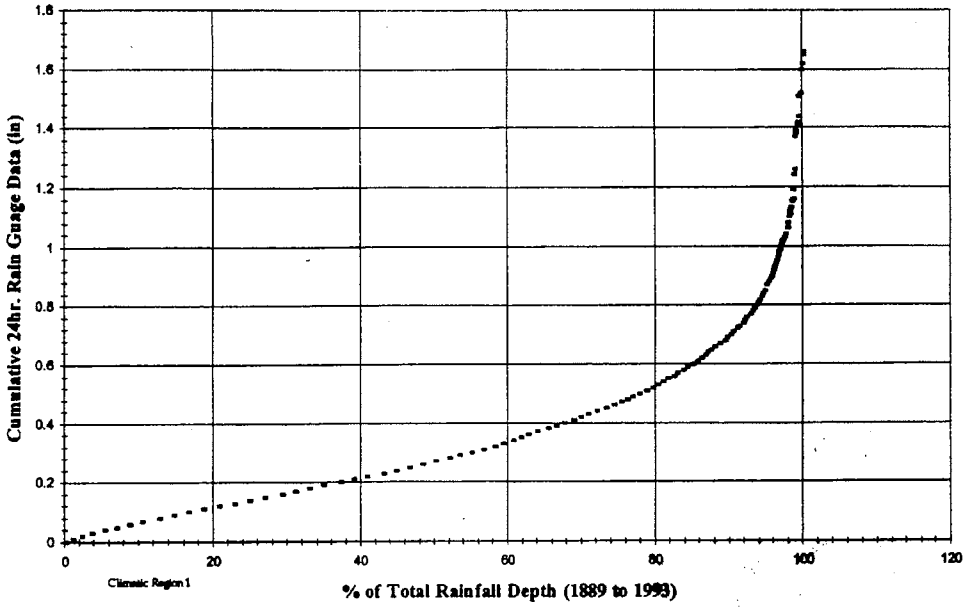
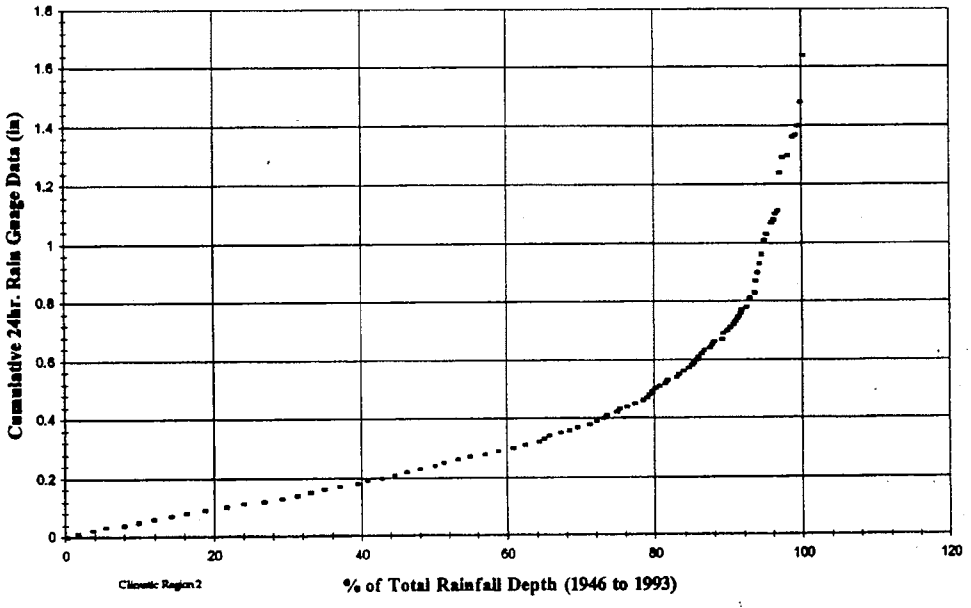
Spokane Stormwater Quality Design Storm



Yakima Stormwater Quality Design Storm



Figures B.3 and B.4: 24-hour Rainfall Amounts vs. Total Rainfall Depth

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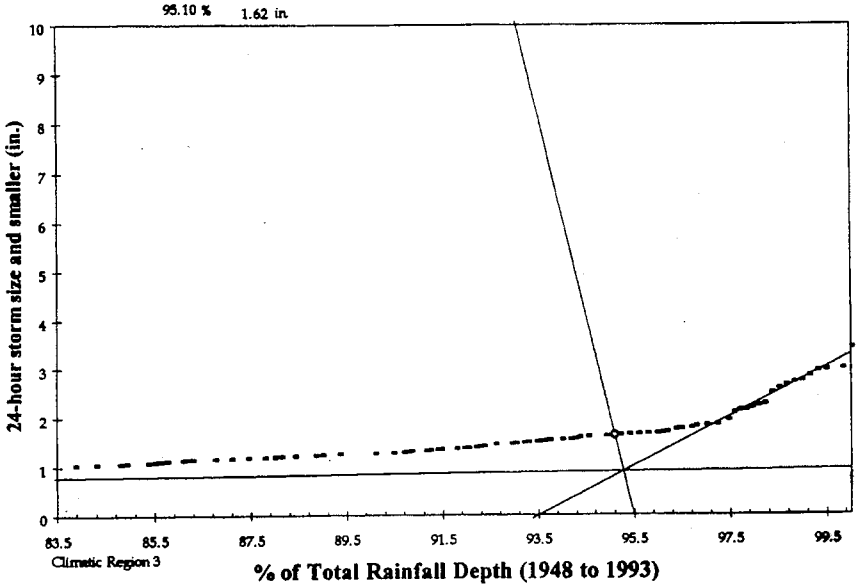
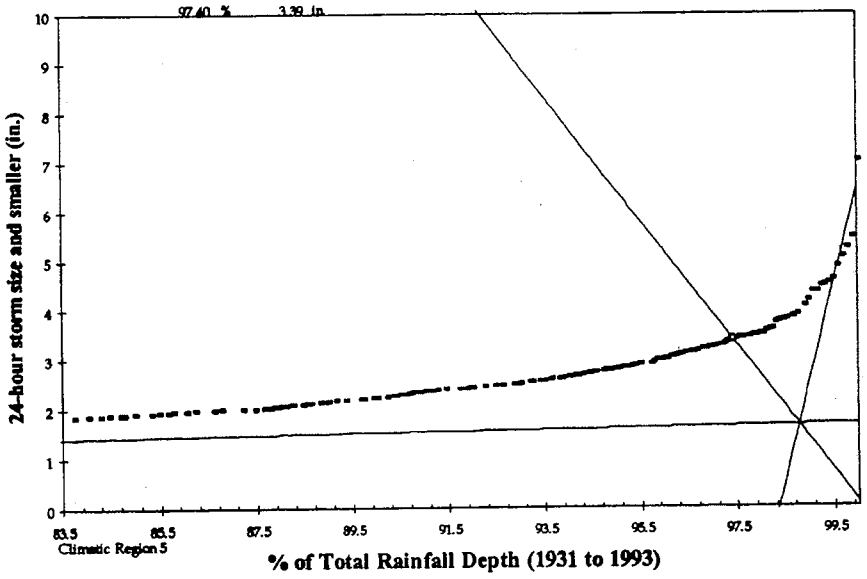
Sea-Tac Stormwater Quality Design Storm



Aberdeen Stormwater Quality Design Storm



Figures B.5 and B.6: Knee of Curve Estimates

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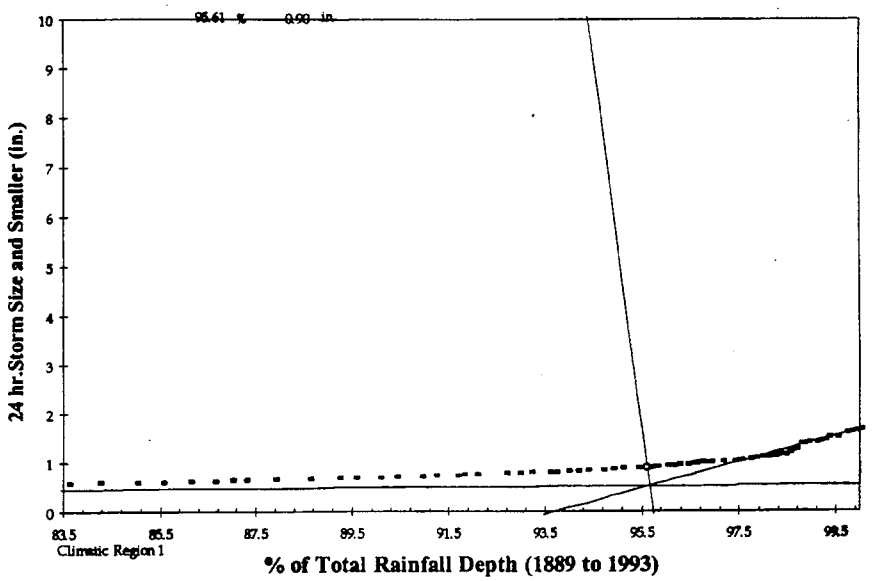
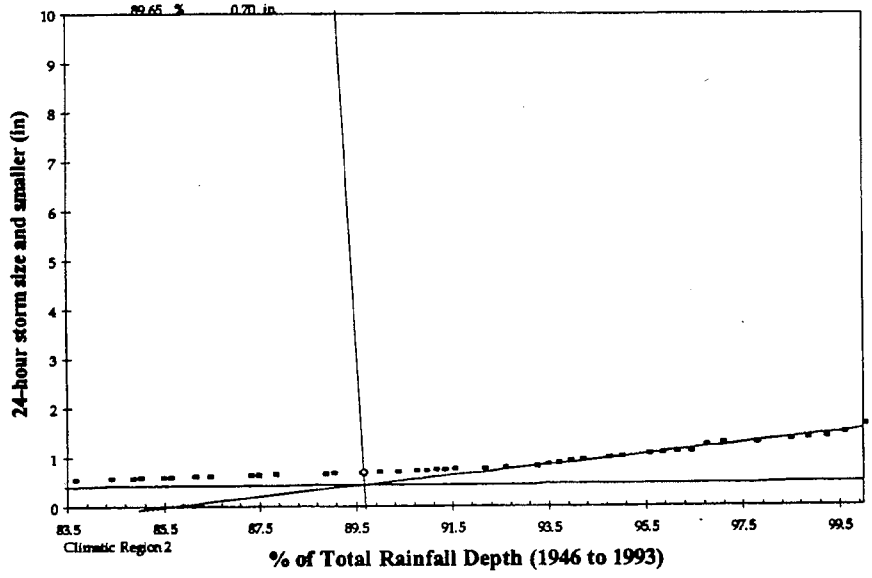
Spokane Stormwater Quality Design Storm



Yakima Stormwater Quality Design Storm



Figures B.7 and B.8: Knee of Curve Estimates

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GLOSSARY AND NOTATIONS

The following terms are provided for reference and use with this manual. They shall be superseded by any other definitions for these terms adopted by ordinance unless they are defined in a Washington State WAC or RCW or are used and defined as part of the Minimum Requirements for all new development and redevelopment.

AASHTO classification The official classification of soil materials and soil aggregate mixtures for highway construction, used by the American Association of State Highway and Transportation Officials.

Absorption The penetration of a substance into or through another, such as the dissolving of a soluble gas in a liquid.

Adjacent steep slope A slope with a gradient of 15 percent or steeper within five hundred feet of the site.

Adsorption The adhesion of a substance to the surface of a solid or liquid; often used to extract pollutants by causing them to be attached to such adsorbents as activated carbon or silica gel. Hydrophobic, or water-repulsing adsorbents, are used to extract oil from waterways when oil spills occur. Heavy metals such as zinc and lead often adsorb onto sediment particles.

Aeration The process of being supplied or impregnated with air. In waste treatment, the process used to foster biological and chemical purification. In soils, the process by which air in the soil is replenished by air from the atmosphere. In a well aerated soil, the soil air is similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen.

Aerobic Living or active only in the presence of free (dissolved or molecular) oxygen.

Aerobic bacteria Bacteria that require the presence of free oxygen for their metabolic processes.

Aggressive plant species Opportunistic species of inferior biological value that tend to out-compete more desirable forms and become dominant; applied to native species in this manual.

Algae Primitive plants, many microscopic, containing chlorophyll and forming the base of the food chain in aquatic environments. Some species may create a nuisance when environmental conditions are suitable for prolific growth.

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Algal bloom	Proliferation of living algae on the surface of lakes, streams or ponds; often stimulated by phosphate over-enrichment. Algal blooms reduce the oxygen available to other aquatic organisms.
American Public Works Association or APWA	The adopted edition of the Washington State Chapter of the American Public Works Association.
Anadromous	Fishes ascending rivers from the sea for breeding.
Anaerobic	Living or active in the absence of oxygen.
Anaerobic bacteria	Bacteria that do not require the presence of free or dissolved oxygen for metabolism.
Annual flood	The highest peak discharge on average which can be expected in any given year.
Antecedent moisture conditions	The degree of wetness of a watershed or within the soil at the beginning of a storm.
Anti-seep collar	A device constructed around a pipe or other conduit and placed through a dam, levee, or dike for the purpose of reducing seepage losses and piping failures.
Anti-vortex device	A facility placed at the entrance to a pipe conduit structure such as a drop inlet spillway or hood inlet spillway to prevent air from entering the structure when the pipe is flowing full.
Applicant	The person who has applied for a development permit or approval.
Approved manual	Means a stormwater management manual approved by Ecology.
Appurtenances	Machinery, appliances, or auxiliary structures attached to a main structure, but not considered an integral part thereof, for the purpose of enabling it to function.
Aquifer	A geologic stratum containing ground water that can be withdrawn and used for human purposes.
As-built drawings	Engineering plans which have been revised to reflect all changes to the plans which occurred during construction.
As-graded	The extent of surface conditions on completion of grading.
BSBL	See Building set back line.
Background	A description of pollutant levels arising from natural sources, and not because of man's immediate activities.
Backwater	Water upstream from an obstruction which is deeper than it would normally be without the obstruction.

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Bankfull discharge	A flow condition where streamflow completely fills the stream channel up to the top of the bank. In undisturbed watersheds, the discharge conditions occurs on average every 1.5 to 2 years and controls the shape and form of natural channels.
Base flood	A flood having a one percent chance of being equaled or exceeded in any given year. This is also referred to as the 100-year flood.
Base flood elevation	The water surface elevation of the base flood. It shall be referenced to the National Geodetic Vertical Datum of 1929 (NGVD).
Baseline sample	A sample collected during dry-weather flow (i.e., it does not consist of runoff from a specific precipitation event).
Basin plan	A plan and all implementing regulations and procedures including but not limited to land use management adopted by ordinance for managing surface and stormwater quality and quantity management facilities and features within individual subbasins.
Bearing capacity	The maximum load that a material can support before failing.
Bedrock	The more or less solid rock in place either on or beneath the surface of the earth. It may be soft, medium, or hard and have a smooth or irregular surface.
Bench	A relatively level step excavated into earth material on which fill is to be placed.
Berm	A constructed barrier of compacted earth, rock or gravel.
Best management practice (BMP)	The schedules of activities, prohibitions of practices, maintenance procedures, and structural and/or managerial practices, that when used singly or in combination, prevent or reduce the release of pollutants to waters of Washington State.
Biochemical oxygen demand (BOD)	An indirect measure of the concentration of biologically degradable materials present in organic wastes. The amount of free oxygen utilized by aerobic organisms when allowed to attack the organic material in an aerobically maintained environment at a specified temperature (20ΘC) for a specific time period (5 days), and thus stated as BOD_5. It is expressed in milligrams of oxygen utilized per liter of liquid waste volume (mg/l) or in milligrams of oxygen per kilogram of waste solution (mg/kg = ppm = parts per million parts). Also called biological oxygen demand.
Biodegradable	Capable of being readily broken down by biological means, especially by bacterial action. Degradation can be rapid or may take many years depending upon such factors as available oxygen and moisture.

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Bioengineering	Restoration or reinforcement of slopes and stream banks with living plant materials.
Biofilter	A designed, vegetated treatment facility where the more or less simultaneous processes of filtration, infiltration, adsorption and biological uptake of pollutants in stormwater takes place when runoff flows over and through . Vegetation growing in these facilities acts as both a physical filter which causes gravity settling of particulates by regulating velocity of flow, and also as a biological sink when direct uptake of dissolved pollutants occurs. The former mechanism is probably the most important in western Washington where the period of major runoff coincides with the period of lowest biological activity.
Biofiltration	The process of reducing pollutant concentrations in water by filtering the polluted water through biological materials.
Biological control	A method of controlling pest organisms by means of introduced or naturally occurring predatory organisms, sterilization, the use of inhibiting hormones, or other means, rather than by mechanical or chemical means.
Biological magnification	The increasing concentration of a substance along succeeding steps in a food chain. Also called biomagnification.
Bollard	A post (may or may not be removable) used to prevent vehicular access.
Bond	A surety bond, cash deposit or escrow account, assignment of savings, irrevocable letter of credit or other means acceptable to or required by the manager to guarantee that work is completed in compliance with the project's drainage plan and in compliance with all local government requirements.
Borrow area	A source of earth fill material used in the construction of embankments or other earth fill structures.
Buffer	The zone contiguous with a sensitive area that is required for the continued maintenance, function, and structural stability of the sensitive area. The critical functions of a riparian buffer (those associated with an aquatic system) include shading, input of organic debris and coarse sediments, uptake of nutrients, stabilization of banks, interception of fine sediments, overflow during high water events, protection from disturbance by humans and domestic animals, maintenance of wildlife habitat, and room for variation of aquatic system boundaries over time due to hydrologic or climatic effects. The critical functions of terrestrial buffers include protection of slope stability, attenuation of surface water flows from stormwater runoff and precipitation, and erosion control.

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Building setback line (BSBL)	A line measured parallel to a property, easement, drainage facility or buffer boundary, that delineates the area (defined by the distance of separation) where buildings, or other obstructions are prohibited (including decks, patios, outbuildings, or overhangs beyond 18 inches). Wooden or chain link fences and landscaping are allowable within a building setback line. In this manual the minimum building setback line shall be 5 feet.
CIP	See Capital Improvement Project.
Capital Improvement Project or Program (CIP)	A project prioritized and scheduled as a part of an overall construction program or, the actual construction program.
Catchbasin	A chamber or well, usually built at the curb line of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow.
Catchline	The point where a severe slope intercepts a different, more gentle slope.
Catchment	Surface drainage area.
Channel	A feature that conveys surface water and is open to the air.
Channel, constructed	Channels or ditches constructed (or reconstructed natural channels) to convey surface water.
Channel, natural	Streams, creeks, or swales that convey surface/ground water and have existed long enough to establish a stable route and/or biological community.
Channel stabilization	Erosion prevention and stabilization of velocity distribution in a channel using vegetation, jetties, drops, revetments, and/or other measures.
Channel storage	Water temporarily stored in channels while enroute to an outlet.
Channelization	Alteration of a stream channel by widening, deepening, straightening, cleaning, or paving certain areas to change flow characteristics.
Check dam	Small dam constructed in a gully or other small watercourse to decrease the streamflow velocity, minimize channel scour, and promote deposition of sediment.
Chemical oxygen demand (COD)	A measure of the amount of oxygen required to oxidize organic and oxidizable inorganic compounds in water. The COD test, like the BOD test, is used to determine the degree of pollution in water.

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Civil engineer	A professional engineer licensed in the State of Washington in Civil Engineering who is experienced and knowledgeable in the practice of soils engineering.
Civil engineering	The application of the knowledge of the forces of nature, principles of mechanics and the properties of materials to the evaluation, design and construction of civil works for the beneficial uses of mankind.
Clay lens	A naturally occurring, localized area of clay which acts as an impermeable layer to runoff infiltration.
Clearing	The destruction and removal of vegetation by manual, mechanical, or chemical methods.
Closed depression	An area which is lowlying and either has no, or such a limited, surface water outlet that during storm events the area acts as a retention basin.
Cohesion	The capacity of a soil to resist shearing stress, exclusive of functional resistance.
Coliform bacteria	Microorganisms common in the intestinal tracts of man and other warm-blooded animals; all the aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35ΘC. Used as an indicator of bacterial pollution.
Commercial agriculture	Those activities conducted on lands defined in RCW 84.34.020(2), and activities involved in the production of crops or livestock for wholesale trade. An activity ceases to be considered commercial agriculture when the area on which it is conducted is proposed for conversion to a nonagricultural use or has lain idle for more than five (5) years, unless the idle land is registered in a federal or state soils conservation program, or unless the activity is maintenance of irrigation ditches, laterals, canals, or drainage ditches related to an existing and ongoing agricultural activity.
Compaction	Densification of a fill by mechanical means.
Compensatory storage	New excavated storage volume equivalent to the flood storage capacity eliminated by filling or grading within the flood fringe. Equivalent shall mean that the storage removed shall be replaced by equal volume between corresponding one foot contour intervals that are hydraulically connected to the floodway through their entire depth.
Compost	Organic residue or a mixture of organic residues and soil, that has undergone biological decomposition until it has become relatively stable humus.

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Composting	A controlled process of degrading organic matter by microorganisms. Present day composting is the aerobic, thermophilic decomposing of organic waste to relatively stable humus. Humus with no more than 25 percent dead or living organisms is stable enough not to reheat or cause odor or fly problems. It can undergo further, slower decay.
Comprehensive planning	Planning that takes into account all aspects of water, air, and land resources and their uses and limits.
Conservation district	A public organization created under state enabling law as a special-purpose district to develop and carry out a program of soil, water, and related resource conservation, use, and development within its boundaries, usually a subdivision of state government with a local governing body and always with limited authority. Often called a soil conservation district or a soil and water conservation district.
Constructed wetland	Those wetlands intentionally created on sites that are not wetlands for the primary purpose of wastewater or stormwater treatment and managed as such. Constructed wetlands are normally considered as part of the stormwater collection and treatment system.
Contour	An imaginary line on the surface of the earth connecting points of the same elevation.
Conveyance	A mechanism for transporting water from one point to another, including pipes, ditches, and channels.
Conveyance system	The drainage facilities, both natural and man-made, which collect, contain, and provide for the flow of surface and stormwater from the highest points on the land down to a receiving water. The natural elements of the conveyance system include swales and small drainage courses, streams, rivers, lakes, and wetlands. The human-made elements of the conveyance system include gutters, ditches, pipes, channels, and most retention/detention facilities.
Cover crop	A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of permanent vegetation.
Created wetland	Means those wetlands intentionally created from nonwetland sites to produce or replace natural wetland habitat (e.g., compensatory mitigation projects).
Critical Areas	At a minimum, areas which include wetlands, areas with a critical recharging effect on aquifers used for potable water, fish and wildlife habitat conservation areas, frequently flooded areas, geologically hazardous areas, including unstable slopes, and associated areas and ecosystems.

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Critical depth	The depth which minimizes the specific energy of flow (E).
Critical Drainage Area	An area with such severe flooding, drainage and/or erosion/sedimentation conditions that the area has been formally adopted as a Critical Drainage Area by rule under the procedures specified in an ordinance.
Critical flow	Flow at the critical depth and velocity.
Critical reach	The point in a receiving stream below a discharge point at which the lowest dissolved oxygen level is reached and stream recovery begins.
Culvert	Pipe or concrete box structure which drains open channels, swales or ditches under a roadway or embankment. Typically with no catchbasins or manholes along its length.
Cut	Portion of land surface or area from which earth has been removed or will be removed by excavating; the depth below original ground surface to excavated surface.
Cut-and-fill	Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.
DNS	See Determination of nonsignificance.
Dead storage	The volume available in a depression in the ground below any conveyance system, or surface drainage pathway, or outlet invert elevation that could allow the discharge of surface and stormwater runoff.
Dedication of land	Refers to setting aside a portion of a property for a specific use or function.
Degradation	(Biological or chemical) The breakdown of complex organic or other chemical compounds into simpler substances, usually less harmful than the original compound, as with the degradation of a persistent pesticide. (Geological) Wearing down by erosion. (Water) The lowering of the water quality of a watercourse by an increase in the pollutant loading.
Degraded (disturbed) wetland (community)	A wetland (community) in which the vegetation, soils, and/or hydrology have been adversely altered, resulting in lost or reduced functions and values; generally, implies topographic isolation; hydrologic alterations such as hydroperiod alteration (increased or decreased quantity of water), diking, channelization, and/or outlet modification; soils alterations such as presence of fill, soil removal, and/or compaction; accumulation of toxicants in the biotic or abiotic components of the wetland; and/or low plant species richness with dominance by invasive weedy species.
Denitrification	The biochemical reduction of nitrates or nitrites in the soil or organic deposits to ammonia or free nitrogen.

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Depression storage	The amount of precipitation that is trapped in depressions on the surface of the ground.
Design engineer	The professional civil engineer licensed in the State of Washington who prepares the analysis, design, and engineering plans for an applicant's permit or approval submittal.
Design storm	A prescribed hyetograph and total precipitation amount (for a specific duration recurrence frequency) used to estimate runoff for a hypothetical storm of interest or concern for the purposes of analyzing existing drainage, designing new drainage facilities or assessing other impacts of a proposed project on the flow of surface water. (A hyetograph is a graph of percentages of total precipitation for a series of time steps representing the total time during which the precipitation occurs.)
Detention	The release of stormwater runoff from the site at a slower rate than it is collected by the stormwater facility system, the difference being held in temporary storage.
Detention facility	An above or below ground facility, such as a pond or tank, that temporarily stores stormwater runoff and subsequently releases it at a slower rate than it is collected by the drainage facility system. There is little or no infiltration of stored stormwater.
Detention time	The theoretical time required to displace the contents of a stormwater treatment facility at a given rate of discharge (volume divided by rate of discharge).
Determination of Nonsignificance (DNS)	The written decision by the responsible official of the lead agency that a proposal is not likely to have a significant adverse environmental impact, and therefore an EIS is not required.
Development	Means new development, redevelopment, or both. See definitions for each.
Discharge	Outflow; the flow of a stream, canal, or aquifer. One may also speak of the discharge of a canal or stream into a lake, river, or ocean. (Hydraulics) Rate of flow, specifically fluid flow; a volume of fluid passing a point per unit of time, commonly expressed as cubic feet per second, cubic meters per second, gallons per minute, gallons per day, or millions of gallons per day.
Dispersed discharge	Release of surface and stormwater runoff from a drainage facility system such that the flow spreads over a wide area and is located so as not to allow flow to concentrate anywhere upstream of a drainage channel with erodible underlying granular soils.
Ditch	A long narrow excavation dug in the earth for drainage with its top width less than 10 feet at design flow.

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Divide, Drainage — The boundary between one drainage basin and another.

Drain — A buried pipe or other conduit (closed drain). A ditch (open drain) for carrying off surplus surface water or ground water.

(To) Drain — To provide channels, such as open ditches or closed drains, so that excess water can be removed by surface flow or by internal flow. To lose water (from the soil) by percolation.

Drainage — Refers to the collection, conveyance, containment, and/or discharge of surface and stormwater runoff.

Drainage basin — A geographic and hydrologic subunit of a watershed.

Drainage channel — A drainage pathway with a well-defined bed and banks indicating frequent conveyance of surface and stormwater runoff.

Drainage course — A pathway for watershed drainage characterized by wet soil vegetation; often intermittent in flow.

Drainage easement — A legal encumbrance that is placed against a property's title to reserve specified privileges for the users and beneficiaries of the drainage facilities contained within the boundaries of the easement.

Drainage pathway — The route that surface and stormwater runoff, leaving any part of the site, follows downslope.

Drainage review — An evaluation by Plan Approving Authority staff of a proposed project's compliance with the drainage requirements in this manual or its technical equivalent.

Drainage, Soil — As a natural condition of the soil, soil drainage refers to the frequency and duration of periods when the soil is free of saturation; for example, in well-drained soils the water is removed readily but not rapidly; in poorly drained soils the root zone is waterlogged for long periods unless artificially drained, and the roots of ordinary crop plants cannot get enough oxygen; in excessively drained soils the water is removed so completely that most crop plants suffer from lack of water. Strictly speaking, excessively drained soils are a result of excessive runoff due to steep slopes or low available water-holding capacity due to small amounts of silt and clay in the soil material. The following classes are used to express soil drainage:

- Well drained - Excess water drains away rapidly and no mottling occurs within 36 inches of the surface.
- Moderately well drained - Water is removed from the soil somewhat slowly, resulting in small but significant periods of wetness. Mottling occurs between 18 and 36 inches.
- Somewhat poorly drained - Water is removed from the soil slowly enough to keep it wet for significant periods but not all of the time. Mottling occurs between 8 and 18 inches.

Drainage, Soil (continued)

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- Poorly drained - Water is removed so slowly that the soil is wet for a large part of the time. Mottling occurs between 0 and 8 inches.
- Very poorly drained - Water is removed so slowly that the water table remains at or near the surface for the greater part of the time. There may also be periods of surface ponding. The soil has a black to gray surface layer with mottles up to the surface.

Drawdown — Lowering of the water surface (in open channel flow), water table or piezometric surface (in ground water flow) resulting from a withdrawal of water.

Drop-inlet spillway — Overall structure in which the water drops through a vertical riser connected to a discharge conduit.

Drop spillway — Overall structure in which the water drops over a vertical wall onto an apron at a lower elevation.

Drop structure — A structure for dropping water to a lower level and dissipating its surplus energy; a fall. A drop may be vertical or inclined.

Dry weather flow — The combination of sanitary sewage, and industrial and commercial wastes normally found in sanitary or storm sewers during the dry weather season of the year. Also that flow in streams during the dry season.

EIS — See Environmental Impact Statement.

ESC — Erosion and Sediment Control (Plan).

Earth material — any rock, natural soil or fill and/or any combination thereof.

Easement — The legal right to use a parcel of land for a particular purpose. It does not include fee ownership, but may restrict the owners use of the land.

Embankment — A structure of earth, gravel, or similar material raised to form a pond bank or foundation for a road.

Emergent plants — Aquatic plants that are rooted in the sediment but whose leaves are at or above the water surface. These wetland plants often have high habitat value for wildlife and waterfowl, and can aid in pollutant uptake.

Emergency spillway — A vegetated earth channel used to safely convey flood discharges in excess of the capacity of the principal spillway.

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Energy dissipator	Any means by which the total energy of flowing water is reduced. In stormwater design, they are usually mechanisms that reduce velocity prior to, or at, discharge from an outfall in order to prevent erosion. They include rock splash pads, drop manholes, concrete stilling basins or baffles, and check dams.
Energy gradient	The slope of the specific energy line (i.e., the sum of the potential and velocity heads.)
Engineering geologist	A geologist experienced and knowledgeable in engineering geology.
Engineering geology	The application of geologic knowledge and principles in the investigation and evaluation of naturally occurring rock and soil for use in the design of civil works.
Engineering plan	A plan prepared and stamped by a professional civil engineer. An engineering plan contains a Technical Information Report and Site Improvement Plans which are described in detail in Chapter I-3.
Enhancement	To raise value, desirability, or attractiveness of an environment associated with surface water.
Environmental Impact Statement (EIS)	A document that discusses the likely significant adverse impacts of a proposal, ways to lessen the impacts, and alternatives to the proposal. They are required by the national and state environmental policy acts when projects are determined to have significant environmental impact.
Erodible granular soils	Soil materials that are easily eroded and transported by running water, typically fine or medium grained sand with minor gravel, silt, or clay content. Such soils are commonly described as Everett or Indianola series soil types in the SCS classification. Also included are any soils showing examples of existing severe stream channel incision as indicated by unvegetated streambanks standing over two feet high above the base of the channel.
Erosion	The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. Also, detachment and movement of soil or rock fragments by water, wind, ice, or gravity. The following terms are used to describe different types of water erosion: • Accelerated erosion - Erosion much more rapid than normal or geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of the animals or natural catastrophes that expose bare surfaces (e.g., fires). • Geological erosion - The normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of mountains, the building up of floodplains, coastal plains, etc. Synonymous with natural erosion.

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Erosion (continued)	• Gully erosion - The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 to 2 feet to as much as 75 to 100 feet. • Natural erosion - Wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, etc., undisturbed by man. Synonymous with geological erosion. • Normal erosion - The gradual erosion of land used by man which does not greatly exceed natural erosion. See Natural erosion. • Rill erosion - An erosion process in which numerous small channels only several inches deep are formed; occurs mainly on recently disturbed and exposed soils. See Rill. • Sheet erosion - The removal of a fairly uniform layer of soil from the land surface by runoff. • Splash erosion - The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff.
Erosion classes (soil survey)	A grouping of erosion conditions based on the degree of erosion or on characteristic patterns. Applied to accelerated erosion, not to normal, natural, or geological erosion. Four erosion classes are recognized for water erosion and three for wind erosion.
Erosion/sedimentation control	Any temporary or permanent measures taken to reduce erosion; control siltation and sedimentation; and ensure that sediment-laden water does not leave the site.
Erosion and sediment control facility	A type of drainage facility designed to hold water for a period of time to allow sediment contained in the surface and stormwater runoff directed to the facility to settle out so as to improve the quality of the runoff.
Escarpment	A steep face or a ridge of high land.
Estuarine wetland	Generally, an eelgrass bed; salt marsh; or rocky, sandflat, or mudflat intertidal area where fresh and salt water mix. (Specifically, a tidal wetland with salinity greater than 0.5 parts per thousand, usually semi-enclosed by land but with partially obstructed or sporadic access to the open ocean).
Estuary	An area where fresh water meets salt water, or where the tide meets the river current (e.g., bays, mouths of rivers, salt marshes and lagoons). Estuaries serve as nurseries and spawning and feeding grounds for large groups of marine life and provide shelter and food for birds and wildlife.

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Eutrophication	Refers to the process where nutrient over-enrichment of water leads to excessive growth of aquatic plants, especially algae.
Evapotranspiration	The collective term for the processes of evaporation and plant transpiration by which water is returned to the atmosphere.
Excavation	The mechanical removal of earth material.
Exfiltration	The downward movement of runoff through the bottom of an infiltration BMP into the soil layer or the downward movement of water through soil.
Existing site conditions means	(a) For developed sites with stormwater facilities that have been constructed to meet the standards in the Minimum Requirements of this manual, existing site conditions shall mean the existing conditions on the site. (b) For developed sites that do not have stormwater facilities that meet the Minimum Requirements, existing site conditions shall mean the conditions that existed prior to the development of the project site. If in question, the existing site conditions shall be documented by aerial photograph records, or other appropriate means. (c) (c) For undeveloped sites existing site conditions shall mean the existing conditions on the site.
Experimental best management practice (BMP)	A BMP that has not been tested and evaluated by the Department of Ecology in collaboration with local governments and technical experts.
FIRM	See Flood Insurance Rate Map.
Fertilizer	Any material or mixture used to supply one or more of the essential plant nutrient elements.
Fill	A deposit of earth material placed by artificial means.
Filter fabric	A woven or nonwoven, water-permeable material generally made of synthetic products such as polypropylene and used in stormwater management and erosion and sediment control applications to trap sediment or prevent the clogging of aggregates by fine soil particles.
Filter fabric fence	A temporary sediment barrier consisting of a filter fabric stretched across and attached to supporting posts and entrenched. The filter fence is constructed of stakes and synthetic filter fabric with a rigid wire fence backing where necessary for support.
Filter strip	A strip of vegetation used to retard or collect sediment for the protection of diversions, drainage basins, or other structures. Often used in conjunction with a level spreader to keep flow from becoming channelized in the filter strip.

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Flocculation	The process by which suspended colloidal or very fine particles are assembled into larger masses or floccules which eventually settle out of suspension. This process occurs naturally but can also be caused through the use of such chemicals as alum.
Flood	An overflow or inundation that comes from a river or any other source, including (but no limited to) streams, tides, wave action, storm drains or excess rainfall. Any relatively high stream flow overtopping the natural or artificial banks in any reach of a stream.
Flood control	Methods or facilities for reducing flood flows and the extent of flooding.
Flood control project	A structural system installed to protect land and improvements from floods by the construction of dikes, river embankments, channels, or dams.
Flood frequency	The frequency with which the flood of interest may be expected to occur at a site in any average interval of years. Frequency analysis defines the "n-year flood" as being the flood that will, over a long period of time, be equaled or exceeded on the average once every "n" years.
Flood fringe	That portion of the floodplain outside of the floodway which is covered by floodwaters during the base flood; it is generally associated with standing water rather than rapidly flowing water.
Flood Hazard Areas	Those areas subject to inundation by the base flood. Includes, but is not limited to streams, lakes, wetlands, and closed depressions.
Flood Insurance Rate Map (FIRM)	The official map on which the Federal Insurance Administration has delineated many areas of flood hazard, floodway, and the risk premium zones.
Flood Insurance Study	The official report provided by the Federal Insurance Administration that includes flood profiles and the FIRM.
Flood peak	The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge.
Floodplain	The total area subject to inundation by the base flood including the flood fringe and floodway.
Flood-proofing	Adaptations that ensure a structure is substantially impermeable to the passage of water below the flood protection elevation that resists hydrostatic and hydrodynamic loads and effects of buoyancy.
Flood protection elevation	The base flood elevation or higher as defined by the local government.

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Flood protection facility Any levee, berm, wall, enclosure, raise bank, revetment, constructed bank stabilization or armoring, that is commonly recognized by the community as providing significant protection to a property from inundation by flood waters.

Flood routing An analytical technique used to compute the effects of system storage dynamics on the shape and movement of flow represented by a hydrograph.

Flood stage The stage at which overflow of the natural banks of a stream begins.

Floodway The channel of the river or stream and those portions of the adjoining floodplains which are reasonably required to carry and discharge the base flood flow. The portions of the adjoining floodplains which are considered to be "reasonably required" is defined by flood hazard regulations.

Forebay An easily maintained, extra storage area provided near an inlet of a BMP to trap incoming sediments before they accumulate in a pond or wetland BMP.

Forest practice Any activity conducted on or directly pertaining to forest land and relating to growing, harvesting, or processing timber, including but not limited to:

a. Road and trail construction.
b. Harvesting, final and intermediate.
c. Precommercial thinning.
d. Reforestation.
e. Fertilization.
f. Prevention and suppression of diseases and insects.
g. Salvage of trees.
h. Brush control.

Forested communities (wetlands) In general terms, communities (wetlands) characterized by woody vegetation that is greater than or equal to 6 meters in height; in this manual the term applies to such communities (wetlands) that represent a significant amount of tree cover consisting of species that offer wildlife habitat and other values and advance the performance of wetland functions overall.

Freeboard The vertical distance between the design water surface elevation and the elevation of the barrier which contains the water.

Frequently flooded areas the 100-year floodplain designations of the Federal Emergency Management Agency and the National Flood Insurance Program or as defined by the local government.

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Frost-heave	The upward movement of soil surface due to the expansion of water stored between particles in the first few feet of the soil profile as it freezes. May cause surface fracturing of asphalt or concrete.
Frequency of storm (design storm frequency)	The anticipated period in years that will elapse, based on average probability of storms in the design region, before a storm of a given intensity and/or total volume will recur; thus a 10-year storm can be expected to occur on the average once every 10 years. Sewers designed to handle flows which occur under such storm conditions would be expected to be surcharged by any storms of greater amount or intensity.
Functions	The ecological (physical, chemical, and biological) processes or attributes of a wetland without regard for their importance to society (see also values). Wetland functions include food chain support, provision of ecosystem diversity and fish and wildlife habitat, floodflow alteration, ground water recharge and discharge, water quality improvement, and soil stabilization.
Gabion	A rectangular or cylindrical wire mesh cage (a chicken wire basket) filled with rock and used as a protecting agent, revetment, etc., against erosion. Soft gabions, often used in streambank stabilization, are made of geotextiles filled with dirt, in between which cuttings are placed.
Gage or gauge	Device for registering precipitation, water level, discharge, velocity, pressure, temperature, etc. Also, a measure of the thickness of metal; e.g., diameter of wire, wall thickness of steel pipe.
Gaging station	A selected section of a stream channel equipped with a gage, recorder, or other facilities for determining stream discharge.
Geologist	A person who has earned a degree in geology from an accredited college or university or who has equivalent educational training and has at least five years of experience as a practicing geologist or four years of experience and at least two years post-graduate study, research or teaching. The practical experience shall include at least three years work in applied geology and landslide evaluation, in close association with qualified practicing geologists or geotechnical professional/civil engineers.
Geologically hazardous areas	Areas that because of their susceptibility to erosion, sliding, earthquake or other geological events, are not suited to the siting of commercial, residential or industrial development consistent with public health or safety concerns.
Geometrics	The mathematical relationships between points, lines, angles and surfaces used to measure and identify areas of land.

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Geotechnical professional civil engineer	A practicing, geotechnical/civil engineer licensed as a professional Civil Engineer with the State of Washington who has at least four years of professional employment as a geotechnical engineer in responsible charge, including experience with landslide evaluation.
Grade	The slope of a road, channel, or natural ground. The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction such as paving or the laying of a conduit.
(To) Grade	To finish the surface of a canal bed, roadbed, top of embankment or bottom of excavation.
Gradient terrace	An earth embankment or a ridge-and-channel constructed with suitable spacing and an acceptable grade to reduce erosion damage by intercepting surface runoff and conducting it to a stable outlet at a stable nonerosive velocity.
Grassed waterway	A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses, used to conduct surface water from an area at a reduced flow rate. See also **biofilter**.
Ground water	Water in a saturated zone or stratum beneath the land surface or a surface water body.
Ground water recharge	Inflow to a ground water reservoir.
Ground water table	The free surface of the ground water, that surface subject to atmospheric pressure under the ground, generally rising and falling with the season, the rate of withdrawal, the rate of restoration, and other conditions. It is seldom static.
(the) Guidance Manual	"The Stormwater Program Guidance Manual for the Puget Sound Basin," a companion manual to this technical manual which contains program implementation guidance for local governments. Examples of the guidance contained are model ordinances, public education information, and guidance on setting up a stormwater utility.
Gully	A channel caused by the concentrated flow of surface and stormwater runoff over unprotected erodible land.
Habitat	The specific area or environment in which a particular type of plant or animal lives. An organism's habitat must provide all of the basic requirements for life and should be protected from harmful contaminants.
Hardpan	A cemented or compacted and often clay-like layer of soil that is impenetrable by roots.

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Harmful pollutant	A substance that has adverse effects to an organism including immediate death, chronic poisoning, impaired reproduction, cancer or other effects.
Head (Hydraulics)	The height of water above any plain of reference. The energy, either kinetic or potential, possessed by each unit weight of a liquid, expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various compound terms such as pressure head, velocity head, and head loss.
Head loss	Energy loss due to friction, eddies, changes in velocity, or direction of flow.
Heavy metals	Metals of high specific gravity, present in municipal and industrial wastes, that pose long-term environmental hazards. Such metals include cadmium, chromium, cobalt, copper, lead, mercury, nickel, and zinc.
Humus	Organic matter in or on a soil, composed of partly or fully decomposed bits of plant tissue or from animal manure.
Hydraulic gradient	Slope of the potential head relative to a fixed datum.
Hydrodynamics	Means the dynamic energy, force, or motion of fluids as affected by the physical forces acting upon those fluids.
Hydrograph	A graph of runoff rate, inflow rate or discharge rate, past a specific point over time.
Hydrologic cycle	The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.
Hydrologic Soil Groups	A soil characteristic classification system defined by the U.S. Soil Conservation Service in which a soil may be categorized into one of four soil groups (A, B, C, or D) based upon infiltration rate and other properties.
Hydrology	The science of the behavior of water in the atmosphere, on the surface of the earth, and underground.
Hydroperiod	A seasonal occurrence of flooding and/or soil saturation; it encompasses depth, frequency, duration, and seasonal pattern of inundation.
Hyetograph	A graph of percentages of total precipitation for a series of time steps representing the total time in which precipitation occurs.

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Illicit discharge	All non-stormwater discharges to stormwater drainage systems that cause or contribute to a violation of state water quality, sediment quality or ground water quality standards, including but not limited to sanitary sewer connections, industrial process water, interior floor drains, car washing and greywater systems.
Impact basin	A device used to dissipate the energy of flowing water. Generally constructed of concrete in the form of a partially depressed or partially submerged vessel, it may utilize baffles to dissipate velocities.
Impervious	A surface which cannot be easily penetrated. For instance, rain does not readily penetrate paved surfaces.
Impervious surface	A hard surface area which either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development. A hard surface area which causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development. Common impervious surfaces include, but are not limited to, roof tops, walkways, patios, driveways, parking lots or storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled, macadam or other surfaces which similarly impede the natural infiltration of stormwater. Open, uncovered retention/detention facilities shall not be considered as impervious surfaces.
Impoundment	A natural or man-made containment for surface water.
Improvement	Streets (with or without curbs or gutters), sidewalks, crosswalks, parking lots, water mains, sanitary and storm sewers, drainage facilities, street trees and other appropriate items.
Industrial activities	Material handling, transportation, or storage; manufacturing; maintenance; treatment; or disposal. Areas with industrial activities include plant yards, access roads and rail lines used by carriers of raw materials, manufactured products, waste material, or by-products; material handling sites; refuse sites; sites used for the application or disposal of process waste waters; sites used for the storage and maintenance material handling equipment sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas for raw materials, and intermediate and finished products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to stormwater.
Infiltration	Means the downward movement of water from the surface to the subsoil.

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Infiltration facility (or system)	A drainage facility designed to use the hydrologic process of surface and stormwater runoff soaking into the ground, commonly referred to as a percolation, to dispose of surface and stormwater runoff.
Ingress/egress	The points of access to and from a property.
Inlet	A form of connection between surface of the ground and a drain or sewer for the admission of surface and stormwater runoff.
Insecticide	A substance, usually chemical, that is used to kill insects.
Interception (Hydraulics)	The process by which precipitation is caught and held by foliage, twigs, and branches of trees, shrubs, and other vegetation. Often used for "interception loss" or the amount of water evaporated from the precipitation intercepted.
Interflow	That portion of rainfall that infiltrates into the soil and moves laterally through the upper soil horizons until intercepted by a stream channel or until it returns to the surface for example, in a wetland, spring or seep.
Intermittent stream	A stream or portion of a stream that flows only in direct response to precipitation. It receives little or no water from springs and no long-continued supply from melting snow or other sources. It is dry for a large part of the year, ordinarily more than three months.
Invasive weedy plant species	Opportunistic species of inferior biological value that tend to out-compete more desirable forms and become dominant; applied to non-native species in this manual.
Invert	The lowest point on the inside of a sewer or other conduit.
Invert elevation	The vertical elevation of a pipe or orifice in a pond which defines the water level.
Isopluvial map	A map with lines representing constant depth of total precipitation for a given return frequency.
Lag time	The interval between the center of mass of the storm precipitation and the peak flow of the resultant runoff.
Lake	An area permanently inundated by water in excess of two meters deep and greater than 20 acres in size as measured at the ordinary high water marks.
Land disturbing activity	Any activity that results in a change in the existing soil cover (both vegetative and nonvegetative) and/or the existing soil topography. Land disturbing activities include, but are not limited to demolition, construction, clearing, grading, filling and excavation.

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Landslide	Episodic downslope movement of a mass of soil or rock that includes but is not limited to rockfalls, slumps, mudflows, and earthflows. For the purpose of these rules, snow avalanches are considered to be a special case of landsliding.
Landslide Hazard Areas	Those areas subject to a severe risk of landslide.
Large Parcel Erosion and Sediment Control Plan" or "LPESC Plan"	A plan to implement BMPs to control pollution generated during land disturbing activity. Guidance for preparing a Large Parcel ESC Plan is contained in Chapter II-4. *[Note: Ecology will be adding a sample Large Parcel ESC Plan to the Guidance Manual.]*
Leachate	Liquid that has percolated through soil and contains substances in solution or suspension.
Leaching	Removal of the more soluble materials from the soil by percolating waters.
Legume	A member of the legume or pulse family, Leguminosae, one of the most important and widely distributed plant families. The fruit is a "legume" or pod. Includes many valuable food and forage species, such as peas, beans, clovers, alfalfas, sweet clovers, and vetches. Practically all legumes are nitrogen-fixing plants.
Level spreader	A temporary ESC device used to spread out stormwater runoff uniformly over the ground surface as sheet flow (i.e., not through channels). The purpose of level spreaders are to prevent concentrated, erosive flows from occurring, and to enhance infiltration.
Local government	Any county, city, or town having its own incorporated government for local affairs.
Low flow channel	An incised or paved channel from inlet to outlet in a dry basin which is designed to carry low runoff flows and/or baseflow, directly to the outlet without detention.
Lowest floor	The lowest enclosed area (including basement) of a structure. An area used solely for parking of vehicles, building access, or storage, in an area other than a basement area, is not considered a building's lowest floor, provided that the enclosed area meets all of the structural requirements of the flood hazard standards.
MDNS	A Mitigated Determination of Nonsignificance (See DNS and Mitigation).

Manning's equation (Hydraulics)

An equation used to predict the velocity of water flow in an open channel or pipelines:

$$V = \frac{1.486R^{2/3}S^{1/2}}{n}$$

where:

V is the mean velocity of flow in feet per second

R is the hydraulic radius in feet

S is the slope of the energy gradient or, for assumed uniform flow, the slope of the channel in feet per foot; and

n is Manning's roughness coefficient or retardance factor of the channel lining.

Mass wasting

The movement of large volumes of earth material downslope.

Master Drainage Plan

A comprehensive drainage control plan intended to prevent significant adverse impacts to the natural and manmade drainage system, both on and off-site.

Mean annual water level fluctuation

Derived as follows--

(1) Measure the maximum water level (e.g., with a crest stage gage, Reinelt and Horner 1990) and the existing water level at the time of the site visit (e.g., with a staff gage) on at least eight occasions spread through a year.

(2) Take the difference of the maximum and existing water level on each occasion and divide by the number of occasions.

Mean depth (Hydraulics)

Average depth; cross-sectional area of a stream or channel divided by its surface or top width.

Mean velocity

The average velocity of a stream flowing in a channel or conduit at a given cross-section or in a given reach. It is equal to the discharge divided by the cross-sectional area of the reach.

Measuring weir

A shaped notch through which water flows are measured. Common shapes are rectangular, trapezoidal, and triangular.

Mechanical analysis

The analytical procedure by which soil particles are separated to determine the particle size distribution.

Mechanical practices

Soil and water conservation practices that primarily change the surface of the land or that store, convey, regulate, or dispose of runoff water without excessive erosion.

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Metals — Elements, such as mercury, lead, nickel, zinc and cadmium, that are of environmental concern because they do not degrade over time. Although many are necessary nutrients, they are sometimes magnified in the food chain, and they can be toxic to life in high enough concentrations. They are also referred to as heavy metals.

Mitigation — Means, in the following order of preference:

(a) Avoiding the impact altogether by not taking a certain action or part of an action;

(b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation, by using appropriate technology, or by taking affirmative steps to avoid or reduce impacts;

(c) Rectifying the impact by repairing, rehabilitating or restoring the affected environment;

(d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and

(e) Compensation for the impact by replacing, enhancing, or providing substitute resources or environments.

Modification, Modified (wetland) — A wetland whose physical, hydrological, or water quality characteristics have been purposefully altered for a management purpose, such as by dredging, filling, forebay construction, and inlet or outlet control.

Monitor — To systematically and repeatedly measure something in order to track changes.

Monitoring — The collection of data by various methods for the purposes of understanding natural systems and features, evaluating the impacts of development proposals on such systems, and assessing the performance of mitigation measures imposed as conditions of development.

NGPE — See Native Growth Protection Easement.

NGVD — National Geodetic Vertical Datum (see Base flood elevation).

NPDES — The National Pollutant Discharge Elimination System as established by the Federal Clean Water Act.

National Pollutant Discharge Elimination System (NPDES) — The part of the federal Clean Water Act, which requires point source dischargers to obtain permits. These permits are referred to as NPDES permits and, in Washington State, are administered by the Washington State Department of Ecology.

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Native Growth Protection Easement (NGPE)	An easement granted for the protection of native vegetation within a sensitive area or its associated buffer. The NGPE shall be recorded on the appropriate documents of title and filed with the County Records Division.
Natural location	Means the location of those channels, swales, and other non-manmade conveyance systems as defined by the first documented topographic contours existing for the subject property, either from maps or photographs, or such other means as appropriate.
New development	Land disturbing activities, including Class IV -general forest practices that are conversions from timber land to other uses; structural development, including construction or installation of a building or other structure; creation of impervious surfaces; subdivision, short subdivision and binding site plans, as defined and applied in Chapter58.17 RCW. All other forest practices and commercial agriculture are not considered new development.
Nitrate (NO_3)	A form of nitrogen which is an essential nutrient to plants. It can cause algal blooms in water if all other nutrients are present in sufficient quantities. It is a product of bacterial oxidation of other forms of nitrogen, from the atmosphere during electrical storms and from fertilizer manufacturing.
Nitrification	The biochemical oxidation process by which ammonia is changed first to nitrites and then to nitrates by bacterial action, consuming oxygen in the water.
Nitrogen, Available	Usually ammonium, nitrite, and nitrate ions, and certain simple amines available for plant growth. A small fraction of organic or total nitrogen in the soil is available at any time.
Nonpoint source pollution	Pollution that enters a water body from diffuse origins on the watershed and does not result from discernible, confined, or discrete conveyances.
Normal depth	The depth of uniform flow. This is a unique depth of flow for any combination of channel characteristics and flow conditions. Normal depth is calculated using Manning's Equation.
Nutrients	Essential chemicals needed by plants or animals for growth. Excessive amounts of nutrients can lead to degradation of water quality and algal blooms. Some nutrients can be toxic at high concentrations.
Off-site	Any area lying upstream of the site that drains onto the site and any area lying downstream of the site to which the site drains.

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Off-system storage	Facilities for holding or retaining excess flows over and above the carrying capacity of the stormwater conveyance system, in chambers, tanks, lagoons, ponds, or other basins that are not a part of the subsurface sewer system.
On-site	The entire property that includes the proposed development.
OperationalBMPs	Schedules of activities, prohibition of practices, and other managerial practices to prevent or reduce pollutants from entering stormwater. Operational BMPs are a type of Source Control BMP.
Ordinary High Water Mark	The term ordinary high water mark means the line on the shore established by the fluctuations of water and indicated by physical characteristics such as a clear, natural line impressed on the bank; shelving; changes in the character of soil destruction on terrestrial vegetation, or the presence of litter and debris; or other appropriate means that consider the characteristics of the surrounding area. The ordinary high water mark will be found by examining the bed and banks of a stream and ascertaining where the presence and action of waters are so common and usual, and so long maintained in all ordinary years, as to mark upon the soil a character distinct from that of the abutting upland, in respect to vegetation. In any area where the ordinary high water mark cannot be found, the line of mean high water shall substitute. In any area where neither can be found, the channel bank shall be substituted. In braided channels and alluvial fans, the ordinary high water mark or substitute shall be measured so as to include the entire stream feature.
Orifice	An opening with closed perimeter, usually sharp-edged, and of regular form in a plate, wall, or partition through which water may flow, generally used for the purpose of measurement or control of water.
Outlet	Point of water disposal from a stream, river, lake, tidewater, or artificial drain.
Outlet channel	A waterway constructed or altered primarily to carry water from man-made structures, such as terraces, tile lines, and diversions.
Overflow	A pipeline or conduit device, together with an outlet pipe, that provides for the discharge of portions of combined sewer flows into receiving waters or other points of disposal, after a regular device has allowed the portion of the flow which can be handled by interceptor sewer lines and pumping and treatment facilities to be carried by and to such water pollution control structures.
Overflow rate	Detention basin release rate divided by the surface area of the basin. It can be thought of as an average flow rate through the basin.
Overtopping	To flow over the limits of a containment or conveyance element.

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Peak discharge — The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

Peak-shaving — Controlling post-development peak discharge rates to pre-development levels by providing temporary detention in a BMP.

Percolation — The movement of water through soil.

Percolation rate — The rate, usually expressed as a velocity, at which water moves through saturated granular material.

Permanent Stormwater Quality Control (PSQC) Plan — A plan which includes permanent BMPs for the control of pollution from stormwater runoff after construction and/or land disturbing activity has been completed. For small sites, this requirement is met by implementing a Small Parcel Erosion and Sediment Control Plan. Guidance on preparing a PSQC Plan is contained in Chapter I-3 and Chapter I-4. *[Note: Ecology will add a sample Large Parcel ESC Plan to the Guidance Manual.]*

Permeability rate — The rate at which water will move through a saturated soil. Permeability rates are classified as follows:

a. Very slow - Less than 0.06 inches per hour.
b. Slow - 0.06 to 0.20 inches per hour.
c. Moderately slow - 0.20 to 0.63 inches per hour.
d. Moderate - 0.63 to 2.0 inches per hour.
e. Moderately rapid - 2.0 to 6.3 inches per hour.
f. Rapid - 6.3 to 20.0 inches per hour.
g. Very rapid - More than 20.0 inches per hour.

Permeable soils — Soil materials with a sufficiently rapid infiltration rate so as to greatly reduce or eliminate surface and stormwater runoff. These soils are generally classified as SCS hydrologic soil types A and B.

Person — Any individual, partnership, corporation, association, organization, cooperative, public or municipal corporation, agency of the state, or local government unit, however designated.

Perviousness — Related to the size and continuity of void spaces in soils; related to a soil's infiltration rate.

Pesticide — A general term used to describe any substance - usually chemical - used to destroy or control organisms; includes herbicides, insecticides, algicides, fungicides, and others. Many of these substances are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins which are extracted from plants and animals.

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pH	A measure of the alkalinity or acidity of a substance which is conducted by measuring the concentration of hydrogen ions in the substance. A pH of 7.0 indicates neutral water. A 6.5 reading is slightly acid.
Physiographic	Characteristics of the natural physical environment (including hills).
Planned unit development (PUD)	A special classification authorized in some zoning ordinances, where a unit of land under control of a single developer may be used for a variety of uses and densities, subject to review and approval by the local governing body. The locations of the zones are usually decided on a case-by-case basis.
Plat	A map or representation of a subdivision showing the division of a tract or parcel of land into lots, blocks, streets, or other divisions and dedications.
Plunge pool	A device used to dissipate the energy of flowing water that may be constructed or made by the action of flowing. These facilities may be protected by various lining materials.
Point discharge	The release of collected and/or concentrated surface and stormwater runoff from a pipe, culvert, or channel.
Pollution	Contamination or other alteration of the physical, chemical, or biological properties, of waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive or other substance into any waters of the state as will or is likely to create a nuisance or render such waters harmful, detrimental or injurious to the public health, safety or welfare, or to domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or to livestock, wild animals, birds, fish or other aquatic life.
Pollution-generating impervious surface(PGIS)	Those impervious surfaces considered to be a significant source of pollutants in stormwater runoff. Such surfaces include those which are subject to: vehicular use; industrial activities; or storage of erodible or leachable materials, wastes, or chemicals, and which receive direct rainfall or the run-on or blow-in of rainfall. Metal roofs are also considered to be PGIS unless they are treated to prevent leaching. A surface, whether paved or not, shall be considered subject to vehicular use if it is regularly used by motor vehicles. The following are considered regularly-used surfaces: roads, unvegetated road shoulders, bike lanes within the traveled lane of a roadway, driveways, parking lots, unfenced firelanes, diesel equipment storage yards, and airport runways.

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Pollution-generating impervious surface(PGIS) (continued)	The following are not considered regularly-used surfaces: road shoulders primarily used for emergency parking, paved bicycle pathways, bicycle lanes adjacent to unpaved or paved road shoulders primarily used for emergency parking, fenced firelanes, and infrequently used maintenance access roads.
Pollution-generating pervious surface	Any non-impervious surface subject to use of pesticides and fertilizers or loss of soil. Modified PGPS means any existing PGPS that is re-graded or re-contoured by the proposed project.
Prediction	For the purposes of this document an expected outcome based on the results of hydrologic modelling and/or the judgment of a trained professional civil engineer or geologist.
Pretreatment	The removal of material such as gross solids, grit, grease, and scum from flows prior to physical, biological, or physical treatment processes to improve treatability. Pretreatment may include screening, grit removal, stormwater, and oil separators.
Priority peat systems	Unique, irreplaceable fens that can exhibit water pH in a wide range from highly acidic to alkaline, including fens typified by Sphagnum species, Ledum groenlandicum (Labrador tea), Drosera rotundifolia (sundew), and Vaccinium oxycoccos (bog cranberry); marl fens; estuarine peat deposits; and other moss peat systems with relatively diverse, undisturbed flora and fauna. Bog is the common name for peat systems having the Sphagnum association described, but this term applies strictly only to systems that receive water income from precipitation exclusively.
Professional civil engineer	A person registered with the state of Washington as a professional engineer in civil engineering.
Project	The proposed action of a permit application or an approval which requires a drainage review.
Project site	That portion of a property or properties subject to proposed project improvements including those required by this manual.
Puget Sound basin	Puget Sound south of Admiralty Inlet (including Hood Canal and Saratoga Passage); the waters north to the Canadian border, including portions of the Strait of Georgia; the Strait of Juan de Fuca south of the Canadian border; and all the lands draining into these waters as mapped in Water Resources Inventory Areas numbers 1 through 19, set forth in WAC 173-500-040.
R/D	See Retention/detention facility.

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Rare, threatened, or endangered species	Plant or animal species that are regional relatively uncommon, are nearing endangered status, or whose existence is in immediate jeopardy and is usually restricted to highly specific habitats. Threatened and endangered species are officially listed by federal and state authorities, whereas rare species are unofficial species of concern that fit the above definitions.
Rational method	A means of computing storm drainage flow rates (Q) by use of the formula Q = CIA, where C is a coefficient describing the physical drainage area, I is the rainfall intensity and A is the area. This method is no longer used in the technical manual.
Reach	A length of channel with uniform characteristics.
Receiving waters	Bodies of water or surface water systems receiving water from upstream manmade (or natural) streams.
Recharge	The flow to ground water from the infiltration of surface and stormwater runoff.
Redevelopment	On an already developed site, the creation or addition of impervious surfaces, structural development including construction, installation or expansion of a building or other structure, and/or replacement of impervious surface that is not part of a routine maintenance activity; and land disturbing activities associated with structural or impervious redevelopment.
Regional	An action (here, for stormwater management purposes) that involves more than one discrete property.
Regional detention facility	A stormwater quantity control structure designed to correct existing excess surface water runoff problems of a basin or subbasin. The area downstream has been previously identified as having existing or predicted significant and regional flooding and/or erosion problems. This term is also used when a detention facility is used to detain stormwater runoff from a number of different businesses, developments or areas within a catchment. The use of regional detention facilities may be more efficient than on-site stormwater treatment although the preferred option is to include some on-site stormwater treatment through the use of grassy swales etc. even when regional detention facilities are used.
Release rate	The computed peak rate of surface and stormwater runoff for a particular design storm event and drainage area conditions.
Replaced impervious surface	For structures, the removal and replacement of any exterior surfaces or foundation. For other impervious surfaces, the removal down to bare soil or base course and replacement, excluding impervious surfaces removed for the sole purpose of installing underground utilities.

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Residential density	The number of persons per unit of residential land area. Net density includes only occupied land. Gross density includes unoccupied portions of residential areas, such as roads and open space.
Restoration	Actions performed to reestablish wetland functional characteristics and processes that have been lost by alterations, activities, or catastrophic events in an area that no longer meets the definition of a wetland.
Retention	The process of collecting and holding surface and stormwater runoff with no surface outflow.
Retention/detention facility (R/D)	A type of drainage facility designed either to hold water for a considerable length of time and then release it by evaporation, plant transpiration, and/or infiltration into the ground; or to hold surface and stormwater runoff for a short period of time and then release it to the surface and stormwater management system.
Retrofitting	The renovation of an existing structure or facility to meet changed conditions or to improve performance.
Return interval	A statistical term for the average time of expected interval that an event of some kind will equal or exceed given conditions (e.g., a stormwater flow that occurs every 2 years).
Rhizome	A modified plant stem that grows horizontally underground.
Riffles	Fast sections of a stream where shallow water races over stones and gravel. Riffles usually support a wider variety of bottom organisms than other stream sections.
Rill	A small intermittent watercourse with steep sides, usually only a few inches deep. Often rills are caused by an increase in surface water flow when soil is cleared of vegetation.
Riprap	A facing layer or protective mound of stones placed to prevent erosion or sloughing of a structure or embankment due to flow of surface and stormwater runoff.
Riparian	Pertaining to the banks of streams, wetlands, lakes or tidewater.
Riser	A vertical pipe extending from the bottom of a pond BMP that is used to control the discharge rate from a BMP for a specified design storm.
Rodenticide	A substance used to destroy rodents.
Runoff	Water originating from rainfall and other precipitation that is found in drainage facilities, rivers, streams, springs, seeps, ponds, lakes and wetlands as well as shallow ground water.
SCS	Soil Conservation Service, U.S. Department of Agriculture.

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SCS Method	A hydrologic analysis based on the Curve Number method (National Engineering Handbook - Section 4: Hydrology, August 2971).
SEPA	See State Environmental Policy Act.
Salmonid	A member of the fish family Salmonidae. Chinook, coho, chum, sockeye and pink salmon; cutthroat, brook, brown, rainbow and steelhead trout; Dolly Varden, kokanee and char are examples of salmonid species.
Saturation point	In soils, the point at which a soil or an aquifer will no longer absorb any amount of water without losing an equal amount.
Scour	Erosion of channel banks due to excessive velocity of the flow of surface and stormwater runoff.
Sediment	Fragmented material that originates from weathering and erosion of rocks or unconsolidated deposits, and is transported by, suspended in, or deposited by water.
Sedimentation	The depositing or formation of sediment.
Sensitive emergent vegetation communities	Assemblages of erect, rooted, herbaceous vegetation, excluding mosses and lichens, at least some of whose members have relatively narrow ranges of environmental requirements, such as hydroperiod, nutrition, temperature, and light. Examples include fen species such as sundew and, as well as a number of species of Carex (sedges).
Sensitive life stages	Stages during which organisms have limited mobility or alternatives in securing the necessities of life, especially including reproduction, rearing, and migration periods.
Sensitive scrub-shrub vegetation communities	Assemblages of woody vegetation less than 6 meters in height, at least some of whose members have relatively narrow ranges of environmental requirements, such as hydroperiod, nutrition, temperature, and light. Examples include fen species such as Labrador tea, bog laurel, and cranberry.
Settleable solids	Those suspended solids in stormwater that separate by settling when the stormwater is held in a quiescent condition for a specified time.
Sheet erosion	The relatively uniform removal of soil from an area without the development of conspicuous water channels.
Sheetflow	Runoff which flows over the ground surface as a thin, even layer, not concentrated in a channel.

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Shoreline development	The proposed project as regulated by the Shoreline Management Act. Usually the construction over water or within a shoreline zone (generally 200 feet landward of the water) of structures such as buildings, piers, bulkheads, and breakwaters, including environmental alterations such as dredging and filling, or any project which interferes with public navigational rights on the surface waters.
Short circuiting	The passage of runoff through a BMP in less than the design treatment time.
Siltation	The process by which a river, lake, or other water body becomes clogged with sediment. Silt can clog gravel beds and prevent successful salmon spawning.
Site	A property which is subject to development.
Slope	Degree of deviation of a surface from the horizontal; measured as a numerical ratio, percent, or in degrees. Expressed as a ratio, the first number is the horizontal distance (run) and the second is the vertical distance (rise), as 2:1. A 2:1 slope is a 50 percent slope. Expressed in degrees, the slope is the angle from the horizontal plane, with a 90° slope being vertical (maximum) and 45° being a 1:1 or 100 percent slope.
Sloughing	The sliding of overlying material. It is the same effect as caving, but it usually occurs when the bank or an underlying stratum is saturated or scoured.
Small Parcel	Single family residential and small subdivision projects that add less than 10,000 ft2 of impervious surface and disturb less than 1 acre. Other types of development projects that add less than 5,000 ft2 of impervious surface and disturb less than 1 acre.
Soil	The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.
Soil group, hydrologic	A classification of soils by the Soil Conservation Service into four runoff potential groups. The groups range from A soils, which are very permeable and produce little or no runoff, to D soils, which are not very permeable and produce much more runoff.
Soil horizon	A layer of soil, approximately parallel to the surface, that has distinct characteristics produced by soil-forming factors.
Soil profile	A vertical section of the soil from the surface through all horizons, including C horizons.

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Soil structure	The relation of particles or groups of particles which impart to the whole soil a characteristic manner of breaking; some types are crumb structure, block structure, platy structure, and columnar structure.
Soil permeability	The ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil.
Soil stabilization	The use of measures such as rock lining, vegetation or other engineering structures to prevent the movement of soil when loads are applied to the soil.
Sorption	The physical or chemical binding of pollutants to sediment or organic particles.
Source control BMP	A BMP that is intended to prevent pollutants from entering stormwater. A few examples of source control BMPs are erosion control practices, maintenance of stormwater facilities, constructing roofs over storage and working areas, and directing wash water and similar discharges to the sanitary sewer or a dead end sump.
Specific energy	The total energy within any system with respect to the channel bottom, equal to the potential head plus velocity and pressure heads.
Spillway	A passage such as a paved apron or channel for surplus water over or around a dam or similar obstruction. An open or closed channel, or both, used to convey excess water from a reservoir. It may contain gates, either manually or automatically controlled, to regulate the discharge of excess water.
State Environmental Policy Act (SEPA)	The Washington State law intended to minimize environmental damage. SEPA requires that state agencies and local governments consider environmental factors when making decisions on activities, such as development proposals over a certain size and comprehensive plans. As part of this process, environmental documents are prepared and opportunities for public comment are provided.
Steep slope	Slopes of 40 percent gradient or steeper.
Storm drains	The enclosed conduits that transport surface and stormwater runoff toward points of discharge (sometimes called storm sewers).
Storm drain system	Refers to the system of gutters, pipes, streams, or ditches used to carry surface and stormwater from surrounding lands to streams, lakes, or Puget Sound.
Storm frequency	The time interval between major storms of predetermined intensity and volumes of runoff for which storm sewers and other structures are designed and constructed to handle hydraulically without surcharging and backflooding, e.g., a 2-year, 10-year or 100-year storm.

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Storm sewer	A sewer that carries stormwater and surface water, street wash and other wash waters or drainage, but excludes sewage and industrial wastes. Also called a storm drain.
Stormwater	That portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, channels or pipes into a defined surface water channel, or a constructed infiltration facility.
Stormwater drainage system	constructed and natural features which function together as a system to collect, convey, channel, hold, inhibit, retain, detain, infiltrate, divert, treat or filter stormwater.
Stormwater facility	A constructed component of a stormwater drainage system, designed or constructed to perform a particular function, or multiple functions. Stormwater facilities include, but are not limited to, pipes, swales, ditches, culverts, street gutters, detention basins, retention basins, constructed wetlands, infiltration devices, catchbasins, oil/water separators, sediment basins and modular pavement.
Stormwater Management Manual for the Puget Sound Basin or "Manual"	this manual as prepared by Ecology that contains BMPs to prevent, control or treat pollution in stormwater [or a technically equivalent Manual approved by Ecology].
Stormwater Program	Either the Basic Stormwater Program or the Comprehensive Stormwater Program as appropriate to the context of the reference. See the "Stormwater Program Guidance Manual for the Puget Sound Basin" for a complete description of the requirements of each program.
Stormwater Site Plan	a plan which includes an Erosion and Sediment Control (ESC) Plan and/or a Permanent Stormwater Quality Control Plan (PSQC). For small sites, this plan is the equivalent of a Small Parcel Erosion and Sediment Control Plan. Guidance on preparing a Stormwater Site Plan is contained in Chapter I-3.
Stream gaging	The quantitative determination of stream flow using gages, current meters, weirs, or other measuring instruments at selected locations. See Gaging station.
Streambanks	The usual boundaries, not the flood boundaries, of a stream channel. Right and left banks are named facing downstream.

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Stream classification

The following stream classification which applies to all streams.

1. Type 1 streams are all streams inventoried as Shorelines of the State under Chapter 90.58 RCW.
2. Type 2 streams are all streams smaller than Type 1 streams that flow year around during years of normal rainfall, or are used by salmonids.
3. Type 3 streams are streams that are intermittent or ephemeral during years of normal rainfall and are not used by salmonids.

Streams

Those areas where surface waters flow sufficiently to produce a defined channel or bed. A defined channel or bed is indicated by hydraulically sorted sediments or the removal of vegetative litter or loosely rooted vegetation by the action of moving water. The channel or bed need not contain water year-round. This definition is not meant to include irrigation ditches, canals, stormwater runoff devices or other entirely artificial watercourses unless they are used to convey Type 1 and 2 streams naturally occurring prior to construction. Those topographic features that resemble streams but have no defined channels (i.e. swales) shall be considered streams when hydrologic and hydraulic analyses done pursuant to a development proposal predict formation of a defined channel after development.

Structure

A catchbasin or manhole in reference to a storm drainage system.

Structural Source Control BMPs

Physical, structural, or mechanical devices that are intended to prevent pollutants from entering stormwater.

Stub-out

A short length of pipe provided for future connection to a storm drainage system.

Subbasin

A drainage area which drains to a water course or waterbody named and noted on common maps and which is contained within a basin.

Subcatchment

A subdivision of a drainage basin (generally determined by topography and pipe network configuration).

Subcritical flow

Flow at depths greater than the critical depth.

Sub-division retention/detention facility

A retention/detention facility which is both (1) located within or associated with a short or formal plat sub-division containing only single family or duplex residential structures located on individual lots; and 2) which is required to handle excess runoff generated by development of an area of which two-thirds or more is designated for single family or duplex residential structures located on individual lots.

Subdrain

A pervious backfilled trench containing stone or a pipe for intercepting ground water or seepage.

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Subgrade	A layer of stone or soil used as the underlying base for a BMP.
Subsoil	The B horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the soil below the plowed soil (or its equivalent of surface soil), in which roots normally grow. Although a common term, it cannot be defined accurately. It has been carried over from early days when "soil" was conceived only as the plowed soil and that under it as the "subsoil."
Substrate	The natural soil base underlying a BMP.
Supercritical flow	Flow at depths less than the critical depth.
Surcharge	The flow condition occurring in closed conduits when the hydraulic grade line is above the crown of the sewer.
Surface and stormwater	Water originating from rainfall and other precipitation that is found in drainage facilities, rivers, streams, springs, seeps, ponds, lakes, and wetlands as well as shallow ground water.
Surface and stormwater management system	Drainage facilities and any other natural features which collect, store, control, treat and/or convey surface and stormwater.
Suspended solids	Organic or inorganic particles that are suspended in and carried by the water. The term includes sand, mud, and clay particles (and associated pollutants) as well as solids in stormwater.
Swale	A shallow drainage conveyance with relatively gentle side slopes, generally with flow depths less than one foot.
Terrace	An embankment or combination of an embankment and channel across a slope to control erosion by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope.
Threshold Discharge Area	An onsite area draining to a single natural discharge location or multiple natural discharge locations that combine within one-quarter mile downstream (as determined by the shortest flowpath). The examples below illustrate this definition. The purpose of this definition is to clarify how the thresholds of this manual are applied to project sites with multiple discharge points.

Drawings of three different situations depicting the relationship of project sites, natural discharge locations, and threshold discharge areas.

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Tile, Drain	Pipe made of burned clay, concrete, or similar material, in short lengths, usually laid with open joints to collect and carry excess water from the soil.
Tile drainage	Land drainage by means of a series of tile lines laid at a specified depth and grade.
Time of concentration	The time period necessary for surface runoff to reach the outlet of a subbasin from the hydraulically most remote point in the tributary drainage area.
Toe of slope	A point or line of slope in an excavation or cut where the lower surface changes to horizontal or meets the exiting ground slope.
Top of slope	A point or line on the upper surface of a slope where it changes to horizontal or meets the original surface.
Topography	General term to include characteristics of the ground surface such as plains, hills, mountains; degree of relief, steepness of slopes, and other physiographic features.
Total dissolved solids	The dissolved salt loading in surface and subsurface waters.
Total solids	The solids in water, sewage, or other liquids, including the dissolved, filterable, and nonfilterable solids. The residue left when the moisture is evaporated and the remainder is dried at a specified temperature, usually 130°C.
Toxic	Poisonous, carcinogenic, or otherwise directly harmful to life.
Tract	A legally created parcel of property designated for special nonresidential and noncommercial uses.
Trash rack	A structural device used to prevent debris from entering a spillway or other hydraulic structure.
Travel time	The estimated time for surface water to flow between two points of interest.
Treatment BMP	A BMP that is intended to remove pollutants from stormwater. A few examples of treatment BMPs are detention ponds, oil/water separators, biofiltration swales and constructed wetlands.
Turbidity	Dispersion or scattering of light in a liquid, caused by suspended solids and other factors; commonly used as a measure of suspended solids in a liquid.
Underdrain	Plastic pipes with holes drilled through the top, installed on the bottom of an infiltration BMP which are used to collect and remove excess runoff.

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Undisturbed buffer	A zone where development activity shall not occur, including logging, and/or the construction of utility trenches, roads, and/or surface and stormwater facilities.
Undisturbed low gradient uplands	Forested land, sufficiently large and flat to infiltrate surface and storm runoff without allowing the concentration of water on the surface of the ground.
Unstable slopes	Those sloping areas of land which have in the past exhibited, are currently exhibiting, or will likely in the future exhibit, mass movement of earth.
Unusual biological community types	Assemblages of interacting organisms that are relatively uncommon regionally.
Urbanized area	Areas designated and identified by the U.S. Bureau of Census according to the following criteria: an incorporated place and densely settled surrounding area that together have a maximum population of 50,000.
USEPA	The United States Environmental Protection Agency.
Values	Wetland processes or attributes that are valuable or beneficial to society (also see Functions). Wetland values include support of commercial and sport fish and wildlife species, protection of life and property from flooding, recreation, education, and aesthetic enhancement of human communities.
Vegetation	All organic plant life growing on the surface of the earth.
Water body	Surface waters including rivers, streams, lakes, marine waters, estuaries, and wetlands.
Water quality	A term used to describe the chemical, physical, and biological characteristics off water, usually in respect to its suitability for a particular purpose.
Water quality BMP	A BMP specifically designed for pollutant removal.
Water quality design storm	The 6-month 24-hour design storm.
Water quality standards	Minimum requirements of purity of water for various uses; for example, water for agricultural use in irrigation systems should not exceed specific levels of sodium bicarbonate, pH, total dissolved salts, etc. In Washington, the Department of Ecology sets water quality standards.
Water quality swale	An open vegetated drainage channel intended to optimize water quality treatment of surface and stormwater runoff by following the specific design criteria described in the manual.

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Watershed	A geographic region within which water drains into a particular river, stream, or body of water as identified and numbered by the State of Washington Water Resource Inventory Areas (WRIAs) as defined in Chapter 173-500 WAC.
Water table	The upper surface or top of the saturated portion of the soil or bedrock layer, indicates the uppermost extent of ground water.
Weir	Device for measuring or regulating the flow of water.
Weir notch	The opening in a weir for the passage of water.
Wetlands	Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. This includes wetlands created, restored or enhanced as part of a mitigation procedure. This does not include constructed wetlands or the following surface waters of the state intentionally constructed from sites that are not wetlands: Irrigation and drainage ditches, grass-lined swales, canals, agricultural detention facilities, farm ponds, and landscape amenities.
Wetland edge	Delineation of the wetland edge shall be based on the U.S. Army Corps of Engineers Wetlands Delineation Manual, Technical Report Y-87-1, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Miss. (1987)
Wetponds and wetvaults	Drainage facilities for water quality treatment that contain permanent pools of water that are filled during the initial runoff from a storm event. They are designed to optimize water quality by providing retention time in order to settle out particles of fine sediment to which pollutants such as heavy metals absorb, and to allow biologic activity to occur that metabolizes nutrients and organic pollutants.
Zoning ordinance	An ordinance based on the police power of government to protect the public health, safety, and general welfare. It may regulate the type of use and intensity of development of land and structures to the extent necessary for a public purpose. Requirements may vary among various geographically defined areas called zones. Regulations generally cover such items as height and bulk of buildings, density of dwelling units, off-street parking, control of signs, and use of land for residential, commercial, industrial, or agricultural purposes. A zoning ordinance is one of the major methods for implementation of a comprehensive plan.

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Notations

This list of notations is provided only as a guide to some of the notations used in this report. The exact definition and units are listed when the symbol is used. Since the same symbol can be used for different design methods, the exact definition should be obtained directly from the appropriate section of the report.

A = drainage area (mi^2), also full cross-sectional area of culvert barrel (ft^2)

A_b = top surface area of basin (ft^2), also area of pond bottom (ft^2)

A_d = drainage area

A_p = surface area of porous asphalt pavement (ft^2)

A_s = surface area of swale (ft^2), also average surface area for detention BMP

A_t = total area (acres)

C = estimated runoff coefficient

CN = SCS runoff curve number

ΔCN = change in curve number

D = interior height of culvert barrel (ft)

D_{50} = median stone diameter (riprap)

d = average permanent pool depth of a detention BMP

d_b = basin depth (ft)

d_c = critical depth (ft)

d_p = depth of porous asphalt paving stone subbase (ft)

d_s = depth of swale check dam (ft)

dt = time interval in minutes

d_x = a mixture of riprap sizes where the percent of stone by weight is <x (the specified diameter)

E = designated fraction of particulates to be removed by a BMP

f = final infiltration rate of soil (in/hr)

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f_d	=	infiltration rate including a safety factor of two
g	=	acceleration due to gravity, 32.2 ft/sec^2
H	=	stage height (ft) or water depth above pond bottom, also $H = H_f + H_e + H_{ex}$; head on orifice
H_c	=	specific head at critical depth ($d_c + V_c^2/2g$) (ft)
H_d	=	design depth of pond
H_e	=	entrance head loss (ft) = $K_e(V^2/2g)$
H_{ex}	=	exit head loss (ft) = $V^2/2g$
H_f	=	Friction loss (ft) = $V^2n^2L/2.22R^{1.35}$ Note: if (H_f + TW - LS) <D, adjust H_f such that (H_f + TW - LS) = D. This will keep the analysis simple and still yield reasonable results (erring on the conservative side)
HW	=	headwater depth above inlet invert (ft)
h_b	=	distance from the hydraulic grade line at the 2-year flow on the outflow pipe to the overflow elevation
I	=	inflow at time 1 and time 2
I(t)	=	instantaneous hydrograph, in cfs (SBUH hydrograph method)
i	=	hydraulic gradient (ft/ft)
K_e	=	entrance loss coefficient
k	=	time of concentration velocity factor (feet/second)
k_c	=	time of concentration velocity factor; channel flow
k_s	=	time of concentration velocity factor; shallow flow
L	=	distance of flow across a given segment, also length of culvert (ft), also width of emergency overflow weir
MB_{el}	=	mean tributary basin elevation above sea level (ft)
M_s	=	potential average snowmelt during storms (in)
m	=	number of flow segments
N_s	=	number of check dams along total length of swale

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n	=	Manning's "n"
n_s	=	sheet flow; Manning's effective roughness coefficient
O	=	outflow at time 1 and time 2
P	=	rainfall depth (inches)
P_R	=	the total precipitation at a site for the 24-hour design storm event for the given return frequency (R)
Q	=	flow or discharge (cfs), also runoff depth from overlying area of dry well (ft), also orifice area
Q_a	=	after development depth of runoff (inches)
Q_b	=	before development depth of runoff (inches)
Q_c	=	depth of runoff from contributing area (ft)
Q_d	=	runoff depth in inches over a given area
Q_o	=	average release rate from detention BMP
Q_s	=	depth of runoff controlled by vegetated swale (inches)
Q_t	=	release rate for orifice
Q_{total}	=	total flow at maximum head
Q(t)	=	the routed flow of the runoff hydrograph (SBUH method)
$Q_{10\%}$	=	the flow that is not exceeded more than 10% of the time during the months of adult (salmonid) migration
ΔQ	=	change in runoff depth (inches)
Δq	=	change in peak discharge (cfs)
R	=	hydraulic radius (ft) in Manning's equation
R(t)	=	the total runoff depth at time increment dt, in inches; also known as precipitation excess
S	=	storage at time 1 and time 2, also culvert barrel slope (ft/ft)
S(H)	=	storage (ft^3) at stage height (H)
S_d	=	the largest volume from an initial pond sizing

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s_f	=	friction slope = $n^2V^2/2.21R^{4/3}$
s_o	=	slope of flow path (ft/ft), also bottom slope
T	=	width of swale or vegetated filter strip
T_c	=	time of concentration (hrs)
T_t	=	travel time of overland flow across separate flow path segments
$T_{1,2,n}$	=	the consecutive flow paths of different land cover categories having significant differences in flow path slope
TW	=	tailwater depth above invert of culvert outlet (ft) Note: if TW < $(D + d_c)/2$, set TW = $(D + d_c)/2$.
t_d	=	design detention time of a BMP
Δt	=	time interval; time 2 - time 1
V	=	average velocity across the land cover (ft/sec), also barrel velocity (fps), also mean velocity
V_c	=	flow velocity at critical depth (fps)
V_{max}	=	maximum allowed velocity of runoff in a biofilter
V_{pp}	=	permanent pool volume
V_r	=	void ratio
V_{sed}	=	settling velocity of the deign soil particle
W_{50}	=	the median stone size (riprap)
w	=	settling velocity of target particle
y	=	depth of flow
y_n	=	normal flow depth
Z	=	basin side slope ratio (h:v)
Z^1, Z^2	=	side slope ratio of swale cross section (h:v)
α	=	energy coefficient which corrects for the non-uniform distribution of velocity over the channel cross-section

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Draft

Phase I Municipal Stormwater NPDES and State Waste Discharge General Permit

February 15, 2006

Permit No._____

Coverage Date_____

Issuance Date:
Effective Date:
Expiration Date:

National Pollutant Discharge Elimination System and State Waste Discharge General Permit for Discharges from Large and Medium Municipal Separate Storm Sewer Systems

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
OLYMPIA, WASHINGTON 98504-7600

In compliance with the provisions of
The State of Washington Water Pollution Control Law
Chapter 90.48 Revised Code of Washington
and
The Federal Water Pollution Control Act
(The Clean Water Act)
Title 33 United States Code, Section 1251 et seq.

Until this permit expires, is modified, or revoked, Permittees that have properly obtained coverage under this permit are authorized to discharge to waters of the state in accordance with the special and general conditions which follow.

_____

Dave C. Peeler
Water Quality Program Manager
Department of Ecology

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[1] Terms that are included in the definitions and acronyms section are indicated in italics the first time they are used in the text of the permit.

SPECIAL CONDITIONS

S1. PERMIT COVERAGE AND PERMITTEES

A. Permit Coverage Area
This permit covers *discharges* from Large and Medium Municipal Separate Storm Sewer Systems (MS4s) as established at Title *40 CFR* 122.26, except for municipal separate storm sewers (MS3s) owned or operated by the Washington State Department of Transportation. Large and medium MS4s include all MS3s located within cities or counties required to have permit coverage.

B. The following entities had coverage under a previous municipal *stormwater* permit and reapplied for coverage. Their coverage date under this permit begins on the effective date of this permit. These entities are covered under this permit as Permittees:

- The City of Seattle
- The City of Tacoma
- King County
- Snohomish County
- Pierce County
- Clark County

C. King County had coverage under a previous municipal stormwater permit, as a *Co-Permittee* with the City of Seattle, and reapplied for coverage. Their coverage date under this permit begins on the effective date of this permit. King County is covered as a Co-Permittee with the City of Seattle for discharges it owns or operates in the City of Seattle.

D. Upon application and coverage in accordance with Special Condition S1.F, the following entities are covered under this permit as *Secondary Permittees*:

1. Port of Seattle, excluding Seattle-Tacoma International Airport
2. Port of Tacoma
3. Drainage, diking, flood control, or diking and drainage districts located in the Cities or unincorporated portions of the Counties listed in S1.B., above, which own or operate municipal separate storm sewers serving non-agricultural land uses.
4. Other owners or operators of municipal separate storm sewers located in the Cities or unincorporated portions of the Counties listed in S1.B., above.

E. Unless otherwise noted, the term "Permittee" shall include Permittee, Co-Permittee, and Secondary Permittee, as defined above in Special Conditions S1.B., S1.C. and S1.D.

F. Coverage for Secondary Permittees

1. To obtain coverage under this permit, each secondary Permittee identified under Special Condition S1.D shall either:

   a. Submit a *Notice of Intent* (NOI) and provide public notice of the application for coverage in accordance with WAC 173-226-130. The NOI shall constitute the application for coverage. Ecology will notify applicants in writing of their status concerning coverage under this permit within 90 days of Ecology's receipt of the NOI and demonstration that the public notice requirements have been met. OR

   b. Submit a co-application jointly with a permittee named in S1.B. and provide public notice of the application for coverage in accordance with WAC 173-226-130. The co-application shall consist of an amendment to the Phase I Part 1 and Part 2 permit applications. Ecology will notify applicants in writing of their status concerning coverage under this permit within 90 days of Ecology's receipt of the NOI and demonstration that the public notice requirements have been met.

2. NOIs and co-applications shall be submitted to:

   Department of Ecology
   Water Quality Program
   Municipal Stormwater Permit Program
   P.O. Box 47696
   Olympia, WA 98504-7696

S2. AUTHORIZED DISCHARGES

A. This permit authorizes the discharge of stormwater to surface waters and to ground *waters of the state* from municipal separate storm sewers owned or operated by each Permittee covered under this permit in the geographic area covered by this permit pursuant to S1.A, subject to the following limitations:

   1. All discharges into and from municipal separate storm sewers owned or operated by Permittees must be in compliance with this permit.

   2. Discharges from municipal separate storm sewers constructed after the effective date of this permit must receive all applicable state and local permits and use authorizations, including compliance with Ch. 43.21C RCW (the State Environmental Policy Act).

   3. Discharges to ground waters of the state through facilities regulated under the Underground Injection Control (UIC) program, Chapter 173-218 WAC, are not covered under this permit.

   4. Discharges to ground waters not subject to regulation under the federal *Clean Water Act* are covered in this permit only under state authorities, Chapter 90.48 RCW, the Water Pollution Control Act

B. This permit authorizes discharges of *stormwater associated with industrial and construction activity* and *process wastewater* discharges from municipal separate storm

sewers owned or operated by the Permittee to waters of the state only under the following conditions:

1. Stormwater associated with construction or industrial activity, as defined by 40CFR122.26, must be authorized by a separate individual or general *National Pollutant Discharge Elimination* (NPDES) permit; or

2. Process wastewater must be authorized by another NPDES permit.

C. This permit authorizes discharges from emergency fire fighting activities unless the discharges from fire fighting activities are identified as significant sources of pollutants to waters of the State.

D. This permit does not authorize any other illicit or non-stormwater discharges except as provided in Special Condition S5.C.8 or S6., nor does it relieve entities responsible for illicit discharges, including spills of oil or hazardous substances, from responsibilities and liabilities under state and federal laws and regulations pertaining to those discharges.

S3. RESPONSIBILITIES OF PERMITTEES, CO-PERMITTEES, AND SECONDARY PERMITTEES

A. Each Permittee, Co-Permittee and Secondary Permittee is responsible for compliance with the terms of this permit for the municipal separate storm sewers it owns or operates.

1. Each Permittee, as listed in S1.B., is required to comply with all conditions of this permit, except for S6., *Stormwater management program* for Co-Permittees and Secondary Permittees.

2. Each Co-Permittee and Secondary Permittee, as defined in S1.C. and S1.D., is required to comply with all conditions of this permit, except for Special Condition S5., Stormwater management program for Permittees. This provision includes Secondary Permittees that co-apply under Special Condition S1.F.1.b.

B. Permittees may rely on another *entity* to meet one or more of the requirements of this permit, if the other entity, in fact, implements the control measure, and agrees to implement the control measure on the Permittee's behalf. Permittees that are relying on another entity to satisfy one or more or their permit obligations remain responsible for permit compliance if the other entity fails to implement the permit conditions. Where permit responsibilities are shared they must be documented as follows:

1. Permittees and Co-Permittees that are continuing coverage under this permit must submit a statement that describes the permit requirements that will be implemented by other entities. The statement must be signed by all participating entities. There is no deadline for submitting such a statement, provided that this does not alter implementation deadlines.

2. Secondary Permittees must submit an NOI that describes which requirements they will implement and identify the entities that will implement the other permit requirements in the area served by the secondary Permittee's MS4. A statement

confirming the shared responsibilities, signed all participating entities, must accompany the NOI. Secondary Permittees may amend their NOI, during the term of the permit, to establish, terminate, or amend shared responsibility arrangements, provided this does not alter implementation deadlines.

C. Unless otherwise noted, all appendices to this permit are incorporated by this reference as if set forth fully within this permit.

S4. COMPLIANCE WITH STANDARDS

A. In accordance with RCW 90.48.520, the discharge of toxicants to waters of the state of Washington which would violate any *water quality standard*, including toxicant standards, sediment criteria, and dilution zone criteria is prohibited.

B. This permit does not authorize a violation of Washington State surface water quality standards (Chapter 173-201A WAC), ground water quality standards (Chapter 173-200 WAC), sediment management standards (chapter 173-204 WAC), or human health-based criteria in the national Toxics Rule (Federal Register, Vol. 57, NO. 246, Dec. 22, 1992, pages 60848-60923).

C. The Permittee shall reduce the discharge of pollutants to the *maximum extent practicable* (MEP).

D. The Permittee shall use *all known, available, and reasonable methods of prevention, control and treatment (AKART*) to prevent and control pollution of waters of the state of Washington.

E. In order to meet the goals of the Clean Water Act, to demonstrate compliance with S4.C and S4.D, and make progress towards compliance with applicable surface water, ground water and sediment management standards, each Permittee shall comply with the requirements of this permit.

F. Ecology may modify or revoke and reissue this *general permit* in accordance with General Condition G14. GENERAL PERMIT MODIFICATION AND REVOCATION, if Ecology becomes aware of additional control measures, management practices or other actions beyond what is required in this permit, that are necessary to:

1. Reduce the discharge of pollutants to the MEP;
2. Comply with the state AKART requirements; or
3. Control the discharge of toxicants to waters of the state of Washington.

S5. STORMWATER MANAGEMENT PROGRAM

A. Each Permittee shall implement a Stormwater Management Program (SWMP) during the term of this permit. For the purpose of this permit a stormwater management program is a set of actions comprising the *components* listed in S5.B., S5.C.1 through S5.C.10., and additional actions and activities, where necessary, to meet the requirements of *applicable TMDLs*.

1. Each Permittee shall prepare written documentation of their SWMP and submit it to Ecology in written and electronic formats with the first year annual report, in accordance with the requirements in S9 Reporting Requirements. The documentation of the SWMP shall be organized according to the program components in S5.C., and shall be updated annually. The SWMP documentation shall include a description of each of the program components included in S5.C, and any additional actions necessary to meet the requirements of applicable TMDLs.

2. Each permittee shall track the cost of development and implementation of the SWMP required by this section. This information shall be included in the annual report.

3. Each Permittee shall track the number of inspections, official enforcement actions and types of public education activities as stipulated by the respective program component. This information shall be included in the annual report.

B. The SWMP shall be designed to reduce the discharge of pollutants from MS4s to the maximum extent practicable, meet state AKART requirements, and protect water quality.

Permittees are to continue implementation of existing stormwater management programs until they begin implementation of the updated stormwater management program in accordance with the terms of this permit, including implementation schedules.

C. The SWMP shall include the components listed below. All components are mandatory and must be implemented by each Permittee within the limits of state and federal law. The requirements of the stormwater management program shall apply to municipal separate storm sewers and areas served by municipal separate storm sewers owned or operated by each Permittee. Co-Permittees and Secondary Permittees are responsible for implementation of Stormwater Management Programs as indicated in Special Condition S6.

1. Legal Authority

a. No later than the effective date of this permit, each Permittee must be able to demonstrate that they can operate pursuant to legal authority which authorizes or enables the Permittee to control discharges to and from municipal separate storm sewers owned or operated by the Permittee.

b. This legal authority, which may be a combination of statute, ordinance, permit, contracts, orders, interagency agreements, or similar means, shall authorize or enable the Permittee, at a minimum, to:

i. Control the contribution of pollutants to municipal separate storm sewers owned or operated by the Permittee from stormwater discharges associated with industrial activity, and control the quality of stormwater discharged from sites of industrial activity;

ii. Prohibit illicit discharges to the municipal separate storm sewer owned or operated by the Permittee;

iii. Control the discharge of spills and the dumping or disposal of materials other than stormwater into the municipal separate storm sewers owned or operated by the Permittee;

iv. Control through interagency agreements among co-applicants, the contribution of pollutants from one portion of the municipal separate storm sewer system to another portion of the municipal separate storm sewer system;

v. Require compliance with conditions in ordinances, permits, contracts, or orders; and,

vi. Within the limitations of state law, carry out all inspection, surveillance, and monitoring procedures necessary to determine compliance and non-compliance with permit conditions, including the prohibition on illicit discharges to the municipal separate storm sewer and compliance with local ordinances.

2. Municipal Separate Storm Sewer System Mapping and Documentation

a. The SWMP shall include an ongoing program for mapping and documenting the MS4.

b. Minimum performance measures. The information and its form of retention shall include:

i. No later than 2 years from the effective date of this permit each permittee shall map all known municipal separate storm sewer *outfalls* and receiving waters, and structural stormwater BMPs owned, operated, or maintained by the Permittee.

ii. No later than 4 years from the effective date of this permit each permittee shall map the attributes listed below for all storm sewer outfalls with a 24" inches nominal diameter or larger, or an equivalent cross-sectional area for non-pipe systems. For Counties, the mapping shall be done within *urban/higher density rural sub-basins*. For Cities, the mapping shall be done throughout the City.

(1) Tributary conveyances (indicate type, material, and size where known);

(2) Associated drainage areas; and

(3) Land use.

iii. Each Permittee shall initiate a program to develop and maintain a map of all connections to the municipal separate storm sewer authorized or allowed by the permittee after the effective date of this permit.

iv. Each Permittee shall map existing connections over 8" to municipal separate storm sewers tributary to all storm sewer outfalls with a 24" inches nominal

diameter or larger, or an equivalent cross-sectional area for non-pipe systems, according to the following schedule:

City of Seattle and City of Tacoma: 2 years after the effective date of this permit

Snohomish, King, Pierce and Clark Counties: one half the area of the County within urban/higher density rural subbasins 4 years after the effective date of this permit.

v. No later than 4 years from the effective date of this permit each permittee shall map geographic areas served by the Permittee's MS4 that do not discharge stormwater to surface water.

vi. Each Permittee shall make available to Ecology, upon request, available maps depicting the information required in S5.C.2b.i. through v., above. The preferred format of submission will be an electronic format with fully described mapping standards. An example description is provided at http://www.ecy.wa.gov/services/gis/data/standards.htm where the preferred standards are described. Notification of updated GIS data layers shall be included in annual reports.

vii. Upon request, and to the extent appropriate, Permittees shall provide mapping information to Co-Permittees and Secondary Permittees.

3. Coordination

a. The SWMP shall include coordination mechanisms among entities covered under a municipal stormwater NPDES permit to encourage coordinated stormwater-related policies, programs and projects within a watershed. The SWMP shall also include coordination mechanisms among departments within each jurisdiction to eliminate barriers to compliance with the terms of this permit.

b. Minimum Performance Measures:

i. No later than 12 months after the effective date of this permit, establish, in writing, and begin implementation of, intragovernmental (internal) coordination agreement to facilitate compliance with the terms of this permit.

ii. No later than 12 months after the effective date of this permit, establish, in writing, and begin implementation of, intergovernmental coordination procedures on stormwater management, including

- Coordination mechanisms clarifying roles and responsibilities to for the control of pollutants between *physically interconnected* MS3s of the Permittee and any other Permittee covered by a municipal stormwater permit.

- Coordinating stormwater management activities, for *shared waterbodies,* among Permittees, to avoid conflicting plans, policies and regulations.

- Coordination necessary to develop an integrated monitoring program.

4. Public Involvement and Participation

   a. The SWMP shall provide ongoing opportunities for public involvement in the Permittee's stormwater management program and implementation priorities.

   b. Minimum performance measures:

      i. No later than 6 months after the effective date of this permit, develop and begin implementing a process to create opportunities for the public to participate in an advisory role in the decision making processes involving the development, implementation and update of the permittee's SWMP. Each Permittee must develop and implement a process for consideration of public comments on their SWMP.

      ii. Each Permittee must make their SWMP, the SWMP documentation required under S5.A.1. and all submittals required by this permit, including annual reports, available to the public, starting with the first annual report, on the permitee's website or submitted in electronic format to Ecology for posting on Ecology's website.

5. Controlling Runoff from New Development, Redevelopment and Construction Sites

   a. The SWMP shall include a program to prevent and control the impacts of runoff from new development, redevelopment, and construction activities. The program shall apply to private and public development, including roads.

   b. Minimum performance measures:

      i. The Minimum Requirements, thresholds, and definitions in Appendix 1, or Minimum Requirements, thresholds, and definitions determined by Ecology to be equivalent to Appendix 1,), for new development, redevelopment, and construction sites must be included in ordinance or other enforceable documents adopted by the local government. Adjustment and variance criteria equivalent to those in Appendix 1 must be included. More stringent requirements may be used, and/or certain requirements may be tailored to local circumstances through the use of basin plans or other similar water quality and quantity planning efforts. Such local requirements and thresholds must provide equal protection of receiving waters and equal levels of pollutant control as compared to Appendix 1.

      ii. The local requirements must include a site planning process and BMP selection and design criteria that, when used to implement the minimum requirements in Appendix 1 (or equivalent requirement approved by Ecology), will protect water quality, reduce the discharge of pollutants to the maximum extent practicable, and satisfy the state requirement under chapter 90.48 RCW to apply all known, available, and reasonable methods of prevention, control and treatment (AKART) prior to discharge. Permittees must document how the criteria and requirements will protect water quality,

reduce the discharge of pollutants to the maximum extent practicable, and satisfy the state AKART requirements.

Permittees who choose to use the site planning process, and BMP selection and design criteria in the 2005 *Stormwater Management Manual for Western Washington*, or an equivalent manual approved by the Department, may cite this choice as their sole documentation to meet this requirement.

iii. The program must allow non-structural preventive actions and source reduction approaches such as *Low Impact Development* Techniques (LID), measures to minimize the creation of impervious surfaces, and measures to minimize the disturbance of soils and vegetation.

iv. Deadlines for and Review of Local Manual and Ordinances. No later than 12 months from the effective date of this permit, each Permittee must adopt a local program that meets the requirements in S5C.5.b.i through iii., above. Ecology review and approval of the local manual and ordinances is required. To ensure compliance with the 12 month deadline, Permittees may use the following review process:

(1) The Permittee submits draft enforceable requirements, technical standards and manual to Ecology no later than 8 months after the effective date of this permit. Ecology will review and provide written response to the Permittee.

(2) If this review process is followed, the deadline for adoption of enforceable requirements, technical standards and manual shall be automatically extended by the number of calendar days that Ecology exceeds a 60 day period for written response.

(3) In the case of circumstances beyond the Permittee's control, such as litigation or administrative appeals, that may result in noncompliance with the requirements of this section, the Permittee shall promptly notify Ecology and submit a written request for an extension. Extensions may be granted by Ecology.

v. No later than 12 months after the effective date of this permit, the program must establish legal authority to inspect private stormwater facilities and enforce maintenance standards for all new development and redevelopment approved under the provisions of this section.

vi. No later than 18 months after the effective date of this permit, the program must include a process of permits, plan review, inspections, and enforcement capability to meet the following standards for both private and public projects, using *qualified personnel*:

(1) Review all stormwater site plans for proposed development involving land disturbing activity that meet the thresholds in S5.C.5.b.i., above.

(2) Inspect prior to clearing and construction, all development sites that have a high potential for sediment transport as determined through plan review based on definitions and requirements in Appendix 7.

(3) Inspect all permitted development sites involving land disturbing activity that meet the thresholds in S5.C.5.b.i., above, during construction to ensure proper installation and maintenance of required erosion and sediment controls. Enforce as necessary based on the inspection.

(4) Inspect all development sites upon completion of construction and prior to final approval/occupancy to ensure proper installation of permanent erosion controls and stormwater facilities/BMPs. Enforce as necessary based on the inspection. Also, complete a maintenance plan and assign responsibility for maintenance.

(5) Compliance with the inspection requirements of S5.C.5.(b)vi.(2), (3), and (4), above shall be determined by the presence of an established inspection program designed to inspect all sites involving land disturbing activity that meet the thresholds in S5.C.5.b.i., above, and achieve inspection of 95% of sites.

(6) The program shall include a procedure for keeping records of inspections and enforcement actions by staff, including inspection reports, warning letters, notices of violations, and other enforcement records. Records of maintenance inspections and maintenance activities shall be maintained.

(7) The program shall include an enforcement strategy to respond to issues of non-compliance.

vii. No later than the effective date of this permit, the Permittee must make available the "*Notice of Intent for Construction Activity*" and/or copies of the "*Notice of Intent for Industrial Activity*" to representatives of proposed new development and redevelopment. Permittees will continue to enforce local ordinances controlling runoff from sites that are also covered by stormwater permits that are issued by Ecology.

viii. No later than 18 months after the effective date of this permit, each permittee shall ensure that all staff responsible for implementing the program to Control Stormwater Runoff from New Development, Redevelopment, and Construction Sites, including permitting, plan review, construction site inspections, and enforcement, are trained to conduct these activities. Follow-up training shall be provided as needed to address changes in procedures, techniques or staffing. Permittees shall document and maintain records of the training provided and the staff trained.

6. Structural Stormwater Controls

a. The SWMP shall include a program to construct structural stormwater controls to address impacts to beneficial uses resulting from disturbances to watershed

hydrology and stormwater pollutant discharges. This program shall consider impacts caused by stormwater discharges from areas of existing development, including runoff from highways, streets and roads owned or operated by the Permittee, and areas of new development, where impacts are anticipated as development proceeds. This program shall address impacts that are not adequately controlled by the other required actions of the SWMP, and shall provide proposed projects and an implementation schedule.

The program shall consider the construction of projects such as regional flow control facilities, water quality treatment facilities, and retrofitting of existing flood control facilities to provide water quality functions. Permittees should also consider other means to address impacts from existing development, such as reduction of hydrologic changes through the use of on-site (infiltration and dispersion) stormwater management BMPs and site design techniques, habitat acquisition or restoration of forest cover and riparian buffers, for compliance with this requirement. Permittees may not use in-stream culvert replacement projects for compliance with this requirement.

b. Minimum Performance Measures:

i. No later than 18 months after the effective date of this permit, each Permittee shall develop and begin implementing a Structural Stormwater Control program designed to control stormwater impacts that are not adequately controlled by the other required actions of the SWMP. Permittees shall provide a list of planned individual projects that are scheduled for implementation during the term of this permit. Updates and revisions to the list will be provided in the annual report.

The Structural Stormwater Control program may also include a program designed to implement small scale projects that are not planned in advance.

ii. Each Permittee shall include a description of the Structural Stormwater Control Program in the written documentation of their SWMP that must be submitted with the first year annual report. The description of the Structural Stormwater Control Program must include the following:

- The goals that the Structural Stormwater Control Program are intended to achieve.
- The planning process used to develop the Structural Stormwater Control Program, including: the geographic scale of the planning process, the issues and regulations addressed, the steps in the planning process, the types of characterization information considered, the amount budgeted for implementation, and the public involvement process.

iii. For planned individual projects, provide the following information:

- The estimated pollutant load reduction that will result from each project designed to provide stormwater treatment.
- The expected outcome of each project designed to provide flow control.
- Any other expected environmental benefits.

- Planned monitoring or evaluation of the project and monitoring/evaluation results.

iv. Information about the Structural Stormwater Control Program shall be updated with each annual report.

7. Source Control Program for Existing Development

a. The SWMP shall include a program to reduce pollutants in runoff from areas that discharge to municipal separate storm sewers owned or operated by the Permittee. The program shall include the following elements within the limits of state and federal law, and implemented by the minimum performance measures, below:

i. Requiring application of operational and structural source control BMPs, and, if necessary, treatment BMPs to pollution generating sources associated with existing land uses and activities.

ii. Inspections of pollutant generating sources at commercial, industrial and multifamily properties to enforce implementation of required BMPs to control pollution discharging into municipal separate storm sewers owned or operated by the Permittee.

iii. Application and enforcement of local ordinances at applicable sites, including sites that are also covered by stormwater permits issued by Ecology. Permittees that are in compliance with the terms of this permit will not be held liable by Ecology for water quality standard violations caused by industries covered under an NPDES permit issued by Ecology.

iv. Reduction of pollutants associated with the application of pesticides, herbicides, and fertilizer discharging into municipal separate storm sewers owned or operated by the Permittee.

b. Minimum Performance Measures for Source Control Program:

i. No later than 12 months after the effective date of this permit, adopt and begin enforcement of an ordinance, or other enforceable documents, requiring the application of source control BMPs for pollutant generating sources associated with existing land uses and activities (See Appendix 3, to identify pollutant generating sources).

The local source control requirements must include operational and structural source control BMPs that, when used on a site specific basis, will protect water quality, reduce the discharge of pollutants to the maximum extent practicable, and satisfy the state requirement under chapter 90.48 *RCW* to apply all known, available, and reasonable methods of prevention, control and treatment (AKART) prior to discharge. Permittees must document how the stormwater source control BMP selection process for different activities and land uses, the types of BMPs and design criteria for those BMPs will protect water quality by reducing the discharge of pollutants to the maximum extent practicable, and satisfy the state AKART requirements.

Permittees who choose to use the source control BMPs in Volume IV of the 2005 Stormwater Management Manual for Western Washington, or an equivalent manual approved by Ecology, may cite this choice as their sole documentation to meet this requirement.

Ecology review and approval of the ordinance, or other enforceable documents, and source control BMPs is required. Each Permittee must submit the proposed source control program and all necessary documentation to Ecology for review, the deadline for doing so is no later than 9 months after the effective date of this permit. If Ecology does not request changes within 30 days, the proposed source control BMPs are considered approved. Operational source control BMPs shall be required for all pollutant generating sources. Structural source control BMPs shall be required for pollutant generating sources if operational source control BMPs are determined not to be effective, resulting in an illicit discharge or causing or contributing to a violation of surface water, ground water, or sediment management standards because of inadequate stormwater controls. Implementation of source control requirements may be done through education and technical assistance programs, provided that formal enforcement authority is available to the Permittee and is used as necessary.

ii. No later than 12 months after the effective date of this permit, establish a program to identify sites which are potentially pollution generating. The program shall include:

(1) Estimating the inventory of land uses/businesses using the categories of land uses and businesses in Appendix 8. The permittee shall update the inventory regularly.

(2) Complaint-based response to identify other pollutant generating sources, such as mobile or home-based businesses

iii. Starting no later than 24 months after the effective date of this permit, implement a self audit/inspection program for sites identified pursuant to S5.C.7.b.ii above , with adequate enforcement capability to ensure implementation of source control BMPs in accordance with the ordinance required in S5.C.7.b.i., above.

(1) All identified sites with a business address shall be provided, by mail, with information about activities that may generate pollutants and the source control requirements. Businesses may self-certify compliance with the source control requirements. The permittee shall inspect 20% of these sites annually to assure BMP effectiveness and compliance with source control requirements.

(2) Each permittee shall inspect 100% of sites identified through legitimate complaints.

iv. No later than 24 months after the effective date of this permit, each Permittee shall implement a progressive enforcement policy to require that

facilities are brought into compliance with stormwater requirements within a reasonable time period as specified below:

(1) In the event that a Permittee determines, based on an inspection conducted above, that a site has failed to adequately implement all necessary BMPs, that Permittee shall take progressive enforcement including, as appropriate, phone calls, reminder letters or follow up inspections within 30 days from the date of the initial inspection, or other time period as specified in the corrective action letter.

(2) When a Permittee determines that a facility has failed to adequately implement BMPs after a follow-up inspection, that Permittee shall take further enforcement action as established through authority in its municipal code and ordinances, or through the judicial system.

(3) Each Permittee shall maintain records, including documentation of each site visit, inspection reports, warning letters, notices of violations, and other enforcement records, demonstrating a good faith effort to bring facilities into compliance. Each permittee shall also maintain records of sites that are not inspected because the property owner denies entry.

(4) A Permittee may refer violations of local ordinances to Ecology provided that the Permittee also makes a good faith effort of progressive enforcement. At a minimum a Permittee's enforcement effort must include documentation of inspections and warning letters or notices of violation.

v. No later than 24 months after the effective date of this permit, each permittee shall ensure that all staff responsible for implementing the source control program are trained to conduct these activities. The training shall cover the legal authority for source control (adopted codes, ordinances, rules, etc.), source control BMPs and their proper application, inspection protocols, and enforcement procedures. Follow-up training shall be provided as needed to address changes in procedures, techniques or staffing. Permittees shall document and maintain records of the training provided and the staff trained

8. *Illicit Connections* and Illicit Discharges Detection and Elimination

a. The SWMP shall include an ongoing program to detect, remove and prevent illicit connections and illicit discharges, including spills, into the municipal separate storm sewers owned or operated by the Permittee.

b. Minimum Performance Measures:

i. No later than the effective date of this permit, each Permittee must continue implementing an on-going program to prevent, identify and respond to illicit connections and illicit discharges. The program shall include procedures for reporting and correcting or removing illicit connections, spills and other illicit discharges when they are suspected or identified. The program shall also include procedures for addressing pollutants entering the MS4 from an

interconnected, adjoining MS4. Illicit connections and illicit discharges shall be identified through field screening, inspections, complaints/reports, construction inspections, maintenance inspections, source control inspections, and/or monitoring information, as appropriate.

ii. No later than 12 months after the effective date of this permit, each Permittee shall evaluate, and if necessary update, existing ordinances or other regulatory mechanisms to effectively prohibit non-stormwater, illegal discharges, and/or dumping into the Permittee's municipal separate storm sewer system, to the maximum extent allowable under State and federal law.

(1) The regulatory mechanism required in S5.C.8.b.ii, above, does not need to prohibit the following categories of non-stormwater discharges, unless the discharges are identified as significant sources of pollutants to waters of the State:

- Diverted stream flows;
- Rising ground waters;
- Uncontaminated ground water infiltration (as defined at 40 CFR 35.2005(20));
- Uncontaminated pumped ground water;
- Foundation drains;
- Air conditioning condensation;
- Irrigation water from agricultural sources that is commingled with urban stormwater;
- Springs;
- Water from crawl space pumps;
- Footing drains; and
- Flows from riparian habitats and wetlands.

(2) The regulatory mechanism required in S5.C.8.b.ii, above, shall prohibit the following categories of non-stormwater discharges unless the following conditions are met:

- Discharges from potable water sources, including water line flushing, hyperchlorinated water line flushing, fire hydrant system flushing, and pipeline hydrostatic test water. Planned discharges shall be de-chlorinated to a concentration of 0.1 ppm or less, pH-adjusted if necessary, and volumetrically and velocity controlled to prevent resuspension of sediments;
- Discharges from lawn watering and other landscape irrigation runoff. These discharges must be reduced through, at a minimum, public education activities (see S5.C.10) and water conservation efforts.

- Dechlorinated swimming pool discharges. The discharges shall be dechlorinated to a concentration of 0.1 ppm or less, pH-adjusted if necessary, reoxygenated, and volumetrically and velocity controlled to prevent resuspension of sediments. Swimming pool cleaning wastewater and filter backwash shall not be discharged to the MS4.
- Street and sidewalk wash water, water used to control dust, and routine external building wash down that does not use detergents. The Permittee shall reduce these discharges through, at a minimum, public education activities (see S5.C.10) and/or water conservation efforts. To avoid washing pollutants into the MS4, Permittees must minimize the amount of street wash and dust control water used. At active construction sites, street sweeping must be performed prior to washing the street.

(3) The Permittee's SWMP shall, at a minimum, address each category in (2) above in accordance with the conditions stated therein.

(4) The SWMP must further address any category of discharges in (1) or (2) above if the discharges are identified as significant sources of pollutants to waters of the State.

(5) The regulatory mechanism required in S5.C.8.b.ii, above, shall include all appropriate enforcement provisions and procedures as allowed under State Law.

iii. No later than 18 months after the effective date of this permit, each Permittee shall ensure that all municipal field staff who are responsible for identification, investigation, termination, cleanup, and reporting illicit discharges, including spills, improper disposal and illicit connections are trained to conduct these activities. Follow-up training shall be provided as needed to address changes in procedures, techniques or staffing. Permittees shall document and maintain records of the training provided and the staff trained.

iv. No later than 24 months after the effective date of this permit, develop and implement an ongoing training program for all municipal field staff, which as part of their normal job responsibilities might come into contact with or otherwise observe an illicit discharge or illicit connection to the storm sewer system shall be trained on the identification of an illicit discharge/connection and on the proper procedures for reporting and responding to the illicit discharge/connection. Follow-up training shall be provided as needed to address changes in procedures, techniques or staffing. Permittees shall document and maintain records of the training provided and the staff trained.

v. Each Permittee shall continue to provide a publicly listed water quality citizen complaints/reports telephone number. This program shall be in place no later than the effective date of this permit. Complaints shall be responded to in accordance with S5.C.8.b.vii. and viii., below.

vi. Each Permittee shall conduct on-going screening to detect illicit connections using the methods identified in Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments, Center for Watershed Protection, October 2004.

(1) Each City covered under this permit shall complete an Outfall Reconnaissance Inventory for each stream and shoreline within the Permittee's incorporated area 180 days prior to expiration of the permit.

(2) Each County covered under this permit shall prioritize streams and shorelines in urban/higher density rural subbasins for screening and shall complete an Outfall Reconnaissance Inventory for at least half of streams and shorelines in these areas 180 days prior to expiration of this permit.

vii. Response to Illicit Connections

(1) Investigation: Upon discovery or upon receiving a report of a suspected illicit connection, Permittees shall initiate an investigation within 21 days, to determine the source of the connection, the nature and volume of discharge through the connection, and the responsible party for the connection.

(2) Termination: Upon confirmation of the illicit nature of a storm drain connection, Permittees shall use their enforcement authority and work with the property owner in a documented effort to eliminate the illicit connection within 6 months.

(3) A permittee may refer illicit connection violations to Ecology provided that the Permittee also makes a good faith effort of progressive enforcement. At a minimum a Permittee's enforcement effort must include documentation of inspections and warning letters or notices of violation.

viii. No later than 6 months after the effective date of this permit, each Permitteeshall develop and implement procedures to prevent, respond to and clean up spills and improper disposal into municipal separate storm sewers owned or operated by the Permittee. Investigate, within 7 days on average, any complaints/reports or monitoring information that indicates a potential illicit discharge, including a spill or illegal dumping. Immediately respond to problems/violations judged to be urgent, severe, or an emergency.

ix. Each Permittee shall track and maintain records of the illicit discharge detection and elimination program, including documentation of inspections, complaint/spill response and other enforcement records.

9. Operation and Maintenance Program

a. The SWMP shall include a program to regulate maintenance activities and to conduct maintenance activities by the Permittee that prevent or reduce

stormwater impacts. Within the limits of state and federal law the program shall include:

i. Maintenance standards and programs for proper and timely maintenance of public and private stormwater facilities.

ii. Practices for operating and maintaining Permittee's streets, roads, and highways to reduce stormwater impacts.

iii. Policies and procedures to reduce pollutants associated with the application of pesticides, herbicides, and fertilizer by the Permittee's agencies or departments.

iv. Practices for reducing stormwater impacts from *heavy equipment maintenance or storage yards*, and from *material storage facilities* owned or operated by the Permittee.

v. A training component.

b. Minimum Performance Measures:

i. Maintenance Standards. No later than 12 months after the effective date of this permit, each Permittee must establish maintenance standards that are as protective or more protective of facility function than those specified in Chapter 4 of Volume V of the 2005 Stormwater Management Manual for Western Washington.

The facility-specific maintenance standards are intended to be conditions for determining if maintenance actions are required as identified through inspection. They are not intended to be measures of the facility's required condition at all times between inspections. Exceeding these conditions at any time between inspections and/or maintenance does not automatically constitute a violation of these standards. However, based upon inspection observations, the inspection and maintenance schedules shall be adjusted to minimize the length of time that a facility is in a condition that requires a maintenance action. These standards are violated when an inspection identifies a required maintenance action related to facility function, and that action is not performed within 6 months for typical maintenance, within 9 months for revegetation, and within 2 years for maintenance that requires capital construction of less than $25,000.

ii. Maintenance of *stormwater facilities regulated by the Permittee*

(1) No later than 1 year after the effective date of this permit, each Permittee shall evaluate and, if necessary, update existing ordinances or other enforceable documents requiring maintenance of all permanent stormwater treatment and flow control facilities regulated by the Permittee (including catch basins), in accordance with maintenance standards established under S5.C.9.b.i, above.

(2) No later than 1 year after the effective date of this permit, each Permittee shall develop and implement an initial inspection schedule for all

known, permanent stormwater treatment and flow control facilities (other than catch basins) regulated by the Permittee to inspect each facility at least once during the term of this permit to enforce compliance with adopted maintenance standards as needed based on the inspection.

(3) No later than 4 years after the effective date of this permit, each Permittee shall develop an on-going inspection schedule for implementation after the initial schedule to annually inspect all stormwater treatment and flow control facilities (other than catch basins) regulated by the Permittee. The annual inspection schedule may be changed to a lesser or greater frequency of inspection, as appropriate to meet the maintenance standards, based on maintenance records of double the length of time of the proposed inspection frequency.

(4) No later than 2 years after the effective date of this permit each Permittee shall manage maintenance activities to inspect all new permanent stormwater treatment and flow control facilities, including catch basins, in new residential developments every 6 months during the period of heaviest house construction (i.e., 1 to 2 years following subdivision approval) to identify maintenance needs and enforce compliance with maintenance standards as needed.

(5) Compliance with the inspection requirements of S5.C.9.b.ii.(2),(3), and (4), above, shall be determined by the presence of an established inspection program designed to inspect all sites, and achieving inspection of 95% of all sites.

(6) The Permittee shall require cleaning of catch basins regulated by the permittee if they are found to be out of compliance with established maintenance standards in the course of inspections conducted at facilities under the requirements of S5.C.7 (Source Control Program), and S5.C.8 (Illicit Connections and Illicit Discharges Detection and Elimination), or if the catch basins are part of the treatment or flow control systems inspected under the requirements of S5.C.9.

iii. Maintenance of stormwater facilities owned or operated by the Permittee

(1) No later than 24 months after the effective date of this permit each Permittee shall begin implementing a program to inspect all permanent stormwater treatment and flow control facilities (other than catch basins) owned or operated by the Permittee annually, and implement appropriate maintenance action in accordance with adopted maintenance standards. The annual inspection schedule may be changed to a lesser or greater frequency of inspection as appropriate to meet the maintenance standards based on maintenance records of double the length of time of the proposed inspection frequency. In the absence of maintenance records for permanent stormwater treatment and flow control facilities, the permittee may substitute written statements, including the signature certification in General Condition G19, proposing a specific less

frequent inspection schedule, based on actual inspection and maintenance experience.

(2) No later than 24 months after the effective date of this program each Permittee shall begin implementing a program to conduct spot checks of potentially damaged permanent treatment and flow control facilities (other than catch basins) after major storm events (24 hour storm event with a 10 year recurrence interval). If spot checks indicate widespread damage/maintenance needs, inspect all stormwater treatment and flow control facilities that may be affected. Conduct repairs or take appropriate maintenance action in accordance with maintenance standards established under S5.C.9.b.i, above, based on the results of the inspections.

(3) Compliance with the inspection requirements of S5.C.9.b.iii.(1) and (2), above, shall be determined by the presence of an established inspection program designed to inspect all sites, and achieving inspection of 95% of all sites.

iv. Maintenance of Catch Basins Owned or Operated by the Permittee

(1) No later than 24 months after the effective date of this permit each Permittee shall begin implementing a program to annually inspect catchbasins and inlets owned or operated by the Permittee.

- Inspections may be conducted on a "circuit basis" whereby a sampling of catchbasins and inlets within each circuit is inspected to identify maintenance needs. Include in the sampling an inspection of the catchbasin immediately upstream of any system outfall. Clean all catchbasins within a given circuit at one time if the inspection sampling indicates cleaning is needed to comply with maintenance standards established under S5.C.9.b.i, above.

- As an alternative to inspecting catchbasins on a "circuit basis," the Permittee may inspect all catchbasins, and clean only catchbasins where cleaning is needed to comply with maintenance standards.

(2) The annual inspection schedule for may be changed to a lesser or greater frequency of inspection as appropriate to meet the maintenance standards based on maintenance records of double the length of time of the proposed inspection frequency. In the absence of maintenance records for catch basins, the permittee may substitute written statements, including the signature certification in General Condition G19, proposing a specific less frequent inspection schedule, not to exceed three years, based on actual inspection and maintenance experience.

(3) The disposal of decant water shall be in accordance with the requirements in Appendix 6.

v. Records of inspections and maintenance or repair activities conducted by the Permittee shall be maintained. Records of maintenance or repair requiring

capital construction of $25,000 or more shall be maintained and provided in the annual report.

vi. Establish practices to reduce stormwater impacts associated with runoff from parking lots, streets, roads, and highways owned or operated by the permittee; and road maintenance activities conducted by the permittee, within 12 months of the effective date of this permit.

Implementation of practices shall begin no later than 18 months after the effective date of this permit, and continue on an ongoing basis throughout the term of the permit. The following activities must be addressed:

(1) Pipe cleaning

(2) Cleaning of culverts that convey stormwater in ditch systems

(3) Ditch maintenance

(4) Street cleaning

(5) Road repair and resurfacing, including pavement grinding

(6) Snow and ice control

(7) Utility installation

(8) Maintaining roadside areas, including vegetation management.

(9) Dust control

(10) Pavement striping maintenance

vii. No later than 12 months after the effective date of this permit each Permittee shall establish and implement policies and procedures to reduce pollutants in discharges from lands owned or maintained by the Permittee subject to this permit, including but not limited to: parks, open space, road right-of-ways, maintenance yards, and at stormwater treatment and flow control facilities. These policies and procedures must address, but are not limited to:

(1) Application of fertilizer, pesticides, and herbicides, including the development of Nutrient management and *Integrated Pest Management* Plans

(2) Sediment and erosion control

(3) Landscape maintenance and vegetation disposal

(4) Trash management

(5) Building exterior cleaning and maintenance

viii. No later than 2 years after the effective date of this permit, develop and implement an ongoing training program for appropriate employees of the Permittee whose construction, operations or maintenance job functions may impact stormwater quality. The training program shall address the importance of protecting water quality, the requirements of this permit, operation and maintenance standards, inspection procedures, selecting

appropriate BMPs, ways to perform their job activities to prevent or minimize impacts to water quality, and procedures for reporting water quality concerns, including potential illicit discharges. Follow-up training shall be provided as needed to address changes in procedures, techniques or staffing. Permittees shall document and maintain records of the training provided and the staff trained.

ix. Develop and implement a Stormwater Pollution Prevention Plan (SWPPP) for all heavy equipment maintenance or storage yards, and material storage facilities owned or operated by the Permittee in areas subject to this permit, that are not covered under the Industrial Stormwater General permit. The SWPPPs must be developed within 18 months of the effective date of this permit. Implementation of non-structural BMPs shall begin immediately after the pollution prevention plan is developed. A schedule for implementation of structural BMPs shall be included in the SWPPP. Generic SWPPPs that can be applied at multiple sites may be used to comply with this requirement. The SWPPP shall include periodic visual observation of discharges from the facility to evaluate the effectiveness of BMPs.

10. Education and Outreach Program

a. The SWMP shall include an education program aimed at residents, businesses, industries, elected officials, policy makers, planning staff and other employees of the Permittee. The goal of the education program is to reduce or eliminate behaviors and practices that cause or contribute to adverse stormwater impacts. An education program may be developed locally or regionally.

b. Minimum Performance Measures:

i. No later than 12 months after the effective date of this permit each Permittee shall implement or participate in an education and outreach program that uses a variety of methods to target the audiences and topics listed in II, below. The outreach program shall be designed to achieve measurable improvements in each target audience's understanding of the problem and what they can do to solve it, and measurable improvements in the percentage of each target audience regularly carrying out the intended action or behavior change.

ii. The education and outreach program shall increase regular adoption of the following behaviors in the following target audiences by the expiration date of this permit:

(1) Awareness among the general public of the importance of improving water quality, reducing impervious surfaces, and protecting the existing and designated uses of waters of the state and the potential impacts caused by stormwater discharges, and promote specific actions and opportunities for avoiding, minimizing, reducing and/or eliminating the adverse impacts of stormwater runoff, especially through the use of source control BMPs.

(2) Awareness of natural yard care techniques (e.g. composting lawn and yard clippings, using compost and mulch, using natural organic fertilizers, watering infrequently and deeply) among homeowners, the general public, landscape professionals, and property managers to protect water quality.

(3) Awareness by homeowners, the general public, landscape professionals, and property managers of the need to protect water quality by reducing their purchase of and properly storing, using and disposing of pesticides, fertilizers, and other yard care chemicals.

(4) Awareness by the general public and businesses of the need to protect water quality by reducing their purchase of and properly storing, using, and disposing of automotive chemicals, hazardous cleaning supplies, and other hazardous materials, and by facilitating use of source control BMPs that minimize the discharge of soap/detergents (e.g., supplying or providing grant funding for carwash kits, etc.).

(5) Use of technical standards to develop stormwater site plans and erosion control plans, and the use of *Best Management Practices* to mitigate contaminated runoff and the quantity of runoff from development sites by engineers, construction contractors, developers, development review staff, and land use planners.

(6) Understanding and use of Low Impact Development (LID) techniques (e.g. appropriate site design, pervious paving, full dispersion BMPs, and retention of forests and mature trees) among engineers, contractors, developers, architects, landscape architects, realtors, and potential home buyers to avoid or minimize stormwater impacts of new development.

(7) Awareness by small businesses and the general public about the impacts of illicit discharges and encourage their identification and removal to avoid impacts to water quality.

(8) Involvement the general public in environmental stewardship activities (e.g. habitat restoration and community involvement and education projects) to increase awareness of the importance of water quality and mitigate, reduce, or eliminate adverse impacts of stormwater runoff.

iii. Each permittee shall implement or participate in an effort to measure understanding and adoption of the targeted behaviors among the targeted audiences. The resulting measurements shall be used to direct education and outreach resources most effectively as well as to evaluate changes in adoption of the targeted behaviors.

iv. Each permittee shall track and maintain records of public education activities.

S6. STORMWATER MANAGEMENT PROGRAM FOR CO-PERMITTEES AND SECONDARY PERMITTEES

A. This section applies to all Secondary Permittees, whether coverage under this Permit is obtained individually or as a Co-Permittee with a City and/or Town and/or County and/or another Secondary Permittee.

Each Co-Permittee and Secondary Permittee shall develop and implement a stormwater management program (SWMP) during the term of this permit. The SWMP shall be designed to reduce the discharge of pollutants from regulated small MS4s to the maximum extent practicable and protect water quality. For the purpose of this permit a SWMP for a Co-Permittee or Secondary Permittee is a set of actions and activities comprising the components in this Special Condition as outlined below. All applicable components are mandatory and must be implemented by each Co-Permittee or Secondary Permittee within the limits of state and federal law. The SWMP must be developed and implemented in accordance with the schedules contained in this section and shall be fully developed and implemented 180 days before the expiration date of this Permit. Notwithstanding the schedules contained in this section for implementation of SWMP components, Secondary Permittees that are already implementing some or all of the SWMP components in this section shall continue implementation of those components of their SWMP.

Each Co-Permittee and Secondary Permittee shall track the cost of development and implementation of the SWMP required by this section. This information shall be included in the annual report.

1. S6.B Coordination, and S8.C Legal Authority are applicable to all Co-Permittees and Secondary Permittees covered under this permit.

2. S6.D is applicable only to the Port of Seattle and the Port of Tacoma.

3. S6.E is applicable only to King County as a Co-Permittee with the City of Seattle for MS4s owned by King County but located within the City of Seattle.

4. S6.F is applicable all other Secondary Permittees.

B. Coordination

The SWMP shall include mechanisms to encourage coordinated stormwater-related policies, programs and projects within a watershed and interconnected MS4s. Where relevant and appropriate, the SWMP shall also include coordination among departments of the Secondary Permittee to ensure compliance with the terms of this Permit.

C. Legal Authority

To the extent allowable under state law and federal law, each Secondary Permittee must be able to demonstrate that they can operate pursuant to legal authority which authorizes or enables the Secondary Permittee to control discharges to and from municipal separate storm sewers owned or operated by the Secondary Permittee.

This legal authority, which may be a combination of statutes, ordinances, permits, contracts, orders, interagency agreements, or similar means, shall include the ability to:

1. Control the contribution of pollutants to municipal separate storm sewers owned or operated by the Secondary Permittee from stormwater discharges associated with industrial activity, and control the quality of stormwater discharged from sites of industrial activity into the Secondary Permittee's municipal separate storm sewer;

2. Prohibit illicit discharges to the municipal separate storm sewer owned or operated by the Secondary Permittee;

3. Control the discharge of spills and the dumping or disposal of materials other than stormwater into the municipal separate storm sewer owned or operated by the Secondary Permittee;

4. Control through interagency agreements among co-applicants, the contribution of pollutants from one portion of the MS4 to another portion of the MS4;

5. Require compliance with conditions in ordinances, permits, contracts, or orders; and,

6. Within the limitations of state law, carry out inspection, surveillance, and monitoring procedures necessary to determine compliance and non-compliance with permit conditions, including the prohibition on illicit discharges to the MS4.

D. Stormwater Management Program for the Port of Seattle and Port of Tacoma:

1. Mapping and Documentation. The SWMP shall include an ongoing program for gathering, maintaining, and using adequate information to conduct planning, priority setting, and program evaluation activities for Port-owned properties.

   Minimum Performance Measures. The following information will be gathered and retained:

   a. Mapping of known municipal separate storm sewer outfalls, and maps depicting land use for property owned by the Port district, and all other properties served by municipal separate storm sewers known to and owned or operated by the Port. The mapping shall be completed within 2 years of receiving coverage under this permit.

   b. Mapping of tributary conveyances, and the associated drainage areas of municipal separate storm sewer outfalls owned or operated by the Port, with a

24 inch nominal diameter or larger, or an equivalent cross-sectional area for nonpipe systems. The mapping will be completed within 2 years of receiving coverage under this permit.

c. To the extent consistent with national security laws and directives, each Port shall make available to Ecology, upon request, GIS data layers generated by the Port depicting outfall locations, land use, tributary conveyances and associated drainage areas of outfalls owned or operated by the Port district. The preferred format of submission will be an electronic format with fully described mapping standards. An example description is provided at http://www.ecy.wa.gov/services/gis/data/standards.htm where the preferred standards are described. Notification of updated GIS data layers shall be included in annual reports.

d. No later than 2 years after receiving coverage under this permit, develop and implement a program to maintain operation and maintenance records for stormwater facilities covered under this permit. The information shall be available for inspection.

e. Upon request, and to the extent consistent with national security laws and directives, mapping information and operation and maintenance records shall be provided to the City or County in which the Port is located.

2. Source Control in existing Developed Areas. The SWMP shall include a program to reduce pollutants in runoff from areas that discharge to municipal separate storm sewers owned or operated by the Port district, through the development and implementation of Stormwater Pollution Prevention Plans (SWPPPs). The SWPPP is a documented plan to implement measures to identify, prevent, and control the contamination of discharges of stormwater to surface or ground water. SWPPPS shall be prepared and implemented for all Port-owned lands with potential pollutant-generating sources (see Appendix 3, for definition of pollutant-generating sources) that are not covered under the Industrial Stormwater General Permit, the Boatyard General Permit or an individual NPDES permit that covers stormwater discharges, and that could contribute pollutants to municipal separate storm sewers owned or operated by the Port.

Minimum Performance Measures

a. SWPPPs must be developed for applicable properties within 24 months of receiving coverage under this permit.

b. The SWPPP shall include a facility assessment including a site plan, identification of pollutant sources and description of the drainage system.

c. The SWPPP shall include a description of the BMPs determined to be appropriate under the 2005 Stormwater Management Manual for Western Washington (or its approved equivalent) to eliminate or reduce stormwater contamination. Implementation of non-structural BMPs shall begin immediately after the pollution prevention plan is developed. A schedule for implementation of structural BMPs shall be included in the SWPPP. Generic

SWPPPs that can be applied at multiple sites may be used to comply with this requirement.

d. The Port shall maintain a list of sites for which SWPPPs are required under this permit. At least 15% of the listed sites shall be inspected annually, and 80% of the total number of listed properties will be inspected by 180 days before the expiration date of the permit.

e. The SWPPPs shall include policies and procedures to reduce pollutants associated with the application of pesticides, herbicides and fertilizer.

f. The SWPPPs shall include measures to prevent, identify and respond to illicit discharges, including illicit connections, spills and improper disposal. Immediately upon becoming aware of a spill into the drainage system owned or operated by the Port, the Port shall notify the City or County it is located in, and notify Ecology.

g. The SWPPPs shall include a component related to inspection and maintenance of stormwater facilities and catchbasins that is consistent with the Port's Operation and Maintenance Program, as specified in S6.D.3, below.

3. Operation and Maintenance Program. The SWMP shall include an operation and maintenance program for all stormwater treatment and flow control facilities, and catchbasins to ensure that BMPs continue to function properly.

Minimum Performance Measures:

a. Each Port must prepare an operation and maintenance manual for all stormwater BMPs that are under the functional control of the Port District that discharge to its MS3s. The deadline for preparing the O&M manual is 2 years after receiving coverage under this permit. A copy of the manual shall be retained in the appropriate Port department. The operation and maintenance manual shall establish facility-specific maintenance standards that are as protective, or more protective than those specified in Chapter 4 of Volume V of the 2005 Stormwater Management Manual for Western Washington.

The facility-specific maintenance standards are intended to be conditions for determining if maintenance actions are required as identified through inspection. They are not a measure of the facilities required condition at all times between inspections. Exceeding the maintenance standards between inspections and/or maintenance does not automatically constitute a violation of these standards. However, based upon inspection observations, the inspection and maintenance schedules shall be adjusted to minimize the length of time that a facility is in a condition that requires a maintenance action. These standards are violated when an inspection identifies a required maintenance action related to facility function, and that action is not performed within 6 months for typical maintenance, within 9 months for re-vegetation, and within 2 years for maintenance that requires capital construction of less than $25,000.

b. The Port will manage maintenance activities to inspect all stormwater BMPs listed in the O&M manual annually, and take appropriate maintenance action in accordance with the O&M manual. The Port may change the annual inspection to a lesser or greater frequency of inspection, as appropriate to comply with maintenance standards, based on maintenance records of double the length of time of the proposed inspection frequency.

c. The Port shall provide appropriate training for Port maintenance staff.

d. The Port will maintain records of inspections and maintenance activities.

4. Education Program. The SWMP shall include an education program aimed at tenants and Port employees. The goal of the education program is to reduce or eliminate behaviors and practices that cause or contribute to adverse stormwater impacts.

Minimum Performance Measure:

a. No later than 18 months after receiving coverage under this permit, the Port shall make educational materials available to tenants and Port employees whose job duties could negatively impact stormwater.

5. Monitoring Program. The monitoring requirements for the Port of Seattle and Port of Tacoma are included in Special Condition S8.

6. Construction Site Stormwater Runoff Control

The SWMP shall include a program to reduce pollutants in stormwater runoff to the MS3s owned or operated by the Port District from the Port District's construction activities that meet the thresholds in Appendix 1 of this permit.

Minimum performance measures:

a. Comply with all relevant ordinances, rules, and regulations of the local jurisdiction(s) in which the Port is located that govern construction phase stormwater pollution prevention measures.

b. Seek coverage under the General NPDES Permit for Stormwater Discharges Associated with Construction Activities, when applicable.

c. Provide training or coordinate with existing training efforts to educate relevant staff in erosion and sediment control BMPs and requirements, or hire trained contractors to perform the work.

7. Post-Construction Stormwater Management for New Development and Redevelopment

The SWMP shall include a program to address post-construction stormwater runoff to the MS3s owned or operated by the Port District from the Port District's new development and redevelopment projects that meet the thresholds in Appendix 1 of this permit. The program must establish controls to prevent or minimize water quality impacts.

Minimum performance measures:

a. Comply with all relevant ordinances, rules and regulations of the local jurisdiction(s) in which the Port District's MS3 is located that govern post-construction stormwater pollution prevention measures, including proper operation and maintenance of the MS3.

b. Provide for the post-construction stormwater controls in Appendix 1 to be included on all land-disturbing projects which exceed regulatory thresholds.

E. Stormwater Management Program for King County as a Co-Permittee

King County as a Co-Permittee with the City of Seattle for the Densmore Metro Drainage Basin, as defined in the Memorandum of Agreement between the City and King County dated September 25, 1995, shall participate in the City of Seattle's Stormwater Management Program in accordance with the Joint Stormwater Management Program element of the Memorandum of Agreement. The Joint Stormwater Management Program shall at a minimum include the following:

1. Stormwater controls for areas of existing development consistent with S5.C.6.
2. A source control program consistent with S5.C.7.
3. An illicit discharge detection and elimination program consistent with S5.C.8.
4. An operation and maintenance program consistent with S5.C.9.
5. A public education program consistent with S5.C.10.

F. Stormwater Management Program for all other Secondary Permittees

All other Secondary Permittees shall develop and implement the following Stormwater Management Program. The term "all other Secondary Permittees" means drainage, diking, flood control, or diking and drainage districts, Ports (other than the Ports of Seattle and Tacoma), public colleges and universities, and any other owners or operators of municipal separate storm sewers located within the municipalities that are listed as Permittees in Special Condition S1.B.

SWMP components

1. Public Education and Outreach

Each Secondary Permittee shall implement the following stormwater education strategies:

a. Storm drain inlets owned and operated by the Secondary Permittee that are located in maintenance yards, in parking lots, along sidewalks, and at pedestrian access points shall be clearly and permanently labeled with the message "Dump no waste" and indicating the point of discharge as a river, lake, bay, or groundwater. No later than three years from the date of permit coverage, at least 50 percent of these inlets must be labeled; and no later than the expiration date of this Permit, all of these inlets shall be labeled. As identified during visual inspection and regular maintenance of storm drain inlets per the

requirements of S6.F.3.iv and S6.F.6.a.i below, or as otherwise reported to the Secondary Permittee, any inlet having a label that is no longer clearly visible and/or easily readable must be re-labeled within 90 days.

b. Each year beginning no later than three years from the date of permit coverage, Public Ports, Colleges and Universities shall distribute educational information to tenants and residents on the impact of stormwater discharges on receiving waters, and steps that can be taken to reduce pollutants in stormwater runoff. Different combinations of topics shall be addressed each year, and, before the expiration date of this Permit, tenants and residents shall receive educational information about the following topics, where relevant:

i. How stormwater runoff affects local waterbodies;

ii. Proper use and application of pesticides and fertilizers;

iii. Benefits of using well-adapted vegetation;

iv. Alternative equipment washing practices including cars and trucks that minimize pollutants in stormwater;

v. Benefits of proper vehicle maintenance and alternative transportation choices; proper handling and disposal of wastes, including the location of hazardous waste collection facilities in the area;

vi. Hazards associated with illicit connections; and

vii. Benefits of litter control and proper disposal of pet waste.

Compliance with this requirement can be achieved through participation in the local jurisdiction's public education and outreach programs.

2. Public Involvement and Participation

180 days before the expiration date of this Permit, each Secondary Permittee shall:

a. Publish a public notice in the local newspaper and solicit public review of their SWMP.

b. Make the latest updated version of the SWMP available to the public. If the Secondary Permittee maintains a website, the SWMP shall be posted on the Secondary Permittee's website.

3. Illicit Discharge Detection and Elimination

Each Secondary Permittee shall:

a. From the date of permit coverage, comply with all relevant ordinances, rules, and regulations of the local jurisdiction(s) in which the Secondary Permittee is located that govern non-stormwater discharges.

b. Develop and adopt appropriate policies prohibiting illicit discharges and illegal dumping no later than one year from the date of permit coverage. Identify possible enforcement mechanisms no later than one year from the date of permit coverage; and, no later than eighteen months from the date of permit coverage,

develop and implement an enforcement plan using these mechanisms to ensure compliance with illicit discharge policies. These policies shall address, at a minimum: illicit connections; non-stormwater discharges as defined below; and spilling, dumping, or otherwise improperly disposing of: hazardous materials, pet waste, and litter.

i. Non-stormwater discharges covered by another NPDES permit and discharges from emergency fire fighting activities are allowed in the MS4 in accordance with S2 Authorized Discharges.

ii. The policies do not need to prohibit the following categories of non-stormwater discharges:

- Diverted stream flows;
- Rising ground waters;
- Uncontaminated ground water infiltration (as defined at 40 CFR 35.2005(20));
- Uncontaminated pumped ground water;
- Foundation drains;
- Air conditioning condensation;
- Irrigation water from agricultural sources that is commingled with urban stormwater;
- Springs;
- Water from crawl space pumps;
- Footing drains; and
- Flows from riparian habitats and wetlands.

iii. The policies shall prohibit the following categories of non-stormwater discharges unless the stated conditions are met:

- Discharges from potable water sources, including water line flushing, hyperchlorinated water line flushing, fire hydrant system flushing, and pipeline hydrostatic test water. Planned discharges shall be de-chlorinated to a concentration of 0.1 ppm or less, pH-adjusted if necessary, and volumetrically and velocity controlled to prevent resuspension of sediments;
- Discharges from lawn watering and other landscape irrigation runoff. These discharges must be reduced through, at a minimum, public education activities and water conservation efforts conducted by the Secondary Permittee and/or the local jurisdiction.
- Dechlorinated swimming pool discharges. The discharges shall be dechlorinated to a concentration of 0.1 ppm or less, pH-adjusted if necessary, reoxygenated, and volumetrically and velocity controlled to

prevent resuspension of sediments. Swimming pool cleaning wastewater and filter backwash shall not be discharged to the MS4.

- Street and sidewalk wash water, water used to control dust, and routine external building wash down that does not use detergents. The Secondary Permittee shall reduce these discharges through, at a minimum, public education activities and/or water conservation efforts conducted by the Secondary Permittee and/or the local jurisdiction. To avoid washing pollutants into the MS4, the Secondary Permittee shall minimize the amount of street wash and dust control water used. At active construction sites, street sweeping must be performed prior to washing the street.

iv. The Secondary Permittee's SWMP shall, at a minimum, address each category in iii above in accordance with the conditions stated therein.

v. The SWMP must further address any category of discharges in ii or iii above if the discharge is identified as a significant source of pollutants to waters of the State.

c. 180 days before the expiration date of this Permit, develop a storm sewer system map showing the locations of all known storm drain outfalls, labeling the receiving waters, and delineating the areas contributing runoff to each outfall. Make the map (or completed portions of the map) available on request to the Department and/or to other Permittees or Secondary Permittees. The preferred, but not required, format of submission will be an electronic format with fully described mapping standards. An example description is provided at http://www.ecy.wa.gov/services/gis/data/standards.htm.

d. Conduct field inspections and visually inspect for illicit discharges at all known outfalls that discharge to surface waters. Visually inspect at least one third (on average) of all known outfalls each year beginning no later than two years from the date of permit coverage. Develop and implement procedures to identify and remove any illicit discharges. Keep records of inspections and follow-up activities.

e. 180 days before the expiration date of this Permit, develop and implement a spill response plan that includes coordination with a qualified spill responder.

f. Provide staff training or coordinate with existing training efforts to educate relevant staff on proper best management practices for preventing spills and illicit discharges. All relevant staff must be trained.

4. Construction Site Stormwater Runoff Control

From the date of permit coverage, each Secondary Permittee shall:

a. Comply with all relevant ordinances, rules, and regulations of the local jurisdiction(s) in which the Secondary Permittee is located that govern construction phase stormwater pollution prevention measures.

b. For all construction projects under the control of the Secondary Permittee which require an NPDES permits under 40 CFR 122.26 and where required by departments General NPDES Permit for Stormwater Discharges Associated with Construction Activities the Secondary Permittees shall obtain coverage under the General NPDES Permit for Stormwater Discharges Associated with Construction Activities or an alternative individual NPDES permit prior to discharging.

c. To the extent allowable under local, state and federal law, coordinate with the local jurisdiction regarding projects owned and operated by other entities which discharge into the Secondary Permittee's MS4, to assist the local jurisdiction with achieving compliance with all relevant ordinances, rules, and regulations of the local jurisdiction(s), including implementation of the Minimum Technical Requirements for Construction Stormwater Pollution Prevention contained in Appendix 1, Minimum Requirement #2.

d. Provide training or coordinate with existing training efforts to educate relevant staff in erosion and sediment control BMPs and requirements, or hire trained contractors to perform the work.

e. Coordinate as requested with the Department or the local jurisdiction to provide access for inspection of construction sites or other land disturbances that are under the control of the Secondary Permittee during the active grading and/or construction period.

5. Post-Construction Stormwater Management for New Development and Redevelopment

From the date of permit coverage, each Secondary Permittee shall:

a. Comply with all relevant ordinances, rules and regulations of the local jurisdiction(s) in which the Secondary Permittee is located that govern post-construction stormwater pollution prevention measures.

b. To the extent allowable under local, state and federal law, coordinate with the local jurisdiction regarding projects owned and operated by other entities which discharge into the Secondary Permittee's MS4, to assist the local jurisdiction with achieving compliance with all relevant ordinances, rules, and regulations of the local jurisdiction(s), including implementation of the Minimum Technical Requirements in Appendix 1.

c. No later than one year from the date of permit coverage, and to the extent allowable under local, state and federal law, new projects owned or operated by the Secondary Permittee, must comply with the Minimum Technical Requirements in Appendix 1 for post construction stormwater controls.

6. Pollution Prevention and Good Housekeeping for Municipal Operations

Each Secondary Permittee shall:

a. No later than three years from the date of permit coverage, develop and implement a municipal operation and maintenance (O&M) plan to minimize

stormwater pollution from activities conducted by the Secondary Permittee. The O&M Plan must include appropriate pollution prevention and good housekeeping procedures for all of the following operations, activities, and/or types of facilities that are present within the Secondary Permittee's boundaries. Record keeping is required to track performance of operational source control activities; performance of scheduled inspections and maintenance activities; and response to spills and other potential pollution incidents not addressed in S6.F.3

i. Stormwater collection and conveyance system, including catch basins, stormwater sewer pipes, open channels, culverts, structural stormwater controls, and structural runoff treatment and/or flow control facilities. The O&M Plan must address, but is not limited to: scheduled inspections and maintenance activities, including cleaning and proper disposal of waste removed from the system. Secondary Permittees shall properly maintain stormwater collection and conveyance systems owned or operated by the Secondary Permittee and regularly inspect and maintain all structural post-construction stormwater BMPs to ensure facility function. The Secondary Permittee shall establish maintenance standards that are as protective or more protective of facility function as those specified in Chapter 4 Volume V of the 2005 Stormwater Management Manual for Western Washington.

   Secondary Permittees shall conduct spot checks of stormwater treatment and flow control facilities following a 24 hour storm event with a 10-year or greater recurrence interval.

ii. Roads, highways, and parking lots. The O&M Plan must address, but is not limited to: deicing, anti-icing, and snow removal practices; snow disposal areas; material (e.g. salt, sand, or other chemical) storage areas; all-season BMPs to reduce road and parking lot debris and other pollutants from entering the MS4. Secondary Permittees shall store all de-icing and anti-icing materials in a permanent walled and roof structure.

iii. Vehicle fleets. The O&M Plan must address, but is not limited to: storage, washing, and maintenance of municipal vehicle fleets; and fueling facilities. Secondary Permittees shall conduct all vehicle and equipment washing and maintenance in a self-contained covered building or in designated wash and/or maintenance areas.

iv. External building maintenance. The O&M Plan must address, building exterior cleaning and maintenance including cleaning, washing, painting and other maintenance activities.

v. Parks and open space. The O&M Plan must address, but is not limited to: proper application of fertilizer, pesticides, and herbicides; sediment and erosion control; BMPs for landscape maintenance and vegetation disposal; and trash management.

vi. Material storage areas, heavy equipment storage areas, and maintenance areas. Secondary Permittees shall develop and implement a Stormwater Pollution Prevention Plan to protect water quality at each of these facilities

owned or operated by the Secondary Permittee and not covered under the General NPDES Permit for Stormwater Discharges Associated with Industrial Activities or under another NPDES permit that covers stormwater discharges associated with the activity.

vii. Other facilities that would reasonably be expected to discharge contaminated runoff. The O&M Plan must address proper stormwater pollution prevention practices for each facility.

viii. The O&M Plan shall include sufficient documentation and records as necessary to demonstrate compliance with the O&M Plan requirements in S6.F.6.a.i through vii above.

b. From the date of coverage under this Permit, also have permit coverage for all facilities owned, operated or maintained by the Secondary Permittee that are required to be covered under the General NPDES Permit for Stormwater Discharges Associated with Industrial Activities.

c. Train all employees whose construction, operations, or maintenance job functions may impact stormwater quality. The training shall address:

i. The importance of protecting water quality,

ii. The requirements of this Permit,

iii. Operation and maintenance requirements,

iv. Inspection procedures,

v. Ways to perform their job activities to prevent or minimize impacts to water quality, and

vi. Procedures for reporting water quality concerns, including potential illicit discharges.

S7. TOTAL MAXIMUM DAILY LOAD ALLOCATIONS

The following requirements apply if an applicable Total Maximum Daily Load (TMDL) is approved for stormwater discharges from MS4s owned or operated by the Permittee. Applicable TMDLs or applicable TMDL requirements are TMDLs which have been approved by EPA on or before the issuance date of this permit, or TMDLs which have been approved by EPA prior to the date that the Permittees application is received by Ecology. All Permittees must be in compliance with applicable TMDL requirements.

A. For applicable TMDLs listed in Appendix 2, affected Permittees shall comply with the specific requirements identified in Appendix 2 in addition to the requirements of this permit. The status of the TMDL implementation must be included as part of the annual report submitted to Ecology for this Permit.

1. Where monitoring is required in Appendix 2, the permittee shall submit a Quality Assurance Project Plan (QAPP) to Ecology for review and approval, or, if available, conduct the monitoring according to a QAPP developed by Ecology.

B. For applicable TMDLs not listed in Appendix 2, compliance with this permit shall constitute compliance with those TMDLs. Each Permittee shall keep records of all actions required by this permit that are relevant to applicable TMDLs within their jurisdiction. The status of the TMDL implementation must be included as part of the annual report submitted to Ecology for this permit.

C. For TMDLs that are approved by EPA after this permit is issued, the Department may establish TMDL related permit requirements through future permit modification or when this permit is reissued. Permittees are encouraged to participate in development of TMDLs within their jurisdiction and to begin implementation. The Department may modify this permit to incorporate requirements from TMDLs completed after the issuance of this permit if the Department determines implementation of actions, monitoring or reporting necessary to demonstrate reasonable further progress toward achieving TMDL waste load allocations, and other targets, are not occurring and must be implemented during the term of this permit.

S8. MONITORING

The Permittees listed in S1.B, Port of Seattle and Port of Tacoma shall develop and implement a comprehensive long-term monitoring program. The monitoring program shall include three components:

Stormwater Monitoring,

Stormwater Management Program effectiveness monitoring

Stormwater Treatment and Hydrologic Management BMP evaluation monitoring.

The results of the monitoring program shall be used to support the adaptive management process and lead to refinements of the Stormwater Management Program. The monitoring program must include Quality Assurance Project Plans (QAPPs) for each monitoring objective, written in accordance with Ecology's QAPP guidelines at http://www.ecy.wa.gov/biblio/0403030.html. The monitoring program must be developed by qualified staff or contractors that have experience in applying Ecology's or EPA's QAPP Guidelines.

Secondary Permittees other than Ports have no requirement for monitoring under this section during this permit term, however, in accordance with S6.F.3.c, they are required to provide information, maps and access for sampling efforts, as necessary. Secondary Permittees are encouraged to participate in the monitoring program

A. Stormwater Monitoring

1. Stormwater monitoring site selection

a. Adequate sites will have the tributary conveyance system and drainage area mapped, and be suitable for permanent installation and operation of flow-weighted composite sampling equipment.

b. Counties shall monitor one outfall or conveyance representing each of the following land uses:

i. Commercial,

ii. Low density residential, and

iii. High density residential.

c. Cities shall monitor one outfall or conveyance representing each of the following land uses:

i. Commercial,

ii. High density residential, and

iii. Industrial.

d. The Ports of Seattle and Tacoma shall each monitor one outfall or conveyance.

2. Stormwater monitoring frequency and type of sampling shall be as follows:

a. Each stormwater monitoring site shall be sampled according to the following frequency:

i. 75% of the qualifying storms up to a maximum of 15 storm events per year, with sampling distributed throughout the year, reflecting the 80%/20% distribution of rainfall between the wet and dry seasons as follows:

(1) 75% of the qualifying storms during the wet season, from October 1 through April 30. A wet season storm event is defined as follows:

- Rainfall volume 0.10" minimum
  No fixed maximum
- Rainfall duration No fixed minimum or maximum
- Antecedent dry period less than 0.02" rain fall in the previous 24 hours
- Inter-event dry period 6 hours

(2) 75% of the qualifying storms during the dry season, from May 1 through September 30. A dry season storm event is defined as follows:

- Rainfall volume 0.10" minimum
  No fixed maximum
- Rainfall duration No fixed minimum or maximum
- Antecedent dry period less than 0.02" in the previous 72 hours
- Inter-event dry period 6 hours

b. Each storm event shall be sampled using flow-weighted composite storm sampling, for the full duration of the storm event, for the constituents/parameters listed below. Chemicals that are below detection limits after two years of data may be dropped from the analysis.

i. Flow, Hydrograph data including antecedent dry period, rainfall and runoff,

ii. TSS and turbidity,

iii. Conductivity if tidally influenced,

iv. Chloride,

v. Metals including, at a minimum, total and dissolved copper, zinc, cadmium, and lead; and mercury sampling in commercial and industrial land use areas,

vi. Hardness,

vii. PAHs associated with vehicles, roads and parking lots; phthalates

viii. Pesticides including:

- Herbicides: 2,4-D, MCPP, Dichlobenil, Prometon, Triclopyr,
- Insecticides: Diazinon, Malathion, Chlorpyrifos
- Fungicides: Pentachlorophenol

ix. Nutrients including total nitrogen, phosphorus, nitrate/nitrite and orthophosphate,

x. Biochemical oxygen demand (BOD), and

c. Toxicity testing of a "seasonal first-flush" storm event defined as an event in August or September, with at least a 1 week antecedent dry period. Required test is the Daphnid acute test, Ceriodaphnia dubia or Daphnia pulex (48-hour static test, method: EPA-821-R-02-012).

d. Each storm event shall be sampled using grab samples for the following constituents/parameters:

i. Total Petroleum Hydrocarbons (TPH) using NWTPH-Gx and NWTPH-Dx. (sample must be collected early in the storm event and skimmed from the surface), and

ii. Fecal coliform bacteria.

e. Sediments will be collected and analyzed for percent solids, total organic carbon, metals, PAHs, phthalates, phenolics and PCBs at all sites in the system proposed for monitoring. Chemicals that are below detection limits after two years of data may be dropped from the analysis. A minimum of 1 independent sample, up to a maximum of 3 independent samples per year should be collected. Use of in-line sediment traps or similar collection system is preferred. Sampling of sediment deposits is an alternative where approved by the department.

3. The objective of the stormwater monitoring is to measure and track long term trends in annual and seasonal pollutant loading of stormwater discharges. A QAPP is required for the stormwater monitoring program. For each stormwater monitoring site, calculate the Event Mean Concentrations (EMCs), total annual pollutant load and the seasonal pollutant load for the wet and dry seasons. The loadings shall be

expressed as total pounds and as pounds per acre, and must take into account potential pollutant load from base flow.

B. Stormwater Management Program Effectiveness Monitoring

1. Each permittee and the Ports of Seattle and Tacoma shall conduct monitoring designed to determine the effectiveness of the permittee's SWMP at controlling a stormwater related problem directly addressable by actions in the SWMP. Each Permittee and the Ports of Seattle and Tacoma shall develop and implement a monitoring program designed to answer one of each type of the following questions, at minimum 2 questions must be addressed:

   a. The effectiveness of a targeted action (or narrow suite of actions), and

   b. The effectiveness of achieving a targeted environmental outcome.

2. The monitoring shall at a minimum include either stormwater or receiving water monitoring of physical, chemical and/or biological characteristics. The monitoring may also include evaluation of regulatory processes, programmatic actions or other similar evaluations.

3. For each of the 2 questions selected for monitoring, the permittee must develop a monitoring program containing the following elements:

   a. Statement of the problem selected and explanation of why the problem is significant to the permittee, and if the problem is significant to other stormwater managers;

   b. Specific hypotheses about the problem or management actions that will be tested by the monitoring problem;

   c. Specific parameters of attributes to be measured;

   d. A QAPP written in accordance with Ecology's QAPP guidelines

   e. Expected modifications to management actions depending on the outcome of hypotheses testing.

C. Stormwater Treatment and Hydrologic Management Best Management Practice (BMP) Evaluation Monitoring

1. Each Permittee listed in S1.B and the Ports of Seattle and Tacoma shall conduct full scale field monitoring to evaluate the effectiveness and operation and maintenance requirements of stormwater treatment and hydrologic management BMPs applied in their jurisdiction. A QAPP is required for each BMP and flow reduction strategy being monitored.

2. Each Permittee listed in S1.B shall monitor at least 2 treatment BMPs, at no less than 2 sites per BMP. The Ports of Seattle and Tacoma shall each monitor at least 1 treatment BMP, at 2 sites. BMPs shall be selected from the following list:

   a. BMP treatment types:

      i. Basic Treatment

(1) Biofiltration swale

(2) Filter strip

(3) Basic wetpond

(4) Treatment wetland

(5) Sand filter

ii. Metals/Phosphorus Treatment

(1) Amended sand filter

(2) Two facility treatment train

(3) Compost amended filter strips

(4) Bioretention

(5) Large wetpond

iii. Oil Control

(1) Linear sand filter

(2) Catch basin insert

b. BMPs shall be designed in accordance with the 2005 Stormwater Management Manual for Western Washington unless Ecology approves of an alternate design in the QAPP review. Permittees may also petition Ecology to monitor a BMP that is not on the above list that they wish to evaluate as a potential option for common use in their jurisdiction.

c. Permittees shall prepare QAPPs consistent with Ecology (guidelines available at: http://www.ecy.wa.gov/biblio/0403030.html) and shall use appropriate sections of "Guidance for Evaluating Emerging Stormwater Treatment Technologies" (Publication Number 02-10-037) - or its updated version if published before the issuance date of this permit – including the "Technology Assessment Protocol-Ecology" (TAPE) for preparing, implementing, and reporting on the results of the BMP evaluation program. The statistical goal is to determine mean effluent concentrations and mean percent removals for each BMP type with 95% confidence and 80% power. However, a maximum of 35 influent and effluent sample pairs will suffice.

Permittees shall use USEPA publication number 821-B-02-001 , "Urban Stormwater BMP Performance Monitoring," as additional guidance for preparing the BMP evaluation monitoring, and shall collect information pertinent to fulfilling the "National Stormwater BMP Data Base Requirements" in section 3.4.3. of that document.

d. Parameters to be monitored in whole water at each test site for Basic, Enhanced, or Phosphorus treatment BMP's include:

i. Total suspended solids

ii. Particle size distribution

iii. pH

iv. Total and ortho-phosphorus

v. Hardness

vi. Total and dissolved copper and zinc

e. Parameters to be monitored in whole water at test sites for Oil Control BMP's include:

i. Total suspended solids

ii. Particle size distribution

iii. pH

iv. NWTPH-Dx and -Gx

v. Visible sheen

f. Parameters to be monitored in accumulated sediment at each test site for Basic, Enhanced, Phosphorus treatment, or Oil Control BMP's include:

i. Percent total solids

ii. Grain size

iii. Total volatile solids

iv. NWTPH-Dx

v. Total cadmium, copper, lead, and zinc

vi. Total phosphorus

3. Each Permittee listed in S1.B. shall monitor the effectiveness of 1 flow reduction strategy that is in use or planned for installation in their jurisdiction.

Monitoring of a flow reduction strategy shall include continuous rainfall and surface runoff monitoring. Flow reduction strategies shall be monitored through either a paired site study or against a predicted outcome.

D. Monitoring Program Development

1. The Permittees listed in S1.B and the Ports of Seattle and Tacoma may choose to develop 1, 2 or all of the components of the monitoring program, conduct the monitoring, and report results through an integrated, long-term, water quality monitoring program in collaboration with other municipal stormwater Permittees; or they may independently develop 1, 2 or all of the components of the monitoring program, conduct the monitoring, and report results.

A collaborative monitoring program may be developed by a third party (or parties) that is not a Permittee, provided that the permittee complies with the provisions of Special Condition S3.B (relying on another entity to meet permit requirements).

2. All QAPPs must be submitted to Ecology, for review, in accordance with the deadlines below. QAPPs for S8.A, Stormwater Monitoring, and S8.C., Stormwater Treatment and Hydrologic Management BMP Evaluation Monitoring Program must be reviewed and approved by Ecology prior to monitoring.

E. Monitoring Program Deadline

1. The deadlines for collaborative, integrated monitoring program are as follows:

a. Permittees that intend to meet all or part of the monitoring requirements through a collaborative process must submit a statement to Ecology explaining their commitment to the collaborative process no later than 1 year after the effective date of this permit

b. The summary description of the monitoring program and QAPPs, as required, shall be submitted to Ecology no later than 2 years after the effective date of this permit. The monitoring program shall be submitted in both paper and electronic form.

c. Approved or final QAPPs must be completed no later than 2.5 years after the effective date of this permit.

d. Full implementation of the stormwater and receiving water monitoring program shall begin no later than 3 years after the effective date of this permit. The third party or parties selected to develop the monitoring plan may continue to be utilized to collect and analyze the data and to write the subsequent reports required under this permit.

e. Data collection and analysis for S8.C. Stormwater Treatment and Hydrologic Management BMP Evaluation Monitoring Program must be complete and submitted to Ecology no later than 4 years from the effective date of this permit.

2. The deadlines for an independently developed monitoring program are as follows:

a. A summary description of the monitoring program and QAPPs, as required, shall be submitted to Ecology no later than 1 year after the effective date of this permit. The monitoring program shall be submitted in both paper and electronic form.

b. Approved or final QAPPs must be completed no later than 1.5 years after the effective date of this permit.

c. Full implementation of the stormwater and receiving water monitoring program shall begin no later than 2 years after the effective date of this permit.

d. Data collection and analysis for S8.C. Stormwater Treatment and Hydrologic Management BMP Evaluation Monitoring Program must be complete and submitted to Ecology no later than 4 years from the effective date of this permit.

F. Monitoring Program Reporting Requirements

1. The stormwater monitoring report shall be submitted by December 31 each year, beginning in 2009 for independent monitoring, and 2010 for collaborative

monitoring. Each report shall include all monitoring data collected during the preceding period from October 1 through September 30. Each report shall also integrate data from earlier years into the analysis of results, as appropriate. Permittees that choose to participate in an integrated water quality monitoring program shall submit a single integrated monitoring report. Reports shall be submitted in both paper and electronic form and shall include:

a. Stormwater Monitoring Reporting

i. A summary including the location, land use, drainage area size, and hydrology for each site,

ii. A comprehensive data and QA/QC report for each part of the monitoring program, with an explanation and discussion of the results of each monitoring project,

iii. The annual pollutant load for each site expressed in total pounds, and pounds/acre, and

iv. The wet and dry season pollutant loads, expressed in total pounds, and pounds/acre.

b. Stormwater Management Program Effectiveness Monitoring Reporting

i. A summary of the purpose, design, and methods of the monitoring program,

ii. The status of implementing the monitoring program,

iii. A comprehensive data and QA/QC report for each part of the monitoring program, with an explanation and discussion of the results of each monitoring project,

iv. An analysis of the results of each part of the monitoring program, including any identified water quality problems or improvements or other trends in stormwater or receiving water quality, and

v. Recommended future actions based on the findings.

c. Stormwater Treatment and Hydrologic Management Best Management Practice (BMP) Evaluation Monitoring Reporting

i. A summary including the BMP type location, land use, drainage area size, and hydrology for each site.

ii. The status of implementing the monitoring program,

iii. A comprehensive data and QA/QC report for each part of the monitoring program, with an explanation and discussion of the results of each monitoring project,

iv. Performance data or flow reduction performance. Performance data for treatment BMPs shall be reported consistent with:

(1) The guidelines in appropriate sections of “Guidance for Evaluating Emerging Stormwater Treatment Technologies” (Publication Number 02-

10-037) - or its updated version if published before the issuance date of this permit – including the "Technology Assessment Protocol-Ecology (TAPE), and

(2) USEPA publication number 821-B-02-00, "Urban Stormwater BMP Performance Monitoring," including information pertinent to fulfilling the "National Stormwater BMP Data Base Requirements" in section 3.4.3. of that document.

d. Monitoring Cost Reporting. Report the cost of development and implementation of the monitoring program including the preparation of monitoring plans, sample collection, sampling equipment, laboratory analysis, data analysis and reporting.

2. If the Permittee monitors any pollutant more frequently than required by the required monitoring program, then the results of this monitoring shall be included in the report. If the Permittee conducts any other stormwater monitoring in addition to that required in the required monitoring program, then it shall provide a description of the additional monitoring in the report.

S9. REPORTING REQUIREMENTS

A. Each Permittee, co-Permittee and secondary Permittee shall submit, no later than March 31 of each year beginning in the year 2008, an annual report. The reporting period for each annual report shall be the previous calendar year.

B. The annual report shall include the following information:

1. Status of compliance with the conditions of this permit, including the status of implementing the components of the stormwater management program, and the implementation schedule. If permit deadlines are not met, Permittees, co-Permittees and secondary Permittees shall report the reasons why the requirement was not met and how the requirements will be met in the future, including projected implementation dates. A comparison of program implementation results to performance standards established in this permit shall be included for each program area.

2. Notification of any recent or proposed annexations or incorporations resulting in an increase or decrease in permit coverage area, and implications for the stormwater management program

3. Expenditures for the reporting period, with a breakdown for the components of the stormwater management program.

4. A summary describing compliance activities, including the nature and number of official enforcement actions, inspections, and types of public education activities; and

5. Identification of known water quality improvements or degradation.

C. Report Format

Each Permittee, co-Permittee or secondary Permittee shall use the attached reporting forms, in Appendices 3 and 4. Each Permittee shall complete the applicable form in its entirety. Two copies of the annual report shall be submitted to Ecology. In addition, an electronic copy of the report, in pdf format, shall be submitted to Ecology

GENERAL CONDITIONS

G1. DISCHARGE VIOLATIONS

All discharges and activities authorized by this permit shall be consistent with the terms and conditions of this permit.

G2. PROPER OPERATION AND MAINTENANCE

The Permittee shall at all times properly operate and maintain all facilities and systems of collection, treatment, and control (and related appurtenances) which are installed or used by the Permittee for pollution control to achieve compliance with the terms and conditions of this permit.

G3. NOTIFICATION OF SPILL

If a Permittee has knowledge of a spill into a municipal storm sewer which could constitute a threat to human health, welfare, or the environment, the Permittee shall notify the Ecology regional office and other appropriate spill response authorities immediately but in no case later than within 24 hours of obtaining that knowledge. Spills which might cause bacterial contamination of shellfish, such as might result from broken sewer lines, shall be reported immediately to the Department of Ecology and the Department of Health, Shellfish Program. The Department of Ecology's Regional Office 24-hr. number is 425 649-7000 for NWRO and 360 407-6300 for SWRO and the Department of Health's Shellfish 24-hr. number is 360-236-3330.

G4. BYPASS PROHIBITED

The intentional *bypass* of stormwater from all or any portion of a stormwater treatment BMP whenever the design capacity of the treatment BMP is not exceeded, is prohibited unless the following conditions are met:

A. Bypass is: (1) unavoidable to prevent loss of life, personal injury, or severe property damage; or (2) necessary to perform construction or maintenance-related activities essential to meet the requirements of the Clean Water Act (CWA); and

B. There are no feasible alternatives to bypass, such as the use of auxiliary treatment facilities, retention of untreated stormwater, or maintenance during normal dry periods.

"Severe property damage" means substantial physical damage to property, damage to the treatment facilities which would cause them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss.

G5. RIGHT OF ENTRY

The Permittee shall allow an authorized representative of Ecology, upon the presentation of credentials and such other documents as may be required by law at reasonable times:

A. To enter upon the Permittee's premises where a discharge is located or where any records must be kept under the terms and conditions of this permit;

B. To have access to, and copy at reasonable cost and at reasonable times, any records that must be kept under the terms of the permit;

C. To inspect at reasonable times any monitoring equipment or method of monitoring required in the permit;

D. To inspect at reasonable times any collection, treatment, pollution management, or discharge facilities; and

E. To sample at reasonable times any discharge of pollutants.

G6. DUTY TO MITIGATE

The Permittee shall take all reasonable steps to minimize or prevent any discharge in violation of this permit which has a reasonable likelihood of adversely affecting human health or the environment.

G7. PROPERTY RIGHTS

This permit does not convey any property rights of any sort, or any exclusive privilege.

G8. COMPLIANCE WITH OTHER LAWS AND STATUTES

Nothing in the permit shall be construed as excusing the Permittee from compliance with any other applicable federal, state, or local statutes, ordinances, or regulations.

G9. MONITORING

A. Representative Sampling:

Samples and measurements taken to meet the requirements of this permit shall be representative of the volume and nature of the monitored discharge, including representative sampling of any unusual discharge or discharge condition, including bypasses, upsets, and maintenance-related conditions affecting effluent quality.

B. Records Retention:

The Permittee shall retain records of all monitoring information, including all calibration and maintenance records and all original recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for this permit, for a period of at least five years. This period of retention shall be extended during the course of any unresolved

litigation regarding the discharge of pollutants by the Permittee or when requested by Ecology. On request, monitoring data and analysis shall be provided to Ecology.

C. Recording of Results:

For each measurement or sample taken, the Permittee shall record the following information: (1) the date, exact place and time of sampling; (2) the individual who performed the sampling or measurement; (3) the dates the analyses were performed; (4) who performed the analyses; (5) the analytical techniques or methods used; and (6) the results of all analyses.

D. Test Procedures:

All sampling and analytical methods used to meet the monitoring requirements specified in the approved stormwater management program shall conform to the Guidelines Establishing Test Procedures for the Analysis of Pollutants contained in 40 CFR Part 136, unless otherwise specified in this permit or approved in writing by Ecology.

E. Flow Measurement:

Where flow measurements are required by other conditions of this Permit, appropriate flow measurement devices and methods consistent with accepted scientific practices shall be selected and used to ensure the accuracy and reliability of measurements of the volume of monitored discharges. The devices shall be installed, calibrated, and maintained to ensure that the accuracy of the measurements are consistent with the accepted industry standard for that type of device. Frequency of calibration shall be in conformance with manufacturer's recommendations or at a minimum frequency of at least one calibration per year. Calibration records should be maintained for a minimum of three years.

F. Lab Accreditation:

Where data collection is required by other conditions of this Permit, all monitoring data, except for flow, temperature, conductivity, pH, total residual chlorine, and other exceptions approved by Ecology, shall be prepared by a laboratory registered or accredited under the provisions of, Accreditation of Environmental Laboratories, Chapter 173-50 WAC. Soils and hazardous waste data are exempted from this requirement pending accreditation of laboratories for analysis of these media by Ecology.

G. Additional Monitoring:

Ecology may establish specific monitoring requirements in addition to those contained in this permit by administrative order or permit modification.

G10. REMOVED SUBSTANCES

With the exception of decant from street waste vehicles, the Permittee shall not allow collected screenings, grit, solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of stormwater to be resuspended or reintroduced to the storm sewer system or to waters of the state. Decant from street waste vehicles resulting

from cleaning stormwater facilities may be reintroduced only when other practical means are not available and only in accordance with the Street Waste Disposal Guidelines in Appendix 6.

G11. SEVERABILITY

The provisions of this permit are severable, and if any provision of this permit, or the application of any provision of this permit to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of this permit shall not be affected thereby.

G12. REVOCATION OF COVERAGE

The director may terminate coverage under this General Permit in accordance with Chapter 43.21B RCW and Chapter 173-226 WAC. Cases where coverage may be terminated include, but are not limited to the following:

A. Violation of any term or condition of this general permit;

B. Obtaining coverage under this general permit by misrepresentation or failure to disclose fully all relevant facts;

C. A change in any condition that requires either a temporary or permanent reduction or elimination of the permitted discharge;

D. A determination that the permitted activity endangers human health or the environment, or contributes significantly to water quality standards violations;

E. Failure or refusal of the Permittee to allow entry as required in RCW 90.48.090;

F. Nonpayment of permit fees assessed pursuant to RCW 90.48.465;

Revocation of coverage under this general permit may be initiated by Ecology or requested by any interested person.

G13. TRANSFER OF COVERAGE

The director may require any discharger authorized by this general permit to apply for and obtain an individual permit in accordance with Chapter 43.21B RCW and Chapter 173-226 WAC.

G14. GENERAL PERMIT MODIFICATION AND REVOCATION

This general permit may be modified, revoked and reissued, or terminated in accordance with the provisions of WAC 173-226-230. Grounds for modification, revocation and reissuance, or termination include, but are not limited to the following:

A. A change occurs in the technology or practices for control or abatement of pollutants applicable to the category of dischargers covered under this general permit;

B. Effluent limitation guidelines or standards are promulgated pursuant to the CWA or chapter 90.48RCW, for the category of dischargers covered under this general permit;

C. A water quality management plan containing requirements applicable to the category of dischargers covered under this general permit is approved; or

D. Information is obtained which indicates that cumulative effects on the environment from dischargers covered under this general permit are unacceptable.

The filing of a request by the permittee for a permit modification, revocation and reissuance, or termination, or a notification of planned changes or anticipated noncompliance does not stay any permit condition.

G15. REPORTING A CAUSE FOR MODIFICATION OR REVOCATION

A Permittee who knows or has reason to believe that any activity has occurred or will occur which would constitute cause for modification or revocation and reissuance under Condition G12 REVOCATION OF COVERAGE, G14 GENERAL PERMIT MODIFICATION AND REVOCATION, or 40 CFR 122.62 must report such plans, or such information, to Ecology so that a decision can be made on whether action to modify, or revoke and reissue this permit will be required. Ecology may then require submission of a new or amended application. Submission of such application does not relieve the Permittee of the duty to comply with this permit until it is modified or reissued.

G16. APPEALS

A. The terms and conditions of this general permit, as they apply to the appropriate class of dischargers, are subject to appeal within thirty days of issuance of this general permit, in accordance with Chapter 43.21B RCW, and Chapter 173-226 WAC.

B. The terms and conditions of this general permit, as they apply to an individual discharger, are appealable in accordance with Chapter 43.21B RCW within thirty days of the effective date of coverage of that discharger. Consideration of an appeal of general permit coverage of an individual discharger is limited to the general permit's applicability or nonapplicability to that individual discharger.

C. The appeal of general permit coverage of an individual discharger does not affect any other dischargers covered under this general permit. If the terms and conditions of this general permit are found to be inapplicable to any individual discharger(s), the matter shall be remanded to ecology for consideration of issuance of an individual permit or permits.

D. Modifications of this permit are appealable in accordance with Chapter 43.21B RCW and Chapter 173-226 WAC.

G17. PENALTIES

40 CFR 122.41(a)(2) and (3), 40 CFR 122.41(j)(5), and 40 CFR 122.41(k)(2) are hereby incorporated into this permit by reference.

G18. DUTY TO REAPPLY

The Permittee must apply for permit renewal at least 180 days prior to the specified expiration date of this permit. An expired permit continues in force and effect until a new permit is issued or until Ecology cancels the permit. Only Permittees who have reapplied for coverage under this permit are covered under the continued permit.

G19. CERTIFICATION AND SIGNATURE

All applications, reports, or information submitted to Ecology shall be signed and certified.

A. All permit applications shall be signed by either a principal executive officer or ranking elected official.

B. All reports required by this permit and other information requested by Ecology shall be signed by a person described above or by a duly authorized representative of that person. A person is a duly authorized representative only if:

1. The authorization is made in writing by a person described above and submitted to Ecology, and

2. The authorization specifies either an individual or a position having responsibility for the overall development and implementation of the stormwater management program. (A duly authorized representative may thus be either a named individual or any individual occupying a named position.)

C. Changes to authorization. If an authorization under General Condition G19.B.2 is no longer accurate because a different individual or position has responsibility for the overall development and implementation of the stormwater management program, a new authorization satisfying the requirements of General Condition G19.B.2 must be submitted to Ecology prior to or together with any reports, information, or applications to be signed by an authorized representative.

D. Certification. Any person signing a document under this permit shall make the following certification:

"I certify under penalty of law, that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for willful violations."

G20. RECORDS RETENTION

Each Permittee is required to keep all records related to this Permit for at least five years.

G21. NON-COMPLIANCE NOTIFICATION

In the event the Permittee is unable to comply with any of the terms and conditions of this permit, including discharges from the Permittees MS4 which may cause a threat to human heath or the environment, the Permittee shall:

A. Take appropriate action to correct or minimize the threat to human health or the environment or otherwise stop or correct the condition of noncompliance.

B. Notify Ecology of the failure to comply with the permit terms and conditions within 30 days of becoming aware of the non-compliance.

C. Notify Ecology immediately in cases where the Permittee becomes aware of a discharge from the Permittees MS4 which may cause or contribute to an eminent threat to human health or the environment.

DEFINITIONS AND ACRONYMS

"AKART" means All Known, Available, and Reasonable methods of prevention, control and Treatment.

"All known, available and reasonable methods of prevention, control and treatment" refers to the State Water Pollution Control Act, Chapter 90.48.010 and 90.48.520 RCW.

"Applicable TMDL" means a TMDL which has been approved by EPA on or before the issuance date of this Permit, or prior to the date that the Permittee's application is received by Ecology, or prior to a modification of this Permit, whichever is later.

"Best Management Practices (BMPs)" means the schedules of activities, prohibitions of practices, maintenance procedures, and structural and/or managerial practices that when used singly or in combination, prevent or reduce the release of pollutants and other adverse impacts to waters of Washington State.

"Bypass" means the diversion of stormwater from any portion of a stormwater treatment facility.

"CWA" means Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972) Pub.L. 92-500, as amended Pub. L. 95-217, Pub. L. 95-576, Pub. L. (6-483 and Pub. L. 97-117, 33 U.S.C. 1251 et.seq.

"Component" or "Program Component" means the elements of the stormwater management program listed in Special Condition S5Stormwater Management Program for Permittees or S6 Stormwater Management Program for Co-Permittees and Secondary Permittees.

"Co-Permittee" means an owner or operator of a municipal separate storm sewer that has co-applied for permit coverage with another permittee, and that is only responsible for permit conditions relating to the discharge for which it is operator. See also 40 CFR 122.26(b)(1).

"Discharge" for the purpose of this permit, unless indicated otherwise, refers to discharges from Municipal Separate Storm Sewers of the Permittees. See also 40 CFR 122.2.

"Entity" means another governmental body, or public or private organization, such as another permittee, a conservation district, or volunteer organization.

"40 CFR" means Title 40 of the Code of Federal Regulations, which is the codification of the general and permanent rules published in the Federal Register by the executive departments and agencies of the federal government.

"General Permit" means a permit which covers multiple dischargers of a point source category within a designated geographical area, in lieu of individual permits being issued to each discharger.

"Heavy equipment maintenance or storage yard" means an uncovered area where any heavy equipment, such as mowing equipment, excavators, dump trucks, backhoes, or bulldozers are

washed or regularly maintained at an established heavy equipment washing facility, or where at least five pieces of heavy equipment are stored on a permanent basis.

"Illicit connection" means any man-made conveyance that is connected to a municipal separate storm sewer without a permit or other legal justification, excluding roof drains and other similar type connections designed to convey drainage, surface water and ground water. Examples of illicit connections include sanitary sewer connections, floor drains, channels, pipelines, conduits, inlets, or outlets that are connected directly to the municipal separate storm sewer system.

"Illicit discharge" means any discharge to a municipal separate storm sewer that is not composed entirely of storm water except discharges pursuant to a NPDES permit (other than the NPDES permit for discharges from the municipal separate storm sewer) and discharges resulting from fire fighting activities.

"Integrated Pest Management (IPM)" means a coordinated decision-making and action process that uses the most appropriate pest control methods and strategy in an environmentally and economically sound manner to meet agency programmatic pest management objectives. The elements of integrated pest management include:

(a) Preventing pest problems;

(b) Monitoring for the presence of pests and pest damage;

(c) Establishing the density of the pest population, that may be set at zero, that can be tolerated or correlated with a damage level sufficient to warrant treatment of the problem based on health, public safety, economic, or aesthetic thresholds;

(d) Treating pest problems to reduce populations below those levels established by damage thresholds using strategies that may include biological, cultural, mechanical, and chemical control methods and that must consider human health, ecological impact, feasibility, and cost-effectiveness; and

(e) Evaluating the effects and efficacy of pest treatments.

"Pest" means, but is not limited to, any insect, rodent, nematode, snail, slug, weed, and any form of plant or animal life or virus, except virus, bacteria, or other microorganisms on or in a living person or other animal or in or on processed food or beverages or pharmaceuticals, which is normally considered to be a pest, or which the director of the department of agriculture may declare to be a pest.

"Large Municipal Separate Storm Sewer System (Large MS4)" means all Municipal Separate Storm Sewers located in an incorporated place with a population of 250,000 or more, a County with unincorporated urbanized areas with a population of 250,000 or more, according to the 1990 decennial census by the Bureau of Census. See also 40 CFR 122.26(b)(4).

"Low Impact Development" (LID) means a stormwater management and land development strategy applied at the parcel and subdivision scale that emphasizes conservation and use of on-

site natural features integrated with engineered, small-scale hydrologic controls to more closely mimic pre-development hydrologic functions.

"Major Municipal Separate Storm Sewer Outfall" means a municipal separate storm sewer outfall from a single pipe with an inside diameter of 36 inches or more, or its equivalent (discharge from a single conveyance other than circular pipe which is associated with a drainage area of more than 50 acres); or for municipal separate storm sewers that receive stormwater from lands zoned for industrial activity (based on comprehensive zoning plans or the equivalent), an outfall that discharges from a single pipe with an inside diameter of 12 inches or more or from its equivalent (discharge from other than a circular pipe associated with a drainage area of 12 acres or more). See also 40 CFR 122.26(b)(5).

"Maximum Extent Practicable (MEP)" refers to paragraph 402(p)(3)(B)(iii) of the federal Clean Water Act which reads as follows: Permits for discharges from municipal storm sewers shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques, and system, design, and engineering methods, and other such provisions as the Administrator or the State determines appropriate for the control of such pollutants.

"Material Storage Facilities" means an uncovered area used on a permanent basis for outside storage of uncontained bulk materials (liquid, solid, granular, etc.) in piles, barrels, tanks, bins, crates, or other means.

"Medium Municipal Separate Storm Sewer System (Medium MS4)" means all Municipal Separate Storm Sewers (MS3s) located in an incorporated place with a population of more than 100,000 but less than 250,000, or a county with unincorporated urbanized areas of more than 100,000 but less than 250,000 according to the 1990 decennial census by the Bureau of Census. See also 40 CFR 122.26(b)(7).

"Municipal Separate Storm Sewer (MS3)" means a conveyance, or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains):

(a) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State Law) having jurisdiction over disposal of wastes, storm water, or other wastes, including special districts under State Law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the CWA that discharges to waters of the United States;

(b) designed or used for collecting or conveying stormwater;

(c) which is not a combined sewer; and

(d) which is not part of a Publicly Owned Treatment Works (POTW) as defined at 40 CFR 122.2.

"Municipal separate storm sewer system (MS4)" means all separate storm sewers that are defined as "large" or "medium" or "small" municipal separate storm sewer systems. See also 40 CFR 122.26(b)(18)

"National Pollutant Discharge Elimination System" (NPDES) means the national program for issuing, modifying, revoking, and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Federal Clean Water Act, for the discharge of pollutants to surface waters of the state from point sources. These permits are referred to as NPDES permits and, in Washington State, are administered by the Washington Department of Ecology.

"Notice of Intent" (NOI) means the application for, or a request for coverage under this General Permit pursuant to WAC 173-226-200. See Appendix 5 for the NOI for this permit.

"Notice of Intent for Construction Activity," and "Notice of Intent for Industrial Activity" mean the application forms for coverage under the Construction Stormwater General Permit and the Industrial Stormwater General Permit.

"Outfall" means point source as defined by 40 CFR 122.2 at the point where a municipal separate storm sewer discharges to waters of the State and does not include open conveyances connecting two municipal separate storm sewers, or pipes, tunnels, or other conveyances which connect segments of the same stream or other waters of the State and are used to convey waters of the State.

"Physically Interconnected" means that one MS3 is connected to a second MS3 in such a way that it allows for direct discharges to the second system. For example, the roads with drainage systems and municipal streets of one entity are physically connected directly to a MS3 belonging to another entity.

"Process Wastewater" means any water which, during manufacture or processing, comes into direct contact with or results form the production or use of any raw material, intermediate product, finished product, by product, or waste product.

"Qualified Personnel" means someone who has had professional training in the aspects of stormwater management they are responsible for.

"RCW" means the Revised Code of Washington State.

"Runoff" see Stormwater.

"Secondary Permittee" is an operator of municipal separate storm sewer which is not a city, town or county. Secondary Permittees include special purpose districts and other public entities identified in S1D which operate municipal separate storm sewers.

"Shared Waterbodies" means waterbodies, including downstream segments, lakes and estuaries, that receive discharges from more than one Permittee.

"Stormwater" means stormwater runoff, snow melt runoff, and surface runoff and drainage.

"Stormwater Associated with Industrial and Construction Activity" means the discharge from any conveyance which is used for collecting and conveying stormwater, which is directly related to manufacturing, processing or raw materials storage areas at an industrial plant, or associated with clearing grading and/or excavation, and is required to have an NPDES permit in accordance with 40 CFR 122.26.

"Stormwater facilities regulated by the Permittee" means all known, permanent stormwater treatment and flow control BMPs not owned by the Permittee, that discharge into municipal separate storm sewers owned or operated by the Permittee.

"Stormwater Management Manual for Western Washington" means the 5-volume technical manual (Publication Nos. 05-10-029 through 05-10-033) published by Ecology in February 2005.

"Stormwater Management Program (SWMP)" means a set of actions and activities designed to reduce the discharge of pollutants from the regulated small MS4 to the maximum extent practicable and to protect water quality, and comprising the components listed in S5 or S6 of this Permit and any additional actions necessary to meet the requirements of applicable TMDLs.

"Urban/higher density rural sub-basins" means any sub-basin or portion thereof that is within or proposed to be within the urban growth area (UGA), or any rural area sub-basin or portion thereof, fifty percent or more of which is comprised of lots smaller than 5 acres in size.

"Waters of the State" includes those waters as defined as "waters of the United States" in 40 CFR Subpart 122.2 within the geographic boundaries of Washington State and "waters of the state" as defined in Chapter 90.48 RCW which includes lakes, rivers, ponds, streams, inland waters, underground waters, salt waters and all other surface waters and water courses within the jurisdiction of the State of Washington.

"Water Quality Standards" means Surface Water Quality Standards, Chapter 173-201A WAC, Ground Water Quality Standards, Chapter 173-200 WAC, and Sediment Management Standards, Chapter 173-204 WAC.

Low-Impact Development Strategy for Green Cove Basin: A Case Study in Regulatory Protection of Aquatic Habitat in Urbanizing Watersheds



City of Olympia

Thurston County, Washington

City of
OLYMPIA

SARB_008511

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City of Olympia
Low-Impact Development Standards for Green Cove Basin: A Case Study in Regulatory Protection of Aquatic Habitats in Urbanizing Watersheds

ABSTRACT

In October 2001 the City of Olympia, Washington adopted a unique set of mandatory low-impact development regulations within a single watershed for the purpose of preventing further damage to aquatic habitat from urban development.

While other cities – including Olympia's neighbors, Lacey and Tumwater – have adopted voluntary low-impact standards, or standards affecting one aspect of development, Olympia is the first to complete a comprehensive policy revision covering development density, impervious surface coverage, lot size, open space/tree retention, street design, street width, block sizes, parking, sidewalks, and stormwater management requirements. Changes affecting the Green Cove watershed were made concurrently in Olympia's Comprehensive Plan policies, zoning code, development standards and drainage design requirements. Thurston County, responsible for land use regulation in the unincorporated portion of Olympia's growth management area, simultaneously adopted similar policies for its portion of the watershed. To date (one year after adoption), no applications have been filed for development under the new policies.

The policy changes were based on "best available science" determined during a three-year process of research, analysis and peer review. Lessons learned in the process may be useful to other jurisdictions interested in applying differential policies to certain areas for the purpose of environmental protection.

1 – Summary of adopted regulations

2 – Chronology of Events

SETTING THE STAGE

Beginning in 1998, the City of Olympia, Washington undertook to "define the balance between human activities and protecting habitat" in its stream watersheds. Located at the southern tip of Puget Sound, Olympia, the neighboring cities of Lacey and Tumwater, and Thurston County share responsibility for managing a rapidly growing population while maintaining the environmental quality of life which makes the Pacific Northwest one of the nation's most attractive regions.

3 – Vicinity Map – Green Cove Basin

Olympia is part of the South Puget Sound basin, a naturally watery place that was once covered by extensive wetlands and forests and drained by eight major creeks. Over the last 150 years, human settlements have disrupted the complex

hydrological cycle that maintained the natural ecosystem. Wetlands have been filled, forests cut down, land surfaces covered with buildings and pavement, and creeks routed underground. Impacts to aquatic habitat include increases in seasonal high and low flows, loss of critical streamside vegetation, degradation of water quality, and barriers to fish migration and spawning. The result has been a significant decrease in biological diversity and productivity.

In recent years, local land use goals and policies have reflected a growing ecological awareness and increase in scientific understanding. As required by the state's 1980 Growth Management Act, local comprehensive plans have incorporated policies aimed at protecting the environment while accommodating increased population, which is projected to nearly double by 2020. Olympia and other local jurisdictions are increasing densities in urban areas in order to curb sprawl in surrounding rural areas. At the same time, they have attempted a variety of environmental protection strategies, including: drainage regulations and capital improvement products to control flooding, erosion and sedimentation; critical areas ordinances to maintain a protective buffer of riparian vegetation along creeks and around wetlands; tree retention and open space requirements; capital projects to restore and enhance habitat; and water quality programs to enhance and monitor habitats and encourage people to keep pollutants from entering surface and ground water.

However, despite these efforts, aquatic habitat quality and diversity have continued to decline. Olympia Public Works Department storm and surface water staff closely followed research at the University of Washington confirming that the cumulative effects of urbanization may cause irreversible habitat damage (May, et al., 1997). Research on 19 lowland streams in the Puget Sound basin, including three in the City of Olympia, showed that impacts to stream habitat quality and complexity begin to occur at very low development densities – 8% - 12% total impervious area. Physical and biological conditions change most rapidly during the initial phase of urbanization.

4 – Summary of the Scientific Research

Staff realized the implication of this research is that it may not be possible for a diversity of aquatic habitat to flourish in an urban environment. In other words, the City may not be able to achieve policy goals for habitat protection in all basins, particularly those that are the most urbanized.

MAKING THE CASE FOR LOW-IMPACT DEVELOPMENT STANDARDS (1998-99)

In the fall of 1998, storm and surface water utility staff began talking with City Council about the apparent conflict between environmental policy and growth management requirements, which they observed in their own on-the-ground experiences. Realizing the City did not have the tools to completely mitigate environmental effects of increased development, Council authorized staff to explore the options. The State's Growth Management Act (GMA) presented the choice of either changing Comprehensive Plan policies to acknowledge the continued deterioration of aquatic habitats, or changing regulations to better meet Comprehensive Plan goals for environmental protection. Council chose to try to use science to better manage the highest value habitat in the City.

The Public Works Department hired the environmental consulting firm of CH2M-Hill to develop criteria for evaluating the viability of aquatic habitat in Olympia's eight stream watersheds and a range of management goals corresponding to the potential for maintaining or restoring aquatic habitat. Working with a local consultant, Dorothy P. Craig & Associates, staff then refined and expanded this framework, consolidated data on the eight watersheds, and published a preliminary draft report intended to make the case for differential policy based on the potential for preventing habitat decline. The resulting *Aquatic Habitat Evaluation & Management Report* included:

5 – Executive Summary of Report

6 – Aquatic Habitat Evaluation & Management Report

- A summary of research findings.
- Evaluation criteria, data summary for each basin, and grouping of basins as "sensitive," "impacted," or "degraded."
- A range of management goals and expected environmental consequences of each. Optional goals were: (1) protect property; (2) accommodate growth and maintain aesthetic amenities and water quality; (3) accommodate limited growth *and* protect existing habitat; (4) protect existing habitat, aesthetic amenities and water quality; and (5) restore habitat to natural conditions. All these goals were reflected in the Comprehensive Plan, but the study found that "it is not feasible to achieve all these goals in all basins."
- An attempt to quantify management objectives for the three "middle range goals" (2, 3, 4) and an assessment of the relative effectiveness of 15 potential management tools including zoning and critical areas ordinances, development standards,

land acquisition, public involvement, monitoring, and maintenance.

- Differential strategies, with a range of management tools, that might be applied in basins that are already degraded, basins where continued decline is possible, and basins with potential for long-term habitat protection.

The report concluded that "the goal of both accommodating projected growth and protecting habitat is not realistic in the long term." The suggested approach was to adopt different goals and policies based on the habitat potential of a given basin. These goals would guide decisions about development regulations, public expenditures, and landowner incentives, applying these and other management tools where they would likely have the most effect. In general the approach would be to make the goal of preserving habitat primary in those basins where habitat is still intact; for basins where habitat is still intact, but vulnerable to strong development pressure, attempt to protect habitat while accommodating growth, and realize the outcome is uncertain; and to make the goal of accommodating growth primary in basins where habitat is already degraded by urbanization. This approach would be used to design management tools and make investment decisions based on the potential for habitat protection in each basin.

In August 1999, storm and surface water utility staff assembled a team of six scientists, including the primary author of the University of Washington research, and biologists and hydrologists from the public and private sectors who are experienced with urban stream and wetland dynamics. The scientists were asked to critique the report and assess whether the policy suggestions were consistent with the research findings. The team concurred with the report and prepared a written assessment.

7 – Science Team Meeting Summary

8 – Sample Council Update

Throughout the study process, Council members and others had been kept informed through periodic "Council Updates." Following a staff briefing, based on the draft report and science team findings, City Council decided to narrow the scope of the project to the 2,600-acre Green Cove Creek watershed on the west side of Olympia. This watershed had been identified as "sensitive," since it has a relatively low impervious surface coverage (10% current, 24% potential build out), good forest cover (64%), extensive and intact wetlands, and good riparian and in-stream conditions, with good water quality, that support coho and chum salmon. A substantial portion of the basin (38%) is within the City limits and its growth management area. A joint meeting of City Council members and County Commissioners was held in January 2000. They agreed there was no time to waste and began work on developing a set of

interim development standards for Green Cove Creek watershed.

9 – Ordinance 5993 – Interim Standards

10 – Newsletter –Interim Standards

Interim standards were unanimously adopted by the City Council (February 8, 2000) and County Commissioners (May 9, 2000), following a brief period of public involvement that included notification of all property owners in the watershed and a public hearing. Public opinion was mixed more or less equally between pro and con. The interim standards, in place for one year, were as follows:

- **Zoning density.** Maximum density was limited to four housing units/acre within City limits.
- **Stormwater management standards.** New developments had to have "post-development" stormwater runoff releases (peak and average) that matched "pre-development" releases. This very rigorous standard required developments to maximize forest evapotranspiration and soil infiltration while minimizing impervious surface coverage.
- **Seasonal grading restrictions.** Site clearing and grading was allowed only between May 1 and October 1. This restriction to dry season activity was to protect water quality and help preserve soil infiltration capacity.
- **Tree protection.** Tree retention requirements were increased from 30 trees per acre to 60 trees per acre of buildable land on the development site. Protected tree areas were expected to increase from about 4-7% to 8-14% of the site.

FURTHER ANALYSIS (2000-2001)

While no developments were approved under the interim standards, their adoption gave staff time to develop science-based, long-term recommendations. The key to this phase was determining what could feasibly be adopted within the one-year time frame. Building consensus became essential.

City planners and engineers worked together in a day-long exercise, analyzing how improved environmental protection could be accomplished in new subdivisions in Green Cove Basin. They generated tangible ideas and concluded that relatively simple changes in existing regulations were available. The potential changes could have significant implications for development, but could be easily defined and implemented.

Storm and surface water utility staff searched regionally and nationally for comprehensive examples of science-based low-impact development techniques that could be mimicked. They

also asked planners, engineers and biologists for examples of successful low-impact developments. Pieces of the puzzle had been tried elsewhere. For example, several cities had adopted voluntary forest retention standards or narrow lanes. A few developments had been designed with features like swales or clustered housing with large sections of intact forest. They found no municipal jurisdictions that had put together all the habitat protection pieces that were identified in the scientific research. Environmental outcomes of the piecemeal approaches remained highly uncertain.

Given the lack of available models, staff realized they would have to craft a science-based approach, knowing that low-impact developments would be challenging to accomplish in small-lot subdivisions typical of development in Olympia. Since this was a new approach, they asked a local watershed biological consultant, Caldwell & Associates, to evaluate the appropriateness of developing basin biological goals and parameters to guide development regulations. Staff also realized that to be credible, they would need to base the new standards on actual site conditions in the watershed, and to enlist consultants familiar with local site design and development practices. In February 2000, Olympia staff and a local development consultant (SCA Consultants) looked at actual development proposals in the Green Cove basin and brainstormed changes that would meet aquatic habitat protection and other goals:

11 – Biological Goals Evaluation

- Maintain natural hydrologic conditions
- Maintain a minimum of 60% natural vegetation
- Meet current development density requirements
- Minimize the number of variances or regulatory changes
- Minimize impervious surfaces
- Maintain urban level for emergency vehicle access
- Produce a marketable development
- Maximize single family homes

12 – Site Plans for Case Study

The two sites chosen for the case study were a 35-acre, flat, forested site with minimal environmental constraints and a 50-acre, hilly site with extensive environmental constraints (steep slopes and wetlands). Both had been proposed for standard subdivisions with relatively small lot (5000-6000 square feet) single-family housing. Based on the goals, SCA developed two alternate site plans, which were presented to the City's site plan review committee and subsequently to the City Council in the fall of 2000. In evaluating the low-impact site plans compared to conventional subdivision design, the most critical issues were development density, forest retention, and street

designs. Ultimately, development density was reduced by about 40%, forest retention increased to 55%, and street related impervious surface decreased by about 25%. Overall, impervious surface coverage was reduced by about 50%.

13 – Case Study Results
a – Report Summary
b – Cost Comparisons
c – Cost Analysis - Summary
d – Other Comparisons

The following March, J.W. Morrissette Associates, Inc., a local development engineering firm, completed a hydrologic analysis and infrastructure design for the low-impact and conventional site plans, and prepared a comparison of land use and unit costs for the two alternatives. A hydrologic consultant, AquaTerra, was hired to develop a computer model capable of evaluating different development scenarios, and the City prepared graphic comparisons of such factors as impervious surface coverage, stormwater pond area, and tree tracts as well as costs.

14 – Summary of Interviews

In May 2001, The Shea Group, another local consultant, conducted interviews with realtors, development engineers, bankers, and developers, asking for feedback on the low-impact site plan. In response, further revisions in the low-impact designs were made, specifically: (1) tree lots were not required in front of homes, but moved to dedicated tree tracts; (2) 25-foot planter strips on streets became optional; (3) minimal street parking was added on alternate sides of street.

15 – Chart Comparing Impacts

Staff then prepared a chart comparing how build out of the watershed under current standards and four alternative zoning scenarios would impact the key watershed quality indices (total impervious area, forest retention, riparian corridor integrity, and in-stream conditions). Comparisons were quantified where possible and otherwise described in relative terms.

16 – Science Team Meeting Summary

The science team was reconvened to discuss the proposed low-impact development standards for Green Cove Basin. Their report confirmed that the proposed subdivision designs were generally consistent the scientific findings and that implementation would have the potential to maintain habitat conditions equivalent to the present. They concurred that Green Cove is a good basin to test the hypothesis that this level of housing density can co-exist with aquatic wetland and riparian resources. They also found that with current methods, environmental benefits represented in the comparative chart could not be quantified more precisely.

ADOPTED POLICY AND REGULATIONS – CITY OF OLYMPIA (2001)

Once the analysis, scientific review, and recommendations were complete, the City and County embarked on a sequential process of adopting changes in Comprehensive Plans, zoning and tree protection ordinances; street, sidewalk, and parking

standards; and drainage design and erosion control standards. The Comprehensive Plan amendment process began earlier and took a year, from September 2000 to September 2001. The Olympia Planning Commission reviewed the entire package – the first time it had considered anything other than Comprehensive Plan revisions. During review of the Comprehensive Plan amendments, the chart comparing impacts with conventional and low-impact design helped convince both City and County Planning Commissions that the approach was viable.

17 – Newsletter

To make the complicated process as transparent as possible, newsletters were mailed every few months to all basin property owners and other stakeholders. Each newsletter explained the context for each policy or regulatory proposal, upcoming meetings or hearings in both jurisdictions, and what would be discussed or decided in each meeting.

In Olympia, the following policy and regulatory changes were adopted in sequence between August 1 and September 15, 2001. All became effective October 1, 2001.

Comprehensive Plan Amendments

18 – Ordinance 6140 Comprehensive Plan Amendments
- a – Excerpts
- b – Permitted and Conditional Uses
- c – Residential Development Standards
- d – Zoning Map

By adoption of Ordinance 6140, the City supplemented the Comprehensive Plan's Chapter 1 (Land Use and Urban Design), Chapter 2 (Environment), Chapter 5 (Utilities and Public Facilities), and Chapter 6 (Transportation) with goals and policies that establish Green Cove basin as a unique area, subject to enhanced environmental regulations. Primary goals and policy changes for Green Cove basin included the following:

- Designate Green Cove Creek as a sensitive drainage basin.
- Avoid high-density development where new development would have a significant adverse impact upon the habitat within designated sensitive drainage basins.
- Administer development regulations that protect critical areas and designated sensitive drainage basins.
- Adopt low-impact development regulations within designated sensitive drainage basins that may include stormwater standards, critical area regulations, zoning designations, and other development standards.
- Establish street designs that minimize impacts to the natural environment especially within a designated sensitive drainage basin.

Olympia Municipal Code (OMC)

Ordinance 6140 also supplemented the OMC with requirements for designated sensitive drainage basins, Green Cove basin in particular. The ordinance created a new zoning district and increased tree protection and replacement requirements.

Title 18 Unified Development Code: Article II - Land Use Districts

The new district, Residential Low Impact (RLI), applied to Green Cove basin within Olympia city limits. Parcels along the basin boundary that have at least 50% of their surface area within the basin were included in the district. Traits of the district included:

- Residential densities of two to four units per acre. Duplex, townhouse, and multifamily uses are allowed.
- Lot widths and rear setbacks are reduced and maximum building heights are increased, compared to the other residential districts.
- Maximum impervious surface coverage per lot is limited to 2,500 square feet.
- Several land uses, including duplexes and parking lots, not typically permitted in single-family residential developments, are allowed in the Green Cove basin.

New Chapter 16.54 Tree Protection and Replacement for Green Cove Basin

- A minimum tree density requirement of 220 tree units per acre is required. The requirement will result in approximately 55% tree cover in any given development. Trees within critical areas can be included in the density calculation.

Development Guidelines and Public Works Standards (DGPWS)

Ordinance 6143 created a new chapter in the DGPWS, containing specific standards for engineered features of a new development in Green Cove basin. The Green Cove requirements focus on street designs and stormwater conveyance. Chapter 9 includes the following requirements:

- Residential block perimeters cannot exceed 1,700 feet.
- Driveways and sidewalks can be constructed of porous surfaces with City approval.
- Sidewalks are required on one side of local access streets.

19 – Ordinance 6143 – Development Standards
- a – Summary
- b – Complete Text
- c – Permitted and Conditional Uses (revised)
- d – Street Standards (schematics)
- e – Minimum Street Standards
- f – Street Design Standards

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- Sidewalk planter widths can be increased from the required eight feet to an optional 25 feet. The parameters for the optional cross-section, species, and plant stock are provided.
- Additional parking within low-impact developments can be provided by the construction of porous surface lots subject to City approval.
- A rocked infiltration gallery/conveyance system is to be constructed when street slopes are 5% or less. Use of the system on greater slopes requires geotechnical and engineering evaluation.
- Neighborhood collector streets are to be 25 feet wide, with parking provided on alternating sides of the street. Local access streets are to be 18 feet wide, with similar parking arrangements. Additional street and right-of-way design traits are provided.

Drainage Design and Erosion Control Manual

Administrative changes to the City's stormwater management manual resulted in increased stormwater storage requirements and seasonal grading limitations in Green Cove basin. Specific changes included:

- Stormwater discharges shall be controlled by matching developed discharge durations to pre-developed durations, for the range of pre-developed discharge rates from 50% of the two-year peak flow to the 50-year peak flow. The application of the requirement is defined in the *Stormwater Management Manual for Western Washington*, Washington Department of Ecology, August 2001 (Publication 99-11 through 99-15).
- Clearing and grading within the basin is allowed only between May 1 and October 1 of any given year.

ADOPTED POLICY AND REGULATIONS – THURSTON COUNTY (2001)

Thurston County adopted the following policy and regulatory changes over the same time period, affecting new development in the portion of Green Cove Basin that is outside Olympia city limits but within the City's urban growth area (UGA).

Comprehensive Plan

Comprehensive Plan policies for the urban growth area were amended to create guidance for low-impact development and habitat preservation, and land use designations and zoning in

the Green Cove Creek basin were amended to be consistent with those of Olympia.

Zoning

The County's Olympia Urban Growth Area Zoning Code (TCC 20.23), was amended to be generally consistent with City of Olympia zoning. The urban growth area within Green Cove Creek Drainage Basin was rezoned from predominately 4-8 units per acre to 2-4 units per acre. The exception was a forested area along the creek where density was limited to one unit per five acres, to reduce the overall impervious surface in the basin to levels likely to enable preservation of anadromous fish and to buffer the creek from the impacts of urban density development up slope. The zoning amendments also required that, within the urban growth area, 60% of each site be retained in open space and that existing vegetation in these areas be preserved. The Planning Commission recommendation that this open space requirement be extended to the area of the basin outside the urban growth area will be considered in 2002.

Open space program

The County will also consider in 2002 the Planning Commission recommendation to amend the open space program to extend tax incentive eligibility to small property owners in the entire basin who maintain (or replant) native trees on 60% of their property and/or maintain a suitable buffer along the banks of creeks and wetlands.

LESSONS LEARNED

Since adoption of the new low-impact development regulations in October 2001, no development proposals have been submitted for Green Cove basin (nor in neighboring Tumwater or Lacey under their voluntary low-impact standards). One Olympia developer has completed an initial site design and cost estimate that establishes feasibility, and offered to make the low-impact standards a mandatory condition of his project; however the project is now on hold for other reasons. Following are several lessons from the Olympia experience that may prove helpful for other jurisdictions.

What Works Well

1. **Stick closely with science.** Because the standards were to be mandatory, they had to be legally defensible in terms of property rights, growth management law, and public safety. Several developers challenged City's right to make these restrictions.

2. **Document the need thoroughly.** Olympia staff spent an entire year confirming that a problem existed and making sure City Council and Planning Commission acknowledged the problem and were willing to tackle it, knowing the high value the community places on environmental protection. Elected officials also became convinced that it is appropriate to do things differently in different basins, and that the Comprehensive Plan could be changed based on new information.
3. **Adopt interim measures.** Once the need was established, this step gave the City a full year to make sure the final recommendations were feasible.
4. **Assume a lengthy process.** Storm and surface water utility staff realized time would be needed to develop internal consensus among City planners, engineers, and fire officials. They knew cooperation with County staff and officials would be needed to ensure consistency between the two jurisdictions. Concerns such as public safety and emergency vehicle access took time to resolve.
5. **Bring in outside people.** Respected local experts were consulted throughout the process to lend credibility and ensure feasibility. For example the City used a science peer review team, hired engineering and design consultants, and interviewed local developers and bankers.
6. **Focus on feasible changes to existing requirements.** Early in the process, the City acknowledged that changes necessary to achieve ideal conditions for watershed habitat could not be achieved within the time available. Although the effects on aquatic habitat were uncertain, the City wanted to see what could be accomplished with more environmentally friendly regulations. The agenda remains unfinished; however, the City did what was possible in 2001.

What Could Be Done Better

1. Plan for low-impact development in less developed basins, for example in more rural counties where there has been less development impact.
2. Include developers earlier and more thoroughly. Delaying involvement became a reason for them to criticize later.
3. Communicate clearly with the public. Changing all the policies at once was confusing to both the public and developers, though the mailings during the adoption process helped. It is important to communicate the big picture, the interrelationships among all the policies and standards, and the separate processes for changing different documents.

Lingering Questions

Several questions have not been resolved so far in the Green Cove basin process:

1. Extra costs of non-standard development techniques.
2. Home buyers' willingness to purchase homes in a "low-impact" neighborhood with narrower streets, less parking, smaller home footprints, and regulatory limits to additions that would increase impervious surfaces.
3. Environmental benefits of development restrictions, given the overall pattern of development and previous disruption of natural hydrology.

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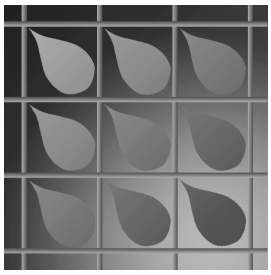
City of Seattle

Stormwater, Grading and Drainage Control Code



ORDINANCE 116425
Effective February 11, 1993

ORDINANCE 117432
Effective January 19, 1995

ORDINANCE 117697
Effective August 13, 1995

ORDINANCE 117789
Effective October 1, 1995

ORDINANCE 119965
Effective July 5, 2000



City of Seattle
Department of Design, Construction and Land Use

R. F. Krochalis, Director
Paul Schell, Mayor

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Chapter 22.800

TITLE, PURPOSE, SCOPE AND AUTHORITY

22.800.010 TITLE

This subtitle, comprised of SMC Chapters 22.800 through 22.808, shall be known as the "Stormwater, Grading and Drainage Control Code," and may be cited as such.

22.800.020 PURPOSE

A. The provisions of this subtitle shall be liberally construed to accomplish its remedial purposes, which are:

1. Protect, to the greatest extent practicable, life, property and the environment from loss, injury and damage by pollution, erosion, flooding, landslides, strong ground motion, soil liquefaction, accelerated soil creep, settlement and subsidence, and other potential hazards, whether from natural causes or from human activity;
2. Protect the public interest in drainage and related functions of drainage basins, watercourses and shoreline areas;
3. Protect surface waters and receiving waters from pollution, mechanical damage, excessive flows and other conditions in their drainage basins which will increase the rate of downcutting, streambank erosion, and/or the degree of turbidity, siltation and other forms of pollution, or which will reduce their low flows or low levels to levels which degrade the environment, reduce recharging of groundwater, or endanger aquatic and benthic life within these surface waters and receiving waters of the State;
4. Meet the requirements of state and federal law and the City's municipal stormwater NPDES permit; and
5. Fulfill the responsibilities of the City as trustee of the environment for future generations.

It is expressly the purpose of this subtitle to provide for and promote the health, safety and welfare of the general public. This subtitle is not intended to create or otherwise establish or designate any particular class or group of persons who will or should be especially protected or benefited by its terms.

C. It is expressly acknowledged that water quality degradation can result either directly from one discharge or through the collective impact of many small discharges. Therefore, the water quality protection measures in this subtitle are necessary to protect the health, safety and welfare of the residents of Seattle and the integrity of natural resources for the benefit of all and for the purposes of this subtitle. Such water quality protection measures are required under the federal Clean Water Act, 33 U.S.C. Section 1251, et seq., and in response to the obligations of the City's municipal stormwater discharge permit, issued by the State of Washington under the federal National Pollutant Discharge Elimination System program.

22.800.030 SCOPE

This subtitle applies to:

A. All grading and drainage and erosion control, whether or not a permit is required; and

B. All new or replaced impervious surface and all land disturbing activities, whether or not a permit is required; and

C. All discharges directly or indirectly to a public drainage control system; and

D. All new and existing land uses.

22.800.050 POTENTIALLY HAZARDOUS LOCATIONS

A. Any site on a list, register, or data base compiled by the United States Environmental Protection Agency ("EPA") or the Washington State Department of Ecology ("DOE") for investigation, clean up, or other action regarding contamination under any

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federal or state environmental law shall be a potentially hazardous location under this subtitle. When EPA or DOE removes the site from the list, register or data base, or when the owner otherwise establishes contamination does not pose a present or potential threat to human health or the environment, the site will no longer be considered a potentially hazardous location.

B. The following property may also be designated by the Director of the Department of DCLU as potentially hazardous locations:

1. Existing and abandoned solid waste disposal sites;
2. Hazardous waste treatment, storage, or disposal facilities, all as defined by the federal Solid Waste Disposal Act, 42 U.S.C. 6901, et seq.

22.800.060 COMPLIANCE WITH OTHER LAWS

A. The requirements of this subtitle are minimum requirements. They do not replace, repeal, abrogate, supersede or affect any other more stringent requirements, rules, regulations, covenants, standards, or restrictions. Where this subtitle imposes requirements which are more protective of human health or the environment than those set forth elsewhere, the provisions of this subtitle shall prevail.

B. Approvals and permits granted under this subtitle are not waivers of the requirements of any other laws, nor do they indicate compliance with any other laws. Compliance is still required with all applicable federal, state and local laws and regulations, including rules promulgated under authority of this subtitle.

C. Compliance with the provisions of this subtitle and of regulations and manuals adopted by the City in relation to this subtitle does not necessarily mitigate all impacts to the environment. Thus, compliance with this subtitle and related regulations and manuals should not be construed as mitigating all stormwater impacts, and additional mitigation may be required to protect the environment. The primary obligation for compliance with this chapter, and for preventing environmental harm on or from property, is placed upon responsible parties as defined by this subtitle.

22.800.070 CITY PROJECTS

A. Compliance.

1. City agencies shall comply with all the requirements of this subtitle except they shall not be required to obtain permits and approvals under this subtitle for work performed within a public right-of-way and for work performed for the operation and maintenance of park lands under the control or jurisdiction of the Department of Parks and Recreation. Where the work occurs in a public right-of-way, it shall comply with Seattle Municipal Code Title 15, Street and Sidewalk Use, including the applicable requirements to obtain permits or approvals. Where appropriate as set forth in Section 22.804.040C of this Code, a soils report and analysis by an experienced geotechnical engineer shall be prepared for City projects.
2. A City agency project, as defined in Section 22.801.170, that is not required to obtain permit(s) and approval(s) per subsection A1 above, is not required to comply with Sections 22.802.015 C4, 22.802.016 B1, and 22.802.016 B2, if the project begins land disturbing activities on or before July 1, 2002, and if the project meets one or more of the following criteria:
   a. Project funding was appropriated as identified in Ordinance 119750, titled, "An ordinance adopting a budget, including a capital improvement program and a position list, for the City of Seattle for fiscal year 2000," or
   b. Project received or will receive voter approval of financing before January 1, 2001, or

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c. Project received or will receive funds based on grant application(s) submitted before January 1, 2001, or

d. Project conducted or will conduct land disturbing activity before January 1, 2001.

B. Inspection.

1. When the City conducts projects for which review and approval is required under Section 22.802.020 or 22.804.030, the work shall be inspected by the City agency conducting the project or supervising the contract for the project. The inspector for the City agency shall be responsible for insuring that the grading and drainage control is done in a manner consistent with the requirements of this subtitle.
2. Where a soils analysis and report has been prepared as required under subsection A of this section, the grading shall also be inspected by the geotechnical engineer who prepared the report.
3. A City agency need not provide an inspector from its own agency provided either:
   a. the work is inspected by an appropriate inspector from another City agency; or
   b. the work is inspected by the licensed civil or geotechnical engineer who prepared the plans and specifications for the work; or
   c. a permit or approval is obtained from the Director of DCLU, and the work is inspected by the Director.

C. Certification of Compliance. City agencies shall meet the same standards as non-City projects, and shall certify that each individual project meets those standards.

22.800.080 AUTHORITY

A. 1. The Director of DCLU has authority regarding the provisions of this subtitle pertaining to grading, review of drainage control plans, and review of erosion control plans, and has inspection and enforcement authority pertaining to temporary erosion/sediment control measures.

2. The Director of SPU has authority regarding all other provisions of this subtitle pertaining to stormwater, drainage, and erosion control, including inspection and enforcement authority.

B. The Directors of DCLU and SPU are authorized to take actions necessary to implement the provisions and purposes of this subtitle in their respective spheres of authority, including, but not limited to, the following: promulgating and amending rules and regulations, pursuant to the Administrative Code, Chapter 3.02 of the Seattle Municipal Code; establishing and conducting inspection programs; establishing and conducting or, as set forth in Section 22.802.012, requiring responsible parties to conduct, monitoring programs, which may include sampling of discharges to or from drainage control facilities, the public drainage control system, or surface water; taking enforcement action; abating nuisances; promulgating guidance and policy documents; and reviewing and approving or disapproving required submittals and applications for approvals and permits.

C. The Director of SPU is authorized to develop drainage basin plans for managing surface water, drainage water, and erosion within individual subbasins. A drainage basin plan may, when approved by the Director of SPU, be used to modify requirements of this subtitle, provided the level of protection for human health, safety and welfare, the environment, and public or private property will equal or exceed that which would otherwise be achieved.

22.800.090 CITY NOT LIABLE

A. Nothing contained in this subtitle is intended to be nor shall be construed to create or form the basis for any liability on the part of the City, or its officers, employees or agents for any injury or damage resulting from the failure of responsible parties to comply with the provisions of this subtitle, or by reason or

in consequence of any inspection, notice, order, certificate, permission or approval authorized or issued or done in connection with the implementation or enforcement of this subtitle, or by reason of any action or inaction on the part of the City related in any manner to the enforcement of this subtitle by its officers, employees or agents.

B. The Director or any employee charged with the enforcement of this subtitle, acting in good faith and without malice on behalf of the City, shall not be personally liable for any damage that may accrue to persons or property as a result of any act required by the City, or by reason of any act or omission in the discharge of these duties. Any suit brought against the Director of DCLU, Director of SPU or other employee because of an act or omission performed in the enforcement of any provisions of this subtitle, shall be defended by the City.

C. Nothing in this subtitle shall impose any liability on the City or any of its officers or employees for clean up or any harm relating to sites containing hazardous materials, wastes or contaminated soil.

Chapter 22.801
DEFINITIONS

22.801.010 GENERAL

For the purpose of this subtitle, the words listed in this Chapter have the following meanings unless the context clearly indicates otherwise. Terms relating to pollutants and to hazardous wastes, materials, and substances, where not defined in this subtitle, shall be as defined in Washington Administrative Code Chapters 173-303, 173-304 and 173-340, the Seattle Building Code or the Seattle Fire Code, including future amendments to those codes. Words used in the singular include the plural, and words used in the plural include the singular.

Effective July 5, 2000, all references in the Seattle Municipal Code Chapters 22.800 through 22.808 to "Department of Construction and Land Use," "Department of Design, Construction and Land Use," "Director of Construction and Land Use," "Director of Design, Construction and Land Use," or "Seattle Public Utilities" shall be deemed references to "DCLU," "DCLU," "Director of DCLU," "Director of DCLU" or "SPU," respectively. The City's Code Reviser is authorized to amend the Seattle Municipal Code Chapters 22.802 through 22.808 over time as he or she deems appropriate in order to carry out these changes.

22.801.020 "A"

ABANDONED SOLID WASTE DISPOSAL SITE means a site that is no longer in use and where solid waste was disposed with or without a permit.

AGENCY means any governmental entity or its subdivision.

AGENCY WITH JURISDICTION means those agencies with statutory authority to approve, condition or deny permits, such as the United States Environmental Protection Agency, the Washington State Department of Ecology or the Seattle/King County Department of Public Health.

AMERICAN PETROLEUM INSTITUTE (API) OIL/WATER SEPARATOR: See

OIL/WATER SEPARATOR, AMERICAN PETROLEUM INSTITUTE (API).

APPROVED means approved by either the Director of Design, Construction and Land Use or the Director of Seattle Public Utilities.

AS-GRADED means the surface condition existing after completion of grading.

22.801.030 "B"

BACKFILLING means returning a site to its original or approved contours after earth materials were removed for construction purposes.

BASIN PLAN means a plan to manage the quality and quantity of stormwater in a watershed, including watershed action plans.

BENCH means a relatively level step excavated into earth material on which fill is to be placed.

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BEST MANAGEMENT PRACTICE (BMP) means a physical, chemical, structural or managerial practice or device that prevents, reduces, or treats contamination of water or which prevents or reduces soil erosion. When the Directors develop rules and/or manuals prescribing best management practices for particular purposes, whether or not those rules and/or manuals are adopted by ordinance, BMPs prescribed in the rules and/or manuals shall be the BMPs required for compliance with this subtitle.

1. NON-STRUCTURAL or OPERATIONAL BEST MANAGEMENT PRACTICES are those pollution control strategies that require modified or additional behavioral practices, such as sweeping a parking lot, or maintaining special equipment on site, such as spill response equipment.
2. STRUCTURAL: BEST MANAGEMENT PRACTICES are those pollution control strategies that require the construction of a structure or other physical modification on the site.

BIOFILTRATION SWALE means a long, gently sloped, vegetated channel designed and maintained to treat stormwater runoff through sedimentation, adsorption, and biological uptake. Grass is the most common vegetation, but wetland vegetation can be used if the soil is saturated.

BUILDING PERMIT means a document issued by The City of Seattle Department of Design, Construction and Land Use giving permission for construction or other specified activity in accordance with the Seattle Building Code (Chapter 22.100 SMC).

22.801.040 "C"

CAUSE OR CONTRIBUTE TO A VIOLATION means and includes acts or omissions that create a violation, that increase the duration, extent or severity of a violation, and that aid or abet a violation.

CIVIL ENGINEER, LICENSED means a person who is a licensed by the State of Washington to practice civil engineering.

COALESCING PLATE OIL/WATER SEPARATOR means a multi-chambered vault, containing a set of parallel, corrugated plates that are stacked and bundled together in the center of the vault. Coalescing plate separators are designed to remove dispersed oil and floating debris as well as in containing spills.

COMBINED SEWER - see PUBLIC COMBINED SEWER.

COMPACTION means the densification of a fill by mechanical means.

CONTAINMENT AREA means the area designated for conducting high-risk pollution generating activities for the purposes of implementing operational source controls or designing and installing structural source controls or treatment facilities.

CONTAMINATE means the addition of sediment, any other pollutant or waste, or any illicit discharge.

CUT means the changing of a grade by excavation.

22.801.050 "D"

DCLU means the Department of Design, Construction and Land Use.

DAMAGES means monetary compensation for harm, loss, costs, or expenses incurred by the City, including, but not limited to, the following: costs of abating violations of this subtitle or public nuisances; fines or penalties the City incurs as a result of a violation of this subtitle; and costs to repair or clean the public drainage control system as a result of a violation. For the purposes of this subtitle, it does not include compensation to any person other than the City.

DESIGN STORM means a rainfall event used in the analysis and design of drainage facilities.

DESIGNATED RECEIVING WATERS means the Duwamish River, Puget Sound,

Lake Washington, Lake Union, and the Lake Washington Ship Canal, and other receiving waters designated by the Director of SPU as having the capacity to receive drainage discharges.

DETENTION means temporary storage of drainage water for the purpose of controlling the drainage discharge rate.

DETENTION SYSTEM means a facility designed to control the discharge rate of stormwater runoff from a site by detaining flows in a tank or vault.

DEVELOPMENT means land disturbing activity or the addition or replacement of impervious surface.

DEVELOPMENTAL COVERAGE means all areas within a site planned for land disturbing activity or new or replaced impervious surface.

DIRECTOR means the Director of the Department authorized to take a particular action, and the Director's designees, who may be employees of that department or another City department.

DIRECTOR OF DESIGN, CONSTRUCTION AND LAND USE means the Director of the Department of Design, Construction and Land Use of The City of Seattle and/or the designee of the Director of Department of Design, Construction and Land Use, who may be employees of that department or another City department.

DIRECTOR OF SEATTLE PUBLIC UTILITIES means the Director of Seattle Public Utilities of The City of Seattle and/or the designee of the Director of Seattle Public Utilities, who may be employees of that department or another City department.

DISCHARGE POINT means the location to which drainage water from a specific site is released.

DISCHARGE RATE means the rate at which drainage water is released from a specific site. The discharge rate is expressed as volume per unit of time, such as cubic feet per second.

DRAINAGE BASIN means the tributary area through which drainage water is collected, regulated, transported, and discharged to receiving waters.

DRAINAGE CONTROL means the management of drainage water. Drainage control is accomplished through the collection, conveyance, and discharge of drainage water, controlling the rate of discharge from a site, or separating, treating or preventing the introduction of pollutants.

DRAINAGE CONTROL FACILITY means any facility, including best management practices, installed or constructed for the purpose of controlling the flow, quantity, and/or quality of drainage water.

DRAINAGE CONTROL PLAN means a plan for collecting, controlling, transporting and disposing of drainage water falling upon, entering, flowing within, and exiting the site, including designs for drainage control facilities.

DRAINAGE CONTROL SYSTEM means a system intended to collect, convey and control release of only drainage water. The system may serve public or private property. It includes constructed and/or natural components such as ditches, culverts, streams and drainage control facilities.

DRAINAGE WATER means stormwater, snow melt, surface water, surface and irrigation runoff, water from footing drains and other drains approved by the Director of SPU or installed in compliance with this subtitle and rules which may be adopted hereunder. Other water which is not an illicit discharge as defined in Section 22.802.012C shall be considered drainage water if it drains from the exterior of a building or structure, a pervious or impervious surface, or undeveloped land, or by surface or shallow subsurface flow.

DREDGING means the excavation of earth materials from land covered by water. The

term includes dredging that maintains an established water depth.

22.801.060 "E"

EARTH MATERIAL means any rock, gravel, natural soil or resedimented soil, or any combination thereof, and does not include any solid waste as defined by RCW Chapter 70.95.

ENVIRONMENTALLY CRITICAL AREA means an area designated in Chapter 25.09 of the Seattle Municipal Code.

EROSION means the wearing away of the ground surface as a result of mass wasting or of the movement of wind, water and/or ice.

EXCAVATION means the mechanical removal of earth material.

EXISTING GRADE means the natural surface contour of a site, including minor adjustments to the surface of the site in preparation for construction.

EXPLORATORY EXCAVATION means borings, or small pits, hand-dug or excavated by mechanical equipment. Exploratory excavation does not include preloading of the site.

22.801.070 "F"

FILL means material deposited, placed, pushed, pulled or transported to a place other than the place from which it originated.

FILTER STRIP means a gently sloping vegetated area that is designed and maintained to treat, through sedimentation, adsorption and biological uptake, stormwater runoff from overland sheet flow from adjacent paved areas before it concentrates into a discrete channel.

FINISHED GRADE means the grade upon completion of the fill or excavation.

FLOW CONTROL means controlling the discharge rate of stormwater runoff from the site through means such as infiltration or detention.

FLOW CONTROL FACILITY means a method, such as pursuant to this subtitle or associated rules, for controlling the discharge rate of stormwater runoff from a site.

22.801.080 "G"

GARBAGE means putrescible waste.

GEOTECHNICAL ENGINEER, EXPERIENCED or **GEOTECHNICAL/CIVIL ENGINEER, EXPERIENCED** means a professional civil engineer licensed by the State of Washington who has at least four years of professional experience as a geotechnical engineer, including experience with landslide evaluation.

GRADE means the ground surface contour (see also EXISTING GRADE and FINISHED GRADE).

GRADING means excavation, fill, in-place ground modification, or any combination thereof, including the establishment of a grade following demolition of a structure.

GRADING APPROVAL means an approved component of a building permit relating to grading, as required by this subtitle.

22.801.090 "H."

HIGH-RISK POLLUTION GENERATING ACTIVITIES are the following:

1. Fueling operations that involve transferring fuel into mobile vehicles or equipment at permanent stations, temporary stations, and mobile fueling stations. Permanent stations include facilities, such as, but not limited to, commercial gas stations, maintenance yards, and private fleet fueling stations, where fuel is transferred from a dedicated fueling station. Temporary fueling stations include, but are not limited to, construction sites and any other site where fuel is temporarily stored and dispensed into vehicles or equipment. Mobile fueling stations are fueling operations where fuel is delivered to vehicles and equipment via mobile tank trucks.
2. Vehicle, equipment or building washing or cleaning, including any of the following:

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mobile vehicle steam cleaning operations or vehicle washing at commercial car wash facilities, charity car washes, or permanent parking lots such as new, used, and rental car lots and fleet lots; outside washing of tools or other manufacturing equipment; outside cleaning of commercial cooking equipment such as filters and grills; or washing of buildings, including exteriors or mobile interior building cleaning services.

3. Truck or rail loading or unloading of liquid or solid materials that involves transferring non-containerized bulk liquids from truck or rail, or loading/unloading materials at a commercial or industrial loading dock.
4. Liquid storage in stationary above ground tanks, including storing liquid chemicals, fertilizers, pesticides, solvents, grease, or petroleum products in stationary above ground tanks.
5. Outside portable container storage of liquids, food wastes, or dangerous wastes including storing any of the following: vegetable grease, animal grease, or other accumulated food wastes; used oil; liquid feedstock; cleaning compounds; chemicals; solid waste as defined by SMC 21.36; or dangerous waste.
6. Outside storage of non-containerized materials, by-products, or finished products, including outside storage of any of the following: non-liquid pesticides or fertilizers; contaminated soil; food products or food wastes; metals; building materials, including, but not limited to, lumber, roofing material, insulation, piping, and concrete products; or erodible materials, including, but not limited to, sand, gravel, road salt, topsoil, compost, excavated soil, and wood chips.
7. Outside manufacturing activity including any of the following: processing; fabrication; repair or maintenance of vehicles, products or equipment; mixing; milling; refining; or sand blasting, coating, painting, or finishing of vehicles, products, or equipment.
8. Landscape construction or maintenance, including any of the following: land disturbing activities as described in SMC 22.801.130; fertilizer or pesticide application near public drainage control system; and disposal of yard waste near a public drainage control system or riparian corridor.

HIGH-USE means any project planned to generate or accommodate any of the following:

1. Expected average daily traffic (ADT) count equal to or greater than 100 vehicles per 1,000 square feet of gross building area. In addition, the following is high-use unless the responsible party demonstrates to the satisfaction of the Director of DCLU or of the Director of SPU that the project will generate less than 100 vehicles per 1,000 square feet of gross building area: uncovered parking lot accessory to any fast-food restaurant, convenience market, supermarket, shopping center, discount store, movie theater, athletic club, or bank.
2. Petroleum storage or transfer in excess of 1,500 gallons per year, not including delivered heating oil.
3. Storage, or maintenance of a fleet of 25 or more diesel vehicles that are over 10 tons net weight (including, but not limited to, trucks, buses, trains, heavy equipment).
4. Road intersections with a measured ADT count of 25,000 vehicles or more on the main roadway and 15,000 or more on any intersecting roadway, excluding projects proposing primarily pedestrian or bicycle use improvements.

22.801.100 "I"

ILLICIT DISCHARGE means the discharges defined by Section 22.802.012.

IMPERVIOUS SURFACE means any surface exposed to rainwater from which most water runs off including, but not limited to, paving,

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packed earth material, oiled macadam or other treated surfaces, and roof surfaces, patios, and formal planters.

IMPERVIOUS SURFACE, REPLACED - See REPLACED OR REPLACEMENT OF IMPERVIOUS SURFACE.

INFILTRATION FACILITY means a drainage facility that temporarily stores, and then percolates stormwater runoff into the underlying soil. Examples include, but are not limited to, infiltration trenches, ponds, vaults, and tanks.

IN-PLACE GROUND MODIFICATION means activity occurring at or below the surface which is designed to alter the engineering parameters and physical characteristics of soil or rock, including, but not limited to, in-situ consolidation, solidification, void space reduction and infilling.

INSPECTOR means the City inspector, inspection agency, or licensed civil engineer performing the inspection work required by this subtitle.

22.801.130 "L"

LAND-DISTURBING ACTIVITY means any activity that results in a movement of earth, or a change in the existing soil cover (both vegetative and nonvegetative) or the existing topography. Land-disturbing activities include, but are not limited to, clearing, grading, filling, excavation or addition or replacement of impervious surface.

LARGE PROJECT means a project including 5,000 square feet or more of new or replaced impervious surface or 1 acre or more of land disturbing activity.

22.801.140 "M"

MASTER USE PERMIT means a document issued by DCLU giving permission for development or use of land or street right-of-way in accordance with the Land Use Code (Title 23, Seattle Municipal Code).

MEDIA FILTER means a stormwater treatment system that utilizes a filtration medium such as sand or leaf compost to remove pollutants via physical filtration and chemical adsorption or precipitation. Filters may be constructed underground in a vault or above ground in a pond. In both systems, stormwater that has passed through the filter media is collected in an underground pipe and discharged to the nearby drainage system.

MUNICIPAL STORMWATER NPDES PERMIT means the permit issued to the City under the federal Clean Water Act for public drainage control systems within the City limits.

22.801.150 "N"

NPDES means National Pollutant Discharge Elimination System, the national program for controlling discharges under the federal Clean Water Act.

NPDES PERMIT means an authorization, license or equivalent control document issued by the United States Environmental Protection Agency or the Washington State Department of Ecology to implement the requirements of the NPDES program.

NONDESIGNATED RECEIVING WATERS means all creeks, streams and lakes in The City of Seattle not designated as receiving waters, including Green Lake, Haller Lake, and Bitter Lake and all the creeks and streams.

22.801.160 "O"

OIL/WATER SEPARATOR means a structure, usually underground, that is designed to provide quiescent flow conditions so that globules of free oil or other floatable materials that may be present in stormwater can float to the water surface and become trapped in the structure.

OIL/WATER SEPARATOR, AMERICAN PETROLEUM INSTITUTE (API) means a vault that has multiple chambers separated by baffles and weirs to trap oil in the vault. API oil/water separators are designed to remove

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dispersed oil and floating debris and in containing spills.

OIL/WATER SEPARATOR, COALESCING PLATE. See COALESCING PLATE OIL/WATER SEPARATOR.

OWNER means any person having title to and/or responsibility for, a building or property, including a lessee, guardian, receiver or trustee, and the owner's duly authorized agent.

22.801.170 "P"

PERSON means an individual, firm, partnership, corporation, municipal corporation, and government, and the individual's or entity's heirs, successors and assigns.

PLAN means, for the purposes of this subtitle, and unless a different meaning is set forth or clearly required, a graphic or schematic representation, with accompanying notes, schedules, specifications and other related documents.

PLOT PLAN means a scaled map of a site and adjacent public rights-of-way showing locations and dimensions of various existing and proposed features, such as buildings, curbs, driveways, sidewalks, trees, grades and drainage patterns.

PRELOADING means the temporary stockpiling of earth material over a site for the purpose of consolidating the existing soils.

PROJECT means the addition or replacement of impervious surface or the undertaking of land disturbing activity on a site.

PUBLIC COMBINED SEWER means a publicly owned and maintained sewage system which carries drainage water and sewage and flows to a publicly owned treatment works.

PUBLIC DRAINAGE CONTROL SYSTEM means a drainage control system owned or used by The City of Seattle serving City streets and adjacent property.

PUBLIC PLACE means and includes streets, avenues, ways, boulevards, drives, places, alleys, sidewalks, and planting (parking) strips, squares, triangles and right-of-way for public use and the space above or beneath its surface, whether or not opened or improved.

PUBLIC STORM DRAIN means the part of a public drainage control system which is wholly or partially piped, is owned or operated by a public entity, and is designed to carry only drainage water.

22.801.190 "R"

RECEIVING WATERS means the waters ultimately receiving drainage water, including the Duwamish River, Puget Sound, Lake Washington, Lake Union, and the Lake Washington Ship Canal, including associated bays, but not including tributary streams, creeks and lakes. See also DESIGNATED RECEIVING WATERS and NONDESIGNATED RECEIVING WATERS.

REPLACED IMPERVIOUS SURFACE or **REPLACEMENT OF IMPERVIOUS SURFACE** means impervious surface that is removed down to earth material and a new impervious surface is installed.

RESPONSIBLE PARTY means all of the following persons:

1. owners and occupants of property within The City of Seattle; and,
2. any person causing or contributing to a violation of the provisions of this subtitle.

22.801.200 "S"

SPU means Seattle Public Utilities.

SAND FILTER means a depression or basin with the bottom made of a layer of sand designed and maintained to filter pollutants. Stormwater is treated as it percolates through the sand layer.

SANITARY SEWER is as defined in the Side Sewer Ordinance, Seattle Municipal Code Section 21.16.030.

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SERVE or **SERVICE**, when used regarding a document, means the procedures set forth in Section 22.808.030.

SERVICE DRAIN means a privately owned and maintained drainage control facility or system which carries only drainage water. Service drains include, but are not limited to, conveyance pipes, catch basin connections, downspout connections, pipes, and subsurface drain connections.

SHORELINE DISTRICT means all land regulated by the Shorelines Management Act of 1971 (RCW Chapter 90.58) or City Ordinances implementing it, as defined in the Land Use Code, Title 23 of the Seattle Municipal Code.

SIDE SEWER is as defined in the Side Sewer Ordinance, Seattle Municipal Code Section 21.16.030.

SITE means the lot or parcel, or portion of street, highway or other public right-of-way, or contiguous combination thereof, where a permit for the addition or replacement of impervious surface or the undertaking of land disturbing activity has been issued or where any such work is proposed or performed. For development limited to a public street, each segment from mid-intersection to mid-intersection shall be considered a separate site.

SLOPE means an inclined ground surface. In this subtitle, the inclination of a slope is expressed as a ratio of horizontal distance to vertical distance.

SMALL PROJECT means a project with:

1. less than 5,000 square feet of new and replaced impervious surface; and
2. less than 1 acre of land disturbing activities.

SOIL means naturally deposited non-rock earth materials.

SOLID WASTE means solid waste as defined by SMC Section 21.36.016.

SOURCE CONTROLS mean structures or operations that prevent contaminants from coming in contact with stormwater through physical separation or careful management of activities that are known sources of pollution.

1. OPERATIONAL SOURCE CONTROLS are those which require modified or additional behavioral practices, such as sweeping a parking lot, or maintaining special equipment on site, such as spill response equipment.
2. STRUCTURAL SOURCE CONTROLS are those which require the construction of a structure or other physical modification on the site.

STANDARD DESIGN is a design pre-approved by Seattle Public Utilities for drainage and erosion control available for use by a site with pre-defined characteristics.

STORM DRAIN - see PUBLIC STORM DRAIN and SERVICE DRAIN.

STORMWATER means water originating from rainfall and other precipitation, and from footing drains and other subsurface drains approved by the Director of SPU or installed in compliance with rules which may be adopted hereunder.

22.801.210 "T"

TERRACE means a relatively level step constructed in the face of a graded slope surface for drainage and maintenance purposes.

TOPSOIL means the weathered surface soil, usually including the organic layer, in which plants have most of their roots.

TREATMENT FACILITY means a method, such as pursuant to this subtitle and associated rules, designed to remove pollutants from stormwater runoff.

22.801.220 "U"

UNCONTAMINATED means, for the purposes of this subtitle, not containing sediment or other pollutants or contaminants above natural background levels when referring to surface or groundwater; and not containing pollutants or contaminants in

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levels greater than City-supplied drinking water when referring to potable water.

22.801.240 "W"

WATERCOURSE means the route, constructed or formed by humans or by natural processes, generally consisting of a channel with bed, banks or sides, in which surface waters flow. Watercourse includes small lakes, bogs, streams, creeks, and intermittent artificial components (including ditches and culverts) but does not include receiving waters.

WETPOOL means a permanent pool of water that is contained in the bottom of a wet pond or wet vault stormwater treatment facility. Water in the wetpool is normally lost only through evaporation, evapotranspiration, or slow infiltration into the ground. The wetpool, also referred to as dead storage, is designed to reduce the velocity of incoming stormwater flows, encouraging particulates and particulate-bound pollutants to settle in wet ponds and wet vaults.

WETPOND and **WETVAULT** mean stormwater treatment facilities that contain a permanent pool of water (wetpool). They are designed to settle out particles of fine sediment, and allow biologic activity to occur to metabolize nutrients and organic pollutants, by providing a long retention time. Wetvaults are covered by a lid.

Chapter 22.802

STORMWATER, DRAINAGE, AND EROSION CONTROL

22.802.010 SCOPE AND EXEMPTIONS FROM SUBTITLE

A. General. All discharges subject to this subtitle as set forth in Section 22.800.030, all land uses, additions and replacement of impervious surface, land disturbing activity, and grading shall comply with all requirements of this subtitle unless explicitly exempted by this subtitle or by the Director exercising authority granted under this subtitle.

B. Exemptions. The following land uses are exempt from the provisions of this subtitle.

1. Commercial agriculture, including only those activities conducted on lands defined in RCW 84.34.020(2), and production of crops or livestock for wholesale trade.
2. Forest practices regulated under Title 222 Washington Administrative Code, except for Class IV general forest practices, as defined in WAC 222-16-050, that are conversions from timber land to other uses; and
3. Development undertaken by the Washington State Department of Transportation in state highway right-of-way that complies with standards found in Chapter 173-270 Washington Administrative Code, the Puget Sound Highway Runoff Program.

22.802.012 PROHIBITED DISCHARGES

A. Stormwater Discharges to Sanitary and Combined Sewers. In consultation with the local sewage treatment agency, the Director of SPU may approve discharges of stormwater to a public combined sewer or sanitary sewer if other methods of controlling pollutants in the discharge are not adequate or reasonable, the discharging party certifies that the discharge will not harm the environment and will not overburden or otherwise harm the public combined sewer or sanitary sewer systems. The Director of SPU shall condition approval of such a discharge on compliance with local pretreatment regulations.

B. Discharges Prohibited to Public Drainage Control Systems. It is unlawful to make illicit discharges, as defined in subsection C below, either directly or indirectly to a public drainage control system.

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C. Illicit Discharges Defined.

1. Except as provided in subsection D below, all discharges which are not composed entirely of stormwater are illicit discharges. See Section 22.808.020 for defenses available to responsible parties.
2. The following is a partial list, provided for informational purposes only, of common substances which are illicit discharges when allowed to enter a public drainage control system:

   Solid waste; human and animal waste; antifreeze, oil, gasoline, grease and all other automotive and petroleum products; flammable or explosive materials; metals in excess of naturally occurring amounts, whether in liquid or solid form; chemicals not normally found in uncontaminated water; solvents and degreasers; painting products; drain cleaners; commercial and household cleaning materials; pesticides; herbicides; fertilizers; acids; alkalis; ink; steam-cleaning waste; laundry waste; soap; detergent; ammonia; chlorine; chlorinated swimming pool or hot tub water; domestic or sanitary sewage; animal carcasses; food and food waste; yard waste; dirt; sand; and gravel.

D. Permissible Discharges. Discharges from the sources listed below shall only be illicit discharges if the Director of SPU determines that the type of discharge, whether singly or in combination with others, is causing or contributing to a violation of the City's NPDES stormwater permit or is causing or contributing to a water quality problem, such as those which contain more contamination than typical discharges in the City, or which contain a type of contamination that is more toxic or is otherwise a more serious problem than typical discharges in the City:

Potable water sources; washing of potable water storage reservoirs; flushing of potable water lines; natural uncontaminated surface water; natural uncontaminated groundwater; air conditioning condensation; natural springs; uncontaminated water from crawl space pumps; runoff from lawn watering; irrigation runoff; runoff from residential car washing by individuals; flows from riparian habitats and wetlands; heat; discharges in compliance with an NPDES permit; and discharges from approved footing drains and other subsurface drains or, where approval is not required, installed in compliance with this subtitle and rules promulgated pursuant to this subtitle.

E. Exemption. Discharges resulting from public firefighting activities, but not from activities not related to firefighting such as the maintenance or cleaning of firefighting equipment, are exempt from regulation under this Section.

F. Testing for Illicit Discharges. When the Director of SPU has reason to believe that any discharge is an illicit discharge, the Director of SPU may sample and analyze the discharge and recover the costs from a responsible party in an enforcement proceeding. When the discharge is likely to contain illicit discharges on a recurring basis, the Director of SPU may conduct, or may require the responsible party to conduct, ongoing monitoring at the responsible party's expense.

22.802.013 REQUIREMENTS FOR ALL DISCHARGES AND LAND USES

A. For all discharges except those that drain only to the public combined sewer, responsible parties shall implement and maintain operational source controls, including, but not limited to, the following, as further described in rules promulgated by the Director:

1. Maintaining drainage control systems such as conveyance systems, detention systems and treatment systems;
2. Maintaining streets, driveways, parking lots and sidewalks; and
3. Identifying and eliminating illicit connections to the drainage control system.

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B. For high-risk pollution generating activities except those that discharge only to the public combined sewer:

1. Operational source controls shall be implemented for the high-risk pollution generating activities as specified in rules promulgated jointly by the Directors of SPU and DCLU. Operational source controls for high-risk pollution generating activities shall include, but are not limited to, enclosing, covering, or containing the activity, developing and implementing inspection and maintenance programs, sweeping, and training employees on pollution prevention.
2. Spill prevention shall be required. Parties responsible for undertaking, operating, or maintaining the high-risk pollution generating activities are required to do the following, as further defined in rules promulgated by the Director:
    a. Develop and implement plans and procedures to prevent spills and other accidental releases of materials that may contaminate stormwater. This requirement may be satisfied by a Stormwater Pollution Prevention Plan prepared in compliance with an NPDES industrial stormwater permit for the site;
    b. Implement procedures for immediate containment and other appropriate action regarding spills and other accidental releases to prevent contamination of stormwater; and
    c. Provide necessary containment and response equipment on-site, and training of personnel regarding the procedures and equipment to be used.
3. The responsible parties are required to make plans, procedures, and schedules required by this subsection available to the Director of SPU when requested.

C. If the Director of SPU determines that discharges from a drainage control facility are causing or contributing to a water quality problem, such as, but not limited to, discharges that violate the City's municipal stormwater NPDES permit or that cannot be adequately addressed by the required operational or structural best management practices, then the Director of SPU may require the responsible party to undertake more stringent or additional best management practices. These best management practices may include operational or structural best management practices or other action necessary to cease causing or contributing to the water quality problem or violation of the City's permit. Structural best management practices may include but shall not be limited to drainage control facilities, structural source controls, treatment facilities, constructed facilities such as enclosures, covering and/or berming of container storage areas, and revised drainage systems. For existing discharges as opposed to new projects, the Directors of SPU and DCLU shall allow twelve (12) months to install a new flow control facility, structural source control or treatment facility after a Director determines pursuant to this subsection that discharges from a site are causing or contributing to a water quality problem and notifies the responsible party in writing of that determination and of the flow control facility, structural source control or treatment facility that must be installed.

D. Release reporting requirements. A responsible party is required to, at the earliest possible time, but in any case within 24 hours of discovery, report to the Director of SPU, a spill, release, dumping, or other situation that has contributed or is likely to contribute pollutants to a public drainage control system. This reporting requirement is in addition to, and not instead of, any other reporting requirements under federal, state or local laws.

E. Natural drainage patterns. Natural drainage patterns shall be maintained.

F. Obstruction of watercourses. Watercourses shall not be obstructed.

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22.802.015 DRAINAGE, EROSION CONTROL, AND SOURCE CONTROL REQUIREMENTS FOR ALL LAND DISTURBING ACTIVITIES OR ADDITION OR REPLACEMENT OF IMPERVIOUS SURFACE

A. Compliance required. All land disturbing activities or addition or replacement of impervious surface are required to comply with this section, even where drainage control review is not required. Exception: Maintenance, repair, or installation of underground or overhead utility facilities, such as, but not limited to, pipes, conduits and vaults, is not required to comply with the provisions of this section except subsection C3 below.

B. Approval of exceptions required. Exceptions to the requirements of this subtitle may not be used on any projects, including those that do not require drainage control review, unless allowed by this subtitle, by rule promulgated jointly by the Director of SPU and the Director of DCLU, or approved by the Director of DCLU. Approval shall be obtained prior to initiating land disturbing activities or adding or replacing impervious surface. Approvals are required for exceptions to any and all requirements of this subtitle, including, but not limited to, the requirement that natural drainage patterns be maintained and the requirement that watercourses not be obstructed.

C. Requirements for all projects.

1. Discharge Point. The discharge point for drainage water from each site shall be selected as set forth in rules promulgated jointly by the Directors of SPU and DCLU specifying criteria, guidelines, and standards for determining drainage discharge points to meet the purposes of this subtitle. The criteria shall include, but not be limited to, preservation of natural drainage patterns and whether the capacity of the drainage control system is adequate for the additional volume. For those projects meeting the drainage review threshold, the proposed discharge point shall be identified in the drainage control plan required by Section 22.802.020, for review and approval or disapproval by the Director of DCLU.
2. Flow control. The peak drainage water discharge rate from the portion of the site being developed shall not exceed 0.2 cubic feet per second per acre under 25-year, 24-hour design storm conditions or 0.15 cubic feet per second per acre under 2-year, 24-hour design storm conditions unless the site discharges water directly to a designated receiving water or to a public storm drain which the Director of SPU determines has sufficient capacity to carry existing and anticipated loads from the point of connection to a designated receiving water body. Projects with more than 2,000 square feet of new and replaced impervious surface shall be required to install and maintain a flow control facility, in accordance with rules promulgated by the Director, that is sized for the volume of runoff routed through the facility. Approved exceptions and flow control methods may be prescribed in rules promulgated by the Director.
3. Construction stormwater control. During land disturbing activities or addition or replacement of impervious surface, temporary and permanent construction controls shall be used to accomplish the following (a-g). Rules promulgated jointly by the Directors of SPU and DCLU specify the minimum required controls as well as additional controls that may be required by the Director of DCLU when minimum controls are not sufficient to prevent erosion or transport of sediment or other pollutants from the site.
    a. Prevent on-site erosion by stabilizing all soils, including stock piles, that are temporarily exposed. Methods such as, but not limited to, the installation of seeding, mulching, matting, and covering may be specified by rules promulgated by the Director. From October 1 to April 30, no soils shall remain unstabilized for more than two

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days. From May 1 to September 30, no soils shall remain unstabilized for more than seven days.

b. Before the completion of the project, permanently stabilize all exposed soils that have been disturbed during construction. Methods such as permanent seeding, planting, and sodding may be specified by rules promulgated by the Director.

c. Prevent the transport of sediment from the site. Appropriate use of methods such as, but not limited to, vegetated buffer strips, stormdrain inlet protection, silt fences, sediment traps, settling ponds, and protective berms may be specified in rules promulgated by the Director.

d. During construction, prevent the introduction of pollutants in addition to sediment into stormwater. Appropriate methods, as prescribed in rules promulgated by the Director, include operational source controls such as, but not limited to, spill control for fueling operations, equipment washing, cleaning of catch basins, treatment of contaminated soils, and proper storage and disposal of hazardous materials.

e. Limit construction vehicle access, whenever possible, to one route. Stabilize access points as specified in rules promulgated by the Director to minimize the tracking of sediment onto public roads.

f. Inspect and maintain required erosion and sediment controls as prescribed in rules promulgated by the Director to ensure continued performance of their intended function.

g. Prevent sediment from entering all storm drains, including ditches, which receive runoff from the disturbed area.

4. Source control.

a. Effective January 1, 2001, structural source controls shall be installed for high-risk pollution generating activities to the maximum extent practicable to the portion of the site being developed, in accordance with rules promulgated by the Director, except in the following circumstances:

i. When that portion of the site being developed discharges only to the public combined sewer; or

ii. For normal residential activities unless the Director determines that these activities pose a hazard to public health, safety or welfare; endanger any property; or adversely affect the safety and operation of city right-of-way, utilities, or other property owned or maintained by the City.

b. The structural source controls shall include, but not be limited to, the following, as further defined in rules promulgated jointly by the Directors:

i. Enclose, cover, or contain within a berm or dike the high-risk pollution generating activities;

ii. Direct drainage from containment area of high-risk pollution generating activity to a closed sump or tank for settling and appropriate disposal, or treat prior to discharging to a public drainage control system;

iii. Pave, treat, or cover the containment area of high-risk pollution generating activities with materials that will not interact with or break down in the presence of other materials used in conjunction with the pollution generating activity; and

iv. Prevent precipitation from flowing or being blown onto containment areas of high-risk pollution generating activities.

5. Flood-prone areas. On sites within flood prone areas, responsible parties are

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required to employ procedures to minimize the potential for flooding on the site and for the project to increase the risk of floods on adjacent or nearby properties. Flood control measures shall include those set forth in other titles of the Seattle Municipal Code and rules promulgated thereunder, including, but not limited to, SMC Chapter 25.06 (Floodplain Development) and Chapter 25.09 (Environmentally Critical Areas), and in rules promulgated jointly by the Directors of SPU and DCLU to meet the purposes of this subtitle.

6. Natural drainage patterns. Natural drainage patterns must be maintained.
7. Obstruction of watercourses. Watercourses shall not be obstructed.
8. Water Quality Sensitive Areas. The Director of SPU may impose additional requirements for areas determined to be water quality sensitive areas.

D. The Director of DCLU may require sites with addition or replacement of 5,000 square feet or less of impervious surface and with less than one acre of land disturbing activity to comply with the requirements set forth in 22.802.016, in addition to the requirements set forth in this Section, when necessary to accomplish the purposes of this subtitle. In making this determination, the Director of DCLU may consider, but not be limited to, the following attributes of the site: location within an Environmentally Critical Area; proximity and tributary to an Environmentally Critical Area; proximity and tributary to an area with known erosion or flooding problems.

22.802.016 ADDITIONAL REQUIREMENTS FOR LARGE PROJECTS

A. Applicability. One acre or more of land disturbing activity or addition or replacement of 5,000 square feet or more of impervious surface shall comply with the requirements set forth in this section, in addition to the other applicable requirements of this subtitle.

Exception: Maintenance, repair, or installation of underground or overhead utility facilities, such as, but not limited to, pipes, conduits and vaults, is not required to comply with the provisions of this section except subsection B7.

B. Requirements

1. Flow Control. Effective January 1, 2001, in addition to the discharge rate specified in Section 22.802.015, the peak drainage water discharge rate shall not exceed 0.5 cubic feet per second per acre in a 100-year, 24-hour design storm for portions of the site being developed that drain to a Class A or Class B Riparian Corridor, excluding Bitter Lake and Haller Lake, as defined by Section 25.09.020 or to a drainage control system that drains to a Class A or Class B Riparian Corridor, excluding Bitter Lake and Haller Lake.
2. Stormwater Treatment.
   a. Effective January 1, 2001, stormwater treatment facilities shall be installed and maintained to treat that portion of the site being developed, as specified in this section and in rules promulgated jointly by the Directors of DCLU and SPU, unless the following conditions exist:
      i. The site produces no stormwater runoff discharge as determined by a licensed civil engineer; or
      ii. The entire project drains to a public combined sewer.
   b. Stormwater treatment facilities shall be designed to treat the runoff volume from the 6-month, 24-hour storm, collected from the drainage area being routed through the facility.
   c. One of the following stormwater treatment facilities shall be installed and maintained in accordance with rules promulgated jointly by the Directors: infiltration, wetpond, stormwater wetland, biofiltration swale, filter strip, wet vault, media filter, or an

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alternative technology if the conditions in subsection e below are met.

d. For high-use sites, one of the following stormwater treatment facilities shall be installed and maintained in accordance with rules promulgated by the Director, in addition to other required treatment facilities:
    i. Coalescing plate/oil water separator;
    ii. Media filter;
    iii. API oil/water separator; or
    iv. An alternative technology if the conditions in subsection e below are met.

e. Alternative technology to meet runoff treatment requirements may be permitted if the following criteria are met, as further specified in rules promulgated jointly by the Directors of SPU and DCLU:
    i. Treatment effectiveness monitoring is conducted, which requirement may be waived if sufficient research has been conducted to demonstrate to the Director of SPU's satisfaction that an alternative technology offers equivalent protection;
    ii. Monitoring and maintenance records are reported to the Director of SPU at the end of each of the first three years following installation; and
    iii. The applicant demonstrates to the Director of SPU's satisfaction that the alternative will provide protection equivalent to the methods prescribed in the applicable subsection c or d above.

f. The Director of SPU may ask the Washington State Department of Ecology to approve a commitment by the City to develop a water quality improvement plan to identify pollutants of concern and associated sources, prioritize drainage basins, and evaluate alternative improvement strategies. After such approval and consistent with its terms, the Directors may grant exemptions to or make inapplicable the treatment requirements of this Section 22.802.016 B2, pursuant to rules promulgated by the Directors.

3. Protection of Streams. Where stormwater is discharged directly to a stream or to a conveyance system that discharges to a stream, streambank erosion and effects on water quality in streams shall be minimized through the selection, design, installation, and maintenance of temporary and permanent controls.

4. Protection of Wetlands. Where stormwater discharges directly to a wetland, as defined by SMC Chapter 25.09, or to a conveyance system that discharges to a wetland, the introduction of sediment, heat, and other pollutants and contaminants into wetlands shall be minimized through the selection, design, installation, and maintenance of temporary and permanent controls. Discharges to wetlands of exceptional value, as defined by SMC Chapter 25.09, shall maintain existing flows to the extent necessary to protect the functions and values of the wetland. Detention and treatment systems shall not be located within any wetland or its buffer. Prior to discharging to a wetland, alternative discharge locations shall be evaluated and infiltration options outside the wetland shall be maximized.

5. Off-site Analysis. When the portion of a site being developed is within 1/4 mile of a stream and discharges directly to that stream, or to a drainage system that drains to that stream, impacts to off-site water quality resulting from the project are to be analyzed and mitigated. The analysis shall comply with this Section and rules the Directors may jointly promulgate pursuant to this Section. The analysis shall provide for mitigation of all surface water quality

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or sediment quality impacts. The analysis shall evaluate impacts likely to occur 1/4 mile downstream from the project. The impacts to be evaluated and mitigated shall include at least the following:

a. Amount of sedimentation;

b. Streambank erosion;

c. Discharges to groundwater contributing to recharge zones;

d. Violations of state or federal surface water, groundwater, or sediment quality standards; and

e. Spills and other accidental illicit discharges;

6. Inspection and Maintenance Schedule. Temporary and permanent drainage control and stormwater treatment facilities and other controls shall be inspected and maintained according to a schedule submitted to the Director. The schedule shall meet the requirements of this subtitle and rules promulgated under this subtitle.

7. Construction Stormwater Control. In addition to the requirements described above in Section 22.802.015, construction stormwater controls shall be used to accomplish the following (a-j). Rules promulgated by the Directors of SPU and DCLU specify the minimum required controls as well as additional controls that may be required by the Director when minimum controls are not sufficient to prevent the erosion or transport of sediment or other pollutants from the site. These controls (a-j below) and those required by 22.802.015 C3 shall be shown on a construction stormwater control plan complying with the requirements and purposes of this subtitle and rules promulgated hereunder and submitted to the Director. The construction stormwater control plan shall address at least the following (a-j) and Section 22.802.015 C3:

a. Before leaving the site, stormwater runoff shall pass through a sediment trap, sediment pond, or similar device;

b. In the field, clearing limits and any easements, setbacks, critical areas and their buffers, trees, and drainage courses shall be marked;

c. Sediment ponds and traps, perimeter dikes, sediment barriers, and other erosion and sedimentation controls intended to trap sediment on site shall be constructed as a first step in grading. These controls shall be functional before the land disturbing activities take place. Earthen structures such as dams, dikes, and diversions shall be stabilized in accordance with Section 22.802.015 C3;

d. Cut and fill slopes shall be designed and constructed in a manner that will minimize erosion. In addition, slopes will be stabilized in accordance with Section 22.802.015 C3 above;

e. Properties and waterways downstream from the project site shall be protected from erosion due to increases in the volume, velocity, and peak flow rate of stormwater from the project site;

f. All temporary on-site conveyance channels shall be designed, constructed, and stabilized to prevent erosion from the expected velocity of a 2-year, 24-hour design storm for the developed condition. Stabilization adequate to prevent erosion of outlets, adjacent streambanks, slopes, and downstream reaches shall be provided at the outlets of all conveyance systems;

g. Whenever construction vehicle access routes intersect paved roads, the transport of sediment onto the paved road shall be minimized. If sediment is transported onto a paved road surface, the roads shall be cleaned thoroughly at the end of each day. Sediment shall be removed from paved roads by shoveling or sweeping and shall be

transported to a controlled sediment disposal area. Street washing shall be allowed only after sediment is removed in this manner;

h. All temporary erosion and sediment controls shall be removed within 30 days after final site stabilization is achieved or after the temporary controls are no longer needed, whichever is later. Trapped sediment shall be removed or stabilized on site. Disturbed soil areas resulting from removal shall be permanently stabilized;

i. When dewatering devices discharge on site or to a public drainage control system, dewatering devices shall discharge into a sediment trap or sediment pond or gently sloping vegetated area; and

j. In the construction of underground utility lines, where feasible, no more than 500 feet of trench shall be opened at one time, unless soil is replaced within the same working day, and where consistent with safety and space considerations, excavated material shall be placed on the uphill side of trenches. Trench dewatering devices shall discharge into a sediment trap or sediment pond.

22.802.020 DRAINAGE CONTROL REVIEW AND APPLICATION REQUIREMENTS

A. Thresholds for drainage control review. Drainage control review and approval shall be required for any of the following:

1. Standard drainage control review and approval shall be required for the following:

   a. Any land disturbing activity encompassing an area of 750 square feet or more;

   b. Applications for either a master use permit or building permit that includes the cumulative addition of 750 square feet or more of land disturbing activity and new and replaced impervious surface;

   c. Applications for which a grading permit or approval is required;

   d. Applications for street use permits for the cumulative addition of 750 square feet or more of new and replaced impervious surface and land disturbing activity after the effective date of the Ordinance codified in this subtitle;

   e. City public works project or construction contracts, including contracts for day labor and other public works purchasing agreements, for the cumulative addition of 750 square feet or more of new and replaced impervious surface and land disturbing activity to the site after the effective date of the Ordinance codified in this subtitle, except for projects in a City-owned right-of-way and except for work performed for the operation and maintenance of park lands under the control or jurisdiction of the Department of Parks and Recreation;

   f. Permit approvals and contracts that include any new or replaced impervious surface on a site deemed a potentially hazardous location, as specified in Section 22.800.050; or

   g. Whenever an exception to a requirement set forth in this subtitle or in a rule promulgated under this subtitle is desired, whether or not review and approval would otherwise be required, including, but not limited to, alteration of natural drainage patterns or the obstruction of watercourses.

2. Large project drainage control review and approval shall be required for projects that include:

   a. 5,000 square feet or more of new or replaced impervious surface; or

   b. 1 acre or more of land disturbing activity.

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3. The City may, by interagency agreement signed by the Directors of SPU and DCLU, waive the drainage and erosion control permit and document requirements for property owned by public entities, when discharges for the property do not enter the public drainage control system or the public combined sewer system. Whether or not they are required to obtain permits or submit documents, public entities are subject to the substantive requirements of this subtitle, unless exceptions are granted as set forth in Section 22.808.010.

B. Submittal requirements for drainage control review and approval

1. Information Required for Standard Drainage Control Review. The following information shall be submitted to the Director for all projects for which drainage control review is required.
   a. Standard Drainage Control Plan. A drainage control plan shall be submitted to DCLU. Standard designs for drainage control facilities as set forth in rules promulgated by the Director may be used.
   b. Construction Stormwater Control Plan (Standard Erosion and Sediment Control Plan). A construction stormwater control plan demonstrating controls sufficient to determine compliance with Section 22.802.015 C3 shall be submitted. The Director may approve a checklist in place of a plan, pursuant to rules promulgated by the Director.
   c. Memorandum of Drainage Control. The owner(s) of the site shall sign a "memorandum of drainage control" that has been prepared by the Director of SPU. Completion of the memorandum shall be a condition precedent to issuance of any permit or approval for which a drainage control plan is required. The applicant shall file the memorandum of drainage control with the King County Department of Records and Elections so as to become part of the King County real property records. The applicant shall give the Director of SPU proof of filing of the memorandum. The memorandum shall not be required when the drainage control facility will be owned and operated by the City. A memorandum of drainage control shall include:
      i. The legal description of the site;
      ii. A summary of the terms of the drainage control plan, including any known limitations of the drainage control facilities, and an agreement by the owners to implement those terms;
      iii. An agreement that the owner(s) shall inform future purchasers and other successors and assignees of the existence of the drainage control facilities and other elements of the drainage control plan, the limitations of the drainage control facilities, and of the requirements for continued inspection and maintenance of the drainage control facilities;
      iv. The side sewer permit number and the date and name of the permit or approval for which the drainage control plan is required;
      v. Permission for the City to enter the property for inspection, monitoring, correction, and abatement purposes;
      vi. An acknowledgment by the owner(s) that the City is not responsible for the adequacy or performance of the drainage control plan, and a waiver of any and all claims against the City for any harm, loss, or damage related to the plan, or to drainage or erosion on the property, except for claims arising from the City's sole negligence; and

vii. The owner(s)' signatures acknowledged by a notary public.

2. Information required for large project drainage control review. In addition to the submittal requirements for Standard Drainage Control Review, the following information is required for projects that include 1 acre or more of land disturbing activities or 5,000 square feet or more of new and replaced impervious surface.
   a. Comprehensive Drainage Control Plan. A comprehensive drainage control plan, in lieu of a Standard Drainage Control Plan, to comply with the requirements of this subtitle and rules promulgated hereunder and to accomplish the purposes of this subtitle shall be submitted with the permit application. It shall be prepared by a licensed civil engineer in accordance with standards adopted by the Director of DCLU.
   b. Inspection and Maintenance Schedule. A schedule shall be submitted that provides for inspection of temporary and permanent drainage control facilities, treatment facilities, and source controls to comply with Sections 22.802.015 and 22.802.016.
   c. Off-site analysis. When the portion of a site being developed is within 1/4 mile of a stream and discharges directly to that stream, or to a drainage control system that discharges to that stream, an analysis of impacts to off-site water quality resulting from the project prepared in accordance with Section 22.802.016 shall be submitted.
   d. Construction Stormwater Control Plan. A construction stormwater control plan prepared in accordance with Sections 22.802.015 and 22.802.016 shall be submitted.
3. Applications for drainage control review and approval shall be prepared and submitted in accordance with provisions of this Section, with Chapter 21.16, Side Sewers, and with associated rules and regulations adopted jointly by the Directors of DCLU and SPU.
4. The Director of DCLU may require additional information necessary to adequately evaluate applications for compliance with the requirements and purposes of this subtitle and other laws and regulations, including, but not limited to, SMC Chapter 25.09, Regulations for Environmentally Critical Areas. The Director of DCLU may also require appropriate information about adjoining properties that may be related to, or affected by, the drainage control proposal in order to evaluate effects on the adjacent property. This additional information may be required as a precondition for permit application review and approval.
5. Where an applicant simultaneously applies for more than one of the permits listed in subsection A above for the same property, the application shall comply with the requirements for the permit that is the most detailed and complete.

C. Authority to Review. The Director of DCLU may approve those plans that comply with the provisions of this subtitle and rules promulgated hereunder, and may place conditions upon the approval in order to assure compliance with the provisions of this subtitle. submission of the required drainage control application information shall be a condition precedent to the processing of any of the above-listed permits. Approval of drainage control shall be a condition precedent to issuance of any of the above-listed permits. The Director of DCLU may review and inspect activities subject to this subtitle and may require compliance regardless of whether review or approval is specifically required by this Section. The Director of DCLU may disapprove plans that do not comply with the provisions of this subtitle and rules promulgated hereunder. Disapproved plans shall be returned to the applicant, who may correct and resubmit the plans.

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22.802.040 DRAINAGE CONTROL PLAN REGISTRY

The Director of SPU shall maintain an official registry and permanent file of all approved drainage control plans. Each plan shall be cataloged in the registry according to the property address, legal description of the property, and the side sewer permit number of the permit or approval for which the plan is required. Where a drainage control plan covers more than one property, the approved plan shall be cataloged for each property covered by the plan.

22.802.060 INSTALLATION OF DRAINAGE CONTROL FACILITIES

A. All privately owned and operated drainage control facilities or systems, whether or not they discharge to a public drainage control system, shall be considered side sewers and shall be subject to Title 21 of the Seattle Municipal Code, the SPU Director's Rules promulgated under that Title, and the design and installation specifications and permit requirements of the SPU and the Department of DCLU for side sewer and drainage control systems.

B. Side sewer permits and inspections shall be required for construction, capping, alterations, or repairs of privately owned and operated drainage control systems as provided in Chapter 21.16 of the Seattle Municipal Code. When the work is ready for inspection, the permittee shall notify the Director of SPU. If the work is not in accordance with plans approved under this subtitle and in accordance with Chapter 21.16, SPU and Department of DCLU Director's Rules, and SPU and Department of DCLU design and installation specifications, the SPU, after consulting with the Department of DCLU, may order the work stopped by written notice to the persons engaged in performing the work or causing the work to be done, and may require modifications as provided in this subtitle and Chapter 21.16.

22.802.070 MODIFICATIONS OF DRAINAGE CONTROL FACILITIES DURING CONSTRUCTION

A. During construction the Director of SPU may require, or the applicant may request, that the construction of drainage control facilities and associated project designs be modified if physical conditions are discovered on the site which are inconsistent with the assumptions upon which the approval was based, including, but not limited to, unexpected soil and/or water conditions, weather generated problems, or changes in the design of the improved areas. Modifications shall be submitted to the Director of DCLU for approval prior to implementation.

B. Any such modifications made during the construction of drainage control facilities shall be recorded on the final approved drainage control plan, a revised copy of which shall be filed by the Director of SPU.

22.802.090 MAINTENANCE AND INSPECTION

A. Responsibility for Maintenance and Inspection. Drainage control facilities, source controls, and stormwater treatment facilities required by this subtitle and by rules adopted hereunder, shall be maintained as specified in rules promulgated by the Director, by the owner and other responsible party. The owner and other responsible party shall inspect permanent drainage control facilities at least annually, and shall inspect temporary drainage control facilities and other temporary best management practices or facilities on a schedule consistent with Section 22.802.016 B6 of this subtitle and sufficient for the facilities to function at design capacity. The Director of SPU may require the responsible party to conduct more frequent inspections and/or maintenance when necessary to insure functioning at design capacity. The owner(s) shall inform future purchasers and other successors and assignees to the property of the existence of the drainage control facilities and the elements of the drainage control plan, the

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limitations of the drainage control facilities, and the requirements for continued inspection and maintenance of the drainage control facilities.

B. Inspection by City. The Director of SPU may establish inspection programs to insure compliance with the requirements of this subtitle and accomplishment of its purposes. Inspection programs may be established on any reasonable basis, including, but not limited to: routine inspections; random inspections; inspections based upon complaints or other notice of possible violations; inspection of drainage basins or areas identified as higher than typical sources of sediment or other contaminants or pollutants; inspections of businesses or industries of a type associated with higher than usual discharges of contaminants or pollutants or with discharges of a type which are more likely than the typical discharge to cause violations of state or federal water or sediment quality standards or the City's NPDES stormwater permit; and joint inspections with other agencies inspecting under environmental or safety laws. Inspections may include, but are not limited to: reviewing maintenance and repair records; sampling discharges, surface water, groundwater, and material or water in drainage control facilities; and evaluating the condition of drainage control facilities and other best management practices.

C. Entry for Inspection and Abatement Purposes.

1. New Installations and Connections. When any new drainage control facility is installed on private property, and when any new connection is made between private property and a public drainage control system, sanitary sewer or combined sewer, the property owner shall execute a permission form provided by the Director of SPU. The property owner shall grant the City the right to enter the property at reasonable times and in a reasonable manner pursuant to an inspection program established pursuant to subsection B above, and to enter the property when the City has a reasonable basis to believe that a violation of this subtitle is occurring or has occurred, and to enter when necessary for abatement of a public nuisance or correction of a violation of this subtitle.
2. Existing Land Uses and Discharges. Owners of property with existing discharges or land uses subject to this subtitle who are not installing a new drainage control facility or making a new connection between private property and a public drainage control system, sanitary sewer or combined sewer, has the option to execute a permission form for the purposes described above when provided with the form by the Director of SPU.

D. Disposal of Waste from Maintenance Activities. Disposal of waste from maintenance of drainage and stormwater control facilities shall be conducted in accordance with federal, state and local regulations, including the Minimum Functional Standards for Solid Waste Handling, Chapter 173-304 WAC, guidelines for disposal of waste materials, and, where appropriate, Dangerous Waste Regulations, Chapter 173-303 WAC, including any subsequent amendments to these provisions.

E. Records of Installation and Maintenance Activities. When a new drainage control facility is installed, the party having the facility installed shall obtain a copy of the as-built plans from the Director of SPU. Responsible parties shall make records of the installation and of all maintenance and repair, and shall retain the records for at least ten years. These records shall be made available to the Director of SPU during inspection of the facility and at other reasonable times upon request of the Director of SPU.

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CHAPTER 22.804

GRADING

22.804.010 SCOPE

All grading shall comply with this subtitle and with federal, state and local laws and regulations, even where no permit or approval is required.

22.804.020 GRADING IN AREAS OF SPECIAL FLOOD HAZARD

In addition to requirements for grading approval or permit set forth in this subtitle, any grading in areas of special flood hazard, as identified in the report entitled "Flood Insurance Study for King County, Washington and Incorporated Areas" and the accompanying Flood Insurance Rate Maps that are filed with the City Clerk in C.F. 296948, or located in a flood-prone area, is subject to additional standards and requirements, including floodplain development approval or a Floodplain Development License, as set forth in Chapter 25.06, the Seattle Floodplain Development Ordinance, of the Seattle Municipal Code, and any applicable requirements of Chapter 25.09, the Environmentally Critical Areas Ordinance.

22.804.030 GRADING PERMIT OR APPROVAL REQUIRED

A. Grading Permit Required. A grading permit is required for all grading activities as specified below. Actions exempt from a grading permit are specified in subsection C.

1. Special Sites. A permit shall be required for any site located in any of the following areas if the combined volume of excavation, fill, dredging, or other movement of earth materials is more than twenty-five (25) cubic yards:

a. Shoreline districts as defined in SMC 23.60.010. In addition to the permit requirement established in A.1, a permit is also required for any grading within ten feet (10') of the line of mean higher high tide adjoining saltwater or the line of mean high water adjoining fresh water and for any grading of lands covered by water;

b. Environmentally Critical Areas as defined in SMC 25.09 except liquefaction-prone and abandoned landfills. In addition to the permit requirement established in A.1:

i. A permit is required for any grading within wetlands and their buffers, or Riparian corridor buffers;

ii. Grading activities that increase the potential for earth movements or the risk of damage due to earth movement within steep slopes or other landslide hazard areas is prohibited;

c. The drainage basins of Thornton Creek, Pipers Creek, Longfellow Creek, and Taylor Creek, as mapped by SPU, unless stormwater runoff from the site is discharged to a combined sewer system or otherwise piped (tightlined) to a drainage basin other than the named drainage basin.

2. Potentially Hazardous Locations. A permit is required for any site identified under the provisions of Section 22.800.050 for any volume of excavation, fill, dredging or other movement of earth materials.

3. Grading Near Public Places. A permit is required for all grading activities in excess of four feet (4'), measured vertically, on private property within any area between the vertical prolongation of the margin of a public place, and a one hundred percent (100%) slope line (forty-five degrees (45°) from a horizontal line) from the existing elevation of the margin of a public place to the proposed elevation of the private property.

4. General Sites. For sites not included in subsections A.1 and A.2 above, a permit is required where the grade at any location is

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changed more than three feet (3') and either:

a. The cumulative volume of excavation, fill, dredging or other movement of earth materials is more than 100 cubic yards over the lifetime of the site; or

b. The grading will result in a slope steeper than three (3) horizontal to one (1) vertical.

5. **In-Place Ground Modification.** A permit is required for any site where in-place ground modification will take place. The Director of DCLU may waive the requirement for a permit when the Director determines the in-place ground modification will be insignificant in amount or type.

6. **Temporary Stockpiles.** A grading permit or approval is required for temporary stockpiles which meet the thresholds of subsections A-1, A-2 and A-4 above and are not located on sites for which a valid grading permit or grading approval has been issued.

B. Grading Approvals Required.

1. A grading approval is required for grading activities located on any site where a concurrent building permit is requested except that no approval is required for grading activities where the combined volume is less than the amounts specified for each site in subsection A above.

2. Where a grading approval is required and issued as a component of a building permit, no separate grading permit shall be required. This provision shall apply to grading which is incidental to construction, the temporary stockpiling of earth materials during construction and grading needed for other site improvements. Where there will be construction or placement of a building within the lifetime of the permit, the grading approval shall be a component of the building permit.

C. Exemptions. The following grading activities shall be exempt from a grading permit, but shall still comply with the provisions of this subtitle:

1. Activity conducted under a street use permit that specifically authorizes the grading work to be performed;

2. Excavations and filling of cemetery graves;

3. Exploratory excavations that comply with the requirements of Section 22.804.050;

4. Operation of sewage treatment plant sludge settling ponds;

5. Operation of surface mines for the extraction of mineral and earth materials subject to the regulations and under a permit of the State of Washington;

6. Stockpiling and handling of earth material when the earth material is consumed or produced in a process which is the principal use of the site and which complies with the requirements of Section 22.804.050;

7. Maintenance or reconstruction of active tracks and yards of a railroad in interstate commerce within its existing right-of-way;

8. Maintenance or reconstruction of the facilities of parks and playgrounds including work required for the protection, repair, replacement or reconstruction of any existing paths, trails, sidewalks, public improvement or public or private utility, and the stockpiling of material for maintenance activities;

9. Excavation and filling of post holes;

10. On-site work required for construction, repair, repaving, replacement or reconstruction of an existing road, street or utility installation in a public right-of-way;

11. Trenching and backfilling for the installation, reconstruction or repair of utilities on property other than a public right-of-way;

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12. Grading done in performance of work authorized by the City for public works projects (see also Section 22.800.070);

13. Public works and other publicly funded activities on property owned by public entities, when discharges from the property do not enter the public drainage control system or the public combined sewer system, and the project will not undercut or otherwise endanger adjacent property, and the Director has waived the permit requirements by interagency agreement;

14. Underground storage tank removal and replacement that is subject to regulation by a state or federal agency, except where excavation meets the criteria of Section 22.804.030 A3, Grading Near Public Places.

D. Compliance Required for All Grading. Any grading activity, whether or not it requires a grading permit or approval, shall comply with the provisions of this subtitle.

22.804.040 GRADING PERMIT OR APPROVAL: APPLICATION REQUIREMENTS

A. General. Application for a grading permit or approval shall be made to the Director of DCLU by the owner of the property to be graded. All applications shall contain the submittal information detailed in this section.

B. Plans Required.

1. Projects Requiring Plans. The information listed in subsection B2 below shall be provided on plans submitted with each application for a grading permit or approval. However, when the only grading included in an application is for an approved drainage control plan or is for excavation and replacement of earth material within an area four feet or less from the footing lines of a building or structure, the only information required is the location of temporary stockpiles.

2. Information to Be submitted on Plans. The following information shall be submitted with applications for projects requiring plans.

   a. A general vicinity map and legal description of the site;

   b. A plot plan showing: location of existing buildings and structures, easements, utilities and other surface and above-ground improvements on the property where the work is to be performed; the approximate location of all buildings, structures and other improvements on adjacent land; the location of existing and planned temporary and permanent drainage control facilities, existing and proposed drainage discharge points, watercourses, drainage patterns, environmentally critical areas, and areas of standing water; the approximate location, type and size of trees and other vegetation on the site; designation of trees and vegetation to be removed, and the minimum distance between tree trunks and the nearest excavation and/or fill; and areas where equipment traffic will be permitted and excluded;

   c. The latest available topographic map, including cross-sections of the site and adjacent property, showing the present and proposed contours of the land at not more than two-foot (2') contour intervals, and the location and amount of all temporary stockpiles and excavations. On steeper sites, the Director of DCLU may authorize plans to show a contour interval greater than two feet (2') but in no case more than a five-foot (5') interval. The information relating to adjacent properties may be approximated;

   d. A drainage control plan as set forth in Section 22.802.020, except when the grading is limited to the area providing for vehicular and pedestrian access to the building or to the temporary stockpiling of excavated material.

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3. Number Required. A minimum of three (3) sets of plans shall be submitted with each application for a grading permit. The number of plan sets required for grading approval applications shall be the same as required for the specific permit application. Additional sets may be required by the Director.
4. Clarity of Plans. Plans shall be drawn to a clearly indicated and commonly accepted scale upon substantial paper such as blueprint quality or standard drafting paper. Tissue paper, posterboard or cardboard will not be accepted. The plans shall be of microfilm quality and limited to a minimum size of 18 inches by 18 inches (18" x 18") and a maximum size of 41 inches by 54 inches (41" x 54").
5. Preparation by Civil Engineer. The grading plans shall be prepared by, or under the direction of, a licensed civil engineer for all applications where the total amount of materials graded is more than two thousand five hundred (2,500) cubic yards. The Director of DCLU may require that grading plans for lesser quantities be prepared by or under the direction of a licensed civil engineer for sites such as, but not limited to, those in geologic hazard zones and areas with known erosion problems.
6. Stamping by Geotechnical Engineer. When required by the Director of DCLU in accordance with the provisions of this subtitle, the grading plans shall be reviewed and stamped by the geotechnical engineer who performed the site analysis and report to indicate that the plans conform to the conclusions and recommendations of the report.

C. Information Required.

1. Required with Application. The following information shall be submitted with grading plans at the time of application:
   a. The disposal site for any excavated materials to be removed from the site. If the disposal site is located within the City limits and is not an approved disposal site, an application for a grading permit for the disposal site shall be submitted at the same time as the application for grading permit or approval at the excavation site. In the event that the applicant is unable to specify the disposal site at the time of application, the applicant shall request, in writing, a postponement of the identification of the disposal site. The request shall include a commitment that the applicant will specify a disposal site acceptable to the Director of DCLU prior to any excavation;
   b. Where placement of a fill is proposed, a description of the composition of fill material and its structural qualities;
   c. Where any portion of the grading will encroach on an adjacent property, proof of ownership and an easement or authorization in accordance with Section 22.804.100;
   d. The immediate and long-term intended use of the property;
   e. Identification of past industrial or manufacturing uses or hazardous materials treatment, disposal or storage that have occurred on the site;
   f. Where a site is located in an area identified pursuant to Section 22.800.050, a copy of all applicable permit or approval applications, and/or permits and approvals from the appropriate regulatory agencies;
   g. When required by Section 22.802.020, an erosion/sediment control plan;
   h. Where the site is located in an area of potential landslide, a draft covenant complying with the requirements of Section 22.808.130.
   i. Each grading proposal shall contain provisions for the preservation of natural drainage patterns and watercourses; for reasonable

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preservation of natural land and water features and other indigenous natural features of the site; and for replacement, where necessary, of vegetation or other means to control runoff.

2. Required after Initial Screening. The Director of DCLU may require the following information after the initial screening of a grading application:
   a. A description of methods to be used to minimize sediment or other pollution from leaving the site during and after construction and to protect cleared areas and cut and fill slopes from erosion;
   b. A time schedule of operations, including, but not limited to, implementation of the applicable requirements of Sections 22.802.015 and 22.802.016, clearing, minimization of grading of unprotected soil surfaces, restoration of topsoil and vegetative cover, and construction of improvements;
   c. A survey of boundaries and topography of the site and the grades of adjacent public rights-of-way prepared by a surveyor licensed by the State of Washington;
   d. A soils analysis complying with the following:
      i. When Required. A soils analysis and report may be required when an application for a grading permit or approval is made for property located:
         (A) In areas described in Section 22.800.050
         (B) In areas where there is a potential for landslide
         (C) In areas where grading may result in instability of the site or adjoining property
         (D) In areas where soils may not be suitable for the use intended
         (E) In areas where the Director determines pollutants are likely to be present or
         (F) In any area where the Director determines that the information which would be supplied by a soils analysis and report is necessary for the review of the application.
      ii Contents. The soils analysis and report shall include:
         (A) Data regarding the nature, distribution and strength of existing soils and subsurface conditions
         (B) History of the site including history of landslides, known excavations and fills, and location of utilities
         (C) Where appropriate as indicated by information provided under subsection B above, analytical testing of soils to determine the concentration of pollutants
         (D) Conclusions and recommendations for clearing the site, of the adequacy of the site for proposed immediate and long-term intended use, foundation, retaining and structural designs, grading methods, and construction and post-construction monitoring and
         (E) Other information as determined necessary by the Director to adequately evaluate compliance with the requirements of this subtitle and accomplishment of its purposes, such as an assessment of contamination when past industrial or chemical use have been present on the site.
      iii. Preparation. The soils analysis and report shall be prepared by an

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experienced geotechnical engineer or other equally qualified person approved by the Director. The Director may require that the plans and specifications be stamped and signed by the geotechnical engineer to indicate that the grading and proposed structure comply with the conclusions and recommendations of the reports.

iv. Minimal Risk. In geologic hazard areas as identified in SMC Chapter 25.09, Regulations for Environmentally Critical Areas, the geotechnical engineer who prepared the soils analysis and report may be required to submit a letter stating that the plans and specifications conform to the recommendations of the soils analysis and report. The letter shall also state that, so long as conditions stated in the soils report are satisfied, areas disturbed by construction will be stabilized, the risk of damage to the proposed development or to adjacent properties from soil instability will be minimal, and the proposed grading and development will not increase the potential for soil movement.

e. Site Analysis. For properties located in any of the areas identified in subsection d, an analysis and report of the following site factors. The analysis and report shall be prepared by a licensed civil engineer or other person approved by the Director.

i. A description of the hydrology of the site and the drainage basin in which the development is located.

ii. The effect of grading upon surrounding properties, watercourses and the drainage basin, including impacts on water quality and fish habitat when a stream, lake or other body of water is affected. Where applicable, the analysis specified in Section 22.802.016 B5 may also be required.

f. A letter in a form acceptable to the Director from the owner of the site stating that the owner understands and accepts the risk of developing in an area with potentially unstable soils and that the owner will advise, in writing, any prospective purchasers of the site, structures or portions of a structure about the landslide potential of the site.

g. The Director may require additional information pertaining to the specific site and any other relevant information needed in order to assess potential hazards associated with the site and to determine whether a grading permit or approval should be issued.

22.804.050 GRADING REQUIREMENTS

A. Earth Movement. Grading shall not create or increase the likelihood of earth movement, including, but not limited to, landslides, accelerated soil creep, settlement and subsidence, and hazards associated with strong ground motion and soil liquefaction of the site to be graded and adjoining properties.

B. Natural Features. Each grading proposal shall contain provisions for the preservation of natural drainage patterns and watercourses; for reasonable preservation of natural land and water features and other indigenous natural features of the site; and replacement, where necessary, of vegetation or other means to control runoff.

C. Watercourses. Grading shall not create or contribute to flooding, erosion, or increased turbidity, siltation or other forms of pollution in a watercourse, and shall comply with the applicable requirements of Chapter 22.802.

D. Pollution Control. Grading shall be performed, and the completed work shall be in accordance with, all applicable environmental laws, rules and regulations,

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and with the applicable requirements of Chapter 22.802.

E. Conformance with Plans. Grading shall be performed in accordance with the plans approved by the Director of DCLU.

F. Slopes. Final graded slopes shall be no steeper than is safe for the intended use, and shall in no case be steeper than two (2) horizontal to one (1) vertical. For requirements for temporary slopes see Sections 22.804.050M and 22.804.100.

G. Surface Preparation. The ground surface shall be prepared to receive fill by removing vegetation, non-approved materials, topsoil and other unsuitable materials, including, but not limited to, mud, peat, and other materials with insufficient strength to satisfy the design as determined by the Director.

H. Fills. Fills shall be located so that the base edge of the fill is located more than 12 feet (12') horizontally from the top edge of an existing slope or a planned cut slope. A sloping fill shall not be placed on top of slopes which are steeper than one and one-half (1 ½) horizontal to one vertical (1).

I. Requirements For Fill Material. Materials used in fills shall comply with the following requirements:

1. Material used in filling shall be appropriate to the site and the intended use of that portion of the site.
2. Fill shall be composed of earth materials. Any rock or other similar irreducible material used in a fill shall be of a maximum diameter of 12 inches (12") and shall compose not more than twenty percent (20%) of the total fill material.
3. Topsoil shall not be used as a fill material except that the upper 12 inches (12") of a fill site may be covered with topsoil.
4. No frozen or thawing material shall be used in a fill.
5. No solid waste, hazardous waste or hazardous material may be used in a fill.
6. No organic material shall be used in a fill unless approved by the Director.
7. As necessary, the Director shall specify other characteristics of the fill material used, the degree of compaction, moisture content and the method of placement appropriate to the site and the intended use of that portion of the site and the requirements for water retention, drainage control and erosion control.

J. Terraces. The Director may require steps and terraces sufficient to control surface drainage and deposit of debris. Suitable access to the terraces shall be provided to permit proper cleaning and maintenance.

K. Subsurface Drainage. Cut and fill slopes shall be provided with subsurface drainage when needed to maintain slope stability.

L. Access. When an adjoining site relies on the site to be graded for pedestrian or vehicular access, the Director may require reasonable access to be maintained to the adjoining site.

M. Stockpiling of Earth Materials.

1. General. Stockpiling of any kind shall not adversely affect the lateral support or significantly increase the stresses in or pressure upon any adjacent or contiguous property. Stockpiling shall comply with the applicable erosion control requirements for temporarily exposed soils set forth in Sections 22.802.015 and 22.802.016, and rules promulgated under those Sections.
2. Temporary Stockpiling During Construction or Grading. Temporary stockpiles of earth materials during construction or grading shall not exceed ten feet (10') in height. Stockpiles has slopes no greater than one (1) horizontal to one vertical (1).
3. Temporary Stockpiling During Dredging. Temporary stockpiles of earth materials excavated during dredging or maintenance dredging shall be subject to the approval of the Director of DCLU.
4. Stockpiling and Handling of Earth Materials in Processing. Earth materials consumed or produced in a process may

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be stockpiled and handled on a site provided the process is the principal use of the site.

5. Removal**.** Temporary stockpiles shall be removed prior to final inspection for a grading permit where no building permit is issued on the same site. Where grading is approved as a component of a building permit, temporary stockpiles shall be removed prior to issuance of a Final Certificate of Occupancy or approval for occupancy after a final inspection.

N. Exploratory Excavations. Exploratory excavations shall be under the direction of a licensed civil engineer or experienced geotechnical engineer. No stockpiles of materials shall remain after completion of the exploratory activities. The grading shall comply with other requirements that may be established by the Director.

22.804.100 PROTECTION OF ADJOINING PROPERTY

A. General. The provisions of this Section shall apply to permanent and temporary protection of, and encroachment on, adjoining property except as specifically limited. Permanent encroachment of grading on adjoining property shall require a separate permit under Section 22.804.030 for the adjoining property.

B. Maximum Slopes. When the existing grade of a site is altered by filling, excavating, dredging or moving of earth materials, the owner shall protect all adjoining property during construction from encroachment or collapse by sloping the sides of the temporary grading at a slope which is safe and not more than one horizontal to one vertical. In addition, adjoining property shall be protected from encroachment or collapse by sloping the sides of the permanent grading at a slope not greater than two horizontal to one vertical. The Director may approve temporary or permanent slopes of greater steepness based on a design by an experienced geotechnical engineer. In areas of known unsuitable soils, the Director may require slopes of lesser steepness to assure protection of adjoining property.

C. Encroachments.

1. All grading shall occur entirely within the site unless encroachment on adjoining property is allowed by the Director of DCLU. Encroachment may be permitted where the applicant provides one of the following:
   a. Proof of ownership; or
   b. An easement, granted by the fee owner of the encroached-upon property, which authorizes the encroachment on the adjoining property; or
   c. A letter signed by the owner of the adjoining property, which authorizes such temporary encroachments during construction on the adjoining property as temporary change of grade, temporary stockpiling or shoring tiebacks.
2. Where an application for grading permit or approval includes an easement authorizing permanent encroachment on adjoining property, the easement instrument shall be provided to the Director by the applicant prior to issuance of any grading permit or approval. The instrument shall specify the purpose for granting the encroachment. The instrument shall be recorded with the King County Department of Records and Elections.
3. Any instrument authorizing temporary encroachment may terminate only after the grading work is completed in accordance with Section 22.804.200.

D. Setbacks. The tops and toes of graded slopes shall be set back from property boundaries and structures as far as is necessary for safety and foundation support and to prevent damage resulting from drainage or other water runoff, erosion or excessive loading.

E. Screening. The Director shall require view-obscuring planting or ground cover on sites with cut or fill slopes more than four feet in

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height adjacent to lots zoned for or developed with residential uses.

22.804.110 EROSION CONTROL

A. Methods. Grading operations shall comply with the applicable requirements set forth in Sections 22.802.015 and 22.802.016 and rules promulgated thereunder. Devices or procedures for erosion control shall be initiated or installed prior to commencing grading operations when technically feasible, and in any case as soon thereafter as is technically feasible, and shall be maintained to function at design capacity.

B. Exposure. Grading operations shall be conducted so as to expose the smallest practical area of soil to erosion for the least possible time. Grading operations shall comply with the applicable requirements for exposed soils, including best management practices, promulgated pursuant to Sections 22.802.015 and 22.802.016.

22.804.120 BOUNDARY LOCATION

The Director may also require sufficient staking of property lines, top and toe of the fill and all areas where equipment traffic is to be excluded. Stakes shall be at least two-inch by two-inch posts or one-half-inch pipes which are readily visible and durable. Stakes shall be maintained and visible during grading operations to enable the Director to determine property lines, the top and toe of the fill and excluded areas. A survey prepared by a land surveyor licensed by the State of Washington may be required.

22.804.130 FENCING

The Director may, where unauthorized material has been deposited during grading operations at a permitted grading site, require fencing and a lockable gate of suitable materials to control access to the grading site until all grading activity is complete, or until a Certificate of Occupancy is issued, whichever occurs last. Failure of the Director to require a fence shall not relieve the owner of liability arising out of access to and use of the site.

22.804.140 GRADING APPLICATION: REFERRAL AND CONSULTATION

The Director of DCLU may refer applications for grading, including plans and other required information and reports, to, and consult with, other agencies or City departments as may be appropriate. Comments and recommendations received shall be considered by the Director in making a decision regarding the grading application.

22.804.150 GRADING APPLICATION: CANCELLATION

An application shall be deemed abandoned and void if a permit is not issued after a period of 60 days from the date of notice of approval for issuance or if corrections are not received after a period of 60 days from the date of notification of required corrections. The Director of DCLU may extend the period for issuance or submission of corrections if it is determined that there are good reasons for the delay, such as litigation or appeals.

If the application is canceled, the site may be inspected to verify that no work has taken place. The application and any accompanying plans and specifications may be destroyed.

22.804.160 GRANTING OR DENIAL OF GRADING APPROVALS AND PERMITS

A. Approval.

1. The Director of DCLU may grant a grading permit or approval that complies with the requirements of this subtitle and rules promulgated thereunder. An approval may be granted with or without conditions, to assure compliance with the requirements of this subtitle. Conditions may include, but are not limited to, the following: restricting permit work to specific seasons or weather conditions; limiting vegetation removal; sequencing of work; requiring recommendations contained in the soils analysis and report to be followed; requiring observation by a licensed civil or geotechnical engineer; requiring special inspection pursuant to

Section 1701 of the Seattle Building Code; limiting quantities of soils; requiring structural safeguards; specifying methods of erosion, sedimentation, and drainage control; requiring compliance with other applicable provisions of this subtitle; specifying methods for maintenance of slope stability; retaining existing trees; requiring revegetation and grass seeding and/or long term maintenance activities; requiring compliance with SMC Chapter 25.09, Regulations for Environmentally Critical Areas, and other regulations of the City or other agencies with jurisdiction.

2. The Director may require that plans and specifications be stamped and signed by a licensed civil engineer or experienced geotechnical engineer to indicate that the grading and proposed structure comply with the conclusions and recommendations of any required reports.

B. Denial. The application for grading permit or approval may be denied if the Director determines that the plans do not comply with the requirements of this subtitle and rules promulgated hereunder, or do not accomplish the purposes of this subtitle, or the grading is inconsistent with the proposed development of the site, or the plans do not comply with other applicable federal, state and local laws and regulations.

C. Limitations. The issuance or granting of a grading permit of approval shall not be construed to be permission for, or an approval of, any violation of any of the provisions of this subtitle or rules promulgated hereunder, or of any other law or regulation.

22.804.170 EXPIRATION OF GRADING PERMIT

Grading permits shall be valid for eighteen (18) months and may be renewed for up to eighteen (18) additional months. Where advisable to satisfy the requirements or purposes of this subtitle, the Director may issue nonrenewable grading approvals which shall expire within a period less than 18 months from date of issue. Requirements of this subtitle that are not explicitly temporary during the grading operations, including, but not limited to, requirements for erosion control, drainage and slope management, do not terminate with the expiration of the grading approval.

22.804.180 GRADING INSPECTION

A. General. The Director of DCLU may conduct or require inspection of grading sites to determine that work is done according to the grading approval. The permittee and owner shall be notified if the work is in violation. The Director may initiate enforcement action for work that is in violation.

B. Preloading. Preloading shall be conducted as directed and supervised by a licensed civil or experienced geotechnical engineer.

C. Special Inspections. The Director of DCLU may require periodic or continuous inspection from site inspection through foundation inspection by a licensed civil engineer, experienced geotechnical engineer or special inspector at the permittee's expense. Licensed civil and experienced geotechnical engineers or special inspectors shall be designated in accordance with Section 1701 of the Seattle Building Code, Chapter 22.100 of the Seattle Municipal Code. The approved inspector shall inspect in accordance with the duties specified in Section 1701 of the Seattle Building Code and rules adopted thereunder and shall:

1. Be present during the execution of all work the inspector has been approved to inspect;
2. Report to the job site in advance of grading operations to become familiar with approved plans and to inspect all materials to be used;
3. Not undertake or engage in other occupations which interfere or create a conflict of interest with the inspection duties during the work on the project;

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4. Inspect the clearing, excavating, filling, compaction, grading, erosion and drainage control measures, and all other soils control aspects of the construction, and observe whether there is compliance with the approved plans;
5. Inspect soils for evidence of hazardous substances or wastes;
6. Observe whether the approved plans are sufficient to control the soil on the site and prevent off-site transport of sediment;
7. Immediately report all evidence of hazardous substances or wastes, irregularities, insufficiencies, substitutions of material or other changes from approved plans, and violations of this subtitle to the owner's architect, engineer or contractor. If the project is not brought immediately into compliance, the Director of DCLU shall be immediately notified. In any event, the Director of DCLU shall be immediately notified when any condition threatens public health, safety or welfare, private or public property, or the environment, whether or not the threat is immediate or likely;
8. Notify DCLU of the time schedule for off-site disposal of excavated material and, when within the City limits, of the location of and permit number of the approved disposal site; and
9. The special inspector may require soil grading reports prepared by a licensed civil engineer or experienced geotechnical engineer. These tests may include field density tests, summaries of field and laboratory tests and other substantiating data and comments on any changes made during grading but not shown on the approved plans and their effect on the recommendations.

D. Other Inspections. subject to the approval of the Director of DCLU, a person other than a licensed civil or experienced geotechnical engineer or special inspector may conduct the required inspection provided the person is under the supervision of a licensed civil engineer or experienced geotechnical engineer and is qualified to conduct the inspection.

22.804.200 COMPLETION OF GRADING WORK

A. Final Inspection. Upon completion of the work, the owner shall notify the Director of DCLU that the grading operation is ready for final inspection. Final approval shall not be given until all work, including installation of all drainage control facilities and their protective devices and all erosion control measures, have been completed in accordance with the final approved plans and required reports have been submitted. The owner also shall submit proof of the approval of other agencies with jurisdiction, if any are required, before a final grading approval is issued.

B. Final Plans and Reports. When grading plans have been modified during construction, the Director of DCLU may require an as-graded plan including original ground surface elevations, as-graded ground surface elevations, lot drainage patterns and locations, location of discharge points, elevations, and location and maintenance requirements of all surface and subsurface drainage control facilities as called out by a drainage control plan. The Director may require the comments from the person who prepared the original grading plans or soils report about changes made during grading and the effect of the changes.

22.804.210 GRADING MODIFICATIONS DURING CONSTRUCTION

The Director of DCLU may require that grading operations and project designs be modified during operations if physical conditions are discovered on the site which are inconsistent with the assumptions upon which the approval was based, including, but not limited to, unexpected soil and/or water conditions, weather-generated problems, and undue delays caused by labor disputes.

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CHAPTER 22.808

ADMINISTRATION AND ENFORCEMENT

22.808.010 EXCEPTIONS TO REQUIREMENTS

A. General. Requests for exceptions to the requirements of this subtitle shall be made according to this section. Exceptions shall include alternative requirements, waivers, reductions, or modifications of the requirements. An exception shall only be granted to the extent necessary to meet the criteria set forth in this Section. An applicant is not entitled to an exception, whether or not the criteria allowing approval of an exception are met. The Director may require an applicant to submit an engineer's report or analysis with a request for an exception. When an exception is granted, the Director may impose new or additional requirements to offset or mitigate harm that may be caused by granting the exception, or that would have been prevented if the exception had not been granted.

B. Equally Protective Exceptions. The Director may approve a request for an exception if the Director determines that it is likely to be equally protective of public health, safety and welfare, the environment, and public and private property as the requirement from which an exception is sought.

C. Other Exceptions. The Director may approve a requested exception even if it is not equally protective of public health, safety and welfare, the environment, and public and private property, or if the Director cannot determine whether it is equally protective, if the Director determines that substantial reasons exist for approving the requested exception. substantial reasons may include, but are not limited to:

1. The requirement is not technically feasible;
2. An emergency situation necessitates approval of the exception;
3. No reasonable use of the property is possible unless the exception is approved;
4. The requirement would cause harm or a significant threat of harm to public health, safety and welfare, the environment, or public and private property, or would cause extreme financial hardship, which outweighs its benefits, and the requested exception would not cause significant harm.

D. Public Notice. Public notice of an application for an exception under the criteria set forth in subsections C3 and C4 above, and of the Director's decision on the application shall be provided in the manner prescribed for Type II land use decisions, as set forth in SMC Chapter 23.76.

E. Appeal. In addition to rights under Chapter 3.02 of the Seattle Municipal Code, any person aggrieved by a Director's decision on an application for an exception under subsections C3 and C4 above may appeal to the Hearing Examiner's Office by filing an appeal, with the applicable filing fee, as set forth in SMC 23.76.022.

F. Burden of Proof on Appeal. The Hearing Examiner shall affirm the Director's determinations unless a determination is clearly erroneous. The person requesting an exception has the burden of proving, by a preponderance of the evidence, all issues related to justifying the exception.

22.808.020 LIABILITY AND DEFENSES OF RESPONSIBLE PARTIES

A. Who Must Comply. It is the specific intent of this subtitle to place the obligation of complying with its requirements upon the responsible parties, as defined in Section 22.801.190. The City of Seattle and its agencies are intended to have the same obligation for compliance when the City is a responsible party. No provision of this

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subtitle is intended to impose any other duty upon the City or any of its officers or employees.

B. Joint and Several Liability. Each responsible party is jointly and severally liable for a violation of this subtitle. The Director of SPU or the Director of DCLU or both of them may take enforcement action, in whole or in part, against any responsible party. All applicable civil penalties may be imposed against each responsible party. In the event enforcement action is taken against more than one responsible party, recoverable damages, costs, and expenses may be allocated among the responsible parties by the court or the Hearing Examiner based upon the extent to which each responsible party's acts or omissions caused the violation, unless this factor cannot be determined, or the party receiving the allocation under this factor is unable to correct the violation, or is unable to pay the damages, costs, expenses, and any penalty imposed, in which case the trier of fact shall consider:

1. Awareness of the violation;
2. Ability to correct the violation;
3. Ability to pay the damages, costs, and expenses;
4. Cooperation with government agencies;
5. Degree to which any impact or threatened impact on water or sediment quality, human health, or the environment is related to acts or omissions by each responsible party.
6. Degree to which the responsible parties made good faith efforts to avoid a violation or to mitigate its consequences; and
7. Other equitable factors.

C. Defenses. A responsible party shall not be liable under this subtitle when the responsible party carries the burden of proving, by a preponderance of the evidence, one of the following defenses:

1. The violation was caused solely by an act of God;
2. The violation was caused solely by another responsible party over whom the defending responsible party had no authority or control and the defending responsible party could not have reasonably prevented the violation;
3. The violation was caused solely by a prior owner or occupant when the defending responsible party took possession of the property without knowledge of the violation, after using reasonable efforts to identify violations. However, the defending responsible party shall be liable for all continuing, recurrent, or new violations after becoming the owner or occupant.
4. The responsible party implemented and maintained all appropriate drainage control facilities, treatment facilities, flow control facilities, erosion and sediment controls, source controls and best management practices identified in rules promulgated by the Director of DCLU and the Director of SPU, or in manuals published by the State Department of Ecology until superseded by rules of the Directors, or as otherwise identified and required of the responsible party by the Director in writing pursuant to this subtitle.

22.808.025 RIGHT OF ENTRY

With the consent of the owner or occupier of a building or premises, or pursuant to a lawfully-issued warrant, the Director of DCLU may enter a building or premises at any reasonable time to perform the duties imposed by this code.

22.808.030 ENFORCEMENT ACTIONS

A. Investigation. The Director of SPU or the Director of DCLU or both of them may investigate any site where there is reason to believe that there may be a failure to comply with the requirements of this subtitle.

B. Notice of Violation.

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1. Issuance. Whenever the Director determines that a violation of this subtitle has occurred or is occurring, the Director is authorized to issue a Notice of Violation to the property owner or other responsible party. The Notice of Violation shall be considered an order of the Director.
2. Contents.
   a. The Notice of Violation shall include the following information:
      (1) A description of the violation and the action necessary to correct it;
      (2) The date of the notice; and
      (3) A deadline by which the action necessary to correct the violation must be completed.
   b. A Notice of Violation may be amended at any time to correct clerical errors and to add citations of authority.
3. Service**.** The Director of SPU or the Director of DCLU shall serve the notice upon the responsible party either by personal service or by certified mail, return receipt requested, sent to the party's last known address and, where possible, by posting a copy on the site. Service by certified mail shall be effective on the date of mailing. If the whereabouts of the responsible party is unknown and cannot be ascertained in the exercise of reasonable diligence, and either Director makes an affidavit to that effect, then service may be accomplished by publishing the notice once each week for two consecutive weeks in the City official newspaper.

C. Alternatives to Notice of Violation.

1. Stop Work Order.
   a. In lieu of issuing a Notice of Violation, the Director of SPU or the Director of DCLU may order work on a site stopped when he or she determines it is necessary to do so in order to obtain compliance with or to correct a violation of any provision of this subtitle or rules promulgated hereunder or to correct a violation of a permit or approval granted under this subtitle. The stop work notice shall contain the following information:
      (1) A description of the violation; and
      (2) An order that the work be stopped until corrective action has been completed and approved by either Director.
   b. The stop work order shall be posted conspicuously on the premises or personally served on the property owner or other person known to be responsible for the work. It is unlawful for any work to be done after posting or service of a stop work order, except work necessary to conduct the required corrective action, until authorization to proceed is given by either Director. It is unlawful for any person to remove, obscure or mutilate a posted stop work order.
2. Emergencies.
   a. The Director of SPU and the Director of DCLU are each authorized to enter any property when it reasonably appears that a condition associated with grading, drainage, erosion control or a drainage control facility creates a substantial and present or imminent danger to the public health, safety or welfare, the environment, or public or private property. The Director of SPU and the Director of DCLU each may enter property without permission or an administrative warrant in the case of an extreme emergency placing human life, property or the environment in immediate and substantial jeopardy which requires corrective action before either permission or an administrative warrant can be obtained.
   b. The Director of SPU or the Director of DCLU or both of them may order the responsible party to take corrective action and set a schedule for compliance and may require immediate

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compliance with an order to correct. Any emergency which is not corrected as ordered by the Director of SPU or the Director of DCLU is a public nuisance which each Director is authorized to abate summarily. The costs of abatement shall be collected as set forth in Section 22.808.080.

D. Appeal of Director's Decisions. Any Notice of Violation or final order other than a stop work order or emergency order issued by the Director of SPU or the Director of DCLU pursuant to this subtitle may be appealed to the Hearing Examiner by an aggrieved person. Appeals shall be initiated by filing a written notice with the applicable fee, as set forth in SMC Section 23.76.022. When, as set forth in Section 22.808.070, an invoice is issued without a prior hearing, the appeal period shall commence upon issuance of the invoice.

E. Filing Notice or Order. A Notice of Violation, voluntary compliance agreement or an order issued by a Director of SPU, Director of DCLU, Hearing Examiner or municipal Judge, may be filed with the King County Department of Records and Elections.

F. Change of Ownership. When a Notice of Violation, voluntary compliance agreement or an order issued by a Director of SPU, Director of DCLU, Hearing Examiner or municipal Judge has been filed with the King County Department of Records and Elections, a Notice of Violation or an order regarding the same violations need not be served upon a new owner of the property where the violation occurred. If no Notice of Violation or order is served upon the new owner, the Director of SPU or Director of DCLU may grant the new owner the same number of days to comply as was given the previous owner. The compliance period for the new owner shall begin on the date that the conveyance of title to the new owner is completed.

22.808.040 ENFORCEMENT OF NOTICE OF VIOLATION

A. Hearing Examiner and Municipal Court. The Director of SPU or Director of DCLU or both of them may choose to enforce a Notice of Violation through either of the following means:

1. An enforcement hearing through the Hearing Examiner's Office, as set forth in this Section; or
2. Referral to the City Attorney's Office for action in the appropriate court according to that court's normal rules and procedures.

B. Enforcement Through Hearing Examiner's Office. Enforcement actions through the Hearing Examiner's Office shall proceed according to this subsection.

1. Hearing Schedule**.** The Hearing Examiner's Office shall schedule a hearing after notification by the Director that enforcement will be pursued through the Hearing Examiner's Office.
2. Conduct of the Hearing**.** The Hearing Examiner shall conduct a hearing on the violation pursuant to the rules of procedure of the Hearing Examiner, as modified by this Section. The Director, the person to whom the Notice of Violation was issued, and any other responsible party regarding the matters addressed in the Notice of Violation may participate as parties in the hearing, with or without representation by an attorney. Each party may call and compel the attendance of witnesses.
3. Standard of Review and Burden of Proof. The determinations of the Director of SPU and the determinations of the Director of DCLU shall be accorded substantial weight by the Hearing Examiner. The defending responsible party has the burden of proving by a preponderance of the evidence all defenses, mitigating factors and objections to the required corrective action or schedule.

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4. Hearing Examiner's Order. The Hearing Examiner shall affirm, vacate or modify the Director's determinations. The Hearing Examiner shall issue an order within 15 days following the close of the record unless all parties agree to an extension of time. The order shall contain the following information:
   a. The decision regarding the alleged violation;
   b. Findings of fact and conclusions based thereon in support of the decision;
   c. The required corrective action (if any);
   d. The date and time by which the corrective action must be completed;
   e. The monetary penalties and other costs, expenses, or damages being assessed against the responsible party;
   f. Notice that the responsible party has twenty-one days from the date of issuance of the decision to petition for judicial review; and
   g. Authorization for the City to abate or correct the violation following expiration of the appeal period and the time set for compliance with the order if the responsible party has not completed the required corrective action, and to charge the responsible party for its costs, as set forth in Section 22.808.080. The order shall not require the City to abate or correct the violation.
5. Failure to Appear. If the responsible party to whom the Notice of Violation was issued fails to appear at a scheduled hearing before the Hearing Examiner, and no other responsible party appears to defend, then, upon an offer of proof by the City, which may be made by declaration, the Hearing Examiner shall issue an order finding that the violation occurred. The order shall contain the information set forth in subsection B4 above. In the absence of an offer of proof by the City, the Hearing Examiner shall issue an order finding the responsible party to be in default, and setting forth the penalties and other relief described in subsection B4.

22.808.050 VOLUNTARY COMPLIANCE AGREEMENT

A. Initiation. Either a responsible party or the Director of SPU or the Director of DCLU may initiate negotiations for a voluntary compliance agreement at any time. Neither Director has any obligation to enter into any voluntary compliance agreement.

B. Contents. A voluntary compliance agreement shall set forth actions to be taken by the responsible party that will correct past or existing violations of this subtitle. It may also set forth actions to mitigate the impacts of violations. The voluntary compliance agreement shall set forth a schedule for completion of the corrective and mitigating actions. It shall contain a provision allowing the Director of SPU and the Director of DCLU to inspect the premises to determine compliance with the agreement.

C. Effect of Agreement.

1. A voluntary compliance agreement is a binding contract between the party executing it and the City. It is not enforceable by any other party. All voluntary compliance agreements shall provide that the responsible party agrees the City may perform the actions set forth in the agreement if the responsible party fails to do so according to the terms and schedule of the agreement, and the responsible party will pay the costs, expenses and damages the City incurs in performing the actions, as set forth in Section 22.808.080 regarding abatements. By entering into a voluntary compliance agreement, a responsible party waives the right to an administrative appeal of the violation.
2. Penalties may be reduced or waived if violations are corrected or mitigated according to the terms and schedule of a voluntary compliance agreement. If the

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responsible party fails to perform according to the terms and schedule of the voluntary compliance agreement, penalties for each violation addressed in the agreement may be assessed starting from the date the violation occurred.

D. Modification. The terms and schedule of the voluntary compliance agreement may be modified by mutual agreement of the responsible party and either Director if circumstances or conditions outside the responsible party's control, or unknown at the time the agreement was made, or other just cause necessitate such modifications.

22.808.060 PENALTIES AND DAMAGES

A. Commencement of Penalties. The Hearing Examiner and any Judge hearing matters under this subtitle has the following options in assessing monetary penalties:

1. Assess monetary penalties beginning on the date the Notice of Violation was issued and thereafter; or
2. Assess monetary penalties beginning on the correction deadline set by the Director or an alternate deadline for corrective action set by the Judge or Hearing Examiner, and thereafter; or
3. Assess no monetary penalties; or
4. When it appears likely the responsible party will perform the required corrective action, suspend assessment of the penalty conditioned upon completion of the corrective action by the ordered deadline.

B. Schedule of Penalties.

1. Basic Penalty. Each day or portion thereof during which a violation of this subtitle exists is a separate violation of this subtitle. The cumulative monetary penalty for each violation of this subtitle shall be as follows:
   a. The penalty for the first day a violation exists is one hundred dollars;
   b. The penalty for the second day a violation exists is two hundred dollars;
   c. The penalty for the third day a violation exists is three hundred dollars;
   d. The penalty for the fourth day a violation exists is four hundred dollars;
   e. The penalty for each day a violation exists beyond four days is five hundred dollars.

Schedule of Penalties per Violation

Day	*Fine for that Day*	*Cumulative Total*
1	$100	$100
2	$200	$300
3	$300	$600
4	$400	$1000
5	$500	$1500
6&up	$500	

2. Triple penalties. Penalties may be trebled for:
   a. A repeat violation, which means an additional violation of a requirement of this subtitle for which the responsible party has previously received a Notice of Violation and failed to correct the violation by the compliance date;
   b. A violation resulting in physical harm to persons or to private or public property;
   c. A knowing or deliberate violation;
   d. A violation resulting from gross negligence or reckless conduct.
3. Reduction of Penalties**.** Penalties may be reduced based upon one or more of the following mitigating factors:
   a. The person showed due diligence and/or substantial progress in correcting the violation;
   b. Another responsible party was the primary cause of the violation;
   c. The person was unaware of the violation and had not acted negligently or recklessly.

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4. Penalty for Significant Violation. Responsible parties for violations causing significant harm to public health, safety or welfare, the environment, or public or private property shall be assessed the penalties set forth in the schedule above, or an amount equivalent to the economic benefit the responsible party derived from the violation, whichever is greater. "Significant harm" is harm which cannot be fully corrected or mitigated by the responsible party, and which cannot be adequately compensated for by assessment of penalties, costs, expenses or damages under this subtitle. Economic benefit may be determined by an increase in market value of property, value received by the responsible party, savings in costs realized by the responsible party, increased income to the responsible party, or any other method reasonable under the circumstances.

C. Damages. Whoever violates any of the provisions of this subtitle shall, in addition to any penalties provided for such violation, be liable for any cost, expense, loss or damage occasioned thereby to the City, plus a charge of 15% for administrative costs. This subtitle does not establish a cause of action that may be asserted by any party other than the City. Penalties, damages, costs and expenses may be recovered only by the City.

D. Effect of Payment of Penalties. The person to whom an order is directed is not relieved of the duty to take corrective action to correct the violation by payment of a monetary penalty pursuant to this subtitle.

22.808.070 COLLECTION OF COSTS AND PENALTIES

A. Invoice and Demand for Payment. When either Director has abated a public nuisance or corrected a violation of this subtitle and a hearing has not been conducted, the Director shall issue an invoice and demand for payment of the City's abatement costs. The invoice shall include:

1. The amount of the City's abatement or correction costs;
2. Either a legal description of the property corresponding as nearly as possible to that used for the property on the rolls of the King County Assessor or, where available, the property's street address;
3. A notice that the Director's determinations regarding the abatement and correction, including the amount owed, may be appealed to the Hearing Examiner by following the procedure set forth in SMC Section 23.76.022;
4. Notice that if the amount due is not paid within 30 days, the outstanding balance may be collected in any of the manners set forth in subsection B of this Section; and
5. Notice that interest shall accrue on the unpaid balance.

B. Collection Following a Hearing. The Director of DCLU and the Director of SPU are not required to issue an invoice for payment when a hearing has been conducted as set forth in Section 22.808.040, and an order has issued imposing any penalties, costs, damages, expenses or abatement costs. If the order is not appealed within 15 days of mailing or other delivery of the order to the responsible party, the Director of DCLU or the Director of SPU may immediately seek to collect the amounts owed by:

1. Referral to the City Attorney's Office for action in the appropriate court; or
2. Referral, after consultation with the City Attorney's Office to a collection agency; or
3. Addition of a surcharge in the amount owed under the order to the bill for drainage and wastewater services to the site. If unpaid, the surcharge may become a lien on the property, may be foreclosed, and may accrue interest as provided by state law or SMC Section 21.33.110.

22.808.080 PUBLIC NUISANCE

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A. Abatement Required. A public nuisance affecting stormwater, drainage, erosion control, grading and other public nuisances set forth in this Section are violations of this subtitle. A responsible party shall immediately abate a public nuisance upon becoming aware of its existence.

B. Dysfunctional Facility or Practice. Any private drainage control facility or best management practice relating to grading, stormwater, drainage control or erosion not installed or maintained as required by this subtitle, or otherwise found to be in a state of dysfunction creating, presently or in the event of a design storm, a threat to the public health, safety or welfare, the environment, or public or private property is hereby declared to be a public nuisance.

C. Obstruction of Watercourse. Obstruction of a watercourse without authorization by the Director, and obstruction in such a manner as to increase the risk of flooding or erosion should a design storm occur, is hereby declared to be a public nuisance.

D. Dangerous Conditions. Any condition relating to grading, stormwater, drainage or erosion which creates a present or imminent danger, or which is likely to create a danger in the event of a design storm, to the public health, safety or welfare, the environment, or public or private property is hereby declared to be a public nuisance.

E. Abatement by the City. The Director of SPU and the Director of DCLU are authorized, but not required, to investigate a condition that either Director suspects of being a public nuisance under this subtitle, and to abate any public nuisance. If a public nuisance is an immediate threat to the public health, safety or welfare or to the environment, the Director of SPU or the Director of DCLU may summarily and without prior notice abate the condition. The Director of SPU or the Director of DCLU shall give notice of the abatement to the responsible party as soon as reasonably possible after the abatement.

F. Collection of Abatement Costs. The costs of abatement may be collected from the responsible party, including a reasonable charge for attorney time and a 15 percent charge for administrative expenses as set forth in Section 22.808.060C. Abatement costs and other damages, expenses and penalties collected by the City shall go into an abatement account for the department collecting the monies. The money in the abatement account shall be used for abatements and corrections of violations conducted by the City. When the account is insufficient the Director of SPU and the Director of DCLU may use other available funds.

22.808.090 VIOLATIONS

A. Civil Violations.

1. General. It is a violation of this subtitle to not comply with any requirement of, or to act in a manner prohibited by, this subtitle, or a permit, approval, rule, manual or order issued pursuant to this subtitle.
2. Aiding and Abetting. It is a violation of this subtitle to aid, abet, counsel, encourage, commend, incite, induce, hire or otherwise procure another person to violate this subtitle.
3. Alteration of Existing Drainage**.** It is a violation of this subtitle to alter existing drainage patterns which serve a tributary area of more than five acres without authorization or approval by the Director.
4. Obstruction of Watercourse. It is a violation of this subtitle to obstruct a watercourse without authorization or approval by the Director.
5. Dangerous Condition. It is a violation of this subtitle to allow to exist, or cause or contribute to, a condition of a drainage control facility, or condition related to grading, stormwater, drainage or erosion that is likely to endanger the public health, safety or welfare, the environment, or public or private property.

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6. Interference. It is a violation of this subtitle for any person to interfere with or impede the correction of any violation, or compliance with any notice of violation, emergency order, stop work order, or the abatement of any nuisance.

B. Criminal Violations.

1. Failing to Comply with Orders. Failing to comply with an order properly issued pursuant to this subtitle by the Director of SPU, the Director of DCLU, the Hearing Examiner, or a Judge is a criminal violation, punishable upon conviction by a fine of not more than $5,000 per day of each violation or imprisonment for each violation for not more than 360 days or both such fine and imprisonment.
2. Tampering and Vandalism. Tampering with or vandalizing a drainage control facility or other best management practice, a public or private drainage control system, monitoring or sampling equipment or records, or notices posted pursuant to this subtitle is a criminal violation, punishable upon conviction by a fine of not more than $5,000 or imprisonment for not more than 360 days or both such fine and imprisonment.
3. Repeat Violations. Anyone violating this subtitle who has had a judgment or Hearing Examiner's order against them pursuant to this subtitle in the preceding five years, shall be subject to criminal penalties for the present violation, and, upon conviction thereof, be fined in a sum not to exceed $5,000 dollars, or imprisonment for not more than 360 days, or both such fine and imprisonment.

22.808.100 ADDITIONAL RELIEF

In lieu of or in addition to any enforcement procedure provided in this subtitle, the Directors of SPU and DCLU e may seek any other available legal or equitable relief, including to enjoin any acts or practices and abate any condition which constitutes or will constitute a violation of this subtitle or a public nuisance.

22.808.110 SUSPENSION OR REVOCATION

Approvals or permits granted in error, or on the basis of incomplete, inaccurate or misleading information, or in violation of any law, ordinance or regulation may be suspended or revoked. Other permits or approvals interrelated with an approval suspended or revoked under this Section, including Certificates of Occupancy or approvals for occupancy, may also be suspended or revoked. When an approval or permit is suspended or revoked, the Director of SPU or the Director of DCLU may require the applicant to take corrective action to bring the project into compliance with this subtitle by a deadline set by the Director of SPU or the Director of DCLU, or may take other enforcement action.

22.808.120 FEES

Fees for grading permits, drainage control plan review and approvals shall be as set forth in the Fee Subtitle, Subtitle IX of Title 22, Seattle Municipal Code. Fees for recordkeeping or other activities pursuant to this subtitle shall, unless otherwise provided for in this subtitle, be prescribed by ordinance.

22.808.130 FINANCIAL ASSURANCE AND COVENANTS

As a condition precedent to issuance of any permit or approval provided for in this subtitle, the Director of DCLU may require an applicant for a permit or approval to submit financial assurances as provided in this Section.

A. Insurance.

1. The Director of DCLU may require the owner(s), or contractor to carry liability and property damage insurance against damage, naming the City as an additional insured. The amount shall be commensurate with the risks as determined by the Director.
2. The Director of DCLU may also require the owner(s) to maintain a policy of general public liability insurance against personal injury, death, property damage and/or loss from activities conducted

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pursuant to the permit or approval, or conditions caused by such activities, and naming the City as an additional insured. The policy shall be in an amount which the Director determines to be commensurate with the risks. It shall cover a period of not more than ten years from the date of issuance of a Certificate of Occupancy or finalization of the permit or approval. A certificate evidencing such insurance shall be filed with the Director of DCLU before issuance of a Certificate of Occupancy or finalization of a permit for any single family dwelling or duplex.

3. The insurance policy shall provide that the City will be notified of cancellation of the policy at least 30 days prior to cancellation. The notice shall be sent to the Director of DCLU who required the insurance and shall state the insured's name and the property address. If a property owner's insurance is canceled and not replaced, the permit or approval and any interrelated permit or approval may be revoked, including a Certificate of Occupancy or approval for occupancy.

B. Bonds, Cash Deposits or Instruments of Credit.

1. Surety Bond.
   a. The Director of DCLU may require that the owner or contractor deliver to the Director for filing in the Office of the City Clerk a surety bond, cash deposit or an instrument of credit in such form and amounts deemed by the Director to be necessary to ensure that requirements of the permit or approval are met. A surety bond may be furnished only by a surety company licensed to do business in the State of Washington. The bond shall be conditioned that the work will be completed in accordance with the conditions of the permit or approval, or, if the work is not completed, that the site will be left in a safe condition. The bond shall also be conditioned that the site and nearby, adjacent or surrounding areas will be restored if damaged or made unsafe by activities conducted pursuant to the permit or approval.
   b. The bond will be exonerated one year after a determination by the Director of DCLU that the requirements of the permit or approval have been met. For work under a building permit, issuance of a Certificate of Occupancy or approval for occupancy following a final inspection shall be considered to be such a determination. For grading, completion of the final grading inspection and submittal of required final reports in accordance with Section 22.804.200 shall be such a determination.
2. Assurance in Lieu of Surety Bond**.** In lieu of a surety bond, the owner may elect to file a cash deposit or instrument of credit with the Director in an amount equal to that which would be required in the surety bond and in a form approved by the Director of DCLU. The cash deposit or instrument of credit shall comply with the same conditions as required for surety bonds.

C. Covenants.

1. The Director of DCLU may require a covenant between the owner(s) of the property and the City. The covenant shall be signed by the owner(s) of the site and notarized prior to issuance of any permit or approval in a potential landslide area, potentially hazardous location, flood prone zone, or other area of potentially hazardous soils or drainage or erosion conditions. The covenant shall not be required where the permit or approval is for work done by the City. The covenant shall include:
   a. A legal description of the property;
   b. A description of the property condition making this subsection applicable;

c. A statement that the owner(s) of the property understands and accepts the responsibility for the risks associated with development on the property given the described condition, and agrees to inform future purchasers and other successors and assignees of the risks;

d. The application date, type, and number of the permit or approval for which the covenant is required; and

e. A statement waiving the right of the owner(s), the owner's heirs, successors and assigns to assert any claim against the City by reason of or arising out of issuance of the permit or approval by the City for the development on the property, except only for such losses that may directly result from the negligence of the City.

2. The covenant shall be filed by the Director of DCLU with the King County Department of Records and Elections, at the expense of the owner, so as to become part of the King County real property records.

D. Bonds for Grading Near Public Places. Security for grading activity covered under Section 15.44.020 shall be in accordance with Section 15.44.030.

22.808.140 SEVERABILITY

The provisions of this subtitle are declared to be separate and severable and the invalidity of any clause, sentence, paragraph, subdivision, Section or portion of this subtitle, or the invalidity of the application thereof to any person or circumstance shall not affect the validity of the remainder of this subtitle or the validity of its application to other persons or circumstances.

22.808.150 DATE OF INITIAL ENFORCEMENT

The Directors of SPU and Construction and Land Use shall allow existing discharges and land uses six (6) months to adopt operational and nonstructural best management practices after adoption of rules or after such best management practices have been communicated in writing by the Director following a site inspection, whichever comes first. The Directors shall allow existing discharges and land uses twelve (12) months to install structural best management practices after the Directors determine that discharges from a site are causing or contributing to a water quality problem, and notify the discharger in writing of that determination and of the best management practices which must be installed.

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WRD 1A-82
Revised 11/03

STATE OF WEST VIRGINIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF WATER AND WASTE MANAGEMENT
1201 GREENBRIER STREET
CHARLESTON, WV 25311

GENERAL
NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM
WATER POLLUTION CONTROL PERMIT

Permit No.: WV0116025

Subject: Storm Water Discharges From Small Municipal Separate Storm Sewer Systems

Issue Date: March 7, 2003

Effective Date: April 7, 2003

Expiration Date: March 6, 2008

Supersedes: N/A

To whom it may concern:

This is to certify that operators of small municipal separate storm sewer systems (MS4s) located in the State of West Virginia who have satisfied the registration requirements and agreeing to be regulated under the terms and conditions of this general permit are hereby granted coverage under the General WV/NPDES Water Pollution Control Permit to allow storm water discharges into the waters of the State.

This permit is subject to the following terms and conditions:

The information submitted on and with the site registration application form will hereby be made terms and conditions of the permit with like effect as if all such information were set forth herein, and other conditions set forth in Parts I, II, III, IV, V, Appendix A and the site approval letter.

The validity of this permit is contingent upon the payment of the applicable annual permit fee, as required by Chapter 22, Article 11, Section 10 of the Code of West Virginia.

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Part I. Coverage Under This General Permit

A. Permit Area

1. This permit covers all areas of the State of West Virginia.

B. Eligibility

1. A. Municipalities with populations greater than or equal to 1000 that have been designated by the Environmental Protection Agency (EPA) under Code of Federal Regulations (CFR) 40.122.32 (a)(1); or

   B. Municipalities that are designated by the Division of Water and Waste Management (DWWM) under 40 CFR 122.32 (a)(2). Designation criteria are included in Appendix A of this general permit.

2. This permit authorizes the following non-storm water discharges provided they have been determined not to be substantial contributors of pollutants to a particular small MS4 applying for coverage under this permit. However, the DWWM recommends that your storm water management program include public education and outreach activities directed at reducing these discharges even if they are not substantial contributors of pollutants to your system.

a) Water line flushing,
b) Landscape irrigation,
c) Diverted stream flows,
d) Rising ground waters,
e) Uncontaminated ground water infiltration (as defined at 40 CFR 35.2005(20)),
f) Uncontaminated pumped groundwater,
g) Discharges from potable water sources,
h) Foundation drains,
i) Air conditioning condensate,
j) Irrigation water,
k) Springs,
l) Water from crawl space pumps,
m) Footing drains,
n) Lawn watering runoff,
o) Water from individual residential car washing,
p) Flows from riparian habitats and wetlands,
q) Dechlorinated swimming pool discharges,
r) Residual street wash water,
s) Discharges or flows from fire fighting activities, and
t) Dechlorinated water reservoir discharges

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Part II. Storm Water Management Program (SWMP)

A. Requirements

Within 12 months of the issuance date of this permit, the permittee must develop and submit a storm water management program (SWMP) designed to reduce the discharge of pollutants from your small municipal separate storm sewer system to the maximum extent practicable (MEP), to protect water quality, and satisfy the appropriate water quality requirements of the Clean Water Act. Each SWMP shall follow the public notice procedures set forth in 47 CSR § 10-12. Your SWMP must include the minimum control measures described in section (B) of this Part along with measurable goals and milestones for each measure and justifications for each milestone. Subject to the five-year limitation noted below in this paragraph, extensions of milestones will be granted for good cause shown. Your SWMP must also provide details on how you will implement and enforce the program. You must fully implement your program within five years of the effective date of this permit.

B. Minimum Control Measures

The six (6) minimum control measures to be included in your SWMP are:

1. Public Education and Outreach on Storm Water Impacts.

Permittee shall implement a public education program to distribute educational materials to the community or conduct equivalent outreach activities about the impacts of storm water discharges on water bodies and the steps that the public can take to reduce pollutants in storm water runoff. At a minimum, the public education program shall contain information about the impacts of storm water discharges on receiving waters, why controlling these discharges is important and what the public can do to reduce pollutants in storm water runoff.

2. Public Involvement/Participation.

Permittee shall implement and maintain a public involvement and participation program. The permittee shall at a minimum, comply with State and local public notice requirements when implementing a public involvement/participation program. The permittee shall also comply with public participation and involvement provisions of the CWA, including public availability of all permits and permit applications (including Site Registration Applications (SRAs)) and the right to a public hearing on proposed permits.

3. Illicit Discharge Detection and Elimination.

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Permittee shall develop, implement and enforce a program to detect and eliminate illicit discharges (as defined at Section 122.26(b)(2)) into your small MS4.

At a minimum, the permittee must:

a) Develop, if not already completed, a storm sewer system map, showing the location of all outfalls and the names and location of all waters of the State that receive discharges from those outlets;

b) To the extent allowable under State or local law, effectively prohibit, through ordinance, or other regulatory mechanism, non-storm water discharges into your storm sewer system and implement appropriate enforcement procedures and actions;

c) Develop, implement, and adequately fund a plan to detect and address non-storm water discharges, including illegal dumping, to your system;

d) Inform public employees, businesses, and the general public of hazards associated with illegal discharges and improper disposal of waste; and

e) Address the following categories of non-storm water discharges or flows (i.e., illicit discharges) only if you identify them as significant contributors of pollutants to your small MS4: water line flushing, landscape irrigation, diverted stream flows, rising ground waters, uncontaminated groundwater infiltration (as defined at 40 CFR 35.2005(20)), uncontaminated pumped groundwater, discharges from potable water sources, foundation drains, air conditioning condensation, irrigation water, springs, water from crawl space pumps, footing drains, lawn watering, individual residential car washing, flows from riparian habitats and wetlands, dechlorinated swimming pool discharges, and street wash water (discharges or flows from fire fighting activities are excluded from the effective prohibition against non-storm water and need only be addressed where they are identified as significant sources of pollutants to waters of the United States).

f) Effectively prohibit non-storm water discharges into the storm sewers.

4. Construction Site Storm water Runoff Control.

Permittee shall develop, implement, and enforce a program to reduce pollutants to the MEP in any storm water runoff to its small MS4 from construction activities that result in a land disturbance of greater than or equal to one acre. Reduction of storm water discharges from construction activity disturbing less than one acre must be included in your program if that construction activity is part of a larger common plan of development or sale that would disturb one acre or more or has been designated by DEP.

The program must include the development and implementation of, at a minimum:

(a) An ordinance or other regulatory mechanism to require erosion and sediment controls, as well as sanctions to ensure compliance, to the extent allowable under State or local law;

(b) Requirements for construction site operators to implement appropriate erosion and sediment control best management practices;

(c) Requirements for construction site operators to control waste such as discarded building materials, concrete truck washout, chemicals, litter, and sanitary waste at the construction site that may cause adverse impacts to water quality;

(d) Procedures for site plan review, which incorporate consideration of potential water quality impacts and review of individual pre-construction site plans to ensure consistency with local sediment and erosion control requirements;

(e) Procedures for receipt and consideration of information submitted by the public; and

(f) Procedures and adequate funding for site inspection and enforcement of control measures.

(g) Include procedures for site inspections and enforcement of control measures including steps to identify priority sites for inspection and enforcement based on the nature of the construction activity, topography, and the characteristics of soils and receiving water quality; and

(h) Provide educational and training measures for construction site operators, including requiring a stormwater pollution prevention plan for construction sites within your jurisdiction.

5. Post-Construction Storm Water Management In New Development and Redevelopment.

The permittee shall develop, implement, and enforce a program to address post-construction storm water runoff from new development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale or that have been designated to protect water quality, that discharge into its small MS4. The program must ensure that controls are in place that will increase groundwater recharge of storm water runoff where and when possible, and would protect water quality and reduce the discharge of pollutants. The permittee shall also develop and implement strategies that include a list of structural best management

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practices (BMPs) designed for maximizing groundwater recharge.

The program shall include, at a minimum:

a) Develop and implement strategies which include a combination of structural and/or non-structural BMPs appropriate for your community that will reduce the discharge of pollutants to the maximum extent practicable and a list of structural BMPs designed for maximizing groundwater recharge; and

b) Use an ordinance or other regulatory mechanism to address post-construction runoff from new development and redevelopment projects to the extent allowable under State or local law; and

c) Ensure adequate long-term operation and maintenance of BMPs, including monitoring to determine whether the BMPs are reducing the discharge of pollutants to the maximum extent practicable; and

d) Develop, implement, and provide adequate resources for a program to inspect development and re-development sites and to enforce and penalize violators.

6. Pollution Prevention/Good Housekeeping For Municipal Operations.

Permittee shall implement and maintain pollution prevention and good housekeeping techniques and procedures to reduce pollutants from municipal operations.

This program shall include, at a minimum:

a) Develop and implement an operation and maintenance program that includes a training component and is designed to reduce the discharge of pollutants to the maximum extent practicable; and

b) Using training materials that are available from EPA, your State, Tribe, or other organizations, the program must include employee training to prevent and reduce storm water pollution from activities such as park and open space maintenance, fleet and building maintenance, new construction and land disturbances, and stormwater system maintenance.

c) Industrial Storm Water Coverage for Municipal Operations

Permittees desiring coverage for storm water associated with industrial activity discharging from their municipal operations must also meet the following monitoring requirements for those discharges:

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Pollutants of Concern	Cut-off Concentration	Measurement Frequency
BOD-5	30 mg/l	1/6 months
COD	120 mg/l	1/6 months
TSS	100 mg/l	1/6 months
Ammonia Nitrogen	4 mg/l	1/6 months
Oil & Grease	15 mg/l	1/6 months
pH	6.0-9.0 s.u.	1/6 months

Permittees desiring coverage for storm water associated with industrial activity discharging from their sewage treatment works must, in addition to the above listed monitoring requirements, also meet the following monitoring requirement for those discharges:

Pollutants of Concern	Cut-off Concentration	Measurement Frequency
Fecal Coliform, General	400 counts/100 ml	1/6 months

When the average concentration for a pollutant calculated from all monitoring data, with a minimum of four (4) consecutive samples, is less than the corresponding listed cut-off concentration for that pollutant, additional monitoring for that is not required. The facility must submit each year, to the DWWM, in lieu of the monitoring data, a certification (form provided) that there has not been a significant change in the industrial activity or the pollution prevention measures in the area of facility that drains to the outlet for which sampling was waived.

Permittee shall review its SWMP each year and revise the plan, if this average concentration for any indicator pollutant in the previous year's sampling was greater than the corresponding cut-off value for that pollutant.

Part III. Special Conditions

A. Sharing Responsibility

If you are relying on another MS4 regulated under the storm water regulations to satisfy one or more of your permit obligations, you must note that fact in your SRA. This other entity must, in fact, implement the control measure(s); the measure of component thereof, must be at least as stringent as the corresponding NPDES permit requirement; and the other entity must agree to implement the control measure on your behalf. This agreement between the two or more parties must be documented in writing in the storm water management plan and be retained by the permittee for the duration of this permit, including any automatic extensions of the permit term.

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B. Discharge Compliance with Water Quality Standards

This general permit requires, at a minimum, that municipalities develop, implement and enforce a storm water management program designed to reduce the discharge of pollutants to the maximum extent practicable. Implementing BMPs as required under the six minimum control measures in Part II above is considered an acceptable effort to reduce pollutants from the municipal storm drain system to the maximum extent practicable.

C. Requiring an Individual Permit

The DWWM may require any person authorized by this permit to apply for and/or obtain an individual NPDES permit. Where the DWWM requires you to apply for an individual NPDES permit, the DWWM will notify you in writing that a permit application is required. This notification shall include a brief statement of the reasons for this decision, an application form and a statement setting a deadline for you to file the application.

D. Discharge to Impaired Waters

This permit does not authorize new sources or new discharges of constituents of concern to impaired waters unless consistent with the approved Total Maximum Daily Load (TMDL) and applicable state law. Impaired waters are those that do not meet applicable water quality standards and are listed on the Clean Water Act Section 303(d) list. Pollutants of concern are those constituents for which the water body is listed as impaired. Discharges of pollutants of concern to impaired water bodies for which there is an approved TMDL are not eligible for coverage under this permit unless they are consistent with the approved TMDL. Within six months of the TMDL approval, permittees must incorporate any limitations, conditions, or requirements applicable to their discharges necessary for compliance with the TMDL, including any monitoring or reporting required by DWWM rules, into their Storm Water Management Program in order to be eligible for coverage under this general permit.

Sites that discharge into a receiving water which has been listed on the Clean Water Act 303(d) list of impaired waters, and with discharges that contain the pollutant(s) for which the water body is impaired, must document in the SWMP how the BMPs will control the discharge of the pollutant(s) of concern.

E. Endangered and Threatened Species

If a site discharges to a stream where a Federally endangered or threatened species or its habitat are present, the applicant shall contact the US Fish and Wildlife Service to insure that requirements of the Federal Endangered Species Act are met.

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Part IV. Monitoring, Recordkeeping, Reporting and Program Review

A. Monitoring

A permittee covered by this general permit or another responsible entity shall use any means thought to be necessary to evaluate the effectiveness of the programs and BMPs implemented to comply with this general permit. Careful consideration must be given to the information, BMPs and measurable goals specified in the SRA submitted to the DWWM. This information shall be submitted in annual reports.

B. Recordkeeping

The permittee shall keep records under this general permit for at least three (3) years after termination of this general permit. Records shall be submitted to the DWWM only when permittees are specifically asked to do so. The permittee shall make its records and its storm water management program information available to the public at reasonable times during regular business hours.

C. Reporting

Annually, the permittee shall submit a report to the DWWM. The report shall include:

1. The status of compliance with permit conditions, an assessment of the appropriateness of the identified BMPs and the progress toward achieving the identified measurable goals for each of the minimum control measures;

2. Results of information collected and analyzed, including monitoring data, if any, during the annual reporting period;

3. A summary of the storm water activities the permittee plans to undertake during the next annual reporting period;

4. A change in any identified measurable goals that apply to the minimum control measures;

5. A description of the coordination efforts with its respective County(ies) regarding the implementation of the minimum control measures including the status of any MOU or other agreement executed between the permittee and another entity; and

6. A fiscal analysis of capital and operating expenditures to implement the minimum control measures. The fiscal analysis shall include only those expenditures by the locality seeking coverage under this general permit and not those for minimum control measures implemented by other entities.

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D. Program Review

In order to assess the effectiveness of the permittee's NPDES program for eliminating non-storm water discharges and reducing the discharge of pollutants to the maximum extent possible, the DWWM will review program implementation and annual reports. Additional periodic evaluations may be conducted to determine compliance with permit conditions.

SARB_008584

Part V

MANAGEMENT CONDITIONS:

1. Duty to Comply

a) The permittee must comply with all conditions of this permit. Permit noncompliance constitutes a violation of the CWA and State Act and is grounds for enforcement action; for permit modification, revocation and reissuance, suspension or revocation; or for denial of a permit renewal application.

b) The permittee shall comply with all effluent standards or prohibitions established under Section 307(a) of the CWA for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.

2. Duty to Reapply

If the permittee wishes to continue an activity regulated by this permit after the expiration date of this permit, the permittee must apply for a new permit at least 180 days prior to expiration of the permit.

3. Duty to Mitigate

The permittee shall take all reasonable steps to minimize or prevent any discharge in violation of this permit, which has a reasonable likelihood of adversely affecting human health or the environment.

4. Permit Actions

This permit may be modified, revoked and reissued, suspended, or revoked for cause. The filing of a request by the permittee for permit modification, revocation and reissuance, or revocation, or a notification of planned changes or anticipated noncompliance, does not stay any permit condition.

5. Property Rights

This permit does not convey any property rights of any sort or any exclusive privilege.

6. Signatory Requirements

All applications, reports, or information submitted to the Director shall be signed and certified as required in Title 47, Series 10, Section 4.6 of the West Virginia Legislative Rules.

7. Transfers

This permit is not transferrable to any person except after notice to the Director. The Director may require modification or revocation and reissuance of the permit to change the name of the permittee and incorporate such other requirements as may be necessary.

8. Duty to Provide Information

The permittee shall furnish to the Director, within a reasonable specified time, any information which the Director may request to determine whether cause exists for modifying, revoking and reissuing, suspending, or revoking this permit, or to determine compliance with this permit. The permittee shall also furnish to the Director, upon request, copies of records required to be kept by this permit.

9. Other Information

Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application or in any report to the Director, it shall promptly submit such facts or information.

10. Inspection and Entry

The permittee shall allow the Director, or an authorized representative, upon the presentation of credentials and other documents as may be required by law, to:

a) Enter upon the permittee's premises in which an effluent source or activity is located, or where records must be kept under the conditions of this permit;

b) Have access to and copy at reasonable times, any records that must be kept under the conditions of this permit;

c) Inspect at reasonable times any facilities, equipment (including monitoring and control equipment), practices, or operations regulated or required under this permit; and

d) Sample or monitor at reasonable times, for the purposes of assuring permit compliance or as otherwise authorized by the State Act, any substances or parameters at any location.

11. Permit Modification

This permit may be modified, suspended, or revoked in whole or in part during its term in accordance with the provisions of Chapter 22-11-12 of the Code of West Virginia.

12. Water Quality

Subject to 47 WV CSR 10.3.4.a, the effluent or effluents covered by this permit are to be of such quality so as not to cause violation of applicable water quality standards adopted by the Environmental Quality Board.

13. Outlet Markers

A permanent marker at the establishment shall be posted in accordance with Title 47, Series 11, Section 9 of the West Virginia Legislative Rules.

14. Liabilities

a) Any person who violates a permit condition implementing sections 301, 302, 306, 307, 308, 318, or 405 of the Clean Water Act is subject to a civil penalty not to exceed $25,000 per day of such violation. Any person who willfully or negligently violates permit conditions implementing sections 301, 302, 306, 307, 308 or 405 of the Clean Water Act is subject to a fine of not less than $2,500 nor more than $25,000 per day of violation, or by imprisonment for not more than 1 year, or both.

b) Any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 2 years, or by both.

c) Any person who knowingly makes any false statement, representation, or certification in any record or other document submitted or required to be maintained under this permit, including monitoring reports or reports of compliance or noncompliance shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 2 years, or by both.

d) Nothing in I.14 a), b), and c) shall be construed to limit or prohibit any other authority the Director may have under the State Water Pollution Control Act, Chapter 22, Article 11.

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The herein described activity is to be operated, used and maintained strictly in accordance with the terms and conditions of this permit; with all plans and specifications previously submitted with the individual site registration application form or individual permit application; with a plan of maintenance and method of operation thereof; and with any applicable rules and regulations promulgated by the State Environmental Quality Board.

Failure to comply with the terms and conditions of this permit, with the plans and specifications previously submitted with the individual site registration application form or individual permit application, and with a plan of maintenance and method of operation thereof shall constitute grounds for the revocation or suspension of this permit and for the invocation of all the enforcement procedures set forth in Chapter 22, Article 11 of the Code of West Virginia.

This permit is issued in accordance with the provisions of Chapter 22, Article 11 of the Code of West Virginia

BY: _____

Director

Appendix A

Designation Criteria for Small MS4s Located Outside of an Urbanized Area With a Population Greater than or Equal to 10,000 AND a Population Density Greater than or Equal to 1000 per Square Mile

The following designation criteria will be evaluated to determine if the subject MS4s require general permit coverage:

1) Discharge to sensitive waters

2) High growth or growth potential

3) High population density

4) Contiguity to an urbanized area

5) Significant contributor of pollutants to waters of the State

6) Ineffective protection of water quality by other programs

SARB_008587



Urban Storm Drainage Criteria Manual

Volume 1

Volume 2

Volume 3

Urban Storm Drainage Criteria Manual

Since 1969 the Urban Drainage and Flood Control District has maintained and distributed the Urban Storm Drainage Criteria Manual which consists of three volumes:

- **Volume 1 and 2 provide guidance for planning and design of drainageway channels and hydraulic structures.**
- **Volume 3 provides guidance for the selection and design of stormwater quality best management practices.**

Volume 3 was completely revised and reprinted in 1999. Volumes 1 and 2 were completely updated in 2001.

Convenient web pages are provided for downloading subseqent revisions and updates to all three volumes.

Volume 1, 2, and 3 are no longer available for purchase. All chapters and related software, spreadsheets and drawings are available for downloads.

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A user group was set up through Google™ to serve as a forum for exchange of information about UDFCD supported software and spreadsheets, all freeware.

You are encouraged to join this group in order to get notices on the latest updates to the software Criteria Manual, and spreadsheets available for download from UDFCD. You will also be able to exchange with other users information about problems, solutions, tricks, etc. that you encounter or find

This site will also contain *Frequently Asked Questions* from the user community to view.

To sign up for this site go to http://groups.google.com/group/UDFCD-support and then proceed to open a Google account if you do not have one, or go to your google account to add this site on your list.

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INSTRUCTIONS: Right click on the selected item and select "Save Target as..." on the drop-down menu. Direct all files to the same directory, either one for each Volume or a single directory containing both Volumes to maintain the hyperlinks between the Table of Contents and individual chapters/sections.

If you download the entire volume at a time, you will be downloading a WinZip file. Extract the files to each Volume's directory to its folder or, if you chose, to a directory containing the files of both Volumes.

Urban Storm Drainage Criteria Manual – 2001 Edition **(Includes Later Revisions)**

The following contains a list of individual Chapters of the 2001 edition of the *Urban Storm Drainage Criteria*

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Manual's Volumes 1 and 2.

All of them may be downloaded for free in Adobe (*.PDF) format.The note within the "{ }" brackets {e.g., 2005-03} gives latest date of that chapter's revision or update.

Each volume contains a section summarizing of the changes made to the 1969 edition of the *Manual* and subsequent revisions/corrections made since the release of the 2001 edition.

If you prefer, you may download the Entire Volume 1 and/or Volume 2 of the *Manual* in WinZip file format by selecting the title of the volume below. Each Volume contains the latest revisions and updates, including the 2005-03 reformatting.

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Urban Storm Drainage Criteria Manual – Volume 1 {2007-06} (WINZIP 10 MB)

- Chapter 00 Preface {2001-06} (PDF 0.06 KB)
- Chapter 01 Drainage Policy {2001-06} (PDF 644 KB)
- Chapter 02 Drainage Law {2001-06} (PDF 407 KB)
- Chapter 03 Planning {2001-06} (PDF 566 KB)
- Chapter 04 Rainfall {2004-01- Minor Rev.} (PDF 2.1 MB)
- Chapter 05 Runoff {2006-08 - Significant Rev.} (PDF 1.8 MB)
- Chapter 06 Streets/Inlets/Storm Sewers {2004-01– Major Rev.} (PDF 2.7 MB)
- Chapter 07 Major Drainage {2006-08 – Significant Rev.} (PDF 4.7 MB)
- Table of Content Vol. 1 {2006-08} (PDF 36 KB)
- Inside Cover Vol. 1 {2006-08} (PDF 118 KB)
- Summary of Changes Vol. 1 and DISCLAIMER {2006-08} (PDF 41 KB)
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- Cover - Outside Spine Vol. 1 {2001-06} (PDF 39 KB)

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- Chapter 08 Hydraulic Structures {2007-02} (PDF 11.7 MB)
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- Chapter 10 Storage {2007-06} (PDF 2.73 MB)
- 10 Chapter Storage rev pp 11, 12, 37, 38 {2007-06} (PDF 136 KB)
- Chapter 11 Flood Proofing {2001-06} (PDF 984 KB)
- Chapter 12 Revegetation {2001-06} (PDF 646 KB)
- Chapter 13 Design Examples – Part 1 {2001-06} (PDF 34 KB)
- Chapter 13 Design Examples – Part 2 {2001-06} (PDF 856 KB)
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Urban Storm Drainage Criteria Manual – 1999 Edition **(Includes Later Revisions)**

The following contains a list of individual Sections and Chapters of the 1999 edition of the *Urban Storm Drainage Criteria Manual's Volume 3 – Best Management Practices* that may be downloaded in Adobe (*.PDF)

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format.

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- **Table of Contents** {2005-10} (PDF 65 KB)
- **Preface** {2007-01} (PDF 94 KB)
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- **Bibliography** {2005-10} (PDF 63 KB)
- **Design Form Examples** {2002-06 MAJOR revision} (PDF 325 KB)
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Policy

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Law

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Planning

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Rainfall

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Storm Sewers

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Major Drainage

◆

Urban Storm Drainage Criteria Manual

Volume 1

June 2001

Revised:
August 2006

SARB_008593

URBAN STORM DRAINAGE

CRITERIA MANUAL

Volume 1



Urban Drainage and Flood Control District
Denver, Colorado June 2001
Revised August 2006

SARB_008594

Drainage Criteria Manual
(Volume 1)

June 2001

Revised August 2006



Urban Drainage and Flood Control District

SARB_008595

SUMMARY OF CHANGES TO VOLUME 1
of the
URBAN STORM DRAINAGE CRITERIA MANUAL
and
DISCLAIMER

2001 Edition vs. 1969 Edition

GENERAL

- All chapters edited; some totally rewritten.
- Many design aids added, including figures, nomographs, spreadsheets, etc.
- New chapters on Revegetation and Design Examples added.
- Emphasis on maintenance, public safety, aesthetics and multidisciplinary design approaches.
- Design checklists added to many chapters.
- Stronger emphasis on "designing with nature" principles such as "bioengineering."

POLICY CHAPTER

- Provides increased emphasis on staying out of the 100-year floodplain.
- Recommends reducing runoff rates, volumes and pollutants to the maximum extent practicable.
- Recommends reserving sufficient rights-of-way for lateral movement of incised floodplains.
- Clarifies the role of irrigation ditches in urban drainage.
- Revises street inundation criteria for the 100-year flood.

DRAINAGE LAW CHAPTER

- Contents totally updated.

PLANNING CHAPTER

- Also addresses the areas now being emphasized in the Policy chapter.

RAINFALL CHAPTER

- Adds a 25-year design storm and its distribution.
- Provides spreadsheets for calculations of design storms and IDF curves.
- Expands rainfall maps to include new areas of District added since 1969.

RUNOFF CHAPTER

- Clarifies the use of flows published in District's master plans and other reports.
- Also clarifies the use and applicability of statistical analysis.
- Provides spreadsheets for the Rational Method and CUHP calculations.
- Describes the use of CUHP and UDSWM software.
- Includes new procedure for calculating the runoff coefficient "*C*" in the Rational Formula.
- Clarifies which hydrologic methods to use as a function of watershed size.

STREETS/INLETS/STORM SEWERS CHAPTER

- Combines three separate chapters on design of streets, inlets and storm sewers.
- Uses protocols from the Federal Highway Administration Engineering Circular Nos. 12 and 22.
- Includes reduction factors for allowable gutter/street flow.
- Provides an inlet capacity reduction protocol that accounts for inlet clogging.
- Also provides spreadsheets for calculations and design examples.

MAJOR DRAINAGE CHAPTER

- Includes expanded and updated design guidance and criteria for each channel type.
- Provides guidance for protection of natural channels from effects of urbanization.
- Adds new section on bioengineered channel design.
- Includes new guidance on use and design of composite channels.
- Adds text on the fundamentals of open channel hydraulics and stream stability.

- Updates text on 404 permitting.
- Revises guidance for sizing trickle channels and low-flow channels.
- Includes new criteria for design of boulders and grouted boulders.
- Provides spreadsheets as design aids.

2002 through 2005 Revisions to 2001 Edition

ENTIRE VOLUME 1

2005-03: Reformat entire Volume 1 to facilitate future updates. (Significant Revision)

RUNOFF CHAPTER

2004-01: Correct typos on Page RO-35.

MAJOR DRAINAGE CHAPTER

2002-06: Correct Table MD-2.
2004-01: Revise text on Page MD-62 and MD-105 and add Figure MD-25. (Significant Revision)

STREETS/INLETS/STORM SEWERS CHAPTER

2002-06: Correct units in Eq. ST-8 and correct Eq. ST-25. (Significant Revision)
2002-06: Replace Sections 4.4.2 and 4.4.13 and UDSEWER example. (Major Revision)
2003-03: Corrects Eq. ST-17. (Significant Revision)

August 2006 Update to 2001 Edition

RUNOFF CHAPTER

- Updated description of CUHP to use of CUHP 2005 software and EPA SWMM 5.0 for routing
- Deleted use of UDSWM and described EPA SWMM 5.0 for routing CUHP 2005 hydrographs.

MAJOR DRAINAGE CHAPTER

- Cleaned up a number of figures using AutoCAD™
- Expanded on the description on use of trickle and low flow channels in grass-lined channels.
- Modified submittal checklist to include some design elements not previously listed in them.
- Clarified Froude Number and Velocity limitations for concrete and riprap lined channels.
- Clarified that concrete-lined channels are not maintenance eligible.
- Expanded the use of soil riprap to now include VL, L and M riprap sizes.
- Clarified the minimum embedment of riprap bank and channel toe lining for sandy soils.
- Clarified the need to check rock sizes for increased velocities at channel bends and transitions.
- Clarifies the use of soil-riprap lining side-slopes above the low-flow section of a channel.
- Added a figure relating grass cover type, velocity, depth and Manning's *n* in grass-lined channels.
- Added details for soil-riprap installation.
- Expanded on the need for air-venting when rectangular storm sewers are used.
- Clarified importance of pipe entrance(s) in design.
- Modified examples to reflect latest spreadsheet workbooks.

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URBAN STORM DRAINAGE CRITERIA MANUAL

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1.0 STATEMENT OF POLICY

1.1 Policy

Adequate drainage for urban areas is necessary to preserve and promote the general health, welfare, and economic well being of the region. Drainage is a regional feature that affects all governmental jurisdictions and all parcels of property. This characteristic of drainage makes it necessary to formulate a program that balances both public and private involvement (Wright-McLaughlin Engineers 1969). Overall, the governmental agencies most directly involved must provide coordination and master planning, but drainage planning must also be integrated on a regional level (FEMA 1995).

When planning drainage facilities, certain underlying principles provide direction for the effort. These principles are made operational through a set of policy statements. The application of the policy is, in turn, facilitated by technical drainage criteria and data. When considered in a comprehensive manner—on a regional level with public and private involvement—drainage facilities can be provided in an urban area in a manner that will avoid uneconomic water losses and disruption, enhance the general health and welfare of the region, and assure optimum economic and social relationships (White 1945).



Photograph DP-1—Denver grass-lined channel after 35 years of service. Ann Spirn of the Massachusetts Institute of Technology refers to this channel as "urban poetry" in her publications. Spirn appreciates the soft natural lines.

The principles and policies for urban storm drainage are summarized below.

1.2 Principles

- **Drainage is a regional phenomenon that does not respect the boundaries between government jurisdictions or between properties.**
- **A storm drainage system is a subsystem of the total urban water resource system.**
- **Every urban area has an initial and a major drainage system, whether or not they are actually planned and designed.**
- **Runoff routing is primarily a space allocation problem.**
- **Planning and design of stormwater drainage systems generally should not be based on the premise that problems can be transferred from one location to another.**
- **An urban storm drainage strategy should be a multi-objective and multi-means effort.**
- **Design of the stormwater drainage system should consider the features and functions of the existing drainage system.**
- **In new developments, attempts should be made to reduce stormwater runoff rates and pollutant load increases after development to the maximum extent practicable.**
- **The stormwater management system should be designed, beginning with the outlet or point of outflow from the project, giving full consideration to downstream effects and the effects of off-site flows entering the system.**
- **The stormwater management system should receive regular maintenance.**
- **Floodplains need to be preserved whenever feasible and practicable.**
- **Reserve sufficient right-of-way to permit lateral channel movement whenever the floodplain is contained within a narrow natural channel.**

1.3 Basic Knowledge

A program for collecting and analyzing storm runoff and flood data should be maintained in order that intelligent and orderly planning may be undertaken in regard to storm drainage facilities.

A program should be maintained to delineate flood hazard areas along all waterways in the region which are urbanized or which may be in the future. This program should make full use of the information and data from the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), private consulting engineers, and the Colorado Water Conservation Board. This information should be

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regularly reviewed and updated to reflect changes due to urbanization, changed channel conditions, and the occurrence of extraordinary hydrologic events.

Before commencing design of any drainage project, comprehensive facts and data should be collected and examined for the particular watershed and area under consideration, and the basis for the design should then be agreed upon by the governmental entities affected.

1.4 Planning

Storm drainage is a part of the total urban environmental system. Therefore, storm drainage planning and design must be compatible with comprehensive regional plans. A master plan for storm drainage should be developed and maintained in an up-to-date fashion at all times for each urbanizing drainage watershed in the Denver region. The planning for drainage facilities should be coordinated with planning for open space and transportation. By coordinating these efforts, new opportunities may be identified that can assist in the solution of drainage problems.

Natural drainageways should be used for storm runoff waterways wherever feasible. Major consideration must be given to the floodplains and open space requirements of the area (White 1945).

Planning and design of stormwater drainage systems should not be based on the premise that problems can be transferred from one location to another.

Stormwater runoff can be stored in detention and retention reservoirs. Such storage can reduce the drainage conveyance capacity required immediately downstream. Acquisition of open space having a relationship to drainageways will provide areas where storm runoff can spread out and be stored for slower delivery downstream.

1.5 Technical Issues

Storm drainage planning and design should follow the criteria developed and presented in this *Urban Storm Drainage Criteria Manual* (*Manual*).

Every urban area has two separate and distinct drainage systems, whether or not they are actually planned and designed. One is the initial system, and the other is the major system. To provide for orderly urban growth, reduce costs to future generations and avoid loss of life and major property damage, both systems must be planned, properly engineered and maintained.

The determination of runoff magnitude should be by the Rational Formula, the Colorado Urban Hydrograph Procedure (CUHP), or statistical analyses based on an adequate record of actual measured flood occurrences as set forth in the RUNOFF chapter of this *Manual*.

Use of streets for urban drainage should fully recognize that the primary use of streets is for traffic.

Streets should not be used as floodways for initial storm runoff. Urban drainage design should have as an objective reduction of street repair and maintenance costs to the public.

Irrigation ditches should not be used as outfall points for initial or major drainage systems, unless such use is shown to be without unreasonable hazard, as substantiated by thorough hydraulic engineering analysis, and written approval of the ditch owner(s) is obtained. In addition, irrigation ditches cannot be relied on for mitigating upstream runoff.

Proper design and construction of stormwater detention and retention basins are necessary to minimize future maintenance and operating costs and to avoid public nuisances and health hazards. This is particularly important, given the many detention and retention facilities in the Denver region.

The various governmental agencies within the Denver region have adopted and need to maintain their floodplain management programs. Floodplain management must encompass comprehensive criteria designed to encourage, where necessary, the adoption of permanent measures which will lessen the exposure of life, property and facilities to flood losses, improve the long-range land management and use of flood-prone areas, and inhibit, to the maximum extent feasible, unplanned and economically unjustifiable future development in such areas.

1.6 Flood Insurance

Flood insurance is an integral part of the strategy to manage flood losses. The Denver region should encourage continued participation in the National Flood Insurance Program, set forth in the National Flood Insurance Act (NFIA) of 1968, as amended.

1.7 Implementation

This *Manual* should continue to be adopted by all governmental agencies operating within the region. Each level of government is encouraged to participate in a successful drainage program.

Problems in urban drainage administration encountered by any governmental agency can be reviewed by the Urban Drainage and Flood Control District (District) to determine if equity or public interests indicate a need for drainage policy, practice, or procedural amendments (Figure DP-1).

The financing of storm drainage improvements is fundamentally the responsibility of the affected property owners—both the persons directly affected by the water and the person from whose land the water flows.

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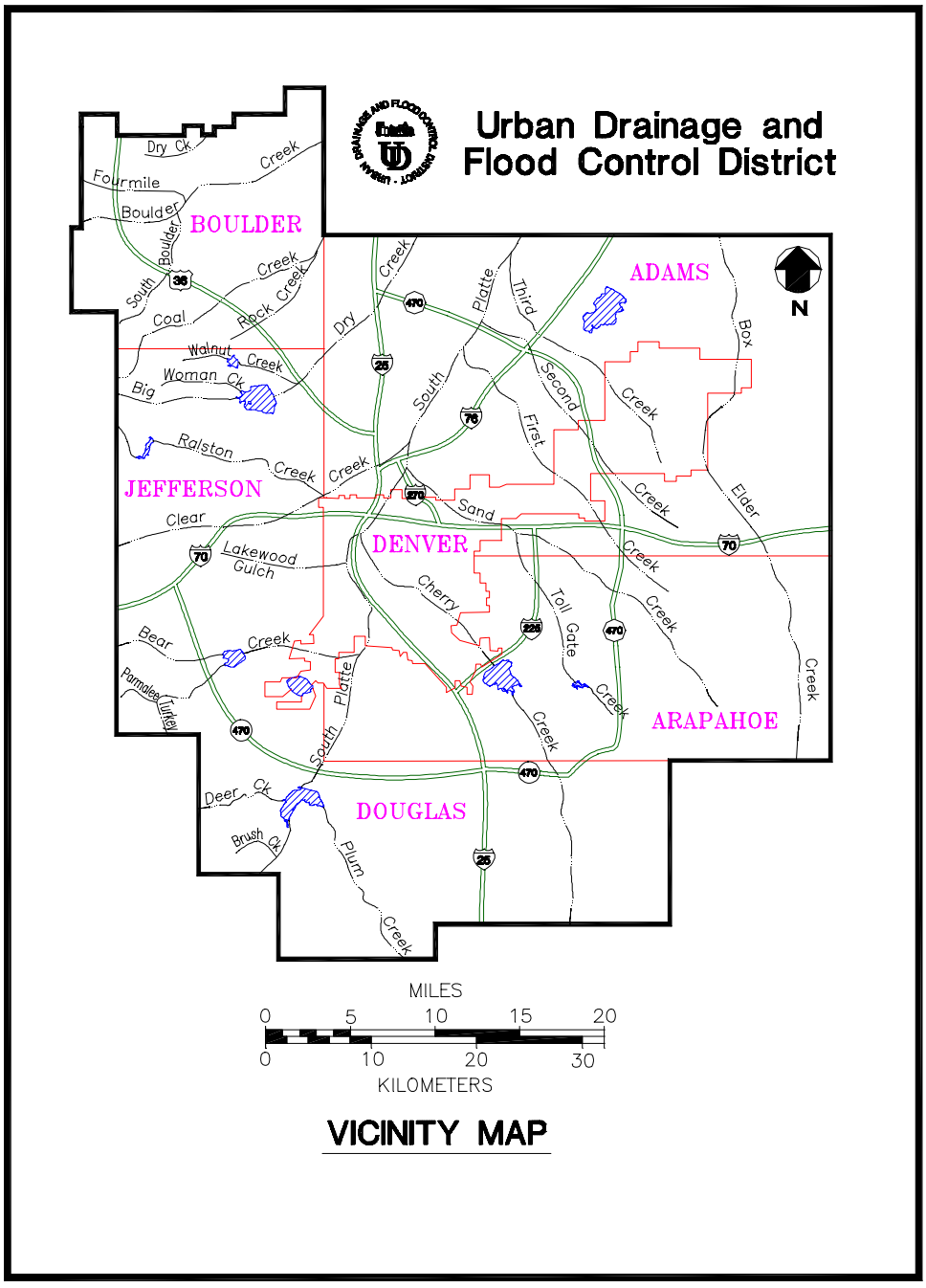

Figure DP-1—Urban Drainage and Flood Control District Boundaries

2.0 PRINCIPLES

2.1 Drainage Is a Regional Phenomenon That Does Not Respect the Boundaries Between Government Jurisdictions or Between Properties

This makes it necessary to formulate programs that include both public and private involvement. Overall, the governmental agencies most directly involved must provide coordination and master planning, but drainage planning must be integrated on a regional level if optimum results are to be achieved. The ways in which proposed drainage systems fit existing regional systems must be quantified and discussed in the master plan.

2.2 A Storm Drainage System Is a Subsystem of the Total Urban Water Resource System

Stormwater system planning and design for any site must be compatible with comprehensive regional plans and should be coordinated, particularly with planning for land use, open space and transportation. Erosion and sediment control, flood control, site grading criteria, and regional water quality all closely interrelate with urban stormwater management. Any individual master plan or specific site plan should normally address all of these considerations.

2.3 Every Urban Area Has an Initial (i.e., Minor) and a Major Drainage System, Whether or Not They Are Actually Planned and Designed

The initial drainage system, sometimes referred to as a “minor system,” is designed to provide public convenience and to accommodate moderate, frequently occurring flows. The major system carries more water and operates when the rate or volume of runoff exceeds the capacity of the minor system. Both systems should be carefully considered.

2.4 Runoff Routing Is Primarily a Space Allocation Problem

The volume of water present at a given point in time in an urban region cannot be compressed or diminished. Channels and storm sewers serve both conveyance and storage functions. If adequate provision is not made for drainage space demands, stormwater runoff will conflict with other land uses, will result in damages, and will impair or even disrupt the functioning of other urban systems.

2.5 Planning and Design of Stormwater Drainage Systems Generally Should Not Be Based on the Premise That Problems Can Be Transferred From One Location to Another

Urbanization tends to increase downstream peak flow by increasing runoff volumes and the speed of runoff. Stormwater runoff can be stored in detention facilities, which can reduce the drainage capacity required immediately downstream.

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2.6 An Urban Storm Drainage Strategy Should Be a Multi-Objective and Multi-Means Effort

The many competing demands placed upon space and resources within an urban region argue for a drainage management strategy that meets a number of objectives, including water quality enhancement, groundwater recharge, recreation, wildlife habitat, wetland creation, protection of landmarks/amenities, control of erosion and sediment deposition, and creation of open spaces.



Photograph DP-2—An urban storm drainage strategy should be a multi-objective and multi-means effort.

2.7 Design of the Stormwater Drainage System Should Consider the Features and Functions of the Existing Drainage System

Every site contains natural features that may contribute to the management of stormwater without significant modifications. Existing features such as natural drainageways, depressions, wetlands, floodplains, permeable soils, and vegetation provide for infiltration, help control the velocity of runoff, extend the time of concentration, filter sediments and other pollutants, and recycle nutrients. Each development plan should carefully map and identify the existing natural system. Techniques that preserve or protect and enhance the natural features are encouraged. Good designs improve the effectiveness of natural systems rather than negate, replace or ignore them.

2.8 In New Developments, Attempts Should Be Made to Reduce Stormwater Runoff Rates and Pollutant Load Increases After Development to the Maximum Extent Practicable

1. The perviousness of the site should be maintained, to the extent feasible.

2. The rate of runoff should be slowed. Preference should be given to stormwater management systems that use practices that maximize vegetative and porous land cover. These systems will promote infiltration, filtering and slowing of the runoff. It should be noted that, due to the principle of mass conservation, it is virtually impossible to prevent increases in post-development runoff volumes when an area urbanizes. However, existing stormwater regulations can require control of peak flows to predevelopment levels to a maximum extent achievable. Increased flow volumes may present no flooding problems if the watershed has a positive outfall to a stream or river; however, these volumes may cause problems for a small, enclosed watershed draining to a lake or into streams of limited capacity.

3. Pollution control is best accomplished by implementing a series of measures, which can include source control, minimization of directly connected impervious areas, and construction of on-site and regional facilities, to control both runoff and pollution.

2.9 The Stormwater Management System Should Be Designed Beginning With the Outlet or Point of Outflow From the Project, Giving Full Consideration to Downstream Effects and the Effects of Off-Site Flows Entering the System

The downstream conveyance system should be evaluated to ensure that it has sufficient capacity to accept design discharges without adverse backwater or downstream impacts such as flooding, stream bank erosion, and sediment deposition. In addition, the design of a drainage system should take into account the runoff from upstream sites, recognizing their urban development potential.

2.10 The Stormwater Management System Should Receive Regular Maintenance

Failure to provide proper maintenance reduces both the hydraulic capacity and pollutant removal efficiency of the system. The key to effective maintenance is clear assignment of responsibilities to an established agency and a regular schedule of inspections to determine maintenance needs and to ensure that required maintenance is done. Local maintenance capabilities should be a consideration when selecting specific design criteria for a given site or project.

2.11 Floodplains Need to Be Preserved Whenever Feasible and Practicable

Nature has claimed a prescriptive easement for floods, via its floodplains, that cannot be denied without public and private cost. Floodplains often provide a natural order to the land surface with drainageways that serve as outfalls for urban drainage, bottomland for wildlife habitat, riparian corridors, and specialized vegetation. Floodplain encroachment can occur only after competent engineering and planning have been conducted to assure that flow capacity is maintained, risks of flooding are defined and risks to life and property are strictly minimized. Preservation of floodplains is a policy of the District to manage flood

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hazards, preserve habitat and open space, create a more livable urban environment, and protect the public health, safety, and welfare (White 1945).



Photograph DP-3—National Medal of Science winner, Dr. Gilbert White, recommends natural-like floodplains because they save people from damages and are good for the economy.

2.12 Reserve Sufficient Right-of-Way for Lateral Movement of Incised Floodplains

Whenever a floodplain is contained within a narrow (i.e., degraded) channel, its lateral movement over time can cause extensive damages to public and private structures and facilities. For this reason, whenever such a condition exists, it is recommended that, at a minimum, the channel be provided with grade control structures and a right-of-way corridor be preserved of a width equivalent to the cross section recommended for a grass-lined channel, including a maintenance access roadway.

3.0 BASIC KNOWLEDGE

3.1 Data Collection

An important step in a drainage program is to get the facts. A program for collecting and analyzing storm runoff and flood data should be maintained to promote intelligent and orderly planning (Jones 1967).

3.1.1 Storm Runoff and Flood Damage

Storm runoff and flood damage data should be collected in a systematic and uniform manner.

3.1.2 Rainfall-Runoff Relationships

A program should be maintained to collect and analyze rainfall-runoff relationships in urban areas of the Denver region.

3.1.3 Inventory of Successful Projects

Some drainage projects function better than others. It is important to determine why, so that key features may be inventoried for use on other succeeding projects.

3.1.4 Library

The District should acquire and actively maintain a library, which should be available for use by all governmental agencies, practicing planners, and engineers. The public should be encouraged to use the library as part of the District's educational and outreach programs.

3.1.5 Runoff Magnitudes

Where practical, the magnitude of computed and measured runoff peaks should be tabulated for Denver region streams and gulches so that comparisons may be readily made between watersheds and erroneous values may be more easily identified.

3.2 Floodplain Data

The program to delineate flood hazard areas along all waterways in the region should be maintained. This program should make full use such sources as the District's Flood Hazard Area Delineation studies, the FEMA Flood Insurance Studies, data from the Natural Resources Conservation Service, the USGS, and floodplain studies by private consulting engineers. This information should be regularly reviewed and updated to reflect changes due to urbanization, changed channel conditions, and the occurrence of extraordinary hydrologic events.

3.2.1 Small Waterways

Small gulches and other waterways, which are often overlooked, have a large damage potential. These waterways should receive early attention in areas subject to urbanization. Floodplain information should be shown on preliminary and final subdivision plats, including the areas inundated by major storm runoff and areas of potential erosion.

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3.2.2 Data Inventory

The information collected should be stored in a central District depository available to all planners, developers, and engineers.

3.2.3 Floodplains

This effort should be aimed towards developing information on those areas that have a one percent chance of being inundated in any given year—that is, the 100-year floodplain. Local governmental agencies may choose to regulate floodplains for other frequencies of flooding; however, the 100-year floodplain based on runoff from the projected fully urbanized watershed must be defined in addition to being the minimum basis for regulation.

3.2.4 Priority for Data Acquisition

The District will establish priorities for acquisition of data because it is recognized that not all of the data can be collected at one time. When setting priorities, consideration should be given to:

a. Areas of rapid urban growth

b. Drainage problem areas

c. Local interest and capabilities in floodplain management

d. Potential for developing significant information

3.3 Data Use

Prior to the commencement of any drainage project, comprehensive facts and data should be collected and examined for the particular watershed and area under consideration.

3.3.1 Master Plan

Drainage design does not lend itself to a piece-meal approach; therefore, master plans for drainage should be prepared on a priority basis. Such plans already cover most of the developed major drainageways in the District. Additional plans will be developed for areas yet unplanned. In addition, existing master plans will be updated as needed to reflect changed conditions that take place over time.

3.3.2 Public Cost

Development of an area without the provision of adequate drainage multiplies the cost to the public because the drainage problem must be corrected later, usually at public expense.

3.3.3 Easements

Where construction occurs along a waterway not yet developed downstream or upstream, and where a master plan is not yet available, flood easements should be left which will include the future development 100-year floodplain. Where an existing master plan recommends the preservation of a defined floodplain,

every effort should be made to acquire and/or preserve an easement or property right (ownership) for such a floodplain.

On any floodplain, nature possesses by prescription an easement for intermittent occupancy by runoff waters. Man can deny this easement only with difficulty. Encroachments upon or unwise land modifications within this easement can adversely affect upstream and downstream flooding occurrences during the inevitable periods of nature's easement occupancy.

Floodplain regulation, then, must define natural easements and boundaries and must delineate floodplain occupancy that will be consistent with total public interests.

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4.0 PLANNING

4.1 Total Urban System

Storm drainage is a part of the total urban environmental system. Therefore, storm drainage planning and design should be compatible with comprehensive regional plans. Master plans for storm drainage have been developed and maintained in an up-to-date fashion for most of the watersheds in the Denver region. An effort to complete the coverage of master plans for yet unplanned areas of the District should be continued until full coverage is achieved.

4.1.1 Development Plan

A development plan should be given direction by broad, general framework goals. Examples of such goals are:

1. Drainage and flood control problem alleviation
2. Economic efficiency
3. Regional development
4. Environmental preservation and enhancement
5. Social and recreational need fulfillment

These goals, or combinations of these goals, as they are pursued within an urban region, have the potential to influence greatly the type of drainage subsystem selected. Planning for drainage facilities should be related to the goals of the urban region, should be looked upon as a subsystem of the total urban system, and should not proceed independent of these considerations (Wright 1967).

4.1.2 Master Plan

Each municipality and county in the Denver region is responsible for master planning for urban storm drainage facilities within its boundaries and environs. The District can help to coordinate efforts. Cooperation between governmental agencies is needed to solve drainage problems and joint city, county and District efforts are encouraged. Carrying forward master planning is best accomplished on a priority-phased basis so that the most demanding problems, such as areas of rapid urbanization, may be addressed at an early date.

Early work includes the planning of major drainageways from the point of outfall, proceeding in an upstream direction. The major drainageways are generally well defined and often dictate the design of the initial drainage system, including storm sewers, detention facilities, and water quality systems.

The District has established a suitable format for master plan reports and drawings so that a uniform planning approach and coordination of efforts can more easily be made. Master planning should be done

in enough detail and with adequate thoroughness to provide a ready drainage development guide for the future in a particular watershed. Generalized concepts based on rule-of-thumb hydrological analyses should not be used as master plans; a more rigorous analysis is necessary.

4.1.3 Planning Process Ingredients

Good urban drainage planning is a complex process. Fundamentals include:

1. Major Drainage Planning. All local and regional planning must take into consideration the major drainage system necessary to manage the runoff that is expected to occur once every 100 years. The major drainage system plans will reduce loss of life and major damage to the community and its infrastructure.

2. Initial Drainage System Planning. All local and regional planning must take into consideration the initial drainage system to transport the runoff from storms expected to occur once every 2 to 10 years. The planner of an initial system must strive to minimize future drainage complaints.

3. Environmental Design. Environmental design teams involving a range of disciplines should be convened whenever desirable to ensure that the benefits to total urban systems receive consideration in the drainage planning work. Planning should address water quality enhancements and include evaluation of the impacts of new facilities, as well as future operation and maintenance by private and public bodies.

4.1.4 Local and Regional Planning

Local and regional planning, whether performed under federal or state assistance programs or under completely local auspices, should consider and evaluate opportunities for multi-objective water resources management.

4.1.5 Site Planning

All land development proposals should receive full site planning and engineering analyses. In this regard, professional consideration must be given to the criteria outlined in the *Manual*. Where flood hazards are involved, the local planning boards should take into consideration proposed land use so that it is compatible with the flood hazard risks involved with the property, and appropriate easements need to be provided to preclude encroachment upon waterways or flood storage areas.

4.1.6 Water Quality

Protecting and enhancing the water quality of public streams is an important objective of drainage planning. Erosion control, maintaining stream channel stability, sediment and debris collection, and pollutant removal from stormwater runoff must be taken into account by using the stormwater runoff best management practices (BMPs) described in Volume 3 of this *Manual*.

Sanitary sewerage systems that overflow or bypass untreated sewage into surface streams should not be

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permitted in the Denver region. Existing systems that discharge sewage should be adjusted by their owners to eliminate this problem.

Full cooperation should be extended to planners and designers of sanitary sewerage works to minimize the hazards involved with the flooding of sanitary sewers by urban storm runoff. Drainage planning should include means to prevent inflow to sanitary sewers because of street flow and flooding of channels.

4.2 Multiple-Objective Considerations

Planning for drainage facilities should be coordinated with planning for open space, recreation and transportation. By coordinating these efforts, new opportunities can be identified which can assist in the solution of drainage problems (Heaney, Pitt and Field 1999).

4.2.1 Lower Drainage Costs

Planning drainage works in conjunction with other urban needs results in more orderly development and lower costs for drainage and other facilities.

4.2.2 Open Space

Open space provides significant urban social benefits. Use of stabilized, natural drainageways often is less costly than constructing artificial channels. Combining the open space needs of a community with major drainageways is a desirable combination of uses that reduces land costs and promotes riparian zone protection and establishment over time.

4.2.3 Transportation

Design and construction of new streets and highways should be fully integrated with drainage needs of the urban area for better streets and highways and better drainages and to avoid creation of flooding hazards. The location of borrow pits needed for road construction should be integrated with broad planning objectives, including storm runoff detention.

4.3 Natural Channels

Natural drainageways should be used for storm runoff waterways wherever practical. Preservation and protection of natural drainageways are encouraged; however, major consideration must be given to their stability as the area urbanizes.

4.3.1 Channelization

Natural drainageways within an urbanizing area are often deepened, straightened, lined, and sometimes put underground. A community loses a natural asset when this happens. Channelizing a natural waterway usually speeds up the flow, causing greater downstream flood peaks and higher drainage costs, and does nothing to enhance the environment.

4.3.2 Channel Storage

Drainageways having "slow-flow" characteristics, vegetated bottoms and sides, and wide water surfaces provide significant floodplain storage capacity. This storage is beneficial in that it reduces downstream runoff peaks and provides an opportunity for groundwater recharge. Wetland channels, wide natural channels, and adjacent floodplains provide urban open space.



Photograph DP-4—Drainageways having "slow-flow" characteristics, with vegetated bottoms and sides can provide many benefits.

4.3.3 Major Runoff Capacity

Drainageways and their residual floodplains should be capable of carrying the major storm runoff, which can be expected to have a one percent chance of occurring in any single year.

4.3.4 Maintenance and Maintenance Access

Waterways will require both scheduled and unscheduled maintenance for a wide array of activities such as sediment, debris and trash removal, mowing, and repair of hydraulic structures. Assured long term maintenance is essential, and it must be addressed during planning and design. The District assists with drainage facility maintenance, provided that the facilities are designed in accordance with the District's Maintenance Eligibility Guidelines. The June 2001 version of these guidelines are available on the CD version of this *Manual*, and updates to these guidelines should be obtained from the District's Web site at www.udfcd.org. Designers are strongly encouraged to adhere to the design criteria listed in the Maintenance Eligibility Guidelines. Waterways, detention structures and other facilities must have permanent access for routine and major maintenance activities.

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4.4 Transfer of Problems

Planning and design of stormwater drainage systems should not be based on the premise that problems can be transferred from one location to another.

4.4.1 Intra-Watershed Transfer

Channel modifications that create unnecessary problems downstream should be avoided, both for the benefit of the public and to avoid damage to private parties. Problems to avoid include land and channel erosion and downstream sediment deposition, increase of runoff peaks, and debris transport, among others.

4.4.2 Inter-Watershed Transfer

Diversion of storm runoff from one watershed to another introduces significant legal and social problems and should be avoided unless specific and prudent reasons justify and dictate such a transfer and no measurable damages occur to the natural receiving water or urban systems or to the public.

4.4.3 Watershed Planning

Master planning must be based upon potential future upstream development, taking into consideration both upstream and downstream existing and future regional publicly owned and operated detention and retention storage facilities. Such facilities must be assured of construction, perpetual operation and maintenance. Urban development causes a major increase in the volume of runoff, even though the peak flows for certain return floods might be managed to simulate those of undeveloped historic conditions. In the absence of such detention and retention facilities, the basis of design for both the initial and major systems is fully developed upstream conditions without storage.

4.5 Detention and Retention Storage

Stormwater runoff can be stored in detention and retention reservoirs. Such storage can reduce the peak flow drainage capacity required, thereby reducing the land area and expenditures required downstream. (However, see limitation in 4.4.3 regarding taking credit for detention.) In some instances of stormwater retention and detention, there may be water rights implications, and in those instances, the State Engineer's Office should be consulted.

4.5.1 Upstream Storage

Storage of storm runoff close to the points of rainfall occurrence includes use of parking lots, ball fields, property line swales, parks, road embankments, borrow pits, and on-site basins and ponds.

Large parking lots, like those at shopping centers, create more runoff volume than before with high runoff discharge rates. The same is true for many small parking lots. Parking lots should be designed to provide for storage of runoff during infrequent events except where clearly shown that such storage is impractical. Wherever reasonably acceptable from a social standpoint, parks should be used for short-

term detention of storm runoff to create drainage benefits. Such use may help justify park and greenbelt acquisition and expenditures.

The difficulty in quantifying the cumulative effects of very large numbers of small (i.e., on-site) detention/retention facilities (Malcomb 1982; Urbonas and Glidden 1983) and the virtual impossibility of assurance of their continued long-term performance or existence (Debo 1982; Prommersberger 1984) requires the District to recognize in its floodplain management only regional, publicly owned facilities. Nevertheless, upstream storage is encouraged, such as with the "Blue-Green" concept first described in *Civil Engineering* magazine (Jones 1967).

4.5.2 Minimized Directly Connected Impervious Area Development

The “minimized directly connected impervious area” (MDCIA) concept (refer to Volume 3 of this *Manual*) provides an approach to upstream stormwater management that reduces the amount of impervious surfaces in a development and their connection to the initial drainage system. In addition, it includes functional grading, wide and shallow surface flow sections, disconnection of hydrologic flow paths, and the use of porous landscape detention and porous pavement areas. Details for its use are presented in Volume 3 of this *Manual*. The technique of MDCIA is also referred to as “low impact development” (LID). Other references include Heaney, Pitt and Field (1999) and Prince George’s County, Maryland (1999).

4.5.3 Downstream Storage

The detention and retention of storm runoff is desirable in slow-flow channels, in storage reservoirs located in the channels, in off-stream reservoirs, and by using planned channel overflow ponding in park and greenbelt areas. Lengthening the time of concentration of storm runoff to a downstream point is an important goal of storm drainage and flood control strategies. This should be achieved via numerous and varied techniques.

4.5.4 Reliance on Non-Flood-Control Reservoirs

Privately owned non-flood-control reservoirs cannot be used for flood mitigation purposes in master planning because their perpetuity cannot be reasonably guaranteed. Publicly owned water storage reservoirs (city, state, water district, irrigation company, etc.) should be assumed to be full for flood planning purposes and, therefore, only the detention storage above the spillway crest can be utilized in regard to the determination of downstream flood peak flows.

4.5.5 Reliance on Embankments

The detention of floodwaters behind embankments created by railroads, highways or roadways resulting from hydraulically undersized culverts or bridges should not be utilized by the drainage engineer for flood peak mitigation when determining the downstream flood peaks for channel capacity purposes unless such detention has been covered by a binding agreement approved by the District.

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5.0 TECHNICAL CRITERIA

5.1 Design Criteria

Storm drainage planning and design should adhere to the criteria developed and presented in this *Manual* maintained by the District.

5.1.1 Design Criteria

The design criteria presented herein represent current good engineering practice, and their use in the Denver region is recommended. The criteria are not intended to be an ironclad set of rules that the planner and designer must follow; they are intended to establish guidelines, standards and methods for sound planning and design.

5.1.2 Criteria Updating

The criteria contained in this *Manual* should be revised and updated as necessary to reflect advances in the field of urban drainage engineering and urban water resources management.

5.1.3 Use of Criteria

Governmental agencies and engineers should utilize this *Manual* in planning new facilities and in their reviews of proposed works by developers, private parties, and other governmental agencies, including the Colorado Department of Transportation and other elements of the state and federal governments.

5.2 Initial and Major Drainage

Every urban area has two separate and distinct drainage systems, whether or not they are actually planned and designed. One is the initial system, and the other is the major system. To provide for orderly urban growth, reduce costs to future generations, and avoid loss of life and major property damage, both systems must be planned and properly engineered.

5.2.1 Design Storm Return Periods

Storm drainage planning and design should fully recognize the need for considering two separate and distinct storm drainage systems: the initial drainage system and the major drainage system. Local governments should not be tempted to specify larger than necessary design runoff criteria for the initial drainage system because of the direct impact on the cost of urban infrastructure.

There are many developed areas within the Denver urban region that do not fully conform to the drainage standards projected in this *Manual*. The multitude of problems associated with these areas historically provided the emphasis required to proceed with development of this *Manual*. It is recognized that upgrading these developed areas to conform to all of the policies, criteria, and standards contained in this *Manual* will be difficult, if not impractical, to obtain, short of complete redevelopment or renewal. However, flood-proofing techniques can be applied to these areas.

Strict application of this *Manual* in the overall planning of new development is practical and economical; however, when planning drainage improvements and the designation of floodplains for developed areas, the use of the policies, criteria, and standards contained in this *Manual* should be adjusted to provide for economical and environmentally sound solutions consistent with other goals of the area. Where the 100-year storm is not chosen for design purposes, the impact of the 100-year storm should be investigated and made known.

5.2.2 Initial Storm Provisions

The initial storm drainage system, capable of safely handling 2- to 10-year floods depending on local criteria, is necessary to reduce the frequency of street flooding and maintenance costs, to provide protection against regularly recurring damage from storm runoff, to help create an orderly urban system, and to provide convenience to urban residents. Normally, the initial drainage system cannot economically carry major runoffs, though the major drainage system can provide for the initial runoff. A well-planned major drainage system will reduce or eliminate the need for storm sewer systems (Jones 1967). Storm sewer systems consisting of underground pipes are a part of initial storm drainage systems.

5.2.3 Major Storm Provisions

In addition to providing the storm drainage facilities for the initial storm runoff, provisions should be made to avoid major property damage and loss of life for the storm runoff expected to occur from an urbanized watershed once every 100 years on average (i.e., one percent probability of occurrence any given year). Such provisions are known as the major drainage system.

5.2.4 Critical Facilities

Drainage engineers and planners should consider that certain critical facilities may need a higher level of flood protection. For instance, hospitals, police, fire stations and emergency communication centers should be designed in a manner so that, even during a 100-year flood, their functioning will not be compromised. The use of a 500-year flood level for such facilities may be justified in many instances.

5.2.5 Major Drainage Channels

Open channels for transporting major storm runoff are more desirable than closed sewers in urban areas, and use of such channels is encouraged. Open channel planning and design objectives are often best met by using natural-type vegetated channels, which characteristically have slower velocities and large width-to-depth ratios. Additional benefits from open channels can be obtained by incorporating parks and greenbelts with the channel layout. When evaluating existing natural water courses (perennial, intermittent and ephemeral), it is desirable to minimize straightening, fill placement, and other alterations. Alterations such as these should be very carefully evaluated. Normally, however, some structural stabilization will be necessary to address the increased effects on stream stability caused by increased flows due to urbanization. For example, grade control structures and structural protection at the channel toe and on outer banks are normally required.

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The filling, straightening or altering of natural water courses, perhaps wet only during and after large rainstorms, is discouraged. Such actions tend to reduce flood storage and increase the velocity to the detriment of those downstream of and adjacent to the channel work. Effort must be made to reduce flood peaks and control erosion so that the natural channel regime is preserved as much as practical. Buffer zones can be used to account for future channel meandering and bank sloughing, at least in part.

Use of open channels should receive early attention when planning a new development, along with other storm runoff features.

5.2.6 Tailwater

The depth of flow in the receiving stream must be taken into consideration for backwater computations for either the initial or major storm runoff.

5.3 Runoff Computation

The determination of runoff magnitude should be made using the techniques described in the RUNOFF chapter of this *Manual*.

5.3.1 Accuracy

The peak discharges determined by any method are approximations. Rarely will drainage works operate at the design discharge. Flow will always be more or less in actual practice as it rises and falls during a storm event. Thus, the engineer should not overemphasize the detailed accuracy of computed discharges but should emphasize the design of practical and hydraulically balanced works based on sound logic and engineering, as well as dependable hydrology. The use of more than three significant figures for estimating the flood magnitudes conveys a false sense of accuracy and should be avoided. Because of the public's reliance on published peak flow estimates, they should only be changed when it is clear that an original error has been made and that continuing their use would not be in the public's interest.

5.4 Streets

5.4.1 Use of Streets

Streets are significant and important in urban drainage, and full use should be made of streets for storm runoff up to reasonable limits, recognizing that the primary purpose of streets is for traffic. Reasonable limits of the use of streets for transportation of storm runoff should be governed by reasonable design criteria as summarized in Table DP-1. Urban drainage design should have as objectives reduction of street repair, maintenance costs, nuisance to the public, and disruption of traffic flow.

Table DP-1—Reasonable Use of Streets for Initial Storm Runoff in Terms of Pavement Encroachment

Street Classification	Maximum Encroachment
Local	No curb overtopping. Flow may spread to crown of street.
Collector	No curb overtopping. Flow spread must leave at least one lane free of water.
Arterial	No curb overtopping. Flow spread must leave at least one lane free of water in each direction but should not flood more than two lanes in each direction.
Freeway	No encroachment is allowed on any traffic lanes.

When maximum allowed encroachment is present, the storm sewer system design based on the initial storm should commence. Development of a major drainage system that can often drain the initial runoff from the streets is encouraged, thus making the point at which the storm sewer system should commence further downstream. Initial and major drainage planning should go hand-in-hand.

While it is the intent of this policy to have major storm runoff removed from public streets at frequent and regular intervals and routed into major drainageways, it is recognized that water will often tend to follow streets and roadways and that streets and roadways often may be aligned so they will provide a specific runoff conveyance function. Planning and design objectives for the major drainage system with regard to public streets should be based upon following the limiting criteria summarized in Table DP-2.

Table DP-2—Major Storm Runoff Recommended Maximum Street Inundation

Street Classification	Maximum Depth and Inundated Areas
Local and Collector	Residential dwellings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of a building. The depth of water over the gutter flow line should not exceed 18 inches for local and 12 inches for collector streets.
Arterial and Freeway	Residential dwellings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of a building. The depth of water should not exceed the street crown to allow operation of emergency vehicles. The depth of water over the gutter flow line should not exceed 12 inches.

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The allowable flow across a street should be within the criteria presented in Table DP-3.

Table DP-3—Allowable Maximums for Cross-Street Flow

Street Classification	Initial Design Runoff	Major Design Runoff
Local	6 inches of depth in cross pan	18 inches of depth above gutter flow line
Collector	Where cross pans allowed, depth of flow should not exceed 6 inches	12 inches of depth above gutter flow line
Arterial/Freeway	None	No cross flow. 12 inches of maximum depth at upstream gutter or roadway edge

An arterial street crossing will generally require that a storm sewer system be commenced, unless the topography is such that day-lighted inlet culverts or other suitable means can transport the initial storm runoff under the arterial street or water can be routed to a major drainage facility. Bubblers (inverted siphons which convey flows beneath roadways) are not encouraged in the Denver region because of possible plugging with sediment and difficulty in maintaining them. Collector streets should have cross pans only at infrequent locations as specified by the governing agency and in accordance with good traffic engineering practices. The local street criteria for overtopping also apply to any private access road that serves commercial areas or more than one residence, for emergency access and safety reasons.

5.5 Irrigation Ditches

Irrigation ditches should not be used as outfall points for initial or major drainage systems, unless such use is shown to be without unreasonable hazard substantiated by adequate hydraulic engineering analysis and approval of the owner of the ditch.

5.5.1 Use of Ditches

The irrigation ditches coursing through urban areas are laid out on flat slopes and with limited carrying capacity. Based on experience and hydraulic calculations, irrigation ditches cannot, as a general rule, be used as an outfall point for the initial storm drainage system because of physical limitations. Exceptions to the rule can occur when the capacity of the irrigation ditch is adequate to carry the normal ditch flow plus the initial storm runoff with adequate freeboard to avoid creating a hazard to those below the ditch. Written approval must be obtained from the ditch owner stating that the owner understands the physical and legal (i.e., liability) consequences of accepting said runoff.

If there is a question about the use of irrigation ditches as outfalls for initial storm runoff, there is no question about their unsuitability as an outfall for the major storm runoff. Without major reworking of irrigation ditches to provide major carrying capacity without undue hazard to those downstream or below

the ditch, the ditches are almost always totally inadequate for such a use and should not be used as an outfall. Moreover, because ditches are normally privately owned, one cannot assume the perpetual existence or function of a ditch. Land planners downhill from a ditch should plan for pre-ditch drainage conditions as well as continued ditch seepage.

5.5.2 Ditch Perpetuation

Irrigation ditches are sometimes abandoned in urban areas after the agricultural land is no longer farmed. Provisions must be made for a ditch's perpetuation, defined as continued operation and serviceability, prior to its being chosen and used as an outfall for urban drainage.

5.5.3 Conformance With Master Plan

Use of irrigation ditches for collection and transport of either initial or major storm runoff should be prohibited unless specifically provided in a District's master plan or approved by the District and the ditch owner.

5.6 Detention and Retention Facilities Maintenance

The significant cost of handling stormwater runoff, coupled with the social benefits to be derived from proper storm drainage facilities, points towards the use of detention and retention basins for storage of stormwater runoff in the Denver region. Maintenance provisions must be arranged. Maintenance of detention or retention facilities includes the removal of debris, excessive vegetation from the embankment, and sediment. Without maintenance, a detention/retention facility will become an unsightly social liability and eventually become ineffective.

5.6.1 Water Quality

Detention and retention facilities provide an opportunity to improve the quality of stormwater runoff before it reaches streams. Water quality BMPs will add an additional level of maintenance obligation because they are designed to remove, among other things, solid constituents from urban runoff.

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Photograph DP-5—Detention basins with permanent ponding help in many ways, including flood reduction, water quality and land values.

6.0 FLOODPLAIN MANAGEMENT

6.1 Purpose

Various governmental agencies within the Denver region should initiate floodplain management programs. Floodplain management includes comprehensive criteria designed to encourage, where necessary, the adoption of permanent state or local measures which will lessen exposure of property and facilities to flood losses, improve long-range land management and use of flood-prone areas, and inhibit, to the maximum extent feasible, unplanned future development in such areas.

6.2 Goals

There are two goals in regard to floodplain management:

- *To reduce the vulnerability of Denver region residents to the danger and damage of floods.*

  The dangers of flooding include threats to life, safety, public health, and mental well being, as well as damage to properties and infrastructure and disruption of the economy. Protection from these hazards should be provided, by whatever measures are suitable, for floods having a one percent reoccurrence probability in any given year (100-year floods), at a minimum, based on projected build-out in the watershed. Protection from the effects of greater, less frequent flooding is also needed in those places where such flooding would cause unacceptable or catastrophic damages.

- *To preserve and enhance the natural values of the region's floodplains.*

  Natural floodplains serve society by providing floodwater storage, groundwater recharge, water quality enhancement, aesthetic pleasure, and habitat for plants and animals. Many floodplains also have cultural and historical significance. It is in the public's interest to avoid development that destroys these values or, in instances where the public good requires development, to assure that measures are taken to mitigate the loss through replacement or other means.

These two goals are reconcilable and achievable through appropriate management shared by the agencies involved.

6.3 National Flood Insurance Program

Flood insurance should be an integral part of a strategy to manage flood losses. The cities and counties in the Denver region are encouraged to continue to participate in the federal flood insurance program set forth in the NFIA of 1968, as amended.

6.3.1 Participation

A prerequisite for participation is the adoption of a floodplain management program by the local government that, where necessary, includes adoption of permanent state or local regulatory measures

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that will lessen the exposure of property and facilities to flood losses. Property owners should be encouraged to buy flood insurance, even outside the designated floodplain, to protect against local flooding where such potential exists.

6.4 Floodplain Management

The objectives of floodplain management are:

a. To adopt effective floodplain regulations.

b. To improve local land use practices, programs, and regulations in flood-prone areas.

c. To provide a balanced program of measures to reduce losses from flooding.

d. To reduce the need for reliance on local and federal disaster relief programs.

e. To minimize adverse water quality impacts.

f. To foster the creation/preservation of greenbelts, with associated wildlife and other ecological benefits, in urban areas.

Floodplain management practices must be implemented to be of value. Although hydrologic data are critical to the development of a floodplain management program, the program is largely dependent on a series of policy, planning, and design decisions. These decisions are essentially political, economic, and social in character and are developed on a geographic scale extending beyond the floodplain itself. These area-wide decisions provide the setting for floodplain usage and, when combined with hydrologic considerations and augmented by both administrative and implementing devices, constitute the floodplain management program. The program must give high priority to both flood danger and public programs, such as urban renewal, open space, etc.

6.5 Floodplain Filling

While floodplain management includes some utilization of the flood fringe (i.e., areas outside of the formal floodway), the planner and engineer should proceed cautiously when planning facilities on lands below the expected elevation of the 100-year flood. Flood peaks from urbanized watersheds are high and short-lived, which makes storage in the flood fringe important and effective. Filling the flood fringe tends to increase downstream peaks.

6.6 New Development

The decision as to whether or not a major flood control measure should be undertaken to permit intensive new urbanization or to maintain an open area within an urban floodplain or any intermediate use should be made on the basis of:

a. Relative costs of the respective alternatives (not only financial, but also non-financial economic costs such as opportunities foregone).

b. The opportunities for flood proofing and other measures in relation to the extent of flood hazard.

c. The availability of lands in non-floodplain areas for needed development.

d. The location of the high flood hazard areas, namely, defined floodways.

e. The potential adverse effect on others in or adjacent to the floodplain.

f. The fact that floods larger than the design flood will occur (i.e., exposure will still exist, even with well-designed facilities, for the one percent flood).

6.7 Strategies and Tools

The strategies and tools available to the drainage engineer for floodplain management are numerous and varied. The following menu is meant to be a list of strategies and tools available for floodplain management, but it should not be considered to be limiting (FEMA 1995).

6.7.1 Exposure to Floods

Reduce exposure to floods and disruptions by employing floodplain regulations and local regulations. The latter would include zoning, subdivision regulations, building codes, sanitary and well codes, and disclosure to property buyers.

6.7.2 Development Policies

Development policies include design and location of utility services, land acquisition, redevelopment, and permanent evacuation (purchase of properties).

6.7.3 Preparedness

Disaster preparedness is an important tool for safeguarding lives and property, and disaster assistance will reduce the impact to citizens from flooding.

6.7.4 Flood Proofing

Flood proofing of buildings is a technique that is wise and prudent where existing buildings are subject to flooding. Flood proofing can help a proposed project achieve a better benefit-cost ratio.

6.7.5 Flood Forecasting

Flood forecasting and early warning systems are important means to reduce flood losses, safeguard health, protect against loss of life and generally provide an opportunity for people to prepare for a flood event before it strikes.

6.7.6 Flood Modification

The use of methods to modify the severity of the flood is a floodplain management tool. These include

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regional detention, channelization, minimizing directly connected impervious area, and on-site detention.

6.7.7 Impact of Modification

Using education, flood insurance, tax adjustments, emergency measures, and a good post-flood recovery plan that can be initiated immediately can modify the impact of flooding.

7.0 IMPLEMENTATION

7.1 Adoption of Drainage Master Plans

This *Manual* and master plans should be adopted and used by all governmental agencies operating within the District.

7.1.1 Manual Potential

From a broad perspective, this *Manual* on drainage disseminated by the District will have the potential to:

a. Give direction to public agency efforts to guide private decisions.

b. Give direction to public agency efforts to regulate private decisions.

c. Provide a framework for a public agency when it seeks to guide other public agencies.

d. Provide a framework to assist in coordinating the range of public and private activities.

e. Provide direction for development of master plans and designs and for implementation of drainage facilities.

7.2 Governmental Operations

Each level of government must participate if a drainage program is to be successful.

7.3 Amendments

Problems in urban drainage administration encountered by any governmental agency should be reviewed by the District to determine if equity or public interests indicate a need for drainage policy, practice, or procedural amendments. The District should continually review the needs of the Denver region in regard to urban runoff criteria and should recommend changes as necessary to this *Manual*.

7.4 Financing

Financing storm drainage improvements is fundamentally the responsibility of the affected property owners (both the persons directly affected by the water and the person from whose land the water flows) and the local governing body.

7.4.1 Drainage Costs

Every effort should be made to keep the cost of drainage solutions reasonable. This will involve careful balancing of storage and conveyance costs and the integration of drainage with other activities such as open space and transportation efforts. Funding must be established, and budgets should be prepared to assure proper maintenance of all new drainage and storage facilities.

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DRAINAGE LAW

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Photographs

Photograph DL-1—Using a natural floodplain, even with a wetland involved, represents sound engineering in concert with established Colorado drainage law. 1

1.0 SUMMARY OF CURRENT GENERAL PRINCIPLES OF DRAINAGE AND FLOOD CONTROL LAW

1.1 Introduction

Drainage law not only has its basis in law made by the courts and the legislature, but also relies to a large extent on the drainage facts that exist in each case. Therefore, a party with the most reliable facts and information will have a distinct advantage in court. Similarly, drainage engineering and design revolves around drainage law as well as the natural laws of gravity.

This chapter deals with the general principles of drainage law along with local government drainage actions, financing, floodplain management, and special matters. This chapter is meant to provide an outline of the general principles of Colorado drainage law for the engineer and agency official. It is not meant to serve as a substitute for a lawyer's opinions, though this chapter may be of interest to practicing attorneys.

In using this chapter of the *Manual*, the reader should be familiar with the entire *Manual*, and should pay particular attention to the POLICY and PLANNING chapters. In the POLICY chapter, 12 principles have been stated, with which the reader of this chapter should be familiar. Similarly, the following legal principles are summarized below for ready reference.



Photograph DL-1—Using a natural floodplain, even with a wetland involved, represents sound engineering in concert with established Colorado drainage law.

1.2 Legal Principles

1. The owner of upstream property possesses a natural easement on land downstream for drainage of surface water flowing in its natural course. The upstream property owner may alter drainage

conditions so long as the water is not sent down in a manner or quantity to do more harm to the downstream land than formerly. Bittersweet Farms, Inc. v. Zimbelman, 976 P.2d 326 (Colo. App. 1998).

2. For purposes of determining liability in a negligence action, the duty of a public entity shall be determined in the same manner as if it were a private party. Leake v. Cain, 720 P.2d 152 (Colo. 1986).

3. A natural watercourse may be used as a conduit or outlet for the drainage of lands, at least where the augmented flow will not tax the stream beyond its capacity and cause flooding of adjacent lands. Ambrosio v. Pearl-Mack Construction Co., 351 P.2d 803 (Colo. 1960).

4. Ditch corporations that own ditches owe a duty to those property owners through which their ditches pass to maintain their ditches using ordinary care so as to prevent damage to adjoining real property. Oliver v. Amity Mut. Irrigation Co., 994 P.2d 495 (Colo. App. 1999).

5. Construction or enlargement of jurisdictional dams or reservoirs is subject to approval by the Colorado State Engineer, which includes consideration of requiring their spillways to be capable of passing the inflow design flood generated by 100 percent of the probable maximum precipitation. A "jurisdictional dam" is defined as a dam that impounds water above the elevation of the natural surface of the ground creating a reservoir with a capacity of more than 100 acre-feet or creating a reservoir with a surface area exceeding 20 acres at the high waterline or exceeding 10 feet in height measured vertically from the elevation of the lowest point of the natural surface of the ground where that point occurs along the longitudinal centerline of the dam up to the flow line crest of the emergency spillway of the dam. Rules 4 & 5 of the Department of Natural Resources, Division of Water Resources, Office of the State Engineer, Rules and Regulations for Dam Safety and Dam Construction.

6. The boundaries of the floodplain should be accurately determined and based on a reasonable standard. Mallett v. Mamarooneck, 125 N.E. 2d 875 (N.Y. 1955).

7. Adoption of a floodplain regulation to regulate flood-prone areas is a valid exercise of police power and is not a taking as long as the regulation does not go beyond protection of the public's health, safety, morals, and welfare. Hermanson v. Board of County Commissioners of Fremont, 595 P.2d 694 (Colo. App. 1979).

8. The adoption by a municipality of floodplain ordinances to regulate flood-prone areas is a valid exercise of police power and is not a taking. Morrison v. City of Aurora, 745 P.2d 1042 (Colo. App. 1987).

9. A zoning ordinance is not unconstitutional because it prohibits a landowner from using or developing

his land in the most profitable manner. It is not required that a landowner be permitted to make the best, maximum or most profitable use of his property. Baum v. City and County of Denver, 363 P.2d 688 (Colo. 1961) and Sundheim v. Board of County Commissioners of Douglas County, 904 P.2d 1337 (Colo. App. 1995).

10. The safest approach to avoiding liability in regard to drainage and flood control improvements is to assume that the defense of a design error will not protect a governmental entity from a lawsuit and liability for injury to property or person. Scott v. City of Greeley, 931 P.2d 525 (Colo. App. 1996) and 24-10-106 (1)(e) and (f) C.R.S.

11. A "dangerous condition" constitutes an unreasonable risk to the health or safety of the public, which is known to exist or which in the exercise of reasonable care should have been known to exist and which condition is proximately caused by the negligent act or omission of the public entity in constructing or maintaining such facility. 24-10-103 C.R.S.

12. Under the Colorado Governmental Immunity Act (CGIA), a drainage and flood control facility is considered to be a "sanitation facility" and thus not protected by the defense that the facility caused damage solely because the design of the facility was inadequate. 24-10-106 (f) and 24-10-103 C.R.S. and Burnworth v. Adams County, 826 P.2d 368 (Colo. App. 1991).

13. Under the CGIA, a governmental entity will be liable for the negligent operation and maintenance of any drainage and flood control facility. 24-10-106 (f) and 24-10-103 C.R.S. and Burnworth v. Adams County, 826 P.2d 368 (Colo. App. 1991).

14. Under the CGIA, a governmental entity will not be liable for its failure to upgrade, modernize, modify, or improve the design or construction of a drainage or flood control facility. 24-10-103 (1) C.R.S.

15. In imposing conditions upon the granting of land-use approvals, no local government shall require an owner of private property to dedicate real property to the public or pay money to a public entity in an amount that is determined on an individual and discretionary basis, unless there is an essential nexus between the dedication or payment and a legitimate local government interest and the dedication or payment is roughly proportional both in nature and extent to the impact of the proposed use or development of such property. This law does not apply to any legislatively formulated assessment, fee, or charge that is imposed on a broad class of property owners by a local government. 29-20-203 C.R.S.

16. Public entities that own dams or reservoirs are not subject to strict liability for damages caused by water escaping from their dams or reservoirs. Further, those public entities have no duty to ensure that waters released from an upstream reservoir because of a dam failure would be contained by

their facilities or would bypass those facilities without augmentation. Kane v. Town of Estes Park, 786 P.2d 412 (Colo. 1990).

17. A professional engineer is required not only to serve the interests of his or her employer/client but is also required, as his or her primary obligation, to protect the safety, health, property, and welfare of the public. Rule I 2. of The Colorado Rules of Professional Conduct of the State Board of Registration for Professional Engineers and Professional Land Surveyors.

18. Where a municipality imposes a special fee upon owners of property for purposes of providing a service and where the fee is reasonably designed to defray the cost of the service provided by the municipality, such a fee is a valid form of governmental charge within the legislative authority of the municipality. Bloom v. City of Fort Collins, 784 P.2d 304 (Colo. 1989).

2.0 GENERAL PRINCIPLES OF DRAINAGE LAW

> Very little is gained if the same act which dries up one tract of land renders the adjoining tract twice as difficult to redeem.
>
> Livingston v. McDonald, 21 Iowa 160, 170 (1866).

2.1 Private Liability

Traditionally, courts have analyzed the legal relations between parties in drainage matters in terms of such property concepts as natural easements, rights, privileges, and servitudes but have based liability for interfering with surface waters on tort principles. See Kenyon and McClure *Interferences With Surface Waters*, 24 Minn. L. Rev. 891 (1940). Drainage and flood control problems attendant with increased urbanization, the trend in tort law toward shifting the burden of a loss to the best risk-bearer, and complete or partial abolition of governmental immunity by the judiciary or the legislature will continue to change the traditional rules that have governed legal relations between parties in drainage matters. These changes are reflected in the three basic rules relating to drainage of surface waters that have been applied over a period of time in the United States: the common enemy rule, the civil law rule (later to be called a "modified civil law rule"), and the reasonable use rule.

2.1.1 Common Enemy Rule

Under the common enemy rule, which is also referred to as the common law rule, surface water is regarded as a common enemy, which each property owner may fight off or control as he or she will or is able, either by retention, diversion, repulsion, or altered transmission. Thus, there is no cause of action even if some injury occurs. All jurisdictions originally following this harsh rule have either modified the rule or adopted the civil law rule or reasonable use rule. 5 *Water and Water Rights*, §§450.6, 451.2 (R.E. Clark ed. 1972).

2.1.2 Civil Law Rule

The civil law rule, or natural flow rule, places a natural easement or servitude upon the lower land for the drainage of surface water in its natural course, and the natural flow of the water cannot be obstructed by the servient owner to the detriment of the dominant owner. 5 *Water and Water Rights*, §452.2A (R.E. Clark ed. 1972). Most states following this rule, including Colorado, have modified the rule. Under the modified rule, the owner of upper lands has an easement over lower lands for drainage of surface waters, and natural drainage conditions can be altered by an upper proprietor provided the water is not sent down in a manner or quantity to do more harm than formerly. Hankins v. Borland, 163 Colo. 575, 431 P.2d 1007 (1967); H. Gordon Howard v. Cactus Hill Ranch Company, 529 P.2d 660 (1974); Hoff v. Ehrlich, 511 P.2d 523 (1973); but see Ambrosio v. Perl-Mack Construction Company, 143 Colo. 49, 351 P.2d 803 (1960) and Bittersweet Farms, Inc. v. Zimbelman, 976 P.2d 326 (Colo. App. 1998).

2.1.3 Reasonable Use Rule

Under the reasonable use rule, each property owner can legally make reasonable use of his land, even though the flow of surface waters is altered thereby and causes some harm to others. However, liability attaches when the harmful interference with the flow of surface water is "unreasonable." Whether a landowner's use is unreasonable is determined by a nuisance-type balancing test. The analysis involves three inquiries:

1. Was there reasonable necessity for the actor to alter the drainage to make use of his or her land?
2. Was the alteration done in a reasonable manner?
3. Does the utility of the actor's conduct reasonably outweigh the gravity of harm to others?

Restatement Torts, §§822-831, 833 (1939); *Restatement (Second) Torts*, §158, Illustration 5. Alaska, Hawaii, Kentucky, Massachusetts, Minnesota, New Hampshire, New Jersey, North Carolina, North Dakota, Ohio and Utah have adopted this rule. Some states have restricted their application of the rule to urban areas (South Dakota and Texas). In Pendegast v. Aiken, 236 S.E. 2d 787 (1977), the North Carolina Supreme Court traces the common law rule to the civil law rule to adoption by that court of the reasonable use rule, starting at page 793:

> It is no longer simply a matter of balancing the interests of individual landowners; the interests of society must be considered. On the whole the rigid solutions offered by the common enemy and civil law rules no longer provide an adequate vehicle by which drainage problems may be properly resolved.

2.2 Municipal Liability

A municipality is generally treated like a private party in drainage matters. Harbison v. City of Hillsboro, 103 Ore. 257, 204 P. 613, 618 (1922); City of Golden v. Western Lumber and Pole Company, 60 Colo. 382, 154 P. 95 (1916) (a municipality undertaking a public improvement is liable like an individual for damage resulting from negligence or an omission of duty); City of Denver v. Rhodes, 9 Colo. 554, 13 P. 729 (1887). In the case of municipalities, however, the distinction between unlawful collection, diversion, or concentration of surface waters and lawful improvement is not always clear, particularly as the pace and extent of urbanization increases. City of Englewood v. Linkenheil, 146 Colo. 493, 362 P.2d 185 (1961); Aicher v. Denver, 10 Colo. App. 413, 52 P. 86 (1897).

Governmental entities are subject to the same civil law rule applied to a private party. In Metro Docheff v. City of Broomfield, 623 P.2d 69 (Colo. App. 1980), the court found that the city had accepted the streets and storm drains in a subdivision for maintenance and control and, therefore, had exclusive control over the water collected in the subdivision. The court determined that, by approving the subdivision and drainage plan and accepting control, the city interfered with the natural conditions and thereby caused

surface water to be collected and discharged upon the plaintiff's land "in greater quantity or in a different manner than had previously occurred under natural conditions." The court found that the discharge of drainage water under the circumstances of the case constituted an enjoinable trespass.

2.2.1 Planning Drainage Improvements

As a general rule, municipalities are under no legal duty to construct drainage improvements unless public improvements necessitate drainage—as in those situations in which street grading and paving or construction of schools accelerates or alters storm runoff. Denver v. Mason, 88 Colo. 294, 295 P. 788 (1931); Denver v. Capelli, 4 Colo. 25, 34 Am. Rep. 62 (1877); Daniels v. City of Denver, 2 Colo. 669 (1875). This is because statutory provisions authorizing municipal drainage improvements and flood control are generally written in non-mandatory language. Thus, absent mandatory statutory language imposing a duty on municipalities or judicial imposition of an implied duty to avoid or abate injuries, municipalities are not liable for failing to provide drainage or flood control.

In Colorado, governmental immunity has been partially waived and the governmental-proprietary distinction has been abolished. 24-10-101 C.R.S. As a result, Colorado municipalities may be exposed to liability in the future for adoption or selection of defective plans or designs for drainage. Although 24-10-103 (1) C.R.S. provides that a "dangerous condition" for which a governmental entity will be liable does not include that caused by the inadequate design of a facility, it is still unclear whether that liability exemption applies to drainage and flood control facilities.

In Scott v. City of Greeley, 931 P.2d 525 (Colo. App. 1996) the court found that the city formulated a comprehensive drainage plan which called for placement of a 42-inch storm sewer line throughout the length of the street adjacent to the property of the plaintiff and down to the river. The city placed a 42-inch pipe under a section of the street. However, the sewer renovation did not extend to the river, and the 42-inch line was instead connected to the pre-existing 15-inch line at a junction near the plaintiff's property. The plaintiff's property suffered flooding several times. The city argued that the damages that the plaintiff suffered were a result of a "design flaw" and thus immunity would apply. However, the court found the plaintiff's property was damaged not as a result of any inadequacy of the plan but rather from the city having departed from it in temporally connecting the new larger pipe to the existing 15-inch pipe.

On the basis of the Scott case, two things are clear. First, once a plan is in place, it should be followed. Second, drainage improvements should be constructed from the downstream end upstream to avoid creating flows that violate the civil law rule, or special arrangements should be made to keep potential flow damage from increasing downstream of the work. One possible exception to this general rule is the construction of detention facilities, which actually reduce the potential for downstream damages.

However, the Scott case also raises the question of whether the defense that the design of a drainage and flood control improvement caused the alleged damage will convey immunity to a governmental entity.

The court in Scott raises the question but fails to answer it. The confusion arises because of two provisions of the CGIA:

> 24-10-106 (1)(e) C.R.S.: A dangerous condition of any...sanitation facility
>
> and
>
> 24-10-106 (1)(f) C.R.S.: The operation and maintenance of any public water facility, . . . sanitation facility,...by such public entity.

Section (f) does not include the defense of a design error, but Section (e) does. A Colorado court has yet to answer the question raised by the Scott case. Therefore, based upon the state of the law, the safest approach to liability in regard to drainage and flood control improvements is to assume that the defense of a design error will not protect a governmental entity from a lawsuit for injury to property or person. Thus, the legal principles of negligence will apply to the actions of a governmental entity in designing, constructing and maintaining a drainage and flood control improvement. Thus, in order to establish a case of negligence, the following must be proved: (1) the existence of a legal duty owed by the defendant to the plaintiff; (2) a breach of that duty; (3) injury to the plaintiff; and (4) a causal relationship between the breach and the injury.

2.2.2 Construction, Maintenance, and Repair of Drainage Improvements

Municipalities can be held liable for negligent construction of drainage improvements. McCord v. City of Pueblo, 5 Colo. App. 48, 36 P. 1109 (1894); Denver v. Rhodes, 9 Colo. 554, 13 P. 729 (1887); Denver v. Capelli, 4 Colo. 25, 34 Am. Rep. 62 (1877); (as well as for negligent maintenance and repair of drainage improvements) Malvernia v. City of Trinidad, 123 Colo. 394, 229 P.2d 945 (1951); Denver v. Mason, 88 Colo. 294, 295 P. 788 (1931).

In addition to negligence, other legal theories have been used to impose liability on municipalities for faulty construction and maintenance of drainage improvements. Thus, a municipality may incur liability for trespass, Barberton v. Miksch, 128 Ohio St. 169, 190 N.E. 387 (1934) (casting water upon the land of another by seepage or percolation resulting from construction and maintenance of a reservoir was a trespass by the municipality); an unconstitutional taking, Mosley v. City of Lorain, 43 Ohio St. 2d 334, 358 N.E. 2d 596 (1976) (the city had effectively appropriated the plaintiff's property by constructing a storm sewer system which channeled a greater volume of water into the creek than the creek could reasonably be expected to handle without flooding); taking, Lucas v. Carney, 167 Ohio St. 416, 149 N.E. 2d (1958) (construction of a public improvement on county property, which greatly increased the amount and force of surface water which flowed onto the plaintiff's property, overflowing and inundating it, raised a claim of pro tanto appropriation); or nuisance, Mansfield v. Bolleet, 65 Ohio St. 451, 63 N.E. 8.6 (1902) (a municipality is liable if it causes drainage to be emptied into a natural watercourse and substantially damages a downstream landowner). Even in the absence of negligence, nuisance, trespass, or taking,

the evolving doctrine of inverse condemnation is being used to permit landowners to obtain compensation from a municipality where storm runoff from municipal projects is diverted across another's land on the theory that the city has taken a drainage easement. Thus, like an easement for noise emanating from the municipal airport, physical entry by the governmental entity or statutory allowance of compensatory damages is not required in order for landowners to recover damages.

In several Colorado cases, however, municipalities have not incurred liability for faulty construction where they are found to be upstream proprietors with a natural easement for drainage—even when water is sent down in a manner or quantity to do more harm than formerly. City of Englewood v. Linkenheil, 362 P.2d 186 (1961) (the city's action in channeling water by a system of drains, catch basins, intakes, and pipes, from a higher place to a place contiguous to the land of the plaintiff, which was a natural drainage area, so as to overflow onto the land of plaintiff did not constitute a taking of property without just compensation); City and County of Denver v. Stanley Aviation Corporation, 143 Colo. 182, 352 P.2d 291 (1960) (plaintiff could not recover from the city for damage caused by flood waters which backed onto lower land on its theory that the city had been negligent or failed to use due care in installing a pipe adequate to carry the waters); Aicher v. Denver, 10 Colo. App. 413, 52 P. 86 (1897) (the city was not found liable for damage where street grade was changed, trolley tracks were permitted in a street, and a culvert was built too small, but the landowner was declared to be in the unfortunate position of having built below the grade of the street).

The CGIA provides in 24-10-103 (1) C.R.S. that maintenance does not include any duty to upgrade, modernize, modify, or improve the design or construction of a facility. Therefore, a governmental entity, under this statute, would not be found to have failed to maintain a facility if it failed to perform one or more of these enumerated actions. However, if a governmental entity fails to maintain a facility other than the excluded enumerated actions above, such failure could subject that entity to a claim that such failure was negligent, and such entity would not be protected by the CGIA.

2.2.3 Summary

In general, in the absence of negligence, a municipality will not be held liable for increased runoff occasioned by the necessary and desirable construction of drains and sewers. Denver v. Rhodes, 9 Colo. 554, 13 P. 729 (1887). Nor will a municipality be held liable for damages caused by overflow of its sewers or drains occasioned by extraordinary, unforeseeable rains or floods. 18 McQuillan, *Municipal Corporations*, §53.124 (3rd ed. 1971).

Municipal liability will attach, however, where a municipality:

1. Collects surface water and casts it in a body onto private property where it did not formerly flow.

2. Diverts, by means of artificial drains, surface water from the course it would otherwise have taken and casts it in a body large enough to do substantial injury on private land, where, but for the artificial drain, it would not go.

3. Fills up, dams back, or otherwise diverts a stream of running water so that it overflows its banks and flows on the land of another. A municipality is also liable if it fails to provide a proper outlet for drainage improvements constructed to divert surface waters or if it fails to exercise ordinary care in the maintenance and repair of drainage improvements.

This latter liability attaches when it is determined that a municipality has not exercised a reasonable degree of watchfulness in ascertaining the condition of a drainage system to prevent deterioration or obstruction. 13 McQuillan, *Municipal Corporations*, §37.254 (3rd ed. 1971). See, also, Malvernia v. City of Trinidad, 123 Colo. 394, 229 P.2d 945 (1951).

Thus, the best rule to follow in planning for the construction of drainage improvements, whether following the natural watercourse or artificially draining surface water, is that a municipality is liable if it actively injures private property as a result of improvements made to handle surface water. A municipality in Colorado appears to be in a much stronger position if it can establish that the improvement followed natural drainage patterns. Drainage District v. Auckland, 83 Colo. 510, 267 P. 605 (1928); City of Englewood v. Linkenheil, 362 P.2d 186 4961); City of Boulder v. Boulder and White Rock Ditch and Reservoir Company, 73 Colo. 426, 216 P. 553 (1923). See Kenworthy, "Urban Drainage: Aspects of Public and Private Liability," July-August 1962, *DICTA*, p. 197; Shoemaker, "An Engineering-Legal Solution to Urban Drainage Problems," 45 *Denver Law Journal* 381 (1968).

2.3 Municipal Liability for Acts of Others

2.3.1 Acts or Omissions of Municipal Officers, Agents, or Employees

The general rule is that a municipality is not liable under the doctrine of respondent superior for the acts of officers, agents, or employees that are governmental in nature but is liable for negligent acts of its agents in the performance of duties relating to proprietary or private corporate purposes of the city. Denver v. Madison, 142 Colo. 1, 351 P.2d 826 (1960). The construction, maintenance and repair of drainage improvements have been regarded as proprietary or corporate functions. Denver v. Maurer, 47 Colo. 209, 106 P. 875 (1910). Although the governmental-proprietary distinction has been abolished by statute in Colorado, the distinction apparently still applies whenever the injury arises from the act, or failure to act, of a public employee who would be, "or heretofore has been personally immune from liability." 24-10-106 C.R.S. Thus, a municipality may be held liable for the acts of its officers, agents or employees for injuries resulting from negligent construction, maintenance, or dangerous conditions of a public facility. 24-10-106 (l)(e), (l)(f) C.R.S. However, it is not clear whether in Colorado liability attaches or, conversely, whether the defense of governmental immunity applies, to the adoption, selection, or

approval of a defective plan or design. The governmental immunity statute provides for a waiver of governmental immunity when injuries result from the operation and maintenance or dangerous condition of a public facility. 24-10-106 (l)(e), (l)(f) C.R.S. The statute also states that "a dangerous condition shall not exist solely because the design of any facility…, is inadequate in relation to its present use." 24-10-103 (1) C.R.S. Since the distinction between construction and design is often vague, it is difficult to predict how the Colorado courts will approach municipal liability for injuries resulting from adoption, selection, or approval of a defective plan or design by municipal officers, agents, or employees.

In three cases considered by the Colorado Court of Appeals since the enactment of the CGIA [Burnworth v. Adams County, 826 P.2d 368 (Colo. App. 1991); Scott v. City of Greeley, 931 P.2d 525 (Colo. App. 1996); and Smith v. Town of Estes Park, 944 P.2d 571 (Colo. App. 1996)], when the court was faced with the questions of whether the damage was caused by a design error or the operation and maintenance of a drainage or flood control facility, the court found that the damage was caused by the operation and maintenance of the facility. Therefore, the governmental entity had no immunity and was treated as a private citizen in regard to its negligence.

Before an individual can recover damages from a public entity for injuries caused by the public entity or one of its employees, the CGIA requires written notice to the public entity involved within 180 days after the date of discovery of the injury. Otherwise, failure to notify is a complete defense to a personal injury action against a municipality. 24-10-109 C.R.S. Kristensen v. Jones, 575 F.2d 854 (1978).

2.3.2 Municipal Liability for Acts of Developers

Unless an ordinance or statute imposes a duty on a municipality to prevent or protect land from surface water drainage, a municipality will not incur liability for wrongfully issuing building permits, failing to enforce an ordinance, or approving defective subdivision plans. Breiner v. C & P Homebuilder's Inc., 536 F.2d 27 (3rd Cir. 1976), reversing the District Court. (In a suit by landowners in an adjacent township against a borough, its engineers, and subdivision developer for damages caused by increased flow of surface water from development where the borough approved a subdivision plan which did not provide drainage facilities and issued building permits, the borough was not liable because it owed no duty to landowners outside its boundaries. However, the developer was held liable.)

One state court, however, has held that a municipality is liable for damages where the municipality has furnished building permits to a contractor for development of an industrial complex which benefited the village financially but also diminished surface area available for drainage of water, causing flooding of neighboring servient estates. Myotte v. Village of Mayfield, 375 N.E.2d 816 (1977). In Myotte, the village's liability was based on the following reasoning:

> To require the developer to pick up the cost of flood prevention by requiring him to acquire land along stream margins for widening or deepening to accommodate accelerated flow, would subject him to possible overreaching by riparian owners. The

> developer has no power of eminent domain. Municipalities do have powers of condemnation. Accordingly, as an advantaged party with the power to protect itself from crisis pricing, it seems reasonable and just that the municipality should either enlarge the stream to accommodate water accelerated from permitted improvements that enrich it or pay the consequences.
>
> Myotte, supra at 820. (Day, J. concurring.). See also, Armstrong v. Francis Corporation, 20 N.J. 320, 120 A.2d 4 (1956); Sheffet v. County of Los Angeles, 3 Cal. App. 3d 720 (1970); Powers, et al., County of Clark and Clark County Flood Control District, District Court, State of Nevada (No. A 125197) (1978).

There is a trend toward imposing a greater burden or responsibility on municipalities for the drainage consequences of urban development. See Wood Brothers Homes, Inc. v. City of Colorado Springs, 568 P.2d 487 (1977) (where the city abused its discretion by not granting variance and by assessing the entire cost of a major drainage channel on the developer, where the area to be served by the major drainage channel already suffered from occasional flooding and needed an expanded drainage facility whether the property was developed or not).

2.4 Personal Liability of Municipal Officers, Agents, and Employees

An injured person always has a remedy against the original tort feasor even if no recovery may be had from the municipality for acts of its officers, agents, or employees in discharge of governmental functions. Denver v. Madison, 142 Colo. 1, 351 P.2d 826 (1960). Thus, public employees generally have been personally liable for injuries caused by their negligent actions within the scope of employment, even when the defense of sovereign immunity was available to their employers. Antonpoulos v. Town of Telluride, 187 Colo. 392, 532 P.2d 346 (1975); Liber v. Flor, 143 Colo. 205, 353 P.2d 590 (1960). Since an injured person's right to sue the negligent employee of an immune entity derives from the common law, the Colorado Supreme Court will not infer legislative abrogation of that right absent clear legislative intent. Thus, the CGIA is only directed toward liability of public entities. Kristensen v. Jones, 574 P.2d 854 (1978) (a bus driver for the regional transportation district was found personally liable for injuries sustained in a collision with the district's bus, and written notice was not a condition precedent to a suit against a public employee in his or her individual capacity).

The CGIA provides both for the defense of any governmental employee who is sued individually as a result of the employee's acts during the performance of his or her duties as well as the payment of any judgment or settlement. The act provides in part that a public entity shall be liable for the payment of all judgments and settlements of claims against any of its public employees where the claim against the public employee arises out of injuries sustained from an act or omission of such employee occurring during the performance of his or her duties and within the scope of employment, except where such act or omission is willful and wanton or where sovereign immunity bars the action against the public entity (24-10-110 [b][I] C.R.S.).

Therefore, it is possible for an employee to be personally liable for a negligent act and the public entity to escape liability. Such a situation would arise when the claimant fails to give proper notice to the public entity, thus providing that entity with the defense of lack of jurisdiction against it. However, the public employee would have no such defense.

3.0 DRAINAGE IMPROVEMENTS BY A LOCAL GOVERNMENT

> In an era of increasing urbanization and suburbanization, drainage of surface water most often becomes a subordinate feature of the more general problem of proper land use—a problem acutely sensitive to social change.
>
> Pendergast v. Arkin, 236 S.E. 2d 787, 796 N. Carolina.

3.1 Constitutional Power

A municipality's inherent police powers enable it to enact ordinances that serve the public's health, safety, morals, or general welfare. Ordinances addressing drainage problems are clearly a proper exercise of a municipality's police powers. Wood Brother's Homes, Inc. v. City of Colorado Springs, 568 P.2d 487, 490 (1977). Hutchinson v. Valdosta, 227 U.S. 303, 308 (1913).

3.2 Statutory Power

3.2.1 Statutes—Municipalities

3.2.1.1 Municipal Powers—Public Property and Improvements

31-15-701, 31-15-714 C.R.S. The statute grants municipalities the power to establish, improve, and regulate such improvements as streets and sidewalks, water and water works, sewers and sewer systems, and water pollution controls. In addition, a municipality may, among other powers, "deepen, widen, cover, wall, alter or change the channel of watercourses." 31-15-711 (1) (a) C.R.S.

3.2.1.2 Public Improvements—Special Improvement Districts in Municipalities

31-25-501, 31-25-540 C.R.S. The statute authorizes municipalities to construct local improvements and assess the cost of the improvements wholly or in part upon property specially benefited by such improvements. By ordinance, a municipality may order construction of district sewers for storm drainage in districts called storm sewer districts.

3.2.1.3 Public Improvements—Improvement Districts in Municipalities

31-25-601, 31-25-630 C.R.S. The statute authorizes municipalities to establish improvement districts as taxing units for the purpose of constructing or installing public improvements. The organization of districts is initiated by a petition filed by a majority of registered electors of the municipality who own real or personal property in the district.

3.2.1.4 Sewer and Water Systems—Municipalities

31-35-401, 31-35-417 C.R.S. The statute authorizes municipalities to operate, maintain, and finance water and sewage facilities for the benefit of users within and without their territorial boundaries. Sewerage facilities are defined as "any one or more of the various devices used in the collection, treatment, or disposition of sewage or industrial wastes of a liquid nature or storm, flood, or surface drainage waters...." 31-35-491(6) C.R.S.

3.2.2 Statutes—County

3.2.2.1 Public Improvements—Sewer and Water Systems

30-20-401, 30-20-422 C.R.S. The statute authorizes county construction, maintenance, improvement and financing of water and sewerage facilities for the county's own use and for the use of the public and private consumers and users within and without the county's territorial limits.

3.2.2.2 County Public Improvement Districts

30-20-501, 30-20-531 C.R.S. The statute authorizes creation of public improvement districts within any county as taxing units for purposes of constructing, installing, or acquiring any public improvement. 30-20-513 C.R.S. lists special benefits for purposes of assessing improvements within a public improvement district, particularly with respect to storm sewer drainage and drainage improvements to carry off surface waters.

3.2.2.3 Public Improvements—Local Improvement Districts—Counties

30-20-601, 30-20-626 C.R.S. The statute authorizes a county by resolution to construct local improvements and assess costs thereof wholly or in part upon property specially benefited by such improvements.

3.2.2.4 Flood Control—Control of Stream Flow

30-30-101, 30-28-105 C.R.S. The statute authorizes the board of county commissioners of each county for flood control purposes only:

> ...to remove or cause to be removed any obstruction to the channel of any natural stream which causes a flood hazard, and for such purpose only the board of county commissioners shall have a right of access to any such natural stream, which access shall be accomplished through existing gates and lanes, if possible. Such authority includes the right to modify existing diversion or storage facilities at no expense to the diverter of a water right, but it shall in no way alter or diminish the quality or quantity of water entitled to be received under any vested water right.
>
> 30-30-102 (1) C.R.S.

3.2.2.5 Conservancy Law—Flood Control

37-1-101, 37-8-101 C.R.S. The statute authorizes the district court for any county to establish conservancy districts for any of the following purposes:

> Preventing floods; regulating stream channels by changing, widening, and deepening the same; regulating the flow of streams; diverting, controlling, or in whole or in part eliminating watercourses; protecting public and private property from inundation…

3.2.2.6 Drainage Districts

37-20-101, 37-33-109 C.R.S. The statute authorizes owners of agricultural lands susceptible to drainage by the same general system of works to petition the board of county commissioners for the organization of a drainage district.

3.2.3 Statutes—State

3.2.3.1 Colorado Land Use Act

24-65-101, 24-65-105 C.R.S. The statute establishes a nine-member Colorado land use commission. Among other powers, the commission has authority to assist counties and municipalities in developing guidelines for developing land uses and construction controls within designated floodways.

3.2.3.2 Drainage of State Lands

37-30-101, 37-30-105 C.R.S. The statute authorizes the state board of land commissioners to make contracts with any person, corporation, association, or drainage district to provide drainage of state lands.

3.2.3.3 Water Conservation Board of Colorado

37-61-101, 37-60-123 C.R.S. The statute creates a 13-member state water conservation board for purposes of water conservation and flood prevention. An important duty of this board is to "designate and approve storm or floodwater runoff channels or basins, and to make such designations available to legislative bodies of cities and incorporated towns, ...and counties of this state." 30-60-123 C.R.S.

3.2.3.4 State Canals and Reservoirs

37-88-101, 37-88-109 C.R.S. The statute authorizes the Department of Corrections to locate, acquire, and construct ditches, canals, reservoirs, and feeders for irrigating and domestic purposes for the use of the State of Colorado. The board of county commissioners have charge and control of any state reservoir in their county including the obligation to maintain and keep said reservoir in good condition at the county's expense. In addition, the county in which the state reservoir is located is liable for any damages resulting from breakage of the dams or water discharges therefrom.

3.2.3.5 Regulatory Impairment of Property Rights

29-20-201 C.R.S. This law became effective July 1, 1999. One of the legislative declarations of the act is that "The general assembly further finds and declares that an individual private property owner should not be required, under the guise of police power regulation of the use and development of property, to bear burdens for the public good that should more properly be borne by the public at large." The main thrust of the act is contained in 29-20-203 (1) C.R.S., which reads as follows:

> In imposing conditions upon the granting of land-use approvals, no local government shall require an owner of private property to dedicate real property to the public, or pay money to a public entity in an amount that is determined on an individual and discretionary basis, unless there is an essential nexus between the dedication or payment and a legitimate local government interest, and the dedication or payment is roughly proportional both in nature and extent to the impact of the proposed use or development of such property. This section shall not apply to any legislatively formulated assessment, fee, or charge that is imposed on a broad class of property owners by local government.

The act goes on to prescribe the remedies available to a private property owner who believes his or her

rights have been violated under the act. However, unlike most litigation, it is the burden of the local government and not the plaintiff "to establish, based upon substantial evidence appearing in the record" that the dedication or payment required by the local government is roughly proportional to the impact of the proposed use of the subject property.

Therefore, the Colorado legislature has now established a standard that is consistent with the leading case law in this area to assist local governments with reaching a safe harbor when imposing conditions on development. The concepts are fairly simple. First, the conditions imposed have to have some causal relationship with the impact of the development and, second, those conditions must be "roughly proportional" to the impact of the development. However, it should be noted that these restrictions relate only to those instances where the local government is negotiating individually with a developer as to what conditions will be imposed by the local government. The act does provide that, if the local government is legislatively imposing conditions for development on a broad class of property owners, the "essential nexus" and "roughly proportional" requirements of the act do not apply to those legislatively imposed conditions.

3.2.3.6 Intergovernmental Relationships

29-1-201 C.R.S. In 1974, Section 2 of Article XI of the state constitution was amended to permit and encourage governments to make the most efficient and effective use of their powers and responsibilities by cooperating and contracting with other governments. 29-1-203 C.R.S. provides more detail in regard to how that cooperation is to be carried out. It reads in part as follows:

> Governments may cooperate or contract with one another to provide any function, service, or facility lawfully authorized to each of the cooperating or contracting units, including the sharing of costs, the imposition of taxes, or the incurring of debt, only if such cooperation or contracts are authorized by each party thereto with the approval of its legislative body or other authority having the power to so approve.

3.2.4 Urban Drainage and Flood Control Act

32-11-101 C.R.S., et. seq., established the Urban Drainage and Flood Control District (District), including all of the City and County of Denver and the urbanized and urbanizing portions or Adams, Arapahoe, Boulder, Douglas and Jefferson Counties. An 18-person board, comprised of 16 elected officials and 2 professional engineers, is given the power to (1) plan solutions to drainage and flood control problems (with an authorized mill levy of 0.1 mill); (2) construct drainage and flood control improvements (with an authorized mill levy of 0.4 mill); (3) maintain such improvements and other natural drainageways in the District (with an authorized mill levy of 0.4 mill); and (4) construct drainage and flood control improvements in and adjacent to the South Platte River (with an authorized mill levy of 0.1 mill). The board also has the power to adopt and enforce a floodplain regulation.

4.0 FINANCING DRAINAGE IMPROVEMENTS

> The ability of one owner to develop land, install impervious surfaces, alter drainage paths, and accelerate runoff onto other properties involves more than issues of what rights and relief should be accorded neighboring property owners. Urbanization may double or triple the peak flows of 5- and 10-year floods. Lands far downstream may be severely affected by the cumulative impact of unplanned and unregulated changes in drainage patterns due to urban clearance, grading, and development. Increasingly, the costs of uncontrolled drainage modifications and storm water management have fallen on the state and federal budgets.
>
> Westen, *Gone With the Water—Drainage Rights and Storm Water Management in Pennsylvania*, 22 Vill. L. Rev. 901, 902 (1976-77).

4.1 Capital Improvement

Resources from the current budget, usually derived from sales, property, and income taxes, can be used to finance drainage improvements. Since the cost is paid from the "general fund" or "capital improvement fund" and no specific property tax is levied, the financing is relatively simple.

4.2 Local Improvement

Financing for drainage improvements through local improvements or as part of a general bond issue requires that all property be assessed on a valuation basis. Since a majority of all taxpaying electors must approve the decision, the success of this method usually turns on how well the facts (needs) have been prepared and how well a plan has been developed.

4.3 Special Improvement

When drainage improvements are financed as special improvements, the property assessed must be specially benefited. In Colorado, benefits, for purposes of special assessments, are defined in several statutory sections. (See 30-20-513, 30-20-606, 31-25-507, and 37-23-101.5 C.R.S.). For example, 37-23-101.5 C.R.S. provides:

> Determination of special benefits—factors considered. (1) The term 'benefit,' for the purposes of assessing a particular property within a drainage system improvement district, includes, but is not limited to, the following: (a) any increase in the market value of the property; (b) the provision for accepting the burden from specific dominant property for discharging surface water onto servient property in a manner or quantity greater than would naturally flow because the dominant owner made some of his property impermeable; (c) any adaptability of property to a superior or more profitable use; (d) any alleviation of health and sanitation hazards accruing to particular property or accruing to public property in the improvement district, if the provision of health and sanitation is paid for wholly or partially out of funds derived from taxation of property owners of the improvement district; (e) any reduction in the maintenance costs of particular property or of public property in the improvement district, if the maintenance of the public property is paid for wholly or partially out of funds derived from taxation of property owners of the improvement district; (f) any increase in convenience or reduction in inconvenience

> accruing to particular property owners, including the facilitation of access to and travel over streets, roads, and highways; (g) recreational improvements accruing to particular property owners as a direct result of drainage improvement.

This statute was adopted by the Colorado legislature to define "benefits," a term previously defined only by courts. See Shoemaker, "What Constitutes 'Benefits' for Urban Drainage Projects," 51 *Denver L. Journal* 551 (1974).

Although a benefit to the premises assessed must at least be equal to the burden imposed, the standard of apportionment of local improvement costs to benefits is not one of absolute equality, but one of reasonable approximation. Satter v. City of Littleton, 185 Colo. 90, 522 P.2d 95 (1974). A presumption of validity inheres in a city council's determination that benefits specifically accruing to properties equal or exceed assessments thereon. Satter, supra. Further, a determination of special benefits and assessments is left to the discretion of municipal authorities, and their determination is conclusive in the courts unless it is fraudulent or unreasonable. Orchard Court Development Co. v. City of Boulder, 182 Colo. 361, 513 P.2d 199 (1973). A determination of no benefit in an eminent domain proceeding does not preclude a subsequent special assessment providing a landowner's property benefited from construction of the improvement. City of Englewood v. Weist, 184 Colo. 325, 520 P.2d 120 (1974). See, also, Denver v. Greenspoon, 140 Colo. 402, 344 P.2d 679 (1959); Town of Fort Lupton v. Union Pacific R.R. Co., 156 Colo. 352, 399 P.2d 248 (1965); Houch v. Little River District, 239 U.S. 254 (1915); and Miller and Lux v. Sacramento Drainage District, 256 U.S. 129 (1921).

4.4 Service Charge

The District can charge service fees for the use of its facilities or services and thereby finance its improvements. 32-11-217 (l)(e), 32-11-306 C.R.S. provides:

> Such service charges may be charged to and collected in advance or otherwise by the District at any time or from time to time from any person owning real property within the District or from any occupant of such property which directly or indirectly is, has been, or will be connected with the drainage and flood control system of the District or from which or on which originates or has originated rainfall, other surface and subsurface drainage, and storm and flood waters (or any combination thereof) which have entered or may enter such system, and such owner or occupant of any such real property shall be liable for and shall pay such service charges to the District at the time when and place where such service charges are due and payable.

Storm and flood control facilities fall within the definition of "sewerage facilities" defined in 30-35-401 (5) C.R.S; 31-35-402 (1) C.R.S. states:

> In addition to the powers which it may now have, any municipality, without any election of the taxpaying or qualified electors thereof, has power under this part for:
>
> (f) to prescribe, revise and collect in advance or otherwise, from any consumer or any owner or occupant of any real property connected therewith or receiving service

> therefrom rates, fees, tolls, and charges or any combination thereof for the services furnished by, or the direct or indirect connection with, or the use of, or any commodity from such water facilities or sewerage facilities or both,...

A service charge is neither a tax nor a special assessment but is a fee for the sole purpose of defraying the cost of establishing and maintaining a storm drainage and flood control utility. Western Heights Land Corp. v. City of Fort Collins, 146 Colo. 464, 362 P.2d 155 (1961). See, also, City of Aurora v. Bogue, 176 Colo. 198, 4-9 P.2d 1295 (1971); Brownbriar Enterprises v. City and County of Denver, 177 Colo. 198, 493 P.2d 352 (1972); and City of Boulder v. Arnold, 978 P.2d 149 (Colo. App. 1976) which upheld the City of Boulder's flood control fee. Counties in Colorado have similar powers pursuant to 30-20-402 (1) C.R.S.

4.5 Developer's Cost

1. A county planning commission or the board of adjustment of any county may condition any portion of a zoning resolution, or any amendments or exceptions thereto, upon "the preservation, improvement, or construction of any storm or floodwater runoff channel designated and approved by the Colorado Water Conservation Board." 30-28-111 (2) C.R.S.

2. Every Colorado county is required to have a planning commission to develop, adopt and enforce subdivision regulations. Among the provisions that the board of county commissioners must include in the county's regulations are those requiring developers to submit:

    a. A plat and other documentation showing the layout or plan of development, including, where applicable, the following information:

        i. Estimated construction cost and proposed method of financing of the streets and related facilities, water distribution system, sewage collection system, storm drainage facilities, and such other utilities as may be required of the developer by the county.

        ii. Maps and plans for facilities to prevent stormwater in excess of historic runoff caused by the proposed subdivision from entering, damaging, or being carried by conduits, water supply ditches and appurtenant structures, and other storm drainage facilities. 30-28-133 (3)(c) C.R.S.

In addition, subdivision regulations must include provisions governing:

> Standards and technical procedures applicable to storm drainage plans and related designs, in order to ensure proper drainage ways, which may require, in the opinion of the board of county commissioners, detention facilities which may be dedicated to the county or the public, as are deemed necessary to control, as nearly as possible, storm waters generated exclusively within a subdivision from a one-hundred year storm which

> are in excess of the historic runoff volume of storm water from the same land area in its undeveloped and unimproved condition.
>
> 30-28-133 (4)(b) C.R.S.

4.6 The Taxpayers Bill of Rights, Article X, Section 20, Colorado Constitution

On December 31, 1992 the Taxpayers Bill of Rights (TABOR) became effective. Its effect is to limit governmental spending generally so that "the maximum annual percentage change in each local district's fiscal year spending equals inflation in the prior calendar year plus annual local growth." In addition to a spending limitation, TABOR imposes a revenue limit that is similar to the spending limit. Finally, districts must have voter approval in advance for:

> ...any new tax, tax rate increase, mill levy above that for the prior year, valuation for assessment ratio increase for a property class, or extension of an expiring tax, or a tax policy change directly causing a net tax revenue gain to any district.

Prior to the passage of TABOR there were a number of cases that addressed whether a service charge was a tax. The first of note was Zelinger v. City and County of Denver, 724 P.2d 1356 (Colo. 1986) wherein a storm drainage service charge was attacked as an unconstitutional property tax and an unconstitutional denial of equal protection and due process guarantees to property owners. The storm drainage service charge applied to all owners of property in Denver and was used to pay for the operation, maintenance, improvement and replacement of the city's storm drainage facilities. The charge was based on the ratio of impervious to pervious land surface. The higher the ratio of impervious to pervious surface, the greater the charge per square foot. The Colorado Supreme Court held that such a service charge was not a tax nor was it a violation of due process or equal protection. The court concluded with the following finding:

> ...although alternative cost allocation schemes may be equally well-suited or arguably better suited to serving the governmental interest in providing storm drainage facilities than the scheme actually adopted, the equal protection clauses do not authorize the invalidation of the scheme chosen unless it is without rational foundation.

The Zelinger case has continued as good law ever since 1986 and has been cited recently as the law of Colorado in regard to these matters. Thus, a storm drainage service charge similar to that adopted by Denver is not a tax and therefore is not subject to the limitations of TABOR.

In 1989 the Colorado Supreme Court revisited fees in the case of Bloom v. City of Fort Collins, 784 P.2d 304 (Colo. 1989). In that case the court considered a transportation utility fee and held that such a fee was not a property tax but rather a special fee imposed upon owners or occupants of developed lots fronting city streets and that such a fee is reasonably related to the expenses incurred by the city in carrying out its legitimate goal of maintaining an effective network of city streets. The court in reaching this conclusion considered any number of possibilities as to what this fee was and rejected the following

as not applying: property tax, excise tax and special assessment. It therefore found that the fee was a special fee that was a charge imposed on persons and property and reasonably designed to meet the overall cost of the service for which the fee is imposed.

Finally, in the case of City of Littleton v. State of Colorado, 855 P.2d 448 (Colo. 1993), the Colorado Supreme Court addressed another stormwater and flood management utility fee. The fee was enacted to prevent damage to property from accumulations and uncontrolled runoff of water. The ordinance declares that as the ultimate beneficiaries and users of the contemplated system, the owners of property within the city shall be required to pay a fee for the costs of constructing, operating, maintaining and replacing the system and its facilities. The state Community Colleges Board challenged the fee as a special assessment and thus something that could not be charged against the state. The court found that, despite the fact that the service fees did not specifically benefit the property owned by the state, it did create the capacity to remove excess water from property and prevent flooding, which benefited all property owners; thus, the fee is a permissible fee.

In conclusion, drainage fees, if properly structured, are not property taxes and can be implemented without TABOR implications. However, outside of Colorado, there have been three recent cases where each have held, for various reasons, that a "stormwater service charge," a "stormwater utility charge" and a "stormwater drainage service charge" are each a tax and not a fee. Those cases are Bolt v. City of Lansing, 561 N.W. 2d 423 (Mich. 1997); Fulton County Taxpayers Association v. City of Atlanta, Georgia, Superior Court of Fulton County, State of Georgia, Civil Action File Number: 1999 cv05897; and City of Cincinnati v. United States, United States Court of Appeals for the Federal Circuit, 98-5039.

4.7 Water Activities—Enterprise Statute 37-45.1-101 C.R.S.

This statute, which was adopted after the passage of TABOR, takes advantage of the exception in TABOR that the same does not apply to governmental enterprises by setting forth, in regard to water activities, what a governmental entity needs to do to become and remain a enterprise and thus not subject to TABOR. Numerous Front Range cities have taken advantage of this statute to adopt enterprises without a vote of the people to address drainage and flooding issues in their municipalities.

The statute provides in regard to the establishment of a water activity enterprise that:

> Any district which under applicable provisions of law has its own bonding authority may establish or may continue to maintain water activity enterprises for the purpose of pursuing or continuing water activities including...water project or facility activities, including the construction, operation, repair, and replacement of water or wastewater facilities. Any water activity enterprise established or maintained pursuant to this article is excluded from the provision of Section 20 of Article X of the state constitution.

The statute defines "water project or facility" as including a dam, storage reservoir, compensatory or replacement reservoir, canal, conduit, pipeline, tunnel, power plant, water or wastewater treatment plant,

and any and all works, facilities, improvements, and property necessary or convenient for the purpose of conducting a water activity. The statute also defines water activity as including stormwater services.

Two restrictions in regard to water activity enterprises are that they cannot receive more than 10 percent of their annual revenues from grants from state and local governmental entities and that an enterprise may not tax.

5.0 FLOODPLAIN MANAGEMENT

Floodplain management involves fuller use of non-structural techniques. See 24-65.1-202 (2)(a)(I) C.R.S. Such techniques include:

1. Floodplain zoning and building code ordinances to regulate flood area construction.
2. Flood insurance programs.
3. Flood warning systems, including notification to occupants of floodplains.

See Westen, *Gone With the Water—Drainage Rights and Storm Water Management in Pennsylvania*, 22 Vill. L. Rev., 901, 972 (1976-77).

5.1 Floodplain Regulations

5.1.1 Constitutional Considerations

The general principles of zoning were established in Village of Euclid v. Amber Realty Co., 272 U.S. 365 (1926), in which the U.S. Supreme Court stated:

> While the meaning of constitutional guarantees never varies, the scope of their application must expand or contract to meet new and different conditions that are constantly coming within the field of their operation.

The court in Colorado has determined that zoning is justified as a valid exercise of police power, and that this legal basis for zoning legislation must be reconciled with the legitimate use of private property, in harmony with constitutional guarantees. Westwood Meat Market, Inc. v. McLucas, 146 Colo. 435, 361 P.2d 776 (1961); People ex rel. Grommon v. Hedgcock, 106 Colo. 300, 104 P.2d 607 (1940).

The adoption by a municipality of floodplain ordinances to regulate flood-prone areas is a valid exercise of police power and is not a taking. Morrison v. City of Aurora, 745 P.2d 1042 (Colo. App. 1987).

5.1.2 Statutory Grants of Power

Specific legislative action has given local governments authority to proceed in floodplain regulation. In Colorado, cities, counties, and the District all have plenary grants of power.

The governing body of each municipality has the following authority:

> To establish, regulate, restrict and limit such uses on or along any storm or floodwater runoff channel or basin, as such storm or floodwater runoff channel or basin has been designated and approved by the Colorado Water Conservation Board, in order to lessen or avoid the hazards to persons and damage to property resulting from the accumulation of storm or floodwaters.
>
> 31-23-301 (1) C.R.S.

Counties in Colorado are directly authorized by statute to adopt zoning plans concerned with regulating use in a floodplain area through the provisions of 30-28-111 (1) C.R.S.:

> ...the county planning commission may include in said zoning plan or plans provisions establishing, regulating, and limiting such uses upon or along any storm or water runoff channel or basin as such storm or runoff channel or basin has been designated and approved by the Colorado Water Conservation Board in order to lessen or avoid the hazards to persons and damage to property resulting from the accumulation of storm or flood waters.

Home rule counties and cities have the same powers as noted above. These powers may be expanded by charter as long as those powers do not violate the Colorado constitution dealing with home rule governmental entities.

The District is authorized to:

> ...adopt, amend, repeal, enforce, and otherwise administer under the police power such reasonable floodplain zoning resolutions, rules, regulations, and orders pertaining to properties within the district of any public body or other person (other than the federal government) reasonably affecting the collection, channeling, impounding or disposition of rainfall, other surface and subsurface drainage, and storm and flood waters (or any combination thereof), including without limitation variances in the event of any practical difficulties or unnecessary hardship and exceptions in the event of appropriate factors, as the board may from time to time deem necessary or convenient. In the event of any conflict between any floodplain zoning regulation adopted under this section and any floodplain zoning regulation adopted by any other public body, the more restrictive regulation shall control. (emphasis added)
>
> 32-11-218 (1) (f) (I) C.R.S.

Because of the underlined language above, the District has proceeded on the basis that if local governments within the District fail to adopt floodplain regulations, then the District would administer its regulation within that local jurisdiction. Further, since the District's regulation prohibits residential development within the floodway (the most hazardous portion of the floodplain), any local government failing to prohibit residential development within the floodway would be governed by the District's regulation inasmuch as the District's regulation would be "more restrictive" and, thus, controlling under the statute.

5.1.3 Court Review of Floodplain Regulations

The leading Colorado case is Famularo v. Adams County, 180 Colo. 333, 505 P.2d 958 (1973), in which the Colorado Supreme Court upheld the District Court's findings that (1) the Adams County Commissioners had authority to regulate, by resolution, the uses of land in unincorporated areas for "trade, industry, residence, recreation, or other purposes, and for flood control"; and (2) the regulation in question did not so limit the uses of plaintiff's land so as to violate the Colorado Constitution, Article II, §25 or the U.S. Constitution, Amendment XIV.

In the case of Kolwicz v. City of Boulder, 538 P.2d 482 (Colo. App. 1975) the court was asked to determine if a city resident had standing to sue the city to require the city council and its administrator to implement floodplain regulations by adopting a map that delineated the floodway and the flood storage areas within the floodplain, for which the city had adopted a map four years prior to the lawsuit. The court denied the city resident's request on the basis that nothing in the record showed that the resident herself had been aggrieved, wronged, or had any of her rights impaired or threatened as a result of the city council's failure to implement its regulations.

In the case of Hermanson v. Board of County Commissioners of Fremont, 595 P.2d 694 (Colo. App. 1979), the court addressed an assertion by the plaintiff that his property had been taken from him because of a series of regulatory obstructions to its development that had been imposed by the county. The plaintiff alleged that his property had been taken by inverse condemnation, and the court found that such an action is justified when there has been a taking of private property for public use without payment of just compensation by some public body that has the power of eminent domain. However, the court did acknowledge that it is true that the use of property may be regulated by valid exercise of the police power, if the regulation does not go beyond protection of the public health, safety, morals, and welfare. Therefore, it found that, when regulations are designed to depress value with a view to future acquisition, this may form the basis of a cause of action for compensation on the theory of inverse condemnation against the public entity initiating the regulation.

Finally, in the case of Morrison v. City of Aurora, 745 P.2d 1042 (Colo. App. 1987), a property owner alleged that the city's adoption of floodway restrictions was a taking of his property. The court found for the city, since an adoption by a municipality of floodplain ordinances to regulate flood-prone areas is a valid exercise of police power and is not a taking.

In Colorado, the legislature has taken the lead in granting local governments power to regulate flood hazard areas. Usually, courts interpret such regulation that follows on a case-by-case basis, depending on what is "reasonable" under the circumstances. Some guidelines that have emerged in anticipating "reasonableness" follow.

5.1.3.1 Restriction of Uses

The restriction of uses on property that would prevent a public harm, as opposed to the creation of a public *benefit,* removes the requirement of compensation to property owners who are restricted from the full use of their property. Dunham, *A Legal and Economic Basis for City Planning*, 58 Colum. L. Rev. 650 (1958).

The restrictions on the uses must not be so severe as to deny the owners a constitutional right to make "beneficial use" of their land because such restrictions would be confiscatory and void. Francis v. City and County of Denver, 160 Colo. 440, 418 P.2d 45 (1966). However, a zoning ordinance is not

unconstitutional because it prohibits a landowner from using or developing his or her land in the most profitable manner. It is not required that a landowner be permitted to make the best, maximum or most profitable use of his or her property. Baum v. City & County of Denver, 363 P.2d 688 (Colo. 1961); and Sundheim v. Board of County Commissioners of Douglas County, 904 P.2d 1337 (Colo. App. 1995).

5.1.3.2 Health Regulations

The relationship of the zoning restrictions to the public's health, safety, morals, and general welfare must be considered. Whether the zoning provisions are reasonable and for the promotion of the public's welfare must be determined by the court from the facts, circumstances, and locality in a particular case. DiSalle v. Giggal, 128 Colo. 208, 261 P.2d 499 (1953).

A similar matter in zoning restrictions was determined by the U.S. Supreme Court in upholding the validity of the police power in a zoning ordinance that prohibited excavation below a certain water table, which in effect deprived the property of its most beneficial use, stated:

> The ordinance in question was passed as a safety measure, and the town is attempting to uphold it on that basis. To evaluate its reasonableness, we therefore need to know such things as to the nature of the menace against which it will protect, the availability and effectiveness of other less drastic protective steps, and the loss which the appellants will suffer from the imposition of the ordinance.
>
> Goldblatt v. Town of Hempstead, (N.Y.) 369 U.S. 590 (1962).

This holding appears to coincide with the Colorado cases on the requirements for the determination by the court from facts, circumstances, and locality in a particular case, as to the reasonableness of the zoning ordinances in their promotion of the general welfare, and to prove that the restrictive use would bear a substantial relation to the public's health, safety, morals, or general welfare. DiSalle v. Giggal, supra; Westwood Meat Market, Inc. v. McLucas, supra.

5.1.3.3 Determination of Boundaries

The boundaries of the floodplain should be accurately determined and based on a reasonable standard. Mallett v. Mamaroneck, 1313 N.Y. 821, 125 N.E. 2d 875 (1955).

The setting of the boundaries of the floodplain zone to determine the hydraulic reach of a potential flood should be determined accurately. The accuracy of which will be affected by terrain, river course, and other factors that will necessarily cause some variation from the initially adopted boundary.

The Federal Emergency Management Agency (FEMA), U.S. Army Corps of Engineers, Colorado Water Conservation Board (CWCB), the District, and local governments have conducted extensive stream surveys throughout Colorado. The surveys have been completed upon reasonable scientific standards and have often become an integral part of the floodplain zoning ordinances and resolutions adopted by Colorado's cities and counties.

The CWCB has actively cooperated in the past to designate and approve such areas as delineated as a storm or "floodwater runoff channel or basin." Such approval or designation of a runoff channel or basin by the CWCB is required by statute prior to any action by a local government, including the District, to set the boundaries on proposed floodplain zoning resolutions.

5.2 Flood Insurance

The National Flood Insurance Act of 1968, as amended in 1973, provides for a federally subsidized flood insurance program conditioned on active management and regulation of flood plan development by states and local governments. 42 U.S.C., §§4001 and 4128; 24 C.F.R., §1979.1-1925.14 (1975). Communities designated as flood prone by FEMA can obtain flood insurance eligibility for structures within the community upon meeting the qualifications of the act by developing a floodplain management system. Development of a floodplain management system requires the community to promulgate a land use and building permit system that restricts development in flood hazard areas. FEMA publishes a list, updated monthly, of the status of communities. Flood insurance is provided on a subsidized basis through all licensed insurance agents.

Federally regulated lending institutions (FDIC, ESLIC, NCUA) must require flood insurance for loans made on structures in FEMA-identified flood hazard areas in communities where flood insurance is available. The lender is required to give notice to the borrower 10 days in advance that the property securing the loan is located in a flood hazard area, and written acknowledgement of the borrower's knowledge of the flood hazard must be obtained. If flood insurance is not available in the community, the lender may still make the loan, but he or she must notify the borrower that federal disaster assistance may not be available in the event of a flood disaster. Federally insured loans (SBA, VA and FHA) have the same requirements, with the exception that they cannot be made on property located in a FEMA identified flood hazard area if flood insurance is not available in the community.

An area of great concern is whether flood hazard boundaries should be based on current development in the drainage watershed or on future development. FEMA uses current development as its criteria. The District uses future development, which results in the regulation of a larger floodplain area in most instances. Although the watershed may take time to develop in accordance with the local government's Master Land Use Plan and land use requirements may call for on-site upstream detention, it is the District's position that "future condition" criterion is preferable because existing floodplain users are put on notice of what the future may bring, and potential users of the floodplain are also put on notice of the potential hazard. The net result is a more restrictive regulation under 32-11-218 (I)(f) C.R.S.

5.3 Flood Warning Systems and Notification

The District has adopted a procedure to notify known occupants of identified flood hazard areas (100-year floodplains). Although larger floods can and do occur, the local governments in Colorado are directed by

the legislature to identify the areas that would be affected by 100-year storms. The CWCB has been directed by the legislature to coordinate this land use program.

The District's "Flood Hazard Information Official Notice" also suggests actions that individuals can take to help themselves mitigate the hazard. This notice is mailed annually to the occupants of all residential units identified as being in the flood hazard area.

With the use of radar and a communications network, the District has put in place a system to help inform all residents of the District of potential flooding.

6.0 SPECIAL MATTERS

6.1 Irrigation Ditches

In situations in which an irrigation ditch intersects a drainage basin, the irrigation ditch does not have to take underground waters diverted by a tile drain. However, the surface drainage must be accepted if the irrigation ditch is constructed in such a way that surface water would naturally flow into it. Clark v. Beauprez, 151 Colo. 119, 377 P.2d 105 (1962) (between private parties, the owner of an irrigation ditch can prevent an upstream landowner from diverting waters from their natural course into the irrigation ditch); City of Boulder v. Boulder and White Rock Ditch & Reservoir Company, 73 Colo. 426, 216 P. 553 (1923) (where an irrigation ditch was constructed in a natural drainageway into which surface water would naturally flow, the ditch owners could not complain merely on the ground that the city, in building storm sewers, collected the surface water and accelerated its flow and precipitated or discharged it at some particular point in the line of the ditch instead of spreading it out at different places of entrance).

In urbanizing areas, the conflict between the natural flow of surface water and irrigation ditches which bisect many drainage basins continues to be a difficult condition to resolve, taking into consideration the rights and liabilities of upstream property owners and irrigation ditch owners. Innumerable natural drainageways have been blocked by irrigation ditches, although they were constructed long before the basin became urbanized. This special area of urban drainage points to the need for good land use requirements, as well as identification of potential problem areas.

7-42-108 C.R.S. provides in part that:

> Every ditch corporation organized under the provisions of law shall be required to keep its ditch in good condition so that the water shall not be allowed to escape from the same to the injury of any mining claim, road, ditch, or other property.

This provision of Colorado law was recently interpreted in the case of Oliver v. Amity Mut. Irrigation Co., 994 P.2d 495 (Colo. App. 1999). In this case, the ditch company was being sued for damages to property resulting from a break in the bank of the ditch company's ditch. The court held that the statute imposed a duty of ordinary care, such as a person of average prudence and intelligence would use, under like circumstances to protect his or her own property. The court went on to state that, in order for the ditch company to fulfill its statutory duty, it had to prevent erosion of the ditch bank, keep the ditch free of sediment and debris, and control the amount of water flowing through its ditch, among other things, keeping the spillway at the intersection of its ditch and another free of obstructions. Finally, the court concluded that, although a ditch company is not liable for damages caused solely by an act of God, the company may not escape liability if its negligence contributed to or cooperated with an act of God to cause the damage.

In conclusion, those that own ditches owe a duty to those property owners through which their ditches

pass to maintain their ditches, using ordinary care so as to prevent damage to the adjoining real property.

6.2 Dams and Detention Facilities

Subdivision regulations adopted by the board of county commissioners must include provisions requiring subdivisions to submit:

> Maps and plans for facilities to prevent storm waters in excess of historic runoff, caused by the proposed subdivision, from entering, damaging, or being carried by conduits, water supply ditches and appurtenant structures, and other storm drainage facilities.
>
> 30-28-133 (3)(c)(VIII) C.R.S.

In addition, the regulations must include provisions governing:

> Standards and technical procedures applicable to storm drainage plans and related designs, in order to ensure proper drainageways, which may require, in the opinion of the board of county commissioners, detention facilities which may be dedicated to the county or the public, as are deemed necessary to control as nearly as possible, storm waters generated exclusively within a subdivision from a one-hundred year storm which are in excess of the historic runoff volume of storm water from the same land area in its undeveloped and unimproved condition.
>
> 30-28-133 (4)(b) C.R.S. See Shoptaugh v. Board of County Commissioners, 543 P.2d 524 (Colo. App. 1975).

The law in regard to liability for damages caused by failure of a dam or detention facility has recently changed. In the case of Kane v. Town of Estes Park, 786 P.2d 412 (Colo. 1990), the Colorado Supreme Court considered the issue of whether the Town of Estes Park was negligent for the failure of its dam and reservoir, which was the result of the failure of an upstream dam. The court held that "To impose a burden on a downstream builder to construct facilities adequate to hold or bypass the entire capacity of an upstream reservoir has the potential for foreclosing construction of beneficial downstream storage facilities because of prohibitive costs." The court then concluded as follows:

> In summary, we hold that public entities that own dams or reservoirs are not subject to strict liability for damages caused by water escaping from their dams or reservoirs. Furthermore, we hold that Estes Park had no duty to ensure that waters released from an upstream reservoir because of a dam failure of this magnitude would be contained by its facilities or would bypass those facilities without augmentation.

The Colorado legislature, in response to the 1982 flood that then resulted in the above-referenced lawsuit, amended the statute in regard to storage reservoirs to clarify the law. The applicable sections of 37-87-104 C.R.S. read as follows:

(1) Any provision of law to the contrary notwithstanding, no entity or person who owns,

> controls, or operates a water storage reservoir shall be liable for any personal injury or property damage resulting from water escaping from that reservoir by overflow or as a result of the failure or partial failure of the structure or structures forming that reservoir unless such failure or partial failure has been proximately caused by the negligence of that entity or person. No entity or person shall be required to pay punitive or exemplary damages for such negligence in excess of that provided by law. Any previous rule or law imposing absolute or strict liability on such an entity or person is hereby repealed.
>
> (2) No such entity or person shall be liable for allowing the inflow to such reservoir to pass through it into the natural stream below such reservoir.

The law therefore is relatively clear now in regard to the ownership of dams and reservoirs and the owner's liability for them. No longer are dam owners subject to strict liability for damages caused by those dams. Meaning, that now in order to hold a dam owner responsible for damage caused by the dam, it must be established that the dam owner was negligent in maintenance or operation of the dam. However, this test of negligence is further limited by the law's permission to dam owners to pass all inflows through the dam.

The court, in the case of Barr v. Game, Fish and Parks Commission, 497 P.2d 340 (Colo. App. 1972), held that the criteria for the construction of a dam is to safely pass the probable maximum precipitation (PMP). In Barr, the Colorado Court of Appeals found that, since modern meteorological techniques provide a method of predicting the probable maximum storm and flood, liability should be imposed for injuries resulting from a failure to determine the probable maximum flood and to design and construct a dam with a spillway having the capacity to handle that storm. The court stated:

> The maximum probable storm, by definition, is both maximum and probable. It can and may occur…Thus being both predictable and foreseeable to the defendant in the design and construction of the dam, the defense of act of God is not available to them.

However, the Colorado State Engineer, pursuant to 37-87-105 (1) and (3) C.R.S. must approve plans and specifications for the alteration, modification, repair, or enlargement of a jurisdictional reservoir or dam and, pursuant to regulation, may impose less stringent requirements than those dictated by consideration of the PMP. In fact, the Colorado State Engineer has issued *Rules and Regulations for Dam Safety and Dam Construction*, 2 CCR 402-1 (September 1988) wherein at Rule 4 dams are classified based upon an evaluation of the consequences of the failure of the dam absent flooding conditions. Based upon that classification, Rule 5 sets forth the inflow design flood to be used in determining the spillway capacity of that dam.

A question arises, however, regarding the proper criteria to use in determining the size of the floodplain or

channel below the dam: the 100-year flood, before the dam was constructed or after construction? This special area has not been resolved by either the legislature or the courts in Colorado. However, since some dams and reservoirs are required by law to safely pass the PMP (storms greater than the 100-year storm) it might be argued that the watercourse below the dam should be constructed to at least carry the same water as before construction of the dam. Assuming the dam safely passes a 500-year flood, for example, the 100-year floodplain would obviously be inadequate. But with no dam in place, the same floodplain would also be inadequate.

Preserving the 100-year floodplain before the dam was constructed will prevent damage below the newly constructed dam in the larger than 100-year storm, although not for the PMP.

6.3 Water Quality

> Stormwater runoff is a major non-point source of water pollution. In urbanizing areas, where land-disturbing activities are numerous, stormwater washes soil and sediment into surface waters causing increased levels of turbidity and eutrophication, threatening fish and wildlife, and blocking drainage. In developed areas, runoff carries with it the pollutants from surfaces over which it runs, including, oil, litter, chemicals, nutrients and biological wastes, together with soils eroded from downstream channels of the flow.
>
> U.S. Environmental Protection Agency, *Legal and Institutional Approaches to Water Quality Management Planning and Implementation*. VI-I (1977).

It is reasoned that water quality control should be an integral part of any drainage or stormwater management program, since stormwater management techniques are often consistent with water quality objectives. However, this special area, as related to urban drainage, has not been researched adequately enough so as to provide the facts upon which a cost-effective approach could integrate water quality objectives with plans for surface drainage improvements. See City of Boulder v. Boulder and White Rock Ditch & Reservoir Company, 73 Colo. 426, 216 P. 553, 555 (1923).

Currently, some counties and municipalities are under regulation through the U.S. Environmental Protection Agency and the State of Colorado to address water quality issues. Other portions of this *Manual* deal in detail with those requirements.

6.4 Professional Responsibility

The Colorado Rules of Professional Conduct of the State Board of Registration for Professional Engineers and Professional Land Surveyors provides in the *Basis and Purpose* section the following:

> In order to safeguard life, health and property, to promote the public welfare, and to establish and maintain a high standard of integrity and practice, the following Rules of Professional Conduct shall be binding on every person holding a certificate of registration and on all partnerships or corporations or other legal entities authorized to offer or perform engineering or land surveying services in Colorado.

> These Rules were authorized by Colorado statute and in 12-25-108 (1) C.R.S.
>
> The board has the power to deny, suspend, revoke, or refuse to renew the license and certificate of registration of, limit the scope of practice of, or place on probation, any professional engineer or engineer-intern who is found guilty of:..(e) Violating, or aiding or abetting in the violation of,...any rule or regulation adopted by the board in conformance with the provisions of this part 1,...Rule I— *Registrants shall hold paramount the safety, health and welfare of the public in the performance of their professional duties.*
>
> 2. Rule I shall include, but not be limited to, the following:
>
> A. Registrants shall at all times recognize that their primary obligation is to protect the safety, health, property and welfare of the public. If their professional judgment is overruled under circumstances where the safety, health, property or welfare of the public are endangered, they shall notify their employer or client and/or such other authority as may be appropriate.

Based upon the law and rule set forth above, a professional engineer is required not only to serve the interests of his or her employer/client but is also required as a primary obligation to protect the safety, health, property, and welfare of the public. Therefore, this obligation of protection is superior to the obligation to an employer/client and therefore must be considered in all professional decisions made by a professional engineer.

7.0 CONCLUSION

> The force of gravity which causes all waters flowing on the earth to seek the lowest level creates natural drainage, and provides for the distribution of all water, whether surface or otherwise. This natural drainage is necessary to render the land fit for the use of man. The streams are the great natural sewers through which the surface water escapes to the sea, and the depressions in the land are the drains leading to the streams. These natural drains are ordained by nature to be used, and so long as they are used without exceeding their natural capacity the owner of land through which they run cannot complain that the water is made to flow in them faster than it does in a state of nature.
>
> 2 Farnham, *Water and Water Rights*, p. 968.

Drainage is both simple and complicated. If the facts are ascertained and a plan is developed before initiating a proposed improvement, the likelihood of an injury to a landowner is remote, and the municipality or developer should be able to undertake such improvements relatively assured of no legal complications and be able to use several different means of financing the improvement.

A legal opinion on proposed drainage improvements should state as a minimum whether:

1. The watercourse under study has been walked.
2. There are problems involved, and what causes them (obstructions, topography, development, present or future).
3. The proposed improvements to make the situation better.
4. The proposal requires that the natural drainage be modified.
5. There is potential liability for doing something versus doing nothing.
6. Someone will benefit from the proposed improvements.
7. In general, what is proposed is “reasonable,” using the criteria set forth in paragraph 2.1.3.

PLANNING

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1.0 THE DRAINAGE SUBSYSTEM

1.1 Planning

Planning of the urban storm runoff system is a very important step that requires a comprehensive understanding of city planning, drainage planning, and many of the social, technical, and environmental issues embedded in each watershed.

Urban storm runoff is a subsystem of the total urban system. It is an integral part of the urban community and should be planned as such. The drainage engineer must be included in all urban planning from the beginning. When drainage planning is done after all the other decisions are already made as to the layout of a new subdivision or commercial area or of the transportation network, drainage and urban space allocation problems often result that are costly and difficult to correct.

The city or county urban design team should think in terms of natural drainage easements and street drainage patterns and should coordinate efforts with the drainage engineers to achieve the policies and objectives presented in this *Manual*. Storm runoff will occur when rain falls or snow melts no matter how well or how poorly drainage planning is done. Drainage and flood control measures are costly when not properly planned. Good planning results in lower-cost drainage facilities for the developer and the community and a more functional community infrastructure (Jones 1967).

The drainage design team is encouraged to consider ways of creating additional benefits from drainage works such as recreation or open space.



Photograph PL-1—Bible Park with fully integrated drainage, flood control, recreation, and open space functions represents a partnership among engineers, landscape architects, planners and recreation professionals.

Consideration of multiple uses and multiple benefits in drainage planning and engineering can reduce

drainage costs and increase benefits to the urban system. One way to ensure maximum consideration of these multiple uses is by preparing master plans for drainage so that the overall effort is coordinated with other predetermined objectives (ASCE and WEF 1992).

During the master planning phase, major decisions are made as to design velocities, location of structures, open space set-asides for drainage, integration with recreation, means of accommodating conflicting utilities, and potential alternate uses for open channels, detention, and water quality facilities. It is also at this time that decisions need be made on the use of downstream detention storage, either off-stream or channel ponds or reservoirs. Upstream storage and land treatment should also be evaluated.

1.2 Planning Philosophy

The planning of urban drainage should proceed on a well-organized basis with a defined set of drainage policies backed up with suitable ordinances. The policies presented in this *Manual* provide a basis upon which additional localized and specific policies can be built.

Planning of urban drainage facilities should be based upon incorporating natural waterways, artificial channels, storm sewers, and other drainage works into the development of a desirable, aesthetic, and environmentally sensitive urban community, rather than attempting to superimpose drainage works on a development after it is laid out, as is often done with water supply and sanitary sewer facilities. Surface drainage, unlike water and sanitation systems, must be integrated early into the fabric of the urban layout.

Urban drainage should be considered on the basis that two separate and distinct drainage systems exist. These are the initial drainage system and the major drainage system.

The *initial system,* as defined in the POLICY chapter, consists of grass and paved swales, streets and gutters, storm sewers, and smaller open channels. This is the system that, if properly planned and designed, will eliminate many "complaint" calls to the city or county. It provides for convenient drainage, reduces costs of streets, and directly affects the orderliness of an urban area.

A well-planned *major system* can reduce or eliminate the need for underground storm sewers, and it can protect the urban area from extensive property damage, injury, and loss of life from flooding. The major system exists in a community whether or not it has been planned and designed and whether or not development is situated wisely in respect to it. Water will obey the law of gravity and flow downhill to seek its lowest level whether or not buildings and people are in its way.

The planning process can best serve the community by making sure that nature’s prescriptive easements are maintained along major drainage routes. Here, floodplain delineation and zoning are tools that should be used freely. Small waterways and gulches lend themselves to floodplain regulations in the same manner as larger creeks.

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Reshaping channel areas along small waterways is often not required, except to provide grade control, protection of certain vulnerable areas (such as the channel toe and outer banks), or unless they are in a degraded or deteriorated condition. The practice of straightening, narrowing, and filling major drainageways such as gulches, dry streams, and other natural channels is not recommended for general use in drainageway master plans.

The urban stormwater planning process should attempt to make drainage, which is often a resource out of place, a "resource in place" which can contribute to the community's general well being.

1.3 Drainage Management Measures

Urban drainage and flood control planning should consider the following management measures:

1. Appropriate measures to limit development of land that is exposed to flood damage including:
    a. Enacting floodplain management or other restrictive ordinances (i.e., building, subdivision, housing and health codes).
    b. Acquiring developed property in built-up areas.
    c. Preempting development of vacant flood fringe areas by public acquisition of land where appropriate for good drainage and community planning.
2. Appropriate measures to guide proposed development away from locations exposed to flood damage including:
    a. Developing floodplain regulations.
    b. Using warning signs.
    c. Limiting access to flood-prone areas.
    d. Using setbacks from channel banks.
    e. Withholding public financing from flood area development.
    f. Withholding utilities (electricity, water, sewers, etc.) from flood area development.
    g. Examining equivalent alternative sites.
    h. Maintaining low property assessment for tax purposes allowing flood-prone land to economically lie idle.
    i. Providing incentives for floodplain dedication to the public such as density credits.
3. Appropriate measures to assist in reducing individual losses by flooding including:
    a. Structural flood abatement devices.

b. Flood-proofing buildings.

c. Early warning systems.

d. Emergency preparedness plans (e.g., sandbagging, evacuation, etc.).

e. Ongoing maintenance of the minor and major drainage systems.

f. Disaster relief (funds and services).

g. Tax subsidies (i.e., ameliorating assessments).

Furthermore, good urban drainage planning practices and management procedures should make it possible to initiate:

1. Land use planning that recognizes flood hazards and flood damage and the value of the riparian zones that often occupy natural major drainageway routes.

2. A plan for expansion of public facilities that recognizes the implications of flood hazards for:

   a. Sewer and water extensions.

   b. Open space acquisition.

   c. Transportation.

3. Implementation measures that demonstrate an existing or proposed floodplain management program including, where appropriate:

   a. Building codes, zoning ordinances, subdivision regulations, floodplain regulations, and map regulations with flooding encroachment lines. These should be consistent with land use recommendations discussed earlier, incorporating flood-proofing requirements and reserving areas used in accordance with flood control recommendations.

   b. Participation in regional land use planning.

   c. Participation in available floodplain management services, including flood warning systems.

   d. Cooperation in flood damage data collection programs.

4. Use of major public programs that are available (e.g., urban renewal, public health, open space, code enforcement, highway programs and demonstration programs).

5. The administrative devices created to undertake and implement a floodplain management program including a commitment of personnel, financing, and other resources.

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1.4 Water Quality

Drainage planning for quantity (rate and volume) should proceed hand-in-hand with planning for water quality management. Generally, in urban areas, water quantity and water quality are inseparable. There are a number of best management practices (BMPs) recommended in Volume 3 of this *Manual* for use in a newly developing area to mitigate the adverse effects of increased runoff rates and volumes and pollution, both during construction and after the occupancy permits have been issued. Another essential aspect of water quality protection is stream channel stability. Unstable channels can experience significant degradation and aggradation, both of which can damage aquatic life. Consequently, channel stability must be assured during the planning process.



Photograph PL-2—A stable channel coupled with wet detention for the outlet of a large storm sewer system provides Denver enhanced water quality in Harvard Gulch.

2.0 EARLY PLANNING ADVANTAGES

2.1 Advantages

There are many advantages to the developers, residents, and local governmental agencies when drainage planning is undertaken early. These advantages include lower-cost drainage facilities and facilities that provide integrated benefits to the community. The drainage engineer, planner, and the entire design team should work in close cooperation to achieve maximum urban benefits.

Good urban drainage planning is a complex process. Basic planning considerations that should be taken up early include planning for the major drainage system, the initial drainage system, and the environment.

2.2 New Development

When planning a new subdivision for residential purposes, various drainage concepts should be evaluated before decisions are made as to street location and block layout. It is perhaps at this point in the development process where the greatest impact can be made as to what the drainage facilities will cost and how well they will do their job. When flood hazards are involved, the planning consultant should take these hazards into consideration in land planning to avoid unnecessary complications with local planning boards and governments.

Planners, both governmental and private, are encouraged to confer and work with the drainage engineer. The earlier drainage problems are identified and planned for, the better the final resulting plan will be. Compromising on drainageways in a new development may appear to have short-term benefits, but long-term urban interests suffer as a result. Good drainage policy and practices should be uniformly and consistently applied.

2.3 Get the Facts

The importance of obtaining the facts, including technical and community-based information that affects the drainage program, cannot be overemphasized even in the early planning stages of development. With the aid of the collected facts, defining the objectives of the drainage system, as well as the problems that will be encountered in implementing the drainage plan, can be the most important step in the planning process. As the planning process progresses, the defined objectives will need to be reevaluated for affordability and practicability of implementation, sometimes requiring adjustment of the initial set of objectives.

2.4 Regulatory Considerations

One of the essential elements of early planning is to address regulatory requirements at the federal, state and local level. Drainage projects will frequently trigger the need for environmental permits related to (for example): wetlands and “Waters of the United States;” stormwater discharges; dewatering discharges;

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and local water quality, wetland or other protection ordinances. A solid understanding of these and other regulatory programs is imperative, as they can significantly affect the design, construction and long-term maintenance of channels, ponds, wetlands, and other facilities.



Photograph PL-3—An engineered wetland channel can serve as a filter for low flows and yet carry the major flood event without damage.

3.0 CONSIDER DRAINAGE BENEFITS

3.1 Benefits

The planner should be cognizant of the additional benefits that can be derived from a good urban drainage plan. It is generally recognized that an urban area that has well-planned drainage facilities is usually an area that experiences orderly growth.

Some of the additional benefits that are derived from good urban drainage systems are:

1. Benefits to upstream property owners resulting from elimination of downstream constrictions and increased conveyance capacity.
2. Reduced problems to downstream property owners and receiving systems resulting from managed runoff and stable waterways.
3. Improved water quality.
4. Protection and enhancement of environmentally sensitive areas.
5. Reduced street maintenance costs.
6. Reduced street construction costs.
7. Improved traffic movement.
8. Improved public health and environment.
9. Lower-cost open space.
10. Lower-cost park areas and more recreational opportunities.
11. Development of otherwise undevelopable land.
12. Opportunities for lower building construction cost.
13. Controlled rising groundwater table after urbanization.

Professionals from other disciplines, including urban hydrologists, sociologists, economists, traffic engineers, civil engineers, public health professionals, attorneys, geographers, ecologists, landscape architects, and others can contribute to the formulation of plans for additional benefits.

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4.0 MASTER PLANNING

4.1 Master Plan

A master plan is an overall plan into which the details of other specific plans are fitted, providing overall guidance for future actions and improvements for all or part of an evolving watershed. It is generally a regionally conceived plan based on examination of the total system that, with the aid of public participation, bridges a variety of perspectives and jurisdictional boundaries. It is a road map for future drainage and flood control watershed actions, irrespective of political boundaries.

A drainage master plan for an urbanizing area is helpful to both the developer and the municipality. The drainage master plan must be based on good environmental design techniques and address the goals and needs of the urban area. It should not be prepared only on the basis of drainage hydraulics and not be limited to moving stormwater runoff from one location to another.

A master plan for drainage will only be effective if it is coordinated with planning for open space, transportation, water quality, urban wildlife, and other urban considerations.

4.2 Uniformity

A uniform approach to master planning of drainage in a region brings better results than when different approaches are utilized by each planning effort, depending upon the particular planning team's past experiences and training.



Photograph PL-4—Use of uniform design standards represents a reasonable standard of care for urban flood channels.

5.0 PLANNING FOR THE FLOODPLAIN

5.1 Floodplains

Planning addresses many issues that deal with floodplains and the necessity of floodplain zoning. It is necessary to understand the nature and concept of floodplain regulation before serious floodplain management planning can proceed intelligently. The planner must also consider the national flood insurance program, set forth in the National Flood Insurance Act of 1968, as amended (NFIA 1968).

5.2 Concept of Floodplain Regulation

On any floodplain, nature possesses, by prescription, an easement for intermittent occupancy by runoff waters. Man can deny this easement only with difficulty. Encroachments upon or unwise land modifications within this easement can adversely affect upstream and downstream flooding occurrences during the inevitable periods of nature's easement occupancy.

Government has a responsibility to protect the public's health and safety. Thus, it is implicit that government may permit unwise occupancy or use of the natural easement only at the risk of incurring liability.

Urbanization typically modifies the natural hydrologic and water quality response of its drainageways. Because urbanization usually proceeds in accordance with land use rules and land development regulations prescribed by local government and with the review and approval of detailed development plans, local government in effect becomes a party to the inevitable hydrologic modifications. It follows that a community cannot disclaim liability from consequences of such development, either upon the developed area itself or downstream there from.

Floodplain regulation is the government's response to limit its liability along natural drainageways and is an exercise of its health and safety protective function. The concept of the existence of a natural easement for the storage and passage of floodwaters is fundamental to the assumption of regulatory powers in a definable flood zone. Floodplain regulation, then, must define the natural easement's boundaries and must delineate easement occupancy that will be consistent with total public interests.

5.3 Tools

Key components of floodplain planning include reduction of the exposure to floods, use of development policies, disaster preparedness, flood proofing (see the FLOOD PROOFING chapter), flood forecasting, flood modification, and modification of the impact of flooding.

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6.0 PLANNING FOR MAJOR DRAINAGE

6.1 Major Drainage

The major drainage system planning is the key to good urban drainage in newly developing areas. The general lack of good, open-surface major drainage in older urban areas often requires expensive storm sewer retrofit projects.

A major conduit or channel has an impact upon an urban area, and much depends upon its proper functioning. It is usually a box culvert, a large pipe, or an open channel. As an open channel, it may be a stabilized natural waterway, a modified natural channel, or an artificial channel with grass or other lining. The character of the major drainageway often changes from reach to reach to account for neighborhood needs and general environmental requirements.

The planner and designer have great opportunities when working on major drainageways to help provide a better urban environment for all citizens. The challenges and opportunities are particularly great for those having the opportunity to plan and design works in core areas of cities.

The conceptual design of a major drainageway channel or conduit is that portion of the engineer's job that is most important and that has the greatest effect on the performance and cost of the works. Imagination and general hydraulic experience of the engineer are the most important tools in the preliminary planning and design stage.

6.2 Initial Route Considerations

A preliminary estimate of the design rate of flow is necessary to approximate the channel's or conduit's capacity and size. This estimate can be made by comparisons with other similar basins where unit rates of discharge have been computed or by computing preliminary hydrographs.

Routing of the major drainageway is usually a straightforward matter of following the natural valley thalweg (i.e., the lowest point in the drainageway, sometimes also called channel invert) and defining it on a map. In many urbanized areas, however, there is no thalweg, or the thalweg has been filled and built upon. For these cases, it is necessary to determine many factors before the route is chosen. A meeting should be held with the owner and with the appropriate government officials to explain the routes studied, the conclusions, and the choice. At the same time, the types of channels or conduits being considered should be presented and suggestions or concurrence should be obtained. A dialogue with citizen groups is encouraged where various alternates can be explained.

6.3 The Master Plan

The major drainage master plan must be true to its name to be effective in urban drainage. It must be a team consensus with thorough attention to engineering concepts and details. The completed plan must

be suitable for day-to-day use by local and regional governmental administrators.

The master plan portion of the planning phase is where major decisions are made as to design velocities, location of structures, means of accommodating conflicting utilities, approaches to minimize adverse environmental impacts and the potential alternate uses in the case of an open channel, among others.

The master plan is also where decisions need be made on the use of downstream detention storage, either off-stream or channel ponds or reservoirs. Upstream storage should also be evaluated along with BMPs for both quantity and quality.

6.4 Open Channels

Open channels for use in the major drainage system have significant advantages in regard to cost, capacity, multiple uses for recreational and aesthetic purposes, environmental protection/enhancement, and potential for detention storage. Disadvantages include right-of-way needs and the need for more frequent maintenance. Careful planning and design are needed to minimize the disadvantages and to increase the benefits.

Channel instability is a well-recognized problem in urbanizing areas because of the significant increase in low flows, storm runoff flow rates and volumes, and erosion along the waterways that cause increased sediment concentrations. The volume of storm runoff, peak discharge rate, and frequency of bankfull discharges from an urban area are usually significantly larger than under historic conditions (Leopold 1994; Urbonas 1980; ASCE and WEF 1992; and WEF and ASCE 1998). A natural channel must be studied to determine what measures are needed to avoid future bottom scour and bank cutting. Structural measures can be implemented that will preserve the natural appearance, minimize cost, and assure proper channel function during large events. These include features such as grade control structures, drop structures, and bank stabilization.

In cases of a meandering channel, it may be necessary to provide a buffer zone outside of the floodway or floodplain to account for future channel movement. Likewise, where a deep, incised channel exists, a buffer zone allowance should be provided for bank sloughing and future channel modification by creating a setback line computed at a bank slope of 4(H) to 1(V) measured from the channel bank's bottom.

The ideal channel is one shaped by nature over a long period of time. Unfortunately, urbanization changes the hydrology that has shaped the channel, which, in turn, destabilizes it. Providing for features to keep a natural channel from rapid degradation is an important part of any master plan. The benefits of a stabilized natural channel can include:

1. Lower flow velocities, resulting in longer concentration times and lower downstream peak flows.
2. Channel and adjacent floodplain storage that tends to decrease peak flows.

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3. Lower maintenance needs.

4. Protection of riparian and aquatic habitat.

5. A desirable greenbelt and recreational area that adds significant social benefits.

While recognizing the need for at least some stabilization measures to address the hydrologic changes caused by urbanization, the closer an artificial channel character can be made to that of a natural channel, the greater the public acceptance.

In many areas about to be urbanized, the runoff has been so minimal that well-defined natural channels do not exist. However, subtle low areas nearly always exist that provide an excellent basis for location and construction of channels. Good land planning should reflect even these minimal drainageways to reduce development costs and minimize drainage problems. In many cases, wise utilization of natural water routes in the development of a major drainage system will eliminate the need for an underground storm sewer system.

A wide variety of channel types are available to the design team, depending on good hydraulic practice, environmental design, sociological impact, basic project requirements and other factors. However, from a practical standpoint, the basic choice to be made initially is whether or not the channel is to be a lined one for higher velocities, a wetland bottom channel, a grass-lined channel, a stabilized existing natural channel, or a bioengineered channel, all of which are discussed in the MAJOR DRAINAGE chapter.

The actual choice must be based upon a variety of multidisciplinary factors and complex considerations that include, among others:

1. Hydraulic Factors

    - Slope of thalweg
    - Right-of-way
    - Capacity needed
    - Basin sediment yield
    - Topography
    - Ability to drain adjacent lands
    - Permitting requirements

2. Structural Factors

    - Costs
    - Availability of material
    - Areas for wasting fill

3. Environmental Factors

    - Water quality
    - Neighborhood character
    - Neighborhood aesthetic requirements
    - Needs for new green and riparian areas
    - Street and traffic patterns
    - Municipal or county policies

4. Sociological Factors

    - Neighborhood social patterns
    - Neighborhood children population
    - Pedestrian traffic
    - Recreational needs

5. Regulatory Factors

    - Federal government permits, such as a Section 404 permit
    - State government permits
    - Local government permits

Prior to choosing the channel type, the designer should be sure to consult with experts in related fields in order that the channel chosen will create the greatest overall benefits. When practical, the channel should have slow flow characteristics, be wide and shallow, and be natural in its appearance and functioning.

Grass-lined channels, wetland bottom channels, and bioengineered channels with adequate structural enhancement may be the most desirable artificial channels. The channel storage, lower velocities, environmental benefits, and sociological benefits obtainable create significant advantages over other types. The design must give full consideration to aesthetics, sediment deposition, water quality, maintenance, scour, and hydraulics.

Many open waterways in the western and southern parts of the Denver region have experienced the effects of urbanization and are often steep-banked gulches that have erodible banks and bottoms. On the other hand, a number of natural waterways exist in the northern and eastern parts of the District that have milder slopes, are somewhat stable, and are not in an obvious state of degradation. However, for either type of channel, when it begins to carry storm runoff from an urbanized area, the changed runoff regime will result in new and highly active erosional tendencies. Careful hydraulic analysis of natural channels must be made to foresee and counteract these tendencies. In nearly all cases, some

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modification of the channel will be required to create a more stabilized condition so it can handle changes to surface runoff created by urbanization.

With most Denver area natural waterways, it is necessary to construct grade controls or drop structures at regular intervals to decrease the thalweg (channel invert) slope and control erosion. When site conditions are conducive, channels should be left in as near a natural condition as feasible, subject to the requirement of demonstrated stability during the major event. Extensive channel modifications should not be undertaken unless they are found to be necessary to avoid excessive erosion with subsequent sediment deposition downstream and water quality deterioration.

Because of the decided advantages that are available to a community by utilizing natural waterways for urban storm drainage purposes, the designer should consult with experts in related fields for the method of development. It is important to convene a design team to develop the best means for using a natural waterway. Sometimes it will be concluded that park and greenbelt areas should be incorporated into the channel works. In these cases the usual constraints of freeboard depth, curvature, and other rules applicable to artificial channels may be different or may not apply. For instance, there are significant advantages that may accrue if the designer incorporates relatively frequent (e.g., every five years) overtopping of the formal channel, thus creating localized flooding of adjacent areas that are laid out and developed for the purpose of being inundated during the major runoff peak.



Photograph PL-5—A wide-open waterway carries floodwater at modest depths while maintaining low velocities to inhibit erosion.

7.0 PLANNING FOR INITIAL DRAINAGE

7.1 Initial Drainage

Planning and design for urban storm runoff must be considered from the viewpoint of the regularly expected storm occurrence, which includes the initial storm and the major storm. The initial storm has been defined for the area served by the District to have a return frequency ranging from once in 2 years to once in 10 years. The major storm has been defined to have a return period of 100 years. The objective of major storm runoff planning and design is to reduce the potential for major damage and loss of life. The initial drainage system is necessary to reduce inconvenience, frequently recurring damages, and high street maintenance and to help create an orderly urban system with significant sociological benefits.

The initial system is sometimes termed the “convenience system,” “minor system,” “local system,” “collector system,” or “storm sewer system.”

The initial drainage system is that part of the storm drainage system frequently used for collecting, transporting, and disposing of snowmelt, miscellaneous minor flows, and storm runoff up to the capacity of the system. The capacity should be equal to the maximum rate of runoff to be expected from the initial design storm.

The initial system may include a variety of features such as swales, curbs and gutters, storm sewer pipes, open drainageways, on-site detention, “minimized directly connected impervious area” features, and water quality BMPs.

7.2 Streets

Streets serve an important and necessary drainage service, even though their primary function is for the movement of traffic. Traffic and drainage uses are compatible up to a point, beyond which drainage is, and must be, subservient to traffic needs.

Gutter flow in streets or flow in adjacent swales is necessary to transport runoff water to storm inlets and to major drainage channels. Good planning of streets can substantially help in reducing the size of, and sometimes eliminate the need for, a storm sewer system in newly urbanized areas.

Design criteria for collecting and moving runoff water on or adjacent to public streets are based on a reasonable frequency of traffic interference. That is, depending on the character of the street and as discussed in the POLICY chapter of this *Manual*, certain traffic lanes can be fully inundated during the initial design storm return period, usually once each two years. However, during this design period, lesser storms occur that will produce runoff, which will inundate traffic lanes to some smaller degree.

Drainage practices as related to streets are dependent on the type of street use and construction.

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Classification of streets is based upon traffic volume, parking practices, design and construction, relationship to cross streets, and other criteria. The classification adopted for use herein includes:

- Local/residential.
- Collector.
- Arterial.
- Freeway.

Streets should be classified with respect to pedestrian traffic as well as vehicular traffic. As an example, streets that are classified as local for vehicles and located adjacent to a school are arterials for pedestrian traffic. The allowable width of gutter or swale flow and ponding should reflect this fact.

Inverted crown or "dished" streets shall not be utilized. The dished street design violates the basic function of a street: that of a safe vehicular traffic carrier.



Photograph PL-6—District drainage criteria are aimed at respecting the needs of safe, unimpeded traffic movement. This intersection represents a long-standing drainage problem needing a solution.

8.0 PLANNING FOR STORAGE

8.1 Upstream Storage

The drainage designer usually controls upstream storage utilization (sometimes called on-site detention) and land-shaping BMPs in the early stages of laying out a development. The architect, engineer, homebuilder, land developer, and governmental officials, however, all have a responsibility to work towards more upstream storage and effective land shaping. Upstream storage and land treatment, such as use of grass buffers and swales described in Volume 3 of this *Manual,* have the greatest potential for making good urban drainage less costly to the urban resident.

Many new urban area plans contain parks, both the neighborhood type and the large central type. Parks and recreational fields create little runoff of their own; however, they provide excellent detention potential for storage of runoff from adjacent areas. The use of parks for temporary detention of stormwater runoff can measurably increase benefits to the public, and the use of parks for such purposes is encouraged.

8.2 Downstream Storage

Downstream storage is defined as retention or detention storage situated in the downstream portions of the basin. Typically these are larger facilities that can include channel reservoirs, channel storage, and off-stream storage. The use of downstream storage to reduce storm runoff, and hence drainage costs, should be considered as supplementary to upstream storage. Benefits to be derived from downstream storage are significant and should be taken advantage of wherever possible.

The construction of pond embankments in the channel, generally where topography is favorable to the storage of stormwater runoff, can provide significant benefits in regard to reducing peak flows and settling sediment and debris, the latter helping to improve the quality of water downstream. Multiple benefits, including water quality, can be obtained by the use of on-stream storage ponds by planning and designing for a small permanent pool.

While upstream storage is usually the responsibility of upstream land developers, downstream storage is usually the responsibility of the local governmental unit because the water stored there is derived from a larger area representing many upstream tributary sources.

8.3 Channel Storage

The use of wide, slow-flow swales and natural-type channels also provides storage without constructing special embankments.

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8.4 Other Benefits

Both upstream storage and downstream storage have significant multipurpose use potentials generally centered around recreational, water quality, aesthetic and, possibly, wildlife benefits. In regard to such multiple uses, it is necessary for the designer to work closely with the city planner and the recreational department of the local government.



Photograph PL-7—Urban stormwater detention basins can create neighborhood amenities that at the same time serve their flood control function.

9.0 PLANNING FOR STORM SEWERS

9.1 Storm Sewers

The term storm sewer system refers to the system of inlets, conduits, manholes, and other appurtenances that are designed to collect and convey storm runoff from the initial storm to a point of discharge into a major drainage outfall. Storm sewers are a portion of the initial drainage system that includes street gutters, roadside drainage ditches and swales, culverts, storm sewers, small open channels, and any other feature designed to handle runoff from the initial storm. Alternate terms for the storm sewer system are convenience or minor drainage system. These names are derived from the function of the storm sewers, which is to prevent inconvenience and frequently recurring damage caused by the more frequently occurring smaller storm events.

The initial drainage system, including storm sewers, is that portion of the total drainage system that often receives the most attention from engineers. It is what the average citizen considers to be the urban drainage system. It is what directly contributes to the orderly growth of a community by handling the storm runoff expected to occur once every two to ten years.

The initial system exists even without storm sewers. Storm sewers are needed only when the other parts of the initial system no longer have capacity for additional runoff. A good major system of drainage coupled with wise layout of streets can often significantly reduce the need for storm sewers. The more inadequate the major system is, the more costly the storm sewers are.

9.2 Function of Storm Sewers

Storm sewers belong to the initial drainage system, as do curbs and gutters, roadside swales and roadside ditches. The more distant the point of outfall for the storm sewer, the more extensive the system must be. It is for this reason that the major drainage system takes on importance in regard to the storm sewer system. Generally, the better the major system is, the shorter the storm sewers.

In older built-up urban areas, the storm sewer system may be the only existing planned drainage works. When the capacity of the storm sewers is exceeded, the excess water flows in an unplanned manner overland, often causing damage and loss. The intent of planning and designing for major drainage is to control and manage the large runoff, which exceeds the capacity of the initial system.

9.3 Layout Planning

The preliminary layout of a storm sewer system should consider urban drainage objectives, urban hydrology, and hydraulics. The preliminary layout of the system has more effect on the success and cost of the storm sewers than the final hydraulic design, preparation of the specifications, and choice of materials.

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The ideal time to undertake early work on the layout of the storm sewers is prior to finalizing the street layout in a new development. Once the street layout is set, the options open to the drainage engineer to provide a more cost-effective system are greatly reduced. Various layout concepts should be developed and reviewed, and critical analyses should be done to arrive at the best layouts. For example, the longer street flow can be kept from concentrating in one street, the further the distance from the divide the storm sewer system can begin. In storm sewer design remember that small-diameter laterals represent a large part of the construction cost. Planning a storm sewer system should have as its objective the design of a balanced system in which all portions will be used to their full capacity without adversely affecting the drainage of any area.

9.4 System Sizing

The runoff or rainfall return period to be utilized for designing a storm sewer system is a choice local governments must make. Whenever the system crosses jurisdictional boundaries, differences in sizing policies for the initial system must be worked out between these jurisdictions so that a consistent design is achieved for the entire system serving two or more communities.

The suggested design return periods to be used by local jurisdictions in the Denver region for storm sewer design for all land uses is 2- to 10-years. This is a departure from the policy of recommending different return periods for different land uses. Experience has shown that it is not practical to vary storm sewer design by land use because a single system often serves multiple land uses. Instead, greater attention is necessary to ensure that the major system is adequate to protect the public and property within all areas, regardless of land use.

Once the overall design return period has been set, the system should be reviewed for points where deviation is justified or necessary. For example, it may be necessary to plan a storm sewer to receive more than the initial runoff from a sump area that has no other method of drainage. The sewer might be planned to receive only necessary initial runoff both upstream and downstream of this particular area.

An area must be reviewed on the basis of both the initial and the major storm occurrence. When an analysis implies that increasing the storm sewer capacity is necessary to help convey the major storm, the basic system layout of the major drainage should be analyzed and changed, as necessary.

9.5 Inlets

A stormwater inlet is an opening into a storm sewer system for entrance of surface storm runoff. There are four typical categories of inlets:

1. Curb opening inlets
2. Grated inlets

3. Combination inlets

4. Multiple inlets

In addition, inlets may be further classified as being on a continuous grade or in a sump. It is recommended that curb opening and combination inlets generally be utilized in the design of storm sewer systems, particularly when a sump condition exists. Although these inlets will not guarantee against plugging, they are the most dependable.

9.6 Alternate Selection

The best alternate is chosen on the basis of numerous considerations, one of which is cost. Cost, however, should not be overemphasized. The choice should be based, in part, upon the total benefit-cost ratio, taking into consideration other community benefits and needs.



Photograph PL-8—Planning for storm sewers is aimed at maintaining an orderly urban area where stormwater street flow is limited to predetermined levels.

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10.0 PLANNING FOR OPEN SPACE

10.1 Greenbelts

Waterways can make excellent greenbelts and riparian zones because the needs for drainage and the needs for greenbelts and riparian zones are often compatible.

The land along natural streams and gulches has already been chosen by Mother Nature as a storm runoff easement for intermittent occupancy. Only humans, based on cost and difficulty, can deny this easement. Nature will always extract some price for use of its floodplains.

Zoning land for floodplains and limiting the potential use of such land provide ideally situated open space, greenbelts and potential riparian zones. Acquisition cost of the land for greenbelts and riparian zones should be lower because of the limited potential of the land for development without costly works and major federal regulatory constraints. In appraisal work, adjustments are made to comparable sales to make them equal to the subject property. One adjustment is typically the risk factor for flooding and whether or not the subject property is in a floodplain or a floodway.

The design team should develop the park and greenbelt needs in conjunction with the master planning of the major drainage channels and floodplain zoning. To wait means that a good opportunity may be lost.



Photograph PL-9—Open space, stable channels and recreation go hand-in-hand towards creating urban amenities.

11.0 PLANNING FOR TRANSPORTATION

11.1 Coordination Needed

The planning, design, and construction of transportation facilities including local, state, and federal highways, railroads, utilities involving conduits, and airports often involve crossing or paralleling major channels and streams. Many of the flood problems presently existing are created by inadequate waterway openings (bottlenecks) under transportation facilities. These inadequate openings have been a result of various deficiencies, including lack of appropriate basic criteria, lack of good planning, lack of proper hydraulic engineering, and lack of coordination between the various agencies involved with drainageways.

Many storm drainage problems can be avoided by special cooperation and coordination between the various governmental, state, county, local, and publicly owned agencies in the very early stages of planning for storm drainage works. This is absolutely essential if proper drainage is to be provided at the lowest reasonable cost. Proper coordination will make it possible to solve many of the inherent initial design and monetary problems connected with storm drainage.

Transportation agencies often get involved in constructing drainage works that are necessary for draining their own facilities. Planning such drainage facilities should be integrated with the total urban system and the drainage subsystem of the adjacent urban area in question. At times this will indicate that the drainage facilities constructed for a transportation facility, for instance, should intercept and convey storm runoff from a significant urban drainage basin. In design and construction of sound barriers along freeways, which in essence can act as dams across drainageways, it is possible for the highway designers to neglect the major drainage needs of the uphill land, sometimes creating flooding problems upstream of the sound barrier. A similar situation develops when a roadway embankment or a median barrier is constructed across a drainageway. These can create community costs that should be avoided. It is in these cases that cooperation with the local governmental entity is particularly advantageous so that joint planning, design, and construction can result in a better urban environment.

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12.0 CLEAN WATER ACT SECTION 404 PERMITTING PROCESS

12.1 Purpose of the 404 Permit

The stated purpose of the U.S. Army Corps of Engineers (USACE) Section 404 program is to insure that the physical, biological, and chemical quality of our nation's water is protected from irresponsible and unregulated discharges of dredged or fill material that could permanently alter or destroy these valuable resources.

12.2 Activities Requiring Permit

Section 404 of the Clean Water Act requires approval from the USACE prior to discharging dredged or fill material into the waters of the United States. Typical activities within the waters of the United States (which include adjacent wetlands) requiring Section 404 permits are:

- Site development fill for residential, commercial, or recreational construction
- Construction of revetments, groins, breakwaters, levees, dams, dikes, and weirs
- Placement of riprap
- Construction of roads
- Construction of dams
- Any grading work affecting waters of the United States

12.3 Who Should Obtain a Permit

Any person, firm, or agency (including federal, state, and local government agencies) planning to work, dump, or place dredged or fill material in waters of the United States, must first obtain a permit from the USACE. Other permits, licenses, or authorizations may also be required by other federal, state, and local agencies, and the issuance of a 404 permit does not relieve the proponent from obtaining such permits, approvals, licenses, etc.

12.4 Definition of Waters of the United States

Waters of the United States include essentially all surface waters such as all navigable waters and their tributaries, all interstate waters and their tributaries, all wetlands adjacent to these waters, and all impoundments of these waters.

"Wetlands" are areas characterized by growth of wetland vegetation (e.g., bulrush, cattails, rushes, sedges, willows, pickleweed, andiodine bush) where the soil is saturated during a portion of the growing

season or the surface is flooded during some part of most years. Wetlands generally include swamps, marshes, bogs, and similar areas.

12.5 Pre-Application Meetings

Pre-application meetings with the USACE and other regulatory agencies are encouraged by the USACE to facilitate the review of potentially complex or controversial projects, or projects that could have significant impacts on the human environment. Pre-application meetings can help streamline the permitting process by alerting the applicant to potentially time-consuming concerns that are likely to arise during the evaluation of their project.

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RAINFALL

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1.0 OVERVIEW

The purpose of this chapter is to present the analytical methods used to develop the rainfall information needed in order to carry out the hydrological analyses described in the RUNOFF chapter of this *Manual*. Specifically, this chapter describes: (a) the development of point precipitation values for locations within the Urban Drainage and Flood Control District (District) (Section 2), (b) the temporal distribution of point rainfall to develop the hyetograph necessary for the Colorado Urban Hydrograph Procedure (CUHP) hydrological modeling (Section 3), and (c) preparation of intensity-duration-frequency graphs used in Rational Method hydrologic computations (Section 4). This chapter includes analysis of the 2-, 5-, 10-, 25-, 50-, and 100-year return storm events. If information is needed regarding other storm return periods or areas in Colorado but outside the District, the reader is directed to the *Precipitation-Frequency Atlas of the Western United States, Volume III-Colorado* (NOAA Atlas) published by the National Oceanic and Atmospheric Administration (NOAA) in 1973, which contains a more complete description of rainfall analysis in the State of Colorado.

The *Urban Storm Drainage Criteria Manual* that was originally published in 1969 contained rainfall depth-duration-frequency maps for the 2-, 10-, and 100-year recurrence frequencies. A detailed set of guidelines was given on how to use the depth-duration-frequency maps to develop design rainstorms and time-intensity-frequency curves for any location within the District. The NOAA Atlas published in 1973 was based on a longer period of record and a large number of gages within Colorado (NOAA 1973). Unfortunately the maps in the *Manual* and the NOAA Atlas did not agree with each other.

Since 1977 the District has studied the rainfall and runoff relationships in the Denver metropolitan area. As part of this effort, the rainfall depth-frequency distribution was investigated for a 73-year period at the Denver rain gage. Inconsistencies between the rainfall frequency distribution obtained using a long-term data record and the rainfall depth-frequency-duration maps in the *Manual* were discovered and reported (Urbonas 1978). Further investigations indicated that the NOAA Atlas maps, although not perfect, were more in line with the rainfall frequency distribution of the long-term record.

As the 1982 version of CUHP was being developed, it became apparent that the information in the NOAA Atlas could be converted to a family of design rainstorms by distributing these design storms in a manner that yielded reasonable peak runoff recurrence frequency distributions. For the above-stated reasons and to use rainfall information consistent with the information being used by the State of Colorado, it was concluded that the NOAA Atlas rainfall information should also be used within the District.

2.0 RAINFALL DEPTH-DURATION-FREQUENCY

In order to use CUHP or the Rational Method, it is necessary to find the 1-hour point rainfall for the area of interest. In order to use CUHP method for watersheds larger than 10 square miles in size, the 3-hour and 6-hour point rainfall depths are also required.

2.1 Rainfall Depth-Duration-Frequency Maps

Using the information contained in the NOAA Atlas, rainfall depth-duration-frequency maps were prepared for the Denver Region. Maps are presented for the 1-hour and 6-hour durations for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence frequencies as Figures RA-1 through RA-12.

2.2 Rainfall Depths For Durations Between 1- and 6-Hours

The 2-hour point rainfall depth can be determined using the nomograph presented in Figure RA-13 or the equation:

$$P_2 = P_1 + (P_6 - P_1)0.342 \qquad \text{(RA-1)}$$

Rainfall depths for the 3-hour storm can be determined using Figure RA-13 or the equation:

$$P_3 = P_1 + (P_6 - P_1)0.597 \qquad \text{(RA-2)}$$

in which:

P_1 = 1-hour point rainfall (inches)

P_2 = 2-hour point rainfall (inches)

P_3 = 3-hour point rainfall (inches)

P_6 = 6-hour point rainfall (inches)

In order to use Figure RA-13, the 1-hour and 6-hour point precipitation depths for any particular storm return period are determined using the maps in Figures RA-1 through RA-12. The two values are plotted on the vertical lines of Figure RA-13 labeled 1- and 6-hour duration. A straight line is drawn between the two points. The intersection with the 2-hour or the 3-hour line yields the point rainfall depth for that duration. See Section 7.1 for an example of the calculation of point rainfall depths.

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3.0 DESIGN STORM DISTRIBUTION FOR CUHP

The 1-hour point precipitation value described in Section 2 is distributed into 5-minute increments for use with CUHP model (i.e., temporal distribution). This is described in Section 3.1 and summarized in Table RA-2. The rainfall duration used with CUHP varies with the size of the watershed being analyzed. Also, for watersheds 10 square miles or greater, there is an adjustment made to the incremental precipitation depths to take into account the greater watershed size (i.e., area adjustment). This is described in Section 3.2 and summarized in Table RA-3. A summary of the storm duration and whether area adjustments for different watershed sizes are needed is provided in Table RA-1.

Table RA-1—Storm Duration and Area Adjustment for CUHP Modeling

Watershed Area (square miles)	Suggested Minimum Storm Duration	Area Adjustment Required?
Less than 10.0	2 hours	No
10.0 to 20.0	3 hours	Yes
20.0 and larger	6 hours	Yes

3.1 Temporal Distribution

The current version of CUHP (see RUNOFF) was designed to be used with the NOAA 1-hour rainfall depths described in Section 2.1. The 1-hour rainfall depths for areas within the District are provided in Figures RA-1 through RA-6. To obtain a temporal distribution for a design storm for use in the Denver region, the 1-hour depth is transferred into a 2-hour design storm by multiplying the 1-hour depth(s) by the percentages for each time increment given in Table RA-2. The resultant design storm(s) may then be used with CUHP.

The total of all the incremental depths for the first hour of the design storm does not agree with the 1-hour depth used to develop the design storm. Do not be alarmed. The temporal distribution presented in Table RA-2 represents a design storm for use with a distributed rainfall-runoff routing model. The distribution is the result of a calibration process performed by the District to provide, in conjunction with the use of CUHP, runoff flow peak rates and volumes of the same return period as the design storm. The NOAA Atlas values are “embedded” in the 2-hour and other duration design storms.

In order to develop the temporal distribution for the 3-hour design storm (for watersheds between 10.0 and 20.0 square miles in size), first prepare the first two hours of the storm using the 1-hour storm point precipitation and the temporal percentage distribution shown in Table RA-2. The difference between the 3-hour point precipitation from Equation RA-2 and the 2-hour point precipitation (Table RA-2) is then distributed evenly over the period of 125 minutes to 180 minutes. In order to develop the temporal distribution for the 6-hour design storm (watersheds greater than 20.0 square miles), first prepare the first three hours of the storm as described above. The difference between the 6-hour point precipitation from

Figures RA-1 through RA-12 and the 3-hour point precipitation is distributed evenly over the period of 185 minutes to 360 minutes.

Table RA-2—Design Storm Distributions of 1-Hour NOAA Atlas Depths

Time Minutes	Percent of 1-Hour NOAA Rainfall Atlas Depth				
	2-Year	5-Year	10-Year	25- and 50-Year	100- and 500-Year
5	2.0	2.0	2.0	1.3	1.0
10	4.0	3.7	3.7	3.5	3.0
15	8.4	8.7	8.2	5.0	4.6
20	16.0	15.3	15.0	8.0	8.0
25	25.0	25.0	25.0	15.0	14.0
30	14.0	13.0	12.0	25.0	25.0
35	6.3	5.8	5.6	12.0	14.0
40	5.0	4.4	4.3	8.0	8.0
45	3.0	3.6	3.8	5.0	6.2
50	3.0	3.6	3.2	5.0	5.0
55	3.0	3.0	3.2	3.2	4.0
60	3.0	3.0	3.2	3.2	4.0
65	3.0	3.0	3.2	3.2	4.0
70	2.0	3.0	3.2	2.4	2.0
75	2.0	2.5	3.2	2.4	2.0
80	2.0	2.2	2.5	1.8	1.2
85	2.0	2.2	1.9	1.8	1.2
90	2.0	2.2	1.9	1.4	1.2
95	2.0	2.2	1.9	1.4	1.2
100	2.0	1.5	1.9	1.4	1.2
105	2.0	1.5	1.9	1.4	1.2
110	2.0	1.5	1.9	1.4	1.2
115	1.0	1.5	1.7	1.4	1.2
120	1.0	1.3	1.3	1.4	1.2
Totals	115.7	115.7	115.7	115.6	115.6

3.2 Adjustment to Rainfall Distribution for Watershed Size

The NOAA Atlas provides guidelines for adjusting the rainfall depths with increasing catchment area. Area-depth adjustments are given in the Atlas for durations of ½-, 1-, 3-, 6- and 24-hours. Figure RA-14 was based on a similar figure in the NOAA Atlas. The 15-minute curve was extrapolated by the District from the information shown for other storm durations on Figure RA-14. The fast response times of urbanized watersheds and sharp rainstorm distribution gradients in the Denver area require adjustments of rainfall depths for storm durations that are less than ½-hour.

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The area adjustment procedure can be tedious and time consuming; therefore, Table RA-3 is provided to assist the engineer with the area-depth adjustment calculations. To adjust the design storm distribution to account for the averaging effects of larger watersheds, follow these three steps:

Step 1—Begin with the unadjusted design rainstorm for the needed storm duration (see Table RA-1) developed using the procedure described in Section 3.1.

Step 2—On the basis of total watershed size, select the appropriate column(s) of adjustment factors in Table RA-3.

Step 3—Multiply each incremental design storm depth by its respective adjustment factor for that time increment.

Table RA-3—Area Adjustment Factors for Design Rainfall Distributions

	2-, 5-, and 10-Year Design Rainfall Area—Square Miles				25-, 50-, 100-, and 500-Year Design Rainfall Area—Square Miles			
Time Minutes	10-20	20-30	30-50	50-75	10-20	20-30	30-50	50-75
5	1.00	1.00	1.10	1.10	1.00	1.00	1.05	1.10
10	1.00	1.00	1.05	1.10	1.00	1.00	1.05	1.10
15	1.00	1.00	1.05	1.00	1.00	1.00	1.05	1.10
20	0.90	0.81	0.74	0.62	1.00	1.00	1.05	1.00
25	0.90	0.81	0.74	0.62	0.90	0.81	0.74	0.60
30	0.90	0.81	0.74	0.62	0.90	0.81	0.74	0.60
35	1.00	1.00	1.05	1.00	0.90	0.81	0.74	0.70
40	1.00	1.00	1.05	1.10	1.00	1.00	1.05	1.00
45	1.00	1.00	1.05	1.10	1.00	1.00	1.05	1.10
50	1.00	1.00	1.05	1.10	1.00	1.00	1.05	1.10
55	1.00	1.00	1.05	1.10	1.00	1.00	1.05	1.10
60	1.00	1.00	1.05	1.10	1.00	1.00	1.05	1.10
65 - 120	1.00	1.00	1.05	1.10	1.00	1.00	1.05	1.10
125 - 180	1.00	1.15	1.20	1.40	1.00	1.15	1.20	1.40
185 - 360	N/A	1.15	1.20	1.20	N/A	1.15	1.20	1.20

See Section 7.2 for an example of the preparation of a design rainfall for use with CUHP.

4.0 INTENSITY-DURATION CURVES FOR RATIONAL METHOD

To develop depth-duration curves or intensity-duration curves for the Rational Method of runoff analysis take the 1-hour depth(s) obtained from Figures RA-1 through RA-6 and multiply by the factors in Table RA-4 to determine rainfall depth and rainfall intensity at each duration. The intensity can then be plotted as illustrated in Figure RA-15.

TABLE RA-4—Factors for Preparation of Intensity-Duration Curves

Duration (minutes)	5	10	15	30	60
Rainfall Depth at Duration (inches)	$0.29P_1$	$0.45P_1$	$0.57P_1$	$0.79P_1$	$1.0P_1$
Intensity (inches per hour)	$3.48P_1$	$2.70P_1$	$2.28P_1$	$1.58P_1$	$1.0P_1$

Alternatively, the rainfall intensity for the area within the District can be approximated by the equation:

$$I = \frac{28.5\ P_1}{(10 + T_c)^{0.786}} \qquad \text{(RA-3)}$$

in which:

I = rainfall intensity (inches per hour)

P_1 = 1-hour point rainfall depth (inches)

T_c = time of concentration (minutes)

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5.0 BASIS FOR DESIGN STORM DISTRIBUTION

The orographic effects of the Rocky Mountains and the high plains near the mountains as well as the semi-arid climate influence rainfall patterns in the Denver area. Rainstorms can often have an "upslope" character where the easterly flow of moisture settles against the mountains. These types of rainstorms have durations that can exceed six hours and, although they may produce large amounts of total precipitation, they are rarely intense. Although upslope storms may cause local drainage problems or affect the flood levels of large watersheds, they are not the cause of 2- through 100-year type of flooding of small urban catchments in the Denver area.

Very intense rainfall in the Denver area results from convective storms or frontal stimulated convective storms. These types of storms often have their most intense periods that are less than one or two hours in duration. They can produce brief periods of high rainfall intensities. It is these short-duration, intense rainstorms that appear to cause most of the flooding problems in the great majority of urban catchments.

Analysis of a 73-year record of rainfall at the Denver rain gage revealed that an overwhelming majority of the intense rainstorms produced their greatest intensities in the first hour of the storm. In fact, of the 73 most intense storms analyzed, 68 had the most intense period begin and end within the first hour of the storm, and 52 had the most intense period begin and end within the first half hour of the storm. The data clearly show that the leading intensity storms predominate among the "non-upslope" type storms in the Denver region.

The recommended design storm distribution takes into account the observed "leading intensity" nature of the convective storms. In addition, the temporal distributions for the recommended design storms were designed to be used with the 1982 and later version of CUHP, the published NOAA 1-hour precipitation values (NOAA 1973) and Horton's infiltration loss equation. They were developed to approximate the recurrence frequency of peak flows and volumes (i.e., 2- through 100-years) that were found to exist for the watersheds for which rainfall-runoff data were collected. The procedure for the development of these design storm distributions and the preliminary results were reported in literature and in District publications (Urbonas 1978; Urbonas 1979). The recommendations contained in this *Manual* are the result of refinements to the work originally reported in 1979.

6.0 SPREADSHEET DESIGN AIDS

Two spreadsheet design aids have been developed in order to facilitate computation of design rainfall.

The UD-Raincurve Spreadsheet computes the temporal distribution and area-adjusted design of rainfall for use with CUHP model. Input to the spreadsheet includes the 1-hour and 6-hour point rainfall amounts determined from Figures RA-1 through RA-12. The rainfall amount(s) should be entered into the page of the spreadsheet with the desired return period. The output is the rainfall distribution in 5-minute increments (including any required area adjustment) that may be used for CUHP modeling.

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7.0 EXAMPLES

7.1 Example Computation of Point Rainfall

Find the 2-year and 100-year design storm point rainfall for Section 1, Township 1 South, Range 68 West.

Determine 1-hour and 6-hour point rainfall values from Figures RA-1, RA-6, RA-7, and RA-12.

Storm Event	Point Precipitation (Inches)	Map Reference
2-year, 1-hour	0.95	RA-1
2-year, 6-hour	1.46	RA-7
100-year, 1-hour	2.67	RA-6
100-year, 6-hour	3.67	RA-12

Determine 2-hour point precipitation values from Equation RA-1:

$$P_2 \text{ (2-year)} = \text{2-year, 2-hour} = 0.95 + (1.46 - 0.95)\ 0.342 = 1.12 \text{ inches}$$

$$P_2 \text{ (100-year)} = \text{100-year, 2-hour} = 2.67 + (3.67 - 2.67)\ 0.342 = 3.01 \text{ inches}$$

Determine 3-hour point precipitation values from Equation RA-2:

$$P_3 \text{ (2-year)} = \text{2-year, 3-hour} = 0.95 + (1.46 - 0.95)\ 0.597 = 1.25 \text{ inches}$$

$$P_3 \text{ (100-year)} = \text{100-year, 3-hour} = 2.67 + (3.67 - 2.67)\ 0.597 = 3.27 \text{ inches}$$

7.2 Example Distribution of Point Rainfall

Prepare a 100-year rainfall distribution to be used in CUHP computer model for a 15-square-mile catchment centered about Section 7, Township 4 South, Range 67 West.

As per Table RA-1, a 15.0-square-mile watershed requires a 3-hour storm with area adjustment.

Using Figures RA-6 and RA-12, the 100-year, 1-hour, and 6-hour point precipitation values are 2.60 inches and 3.50 inches respectively. The 3-hour point precipitation is calculated using Equation RA-2.

$$P_3 = 2.60 + (3.5 - 2.6)\ 0.597 = 3.14 \text{ inches}$$

Use the design storm distribution from Table RA-2 for 0 to 120 minutes. The period 125 to 180 minutes is calculated as the difference of P_3 from Equation RA-2 and P_2 from Table RA-2 evenly distributed over that time period. Area adjustment factors from Table RA-3 are applied. The results of the calculations are shown in Table RA-5.

Table RA-5—CUHP Rainfall Distribution for Example 7.2

Time (minutes)	Percentage of 1-Hour Rainfall[1]	Rainfall Without Area Adjustment (inches)[2]	Area Adjustment Factor[3]	Rainfall With Area Adjustment (inches)[4]
5	1.0%	0.026	1.0	0.026
10	3.0%	0.078	1.0	0.078
15	4.6%	0.120	1.0	0.120
20	8.0%	0.208	1.0	0.208
25	14.0%	0.364	0.9	0.328
30	25.0%	0.650	0.9	0.585
35	14.0%	0.364	0.9	0.328
40	8.0%	0.208	1.0	0.208
45	6.2%	0.161	1.0	0.161
50	5.0%	0.130	1.0	0.130
55	4.0%	0.104	1.0	0.104
60	4.0%	0.104	1.0	0.104
65	4.0%	0.104	1.0	0.104
70	2.0%	0.052	1.0	0.052
75	2.0%	0.052	1.0	0.052
80	1.2%	0.031	1.0	0.031
85	1.2%	0.031	1.0	0.031
90	1.2%	0.031	1.0	0.031
95	1.2%	0.031	1.0	0.031
100	1.2%	0.031	1.0	0.031
105	1.2%	0.031	1.0	0.031
110	1.2%	0.031	1.0	0.031
115	1.2%	0.031	1.0	0.031
120	1.2%	0.031	1.0	0.031
125-180		0.011[5]	1.0	0.011

Notes:

[1] From Table RA-2.

[2] Precipitation = 2.6 inches x Column 2.

[3] From Table RA-3.

[4] Column 3 x Column 4.

[5] (3.14 – (2.6 · 1.156))/12.

Alternatively, the 1-hour and 6-hour point precipitation values can be inserted into the spreadsheet to obtain CUHP rainfall distribution.

7.3 Example Preparation of Intensity-Duration-Frequency Curve

Prepare a rainfall intensity-duration curve for a 2.6-inch, 1-hour point precipitation.

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Calculations are prepared using both Table RA-4 and Equation RA-3. They are summarized below in Table RA-6.

Table RA-6—Rainfall Intensity-Duration Values for a 2.6-inch, 1-Hour Point Precipitation

Duration (minutes)	Rainfall Intensity (inches/hour)	
	Table RA-4	Equation RA-3
5	$3.48 \cdot 2.6 = 9.05$	$28.5 \cdot 2.6/(10 + 5)^{0.786} = 8.82$
10	$2.70 \cdot 2.6 = 7.02$	$28.5 \cdot 2.6/(10 + 10)^{0.786} = 7.03$
15	$2.28 \cdot 2.6 = 5.93$	$28.5 \cdot 2.6/(10 + 15)^{0.786} = 5.90$
30	$1.58 \cdot 2.6 = 4.11$	$28.5 \cdot 2.6/(10 + 30)^{0.786} = 4.08$
60	$1.0 \cdot 2.6 = 2.60$	$28.5 \cdot 2.6/(10 + 60)^{0.786} = 2.63$

Using the two different methods (Table RA-4 and Equation RA-3) yields similar results. The values from Equation RA-3 are plotted in Figure RA-15.

8.0 REFERENCES

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Urbonas, B. 1979. Reliability of Design Storms In Modeling. In *Proceedings International Symposium on Urban Storm Runoff*, 27-36. Lexington, KY: University of Kentucky.

Urbonas, B. 1988. Some Findings in the Rainfall-Runoff Data Collected in the Denver Area. *Flood Hazard News* 18(1):10.

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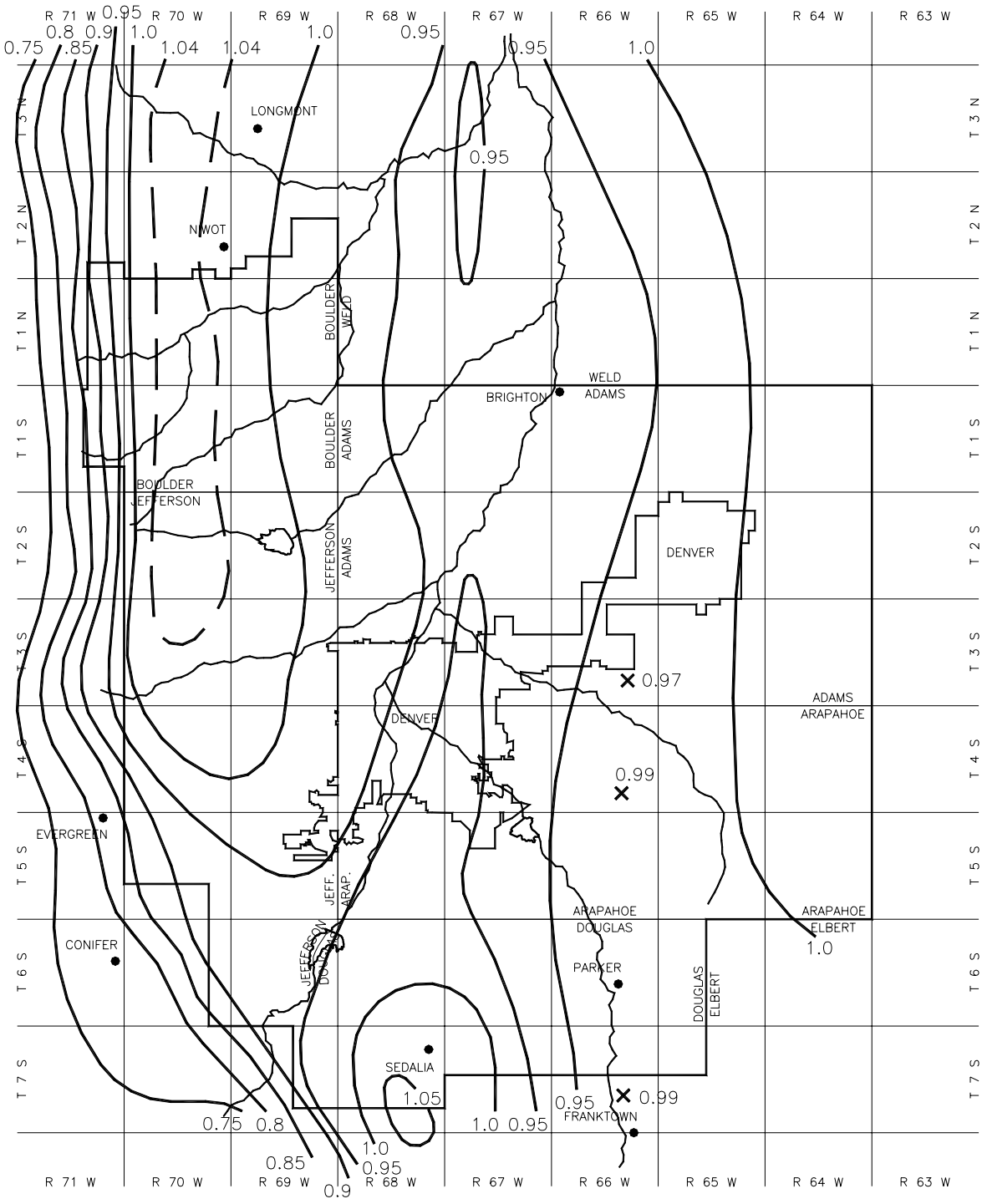

Figure RA-1—Rainfall Depth-Duration-Frequency: 2-Year, 1-Hour Rainfall

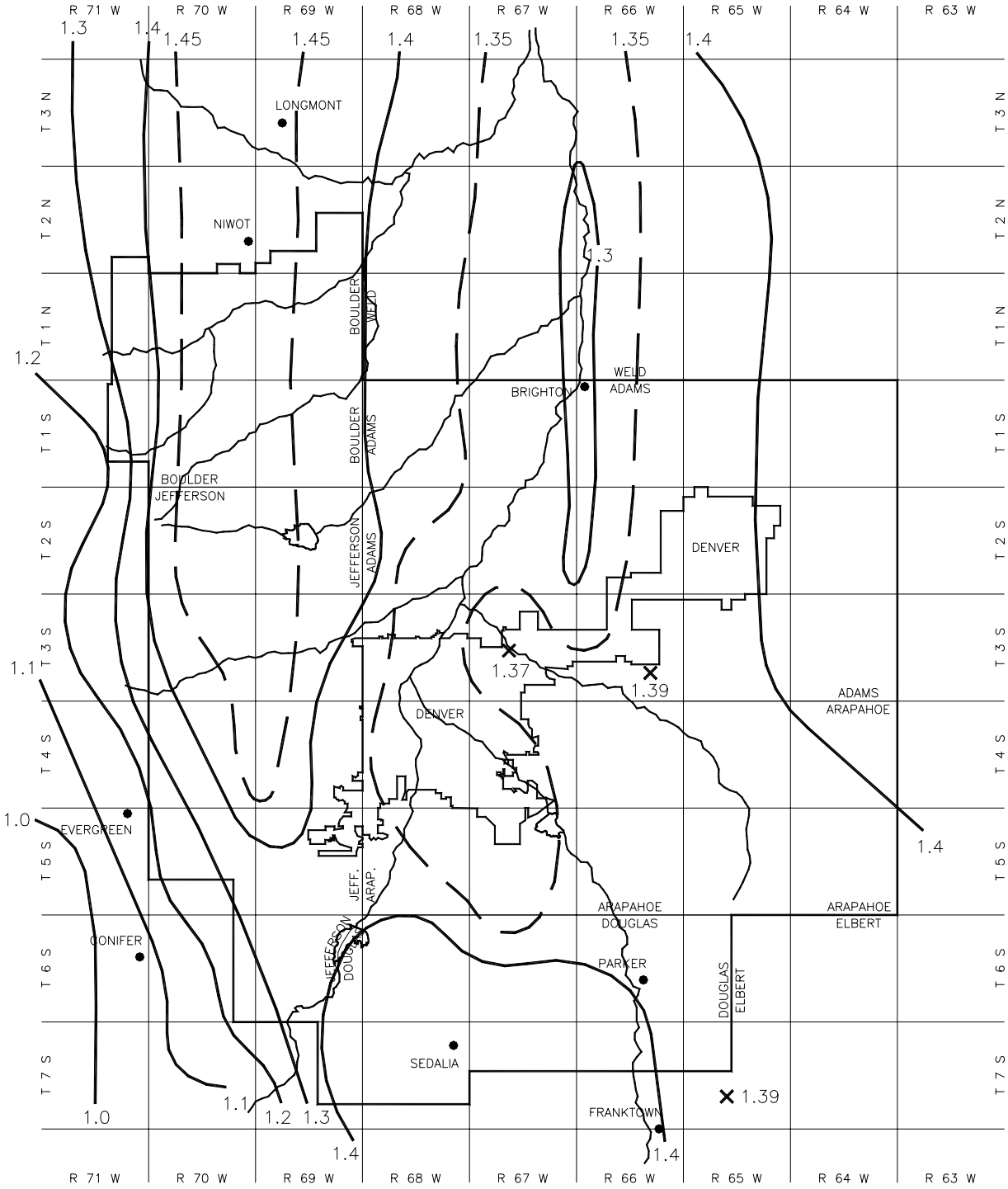

Figure RA-2—Rainfall Depth-Duration-Frequency: 5-Year, 1-Hour Rainfall

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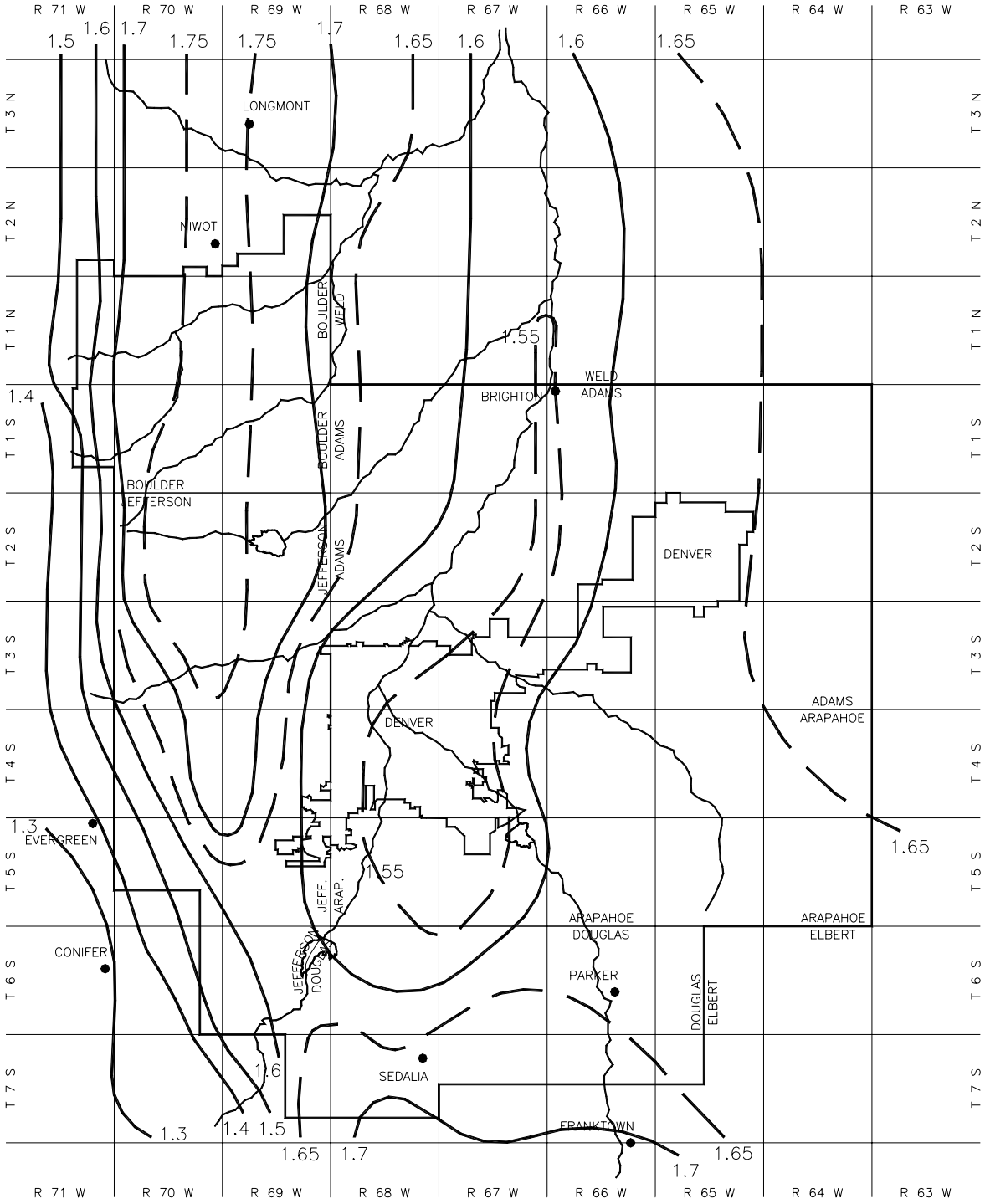

Figure RA-3—Rainfall Depth-Duration-Frequency: 10-Year, 1-Hour Rainfall

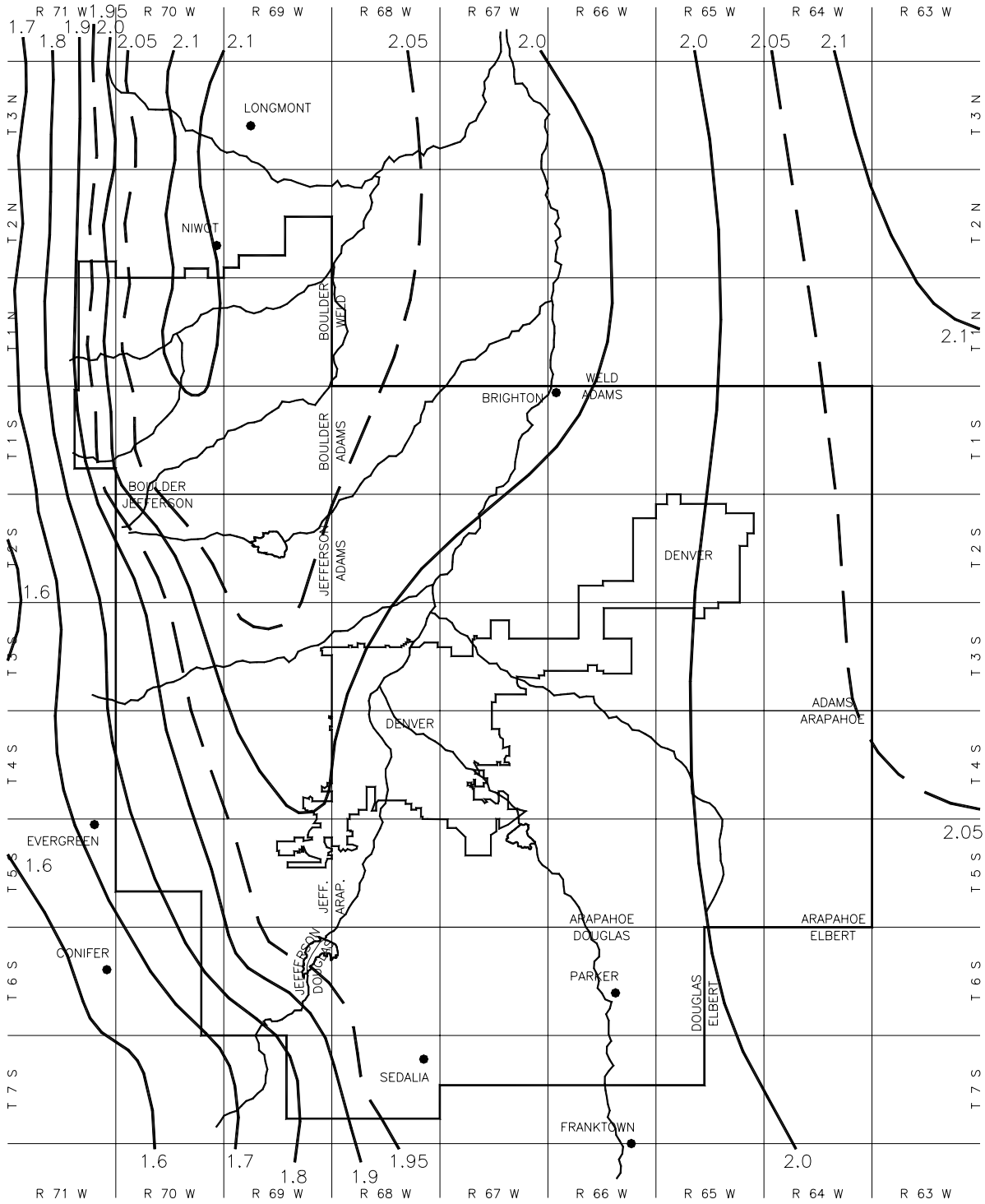

Figure RA-4—Rainfall Depth-Duration-Frequency: 25-Year, 1-Hour Rainfall

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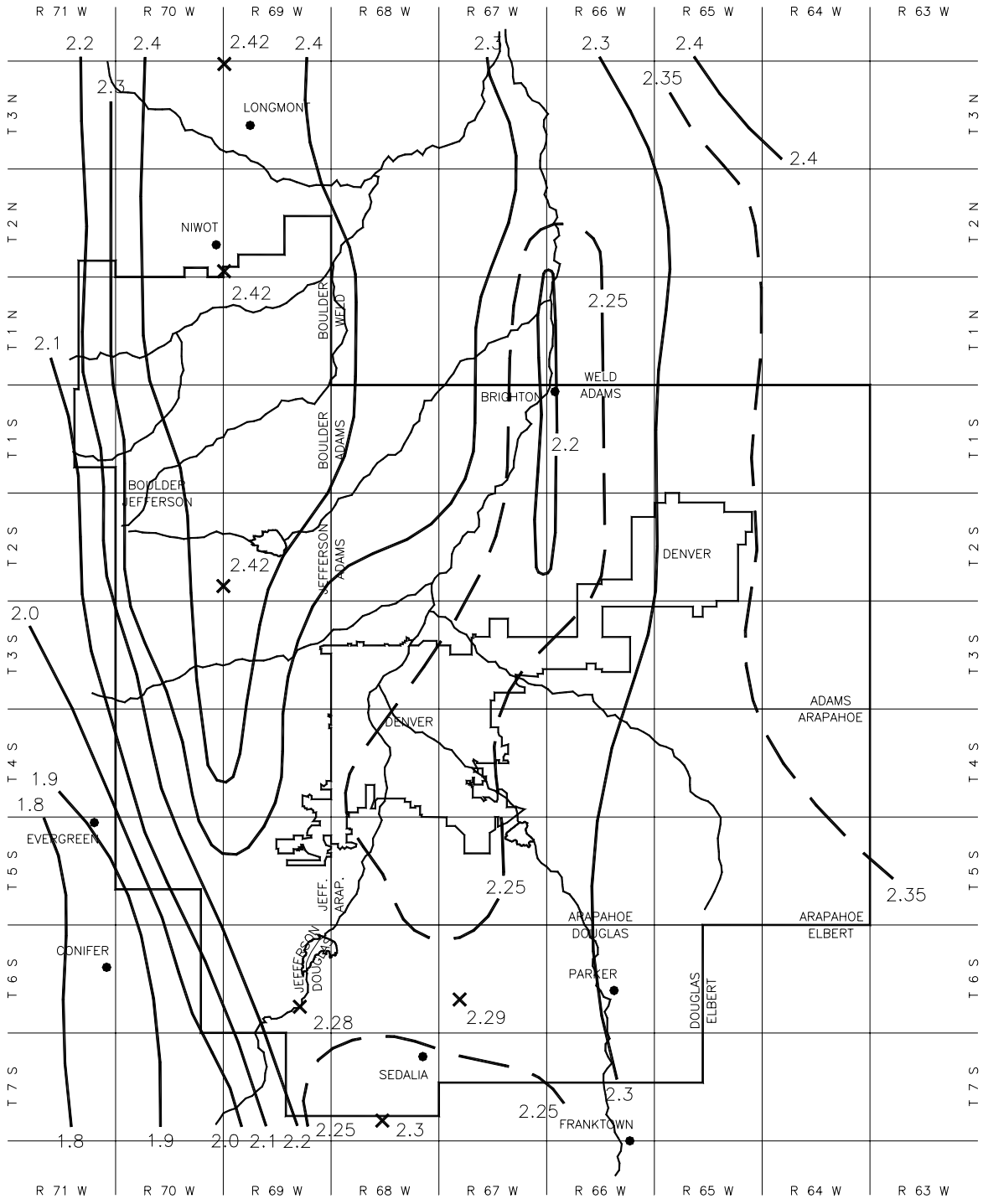

Figure RA-5—Rainfall Depth-Duration-Frequency: 50-Year, 1-Hour Rainfall

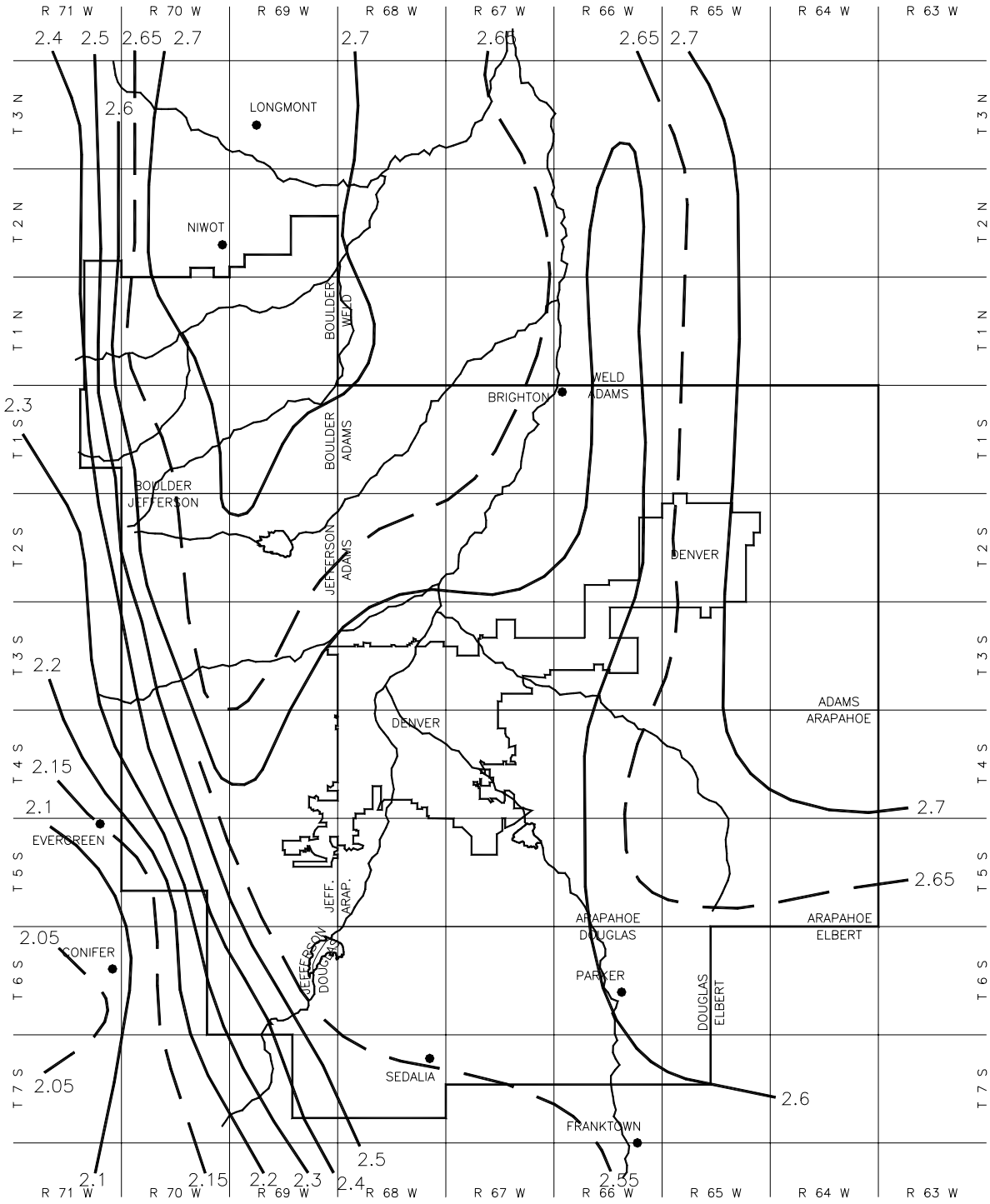

Figure RA-6—Rainfall Depth-Duration-Frequency: 100-Year, 1-Hour Rainfall

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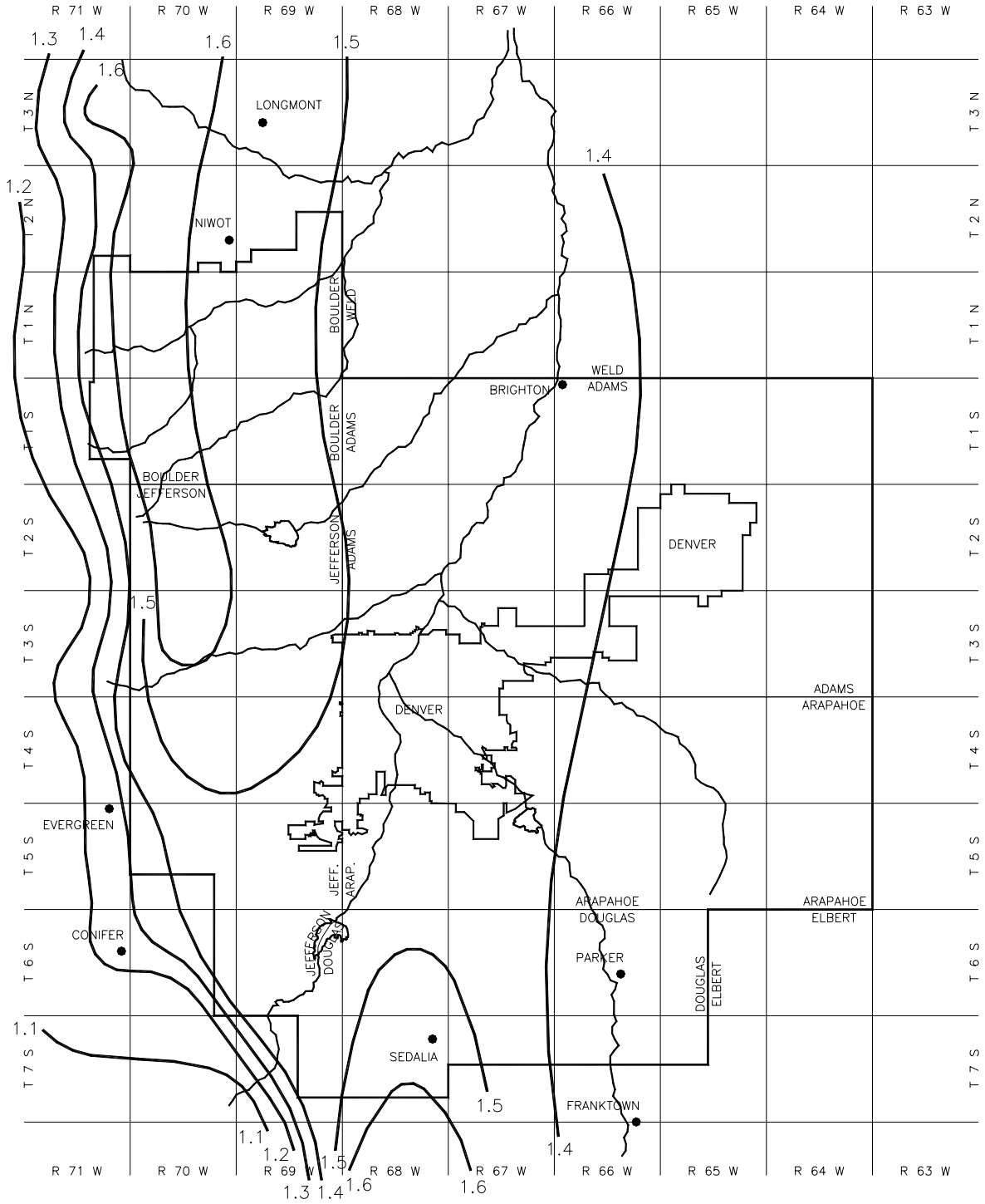

Figure RA-7—Rainfall Depth-Duration-Frequency: 2-Year, 6-Hour Rainfall

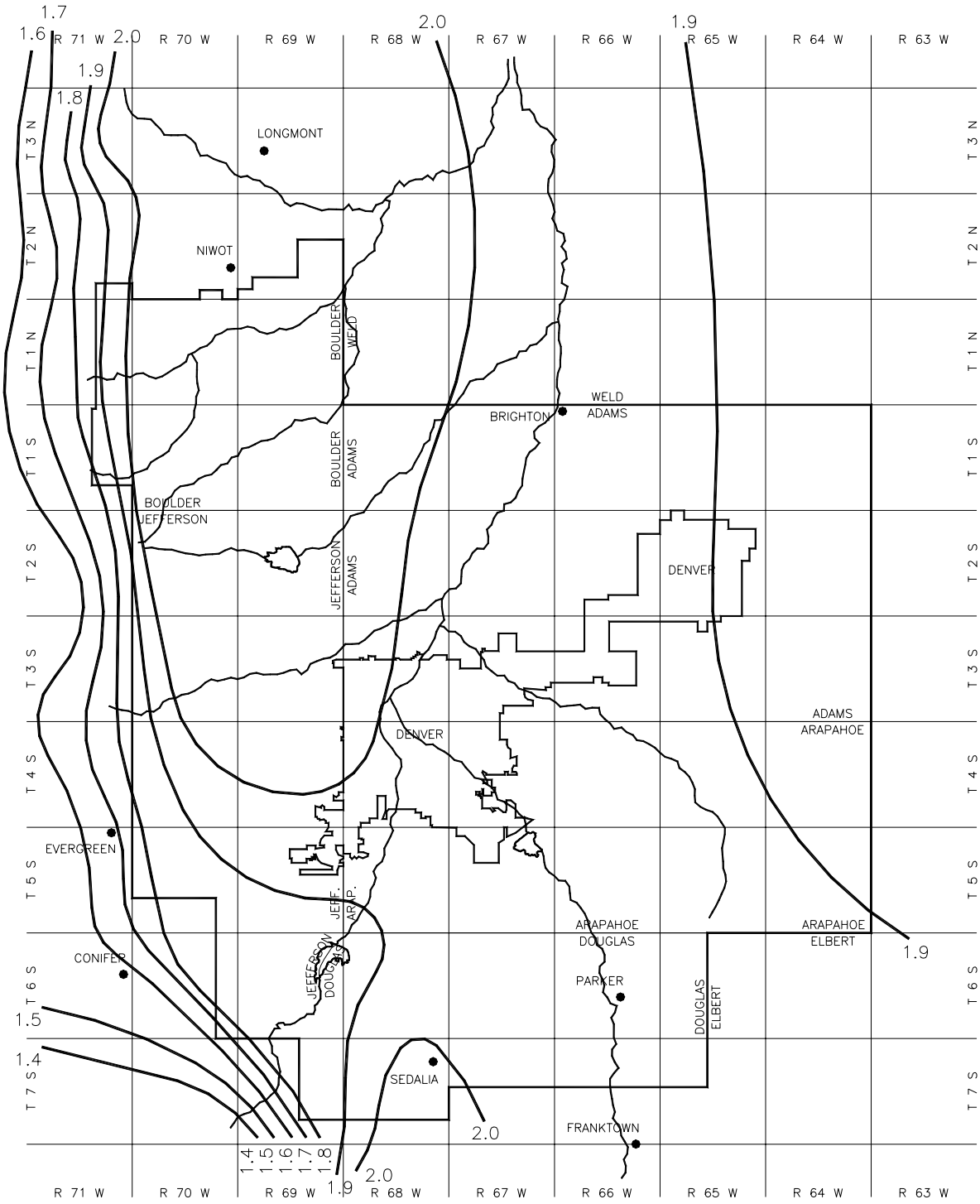

Figure RA-8—Rainfall Depth-Duration-Frequency: 5-Year, 6-Hour Rainfall

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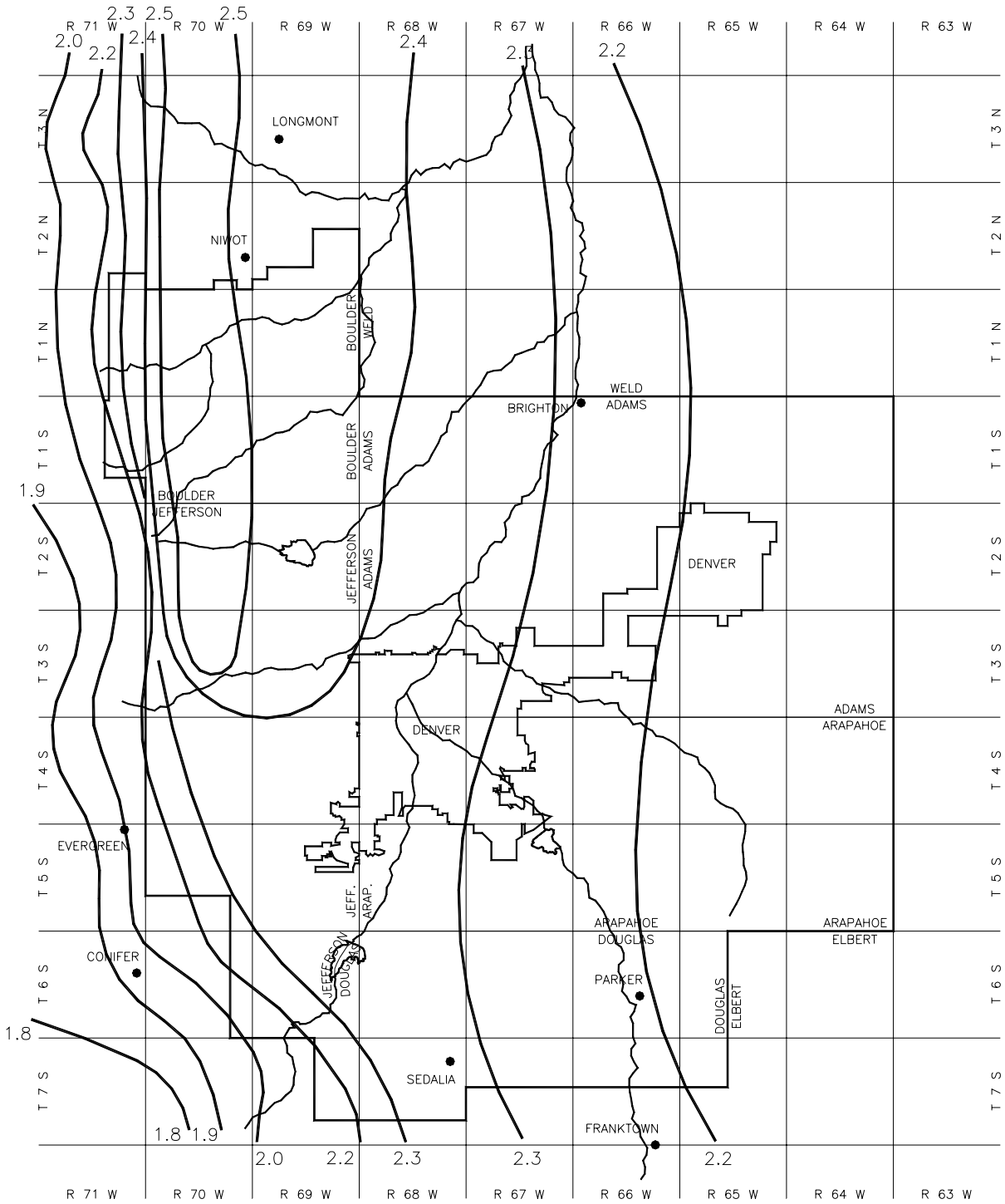

Figure RA-9—Rainfall Depth-Duration-Frequency: 10-Year, 6-Hour Rainfall

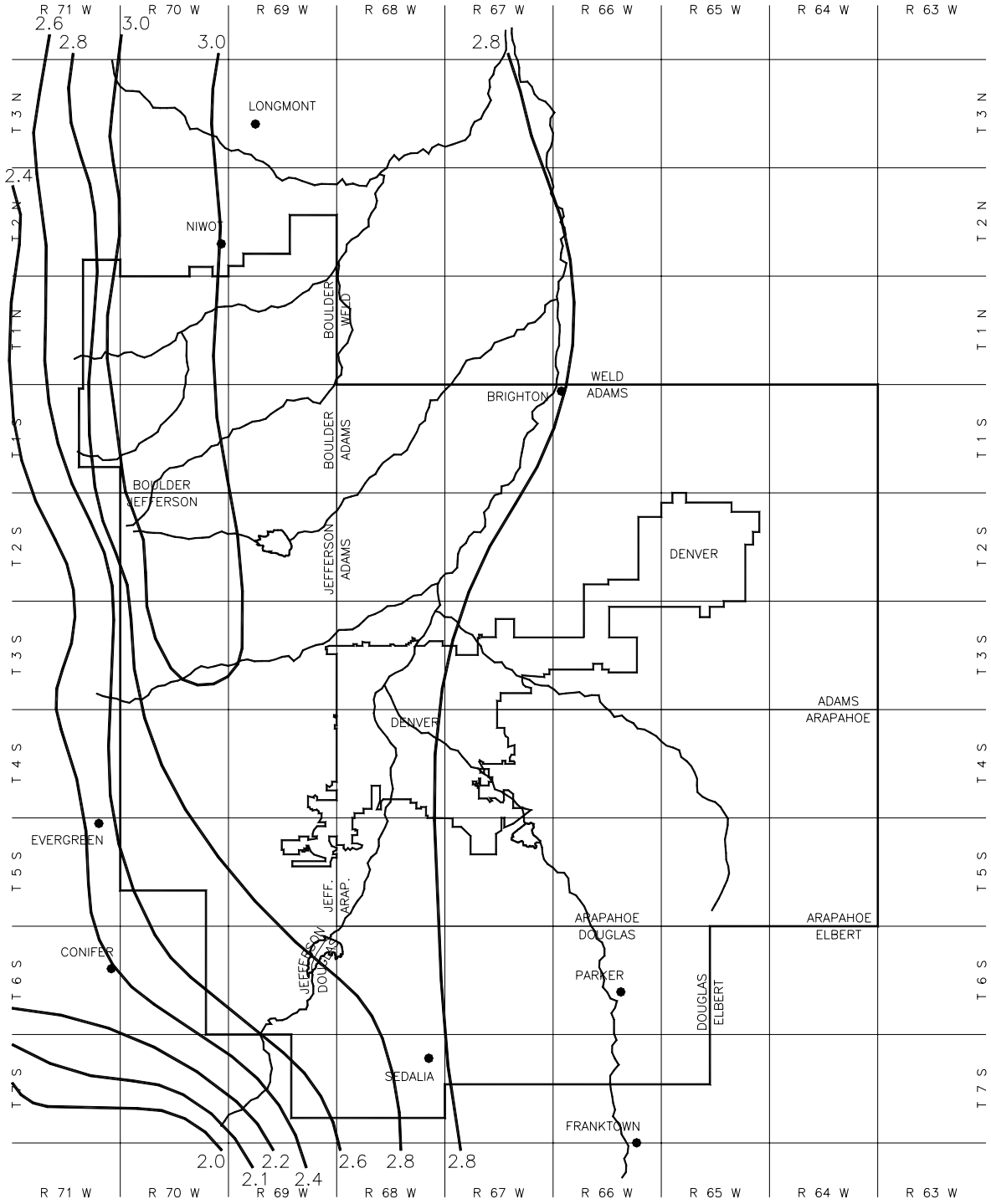

Figure RA-10—Rainfall Depth-Duration-Frequency: 25-Year, 6-Hour Rainfall

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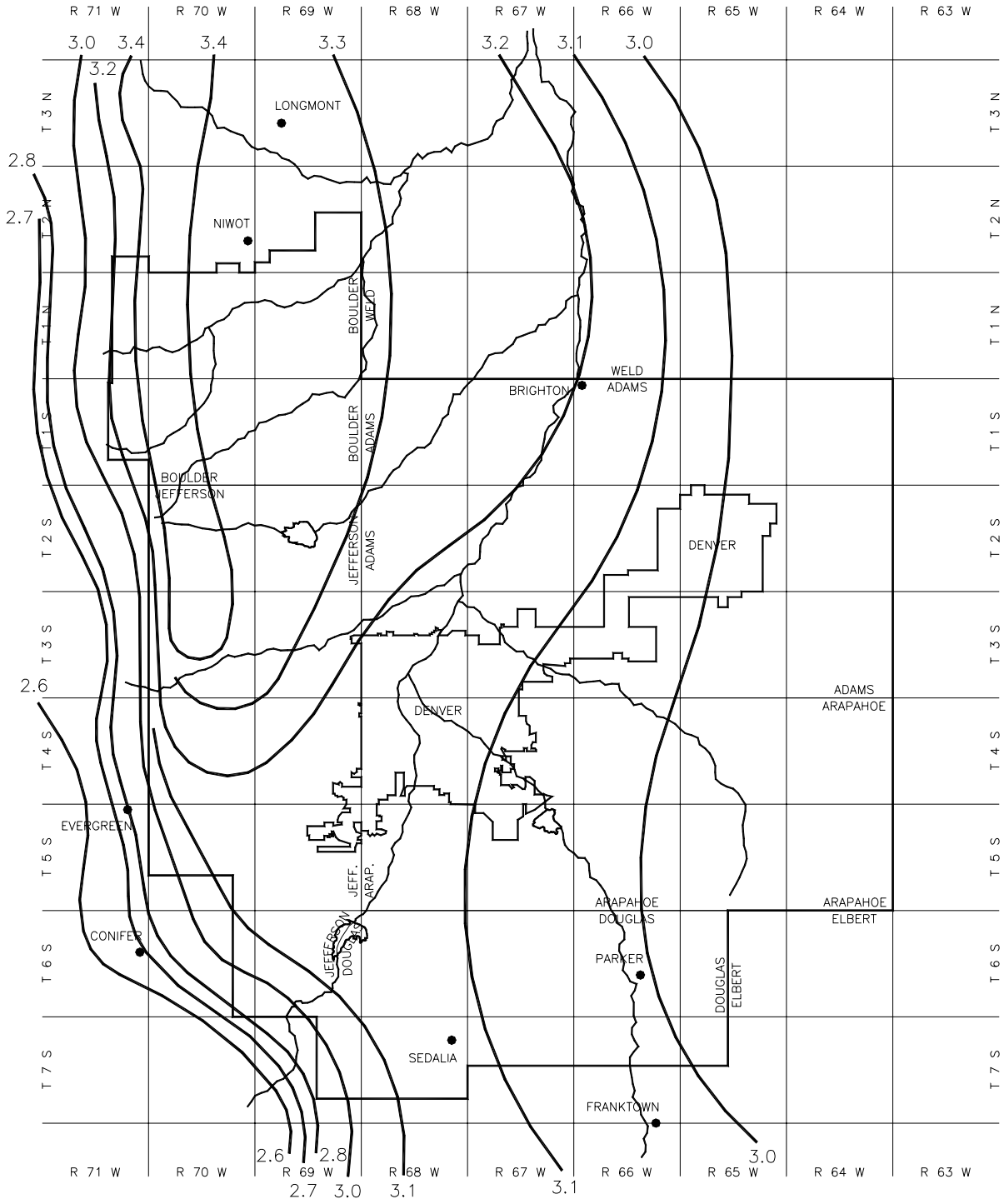

Figure RA-11—Rainfall Depth-Duration-Frequency: 50-Year, 6-Hour Rainfall

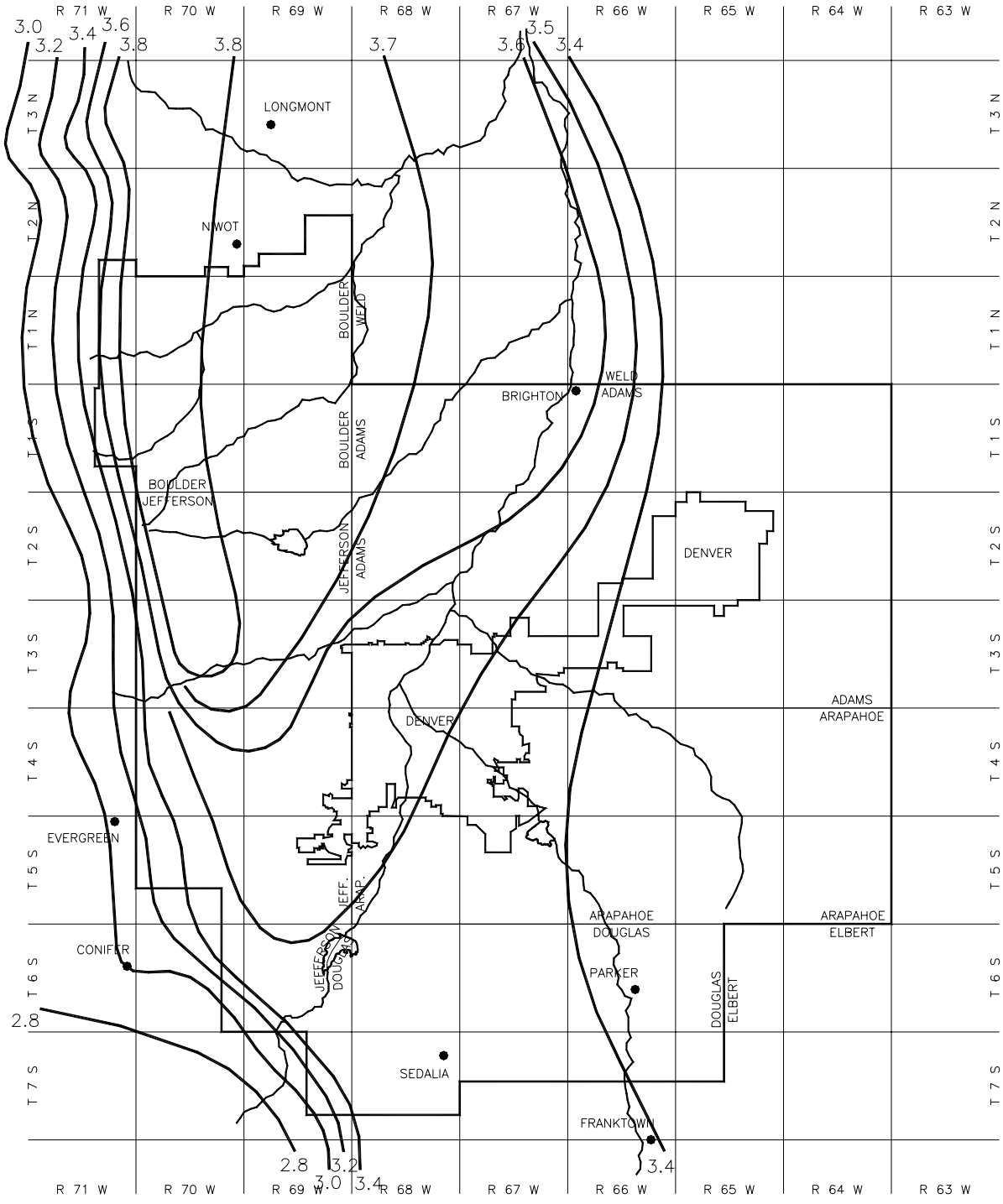

Figure RA-12—Rainfall Depth-Duration-Frequency: 100-Year, 6-Hour Rainfall

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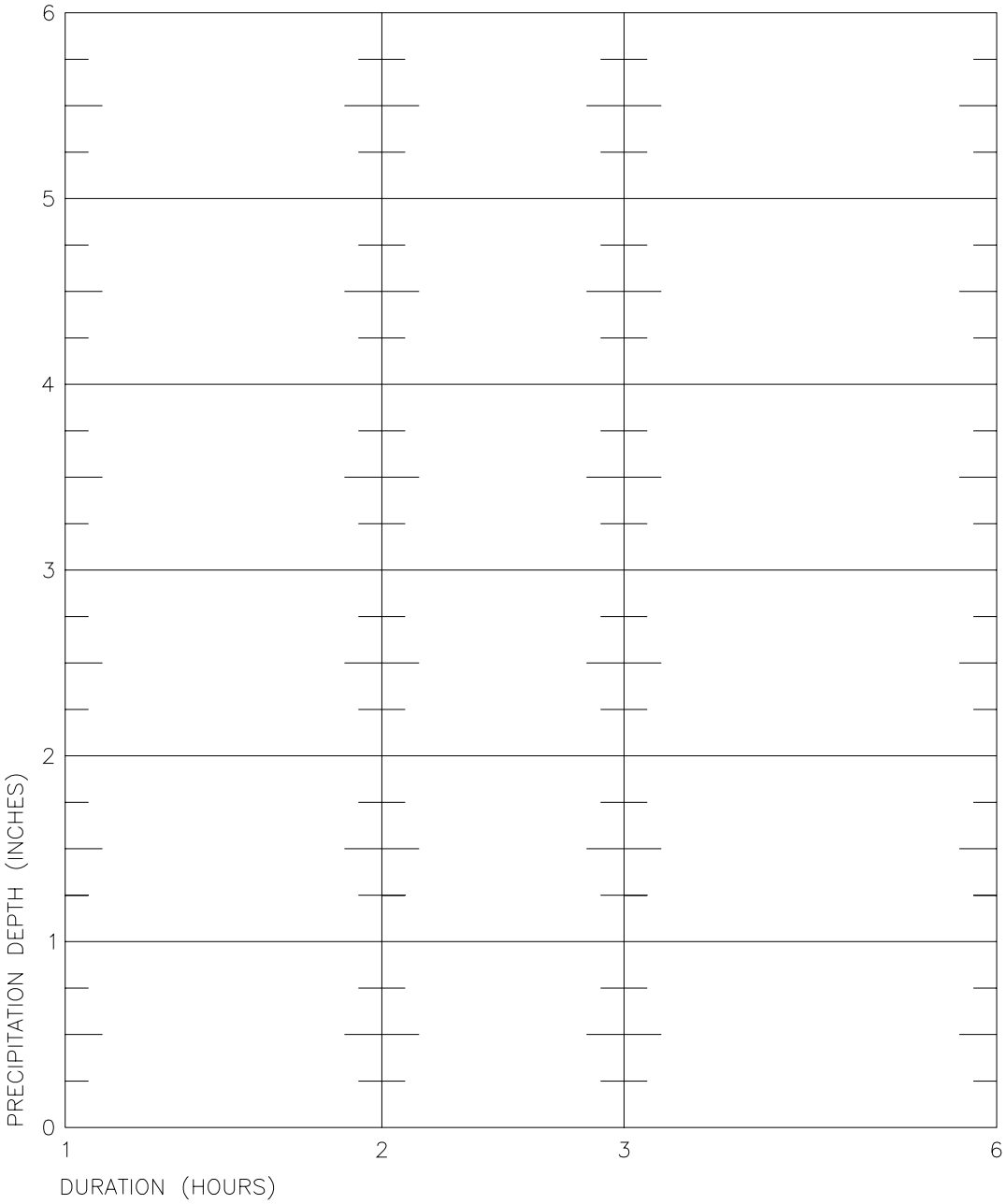

Figure RA-13—Rainfall Depth-Duration-Frequency: Precipitation Depth-Duration Nomograph For Use East of Continental Divide

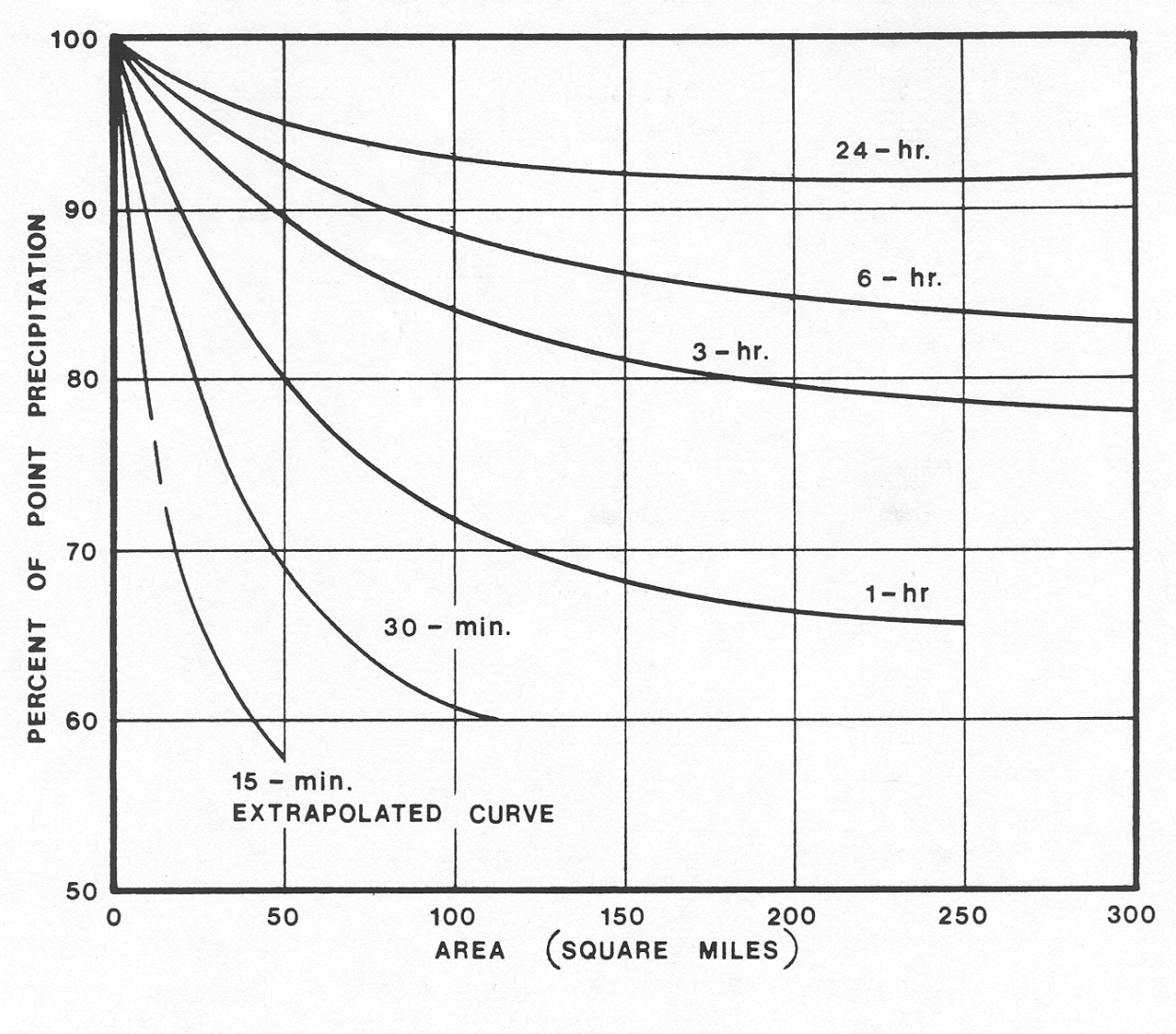

Figure RA-14—Depth-Area Adjustment Curves

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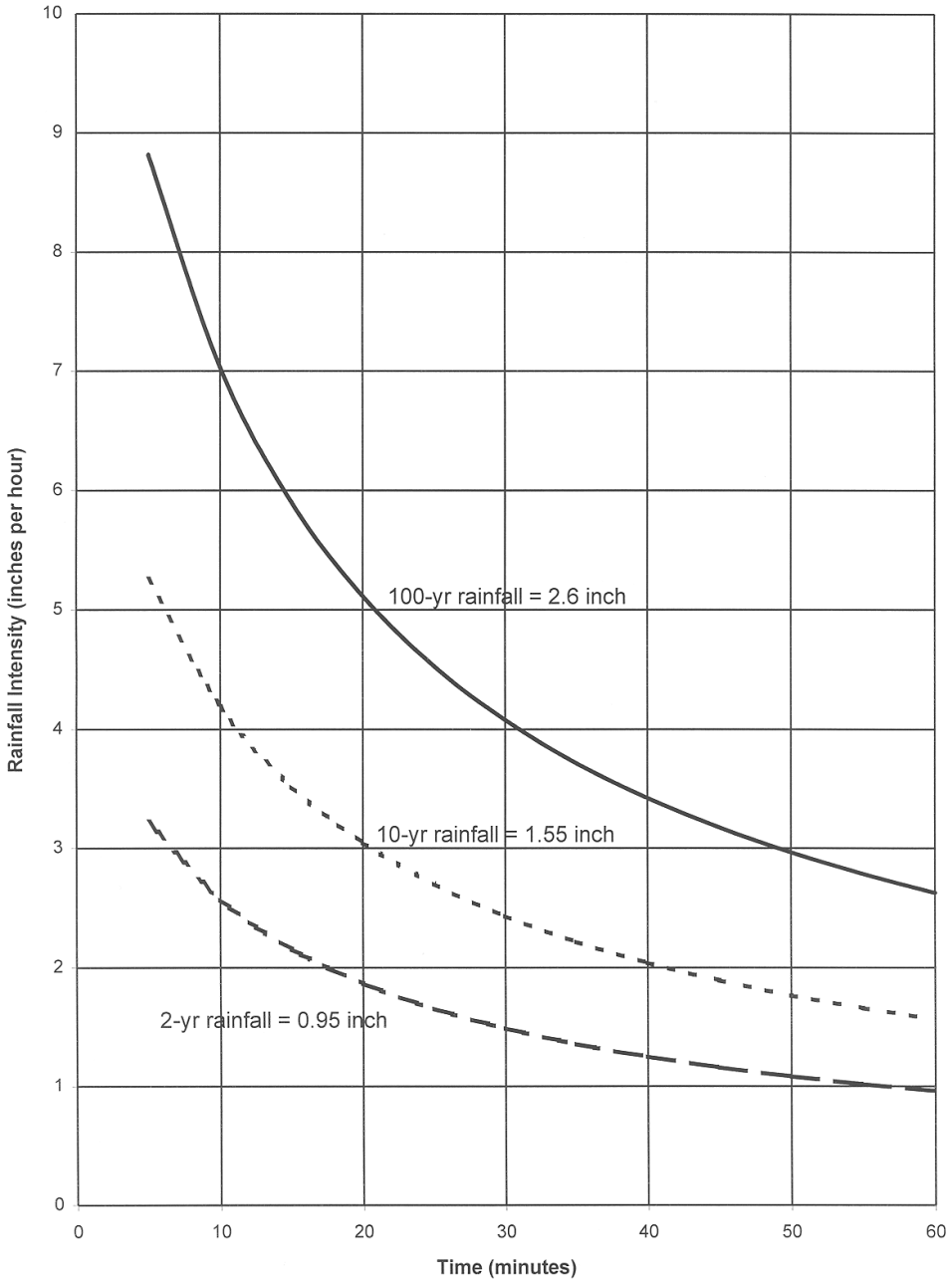

Figure RA-15—Rainfall Intensity-Duration Curves

RUNOFF

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1.0 OVERVIEW

The importance of accurate runoff quantification cannot be overstated. Estimates of peak rate of runoff, runoff volume, and the time distribution of flow provide the basis for all planning, design, and construction of drainage facilities. Erroneous hydrology results in works being planned and built that are either undersized, oversized, or out of hydraulic balance. On the other hand, it must be kept in mind that the result of the runoff analysis is an approximation. Thus, the intent of this chapter of the *Manual* is to provide a reasonably dependable and consistent method of approximating the characteristics of urban runoff for areas of Colorado and the United States having similar meteorology and hydrology to what is found within the Denver region.



Photograph RO-1—Devastating flooding from the South Platte River in 1965 emphasizes the importance of accurate flood flow projections.

Five methods of hydrologic analysis are described in this *Manual:* (1) the Rational Method; (2) the Colorado Urban Hydrograph Procedure (CUHP) for generating hydrographs from watersheds, (3) the EPA's Storm Water Management Model (SWMM), mostly for combining and routing the hydrographs generated using CUHP; (4) use of published runoff information; and (5) statistical analyses. CUHP has been calibrated for the Denver area using data that were collected for a variety of watershed conditions and has been used extensively since 1969. The vast majority of major drainage facilities within the District have been designed based upon the hydrology calculated using the CUHP and a previously used routing model used by the District, namely the Urban Drainage Stormwater Model (UDSWM). In 2005 the District has began using the EPA's SWMM and has also upgraded the CUHP software to be compatible with the EPA model.

There have been hydrologic studies carried out for a majority of the major drainageways within the

District. Often the use of published flow data (available from the District) may make the need for additional hydrologic analysis along major drainageways for a particular study unnecessary.

Statistical analyses may be used in certain situations. The use of this approach requires the availability of acceptable, appropriate, and adequate data.

Calculations for the Rational Method can be carried out by hand or using the UD-Rational Spreadsheet that may be downloaded from the District's Web site (www.udfcd.org). CUHP-SWMM calculations are extensive and are best carried out using the computer models provided by the District as an attachment to the CD version of this *Manual* or downloaded from the District's Web site.

Most of this chapter focuses on the Rational Method and on the CUHP method in combination with SWMM routing. The Rational Method is generally used for smaller catchments when only the peak flow rate or the total volume of runoff is needed (e.g., storm sewer sizing or simple detention basin sizing). CUHP-SWMM is used for larger catchments and when a hydrograph of the storm event is needed (e.g., sizing large detention facilities). A summary of applicability of both the methods is provided in Table RO-1.

Table RO-1—Applicability of Hydrologic Methods

Watershed Size (acres)	Is the Rational Method Applicable?	Is CUHP Applicable?
0 to 5	Yes	Yes (1)
5 to 90	Yes	Yes (1)
90 to 160	Yes	Yes
160 to 3,000	No	Yes (2)
Greater than 3,000	No	Yes (if subdivided into smaller catchments) (2)

(1) If one-minute unit hydrograph is used.

(2) Subdividing into smaller sub-catchments and routing the resultant hydrographs using SWMM may be needed to accurately model a catchment with areas of different soil types or percentages of imperviousness.

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2.0 RATIONAL METHOD

For urban catchments that are not complex and are generally 160 acres or less in size, it is acceptable that the design storm runoff be analyzed by the Rational Method. This method was introduced in 1889 and is still being used in most engineering offices in the United States. Even though this method has frequently come under academic criticism for its simplicity, no other practical drainage design method has evolved to such a level of general acceptance by the practicing engineer. The Rational Method properly understood and applied can produce satisfactory results for urban storm sewer and small on-site detention design.

2.1 Rational Formula

The Rational Method is based on the Rational Formula:

$$Q = CIA \qquad \text{(RO-1)}$$

in which:

Q = the maximum rate of runoff (cfs)

C = a runoff coefficient that is the ratio between the runoff volume from an area and the average rate of rainfall depth over a given duration for that area

I = average intensity of rainfall in inches per hour for a duration equal to the time of concentration, t_c

A = area (acres)

Actually, Q has units of inches per hour per acre (in/hr/ac); however, since this rate of in/hr/ac differs from cubic feet per second (cfs) by less than one percent, the more common units of cfs are used. The time of concentration is typically defined as the time required for water to flow from the most remote point of the area to the point being investigated. The time of concentration should be based upon a flow length and path that results in a time of concentration for only a portion of the area if that portion of the catchment produces a higher rate of runoff.

The general procedure for Rational Method calculations for a single catchment is as follows:

1. Delineate the catchment boundary. Measure its area.
2. Define the flow path from the upper-most portion of the catchment to the design point. This flow path should be divided into reaches of similar flow type (e.g., overland flow, shallow swale flow, gutter flow, etc.). The length and slope of each reach should be measured.
3. Determine the time of concentration, t_c, for the catchment.

4. Find the rainfall intensity, I, for the design storm using the calculated t_c and the rainfall intensity-duration-frequency curve. (See Section 4.0 of the RAINFALL chapter.)

5. Determine the runoff coefficient, C.

6. Calculate the peak flow rate from the watershed using Equation RO-1.

2.2 Assumptions

The basic assumptions that are often made when the Rational Method is applied are:

1. The computed maximum rate of runoff to the design point is a function of the average rainfall rate during the time of concentration to that point.

2. The depth of rainfall used is one that occurs from the start of the storm to the time of concentration, and the design rainfall depth during that time period is converted to the average rainfall intensity for that period.

3. The maximum runoff rate occurs when the entire area is contributing flow. However, this assumption has to be modified when a more intensely developed portion of the catchment with a shorter time of concentration produces a higher rate of maximum runoff than the entire catchment with a longer time of concentration.

2.3 Limitations

The Rational Method is an adequate method for approximating the peak rate and total volume of runoff from a design rainstorm in a given catchment. The greatest drawback to the Rational Method is that it normally provides only one point on the runoff hydrograph. When the areas become complex and where sub-catchments come together, the Rational Method will tend to overestimate the actual flow, which results in oversizing of drainage facilities. The Rational Method provides no direct information needed to route hydrographs through the drainage facilities. One reason the Rational Method is limited to small areas is that good design practice requires the routing of hydrographs for larger catchments to achieve an economic design.

Another disadvantage of the Rational Method is that with typical design procedures one normally assumes that all of the design flow is collected at the design point and that there is no water running overland to the next design point. However, this is not the fault of the Rational Method but of the design procedure. The Rational Method must be modified, or another type of analysis must be used, when analyzing an existing system that is under-designed or when analyzing the effects of a major storm on a system designed for the minor storm.

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2.4 Time of Concentration

One of the basic assumptions underlying the Rational Method is that runoff is a function of the average rainfall rate during the time required for water to flow from the most remote part of the drainage area under consideration to the design point. However, in practice, the time of concentration can be an empirical value that results in reasonable and acceptable peak flow calculations. The time of concentration relationships recommended in this *Manual* are based in part on the rainfall-runoff data collected in the Denver metropolitan area and are designed to work with the runoff coefficients also recommended in this *Manual*. As a result, these recommendations need to be used with a great deal of caution whenever working in areas that may differ significantly from the climate or topography found in the Denver region.

For urban areas, the time of concentration, t_c, consists of an initial time or overland flow time, t_i, plus the travel time, t_t, in the storm sewer, paved gutter, roadside drainage ditch, or drainage channel. For non-urban areas, the time of concentration consists of an overland flow time, t_i, plus the time of travel in a defined form, such as a swale, channel, or drainageway. The travel portion, t_t, of the time of concentration can be estimated from the hydraulic properties of the storm sewer, gutter, swale, ditch, or drainageway. Initial time, on the other hand, will vary with surface slope, depression storage, surface cover, antecedent rainfall, and infiltration capacity of the soil, as well as distance of surface flow. The time of concentration is represented by Equation RO-2 for both urban and non-urban areas:

$$t_c = t_i + t_t \qquad \text{(RO-2)}$$

in which:

t_c = time of concentration (minutes)

t_i = initial or overland flow time (minutes)

t_t = travel time in the ditch, channel, gutter, storm sewer, etc. (minutes)

2.4.1 Initial Flow Time

The initial or overland flow time, t_i, may be calculated using equation RO-3:

$$t_i = \frac{0.395(1.1 - C_5)\sqrt{L}}{S^{0.33}} \qquad \text{(RO-3)}$$

in which:

t_i = initial or overland flow time (minutes)

C_5 = runoff coefficient for 5-year frequency (from Table RO-5)

L = length of overland flow (500 ft maximum for non-urban land uses, 300 ft maximum for urban land uses)

S = average basin slope (ft/ft)

Equation RO-3 is adequate for distances up to 500 feet. Note that, in some urban watersheds, the overland flow time may be very small because flows quickly channelize.

2.4.2 Overland Travel Time

For catchments with overland and channelized flow, the time of concentration needs to be considered in combination with the overland travel time, t_t, which is calculated using the hydraulic properties of the swale, ditch, or channel. For preliminary work, the overland travel time, t_t, can be estimated with the help of Figure RO-1 or the following equation (Guo 1999):

$$V = C_v S_w^{0.5} \qquad \text{(RO-4)}$$

in which:

V = velocity (ft/sec)

C_v = conveyance coefficient (from Table RO-2)

S_w = watercourse slope (ft/ft)

Table RO-2—Conveyance Coefficient, C_v

Type of Land Surface	Conveyance Coefficient, C_v
Heavy meadow	2.5
Tillage/field	5
Short pasture and lawns	7
Nearly bare ground	10
Grassed waterway	15
Paved areas and shallow paved swales	20

The time of concentration, t_c, is then the sum of the initial flow time, t_i, and the travel time, t_t, as per Equation RO-2.

2.4.3 First Design Point Time of Concentration in Urban Catchments

Using this procedure, the time of concentration at the first design point (i.e., initial flow time, t_i) in an urbanized catchment should not exceed the time of concentration calculated using Equation RO-5.

$$t_c = \frac{L}{180} + 10 \qquad \text{(RO-5)}$$

in which:

t_c = maximum time of concentration at the first design point in an urban watershed (minutes)

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L = waterway length (ft)

Equation RO-5 was developed using the rainfall-runoff data collected in the Denver region and, in essence, represents regional "calibration" of the Rational Method.

The first design point is the point where runoff first enters the storm sewer system. An example of definition of first design point is provided in Figure RO-2.

Normally, Equation RO-5 will result in a lesser time of concentration at the first design point and will govern in an urbanized watershed. For subsequent design points, the time of concentration is calculated by accumulating the travel times in downstream drainageway reaches.

2.4.4 Minimum Time of Concentration

Should the calculations result in a t_c of less than 10 minutes, it is recommended that a minimum value of 10 minutes be used for non-urban watersheds. The minimum t_c recommended for urbanized areas should not be less than 5 minutes and if calculations indicate a lesser value, use 5 minutes instead.

2.4.5 Common Errors in Calculating Time of Concentration

A common mistake in urbanized areas is to assume travel velocities that are too slow. Another common error is to not check the runoff peak resulting from only part of the catchment. Sometimes a lower portion of the catchment or a highly impervious area produces a larger peak than that computed for the whole catchment. This error is most often encountered when the catchment is long or the upper portion contains grassy parkland and the lower portion is developed urban land.

2.5 Intensity

The rainfall intensity, I, is the average rainfall rate in inches per hour for the period of maximum rainfall of a given recurrence frequency having a duration equal to the time of concentration.

After the design storm's recurrence frequency has been selected, a graph should be made showing rainfall intensity versus time. The procedure for obtaining the local data and drawing such a graph is explained and illustrated in Section 4 of the RAINFALL chapter of this *Manual*. The intensity for a design point is taken from the graph or through the use of Equation RA-3 using the calculated t_c.

2.6 Watershed Imperviousness

All parts of a watershed can be considered either pervious or impervious. The pervious part is that area where water can readily infiltrate into the ground. The impervious part is the area that does not readily allow water to infiltrate into the ground, such as areas that are paved or covered with buildings and sidewalks or compacted unvegetated soils. In urban hydrology, the percentage of pervious and impervious land is important. The percentage of impervious area increases when urbanization occurs

and the rainfall-runoff relationships change significantly. The total amount of runoff volume normally increases, the time to the runoff peak rate decreases, and the peak runoff rates increase.



Photograph RO-2—Urbanization (impervious area) increases runoff volumes, peak discharges, frequency of runoff, and receiving stream degradation.

When analyzing a watershed for design purposes, the probable future percent of impervious area must be estimated. A complete tabulation of recommended values of the total percent of imperviousness is provided in Table RO-3 and Figures RO-3 through RO-5, the latter developed by the District after the evolution of residential growth patterns since 1990.

2.7 Runoff Coefficient

The runoff coefficient, C, represents the integrated effects of infiltration, evaporation, retention, and interception, all of which affect the volume of runoff. The determination of C requires judgment and understanding on the part of the engineer.

Based in part on the data collected by the District since 1969, an empirical set of relationships between C and the percentage imperviousness for the 2-year and smaller storms was developed and are expressed in Equations RO-6 and RO-7 for Type A and C/D Soil groups (Urbonas, Guo and Tucker 1990). For Type B soil group the impervious value is found by taking the arithmetic average of the values found using these two equations for Type A and Type C/D soil groups. For larger storms (i.e., 5-, 10, 25-, 50- and 100-year) correction factors listed in Table RO-4 are applied to the values calculated using these two equations.

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Table RO-3—Recommended Percentage Imperviousness Values

Land Use or Surface Characteristics	Percentage Imperviousness
Business:	
Commercial areas	95
Neighborhood areas	85
Residential:	
Single-family	*
Multi-unit (detached)	60
Multi-unit (attached)	75
Half-acre lot or larger	*
Apartments	80
Industrial:	
Light areas	80
Heavy areas	90
Parks, cemeteries	5
Playgrounds	10
Schools	50
Railroad yard areas	15
Undeveloped Areas:	
Historic flow analysis	2
Greenbelts, agricultural	2
Off-site flow analysis (when land use not defined)	45
Streets:	
Paved	100
Gravel (packed)	40
Drive and walks	90
Roofs	90
Lawns, sandy soil	0
Lawns, clayey soil	0

* See Figures RO-3 through RO-5 for percentage imperviousness.

$$C_A = K_A + \left(1.31i^3 - 1.44i^2 + 1.135i - 0.12\right) \text{ for } C_A \geq 0, \text{ otherwise } C_A = 0 \qquad \text{(RO-6)}$$

$$C_{CD} = K_{CD} + \left(0.858i^3 - 0.786i^2 + 0.774i + 0.04\right) \qquad \text{(RO-7)}$$

$$C_B = \left(\mathrm{C_A} + C_{CD}\right)/2$$

in which:

i = % imperviousness/100 expressed as a decimal (see Table RO-3)

C_A = Runoff coefficient for Natural Resources Conservation Service (NRCS) Type A soils

C_B = Runoff coefficient for NRCS Type B soils

C_{CD} = Runoff coefficient for NRCS Type C and D soils

K_A = Correction factor for Type A soils defined in Table RO-4

K_{CD} = Correction factor for Type C and D soils defined in Table RO-4

Table RO-4—Correction Factors K_A and K_{CD} for Use with Equations RO-6 and RO-7

NRCS Soil Type	Storm Return Period					
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
C and D	0	-0.10i + 0.11	-0.18i + 0.21	-0.28i + 0.33	-0.33i + 0.40	-0.39i + 0.46
A	0	-0.08i + 0.09	-0.14i + 0.17	-0.19i + 0.24	-0.22i + 0.28	-0.25i + 0.32

The values for various catchment imperviousnesses and storm return periods are presented graphically in Figures RO-6 through RO-8, and are tabulated in Table RO-5. These coefficients were developed for the Denver region to work in conjunction with the time of concentration recommendations in Section 2.4. Use of these coefficients and this procedure outside of the semi-arid climate found in the Denver region may not be valid. The *UD-Rational* spreadsheet performs all the needed calculations to find the runoff coefficient given the soil type and imperviousness and the reader may want to take advantage of this macro-enabled Excel workbook that is available for download from the District's web site www.udfcd.org under "Download" – "Technical Downloads."

See Examples 7.1 and 7.2 that illustrate the Rational method. The use of the Rational method in storm sewer design is illustrated in Example 6.13 of the STREETS/INLETS/STORM SEWERS chapter.

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Table RO-5— Runoff Coefficients, *C*

Percentage Imperviousness	Type C and D NRCS Hydrologic Soil Groups					
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
0%	0.04	0.15	0.25	0.37	0.44	0.50
5%	0.08	0.18	0.28	0.39	0.46	0.52
10%	0.11	0.21	0.30	0.41	0.47	0.53
15%	0.14	0.24	0.32	0.43	0.49	0.54
20%	0.17	0.26	0.34	0.44	0.50	0.55
25%	0.20	0.28	0.36	0.46	0.51	0.56
30%	0.22	0.30	0.38	0.47	0.52	0.57
35%	0.25	0.33	0.40	0.48	0.53	0.57
40%	0.28	0.35	0.42	0.50	0.54	0.58
45%	0.31	0.37	0.44	0.51	0.55	0.59
50%	0.34	0.40	0.46	0.53	0.57	0.60
55%	0.37	0.43	0.48	0.55	0.58	0.62
60%	0.41	0.46	0.51	0.57	0.60	0.63
65%	0.45	0.49	0.54	0.59	0.62	0.65
70%	0.49	0.53	0.57	0.62	0.65	0.68
75%	0.54	0.58	0.62	0.66	0.68	0.71
80%	0.60	0.63	0.66	0.70	0.72	0.74
85%	0.66	0.68	0.71	0.75	0.77	0.79
90%	0.73	0.75	0.77	0.80	0.82	0.83
95%	0.80	0.82	0.84	0.87	0.88	0.89
100%	0.89	0.90	0.92	0.94	0.95	0.96
	TYPE B NRCS HYDROLOGIC SOILS GROUP					
0%	0.02	0.08	0.15	0.25	0.30	0.35
5%	0.04	0.10	0.19	0.28	0.33	0.38
10%	0.06	0.14	0.22	0.31	0.36	0.40
15%	0.08	0.17	0.25	0.33	0.38	0.42
20%	0.12	0.20	0.27	0.35	0.40	0.44
25%	0.15	0.22	0.30	0.37	0.41	0.46
30%	0.18	0.25	0.32	0.39	0.43	0.47
35%	0.20	0.27	0.34	0.41	0.44	0.48
40%	0.23	0.30	0.36	0.42	0.46	0.50
45%	0.26	0.32	0.38	0.44	0.48	0.51
50%	0.29	0.35	0.40	0.46	0.49	0.52
55%	0.33	0.38	0.43	0.48	0.51	0.54
60%	0.37	0.41	0.46	0.51	0.54	0.56
65%	0.41	0.45	0.49	0.54	0.57	0.59
70%	0.45	0.49	0.53	0.58	0.60	0.62
75%	0.51	0.54	0.58	0.62	0.64	0.66
80%	0.57	0.59	0.63	0.66	0.68	0.70
85%	0.63	0.66	0.69	0.72	0.73	0.75
90%	0.71	0.73	0.75	0.78	0.80	0.81
95%	0.79	0.81	0.83	0.85	0.87	0.88
100%	0.89	0.90	0.92	0.94	0.95	0.96

TABLE RO-5 (Continued)—Runoff Coefficients, *C*

Percentage Imperviousness	Type A NRCS Hydrologic Soils Group					
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
0%	0.00	0.00	0.05	0.12	0.16	0.20
5%	0.00	0.02	0.10	0.16	0.20	0.24
10%	0.00	0.06	0.14	0.20	0.24	0.28
15%	0.02	0.10	0.17	0.23	0.27	0.30
20%	0.06	0.13	0.20	0.26	0.30	0.33
25%	0.09	0.16	0.23	0.29	0.32	0.35
30%	0.13	0.19	0.25	0.31	0.34	0.37
35%	0.16	0.22	0.28	0.33	0.36	0.39
40%	0.19	0.25	0.30	0.35	0.38	0.41
45%	0.22	0.27	0.33	0.37	0.40	0.43
50%	0.25	0.30	0.35	0.40	0.42	0.45
55%	0.29	0.33	0.38	0.42	0.45	0.47
60%	0.33	0.37	0.41	0.45	0.47	0.50
65%	0.37	0.41	0.45	0.49	0.51	0.53
70%	0.42	0.45	0.49	0.53	0.54	0.56
75%	0.47	0.50	0.54	0.57	0.59	0.61
80%	0.54	0.56	0.60	0.63	0.64	0.66
85%	0.61	0.63	0.66	0.69	0.70	0.72
90%	0.69	0.71	0.73	0.76	0.77	0.79
95%	0.78	0.80	0.82	0.84	0.85	0.86
100%	0.89	0.90	0.92	0.94	0.95	0.96

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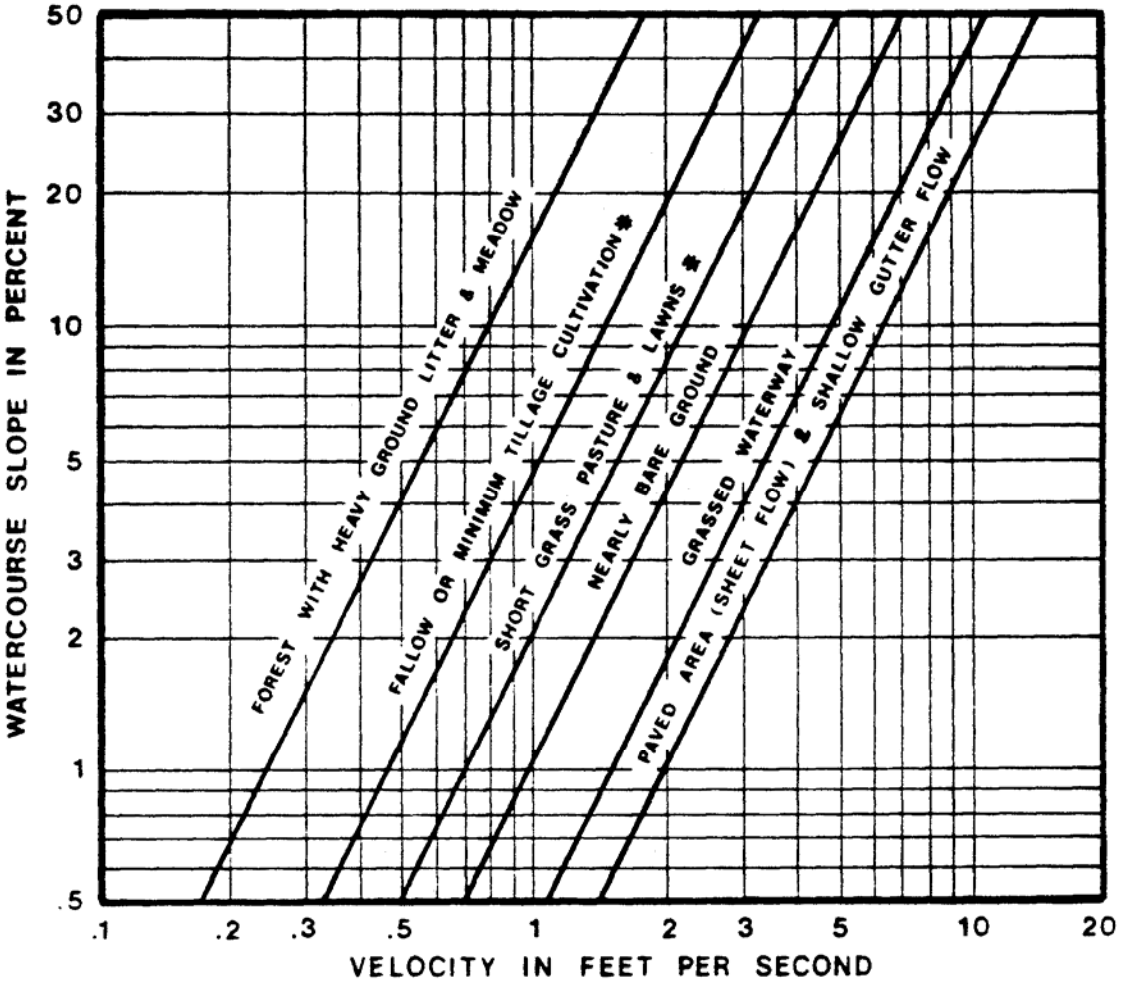
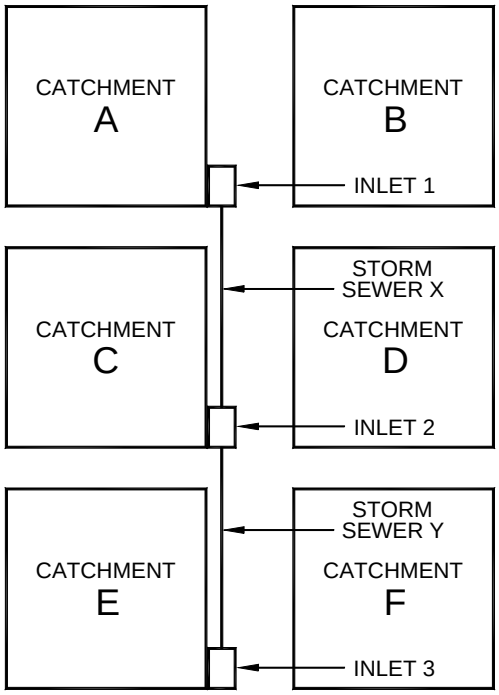


Figure RO-1—Estimate of Average Overland Flow Velocity for Use With the Rational Formula



NOTE:
INLETS 1, 2, 3 AND STORM SEWER X ARE EACH THE "FIRST DESIGN POINT" AND THE REGIONAL Tc SHOULD BE CHECKED. STORM SEWER Y IS NOT THE FIRST DESIGN POINT.

Figure RO-2—Diagram of First Design Point

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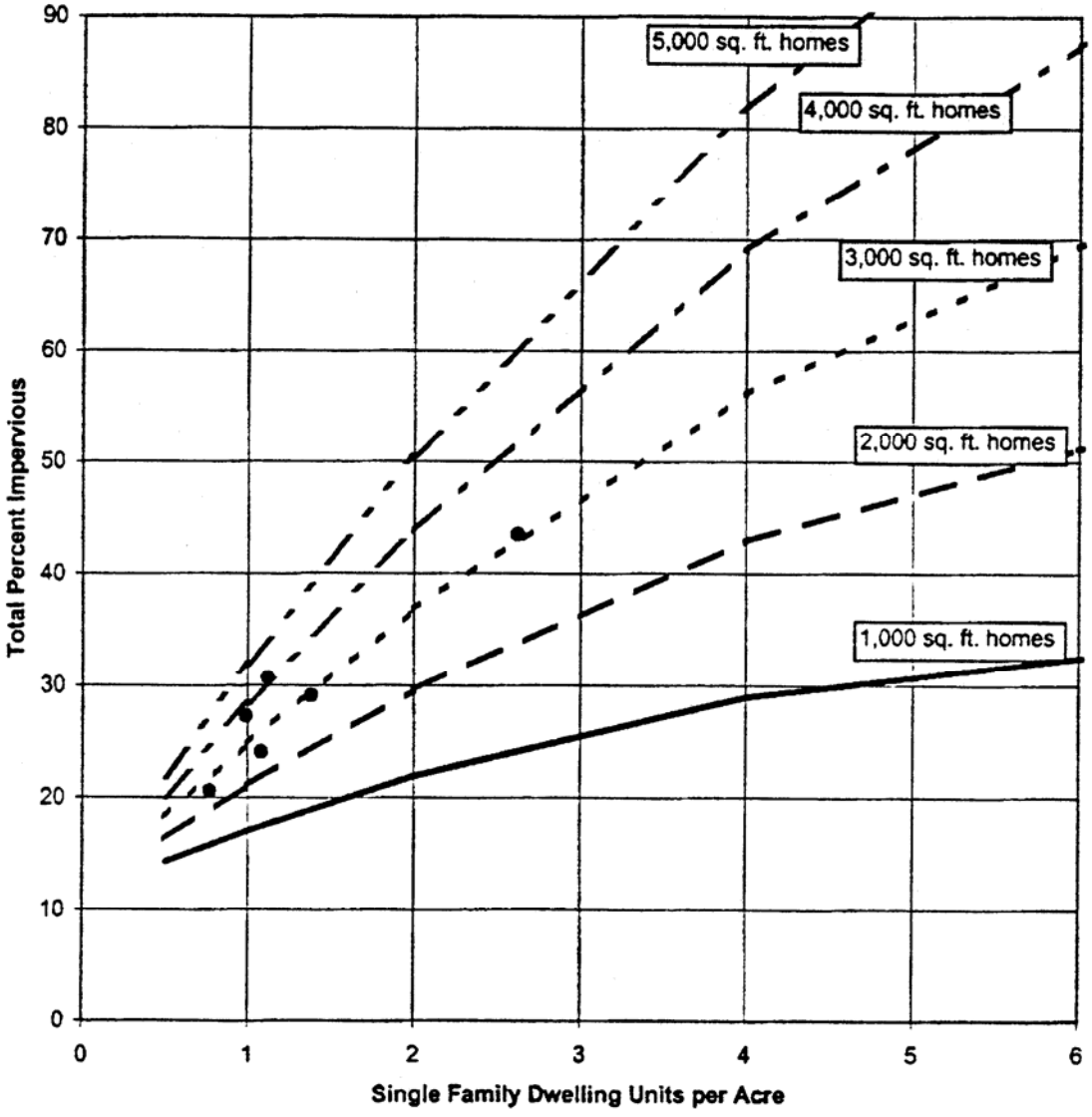

Figure RO-3— Watershed Imperviousness, Single-Family Residential Ranch Style Houses

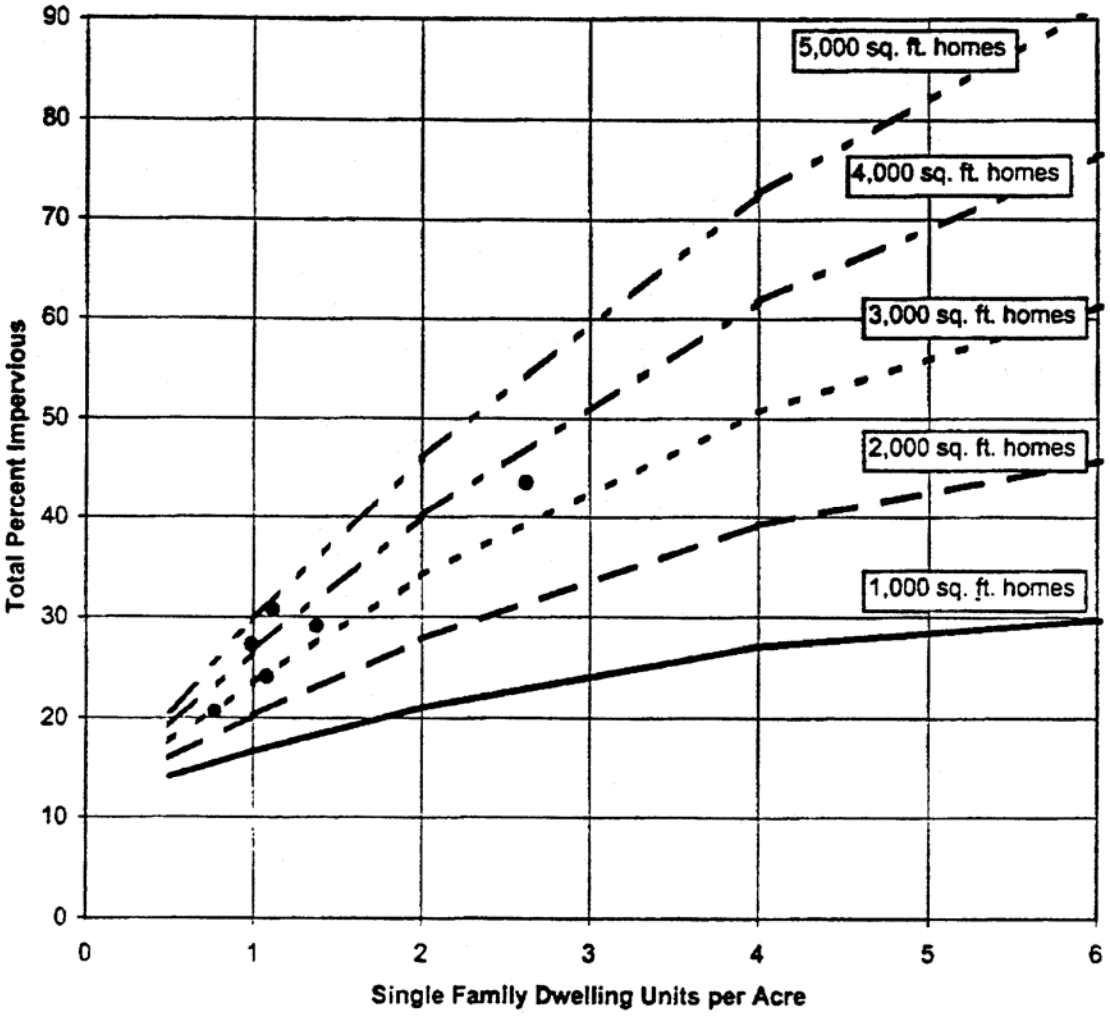

Figure RO-4—Watershed Imperviousness, Single-Family Residential Split-Level Houses

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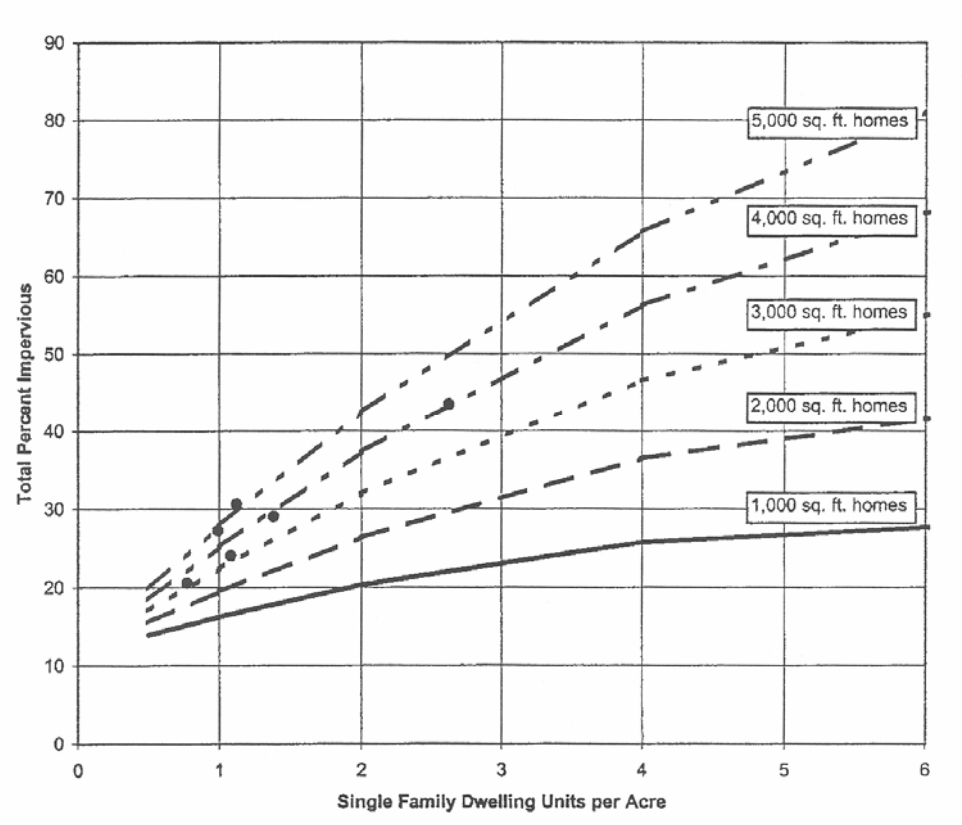

Figure RO-5—Watershed Imperviousness, Single-Family Residential Two-Story Houses

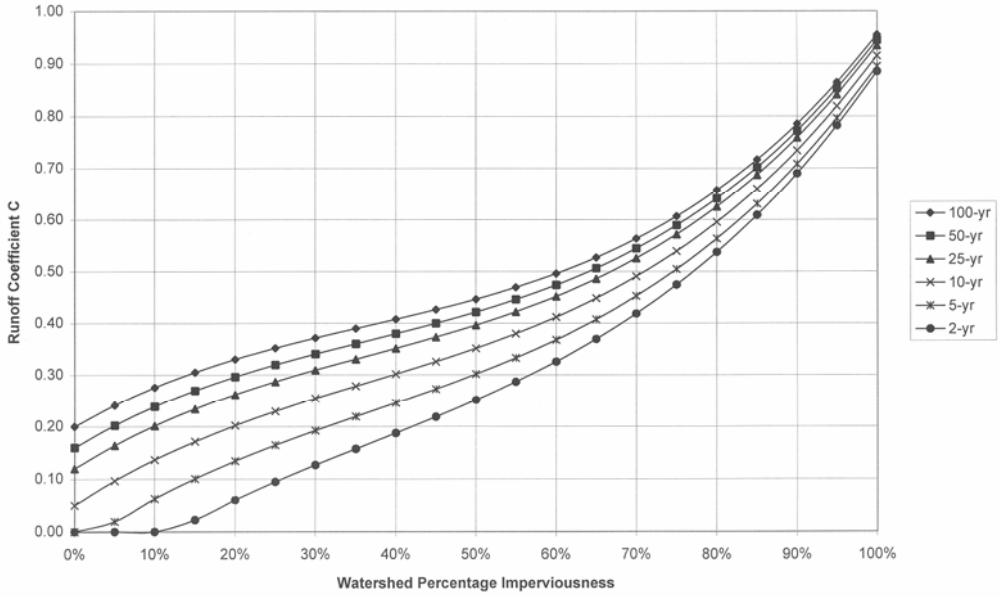

Figure RO-6—Runoff Coefficient, *C*, vs. Watershed Percentage Imperviousness NRCS Hydrologic Soil Group A

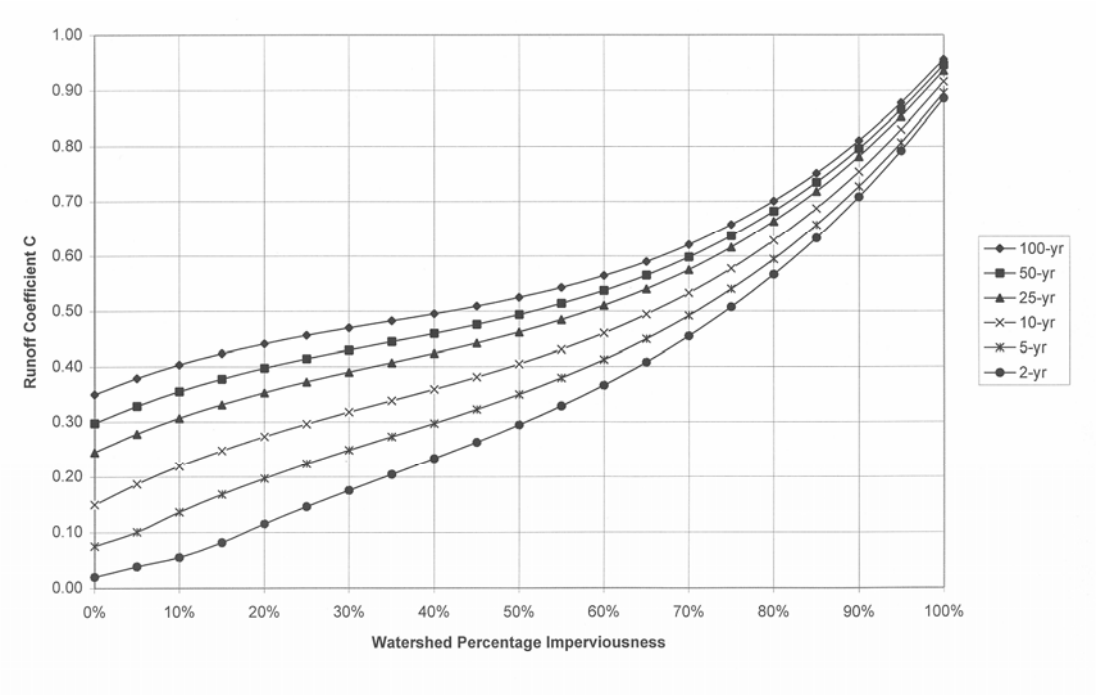

Figure RO-7—Runoff Coefficient, *C*, vs. Watershed Percentage Imperviousness NRCS Hydrologic Soil Group B

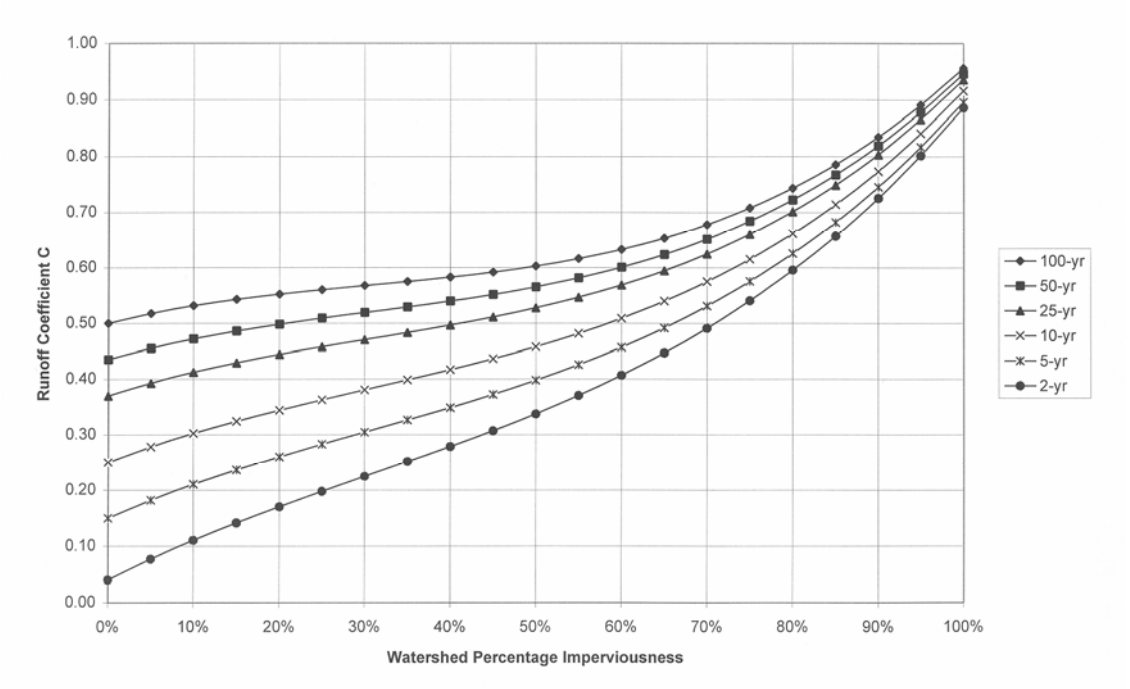

Figure RO-8—Runoff Coefficient, *C*, vs. Watershed Percentage Imperviousness NRCS Hydrologic Soil Groups C and D

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3.0 COLORADO URBAN HYDROGRAPH PROCEDURE

3.1 Background

The Colorado Urban Hydrograph Procedure (CUHP) is a method of hydrologic analysis based upon the unit hydrograph principle. It has been developed and calibrated using rainfall-runoff data collected in Colorado (mostly in the Denver/Boulder metropolitan area). This section provides a general background in the use of the computer version of CUHP to carry out stormwater runoff calculations. A detailed description of the CUHP procedure and the assumptions and equations used, including a hand calculation example, are provided in Appendix A to this chapter. For more detailed information regarding the latest CUHP computer model including data requirements, data format, and model execution, the reader is directed to the program's users' manual. The latest version of CUHP macro-enabled software is ***CUHP 2005*** and users' manual are available for downloading from the District's Web site www.udfcd.org under "Downloads".

3.2 Effective Rainfall for CUHP

Effective rainfall is that portion of precipitation during a storm event that runs off the land to drainageways. Those portions of precipitation that do not reach drainageways are called abstractions and include interception by vegetation, evaporation, infiltration, storage in all surface depressions, and long-time surface retention. The total design rainfall depth for use with CUHP should be obtained from the RAINFALL chapter of this *Manual*. This RUNOFF chapter illustrates a method for estimating the amount of rainfall that actually becomes surface runoff whenever a design rainstorm is used.

3.2.1 Pervious-Impervious Areas

As was described in Section 2.6, the urban landscape is comprised of pervious and impervious surfaces. The degree of imperviousness is the primary variable that affects the volumes and rates of runoff calculated using CUHP. When analyzing a watershed for design purposes, the probable future percent of impervious area must first be estimated. A complete tabulation of recommended values of total percentage imperviousness is provided in Table RO-3 and Figures RO-3 through RO-5. References to impervious area and all calculations in this chapter are based on the input of total impervious areas. The pervious-impervious area relationship can be further refined for use in CUHP as follows:

1. *DCIA*—Impervious area portion directly connected to the drainage system.
2. *UIA*—Impervious area portion that drains onto or across impervious surfaces.
3. *RPA*—The portion of pervious area receiving runoff from impervious portions.
4. *SPA*—The separate pervious area portion not receiving runoff from impervious surfaces.

This further refinement is explained in some detail in the CUHP users' manual and shown schematically

in Figure RO-A6 in Appendix A at the end of this chapter.

3.2.2 Depression Losses

Rainwater that is collected and held in small depressions and does not become part of the general surface runoff is called depression loss. Most of this water eventually infiltrates or is evaporated. Depression losses also include water intercepted by trees, bushes, other vegetation, and all other surfaces. The CUHP method requires numerical values of depression loss as inputs to calculate the effective rainfall. Table RO-6 can be used as a guide in estimating the amount of depression (retention) losses to be used with CUHP.

Table RO-6—Typical Depression Losses for Various Land Covers

(All Values in Inches. For use with the CUHP Method)

Land Cover	Range in Depression (Retention) Losses	Recommended
Impervious:		
Large paved areas	0.05 - 0.15	0.1
Roofs-flat	0.1 - 0.3	0.1
Roofs-sloped	0.05 - 0.1	0.05
Pervious:		
Lawn grass	0.2 - 0.5	0.35
Wooded areas and open fields	0.2 - 0.6	0.4

When an area is analyzed for depression losses, the pervious and impervious loss values for all parts of the watershed must be considered and accumulated in proportion to the percent of aerial coverage for each type of surface.

3.2.3 Infiltration

The flow of water into the soil surface is called infiltration. In urban hydrology much of the infiltration occurs on areas covered with grass. Urbanization can increase or decrease the total amount of infiltration.

Soil type is the most important factor in determining the infiltration rate. When the soil has a large percentage of well-graded fines, the infiltration rate is low. In some cases of extremely tight soil, there may be, from a practical standpoint, essentially no infiltration. If the soil has several layers or horizons, the least permeable layer near the surface will control the maximum infiltration rate. The soil cover also plays an important role in determining the infiltration rate. Vegetation, lawn grass in particular, tends to increase infiltration by loosening the soil near the surface. Other factors affecting infiltration rates include slope of land, temperature, quality of water, age of lawn and soil compaction.

As rainfall continues, the infiltration rate decreases. When rainfall occurs on an area that has little antecedent moisture and the ground is dry, the infiltration rate is much higher than it is with high

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antecedent moisture resulting from previous storms or land irrigation such as lawn watering. Although antecedent precipitation is very important when calculating runoff from smaller storms in non-urbanized areas, the runoff data from urbanized basins indicates that antecedent precipitation has a limited effect on runoff peaks and volumes in the urbanized portions of the District.

There are many infiltration models in use by hydrologists. These models vary significantly in complexity. Because of the climatic condition in the semi-arid region and because runoff from urban watersheds is not very sensitive to infiltration refinements, the infiltration model proposed by Horton was found to provide a good balance between simplicity and reasonable physical description of the infiltration process for use in CUHP. Horton's infiltration model is described by Equation RO-8 and is illustrated graphically in Figure RO-9.

$$f = f_o + (f_i - f_o)e^{-at} \qquad \text{(RO-8)}$$

in which:

f = infiltration rate at any given time t from start of rainfall (in/hr)

f_o = final infiltration rate (in/hr)

f_i = initial infiltration rate (in/hr)

e = natural logarithm base

a = decay coefficient (1/second)

t = time (seconds)

In developing Equation RO-8, Horton observed that infiltration is high early in the storm and eventually decays to a steady state constant value as the pores in the soil become saturated. The coefficients and initial and final infiltration values are site specific and depend on the soils and vegetative cover complex. It is possible to develop these values for each site if sufficient rainfall-runoff observations are made. However, such an approach is rarely practical.

Since 1977, the District has analyzed a considerable amount of rainfall-runoff data. On the basis of this analysis, the values in Table RO-7 are recommended for use within the District with CUHP. The NRCS Hydrologic Soil Groups C and D occur most frequently within the District; however, areas of NRCS Group A and B soils are also fairly common. Consult NRCS soil surveys for appropriate soil classifications.

Table RO-7—Recommended Horton's Equation Parameters

NRCS Hydrologic Soil Group	Infiltration (inches per hour)		Decay Coefficient—a
	Initial—f_i	Final—f_o	
A	5.0	1.0	0.0007
B	4.5	0.6	0.0018
C	3.0	0.5	0.0018
D	3.0	0.5	0.0018

To calculate the maximum infiltration depths that may occur at each time increment, it is necessary to integrate Equation RO-8 and calculate the values for each time increment. Very little accuracy is lost if, instead of integrating Equation RO-8, the infiltration rate is calculated at the center of each time increment. This "central" value can then be multiplied by the unit time increment to estimate the infiltration depth. This was done for the four NRCS hydrologic soil groups, and the results are presented in Table RO-8. Although Tables RO-7 and RO-8 provide recommended values for various Horton equation parameters, these recommendations are being made specifically for the urbanized or urbanizing watersheds in the Denver metropolitan area and may not be valid in different meteorologic and climatic regions.

Table RO-8—Incremental Infiltration Depths in Inches*

Time in Minutes**	NRCS Hydrologic Soil Group		
	A	B	C and D
5	0.384	0.298	0.201
10	0.329	0.195	0.134
15	0.284	0.134	0.096
20	0.248	0.099	0.073
25	0.218	0.079	0.060
30	0.194	0.067	0.052
35	0.175	0.060	0.048
40	0.159	0.056	0.045
45	0.146	0.053	0.044
50	0.136	0.052	0.043
55	0.127	0.051	0.042
60	0.121	0.051	0.042
65	0.115	0.050	0.042
70	0.111	0.050	0.042
75	0.107	0.050	0.042
80	0.104	0.050	0.042
85	0.102	0.050	0.042
90	0.100	0.050	0.042
95	0.098	0.050	0.042
100	0.097	0.050	0.042
105	0.096	0.050	0.042
110	0.095	0.050	0.042
115	0.095	0.050	0.042
120	0.094	0.050	0.042

* Based on central value of each time increment in Horton's equation.
** Time at end of the time increment.

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3.3 CUHP Parameter Selection

3.3.1 Rainfall

The ***CUHP 2005*** Excel-based computer program requires the input of a design storm, either as a detailed hyetograph or as a 1-hour rainfall depth. A detailed hyetograph distribution is generated by the program for the latter using the standard 2-hour storm distribution recommended in the RAINFALL chapter of this *Manual*. In addition, this software will also distribute the one-hour values for longer storm durations with area corrections accounted for cases where larger watersheds are studies.

3.3.2 Catchment Description

The following catchment parameters are required for the program to generate a unit and storm hydrograph.

1. Area—Catchment area in square miles. See Table RO-1 for catchment size limits.

2. Catchment Length—The length in miles from the downstream design point of the catchment or sub-catchment along the main drainageway path to the furthest point on its respective catchment or sub-catchment. When a catchment is subdivided into a series of sub-catchments, the sub-catchment length used shall include the distance required for runoff to reach the major drainageway from the farthest point in the sub-catchment.

3. Centroid Distance—Distance in miles from the design point of the catchment or sub-catchment along the main drainageway path to its respective catchment or sub-catchment centroid.

4. Percent Impervious—The portion of the catchment's total surface area that is impervious, expressed as a percent value between 0 and 100. (See 3.2.1 for more details.)

5. Catchment Slope—The length-weighted, corrected average slope of the catchment in feet per foot.

   There are natural processes at work that limit the time to peak of a unit hydrograph as a natural drainageway becomes steeper. To account for this phenomenon, it is recommended that the slope used in CUHP for natural drainageways and existing manmade grass-lined channels be adjusted using Figure RO-10.

   When a *riprap channel* is evaluated, use the measured (i.e., uncorrected) average channel invert slope.

   In *concrete-lined channels* and *buried conduits,* the velocities can be very high. For this reason, it is recommended that the average ground slope (i.e., not flow-line slope) be used where concrete-lined channels and/or storm sewers dominate the basin drainageways. There is no correction factor or upper limit recommended to the slope for concrete-lined channels and buried conduits.

Where the flow-line slope varies along the channel, calculate a weighted basin slope for use with CUHP. Do this by first segmenting the major drainageway into reaches having similar longitudinal slopes. Then calculate the weighted slope using the Equation RO-9.

$$S = \left[\frac{L_1 S_1^{\,0.24} + L_2 S_2^{\,0.24} + ... + L_n S_n^{\,0.24}}{L_1 + L_2 + L_3 .... L_n} \right]^{4.17} \qquad \text{(RO-9)}$$

in which:

S = weighted basin waterway slopes in ft/ft

$S_1, S_2, \ldots S_n$ = slopes of individual reaches in ft/ft (after adjustments using Figure RO-10)

$L_1, L_2, \ldots L_n$ = lengths of corresponding reaches

6. Unit Hydrograph Time Increment—Typically a 5-minute unit hydrograph is used. For catchments smaller than 90 acres, using a 1-minute unit hydrograph may be needed if significant differences are found between the "excess precipitation" and "runoff hydrograph" volumes listed in the summary output. For very small catchments (i.e. smaller than 10 acres), especially those with high imperviousness the 1-minute unit hydrograph will be needed to preserve runoff volume integrity.

7. Pervious Retention—Maximum depression storage on pervious surfaces in inches. (See Section 3.2.2 for more details.)

8. Impervious Retention—Maximum depression storage on impervious surfaces in inches. (See Section 3.2.2 for more details.)

9. Infiltration Rate—Initial infiltration rate for pervious surfaces in the catchment in inches per hour. If this entry is used by itself, it will be used as a constant infiltration rate throughout the storm. (See Section 4.2.3 for more details.)

10. Decay—Exponential decay coefficient in Horton's equation in "per second" units.

11. Final Infiltration—Final infiltration rate in Horton's equation in inches per hour.

The program computes the coefficients C_t and C_p; however, values for these parameters can be specified by the user as an option. The unit hydrograph is developed by the computer using the algorithm described in *CUHP 2005 User Manual*.

The shaping of the unit hydrograph also relies on proportioning the widths at 50% and 75% of the unit hydrograph peak. The proportioning is based on 0.35 of the width at 50% of peak being ahead of the "time to peak" and 0.45 of the width at 75% of peak being ahead of the "time to peak." These

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proportioning factors were selected after observing a number of unit hydrographs derived from the rainfall-runoff data collected by the USGS for the District. It is possible for the user to override the unit hydrograph widths and the proportioning of these widths built into the program. For drainage and flood studies within the District, the program values shall be used. If the user has derived unit hydrographs from reliable rainfall-runoff data for a study catchment and can develop a "calibrated" unit hydrograph for this catchment, this option permits reshaping the unit hydrograph accordingly.

The following catchment parameters are also optional inputs and are available to the user to account for the effects of directly connected/disconnected impervious areas:

1. DCIA—Specifies the directly connected impervious area (DCIA) level of practice as defined in the STRUCTURAL BMPs chapter in Volume 3 of this *Manual*. The user may specify 1 or 2 for the level of DCIA to model.

2. D—Defines the fraction of the total impervious area directly connected to the drainage system. Values range from 0.01 to 1.0.

3. R—Defines the fraction of total pervious area receiving runoff from the "disconnected" impervious areas. Values range from 0.01 to 1.0.

A sample calculation for effective rainfall is presented in Example 7.3.

3.3.3 Catchment Delineation Criteria

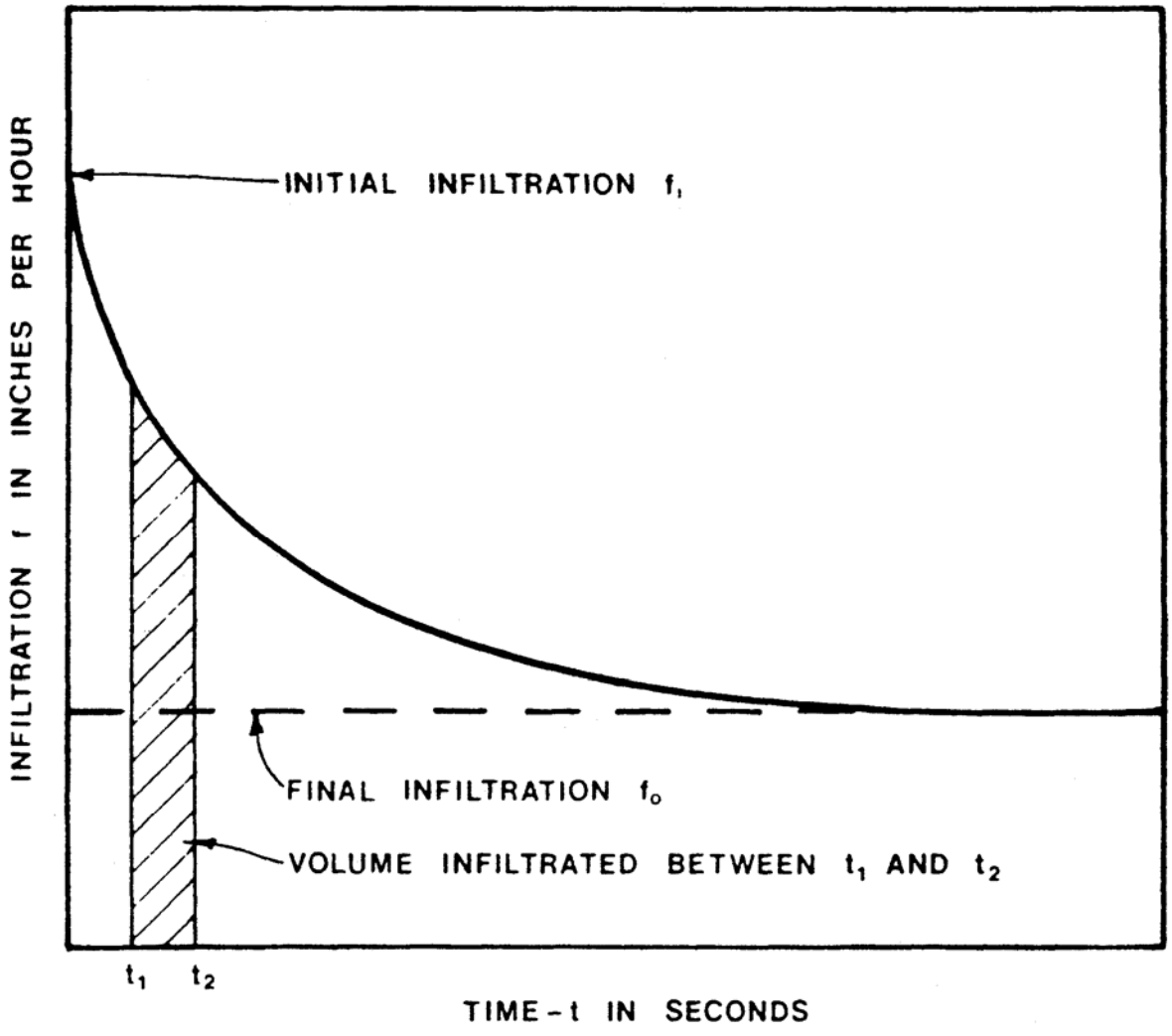
The maximum size of a catchment to be analyzed with a single unit hydrograph is limited to 5 square miles. Whenever a larger catchment is studied, it should be subdivided into sub-catchments of 5 square miles or less and individual sub-catchment storm hydrographs should be routed downstream using appropriate channel routing procedures such as the EPA's SWMM 5 model. The routed hydrographs are then added to develop a single composite storm hydrograph. See Table RO-1 for a description of catchment size limitations for CUHP.

The catchment shape can have a profound effect on the final results and, in some instances, can result in underestimates of peak flows. Experience with the 1982 version of CUHP has shown that, whenever catchment length is increased faster than its area, the storm hydrograph peak will tend to decrease. Although hydrologic routing is an integral part of runoff analysis, the data used to develop CUHP are insufficient to say that the observed CUHP response with disproportionately increasing basin length is valid. For this reason, it is recommended to subdivide irregularly shaped or very long catchments (i.e., catchment length to width ratio of four or more) into more regularly shaped sub-catchments. A composite catchment storm hydrograph can be developed using appropriate routing and by adding the individual sub-catchment storm hydrographs.

3.3.3 Combining and Routing Sub-Catchment CUHP Hydrographs

When analyzing large and complex systems, it is necessary to combine and route the runoff hydrographs from a number of sub-catchments to determine the flows and volumes throughout the system. The ***CUHP 2005*** software provides input parameters that identify to which junction in EPS' SWMM each sub-Catchment's hydrograph is to be linked and to then generate an output file that SWMM recognizes as external flow file. All of these and other features are covered in the ***CUHP 2005*** User's Manual.

Figure RO-9—Representation of Horton's Equation



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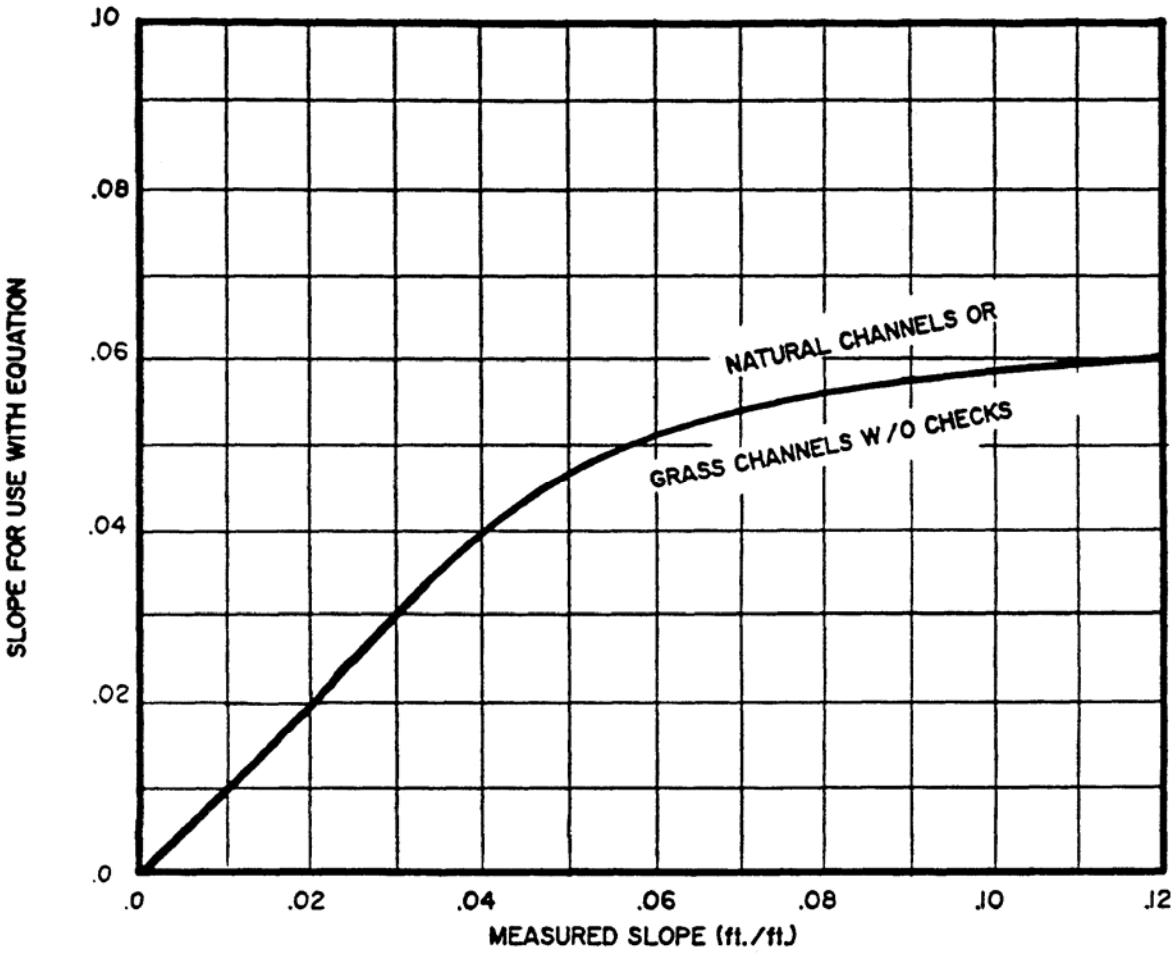

Figure RO-10—Slope Correction for Natural and Grass-Lined Channels

4.0 EPA SWMM AND HYDROGRAPH ROUTING

EPA's SWMM 5 is a computer model that is used to generate surface runoff hydrographs from sub-catchments and then route and combine these hydrographs. The procedure described here is limited to the routing of hydrographs generated using CUHP software. Originally this was done using UDSWM, a modified version of the Runoff Block of the Environmental Protection Agency's (EPA's) SWMM (Storm Water Management Model). It has been modified by the District so that it may be used conjunctively with CUHP. In 2005 the District adopted the use of ***EPA's SWMM 5.0*** model and recommends its use for all future hydrology studies.

The purpose of the discussion of SWMM in this chapter is to provide general background on the use of the model with ***CUHP 2005*** software to perform more complex stormwater runoff calculations using SWMM. Complete details about this model's use, specifics of data format and program execution is provided in the users' manual for SWMM 5.0. Software, users manual and other information about EPA's SWMM 5.0 may be downloaded from http://www.epa.gov/ednnrmrl/models/swmm/index.htm.

4.1 Software Description

SWMM represents a watershed by an aggregate of idealized runoff planes, channels, gutters, pipes and specialized units such as storage nodes, outlets, pumps, etc. The program can accept rainfall hyetographs and make a step-by-step accounting of rainfall infiltration losses in pervious areas, surface retention, overland flow, and gutter flow leading to the calculation of hydrographs. However, this portion of the model is normally not used by the District because the calculation of hydrographs for each sub-catchment is typically carried out using the CUHP software. If, however, the user wants to use SWMM to calculate runoff, the model must be calibrated against the CUHP calculations for the same watershed being studied.

After the CUHP 2005 software is used to calculate hydrographs from a number of sub-watersheds, the resulting hydrographs from these sub-watersheds can be combined and routed through a series of links (i.e., channels, gutters, pipes, dummy links, etc.) and nodes (i.e., junctures, storage, diversion, etc.) to compute the resultant hydrographs at any number of design points within the watershed.

4.1.1 Surface Flows and Flow Routing Features

Stormwater runoff hydrographs generated using CUHP 2005 can be routed through a system of stormwater conveyance, diversion, storage, etc. elements of a complex urban watershed. In setting up the SWMM model, it is critical that overflow links for storm sewers and diversion junctions are provided in the model. The combination of these allows the user to model flows accurately when pipes and/or smaller channels that do not have the capacity to convey higher flows, at which time the excess flows are diverted to the overflow channels and a "choking" of the flow is avoided and errors in the calculated peak flow values downstream are prevented.

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There are several types of conveyance elements that one can select from a menu in SWMM. One element that is now available, that was not available in older versions, is a user-defined irregular channel cross-section, similar to the way cross-sections are defined in HEC-RAS. This makes the model very flexible in modeling natural waterways and composite man-made channels. For a complete description of the routing elements and junction types available for modeling see the SWMM User Manual published by EPA and available from their web site mentioned earlier.

4.1.2 Flow Routing Method of Choice

The District recommends the use of *kinematic wave routing* as the "routing" option in SWMM for planning purposes. *Dynamic wave routing* for most projects is not necessary, does not improve the accuracy of the runoff estimates and can be much more difficult to implement because it requires much information to describe, in minute detail, the entire flow routing system. In addition, it has tendencies to go unstable when modeling some of the more complex elements and/or junctions. When planning for growth, much of the required detail may not even be available (e.g., location of all drop structures and their crest and toe elevations for which a node has to be defined in the model). In addition, with dynamic routing setting up of overflow links and related nodes is much more complicated and exacting.

The use of dynamic wave routing is appropriate when evaluating complex exiting elements of a larger system. It is an option that can also offer some advantages in final design and its evaluation, as it provides hydraulic grade lines and accounts for backwater effects.

4.2 Data Preparation for the SWMM Software

Use of SWMM requires three basic steps:

Step 1—Identify or define the geometries watershed, sub-watersheds and routing/storage elements.
Step 2—Estimates of roughness coefficients and functional/tabular relationships for storage and other special elements.
Step 3—Prepare input data for the model.

4.2.1 Step 1—Method of Discretization

Discretization is a procedure for the mathematical abstraction of the watershed and of the physical drainage system. Discretization begins with the identification of drainage area boundaries, the location of storm sewers, streets, and channels, and the selection of those routing elements to be included in the system. For the computation of hydrographs, the watershed may be conceptually represented by a network of hydraulic elements (i.e., sub-catchments, gutters, pipes, etc.) Hydraulic properties of each element are then characterized by various parameters such as size, slope, and roughness coefficient.

4.2.2 Step 2—Estimate Coefficients and Functional/Tabular Characteristic of Storage and Outlets

For hydrologic routing through conveyance elements such as pipes, gutters, and channels, the resistance (Manning's n) coefficients should not necessarily be the same as those used in performing hydraulic

design calculations. As a general rule, it was found that increasing the "typical" values of Manning's n by approximately 25 percent was appropriate when using UDSWM in the past and should be appropriate for use in SWMM as well. Thus, if a pipe is estimated to have n = 0.013 for hydraulic calculations, it is appropriate to use n = 0.016 in SWMM.

When modeling the hydrologic routing of natural streams, grass-lined channels, or riprap-lined channels in Colorado, it is recommended that Manning's n be estimated for SWMM using Equation RO-10 (Jarrett 1984 and 1985).

$$n = 0.393\, S^{0.38} R^{-0.16} \qquad \text{(RO-10)}$$

in which:

n = Manning's roughness coefficient

S = friction slope (ft/ft)

R = hydraulic radius (ft)

To estimate the hydraulic radius of a natural, grass-lined, or riprap-lined channel for Equation RO-10, it is suggested that one half of the estimated hydrograph peak flow be used to account for the variable depth of flow during a storm event.

SWMM does not have built-in shapes that define geometries of gutters or streets. The user can use the irregular shape option to define the shape of the gutter and street. For storage junctions, the user can define relationships such as stage vs. storage-surface area using mathematical functions or tables. For storage outlets or downstream outfalls, the user can use tables or functions to define their stage-discharge characteristics. As and alternative, the user can define geometries and characteristic for weirs and orifices and let the program calculate the functional relationships. Use of the weirs can sometimes be particularly troublesome when the dynamic wave routing option is used.

4.2.3 Step 3—Preparation of Data for Computer Input

The major preparation effort is forming a tree structure of all the runoff and conveyance elements and dividing the watershed into sub-watersheds. The conveyance elements network is developed using a watershed map, subdivision plans, and "as-built" drawings of the drainage system. Pipes with little or no backwater effects, channels, reservoirs, or flow dividers are usually designated as conveyance elements for computation by SWMM. Once the conveyance element system is set and labeled, CUHP 2005 is used to generate an output file that contains runoff hydrograph for all sub-watersheds. This file is called in by SWMM as an external inflow file and the hydrograph data is then routed by SWMM. The reader needs to study the SWMM users' manual for complete details about data input preparation.

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5.0 OTHER HYDROLOGIC METHODS

5.1 Published Hydrologic Information

The District has prepared hydrologic studies for the majority of the major drainageways within District boundaries. These studies contain information regarding peak flow and runoff volume from the 2-year through 100-year storm events for numerous design points within the watershed. They also contain information regarding watershed and sub-watershed boundaries, soil types, percentage imperviousness, and rainfall. The studies are available at the District library. When published flow values are available from the District for any waterway of interest, these values should be used for design unless there are compelling reasons to modify the published values.

5.2 Statistical Methods

Statistical analysis of measured streamflow data is also an acceptable means of hydrologic analysis in certain situations. Statistical analysis should be limited to streams with a long period of flow data (30 years as a recommended minimum) where there have been no significant changes in land use in the tributary watershed during the period of the flow record. It should be recognized that there is no good way to extrapolate calculated flow from a statistical analysis to estimate the flow for expected future watershed development conditions.

6.0 SPREADSHEETS AND OTHER SOFTWARE

District provides following freeware to help with the calculations and protocols in this *Manual*. All of these can be found on the District's Web site (www.udfcd.org) under Downloads, Technical or Software.

The Colorado Urban Hydrograph Procedure has been computerized and is loaded using macro-driven spreadsheet. The software package is titled **CUHP 2005 Version x.x.x,** and includes a Converter to converts older version CUHP files and UDSWM files into CUHP 2005 and EPA's SWMM 5.0 formats.

A spreadsheet has been prepared to facilitate runoff calculations using the Rational Method, namely, **UD-Rational** (Guo 1995). Inputs needed include catchment area, runoff coefficient, 1-hour point rainfall depth, and flow reach characteristics (length, slope, and type of ground surface). The spreadsheet then calculates the peak runoff flow rate in cfs.

Storm sewers may be designed using the Rational Method with the aid of GUI-based software **Neo UD-Sewe**r. This software will pre-size storm sewers using the same input mentioned for UD-Rational, except that it permits definition of existing sewer link and that it also checks to insure that the most critical portions of the catchment are being accounted for in sizing the sewers. After the sewers are sized, or if you have an existing system, it can be used to analyze the hydraulic and energy grade lines of the system. A recent update includes a feature to generate a profile plot of the sewer, ground line, hydraulic grade line and energy grade line.

UD-RainZone is a spreadsheet that help the user find the Intensity-Duration-Frequency curve for any region in Colorado based on site elevation.

UD-Raincurve is a spreadsheet that helps the user develop design storm distributions for use with CUHP or other models based on the protocols described in this *Manual*. It will generate design storm hyetographs for small catchments (i.e., < 5 sq. mi.) all the way up to ones that are 75 sq. mi. in size, using area correction factors for the latter.

Latest release of the EPA SWMM 5.0 software is available for downloading from EPA's web site at (http://www.epa.gov/ednnrmrl/models/swmm/index.htm)

It is recommended that the users of these software check for updates on regular basis. Corrections of discovered bugs and enhancements are constantly under development and are posted as they are completed.

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7.0 EXAMPLES

7.1 Rational Method Example 1

Find the 100-year peak flow rate for a 60-acre catchment in an undeveloped grassland area located in Section 13, R65W, T1S. The upper 400 feet of the catchment is sloped at 2%, the lower 1,500 feet is grassed waterway that is sloped at 1%. The area has type C soils.

From Figure RA-6, the 1-hour point precipitation value is 2.7 inches. From Table RO-3, in the category "Undeveloped Areas, historic flow analysis," a percent impervious value of 2% (or 0.02) is selected.

Determine C_5 from Equation RO-7:

$$C_5 = \left(-0.10\,(0.02) + 0.11\right) + 0.858(0.02)^3 - 0.786\,(0.02)^2 + 0.774\,(0.02) + 0.04$$

$$= 0.16$$

Determine t_i from Equation RO-3:

$$t_i = \frac{0.395\left(1.1 - 0.16\right)\sqrt{400}}{\left(0.02\right)^{0.33}}$$

$$= 27.0 \text{ minutes}$$

Find t_t:

$$t_t = \frac{L}{60V}$$

From Table RO-2, for a grassed waterway, C_V = 15

From Equation RO-4:

$$V = 15\left(0.01\right)^{0.5}$$

$$= 1.5 \text{ ft/sec}$$

Find t_t:

$$t_t = \frac{1{,}500}{1.5 \cdot 60}$$

$$= 16.67 \text{ minutes}$$

From Equation RO-2:

$$t_c = 27.0 + 16.67$$

$$= 43.67 \text{ minutes}$$

Use 44 minutes

Determine C_{100} from Equation RO-7:

$$C_{100} = \left(-0.39(0.02) + 0.46\right) + 0.858(0.02)^3 - 0.786(0.02)^2 + 0.774(0.02) + 0.04$$

$$= 0.51$$

Determine rainfall intensity, I, from Equation RA-3:

$$I = 28.5 \cdot 2.7 / \left(10 + 44\right)^{0.786}$$

$$= 3.35 \text{ in/hr}$$

Determine Q from Equation RO-1:

$$Q = 0.51 \cdot 3.35 \cdot 60$$

$$= 102 \text{ cfs}$$

Alternately, use the runoff spreadsheet to calculate the peak flow rate as shown.

7.2 Rational Method Example 2

A watershed is divided into three subbasins in the City of Denver. The drainage system is designed to collect Subbasin 1 at Point A, and Subbasins 2 and 3 at Point B, and then drains into a detention system. Determine the 10-year peak discharge at Point B using the watershed parameters summarized in the table.

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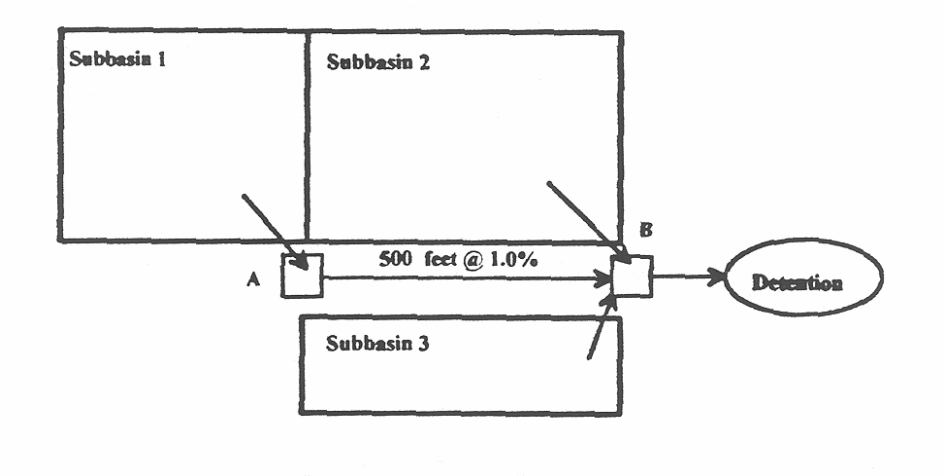

Subbasin	Drainage Area A (acres)	Runoff Coefficient C	Time of Concentration T_c (minutes)
1.00	2.00	0.55	15.00
2.00	5.00	0.65	22.00
3.00	1.50	0.81	12.00

As shown in the figure, there are three flow paths to reach Point B. Their flow times are:

1. From Subbasin 2: T_2 = 22 minutes
2. From Subbasin 3: T_3 = 12 minutes
3. From Subbasin 1: The flow time includes the time of concentration of Subbasin 1, and the flow time from Point A to Point B through the street. According to the SCS upland method, the conveyance parameter for the paved gutter flow is 20.0. The flow time from Subbasin 1 to Point B is the sum of the time of concentration of Subbasin 1 and the flow time through the 500-foot gutter as:

$$T_i = 15 + \frac{500}{60 \cdot 20 \cdot \sqrt{0.01}} = 19.17 \text{ minutes}$$

At Point B, the design rainfall duration T_d = max (T_1, T_2, T_3) = 22 minutes.

The 10-year design rainfall intensity for Denver is:

$$I = \frac{28.5 \cdot 1.61}{(10 + 22)^{0.786}} = 3.01 \text{ in/hr}$$

The total effective area at Point B is:

$$A_e = 0.81 \cdot 1.50 + 0.55 \cdot 2.0 + 0.65 \cdot 5.0 = 5.565 \text{ acres}$$

The 10-year peak discharge is:

$$Q = IA_e = 16.75 \text{ cfs}$$

7.3 Effective Rainfall Example

Calculate the effective rainfall from a 1.6-inch storm for a catchment that is 40% impervious. Sixty percent of the impervious area flows into pervious areas. Half of the pervious area receives flow from the impervious area. The depression losses are 0.1 inches for impervious areas and 0.3 inches for pervious areas.

Calculations are included in Table RO-9.

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Table RO-9—Effective Rainfall Calculations

One hour precipitation 1.6 inches
Impervious Area Depression Loss 0.1 inches
Pervious Area Depression Loss 0.3 inches
Impervious Fraction - IA 40%
CIA 40%
UIA 60%
Pervious Fraction - PA 60%
SPA 50%
RPA 50%

		Pervious Area										Impervious Area						
		SPA- Separate Pervious Fraction				RPA - Receiving Pervious Fraction												
Time (minutes) (1)	Incremental Precipitation (2)	Infiltration (3)	Depression Storage (4)	Effective Precipitation (5)	% Effective Precipitation (6)	UIA Contribution (7)	Infiltration (8)	Depression Storage (9)	Effective Precipitation (10)	% Effective precipitation (11)	Depression Storage (12)	Five Percent Loss (13)	Effective Precipitation (14)	% Effective Precipitation (15)	CIA - Directly Connected Area Runoff (16)	UIA-Unconnected Area Runoff (17)	Total Effective Precipitation (18)
0	0	0.000	0.00	0.00	0.00	0.00	0	0	0.00	0.00	0	0.000	0.00	0.00	0.00	0.00	0.00
5	0.03	0.201	0.00	0.00	0.00	0.00	0.201	0	0.00	0.00	0.03	0.000	0.00	0.00	0.00	0.00	0.00
10	0.06	0.134	0.00	0.00	0.00	0.00	0.134	0	0.00	0.00	0.06	0.000	0.00	0.00	0.00	0.00	0.00
15	0.13	0.096	0.04	0.00	0.00	0.03	0.096	0.06	0.00	0.00	0.01	0.006	0.12	0.05	0.02	0.03	0.02
20	0.24	0.073	0.11	0.06	0.01	0.05	0.073	0.09	0.13	0.04	0	0.012	0.23	0.09	0.04	0.05	0.09
25	0.40	0.060	0.00	0.34	0.09	0.09	0.06	0	0.43	0.13	0	0.020	0.38	0.15	0.06	0.09	0.28
30	0.19	0.052	0.00	0.14	0.04	0.04	0.052	0	0.18	0.06	0	0.010	0.18	0.07	0.03	0.04	0.12
35	0.09	0.048	0.00	0.04	0.01	0.02	0.048	0	0.06	0.02	0	0.004	0.09	0.03	0.01	0.02	0.04
40	0.07	0.045	0.00	0.02	0.01	0.02	0.045	0	0.04	0.01	0	0.003	0.07	0.03	0.01	0.02	0.03
45	0.06	0.044	0.00	0.02	0.00	0.01	0.044	0	0.03	0.01	0	0.003	0.06	0.02	0.01	0.01	0.02
50	0.05	0.043	0.00	0.01	0.00	0.01	0.043	0	0.02	0.01	0	0.003	0.05	0.02	0.01	0.01	0.02
55	0.05	0.042	0.00	0.01	0.00	0.01	0.042	0	0.02	0.01	0	0.003	0.05	0.02	0.01	0.01	0.02
60	0.05	0.042	0.00	0.01	0.00	0.01	0.042	0	0.02	0.01	0	0.003	0.05	0.02	0.01	0.01	0.02
65	0.05	0.042	0.00	0.01	0.00	0.01	0.042	0	0.02	0.01	0	0.003	0.05	0.02	0.01	0.01	0.02
70	0.05	0.042	0.00	0.01	0.00	0.01	0.042	0	0.02	0.01	0	0.003	0.05	0.02	0.01	0.01	0.02
75	0.05	0.042	0.00	0.01	0.00	0.01	0.042	0	0.02	0.01	0	0.003	0.05	0.02	0.01	0.01	0.02
80	0.04	0.042	0.00	0.00	0.00	0.01	0.042	0	0.01	0.00	0	0.002	0.04	0.02	0.01	0.01	0.01
85	0.03	0.042	0.00	0.00	0.00	0.01	0.042	0	0.00	0.00	0	0.002	0.03	0.01	0.00	0.01	0.00
90	0.03	0.042	0.00	0.00	0.00	0.01	0.042	0	0.00	0.00	0	0.002	0.03	0.01	0.00	0.01	0.00
95	0.03	0.042	0.00	0.00	0.00	0.01	0.042	0	0.00	0.00	0	0.002	0.03	0.01	0.00	0.01	0.00
100	0.03	0.042	0.00	0.00	0.00	0.01	0.042	0	0.00	0.00	0	0.002	0.03	0.01	0.00	0.01	0.00
105	0.03	0.042	0.00	0.00	0.00	0.01	0.042	0	0.00	0.00	0	0.002	0.03	0.01	0.00	0.01	0.00
110	0.03	0.042	0.00	0.00	0.00	0.01	0.042	0	0.00	0.00	0	0.002	0.03	0.01	0.00	0.01	0.00
115	0.03	0.042	0.00	0.00	0.00	0.01	0.042	0	0.00	0.00	0	0.001	0.03	0.01	0.00	0.01	0.00
120	0.02	0.042	0.00	0.00	0.00	0.00	0.042	0	0.00	0.00	0	0.001	0.02	0.01	0.00	0.00	0.00
Total	1.85	1.38	0.15	0.67	0.17	0.40	1.384	0.15	1.01	0.30	0.10	0.088	1.66	0.67	0.27	0.40	0.74

Notes:
(1) Enter time in minutes.
(2) Enter rainfall hyetograph.
(3) Enter soil infiltration rate calculated using equation RO-8.
(4) If (3)<(2) the = 0, otherwise = (2) - (3) until the cumulative sum of entries equals the pervious depression loss * SPA.
(5) = (2) - (3) - (4) but not less than 0.0
(6) = (5) * SPA * PA
(7) = (17)
(8) = (3)
(9) If (8) > (2) + (7) then = 0, otherwise = (8) - (2) - (7) until cumulative sum of entries equals the pervious depression loss * RPA
(10) = (2) + (7) - (8) - (9) but not less than 0.0
(11) = (10) * RPA * PA
(12) = (2) until cumulative sum of entries equals the impervious depression loss
(13) = 0.05 * ((2) - (12))
(14) = (2) - (12) - (13)
(15) = (14) * IA
(16) = (15) * CIA
(17) = (15) * UIA
(18) = (6) + (11) + (16)

8.0 REFERENCES

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APPENDIX A -
DETAILS OF THE COLORADO URBAN HYDROGRAPH PROCEDURE (CUHP)

For watersheds that are larger than 90 acres, the District recommends that the design storm runoff be analyzed by deriving synthetic unit hydrographs. Sherman originally developed the unit hydrograph principle in 1932. Snyder developed the synthetic unit hydrograph, which is used for analysis when there are no rainfall-runoff data for the basin under study, as is often the case in the Denver region, in 1938. The presentation given in this chapter is termed CUHP because coefficients and the form of the equation are based upon data collected in the Denver region of Colorado and on studies conducted or financed by the District. The U.S. Geological Survey (USGS) collected the data for use in the development of the 1982 version of CUHP between 1969 and 1981 under a cooperative agreement with the District. Data collection activities are continuing under a similar cooperative agreement between the District and USGS; however, the number of stations has been reduced. The goal of the currently ongoing data collection effort is to develop a long-term database for further refinements to the hydrologic techniques in the Denver region.

A.1 Definition

A unit hydrograph is defined as the hydrograph of one inch of direct runoff from the tributary area resulting from a unit storm. The unit hydrograph thus represents the integrated effects of factors such as tributary area, shape, street pattern, channel capacities, and street and land slopes.

The basic premise of the unit hydrograph is that individual hydrographs resulting from the successive increments of rainfall excess that occur throughout a storm period will be proportional in discharge throughout their runoff period. Thus, the hydrograph of total storm discharge is obtained by summing the ordinates of the individual sub-hydrographs.

A.2 Basic Assumptions

The derivation and application of the unit hydrograph are based on the following assumptions:

1. The rainfall intensity is constant during the storm that produces the unit hydrograph.
2. The rainfall is uniformly distributed throughout the whole area of the watershed.
3. The time duration of the unit hydrograph resulting from an effective rainfall of unit duration is constant.
4. The ordinates of the design runoff with a common unit time are directly proportional to the total amount of direct runoff represented by each sub-hydrograph.
5. The effects of all physical characteristics of a given watershed, including shape, slope, detention,

infiltration, drainage pattern, channel storage, etc., are reflected in the shape of the unit hydrograph for that watershed.

A.3 Equations

There are four basic equations used in defining the limits of the synthetic unit hydrograph. The first equation defines the lag time of the basin in terms of time to peak, t_p, which, for the CUHP method, is defined as the time from the center of the unit duration storm to the peak of the unit hydrograph as shown in Figure RO-A1.

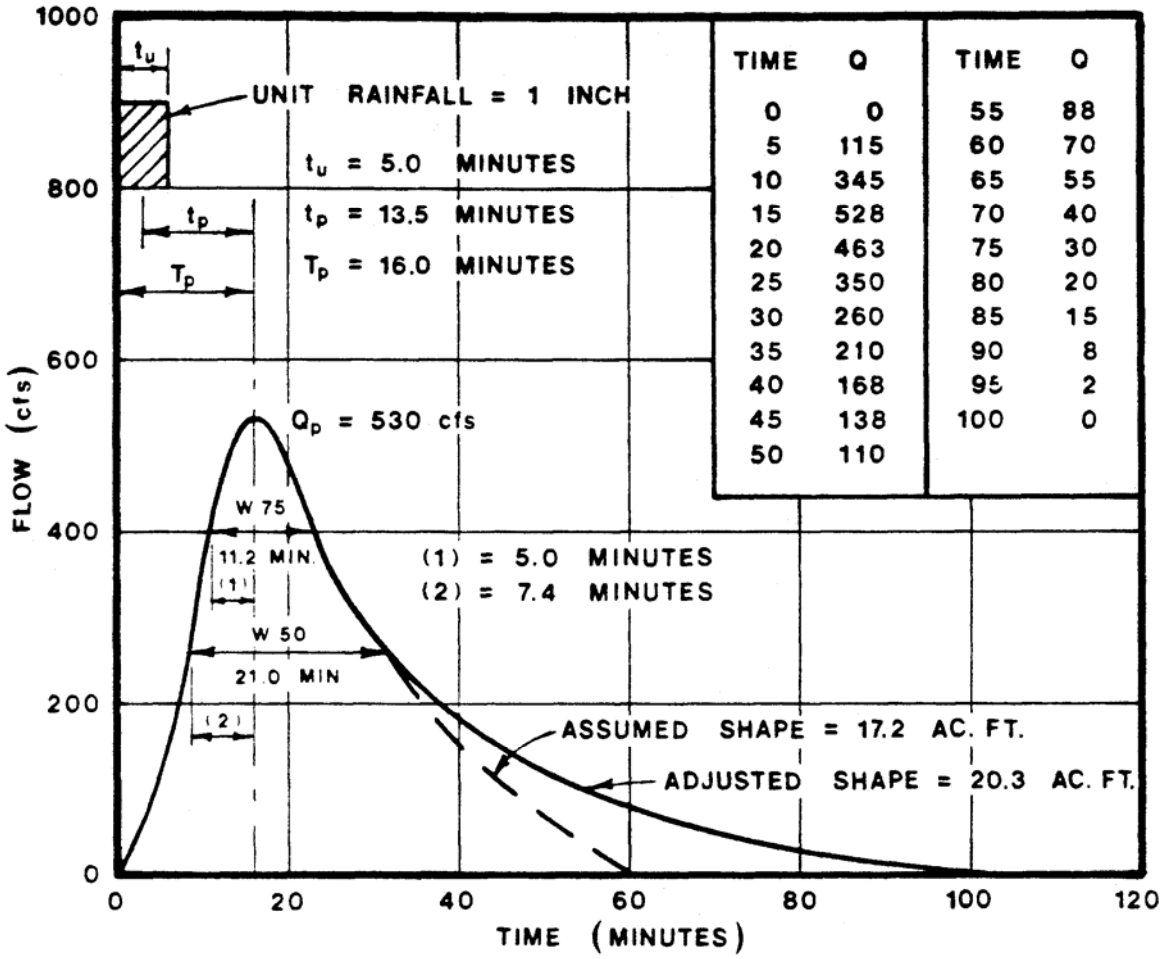

Figure RO-A1—Example of Unit Hydrograph Shaping

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$$t_p = C_t\left(\frac{LL_{ca}}{\sqrt{S}}\right)^{0.48} \quad \text{(RO-A1)}$$

in which:

t_p = time to peak of the unit hydrograph from midpoint of unit rainfall in hours

L = length along stream from study point to upstream limits of the basin in miles

L_{ca} = length along stream from study point to a point along stream adjacent to the centroid of the basin in miles

S = weighted average slope of basin along the stream to upstream limits of the basin in feet per foot

C_t = coefficient reflecting time to peak

The time from the beginning of unit rainfall to the peak of the unit hydrograph is determined by:

$$T_p = 60t_p + 0.5t_u \quad \text{(RO-A2)}$$

in which:

T_p = time from beginning of unit rainfall to peak of hydrograph in minutes

t_u = time of unit rainfall duration in minutes

The unit peak of the unit hydrograph is defined by:

$$q_p = \frac{640C_p}{t_p} \quad \text{(RO-A3)}$$

in which:

q_p = peak rate of runoff in cfs per square mile

C_p = coefficient related to peak rate of runoff

Once q_p is determined, the peak of the unit hydrograph for the basin is computed by:

$$Q_p = q_p A \quad \text{(RO-A4)}$$

in which:

Q_p = peak of the unit hydrograph in cfs

A = area of basin in square miles

A.4 Unit Storm Duration

For most urban studies, the unit storm duration, t_u, should be 5 minutes. However, the unit duration may be increased for larger watersheds. It is convenient to have the unit duration incremented in multiples of 5 minutes (i.e., 10 or 15 minutes) with the maximum unit duration recommended at 15 minutes.

An acceptable unit storm duration, whenever it is larger than 5 minutes, should not exceed one-third of t_p. As an example, if the watershed has a t_p = 35 minutes, then an appropriate unit storm duration would be 5 minutes or 10 minutes (i.e., less than or equal to 1/3 t_p).

A.5 Watershed Size Limits

The rainfall-runoff data used in the development of the current version of CUHP were obtained primarily from small watersheds that ranged from 0.15 square miles to 3.08 square miles. Although some extrapolation is justified, unlimited extrapolation of how the watershed responds to rainfall is not. It is recommended that the maximum size of a watershed to be analyzed with a single unit hydrograph be limited to 5 square miles. Whenever a larger watershed needs to be studied, it is suggested it be subdivided into sub-watersheds of 5 square miles or less and individual sub-watershed storm hydrographs be routed downstream using appropriate channel routing procedures such as SWMM. The routed hydrographs then need to be added to develop a single composite storm hydrograph.

Because of the way a unit hydrograph responds, it is also suggested that the minimum watershed size be 90 acres. The 5-minute unit hydrograph procedure may be used for a smaller watershed provided t_p is greater than 10 minutes.

A.6 Watershed Shape Limits

The watershed shape can have a profound effect on the final results. It affects and suggested limitations in the coding of individual watersheds is discussed in Pragraph 3.3.3 in the main body of this Runoff Chapter.

A.7 Watershed Slope Limits and Considerations

The current version of CUHP was developed using data from watersheds having a range of major drainageway slopes between 0.005 ft/ft and 0.037 ft/ft. Caution must be used when extrapolating beyond this range.

A.7.1 Natural and Grass-Lined Waterways

In natural and grass-lined drainageways, channels become unstable when a Froude Number of 1.0 is approached. There are natural processes at work that limit the time to peak of a unit hydrograph as the drainageway becomes steeper. To account for this phenomenon, it is recommended that the slope used in Equation RO-9 for natural drainageways and existing manmade grass-lined channels be adjusted

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using Figure RO-10.

A.7.2 Grass-Lined Channels

Grass-lined channels designed and built using District criteria have a slope that limits maximum flow velocities. A typical range in longitudinal slopes for such channels is 0.003 ft/ft to 0.006 ft/ft. It is recommended that for preliminary estimating purposes a longitudinal slope of 0.005 ft/ft be used for grass-lined channels that are to be designed using District criteria.

A.7.3 Riprap-Lined Channels

The District's criteria also limit the Froude Number to less than 0.8 for riprap-lined channels. For this reason it is suggested that, for preliminary estimating purposes where riprap channels are contemplated, a longitudinal slope of 0.01 be used with Figure RO-10. When a riprap channel is in existence, use the measured average channel profile slope.

A.7.4 Concrete Channels and Storm Sewers

In concrete-lined channels and buried conduits, the velocities can be very high. For this reason, it is recommended that the average ground slope (i.e., not flow-line slope) be used where concrete-lined channels and/or storm sewers dominate the watershed drainageways. There is no upper limit recommended to the slope for such watersheds.

A.7.5 Weighted Watershed Slope

Where the flow-line slope varies along the channel, calculate a weighted basin slope for use with Equation RO-9. Do this by first segmenting the major drainageway path into reaches having similar longitudinal slopes. Calculate the weighted slope using Equation RO-9.

A.8 Watershed Land Use Consideration

A lumped parameter model such as CUHP relies on data from watersheds having relatively uniform land use. It is recommended that watersheds having zones of differing land use be subdivided into sub-watersheds having relatively uniform land use. As an example, if the lower half of a watershed has been urbanized and the upper half is to remain as open space, it is best to develop two distinct hydrographs. The upper sub-watershed hydrograph will be based on the coefficients for undeveloped land, and the lower sub-watershed hydrograph will be the result of coefficients for the developed area.

A.9 Determination of C_t and C_p Coefficients

The value of C_t in Equation RO-A1 may be determined using Figure RO-A2. Note that the curve in Figure RO-A2 can be represented using parabolic equations having the percent imperviousness, I_a, as an independent variable.

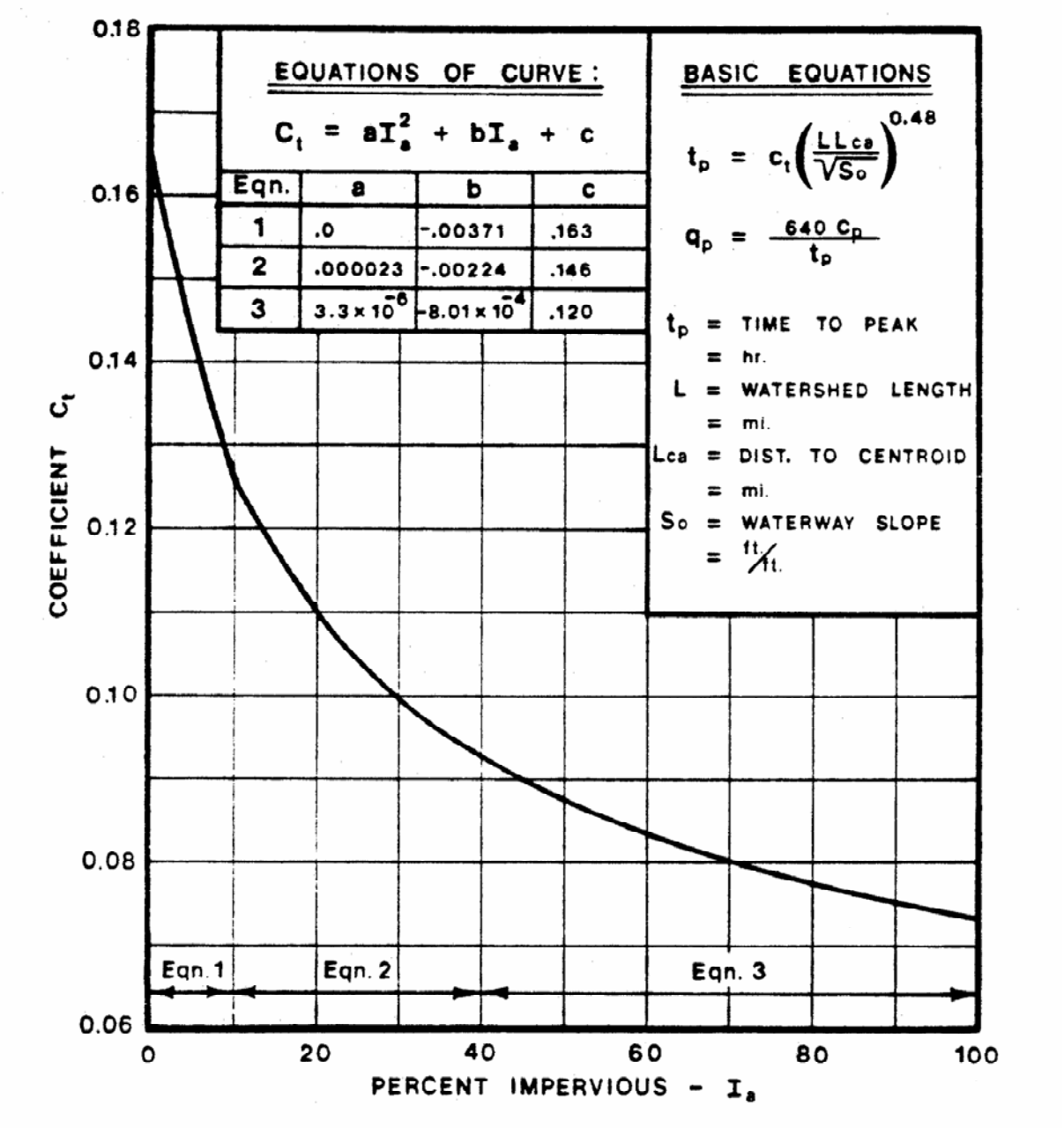

Figure RO-A2—Relationship Between C_t and Imperviousness

The value of C_p to be used in Equation RO-A3 may be determined using Figure RO-A3. The curve in Figure RO-A3 is also represented with a parabolic equation. To determine C_p, first obtain the value of the Peaking Parameter, P, from Figure RO-A3. Then calculate C_p using Equation RO-A5.

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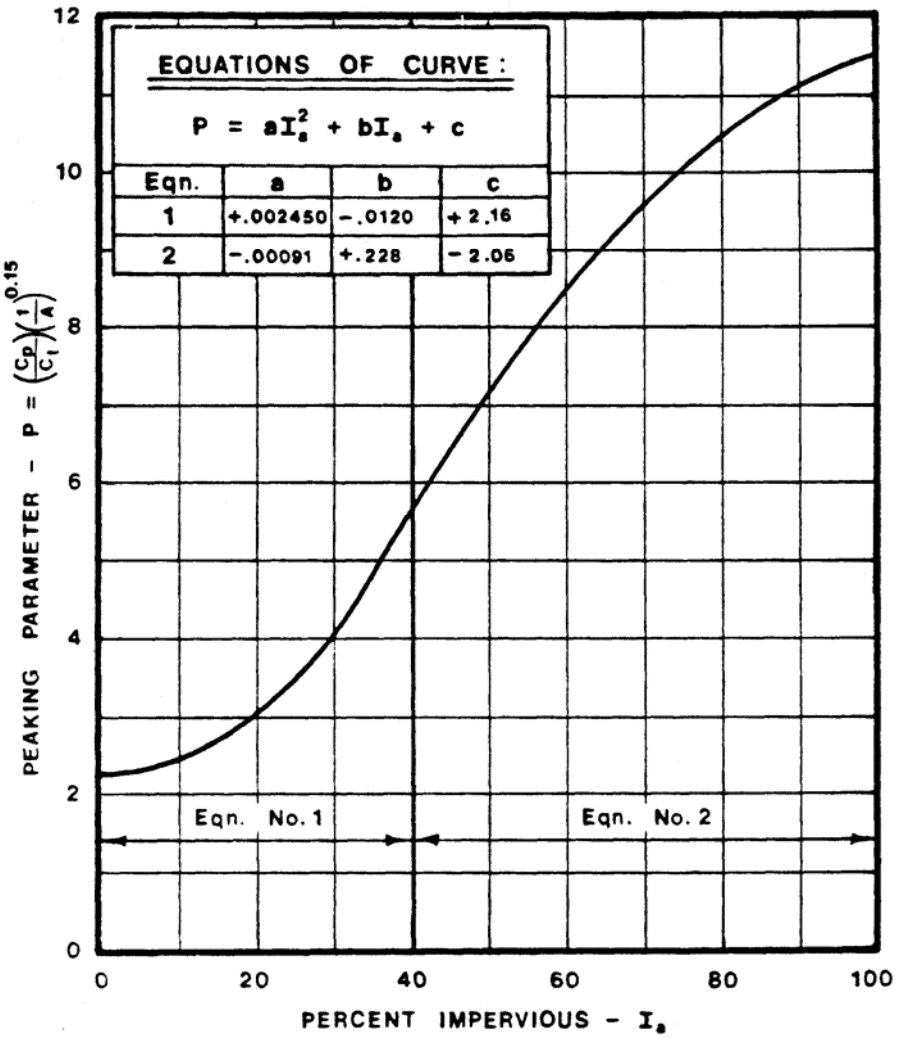

Figure RO-A3—Relationship Between Peaking Parameter and Imperviousness

$$C_p = PC_tA^{0.15} \quad \text{(RO-A5)}$$

in which:

P = peaking parameter from Figure RO-A3

C_t = coefficient from Figure RO-A2

A = basin area in square miles

A.10 Unit Hydrograph Shape

The shape of the unit hydrograph is a function of the physical characteristics of the watershed. It incorporates the effects of watershed size, shape, degree of development, slope, type, and size of drainage system, soils, and many other watershed factors. The shape of the unit hydrograph is also

dependent on the temporal and spatial distribution of rainstorms and will vary with each storm event. As a result, a unit hydrograph based on rainfall-runoff data is an approximation that provides the engineer or hydrologist with a reasonable unit hydrograph shape for a given hydrologic region and land development practices.

Equations RO-A1 through RO-A5 are used to define the peak discharge and its location for the unit hydrograph. The widths of the unit hydrograph at 50% and 75% of the peak can be estimated using Figure RO-A4. Note that the unit hydrograph widths at 50% and 75% of the peak are given in hours. The two equations shown on Figure RO-A4 mathematically describe the two lines on the figure.

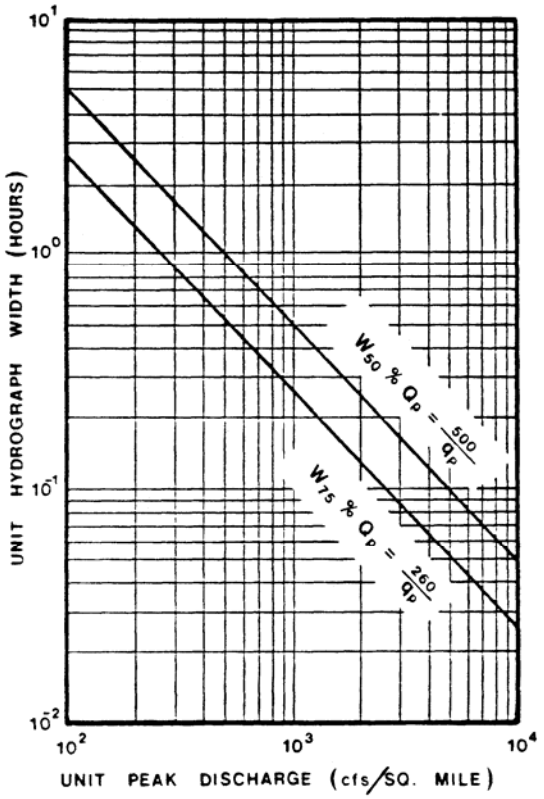

Figure RO-A4—Unit Hydrograph Widths

In addition to knowing the location of the unit hydrograph peak and its width at two points on its ordinate, it also helps to know how to distribute the two widths around the peak. A study of many unit hydrographs generated using recorded rainfall and runoff events indicates that, as a general rule, 0.35 of the width at 50% of peak is to the left of the peak and 0.65 of the width is to the right of the peak. At 75% of the peak, 0.45 of the width is left of the peak and 0.55 of the width is to the right of the peak. However, on some hydrographs this rule needs to be modified. Whenever the above rule results in the hydrograph at 50% of peak being to the left of the peak by more than $0.6T_p$ (T_p = the distance from zero to the peak of the unit

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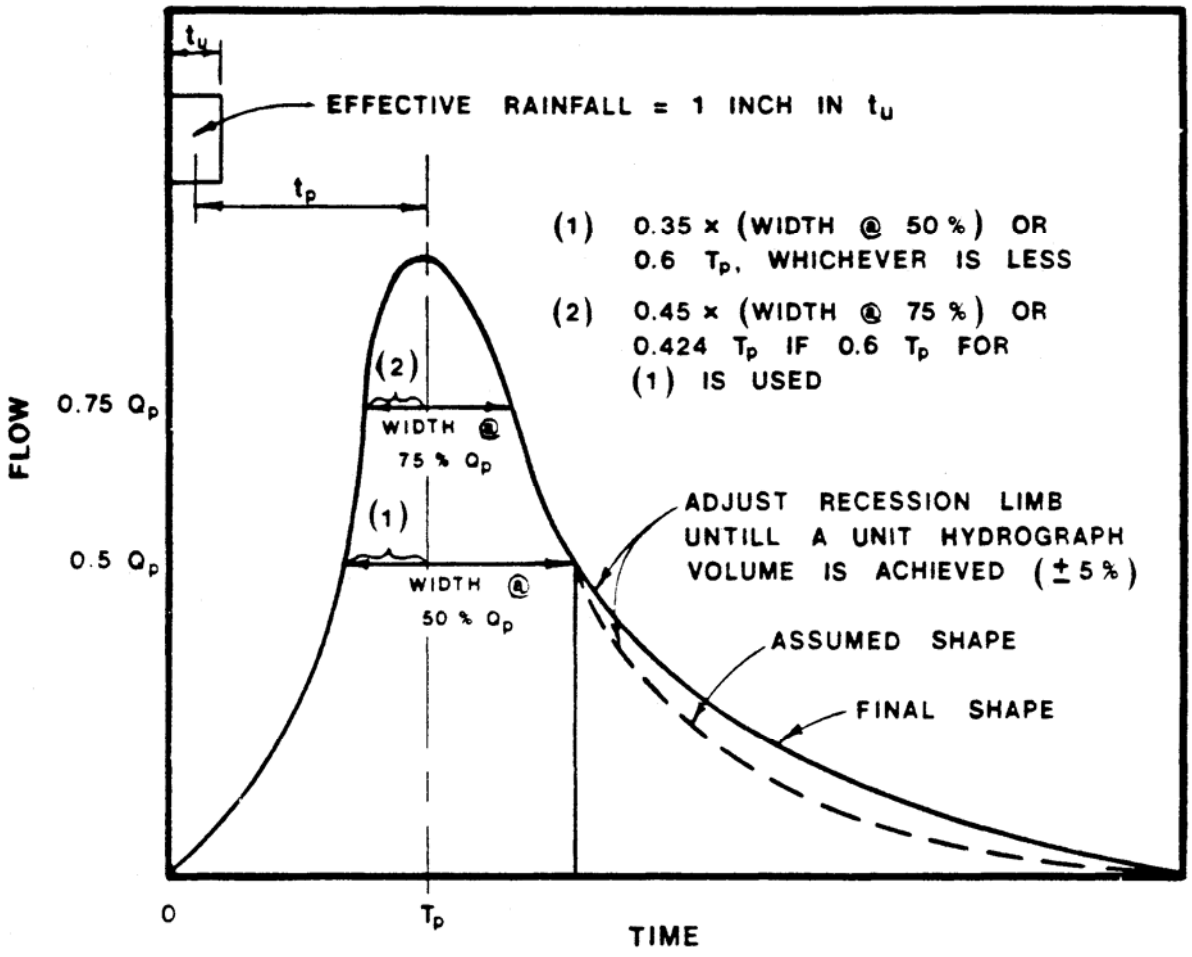
hydrograph); the x coordinate at 50% of peak should be placed at $0.6T_p$, and at 75% of the peak it should be placed at $0.424T_p$. Figure RO-A5 shows how a typical unit hydrograph may be shaped to best approximate the trends found in the rainfall-runoff data.

Figure RO-A5—Unit Hydrograph

A.11 Conceptual Relationships for Directly Connected Imperviousness Modeling



In 1995, the CUHP computer model was modified to recognize the effects of directly connected impervious areas on excess precipitation and its response in calculating runoff volumes and peaks.

It is possible to conceptualize any urban catchment as having four separate surface runoff components:

1. Impervious area directly connected to the drainage system (DCIA).
2. Impervious area that drains onto or across impervious surfaces (UIA).

3. The pervious area receiving runoff from impervious portions (RPA).

4. The separate pervious area (SPA) not receiving runoff from impervious surfaces.

This concept is illustrated in Figure RO-A6. To model the excess precipitation process and the losses to it that occur within an urban catchment, the following variables were defined and used in the CUHPF/PC version of the program:

IA = total impervious fraction

PA = total pervious fraction

PIA = effective precipitation from impervious fraction*

PPA = effective precipitation from impervious fraction*

CIA = directly (hydraulically) connected impervious fraction

ICIA = indirectly connected impervious area

UIA = unconnected impervious fraction

RPA = receiving pervious fraction

SPA = separate pervious fraction

D = CIA/IA, fraction of impervious area directly connected to drainage system

R = RPA/PA, fraction of pervious area receiving disconnected impervious runoff

K = UIA/RPA, the ratio of unconnected impervious area to pervious receiving area

* Effective precipitation before adjustment

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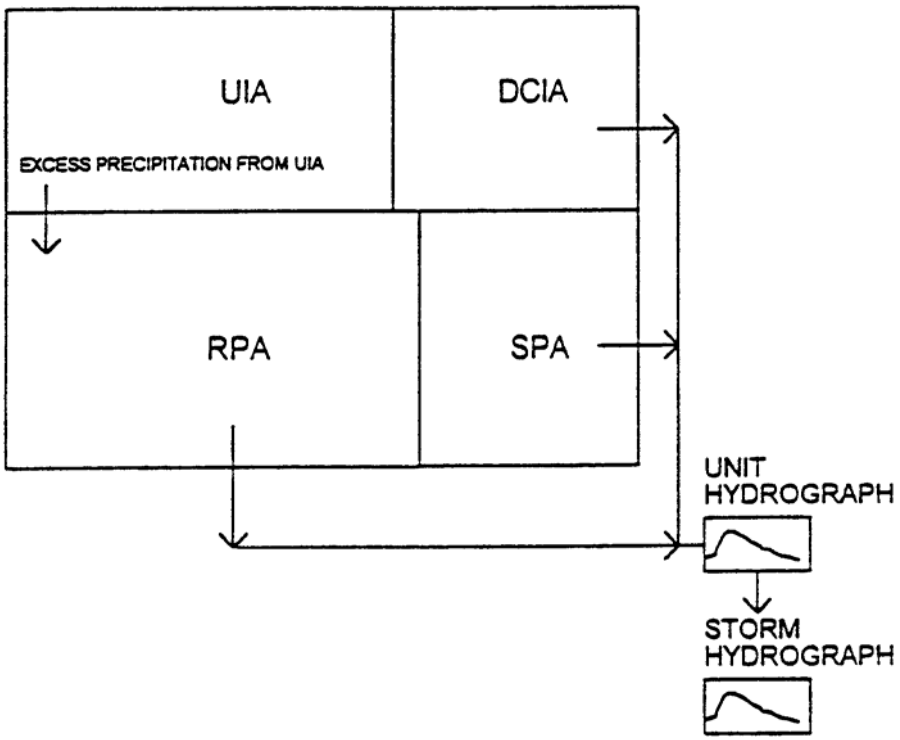

Figure RO-A6—Runoff Flow Diagram for the CUHPF/PC Model

The CUHP model was modified in 1995 to account for the effects on runoff from impervious areas that first travel over pervious areas before entering a drainageway. This was done to estimate the effects on runoff rates and volumes of intentionally routing flow onto pervious areas. Based on field observations, experience, and a lot of assumptions, a set of values was developed defining how much of the total impervious area is likely to drain onto the catchment's impervious area. Likewise, default estimates of how much of the pervious area is likely to receive the "disconnected" impervious drainage were developed. These were then incorporated as default values into the CUHPF/PC model. The flow chart shown in Figure RO-A7 illustrates the concept in more detail.

The default relationships for D, the ratio of directly connected impervious area to the total impervious area, and R, the ratio of pervious area receiving runoff from impervious areas to the total pervious area of the catchment, as a function of the total impervious fraction used as default values in CUHPF are given in Figure RO-A8 and Figure RO-A9. Level 1 of directly connected imperviousness (DCIA) assumes that all roof gutters are disconnected form driveways, gutters and stormwater conveyance elements. All roof drains are drained onto lawns. Level 2 of DCIA is for developments that already use Level 1 and do not have any curbs and gutters, including concrete swale gutters. All runoff from streets and parking areas is directed as sheet flow across grass surfaces. Intermittent curbs with frequent opening to the grass surface qualifies as Level 2 DCIA.

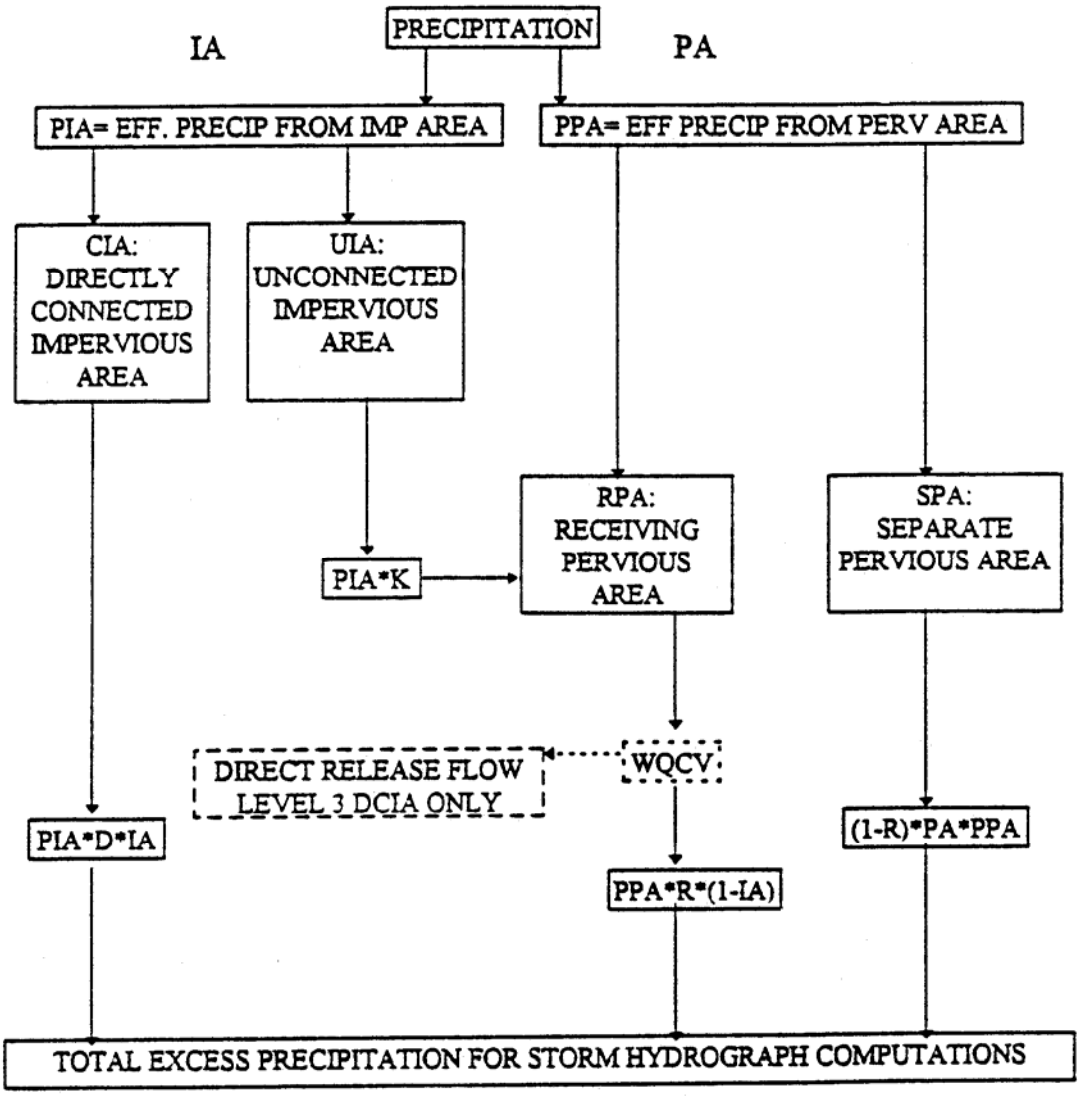

Figure RO-A7—Rainfall and Runoff Schematic for CUHPF/PC

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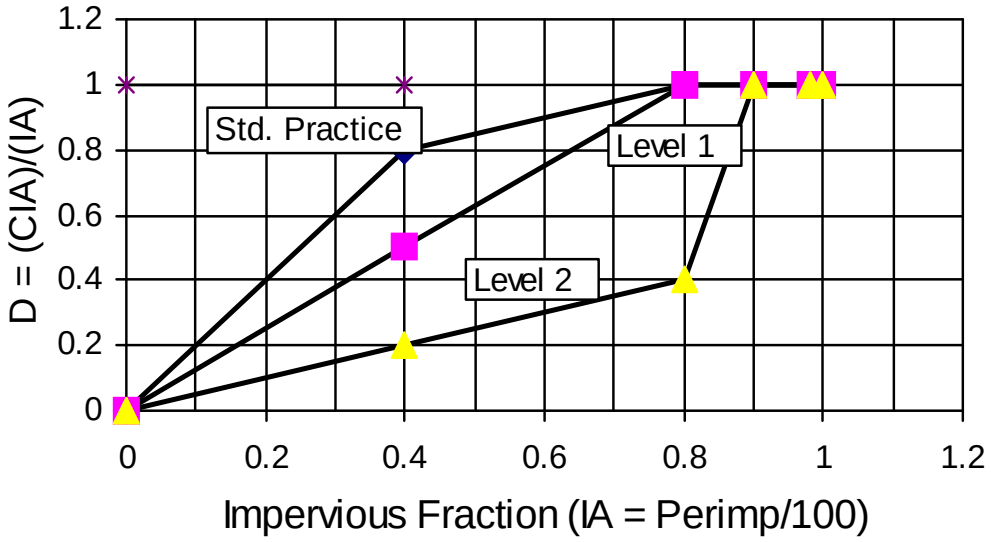

Figure RO-A8—Default Values for Directly Connected Impervious Fraction (D)

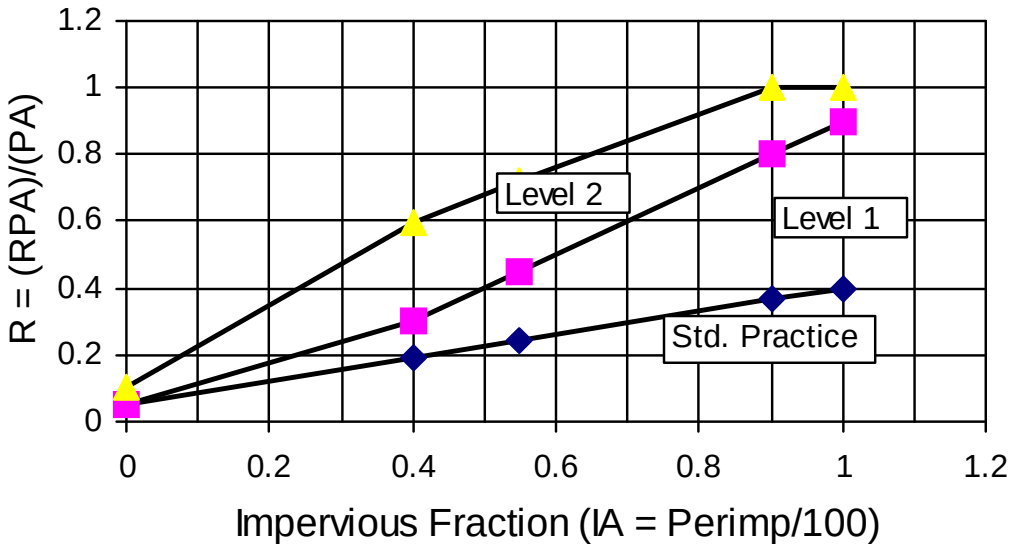

Figure RO-A9—Default Values for Receiving Pervious Area Fraction (R)

The primary change from the earlier version of this software was in the setup and execution of the Effective Rainfall worksheet. The calculations are done for each time increment, same as before, only with the additional losses experienced within the receiving portion of the pervious area taken into account. Whereas the old method was to simply multiply the effective precipitation, if any, by the percentage of the impervious area (IA) and pervious area (PA) as appropriate, each of the four elements illustrated in Figure RO-A7 are now taken into account. Pervious area calculations are segregated using (1-R) to remove the RPA portion. The IA is multiplied by the effective precipitation for impervious area, PIA, and

the directly connected impervious area fraction, D, to find the excess precipitation from the hydraulically connected fraction (CIA). The PIA is multiplied by (1-D)*IA to find the excess precipitation from the unconnected impervious area, UIA, which is added to the incremental pervious area precipitation, PPA, and R*PA to calculate the net water contributed to the receiving pervious area, RPA, during each time step. The excess precipitation form the separate pervious area, SPA, is found by multiplying the remaining fraction of pervious area, (1-R) by PA*PPA. The same values for retention/detention losses are used for each pervious fraction, but they will obviously be filled at different rates. Finally, the sum of the excess precipitations from SPA, CIA, and RPA become the total excess precipitation, sometimes referred to as "effective rainfall." All these calculations are illustrated in Table RO-9 in Section 7.3 *Effective Rainfall Example*.

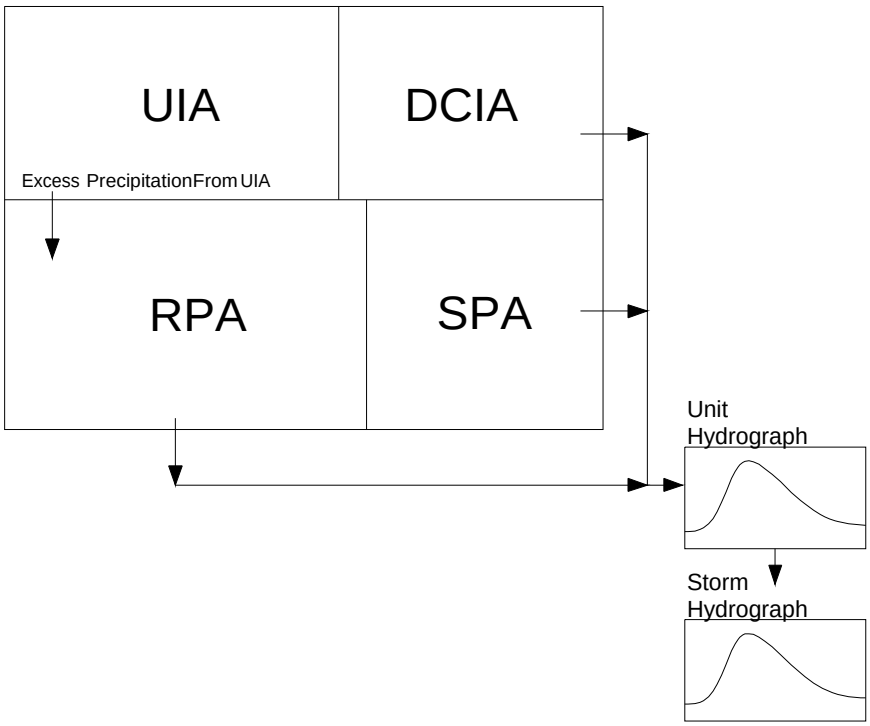

Figure RO-A10—Area and Runoff Diagram With Level 3 DCIA

The "effective" impervious area is determined using Figure ND-1 from the NEW DEVELOPMENT PLANNING chapter of Volume 3 of this *Manual*. However, only 50% of the effects of the effective imperviousness is used for Level 2 DCIA in adjusting lag time.

The user has the option of entering values to override the defaults. Any user-input values for D and R must be accompanied by a specified level of DCIA (i.e., Level 1 or 2) for them to be considered. Note: Since there are default values of D and R for "established practice," the results of CUHP may be somewhat different than from old versions of CUHP for the same catchment.

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For complete instruction and definitions of input parameters, study and follow the latest version of the *USER MANUAL -COLORADO URBAN HYDROGRAPH PROCEDURE, EXCEL-BASED COMPUTER PROGRAM (CUHP2005)*, which may be downloaded from the District's web site.

Calculating the Final Storm Hydrograph: The text in this chapter and in this appendix described how a unit hydrograph is shaped, its ordinates at unit time steps taken off, and how excess precipitation is calculated for each step of the design storm hyetograph. These two sets of calculation need to be now combined to find the storm hydrograph for the catchment given these calculated values. Thus, once the unit hydrograph and the excess precipitation hyetographs are known, the storm hydrograph is calculated by cross-multiplying these two row/column matrixes. Table RO-A1 illustrates these sets of calculations to find the final storm hydrograph for a given catchment and a design storm.

Table RO-A1—Example for Determination a Storm Hydrograph

Time	Unit	Excess Rainfall Depth in Inch																					Hydro
min	Graph cfs	0.04	0.09	0.31	0.15	0.06	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	graph cfs
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
5	115	4.6																						4.6
10	345	13.8	10.4																					24.2
15	520	20.8	31.1	35.7																				87.5
20	463	18.5	46.8	107.0	17.3																			189.5
25	350	14.0	41.7	161.2	51.8	6.9																		275.5
30	260	10.4	31.5	143.5	78.0	20.7	5.8																	289.9
35	210	8.4	23.4	108.5	69.5	31.2	17.3	3.5																261.7
40	168	6.7	18.9	80.6	52.5	27.8	26.0	10.4	3.5															226.3
45	138	5.5	15.1	65.1	39.0	21.0	23.2	15.6	10.4	3.5														198.3
50	110	4.4	12.4	52.1	31.5	15.6	17.5	13.9	15.6	10.4	3.5													176.8
55	88	3.5	9.9	42.8	25.2	12.6	13.0	10.5	13.9	15.6	10.4	3.5												160.8
60	70	2.8	7.9	34.1	20.7	10.1	10.5	7.8	10.5	13.9	15.6	10.4	3.5											147.7
65	55	2.2	6.3	27.3	16.5	8.3	8.4	6.3	7.8	10.5	13.9	15.6	10.4	3.5										136.9
70	40	1.6	5.0	21.7	13.2	6.6	6.9	5.0	6.3	7.8	10.5	13.9	15.6	10.4	2.3									126.7
75	30	1.2	3.6	17.1	10.5	5.3	5.5	4.1	5.0	6.3	7.8	10.5	13.9	15.6	6.9	1.2								114.5
80	20	0.8	2.7	12.4	8.3	4.2	4.4	3.3	4.1	5.0	6.3	7.8	10.5	13.9	10.4	3.5	1.2							98.7
85	15	0.6	1.8	9.3	6.0	3.3	3.5	2.6	3.3	4.1	5.0	6.3	7.8	10.5	9.3	5.2	3.5	1.2						83.3
90	8	0.3	1.4	6.2	4.5	2.4	2.8	2.1	2.6	3.3	4.1	5.0	6.3	7.8	7.0	4.6	5.2	3.5	1.2					70.3
95	2	0.1	0.7	4.7	3.0	1.8	2.0	1.7	2.1	2.6	3.3	4.1	5.0	6.3	5.2	3.5	4.6	5.2	3.5	1.2				60.6
100	0	0.0	0.2	2.5	2.3	1.2	1.5	1.2	1.7	2.1	2.6	3.3	4.1	5.0	4.2	2.6	3.5	4.6	5.2	3.5	1.2			52.4
105			0.0	0.6	1.2	0.9	1.0	0.9	1.2	1.7	2.1	2.6	3.3	4.1	3.4	2.1	2.6	3.5	4.6	5.2	3.5	1.2		45.6
110				0.0	0.3	0.5	0.8	0.6	0.9	1.2	1.7	2.1	2.6	3.3	2.8	1.7	2.1	2.6	3.5	4.6	5.2	3.5	1.2	41.0
115					0.0	0.1	0.4	0.5	0.6	0.9	1.2	1.7	2.1	2.6	2.2	1.4	1.7	2.1	2.6	3.5	4.6	5.2	3.5	36.8
120						0.0	0.1	0.2	0.5	0.6	0.9	1.2	1.7	2.1	1.8	1.1	1.4	1.7	2.1	2.6	3.5	4.6	5.2	31.2
125							0.0	0.1	0.2	0.5	0.6	0.9	1.2	1.7	1.4	0.9	1.1	1.4	1.7	2.1	2.6	3.5	4.6	24.4
130								0.0	0.1	0.2	0.5	0.6	0.9	1.2	1.1	0.7	0.9	1.1	1.4	1.7	2.1	2.6	3.5	18.5
135									0.0	0.1	0.2	0.5	0.6	0.9	0.8	0.6	0.7	0.9	1.1	1.4	1.7	2.1	2.6	14.0
140										0.0	0.1	0.2	0.5	0.6	0.6	0.4	0.6	0.7	0.9	1.1	1.4	1.7	2.1	10.7
145											0.0	0.1	0.2	0.5	0.4	0.3	0.4	0.6	0.7	0.9	1.1	1.4	1.7	8.1
150												0.0	0.1	0.2	0.3	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.4	6.1
155													0.0	0.1	0.2	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.1	4.5
160														0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	3.3
165															0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.7	2.4
170																0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	1.7
175																	0.0	0.0	0.1	0.2	0.2	0.3	0.4	1.2
180																		0.0	0.0	0.1	0.2	0.2	0.3	0.8
185																			0.0	0.0	0.1	0.2	0.2	0.5
190																				0.0	0.0	0.1	0.2	0.3
195																					0.0	0.0	0.1	0.1
200																						0.0	0.0	0.0
205																							0.0	0.0

A.15 Basis for the 1982 Version of the Colorado Urban Hydrograph Procedure

Rainfall and runoff data were collected by U.S. Geological Survey in the Denver metropolitan area since 1969 under a cooperative agreement with the Urban Drainage and Flood Control District. Analysis of this data by the District staff began in earnest in 1977. Of the original thirty gaging stations, data from only seven sites (nine different basin conditions) were used by the District to develop the 1982 version of the Colorado Urban Hydrograph Procedure (CUHP). Data from other sites were also evaluated but were determined not suitable for use due to various gaging problems and watershed definition problems. Because the metropolitan area database lacked an undeveloped watershed, data from a small watershed (Kiowa Creek Tributary at Elbert) recoded by USGS for the Colorado Highway Department was used.

Peak flows from each recorded hydrograph at all test sites were compared with the calculated peak flows using the 1982 version of CUHP. These comparisons are plotted in Figure RO-A12 and substantiate the validity of the CUHP procedure.

Those wishing to compare the older version (i.e., pre 1982) of the CUHP with the new version will find that the new unit hydrograph have a significantly shorter time to peak. This is particularly true for smaller urbanized catchments. However, the new version will often produce peak flow results comparable to those obtained using the old version over a wide range of watershed conditions that are typically used in drainage studies in the Denver Metropolitan Area.

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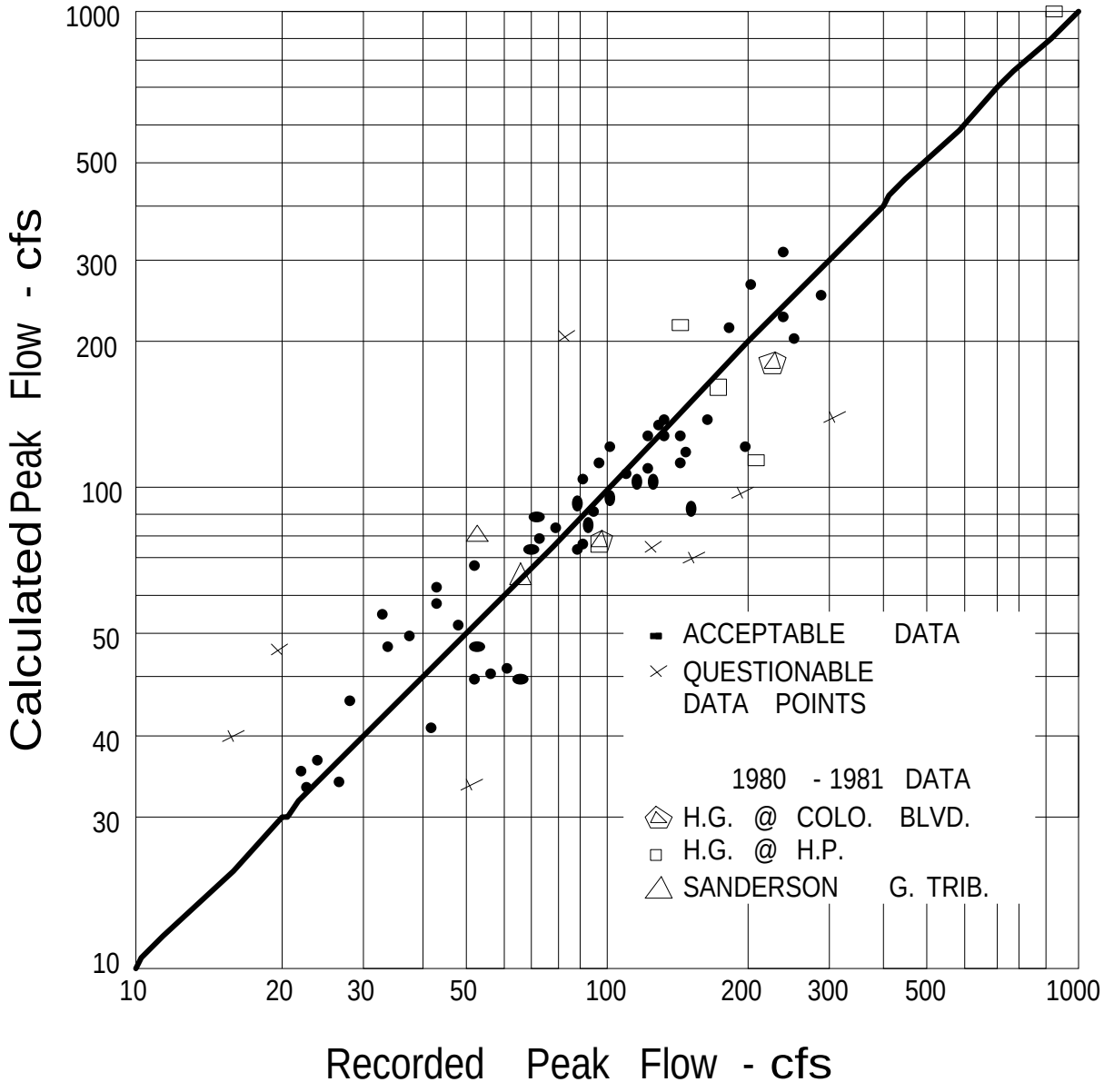

Figure RO-A11—Comparison of Measured Peak Flow Rated Against Peak Flow Rates Calculated Using the Post 1982 Colorado Urban Hydrograph Procedure.

STREETS/INLETS/STORM SEWERS

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1.0 INTRODUCTION

1.1 Purpose

The purpose of this chapter is to give concise, practical guidelines for the design of urban stormwater collection and conveyance systems. Procedures and equations are presented for the hydraulic design of street drainage, locating inlets and determining capture capacity, and sizing storm sewers. In addition, examples are provided to illustrate the hydraulic design process. Spreadsheet solutions accompany the hand calculations for most example problems.

The design procedures presented in this chapter are based upon fundamental hydrologic and hydraulic design concepts. The design equations provided are well accepted and widely used. They are presented without derivations or detailed explanation, but are properly referenced if the reader wishes to study their background. Therefore, it is assumed that the reader has a fundamental understanding of basic hydrology and hydraulics. A working knowledge of the Rational equation (RUNOFF chapter) and open channel hydraulics (MAJOR DRAINAGE chapter) is particularly helpful.

1.2 Urban Stormwater Collection and Conveyance Systems

Urban stormwater collection and conveyance systems are critical components of the urban infrastructure. Proper design of these systems is essential to minimize flood damage and disruptions in urban areas during storm events while protecting the urban water resources environment. Their primary function is to collect excess stormwater from street gutters, convey the excess stormwater through storm sewers and along the street right-of-way, and discharge it into a detention basin, water quality best management practice (BMP) or the nearest receiving water body (FHWA 1996).

Urban stormwater collection and conveyance systems must fulfill many objectives. Properly functioning urban drainage systems:

- Minimize disruption to the natural drainage system.
- Promote safe passage of vehicular traffic during minor storm events.
- Maintain public safety and manage flooding during major storm events.
- Preserve and protect the urban stream environment.
- Minimize capital and maintenance costs of the system.

All of these objectives are important, but the public is the most vocal about disruptions to traffic and street flooding when storm drainage systems are not designed properly.



Photograph ST-1—The critical role that streets play in urban inlet and storm sewer drainage is often not properly taken into account.



Photograph ST-2—The capital costs of storm sewer construction are large, emphasizing the importance of sound design.

1.3 Components of Urban Stormwater Collection and Conveyance Systems

Urban stormwater collection and conveyance systems within the District are comprised of three primary

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components: (1) street gutters and roadside swales, (2) stormwater inlets, and (3) storm sewers (and appurtenances like manholes, junctions, etc.). Street gutters and roadside swales collect runoff from the street (and adjacent areas) and convey the runoff to a stormwater inlet while maintaining the street's level-of-service.

Inlets collect stormwater from streets and other land surfaces, transition the flow into storm sewers, and often provide maintenance access to the storm sewer system. Storm sewers convey stormwater in excess of a street's or a swale's capacity along the right-of-way and discharge it into a stormwater management facility or a nearby receiving water body. In rare instances, stormwater pump stations (the design of which is not covered in this *Manual*) are needed to lift and convey stormwater away from low-lying areas where gravity drainage is not possible. All of these components must be designed properly to achieve the stormwater collection and conveyance system's objectives.

1.4 Minor and Major Storms

Rainfall events vary greatly in magnitude and frequency of occurrence. Major storms produce large flow rates but rarely occur. Minor storms produce smaller flow rates but occur more frequently. For economic reasons, stormwater collection and conveyance systems are not normally designed to pass the peak discharge during major storm events.

Stormwater collection and conveyance systems are designed to pass the peak discharge of the minor storm event (and smaller events) with minimal disruption to street traffic. To accomplish this, the spread of water on the street is limited to some maximum, mandated value during the minor storm event. Inlets must be strategically placed to pick up the excess gutter or swale flow once the limiting spread of water is reached. The inlets direct the water into storm sewers, which are typically sized to pass the peak flow rate from the minor storm without any surcharge. The magnitude of the minor storm is established by local ordinances or criteria, and the 2-, 5-, or 10-year storms are most commonly specified.

On occasion, storms will occur that surpass the magnitude of the minor storm event. When this happens, the spread of water on the street exceeds the allowable spread and the capacity of the storm sewers designed for the minor storm event. Street flooding occurs and traffic is disrupted. However, proper design requires that public safety be maintained and the flooding be managed to minimize flood damage. Thus, local ordinances also often establish the return period for the major storm event, generally the 100-year storm. For this event, the street becomes an open channel and must be analyzed to determine that the consequences of the flood are acceptable with respect to flood damage and public safety.

2.0 STREET DRAINAGE

2.1 Street Function and Classification

The primary function of a street or roadway is to provide for the safe passage of vehicular traffic at a specified level of service. If stormwater collection and conveyance systems are not designed properly, this primary function can be impaired. To make sure this does not happen, streets are classified for drainage purposes based on their traffic volume, parking practices, and other criteria (Wright-McLaughlin Engineers 1969). The four street classifications are:

- Local (low-speed traffic for residential or industrial area access).
- Collector (low/moderate-speed traffic providing service between local streets and arterials).
- Arterial (moderate/high-speed traffic moving through urban areas and accessing freeways).
- Freeway (high-speed travel, generally over long distances).

Table ST-1 provides additional information on the classification of streets for drainage purposes.

Table ST-1—Street Classification for Drainage Purposes

Street Classification	**Function**	Speed/Number of Lanes	**Signalization at Intersections**	**Street Parking**
Local	Provide access to residential and industrial areas	Low speed with 2 moving lanes	Stop signs	One or both sides of the street
Collector	Collect and convey traffic between local and arterial streets	Low to moderate speed with 2 or 4 moving lanes	Stop signs or traffic signals	One or both sides of the street
Arterial	Function as primary through-traffic conduits in urban areas	Moderate to high speeds with 4 to 6 lanes	Traffic signals (controlled access)	Usually prohibited
Freeway	Provide rapid and efficient transport over long distances	High-speed travel with 4 lanes or more	Cloverleafs, access ramps (limited access)	Always prohibited

Streets serve another important function other than traffic flow. They contain the first component in the urban stormwater collection and conveyance system. That component is the street gutter or adjacent swale, which collects excess stormwater from the street and adjacent areas and conveys it to a stormwater inlet. Proper street drainage is essential to:

- Maintain the street's level-of-service.

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- Reduce skid potential.
- Minimize the potential for cars to hydroplane.
- Maintain good visibility for drivers (by reducing splash and spray).
- Minimize inconvenience/danger to pedestrians during storm events (FHWA 1984).

2.2 Design Considerations

Certain design considerations must be taken into account in order to meet street drainage objectives. The primary design objective is to keep the spread (encroachment) of stormwater on the street below an acceptable value for a given return period of flooding. As mentioned previously, when stormwater collects on the street and flows down the gutter, the top width (or spread) of the water widens as more stormwater is collected. If left unchecked, the spread of water would eventually hinder traffic flow and possibly become hazardous (i.e., reduced skid resistance, hydroplaning, splash, etc.). Based on these considerations, the District has established encroachment (spread) standards for the minor storm event. These standards were given in the POLICY chapter and are repeated in Table ST-2 for convenience.

Table ST-2—Pavement Encroachment Standards for the Minor Storm

Street Classification	Maximum Encroachment
Local	No curb overtopping. Flow may spread to crown of street.
Collector	No curb overtopping. Flow spread must leave at least one lane free of water.
Arterial	No curb overtopping. Flow spread must leave at least one lane free of water in each direction, but should not flood more than two lanes in each direction.
Freeway	No encroachment is allowed on any traffic lanes.

Standards for the major storm and street cross flows are also required. The major storm needs to be assessed to determine the potential for flooding and public safety. Cross flows also need to be regulated for traffic flow and public safety reasons. The District has established street inundation standards during the major storm event and allowable cross-street flow standards. These standards were given in the POLICY chapter and are repeated in Table ST-3 and Table ST-4 for convenience.

Table ST-3—Street Inundation Standards for the Major (i.e., 100-Year) Storm

Street Classification	Maximum Depth and Inundated Area
Local and Collector	Residential dwellings and public, commercial, and industrial buildings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of the building. The depth of water over the gutter flow line should not exceed 18 inches.
Arterial and Freeway	Residential dwellings and public, commercial, and industrial buildings should be no less than 12 inches above the 100-year flood at the ground line or lowest water entry of the building. The depth of water should not exceed the street crown to allow operation of emergency vehicles. The depth of water over the gutter flow line should not exceed 12 inches.

Table ST-4—Allowable Cross-Street Flow

Street Classification	Initial Storm Flow	Major (100-Year) Storm Flow
Local	6 inches of depth in cross pan.	18 inches of depth above gutter flow line.
Collector	Where cross pans allowed, depth of flow should not exceed 6 inches.	12 inches of depth above gutter flow line.
Arterial/Freeway	None.	No cross flow. Maximum depth at upstream gutter on road edge of 12 inches.

Once an allowable spread (pavement encroachment) has been established for the minor storm, the placement of inlets can be determined. The inlets will remove some or all of the excess stormwater and thus reduce the spread. The placement of inlets is covered in Section 3.0. It should be noted that proper drainage design utilizes the full allowable capacity of the street gutter in order to limit the cost of inlets and storm sewers.

Another important design consideration is the frequency of occurrence of the minor storm. In other words, how often will the spread of stormwater reach or exceed the maximum encroachment limit. This is addressed by assigning a frequency (or recurrence interval) to the minor storm. The selection of a design frequency is based on many factors including street function, traffic load, vehicle speed, etc. The minor storm is generally between the 2-year and 10-year storm. The major storm is normally defined as the 100-year storm. The minor and major storm return periods are mandated by local governments.

Two additional design considerations of importance in street drainage are gutter (channel) shape and street slope. Most urban streets contain curb and gutter sections. Various types exist which include spill shapes, catch shapes, curb heads, and roll gutters. The shape is chosen for functional, cost, or aesthetic reasons and does not dramatically affect the hydraulic capacity. Swales are common along some urban and semi-urban streets, and roadside ditches are common along rural streets. Their shapes are

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important in determining hydraulic capacity and are covered in the next section.

2.3 Hydraulic Evaluation

Hydraulic computations are performed to determine the capacity of roadside swales and street gutters and the encroachment of stormwater onto the street. The design discharge is usually determined using the Rational method (covered in the next two sections). Stormwater runoff ends up in swales, roadside ditches and street gutters where the flow is unsteady and non-uniform. However, uniform, steady flow is usually assumed for the short period of time during peak flow conditions.

2.3.1 Curb and Gutter

Street slope can be divided into two components: longitudinal slope and cross slope. The longitudinal slope of the gutter essentially mimics the street slope. The hydraulic capacity of a gutter increases as the longitudinal slope increases. The District prescribes a minimum grade of 0.4% (Wright-McLaughlin 1969). The allowable flow capacity of the gutter on steep slopes is limited to provide for public safety. The cross (transverse) slope represents the slope from the street crown to the gutter section. A compromise is struck between large cross slopes that facilitate pavement drainage and small cross slopes for driver safety and comfort. The District prescribes a minimum cross slope of 1% for pavement drainage. Composite sections are often used with gutter cross slopes being steeper than street cross slopes to increase the gutter capacity.

The hydraulic evaluation of street capacity includes the following steps:

1. Calculate the theoretical street gutter flow capacity to convey the minor storm based upon the allowable **spread** defined in Table ST-2.

2. Calculate the theoretical street gutter flow capacity to convey the minor storm based upon the allowable **depth** defined Table ST-2.

3. Calculate the allowable street gutter flow capacity by multiplying the theoretical capacity (calculated in number 2) by a reduction factor. This reduction factor is used for safety considerations. The lesser of the capacities calculated in step 1 and this step is the allowable street gutter capacity.

4. Calculate the theoretical major storm conveyance capacity based upon the road inundation criteria in Table ST-3. Reduce the major storm capacity by a reduction factor to determine the allowable storm conveyance capacity.

2.3.1.1 Gutters With Uniform Cross Slopes (i.e., Where Gutter Cross Slope = Street Cross Slope)

Since gutter flow is assumed to be uniform for design purposes, Manning's equation is appropriate with a slight modification to account for the effects of a small hydraulic radius. For a triangular cross section

(Figure ST-1a), the Manning formula for gutter flow is written as:

$$Q = \frac{0.56}{n} S_x^{5/3} S_L^{1/2} T^{8/3} \quad \text{(ST-1)}$$

in which:

Q = calculated flow rate for the street (cfs)

n = Manning's roughness coefficient, (typically = 0.016)

S_x = street cross slope for the street (ft/ft)

S_L = longitudinal slope (ft/ft)

T = top width of flow spread (ft)

The flow depth, y, at the curb can be found using:

$$y = TS_x \quad \text{(ST-2)}$$

Note that the flow depth must be less than the curb height during the minor storm based on Table ST-2. Manning's equation can be written in terms of the flow depth, as:

$$Q = \frac{0.56}{nS_x} S_L^{1/2} y^{8/3} \quad \text{(ST-3)}$$

The cross-sectional flow area, A, can be expressed as:

$$A = (1/2) S_x T^2 \quad \text{(ST-4)}$$

The gutter velocity at peak capacity may be found from the continuity equation ($V = Q/A$). Triangular gutter cross-section calculations are illustrated in Example 6.1.

2.3.1.2 Gutters With Composite Cross Slopes (i.e., Where Gutter Cross Slope ≠ Street Cross Slope)

Gutters with composite cross slopes (Figure ST-1b) are often used to increase the gutter capacity. For a composite gutter section:

$$Q = Q_w + Q_s \quad \text{(ST-5)}$$

in which:

Q_w = flow rate in the depressed section of the gutter (cfs)

Q_s = discharge in the section that is above the depressed section (cfs)

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The Federal Highway Administration (FHWA 1996) provides the following equations for obtaining the flow rate in gutters with composite cross slopes. The theoretical flow rate, *Q*, is:

$$Q = \frac{Q_s}{1 - E_o} \qquad \text{(ST-6)}$$

in which:

$$E_o = \frac{1}{1 + \dfrac{S_w / S_x}{\left[1 + \dfrac{S_w / S_x}{(T/W) - 1}\right]^{8/3} - 1}} \qquad \text{(ST-7)}$$

in which S_w is the gutter cross slope (ft/ft), and,

$$S_w = S_x + \frac{a}{W} \qquad \text{(ST-8)}$$

in which a is the gutter depression (feet) and W is width of the gutter (ft).

Figure ST-1b depicts all geometric variables. From the geometry, it can be shown that:

$$y = a + TS_x \qquad \text{(ST-9)}$$

and,

$$A = \frac{1}{2} S_x T^2 + \frac{1}{2} aW \qquad \text{(ST-10)}$$

in which *y* is the flow depth (at the curb) and *A* is the flow area. Composite cross-section gutter flow calculations are illustrated in Examples 6.2 and 6.3.

2.3.1.3 Allowable Gutter Hydraulic Capacity

Stormwater flows along streets exert momentum forces on cars, pavement, and pedestrians. To limit the hazardous nature of heavy street flows, it is necessary to set limits on flow velocities and depths. As a result, the allowable gutter hydraulic capacity is determined as the lesser of:

$$Q_A = Q_T \qquad \text{(ST-11)}$$

or

$$Q_A = R\, Q_F \qquad \text{(ST-12)}$$

in which Q_A = allowable street hydraulic capacity, Q_T = street hydraulic capacity limited by the maximum water spread, R = reduction factor, and Q_F = gutter capacity when flow depth equals allowable depth.

There are two sets of reduction factors developed for Denver metropolitan areas (Guo 2000b). One is for the minor event, and another is for the major event. Figure ST-2 shows that the reduction factor remains unity (1.0) for a street slope <1.5%, and then decreases as the street slope increases.

It is important for street drainage designs that the allowable street hydraulic capacity be used instead of the calculated gutter-full capacity. Thus, wherever the accumulated stormwater amount on the street is close to the allowable capacity, a street inlet shall be installed.

2.3.2 Swale Sections (V-Shaped With the Same or Different Side Slopes)

Swales are often used to convey runoff from pavement where curb and gutter sections are not used. It is very important that swale depths and side slopes be as shallow as possible for safety and maintenance reasons. Street-side swales are not the same as roadside ditches that can be considered part of a major drainageway system. Street-side swales serve as collectors of initial runoff and transport it to the nearest inlet or major drainageway. To be effective, they need to be limited to the velocity, depth, and cross-slope geometries considered acceptable. The following limitations shall apply to street-side swales:

- Maximum 2-year flow velocity = 3 ft/sec
- Maximum flow depth = 1.0 ft
- Maximum side slope of each side = 5H:1V.*

  * Use of flatter side slopes is strongly recommended.

Swales generally have V-sections (Figure ST-3). Equation ST-1 can be used to calculate the flow rate in a V-section (if the section has a constant Manning's n value) with an adjusted slope found using:

$$S_x = \frac{S_{x1} S_{x2}}{S_{x1} + S_{x2}} \qquad \text{(ST-13)}$$

in which:

S_x = adjusted side slope (ft/ft)

S_{x1} = right side slope (ft/ft)

S_{x2} = left side slope (ft/ft)

Figure ST-3 shows the geometric variables.

Examples 6.4 and 6.5 show V-shaped swale calculations.

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Under no circumstances shall a street-side swale have a longitudinal slope steeper than 2%. Use grade control checks to control the grade if the adjacent street is steeper.

Note that the slope of roadside ditches and swales is often different than the adjacent street. The hydraulic characteristics of the swale can therefore change from one location to another on a given swale. The flow depth and spread limitations of Tables ST-2 and ST-4 are also valid for swales and roadside ditches. There is no capacity reduction for safety considerations for roadside swales.

The designer is cautioned when using swales. If not properly designed and maintained, they can become a nuisance to the local residents.

Manning's equation can be used to calculate flow characteristics.

$$Q = \frac{1.49}{n} AR^{2/3} S_L^{1/2} \qquad \text{(ST-14)}$$

in which:

Q = flow rate (cfs)

n = Manning's roughness coefficient

A = flow area (ft^2)

R = A/P (ft)

P = wetted perimeter (ft)

S_L = longitudinal slope (ft/ft)

2.4 Major Storm Hydraulics

2.4.1 Purpose and Objectives

As previously mentioned, the primary objective of street drainage design is not to exceed the spread (encroachment) criteria during the minor storm event. Since larger storms do occur, it is prudent to determine the consequences of the major storm event. Table ST-3 lists the street inundation standards recommended by this *Manual* for the major storm event. Proper street design requires that the major storm be assessed in the interest of public safety and to minimize the potential for flood damages.

2.4.2 Street Hydraulic Capacity

During major storms, streets typically become wide, open channels that convey stormwater flow in excess of the storm sewer capacity. Manning's equation (Equation ST-14) is generally appropriate to determine flow depths and street capacities assuming uniform flow.

The general form of Manning's equation is the most appropriate solution method for this situation since many different flow situations and channel shapes may be encountered. The allowable street capacity for a major storm is also subject to safety considerations using the reduction factor taken from Figure ST-2.

Major storm street hydraulic capacity calculations are shown in Example 6.6.

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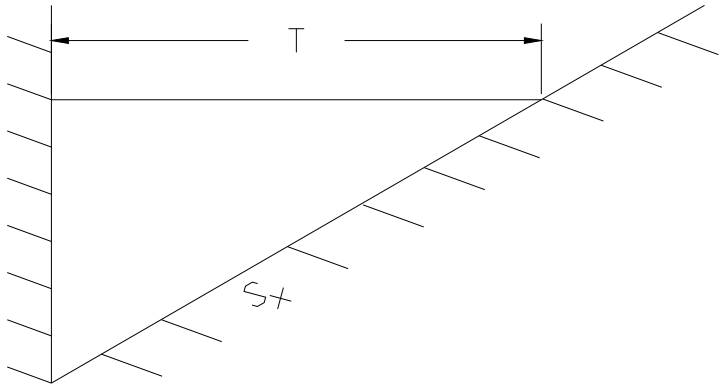

Figure ST-1a—Typical Gutter Sections—Constant Cross Slope

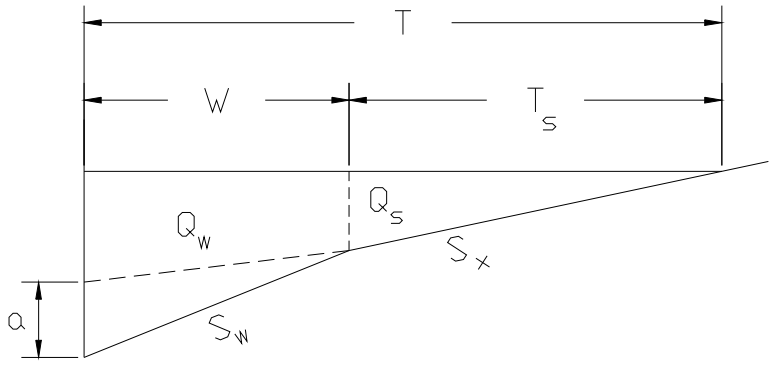

Figure ST-1b—Typical Gutter Sections—Composite Cross Slope

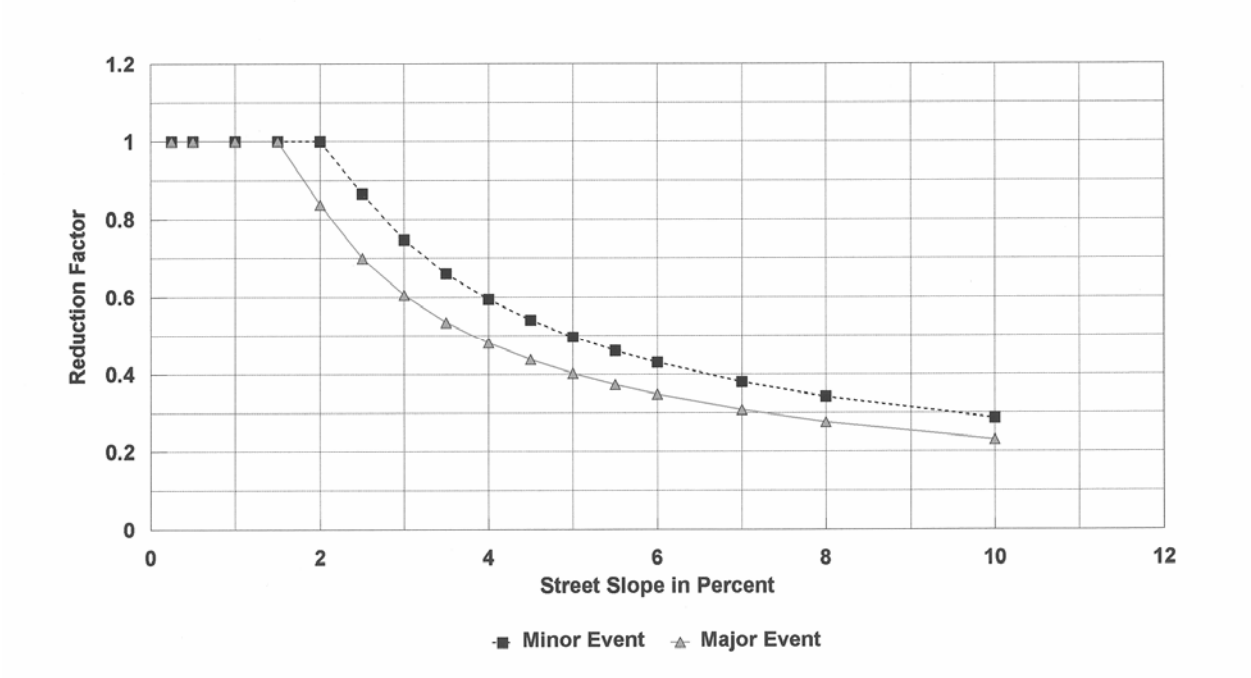

Figure ST-2—Reduction Factor for Gutter Flow

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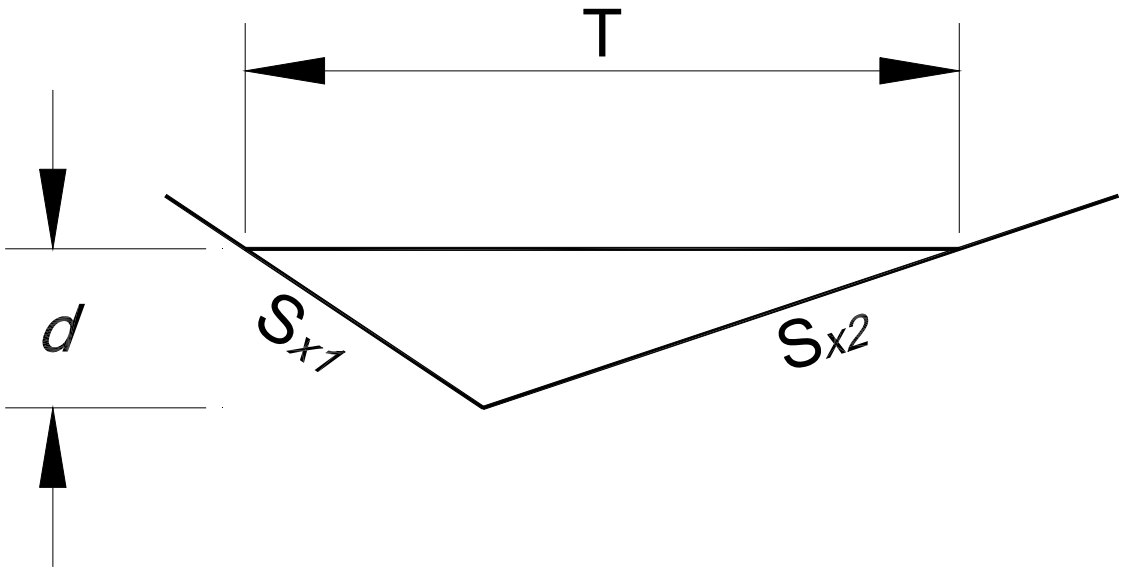

Notes:

1. S_{x1} and S_{x2} ≤ 5H:1V.
2. d ≤ 1.0 feet.
3. Normal flow velocity in a grass-lined swale shall be less than 3 ft/sec during a 2-year storm.
4. Longitudinal grade of a grass-lined swale shall be less than 2%. Use grade control checks if adjacent street is steeper to limit the swale's flow.

Figure ST-3—Typical Street-Side Swale Sections—V-Shaped

3.0 INLETS

3.1 Inlet Functions, Types and Appropriate Applications

Stormwater inlets are a vital component of the urban stormwater collection and conveyance system. Inlets collect excess stormwater from the street, transition the flow into storm sewers, and can provide maintenance access to the storm sewer system. They can be made of cast-iron, steel, concrete, and/or pre-cast concrete and are installed on the edge of the street adjacent to the street gutter or in the bottom of a swale.

Roadway geometrical features often dictate the location of pavement drainage inlets. In general, inlets are placed at all low points (sumps or sags) in the gutter grade, median breaks, intersections, and crosswalks. The spacing of inlets placed between those required by geometric controls is governed by the design flow spread (i.e., allowable encroachment). In other words, the drainage inlets are spaced so that the spread under the design (minor) storm conditions will not exceed the allowable flow spread (Akan and Houghtalen 2002).

There are four major types of inlets: grate, curb opening, combination, and slotted. Figure ST-4 depicts the four major types of inlets along with some associated geometric variables. Table ST-5 provides information on the appropriate application of the different inlet types along with advantages and disadvantages of each.

Table ST-5—Applicable Settings for Various Inlet Types

Inlet Type	Applicable Setting	Advantages	Disadvantages
Grate	Sumps and continuous grades (should be made bicycle safe)	Perform well over wide range of grades	Can become clogged Lose some capacity with increasing grade
Curb-opening	Sumps and continuous grades (but not steep grades)	Do not clog easily Bicycle safe	Lose capacity with increasing grade
Combination	Sumps and continuous grades (should be made bicycle safe)	High capacity Do not clog easily	More expensive than grate or curb-opening acting alone
Slotted	Locations where sheet flow must be intercepted.	Intercept flow over wide section	Susceptible to clogging

3.2 Design Considerations

Stormwater inlet design takes two forms: inlet placement location and inlet hydraulic capacity. As previously mentioned, inlets must be placed in sumps to prevent ponding of excess stormwater. On streets with continuous grades, inlets are required periodically to keep the gutter flow from exceeding the encroachment limitations. In both cases, the size and type of inlets need to be designed based upon their hydraulic capacity.

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Inlets placed on continuous grades rarely intercept all of the gutter flow during the minor (design) storm. The effectiveness of the inlet is expressed as an efficiency, *E*, which is defined as:

$$E = Q_i / Q \quad \text{(ST-15)}$$

in which:

E = inlet efficiency

Q_i = intercepted flow rate (cfs)

Q = total gutter flow rate (cfs)

Bypass (or carryover) flow is not intercepted by the inlet. By definition,

$$Q_b = Q - Q_i \quad \text{(ST-16)}$$

in which:

Q_b = bypass (or carryover) flow rate (cfs)

The ability of an inlet to intercept flow (i.e., hydraulic capacity) on a continuous grade generally increases with increasing gutter flow, but the capture efficiency decreases. In other words, even though more stormwater is captured, a smaller percentage of the gutter flow is captured. In general, the inlet capacity depends upon:

- The inlet type and geometry.
- The flow rate (depth and spread of water).
- The cross (transverse) slope.
- The longitudinal slope.

The hydraulic capacity of an inlet varies with the type of inlet. For grate inlets, the capacity is largely dependent on the amount of water flowing over the grate, the grate configuration and spacing, and the velocity of flow. For curb opening inlets, the capacity is largely dependent on the length of the opening, the flow velocity, street and gutter cross slope, and the flow depth at the curb. Local gutter depression along the curb opening helps boost the capacity. On the other hand, top slab supports can decrease the capacity. Combination inlets do not intercept much more than their grates alone if they are placed side by side and are of nearly equal lengths but are much less likely to clog. Slotted inlets function in a manner similar to curb opening inlets (FHWA 1996).

Inlets in sumps operate as weirs for shallow pond depths, but eventually will operate as orifices as the depth increases. A transition region exists between weir flow and orifice flow, much like a culvert. Grate

inlets and slotted inlets tend to clog with debris, so calculations should take that into account. Curb opening inlets tend to be more dependable for this reason.

3.3 Hydraulic Evaluation

The hydraulic capacity of an inlet is dependent on the type of inlet (grate, curb opening, combination, or slotted) and the location (on a continuous grade or in a sump). The methodology for determination of hydraulic capacity of the various inlet types is described in the following sections: (a) grate inlets on a continuous grade (Section 3.3.1), (b) curb opening inlets on a continuous grade (Section 3.3.2), (c) combination inlets on a continuous grade (Section 3.3.3), (d) slotted inlets on a continuous grade (Section 3.3.4), and (e) inlets located in sumps (Section 3.3.5).

3.3.1 Grate Inlets (On a Continuous Grade)

The capture efficiency of a grate inlet is highly dependent on the width and length of the grate and the velocity of gutter flow. If the gutter velocity is low and the spread of water does not exceed the grate width, all of the flow will be captured by the grate inlet. This is not normally the case during the minor (design) storm. The spread of water often exceeds the grate width and the flow velocity can be high. Thus, some water gets by the inlet. Water going over the grate may be capable of "splashing over" the grate, and usually little of the water outside the grate width is captured.

In order to determine the efficiency of a grate inlet, gutter flow is divided into two parts: frontal flow and side flow. Frontal flow is defined as that portion of the flow within the width of the grate. The portion of the flow outside the grate width is called side flow. By using Equation ST-1, the frontal flow can be evaluated and is expressed as:

$$Q_w = Q\left[1-\left(1-\left(W/T\right)\right)\right]^{2.67} \qquad \text{(ST-17)}$$

in which:

Q_w = frontal discharge (flow within width W) (cfs)

Q = total gutter flow (cfs) found using Equation ST-1

W = width of grate (ft)

T = total spread of water in the gutter (ft)

It should be noted that the grate width is generally equal to the depressed section in a composite gutter section. Now by definition:

$$Q_s = Q - Q_w \qquad \text{(ST-18)}$$

in which:

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Q_s = side discharge (i.e., flow outside the depressed gutter or grate) (cfs)

The ratio of the frontal flow intercepted by the inlet to total frontal flow, R_f, is expressed as:

$$R_f = Q_{wi}/Q_w = 1.0 - 0.09(V - V_o) \text{ for } V \geq V_o, \text{ otherwise } R_f = 1.0 \qquad \text{(ST-19)}$$

in which:

Q_{wi} = frontal flow intercepted by the inlet (cfs)

V = velocity of flow in the gutter (ft/sec)

V_o = splash-over velocity (ft/sec)

The splash-over velocity is defined as the minimum velocity causing some water to shoot over the grate. This velocity is a function of the grate length and type. The splash-over velocity can be determined using the empirical formula (Guo 1999):

$$V_o = \alpha + \beta L_e - \gamma L_e^{\,2} + \eta L_e^{\,3} \qquad \text{(ST-20)}$$

in which:

V_o = splash-over velocity (ft/sec)

L_e = effective unit length of grate inlet (ft)

$\alpha, \beta, \gamma, \eta$ = constants from Table ST-6

Table ST-6—Splash Velocity Constants for Various Types of Inlet Grates

Type of Grate	α	β	γ	η
Bar P-1-7/8	2.22	4.03	0.65	0.06
Bar P-1-1/8	1.76	3.12	0.45	0.03
Vane Grate	0.30	4.85	1.31	0.15
45-Degree Bar	0.99	2.64	0.36	0.03
Bar P-1-7/8-4	0.74	2.44	0.27	0.02
30-Degree Bar	0.51	2.34	0.20	0.01
Reticuline	0.28	2.28	0.18	0.01

The ratio of the side flow intercepted by the inlet to total side flow, R_s, is expressed as:

$$R_s = \frac{1}{1 + \frac{0.15V^{1.8}}{S_x L^{2.3}}} \qquad \text{(ST-21)}$$

in which:

V = velocity of flow in the gutter (ft/sec)

L = length of grate (ft)

The capture efficiency, E, of the grate inlet may now be determined using:

$$E = R_f\left(Q_w/Q\right) + R_s\left(Q_s/Q\right) \qquad \text{(ST-22)}$$

Example 6.9 shows grate inlet capacity calculations.

3.3.2 Curb-Opening Inlets (On a Continuous Grade)

The capture efficiency of a curb-opening inlet is dependent on the length of the opening, the depth of flow at the curb, street cross slope and the longitudinal gutter slope (see Photograph ST-3). If the curb opening is long, the flow rate is low, and the longitudinal gutter slope is small, all of the flow will be captured by the inlet. This is not normally the case during the minor (design) storm. In fact, it is generally uneconomical to install a curb opening long enough to capture all of the flow. Thus, some water gets by the inlet, and the inlet efficiency needs to be determined.



Photograph ST-3—Gutter/street slope is a major design factor for both street and inlet capacity.

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The hydraulics of curb opening inlets are less complicated than grate inlets. The efficiency, *E*, of a curb-opening inlet is calculated as:

$$E = 1 - \left[1 - \left(L/L_T\right)\right]^{1.8} \text{ for } L < L_T, \text{ otherwise } E = 1.0 \qquad \text{(ST-23)}$$

in which:

L = installed (or designed) curb-opening length (ft)

L_T = curb-opening length required to capture 100% of gutter flow (ft)

and, for a curb-opening inlet that is not depressed,

$$L_T = 0.6\, Q^{0.42} S_L^{\,0.3} \left(\frac{1}{nS_x}\right)^{0.6} \qquad \text{(ST-24)}$$

in which:

Q = gutter flow (cfs)

S_L = longitudinal street slope (ft/ft)

S_x = steel cross slope (ft/ft)

n = Manning's roughness coefficient

For a depressed curb-opening inlet,

$$L_T = 0.6\, Q^{0.42} S_L^{\,0.3} \left(\frac{1}{nS_e}\right)^{0.6} \qquad \text{(ST-25)}$$

The equivalent cross slope, S_e, can be determined from

$$S_e = S_x + \frac{a}{W} E_o \qquad \text{(ST-26)}$$

in which *a* = gutter depression and *W* = depressed gutter section as shown in Figure ST-1b. The ratio of the flow in the depressed section to total gutter flow, E_o, can be calculated from Equation ST-7. See Examples 6.8 and 6.9 for curb-opening inlet calculations.

3.3.3 Combination Inlets (On a Continuous Grade)

Combination inlets take advantage of the debris removal capabilities of a curb-opening inlet and the capture efficiency of a grate inlet. If the grate and the curb opening are side-by-side and of approximately equal length, the interception capacity is found by assuming the grate acts alone. If all or part of the curb-opening inlet lies upstream from the grate (a desirable configuration), the inlet capacity is enhanced by

the upstream curb-opening capacity. The appropriate equations have already been presented, but Example 6.10 illustrates the procedure.

3.3.4 Slotted Inlets (On a Continuous Grade)

Slotted inlets can generally be used to intercept sheet flow that is crossing the pavement in an undesirable location. Unlike grate inlets, they have the advantage of intercepting flow over a wide section. They do not interfere with traffic operations and can be used on both curbed and uncurbed sections. Like grate inlets, they are susceptible to clogging.

Slotted inlets function like a side-flow weir, much like curb-opening inlets. The FHWA (1996) suggests the hydraulic capacity of slotted inlets closely corresponds to curb-opening inlets if the slot openings exceed 1.75 inches. Therefore, the equations developed for curb-opening inlets (Equations ST-23 through ST-26) are appropriate for slotted inlets.

3.3.5 Inlets Located in Sumps

All of the stormwater excess that enters a sump (i.e., a depression or low point in grade) must pass through an inlet to enter the stormwater conveyance system. If the stormwater is laden with debris, the inlet is susceptible to clogging. The ponding of water is a nuisance and could be hazardous. Therefore, the capacity of inlets in sumps must account for this clogging potential. Grate inlets acting alone are not recommended for this reason. Curb-opening inlets are more appropriate, as are combination inlets. Photograph ST-4 shows a curb opening inlet in a sump condition.



Photograph ST-4—Inlets that are located in street sags and sumped can be highly efficient.

As previously mentioned, inlets in sumps function like weirs for shallow depths, but as the depth of stormwater increases, they begin to function like an orifice. Orifice and weir flows have been exhaustively

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studied. Equations are readily available to compute requisite flow rates. However, the transition from weir flow to orifice flow takes place over a relatively small range of depth that is not well defined. The FHWA provides guidance on the transition region based on significant testing.

The hydraulic capacity of grate, curb-opening, and slotted inlets operating as weirs is expressed as:

$$Q_i = C_w L_w \, d^{1.5} \qquad \text{(ST-27)}$$

in which:

Q_i = inlet capacity (cfs)

C_w = weir discharge coefficient

L_w = weir length (ft)

d = flow depth (ft)

Values for C_w and L_w are presented in Table ST-7 for various inlet types. Note that the expressions given for curb-opening inlets without depression should be used for depressed curb-opening inlets if L > 12 feet.

The hydraulic capacity of grate, curb-opening, and slotted inlets operating as orifices is expressed as:

$$Q_i = C_o A_o \left(2gd\right)^{0.5} \qquad \text{(ST-28)}$$

in which:

Q_i = inlet capacity (cfs)

C_o = orifice discharge coefficient

A_o = orifice area (ft^2)

d = characteristic depth (ft) as defined in Table ST-7

g = 32.2 ft/sec^2

Values for C_o and A_o are presented in Table ST-7 for different types of inlets.

Combination inlets are commonly used in sumps. The hydraulic capacity of combination inlets in sumps depends on the type of flow and the relative lengths of the curb opening and grate. For weir flow, the capacity of a combination inlet (grate length equal to the curb opening length) is equal to the capacity of the grate portion only. This is because the curb opening does not add any length to the weir equation (Equation ST-27). If the curb opening is longer than the grate, the capacity of the additional curb length should be added to the grate capacity. For orifice flow, the capacity of the curb opening should be added to the capacity of the grate.

Table ST-7—Sag Inlet Discharge Variables and Coefficients

(Modified From Akan and Houghtalen 2002)

Inlet Type	C_w	L_w[1]	Weir Equation Valid For	Definitions of Terms
Grate Inlet	3.00	$L + 2W$	$d < 1.79(A_o/L_w)$	L = Length of grate W = Width of grate d = Depth of water over grate A_0= Clear opening area[2]
Curb Opening Inlet	3.00	L	$d < h$	L = Length of curb opening h = Height of curb opening $d = d_i - (h/2)$ d_i = Depth of water at curb opening
Depressed Curb Opening Inlet[3]	2.30	$L + 1.8W$	$d < (h + a)$	W = Lateral width of depression a = Depth of curb depression
Slotted Inlets	2.48	L	$d < 0.2$ ft	L = Length of slot d = Depth at curb

[1] The weir length should be reduced where clogging is expected.

[2] Ratio of clear opening area to total area is 0.8 for P-1-7/8-4 and reticuline grates, 0.9 for P-1-7/8 and 0.6 for P-1-1/8 grates. Curved vane and tilt bar grates are not recommended at sag locations.

[3] If $L > 12$ ft, use the expressions for curb opening inlets without depression.

	C_o	A_0[4]	Orifice Equation Valid for	Definition of Terms
Grate Inlet	0.67	Clear opening area[5]	$d > 1.79(A_o/L_w)$	d = Depth of water over grate
Curb Opening Inlet (depressed or undepressed, horizontal orifice throat[6])	0.67	$(h)(L)$	$d_i > 1.4h$	$d = d_i - (h/2)$ d_i = Depth of water at curb opening h = Height of curb opening
Slotted Inlet	0.80	$(L)(W)$	$d > 0.40$ ft	L = Length of slot W = Width of slot d = Depth of water over slot

[4] The orifice area should be reduced where clogging is expected.

[5] The ratio of clear opening area to total area is 0.8 for P-1-7/8-4 and reticuline grates, 0.9 for P-1-7/8 and 0.6 for P-1-1/8 grates. Curved vane and tilt bar grates are not recommended at sag locations.

[6] See Figure ST-5 for other types of throats.

3.3.6 Inlet Clogging

Inlets are subject to clogging effects (see Photographs ST-5 and ST-6). Selection of a clogging factor reflects the condition of debris and trash on the street. During a storm event, street inlets are usually

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loaded with debris by the first-flush runoff volume. As a common practice for street drainage, 50% clogging is considered for the design of a single grate inlet and 10% clogging is considered for a single curb-opening inlet. Often, it takes multiple units to collect the stormwater on the street. Since the amount of debris is largely associated with the first-flush volume in a storm event, the clogging factor applied to a multiple-unit street inlet should be decreased with respect to the length of the inlet. Linearly applying a single-unit clogging factor to a multiple-unit inlet leads to an excessive increase in length. For instance, a six-unit inlet under a 50% clogging factor will function as a three-unit inlet. In fact, continuously applying a 50% reduction to the discharge on the street will always leave 50% of the residual flow on the street. This means that the inlet will never reach a 100% capture and leads to unnecessarily long inlets.



Photograph ST-5—Clogging is an important consideration when designing inlets.



Photograph ST-6—Field inlets frequently need maintenance.

With the concept of first-flush volume, the decay of clogging factor to curb opening length is described as (Guo 2000a):

$$C = \frac{1}{N}(C_o + eC_o + e^2C_o + e^3C_o + ... + e^{N-1}C_o) = \frac{C_o}{N}\sum_{i=1}^{i=N} e^{i-1} = \frac{KC_o}{N} \qquad \text{(ST-29)}$$

in which:

C = multiple-unit clogging factor for an inlet with multiple units

C_o = single-unit clogging factor

e = decay ratio less than unity, 0.5 for grate inlet, 0.25 for curb-opening inlet

N = number of units

K = clogging coefficient from Table ST-8

Table ST-8—Clogging Coefficients to Convert Clogging Factor From Single to Multiple Units[1]

N =	1	2	3	4	5	6	7	8	>8
Grate Inlet (K)	1	1.5	1.75	1.88	1.94	1.97	1.98	1.99	2
Curb Opening (K)	1	1.25	1.31	1.33	1.33	1.33	1.33	1.33	1.33

[1] This table is generated by Equation ST-29 with e = 0.5 and e = 0.25.

When N becomes large, Equation ST-29 converges to:

$$C = \frac{C_o}{N(1-e)} \qquad \text{(ST-30)}$$

For instance, when e = 0.5 and C_o = 50%, C = 1.0/N for a large number of units, N. In other words, only the first unit out of N units will be clogged. Equation ST-30 complies with the recommended clogging factor for a single-unit inlet and decays on the clogging effect for a multiple-unit inlet.

The interception of an inlet on a grade is proportional to the inlet length, and in a sump is proportional to the inlet opening area. Therefore, a clogging factor shall be applied to the length of the inlet on a grade as:

$$L_e = (1-C)L \qquad \text{(ST-31)}$$

in which L_e = effective (unclogged) length. Similarly, a clogging factor shall be applied to the opening area of an inlet in a sump as:

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$$A_e = (1 - C)A \qquad \text{(ST-32)}$$

in which:

A_e = effective opening area

A = opening area

3.4 Inlet Location and Spacing on Continuous Grades

3.4.1 Introduction

Locating (or positioning) stormwater inlets rarely requires design computations. They are simply required in certain locations based upon street design considerations, topography (sumps), and local ordinances. The one exception is the location and spacing of inlets on continuous grades. On a long, continuous grade, stormwater flow increases as it moves down the gutter and picks up more drainage area. As the flow increases, so does the spread. Since the spread (encroachment) is not allowed to exceed some specified maximum, inlets must be strategically placed to remove some of the stormwater from the street. Locating these inlets requires design computations by the engineer.

3.4.2 Design Considerations

The primary design consideration for the location and spacing of inlets on continuous grades is the spread limitation. This was addressed in Section 2.2. Table ST-2 lists pavement encroachment standards for minor storms in the Denver metropolitan area.

Proper design of stormwater collection and conveyance systems makes optimum use of the conveyance capabilities of street gutters. In other words, an inlet is not needed until the spread reaches its allowable limit during the design (minor) storm. To place an inlet prior to that point on the street is not economically efficient. To place an inlet after that point would violate the encroachment standards. Therefore, the primary design objective is to position inlets along a continuous grade at the locations where the allowable spread is about to be exceeded for the design storm.

3.4.3 Design Procedure

Based on the encroachment standard and street geometry, the allowable street hydraulic capacity can be determined using Equation ST-11 or Equation ST-12. This flow rate is then equated to some hydrologic technique (equation) that contains drainage area. In this way, the inlet is positioned on the street so that it will service the requisite drainage area. The process of locating the inlet is accomplished by trial-and-error. If the inlet is moved downstream (or down gutter), the drainage area increases. If the inlet is moved upstream, the drainage area decreases.

The hydrologic technique most often used in urban drainage design is the Rational method. The Rational method was discussed in the RUNOFF chapter. The Rational equation, repeated here for convenience,

is:

$$Q = CIA \qquad \text{(ST-33)}$$

in which:

Q = peak discharge (cfs)

C = runoff coefficient described in the RUNOFF chapter

I = design storm rainfall intensity (in/hr) described in the RAINFALL chapter

A = drainage area (acres)

As previously mentioned, the peak discharge is found using the allowable spread and street geometry. The runoff coefficient is dependent on the land use as discussed in the RUNOFF chapter. The rainfall intensity is discussed in the RAINFALL chapter. The drainage area is the unknown variable to be solved.

Once the first inlet is positioned along a continuous grade, an inlet type and size can be specified. The first inlet's hydraulic capacity is then assessed. Generally, the inlet will not capture all of the gutter flow. In fact, it is uneconomical to size an inlet (on continuous grades) large enough to capture all of the gutter flow. Instead, some carryover flow is expected. This practice reduces the amount of new flow that can be picked up at the next inlet. However, each inlet should be positioned at the location where the allowable spread is about to reach its allowable limit.

The gutter discharge for inlets, other than the first inlet, consists of the carryover from the upstream inlet plus the stormwater runoff generated from the intervening local drainage area. The carryover flow from the upstream inlet is added to the peak flow rate obtained from the Rational method for the intervening local drainage area. The resulting peak flow is approximate since the carryover flow peak and the local runoff peak do not necessarily coincide.

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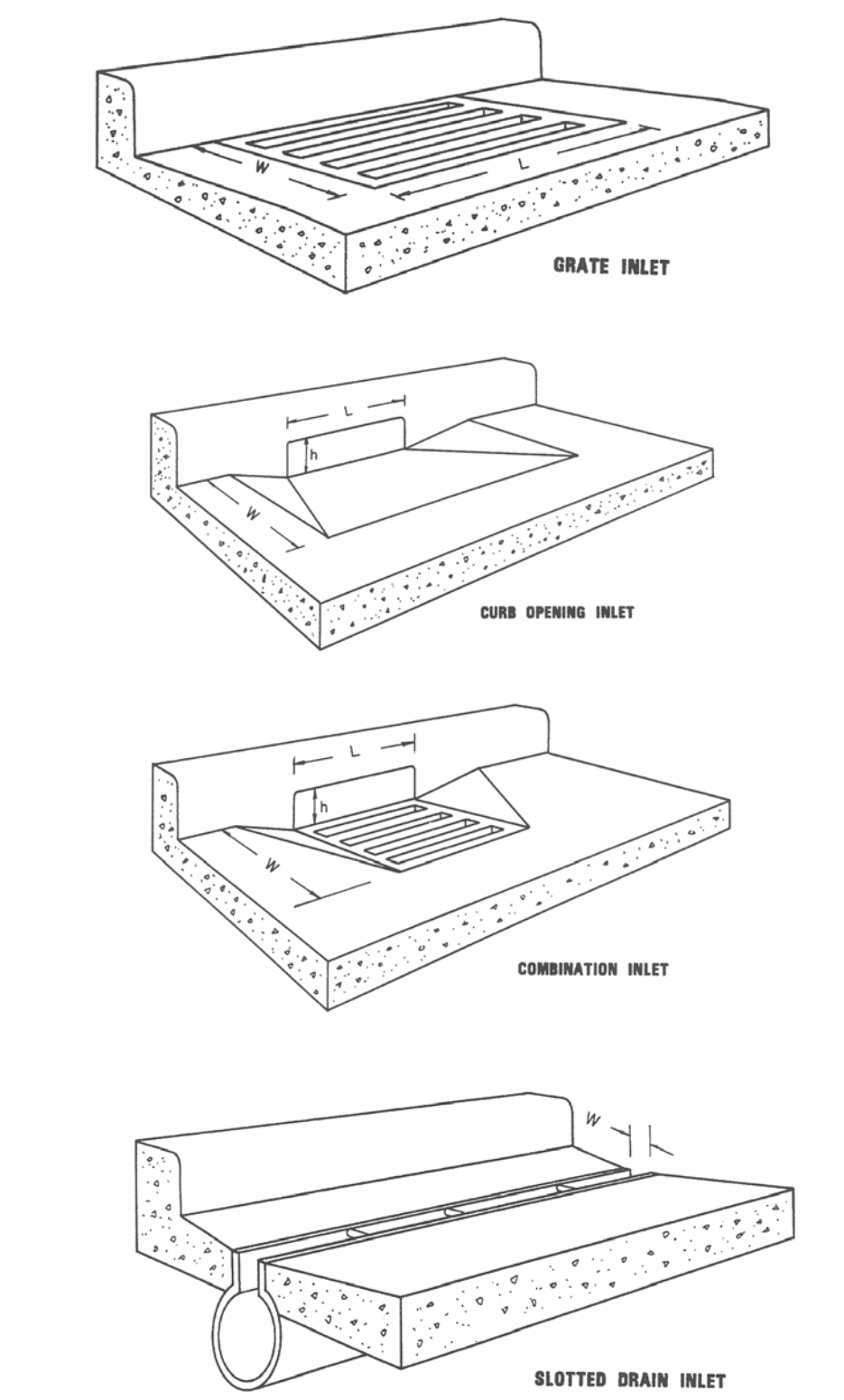

Figure ST-4—Perspective Views of Grate and Curb-Opening Inlets

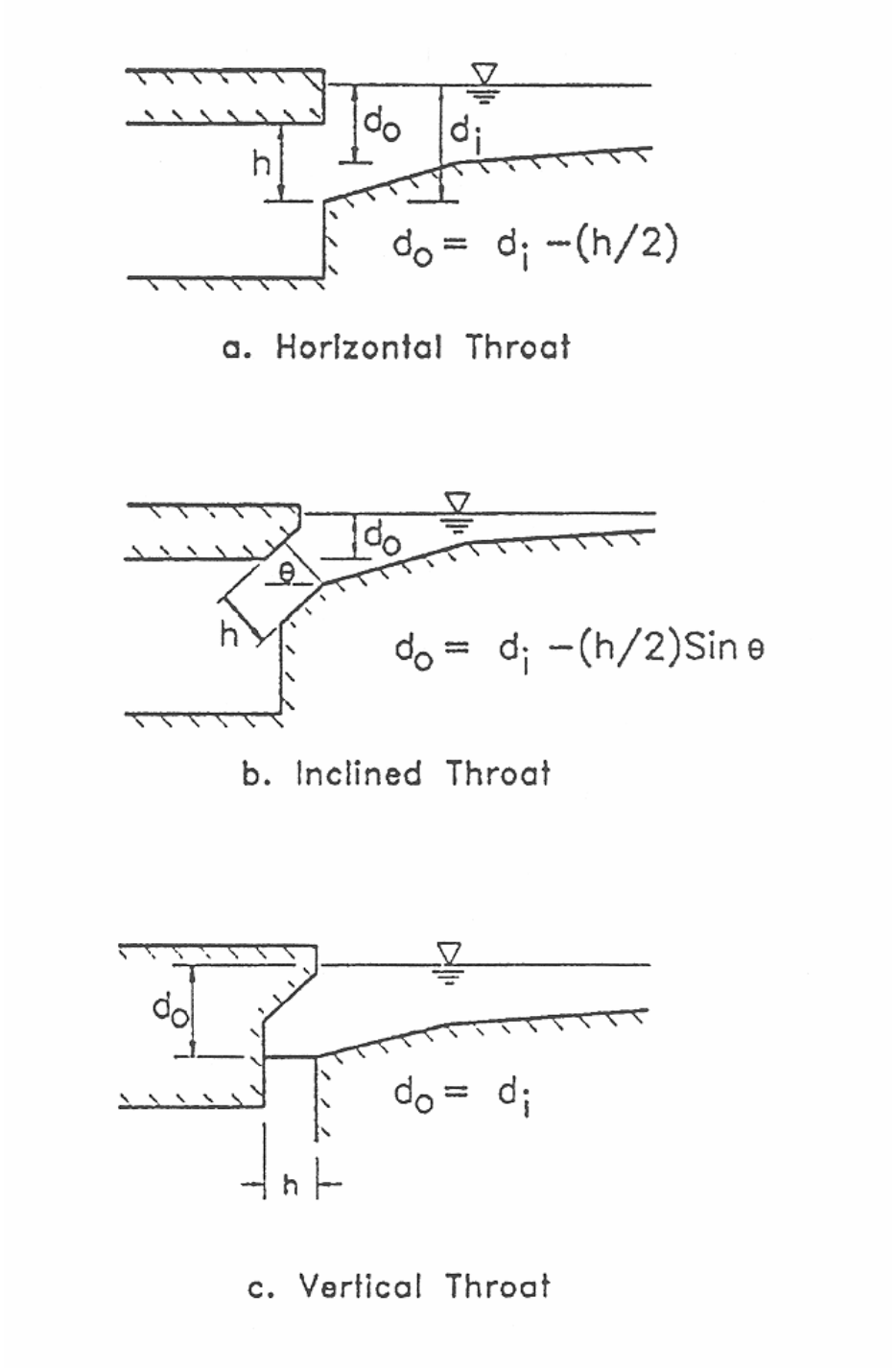

Figure ST-5—Curb-Opening Inlets

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4.0 STORM SEWERS

4.1 Introduction

Once stormwater is collected from the street surface by an inlet, it is directed into the storm sewer system. The storm sewer system is comprised of inlets, pipes, manholes, bends, outlets, and other appurtenances. The stormwater passes through these components and is discharged into a stormwater management device (e.g., infiltration trench, stormwater pond, constructed wetland, etc.) to mitigate adverse downstream effects or discharged directly to a natural or constructed watercourse. Stormwater management devices are constructed to reduce the peak discharge, decrease the volume of runoff, and/or improve the water quality.

Apart from inlets, manholes are the most common appurtenance in storm sewer systems. Their primary functions include:

- Providing maintenance access.
- Providing ventilation.
- Serving as junctions when two or more pipes merge.
- Providing flow transitions for changes in pipe size, slope, and alignment.

Manholes are generally made of pre-cast or cast-in-place reinforced concrete. They are typically 4 to 5 feet in diameter and are required at regular intervals, even in straight sections, for maintenance reasons. Standard size manholes cannot accommodate large pipes, so junction chambers are used for that application.

Other appurtenances are not as common as manholes, but serve vital functions. Occasionally, bends and transitions are accomplished without manholes, particularly for large pipe sizes. These sections provide gradual transitions in size or alignment to minimize energy losses. Outlet structures are transitions from pipe flow into open channel flow or still water (e.g., ponds, lakes, etc.). Their primary function is to minimize erosion in the receiving water body. Flow splitters separate incoming flow and send it in two or more directions. Flow deflectors are used to minimize energy losses in manholes, junction chambers, and flow splitters. Flap gates are placed on outlets to prevent backflow in areas subject to high tailwater or flood flow.

4.2 Design Process, Considerations, and Constraints

The design of a storm sewer system requires a large data collection effort. The data requirements in the proposed service area include topography, drainage boundaries, soil types, and locations of any existing storm sewers, inlets, and manholes. In addition, identification of the type and location of other utilities is

necessary. Alternative layouts of a new system (or modifications to an existing system) can be investigated using this data.

Alternative system layouts rely largely on street right-of-ways and topography. Most layouts are dendritic (tree) networks that follow the street pattern. Dendritic networks collect stormwater from a broad area and tend to converge in the downstream direction. Looping networks shall be avoided because of their complex hydraulics and potentially higher cost. Each layout should contain inlet and manhole locations, drainage boundaries serviced by the inlets, storm sewer locations, flow directions, and outlet locations. A final layout selection is made from the viable alternatives based on likely system performance and cost.

Once a final layout is chosen, storm sewers are sized using hydrologic techniques (to determine peak flows) and hydraulic analysis (to determine pipe capacities). This is accomplished by designing the upstream pipes first and moving downstream. Pipes sizes smaller than 15 inches are not recommended for storm sewers. Pipes generally increase in size moving downstream since the drainage area is increasing. It is not good design practice to decrease the pipe size moving downstream, even if a steeper slope is encountered that will provide sufficient capacity with a smaller pipe. The potential for clogging is always a concern.

Storm sewers are typically sized to convey the minor storm without surcharging using normal flow techniques. In other words, the flow is in a pipe that is flowing *just full* determined by open channel hydraulics calculations.

The minor storm is defined by the return interval that usually varies from the 2-year to the 10-year storm depending on the importance of the infrastructure being served. Refer to the POLICY chapter for guidance regarding selection of the design storm.

Manholes are located in the system prior to and in conjunction with pipe design. Most manhole locations are dictated by proper design practices. For example, manholes are required whenever there is a change in pipe size, alignment, or slope. In addition, manholes are required at pipe junctions. Manholes are also required along straight sections of pipe for maintenance purposes. The distance between manholes is dependent on pipe size. The invert of a pipe leaving a manhole should be at least 0.1 foot lower than the incoming pipe to ensure positive low flows through the manhole. Whenever possible, match the crown of the pipe elevations when the downstream pipe is larger to minimize backwater effects on the upstream pipe.

Once storm sewers are sized and manhole locations are determined, the performance of the sewer system must be evaluated using energy grade line calculations starting at the downstream terminus of the system. As stormwater flows through the storm sewer system, it encounters many flow transitions. These transitions include changes in pipe size, slope, and alignment, as well as entrance and exit conditions. All of these transitions produce energy losses, usually expressed as head losses. These

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losses must be accounted for to ensure that inlets and manholes do not surcharge to a significant degree (i.e., produce street flooding). This is accomplished using hydraulic grade line (HGL) calculations as a check on pipe sizes and system losses. If significant surcharging occurs, the pipe sizes should be increased. High tailwater conditions at the storm sewer outlet may also produce surcharging. This can also be accounted for using HGL calculations.

4.3 Storm Sewer Hydrology

4.3.1 Peak Runoff Prediction

The Rational method is commonly used to determine the peak flows that storm sewers must be able to convey. It is an appropriate method due to the small drainage areas typically involved. It is also relatively easy to use and provides reasonable estimates of peak runoff. The total drainage area contributing flow to a particular storm sewer is often divided up into smaller subcatchments. The Rational method is described in the RUNOFF chapter of this *Manual*.

The first pipe in a storm sewer system is designed using Equation ST-33 to determine the peak flow. Downstream pipes receive flow from the upstream pipes as well as local inflows. The Rational equation applied to the downstream pipes is:

$$Q_p = I \sum_{j=1}^{n} C_j A_j \qquad \text{(ST-34)}$$

in which:

I = design rainfall average intensity, over the time of concentration T_c (in/hr)

n = number of subareas above the stormwater pipe

C_j = runoff coefficient of subarea j

A_j = drainage area of subarea j (acres)

In using this equation, it is evident that the peak flow changes at each design point since the time of concentration, and thus the average intensity, changes at each design point. It is also evident that the time of concentration coming from the local inflow may differ from that coming from upstream pipes. Normally, the longest time of concentration is chosen for design purposes. If this is the case, all of the subareas above the design point will be included in Equation ST-34, and it usually produces the largest peak flow. On rare occasions, the peak flow from a shorter path may produce the greater peak discharge if the downstream areas are heavily developed. It is good practice to check all alternative flow paths and tributary areas to determine the tributary zone that produces the biggest design flow.

4.4 Storm Sewer Hydraulics (Gravity Flow in Circular Conduits)

4.4.1 Flow Equations and Storm Sewer Sizing

Storm sewer flow is usually unsteady and non-uniform. However, for design purposes it is assumed to be steady and uniform at the peak flow rate. Therefore, Manning's equation is appropriate, which can be stated as:

$$Q = \frac{1.49}{n} A R^{2/3} S_f^{1/2} \qquad \text{(ST-35)}$$

in which:

Q = flow rate (cfs)

n = Manning's roughness factor

A = flow area (ft^2)

R = hydraulic radius (ft)

S_f = friction slope (normally the storm sewer slope) (ft/ft)

For full flow in a circular storm sewer,

$$A = A_f = \frac{\pi D^2}{4} \qquad \text{(ST-36)}$$

$$R = R_f = \frac{D}{4} \qquad \text{(ST-37)}$$

in which:

D = pipe diameter

A_f = flow area at full flow (ft^2)

R_f = hydraulic radius at full flow (ft)

If the flow is pressurized (i.e., surcharging at the inlets or manholes is occurring), $S_f \neq S_o$ where S_o is the longitudinal bottom slope of the storm sewer. Design of storm sewers assumes *just full flow*, a reference condition referring to steady, uniform flow with a flow depth, y, nearly equal to the pipe diameter, D. Just full flow discharge, Q_f , is calculated using:

$$Q_f = \frac{1.49}{n} A_f R_f^{2/3} S_o^{1/2} \qquad \text{(ST-38)}$$

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Computations of flow characteristics for partial depths in circular pipes are tedious. Design aids like Figure ST-6 are very helpful when this is necessary.

Storm sewers are sized to flow *just full* (i.e., as open channels using nearly the full capacity of the pipe). The design discharge is determined first using the Rational equation as previously discussed, then the Manning's equation is used (with $S_f = S_o$) to determine the required pipe size. For circular pipes,

$$D_r = \left[\frac{2.16 n Q_p}{\sqrt{S_o}} \right]^{3/8} \qquad \text{(ST-39)}$$

in which D_r is the minimum size pipe required to convey the design flow and Q_p is peak design flow. However, the pipe diameter that should be used in the field is the next standard pipe size larger than D_r.

The typical process proceeds as follows. Initial storm sewer sizing is performed first using the Rational equation in conjunction with Manning's equation. The Rational equation is used to determine the peak discharge that storm sewers must convey. The storm sewers are then initially sized using Manning's equation assuming uniform, steady flow at the peak. Finally, these initial pipe sizes are checked using the energy equation by accounting for all head losses. If the energy computations detect surcharging at manholes or inlets, the pipe sizes are increased.

4.4.2 Energy Grade Line and Head Losses

Head losses must be accounted for in the design of storm sewers in order to find the energy grade line (EGL) and the hydraulic grade line (HGL) at any point in the system. The FHWA (1996) gives the following equation as the basis for calculating the head losses at inlets, manholes, and junctions (h_{LM}, in feet):

$$h_{LM} = K_o C_D C_d C_Q C_p C_B \left(\frac{V_o^2}{2g} \right)$$

in which:

K_o = initial loss coefficient

V_o = velocity in the outflow pipe (ft/sec)

g = gravitational acceleration (32.2 ft/sec^2)

C_D, C_d, C_Q, C_p, and C_B = correction factors for pipe size, flow depth, relative flow, plunging flow and benching

However, this equation is valid only if the water level in the receiving inlet, junction, or manhole is above the invert of the incoming pipe. Otherwise, another protocol has to be used to calculate head losses at

manholes. What follows is a modified FHWA procedure that the engineer can use to calculate the head losses and the EGL along any point in a storm sewer system.

The EGL represents the energy slope between the two adjacent manholes in a storm sewer system. A manhole may have multiple incoming sewers, but only one outgoing sewer. Each sewer and its downstream and upstream manholes form a *sewer-manhole* unit. The entire storm sewer system can be decomposed into a series of sewer-manhole units that satisfy the energy conservation principle. The computation of the EGL does this by repeating the energy-balancing process for each sewer-manhole unit.

As illustrated in Figure ST-6, a *sewer-manhole* unit has four distinctive sections. Section 1 represents the downstream manhole, Section 2 is the point at the exit of the incoming sewer just as enters this manhole, Section 3 is at the entrance to this sewer at the upstream manhole, and Section 4 represents the upstream manhole. For each *sewer-manhole* unit, the head losses are determined separately in two parts as:

- Friction losses through the sewer pipe, and
- Juncture losses at the manhole.

The discussion that follows explains how to apply energy balancing to calculate the EGL through each *sewer-manhole* unit.

4.4.2.1 Losses at the Downstream Manhole—Section 1 to Section 2

The continuity of the EGL is determined between the flow conditions at centerline of the downstream manhole, Section 1, and the exit of the incoming sewer, Section 2, as illustrated in Figure ST-6 and an idealized EGL and HGL profiles in Figure ST-7.

At Section 2 there may be pipe-full flow, critical/supercritical open channel flow, or sub-critical open channel flow. If the sewer crown at the exit is submerged, the EGL at the downstream manhole provides a tailwater condition; otherwise, the manhole drop can create a discontinuity in the EGL. Therefore, it is necessary to evaluate the two possibilities, namely:

$$E_2 = Max(\frac{V_2^{\ 2}}{2g} + Y_x + Z_2, E_1) \qquad \text{(ST-40)}$$

in which:

E_2 = EGL at Section 2

V_2 = sewer exit velocity in fps

Y_2 = flow depth in feet at the sewer exit

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Z_2 = invert elevation in feet at the sewer exit

E_1 = tailwater at Section 1

Equation ST-40 states that the highest EGL value shall be considered as the downstream condition. If the manhole drop dictates the flow condition at Section 2, a discontinuity is introduced into the EGL.

4.4.2.2 Losses in the Pipe, Section 2 to Section 3.

The continuity of the EGL upstream of the manhole depends on the friction losses through the sewer pipe. The flow in the sewer pipe can be one condition or a combination of open channel flow, full flow, or pressurized (surcharge) flow.

When a free surface exists through the pipe length, the open channel hydraulics apply to the backwater surface profile computations. The friction losses through the sewer pipe are the primary head losses for the type of water surface profile in the sewer. For instance, the sewer pipe carrying a subcritical flow may have an M-1 water surface profile if the water depth at the downstream manhole is greater than normal depth in the sewer or an M-2 water surface profile if the water depth in the downstream manhole is lower than normal depth. Under an alternate condition, the pipe carrying a supercritical flow may have an S-2 water surface profile if the pipe entering the downstream manhole is not submerged; otherwise, a hydraulic jump is possible within the sewer.

When the downstream sewer crown is submerged to a degree that the entire sewer pipe is under the HGL, the head loss for this full flow condition is estimated by pressure flow hydraulics.

When the downstream sewer crown is slightly submerged, the downstream end of the sewer pipe is surcharged, but the upstream end of the sewer pipe can have open channel flow. The head loss through a surcharge flow depends on the flow regime. For a subcritical flow, the head loss is the sum of the friction losses for the full flow condition and for the open channel flow condition. For a supercritical flow, the head loss may involve a hydraulic jump. To resolve which condition governs, culvert hydraulic principles can be used under both inlet and outlet control conditions and the governing condition is the one that produces the highest HGL at the upstream manhole.

Having identified the type of flow in the sewer pipe, the computation of friction losses begins with the determination of friction slope. The friction loss and energy balance are calculated as:

$$h_f = LS_f \qquad \text{(ST-41)}$$

$$E_3 = E_2 + \sum h_f \qquad \text{(ST-42)}$$

in which:

h_f = friction loss

L = length in feet of sewer pipe

S_f = friction slope in the pipe in ft/ft

E_3 = EGL at the upstream end of sewer pipe

4.4.2.3 Losses at the Upstream Manhole, Section 3 to Section 4

Additional losses may be introduced at the sewer entrance. The general formula to estimate the entrance loss is:

$$h_E = K_E \frac{V^2}{2g} \quad \text{(ST-43)}$$

in which:

h_E = entrance loss in feet

V = pipe-full velocity in feet per second in the incoming sewer

K_E = entrance loss coefficient between 0.2 to 0.5

In the modeling of sewer flow, the sewer entrance coefficients can be assumed to be part of the bend loss coefficient.

The energy principle between Sections 3 and 4 is determined by:

$$E_4 = E_3 + h_E \quad \text{(ST-44)}$$

in which E_4 = EGL at Section 4.

4.4.2.4 Juncture and Bend Losses at the Upstream Manhole, Section 4 to Section 1

The analysis from Section 4 of the downstream *sewer-manhole* unit to Section 1 of the upstream *sewer-manhole* unit consists only of juncture losses through the manhole. To maintain the conservation of energy through the manhole, the outgoing energy plus the energy losses at the manhole have to equal the incoming energy. Often a manhole is installed for the purpose of maintenance, deflection of the sewer line, change of the pipe size, and as a juncture for incoming laterals. Although there are different causes for juncture losses, they are often, rightly or wrongly, considered as a minor loss in the computation of the EGL. These juncture losses in the sewer system are determined solely by the local configuration and geometry and not by the length of flow in the manhole.

4.4.2.4.1 Bend/Deflection Losses

The angle between the incoming sewer line and the centerline of the exiting main sewer line introduces a bend loss to the incoming sewer. Bend loss is estimated by:

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$$h_b = K_b \frac{V^2}{2g} \quad \text{(ST-45)}$$

in which:

h_b = bend loss in feet

V = full flow velocity in feet per second in the incoming sewer

K_b = bend loss coefficient

As shown in Figure ST-8 and Table ST-9, the value of K_b depends on the angle between the exiting sewer line and the existence of manhole bottom shaping. A shaped manhole bottom or a deflector guides the flow and reduces bend loss. Figure ST-9 illustrates four cross-section options for the shaping of a manhole bottom. Only sections "c. Half" and "d. Full" can be considered for the purpose of using the bend loss coefficient for the curve on Figure ST-9 labeled as "Bend at Manhole, Curved or Shaped."

Because a manhole may have multiple incoming sewers, Equation ST-45 shall be applied to each incoming sewer based on its incoming angle, and then the energy principle between Sections 4 and 1 is calculated as:

$$E_1 = E_4 + h_b \quad \text{(ST-46)}$$

4.4.2.4.2 Lateral Juncture Losses

In addition to the bend loss, the lateral juncture loss is also introduced because of the added turbulence and eddies from the lateral incoming flows. The lateral juncture loss is estimated as:

$$h_j = \frac{V_o^2}{2g} - K_j \frac{V_i^2}{2g} \quad \text{(ST-47)}$$

in which:

h_j = lateral loss in feet

V_o = full flow velocity in feet per second in the outgoing sewer

K_j = lateral loss coefficient

V_i = full flow velocity in feet per second in the incoming sewer

In modeling, a manhole can have multiple incoming sewers, one of which is the main (i.e., trunk) line, and one outgoing sewer. As shown in Table ST-9, the value of K_j is determined by the angle between the lateral incoming sewer line and the outgoing sewer line.

Table ST-9—Bend Loss and Lateral Loss Coefficients (FHWA 1996)

Angle in Degree	Bend Loss Coefficient for Curved Deflector in the Manhole	Bend Loss Coefficient for Non-shaping Manhole	Lateral Loss Coefficient on Main Line Sewer
Straight Through	0.05	0.05	Not Applicable
22.50	0.10	0.13	0.75
45.00	0.28	0.38	0.50
60.00	0.48	0.63	0.35
90.00	1.01	1.32	0.25

At a manhole, the engineer needs to identify the main incoming sewer line (the one that has the largest inflow rate) and determine the value of K_j for each lateral incoming sewer line. To be conservative, the smallest K_j is recommended for Equation ST-44, and the lateral loss is to be added to the outfall of the incoming main line sewer as:

$$E_1 = E_4 + h_b + h_j \qquad (h_j \text{ is applied to main sewer line only}) \quad \text{(ST-48)}$$

The difference between the EGL and the HGL is the flow velocity head. The HGL at a manhole is calculated by:

$$H_1 = E_1 - \frac{V_o^{\,2}}{2g} \quad \text{(ST-49)}$$

The energy loss between two manholes is defined as:

$$\Delta E = (E_1)_{upstream} - (E_1)_{downstream} \quad \text{(ST-50)}$$

in which ΔE = energy loss between two manholes. It is noted that ΔE includes the friction loss, juncture loss, bend loss, and manhole drop.

4.4.2.5 Transitions

In addition to *sewer-manhole* unit losses, head losses in a storm sewer can occur due to a transition in the pipe itself, namely, gradual pipe expansion. Transition loss, h_{LE}, in feet, can be determined using:

$$h_{LE} = K_e\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) \quad \text{(ST-51)}$$

in which K_e is the expansion coefficient and subscripts 1 and 2 refer to upstream and downstream of the transition, respectively. The value of the expansion coefficient, K_e, may be taken from Table ST-10 for

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free surface flow conditions in which the angle of cone refers to the angle between the sides of the tapering section (see Figure ST-10).

Table ST-10—Head Loss Expansion Coefficients in Non-Pressure Flow (FHWA 1996)

D_2/D_1	Angle of Cone						
	10°	20°	30°	40°	50°	60°	70°
1.5	0.17	0.40	1.06	1.21	1.14	1.07	1.00
3	0.17	0.40	.86	1.02	1.06	1.04	1.00

Head losses due to gradual pipe contraction, h_{LC}, in feet, are determined using:

$$h_{LC} = K_c\left(\frac{V_2^2}{2g} - \frac{V_1^2}{2g}\right) \quad \text{(ST-52)}$$

in which K_c = contraction coefficient. Typically, K_c = 0.5 provides reasonable results.

This *Manual* does not recommend pipe contractions for storm sewers.

4.4.2.6 Curved Sewers

Head losses due to curved sewers (sometimes called radius pipe), h_{Lr}, in feet, can be determined using:

$$h_{Lr} = K_r\frac{V^2}{2g} \quad \text{(ST-53)}$$

in which K_r = curved sewer coefficient from Figure ST-8.

4.4.2.7 Losses at Storm Sewer Exit

Head losses at storm sewer outlets, h_{LO}, are determined using:

$$h_{LO} = \frac{V_o^2}{2g} - \frac{V_d^2}{2g} \quad \text{(ST-54)}$$

in which V_o is the velocity in the outlet pipe, and V_d is the velocity in the downstream channel. When the storm sewer discharges into a reservoir or into air because there is no downstream channel, V_d = 0 and one full velocity head is lost at the exit.

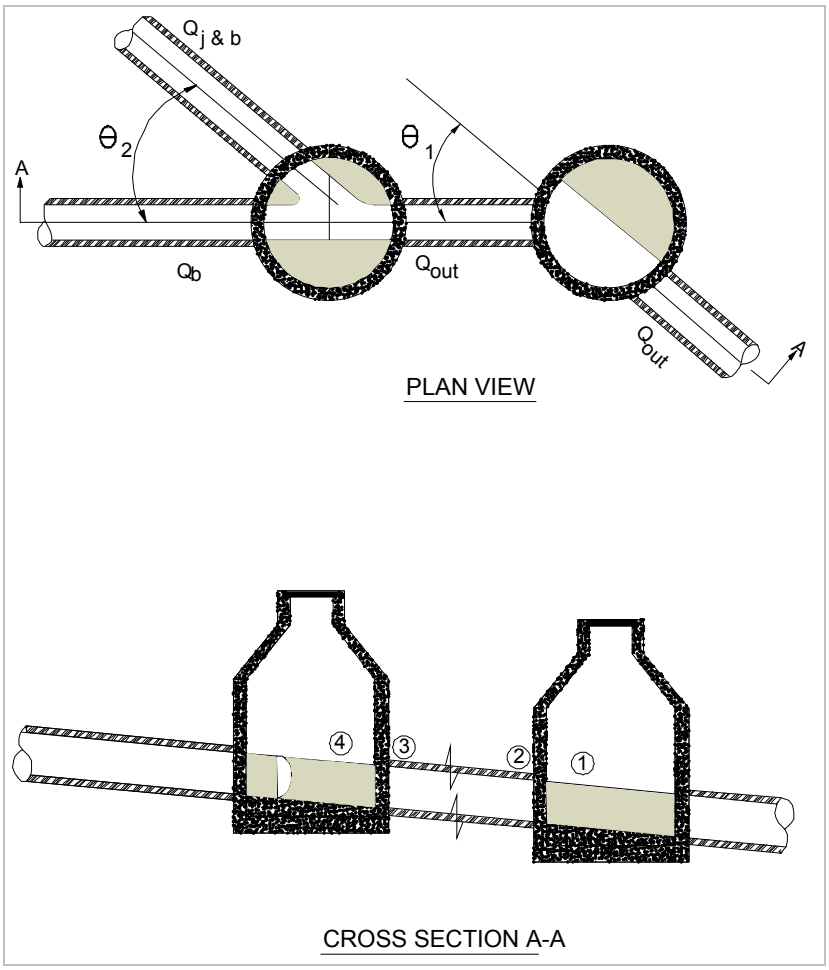

Figure ST-6—A Manhole-Sewer Unit

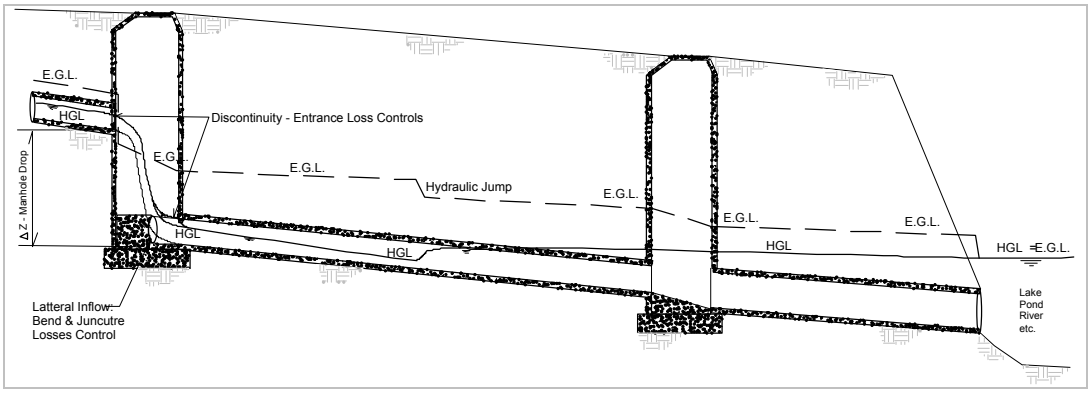

Figure ST-7—Hydraulic and Energy Grade Lines

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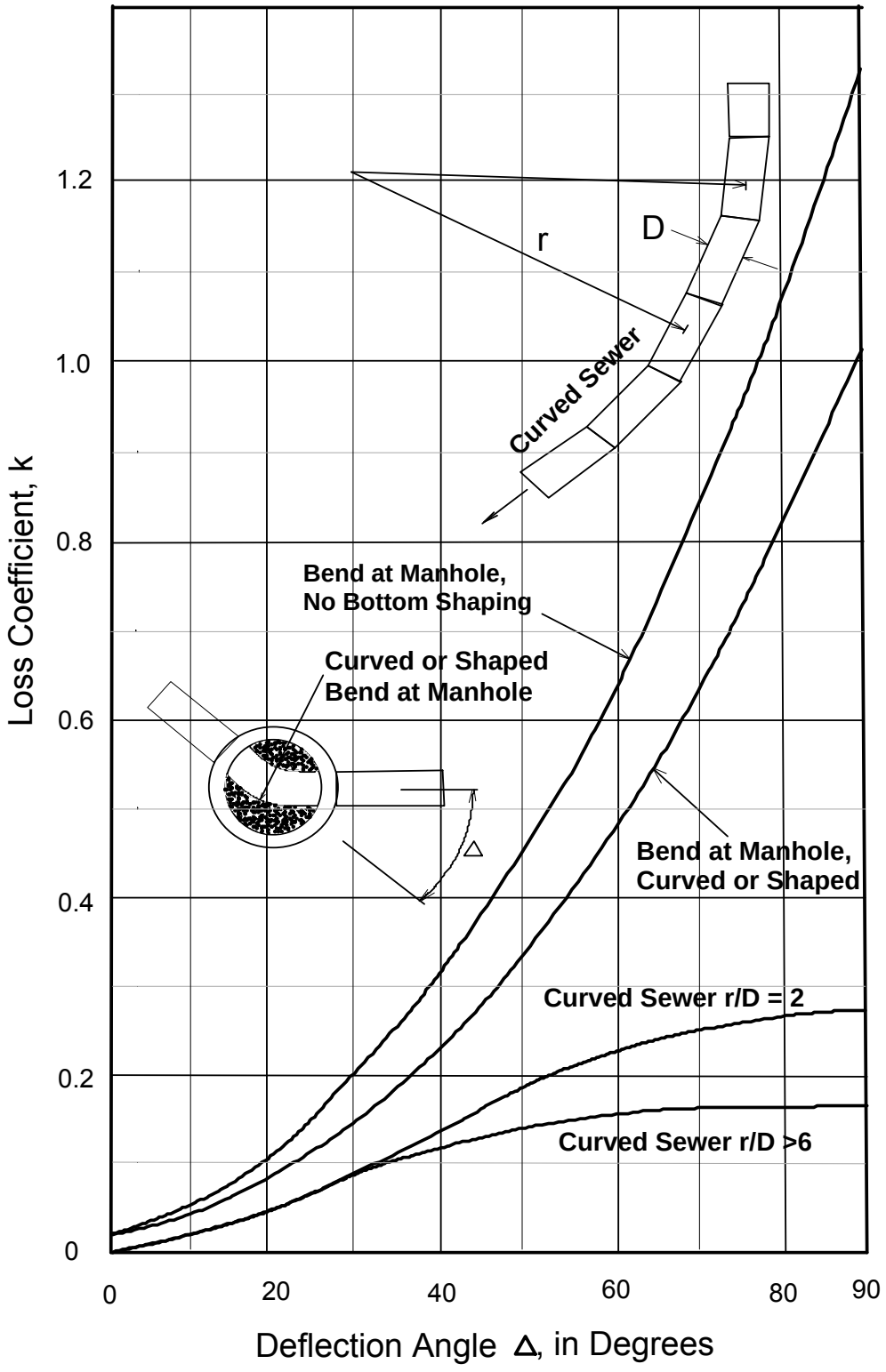

Figure ST-8—Bend Loss Coefficients

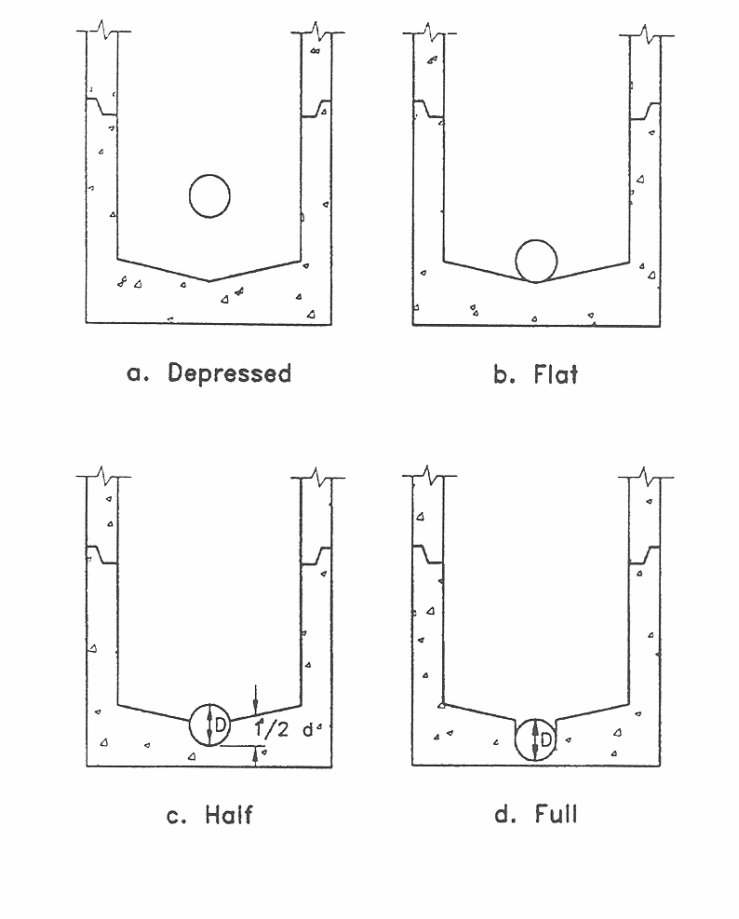

Figure ST-9—Access Hole Benching Methods

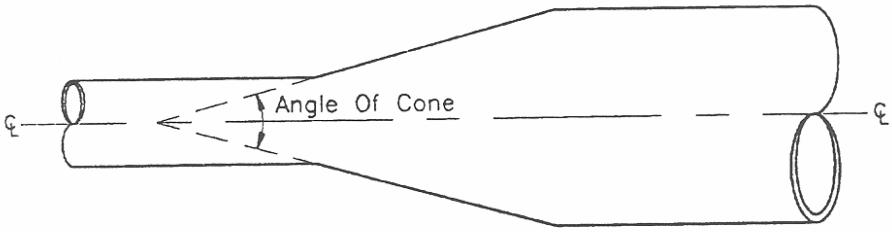

Figure ST-10—Angle of Cone for Pipe Diameter Changes

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5.0 SPREADSHEETS

The UD-Inlet Spreadsheet provides quick solutions for many of the computations described in this chapter. A brief summary of each worksheet of the spreadsheet is provided below. Please note that some of the symbols and nomenclature in the worksheet do not correspond exactly with the nomenclature of the text. The text and the spreadsheets are computationally equivalent.

1. The **Q-Major Worksheet** calculates the gutter capacity for major storm events.
2. The **Q-Minor Worksheet** calculates the gutter capacity for minor storm events.
3. The **Flow Worksheet** provides Rational method hydrologic computations for streets and inlets.
4. The **Street Hy Worksheet** calculates gutter conveyance capacity ***and must be used in conjunction with any of the inlet capacity worksheets***.
5. The **Grate-G Worksheet** calculates the capacity of grate inlets on a grade.
6. The **Curb-G Worksheet** calculates the capacity of curb opening inlets on a grade.
7. The **Slot-G Worksheet** calculates the capacity of slotted inlets on a grade.
8. The **Grate G Worksheet** calculates the capacity of grate inlets in a sump.
9. The **Curb-G Worksheet** calculates the capacity of curb opening inlets in a sump.
10. The **Slot-G Worksheet** calculates the capacity of slotted inlets in a sump.

6.0 EXAMPLES

6.1 Example—Triangular Gutter Capacity

A triangular gutter has a longitudinal slope of S_L = 0.01, cross slope of S_x = 0.02, and a curb depth of 6 inches. Determine the flow rate and flow depth if the spread is limited to 9 feet.

Using Equation ST-1,

$$Q = [(0.56)(0.02)^{5/3}(0.01)^{1/2}(9.0)^{8/3}]/(0.016) = 1.81 \text{ cfs}$$

This is the theoretical flow rate. Then by using Equation ST-2,

$$y = (9.0)(0.02) = 0.18 \text{ ft}$$

Note that the computed flow depth is less than the curb height of 6 inches (0.5 feet). If it was not, the spread and associated flow rate would need to be reduced. A solution of this example using the **Q-Minor Worksheet** of the UD-Inlet Spreadsheet is included below.

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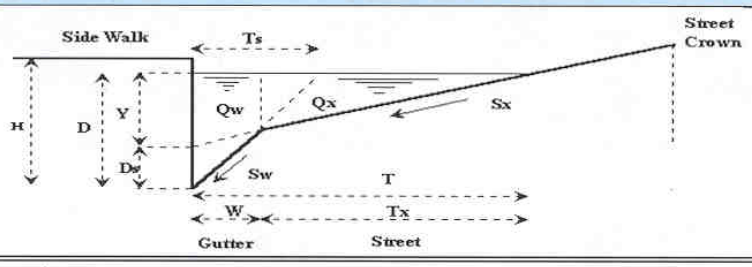
Gutter Storm Water Conveyance Capacity for Minor Event

Project: Example 6.1 - Triangular Gutter Capacity
Street ID:



Gutter Geometry			
Curb Height	H =	6.00	inches
Gutter Width	W =	2.00	ft
Gutter Depression	Ds =	0.00	inches
Street Transverse Slope	Sx =	0.0200	ft/ft
Street Longitudinal Slope	So =	0.0100	ft/ft
Manning's Roughness	N =	0.016	
Maximum Allowable Water Spread for Minor Event	T =	9.00	ft
Gutter Conveyance Capacity Based On Maximum Water Spread			
Gutter Cross Slope:	Sw =	0.0200	ft/ft
Water Depth without Gutter Depression	Y =	0.18	ft
Water Depth with a Gutter Depression	D =	0.18	ft
Spread for Side Flow on the Street	Tx =	7.00	ft
Spread for Gutter Flow along Gutter Slope	Ts =	9.00	ft
Flow Rate Carried by Width Ts	Qws =	1.8	cfs
Flow Rate Carried by Width (Ts - W)	Qww =	0.9	cfs
Gutter Flow	Qw =	0.9	cfs
Side Flow	Qx =	0.9	cfs
Maximum Spread Capacity	**Q-Tm =**	1.8	**cfs**
Gutter Full Conveyance Capacity Based on Curb Height			
Spread for Side Flow on the Street	Tx =	25.00	ft
Spread for Gutter Flow along Gutter Slope	Ts =	25.00	ft
Flow Rate Carried by Width Ts	Qws =	27.5	cfs
Flow Rate Carried by Width (Ts - W)	Qww =	22.0	cfs
Gutter Flow	Qw =	5.5	cfs
Side Flow	Qx =	27.5	cfs
Gutter Full Capacity	**Q-full =**	33.0	**cfs**
Gutter Design Conveyance Capacity Based on Min(Q-Tm, R*Q-full)			
Reduction Factor for Minor Event	R-min =	1.00	
Gutter Design Conveyance Capacity for Minor Event	**Q-min =**	1.8	**cfs**

6.2 Example—Composite Gutter Capacity

Determine the discharge in a composite gutter section if the allowable spread is 9.0 feet, the gutter width, *W*, is 2 feet, and the gutter depression is 1.5 inches. The street's longitudinal slope is 0.01, the cross slope is 0.02, and the curb height is 6 inches.

Equation ST-8 yields the cross slope of the depressed gutter as:

$$S_w = 0.02 + (1.5/12)/2 = 0.083$$

Using Figure ST-1a, W = 2 feet, T_s = 7 feet. Equation ST-1 can now be used to find the flow in the street section.

$$Q_s = [(0.56)(0.02)^{5/3}(0.01)^{1/2}(7.0)^{8/3}]/(0.016) = 0.92 \text{ cfs}$$

Now with S_w/S_x = 0.083/0.02 = 4.1, T/W = 9.0/2.0 = 4.5, and T/W - 1 = 3.5, by using Equation ST-7,

$$E_o = \frac{1}{\left\{1 + \frac{4.1}{\left[1 + \frac{4.1}{3.5}\right]^{8/3} - 1.0}\right\}} = 0.63$$

Now the theoretical flow rate can be found using Equation ST-6 as:

$$Q = [(0.92)/(1 - 0.63)] = 2.49 \text{ cfs}$$

Then by using Equation ST-9,

$$y = 2/12 + (9.0)(0.02) = 0.35 \text{ feet}$$

Note that the computed flow depth is less than the curb height of 6 inches (0.5 feet). Also note that this is the same gutter section as Example 6.1 except for the depressed gutter section. This change has increased the gutter capacity by 38% and almost doubled the depth of flow. A spreadsheet solution of this example problem using the **Q-Minor Worksheet** of the UD-Inlet Spreadsheet is included below.

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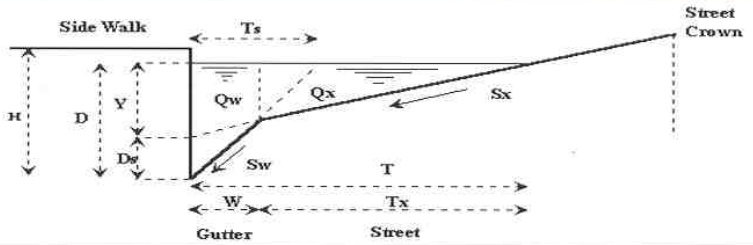
Gutter Storm Water Conveyance Capacity for Minor Event

Project: Example 6.2 - Composite Gutter Capacity
Street ID:



Gutter Geometry			
Curb Height	H =	6.00	inches
Gutter Width	W =	2.00	ft
Gutter Depression	Ds =	1.50	inches
Street Transverse Slope	Sx =	0.0200	ft/ft
Street Longitudinal Slope	So =	0.0100	ft/ft
Manning's Roughness	N =	0.016	
Maximum Allowable Water Spread for Minor Event	T =	9.00	ft
Gutter Conveyance Capacity Based On Maximum Water Spread			
Gutter Cross Slope:	Sw =	0.0825	ft/ft
Water Depth without Gutter Depression	Y =	0.18	ft
Water Depth with a Gutter Depression	D =	0.31	ft
Spread for Side Flow on the Street	Tx =	7.00	ft
Spread for Gutter Flow along Gutter Slope	Ts =	3.70	ft
Flow Rate Carried by Width Ts	Qws =	1.8	cfs
Flow Rate Carried by Width (Ts - W)	Qww =	0.2	cfs
Gutter Flow	Qw =	1.6	cfs
Side Flow	Qx =	0.9	cfs
Maximum Spread Capacity	**Q-Tm =**	**2.5**	**cfs**
Gutter Full Conveyance Capacity Based on Curb Height			
Spread for Side Flow on the Street	Tx =	18.75	ft
Spread for Gutter Flow along Gutter Slope	Ts =	6.06	ft
Flow Rate Carried by Width Ts	Qws =	6.7	cfs
Flow Rate Carried by Width (Ts - W)	Qww =	2.3	cfs
Gutter Flow	Qw =	4.4	cfs
Side Flow	Qx =	12.8	cfs
Gutter Full Capacity	**Q-full =**	**17.1**	**cfs**
Gutter Design Conveyance Capacity Based on Min(Q-Tm, R*Q-full)			
Reduction Factor for Minor Event	R-min =	1.00	
Gutter Design Conveyance Capacity for Minor Event	**Q-min =**	**2.5**	**cfs**

6.3 Example—Composite Gutter Spread

A composite gutter section has S_x = 0.02, S_L = 0.01, a = 2 inches, n = 0.016 and W = 2 feet. Determine the spread, T, at Q = 2.5 cfs (Akan and Houghtalen 2002).

Solving this problem by using Equations ST-6 and ST-7 requires a trial-and-error procedure since the equations are implicit in T. In the trial-and-error procedure, the value of T is guessed, and Q is calculated using Equations ST-6 and ST-7. If the calculated Q is the same as the given Q, the guessed value of T is correct. Otherwise, the procedure is repeated using another guess for T. In this case, a guessed value of a spread equal to 8.5 feet yields the correct flow of 2.5 cfs. A direct solution is possible by using the **Street Hy Worksheet** of the UD-Inlet Spreadsheet.

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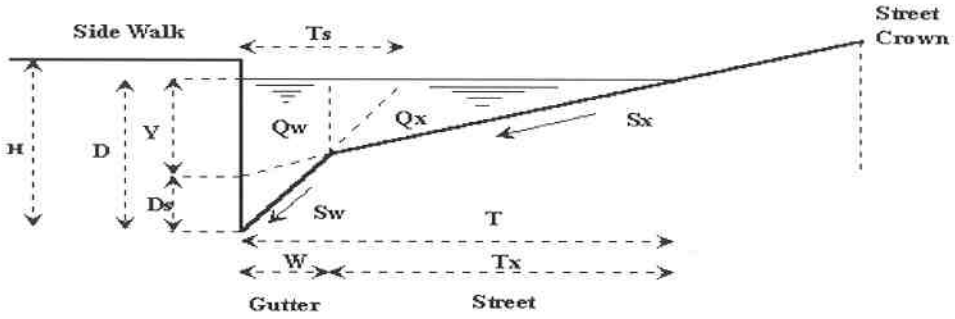
GUTTER CONVEYANCE CAPACITY

Project = Example 6.3 - Composite Gutter Spread
Street ID =



Street Geometry (Input)			
Design Discharge in the Gutter	**Qo =**	2.5	**cfs**
Curb Height	H =	6.00	inches
Gutter Width	W =	2.00	ft
Gutter Depression	Ds =	2.00	inches
Street Transverse Slope	Sx =	0.0200	ft/ft
Street Longitudinal Slope	So =	0.0100	ft/ft
Manning's Roughness	N =	0.016	

Gutter Conveyance Capacity			
Gutter Cross Slope	Sw =	0.10	ft/ft
Water Spread Width	T =	8.58	ft
Water Depth without Gutter Depression	Y =	0.17	ft
Water Depth with a Gutter Depression	D =	0.34	ft
Spread for Side Flow on the Street	Tx =	6.58	ft
Spread for Gutter Flow along Gutter Slope	Ts =	3.27	ft
Flowrate Carried by Width Ts	Qws =	1.9	cfs
Flowrate Carried by Width (Ts - W)	Qww =	0.2	cfs
Gutter Flow	Qw =	1.7	cfs
Side Flow	Qx =	0.8	cfs
Total Flow (Check against Qo)	**Qs =**	2.5	**cfs**
Gutter Flow to Design Flow Ratio	Eo =	0.69	
Equivalent Slope for the Street	Se =	0.08	ft/ft
Flow Area	As =	0.90	sq ft
Flow Velocity	Vs =	2.77	fps
VsD product	**VsD =**	0.94	**ft^2/s**

6.4 Example—V-Shaped Swale Capacity

Determine the maximum discharge and depth of flow in a V-shaped, roadside swale with the following characteristics: S_{x1} = 0.08, S_{x2} = 0.06, n = 0.016, S_L = 0.02, and T = 6 feet.

Equations ST-13, ST-1, and ST-3 are used to determine the adjusted slope, the flow, and the flow depth.

$$S_x = (0.08)(0.06)/(0.08 + 0.06) = 0.034$$

$$Q = [(0.56)(0.034)^{5/3}(0.02)^{1/2}(6.0)^{8/3}]/(0.016) = 2.09 \text{ cfs}$$

$$y = (0.034)(6.0) = 0.20 \text{ feet}$$

6.5 Example—V-Shaped Swale Design

Design a V-shaped swale to convey a flow of 1.8 cfs. The available swale top width is 8 feet, the longitudinal slope is 0.01, and the Manning's roughness factor is 0.016. Determine the cross slopes and the depth of the swale.

Solving Equation ST-1 for S_x (i.e., average side slope) yields:

$$S_x = [(1.8)(0.016)/(0.56)(0.01)^{1/2}(8.0)^{8/3}]^{3/5} = 0.024$$

Now Equation ST-13 is used to solve for the actual cross slope if $S_{x1} = S_{x2}$. Then,

$$0.024 = (S_{x1})^2/2S_{x1} = S_{x1}/2, \text{ and } S_{x1} = 0.048$$

Then using Equation ST-2 yields

$$y = (0.024)(8.0) = 0.19 \text{ ft}$$

The swale is 8-feet wide with right and left side slopes of 0.048 ft/ft.

6.6 Example—Major Storm Street Capacity

Determine the flow capacity of an arterial street during the major storm if the street is 60-feet wide (gutter to gutter) with a cross slope of 0.025 ft/ft, a curb height of 6 inches, and a longitudinal slope of 0.03. A 12-foot-wide sidewalk is adjacent to the curb. Flow capacity beyond the sidewalk cannot be relied upon because buildings often abut the sidewalk in this commercial district.

Table ST-3 shows the limitations on the stormwater depth during the major storm (100-year) event. The depth cannot exceed the crown elevation, nor can it exceed 12 inches over the gutter flow line. If the flow depth was at the street crown elevation, the corresponding depth of flow at the curb would be (0.025)(30) = 0.75 feet. Therefore, assume that the crown elevation controls the flood depth (i.e., the entry level into

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the buildings will assumed to be high enough not to control the flood depth).

Since the street cross section is symmetric, determine the capacity on one side of the street crown and multiply by 2 to get the total capacity and break the flow section up into prismatic shapes. Flow occurs in a triangular section in the street and a rectangular section above the sidewalk (at a depth of 0.75 – 0.5 = 0.25 ft). The street section has a Manning's value of 0.016, and the sidewalk has a value of 0.013. The triangular flow area of the street is (1/2)(30)(0.75) = 11.25 ft^2 and a wetted perimeter of approximately 30 + 0.5 = 30.5 feet (assuming the slope length is roughly equal to the width plus the curb height). The sidewalk section has a flow area of (12)(0.25) = 3.00 ft^2 and a wetted perimeter of 12 feet (ignoring the vertical sides of buildings). Thus, Equation ST-14 yields

$$Q = (1.49/0.016)(11.25)(11.25/30.5)^{2/3}(0.03)^{1/2} = 93.3 \text{ cfs (street section)}$$

$$Q = (1.49/0.013)(3.0)(3.0/12.0)^{2/3}(0.03)^{1/2} = 23.6 \text{ cfs (sidewalk section)}$$

$$Q = 2(93.3 + 23.6) = 234 \text{ cfs (total flow capacity of the section)}$$

Oftentimes, the 100-year flow rate will be available and the flow depth will need to be determined, or the flow cross section will not be prismatic. Fortunately, proprietary software is available to perform normal depth computations (i.e., Manning's depth) for irregular cross sections, rendering these problems trivial.

6.7 Example—Grate Inlet Capacity

Determine the efficiency of a curved vane grate (W = 2 feet and L = 2 feet) when placed in a composite gutter with the following characteristics: S_x = 0.02, S_L = 0.01, a = 0.167 feet, and n = 0.016. The flow rate in the gutter is 2.5 cfs with a spread of 8.5 feet. Note: The depressed section of the composite gutter has a width equal to the width of the grate (Akan and Houghtalen 2002).

Find the gutter slope using Equation ST-8:

$$S_w = 0.02 + \frac{0.167}{2} = 0.1033$$

By using Equation ST-7:

$$E_o = \frac{1}{1 + \left[\dfrac{0.1033/0.02}{\left[1 + \dfrac{(0.1033/0.02)}{(8.5/2) - 1}\right]^{2.67} - 1} \right]} = 0.69$$

The side flow Q_s is calculated using Equation ST-6:

$$Q_s = 2.5(1-0.69) = 0.77 \text{ cfs}$$

The frontal flow Q_w is calculated using Equation ST-5:

$$Q_w = 2.5 - 0.77 = 1.73 \text{ cfs}$$

Next, find the flow area using Equation ST-10 and velocity using the continuity equation $V = Q/A$.

$$A = ½(0.02)(8.5)^2 + ½(0.167)(2) = 0.89 \text{ ft}^2$$

$$V = Q/A = 2.5/0.89 = 2.81 \text{ ft/sec}$$

The splash-over velocity V_o is determined from Equation ST-20:

$$V_o = 0.30 + 4.85(2) - 1.31(2)^2 + 0.15(2)^3 = 5.96 \text{ ft/sec}$$

Because $V_o > V$, $R_f = 1.0$ from Equation ST-20.

Using Equation ST-21, the side-flow capture efficiency is calculated as:

$$R_s = \frac{1}{1 + \frac{0.15\,(2.81)^{1.8}}{0.02\,(2)^{2.3}}} = 0.093$$

Finally, the overall capture efficiency is calculated using Equation ST-22:

$$E = 1.0\left(\frac{1.73}{2.5}\right) + \quad 0.093\left(\frac{0.77}{2.5}\right) = 0.72$$

= 72%

Alternatively, the **Grate-G Worksheet** of the UD-Inlet Spreadsheet also performs the calculations and calculates a capture percentage of 71.94%.

6.8 Example—Curb-Opening Inlet Capacity

Determine the amount of flow that will be captured by a 6-foot-long curb-opening inlet placed in the composite gutter described in Example Problem 6.2. The composite gutter in that example had the following characteristics: T = 9.0 ft., W = 2.0 ft, S_L = 0.01, a = 1.5 inches, S_x = 0.02 and a Manning's roughness factor of n = 0.016. In Example Problem 6.2, it was determined that the frontal to total flow ratio was E_o = 0.63 and the total gutter discharge was Q = 2.49 cfs.

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Equations ST-25 and ST-26 are used to determine the equivalent slope and the length of inlet required to capture 100% of the gutter flow.

$S_e = 0.02 + [(1.5/12)/2]0.63 = 0.059$

$$L_T = 0.60(2.49)^{0.42}(0.01)^{0.3}\left[\frac{1.0}{(0.016)(0.059)}\right]^{0.6} = 14.4 \text{ ft}$$

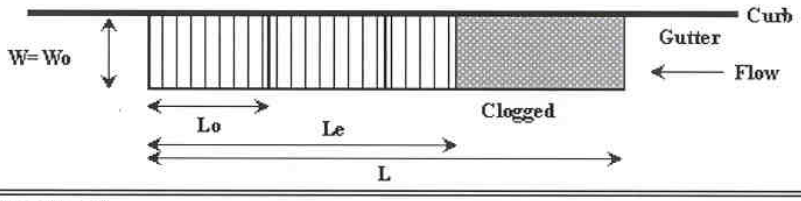
Then, by using Equation ST-23,

$$E = 1.0\left(1.0 - \frac{6.0}{14.4}\right)^{1.8} = 0.62$$

Therefore, $Q_i = EQ = (0.62)(2.49) = 1.54$ cfs will be intercepted by the curb-opening inlet. Note that this problem was performed using the theoretical gutter capacity from Example Problem 6.2. The **Curb-G Worksheet** of the UD-Inlet Spreadsheet also performs these calculations.

GRATE INLET ON A GRADE

Project: Example 6.8 - Grate Inlet Capacity
Inlet ID:



Design Information (Input)			
Design Discharge on the Street (from *Street Hy*)	**Qo =**	**2.5**	**cfs**
Type of Grate	Type =	Vane Grate	
Length of a Unit Grate	Lo =	2.00	ft
Width of a Unit Grate	Wo =	2.00	ft
Clogging Factor for a Unit Grate	Co =	0.00	
Water Depth for Design Condition	Yd =		inches
Number of Grates	No =	1	

Analysis (Calculated)			
Total Length of Grate Inlet	L =	2.00	ft
Ratio of Gutter Flow to Design Flow Eo (from *Street Hy*)	Eo =	0.69	
Equivalent Slope Se (from *Street Hy*)	Se =	0.0800	ft/ft
Flow Velocity Vs (from *Street Hy*)	Vs =	2.77	fps
Spash-over Velocity	Vo =	5.96	fps
Under No-Clogging Condition			
Interception Rate of Gutter Flow	Rf =	1.00	
Effective Length of Grate Inlet	L =	2.00	ft
Interception Rate of Side Flow Rx (from *Street Hy*)	Rx =	0.09	
Interception Capacity	Qi =	1.8	cfs
Under Clogging Condition			
Interception Rate of Gutter Flow	Rf =	1.00	
Clogging Coefficient for Multiple-unit Grate Inlet	Coef =	0.00	
Clogging Factor for Multiple-unit Grate Inlet	Clog =	0.00	
Effective (unclogged) Length of Multiple-unit Grate Inlet	Le =	2.00	ft
Interception Rate of Side Flow Rx (from *Street Hy*)	Rx =	0.09	
Actual Interception Capacity	**Qa =**	**1.8**	**cfs**
Carry-Over Flow = Qo-Qa =	**Q-co =**	**0.7**	**cfs**
Capture Percentage = Qa/Qo =	**C% =**	**71.94**	**%**

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6.9 Example—Curb-Opening Inlet Capacity

Determine the amount of flow that will be captured by the 6-foot-long curb-opening inlet of Example Problem 6.8 if the gutter did not have a depressed curb section.

Since the cross slope is given (S_x = 0.02), an equivalent slope does not have to be determined. Equation ST-24 is used to determine the length of inlet required to capture 100% of the gutter flow.

$$L_T = 0.60(2.49)^{0.42}(0.01)^{0.3}\left[\frac{1.0}{(0.016)(0.02)}\right]^{0.6} = 27.6 \text{ ft}$$

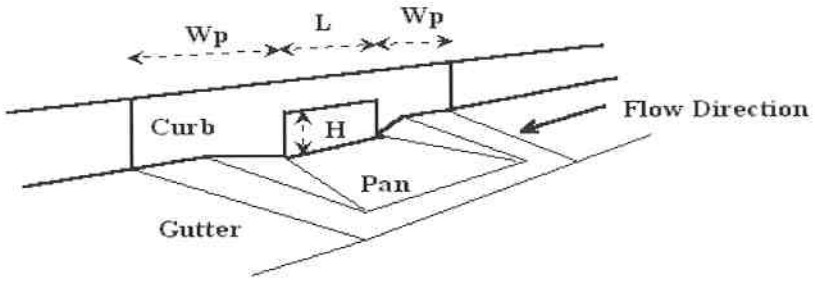
Then, by using Equation ST-23,

$$E = 1.0 - \left(1.0 - \frac{6.0}{27.6}\right)^{1.8} = 0.36$$

Therefore, $Q_i = EQ$ = (0.36)(2.49) = 0.90 cfs will be intercepted by the curb-opening inlet. Note that the curb-opening inlet is far less effective without a depressed curb section. The **Curb-G Worksheet** of the UD-Inlet Spreadsheet also performs these calculations.

CURB OPENING INLET ON A GRADE

Project: Example 6.9 - Curb Opening Inlet Capacity
Inlet ID:



Design Information (Input)			
Design Discharge on the Street (from *Street Hy*)	**Qo =**	**2.5**	**cfs**
Gutter Flow to Design Flow Ratio (from *Street Hy*)	Eo =	0.63	
Length of a Single Inlet Unit	Lu =	6.00	ft
Clogging Factor for a Single Unit Inlet	Co =	0.00	
Number of Inlet Units in Curb Opening	No =	1	

Analysis (Calculated)			
Total Length of Curb Opening Inlet	L =	6.00	ft
Equivalent Slope Se (from *Street Hy*)	Se =	0.0600	ft/ft
Required Length Lo to Have 100% Interception	Lo =	14.32	ft
Clogging Coefficient	C-coeff =	1.00	
Clogging Factor for Multiple-unit Curb Opening Inlet	Clog =	0.00	
Effective (Unclogged) Length	Le =	6.00	ft
Under No-Clogging Condition			
Effective Length of Curb Opening Inlet (must be ≤ Lo)	L =	6.00	ft
Interception Capacity	Qi =	1.6	cfs
Under Clogging Condition			
Effective Length of Curb Opening Inlet (must be ≤ Lo)	Le =	6.00	ft
Interception Capacity	**Qa =**	**1.6**	**cfs**
Carryover flow = Qo - Qa =	**Q-co =**	**0.9**	**cfs**
Capture Percentage for this Inlet = Qa / Qo =	**C% =**	**62.37**	**%**

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6.10 Example—Combination Inlet Capacity

A combination inlet is installed in a triangular gutter carrying a discharge of 7 cfs. The gutter is characterized by S_L = 0.01, S_x = 0.025, and n = 0.016. The curb opening is 10 feet long and the grate is a 2-foot by 2-foot reticuline grate. An 8-foot-long portion of the curb opening is upstream of the grate. Determine the flow intercepted by this combination inlet (Akan and Houghtalen 2002).

First consider the upstream curb-opening portion of the combination inlet. By using Equations ST-24 and ST-23, respectively,

$$L_T = (0.6)(7.0)^{0.42}(0.01)^{0.3}\left[\frac{1.0}{(0.016)(0.025)}\right]^{0.6} = 37 \text{ ft}$$

$$E = 1.0 - \left[1.0 - \frac{8.0}{37}\right]^{1.8} = 0.36$$

Thus, the 8-foot-long portion of the curb opening intercepts (0.36)(7.0) = 2.5 cfs. The remaining flow is 7.0 - 2.5 = 4.5 cfs. The spread corresponding to this discharge is calculated using Equation ST-1 as:

$$T = \left[\frac{(4.5)(0.016)}{(0.56)(0.025)^{1.67}(0.01)^{0.5}}\right]^{3/8} = 11 \text{ ft}$$

Now the flow intercepted by the grate can be computed. By using Equation ST-17,

$$Q_w = 4.5\left[1 - \left(1 - \frac{2.0}{11}\right)^{2.67}\right] = 1.9 \text{ cfs}$$

and $Q_s = Q - Q_w$ = 4.5 - 1.9 = 2.6 cfs. The splash-over velocity for the grate (Equation ST-20) is 0.28 + 2.28(2) – 0.18(2)^2 + 0.01(2)^3 = 4.2 ft/sec. Also, by using Equation ST-4, the flow area just upstream from the grate is A = (0.5)(0.025)(11)^2 = 1.5 ft^2. Likewise, $V = Q/A$ = 4.5/1.5 = 3.0 ft/sec. Because $V < V_o$, R_f = 1.0 by using Equation ST-19. Next, by using Equation ST-21,

$$R_s = \frac{1}{1 + \dfrac{(0.15)(3.0)^{1.8}}{(0.025)(2.0)^{2.3}}} = 0.10$$

Then by using Equation ST-22, the efficiency of the grate is:

$$E = 1.0\left(\frac{1.9}{4.5}\right) + 0.10\left(\frac{2.6}{4.5}\right) = 0.48$$

The flow intercepted by the grate becomes (0.48)(4.5)= 2.2 cfs. The total flow intercepted by the combination inlet is then 2.5 + 2.2 = 4.7 cfs. The overall efficiency is 4.7/ 7.0 = 0.67 and the bypass flow is 7.0 - 4.7 = 2.3 cfs.

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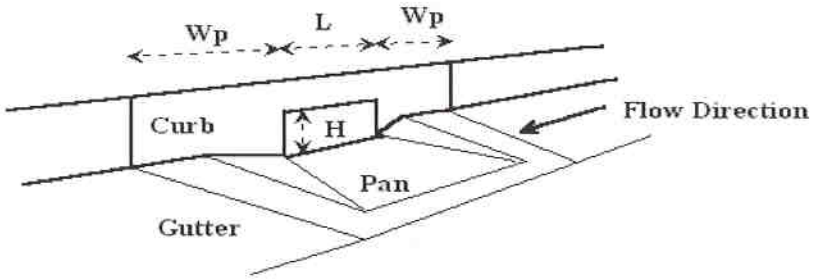
CURB OPENING INLET ON A GRADE

Project: Example 6.10 - Curb Opening Inlet Capacity
Inlet ID:



Design Information (Input)			
Design Discharge on the Street (from *Street Hy*)	**Qo =**	**2.5**	**cfs**
Gutter Flow to Design Flow Ratio (from *Street Hy*)	Eo =	0.44	
Length of a Single Inlet Unit	Lu =	6.00	ft
Clogging Factor for a Single Unit Inlet	Co =	0.00	
Number of Inlet Units in Curb Opening	No =	1	

Analysis (Calculated)			
Total Length of Curb Opening Inlet	L =	6.00	ft
Equivalent Slope Se (from *Street Hy*)	Se =	0.0200	ft/ft
Required Length Lo to Have 100% Interception	Lo =	27.68	ft
Clogging Coefficient	C-coeff =	1.00	
Clogging Factor for Multiple-unit Curb Opening Inlet	Clog =	0.00	
Effective (Unclogged) Length	Le =	6.00	ft
Under No-Clogging Condition			
Effective Length of Curb Opening Inlet (must be ≤ Lo)	L =	6.00	ft
Interception Capacity	Qi =	0.9	cfs
Under Clogging Condition			
Effective Length of Curb Opening Inlet (must be ≤ Lo)	Le =	6.00	ft
Interception Capacity	**Qa =**	**0.9**	**cfs**
Carryover flow = Qo - Qa =	**Q-co =**	**1.6**	**cfs**
Capture Percentage for this Inlet = Qa / Qo =	**C% =**	**35.58**	**%**

6.11 Example—Curb-Opening Inlet in a Sump Condition

Determine the flow depth and spread at a curb-opening inlet placed in a sump given the following conditions: L = 6 ft, h = 0.3 ft, S_x = 0.025, and Q_i = 5.8 cfs. Assume there is no clogging.

The flow condition must be assumed and then verified. Assuming orifice flow, Equation ST-28 yields

$$Q_i = C_o A_o (2gd)^{0.5}$$

Now, based on Table ST-7,

$$Q_i = 0.67(h)(L)[(2g)(d_i - h/2)]^{0.5}$$

and by substituting known values,

$$5.8 = (0.67)(0.3)(6)[(2)(32.2)(d_i - 0.3/2)]^{0.5}$$

which yields:

$$d_i = 0.51 \text{ ft}$$

Since $d_i > 1.4h$, the orifice equation is appropriate. Equation ST-2 yields T = 0.51/0.025 = 20.4 ft.

The **Curb-S Worksheet** performs these calculations.

6.12 Example—Storm Sewer Hydraulics (Akan and Houghtalen 2002)

Determine the depth of flow, y, flow area, and flow velocity in a storm sewer (D = 2.75 ft, n = 0.013, and S_0 = 0.003) for a flow rate of 26.5 cfs.

Just full flow conditions are computed first. From Equations ST-34, ST-37 and ST-38, A_f = 5.94 ft^2, R_f = 0.69 ft, and Q_f = 29.1 cfs. Then, V_f = 29.1/5.94 = 4.90 ft/sec. Now, by using Figure ST-6 with Q/Q_f = 26.5/29.1 = 0.91, it is determined that y/D = 0.73, A/A_f = 0.79, and V/V_f = 1.13. Therefore, y = (0.73)(2.75) = 2.0 ft, A = (0.79)(5.94) = 4.69 ft^2, and V = (1.13)(4.90) = 5.54 ft/sec.

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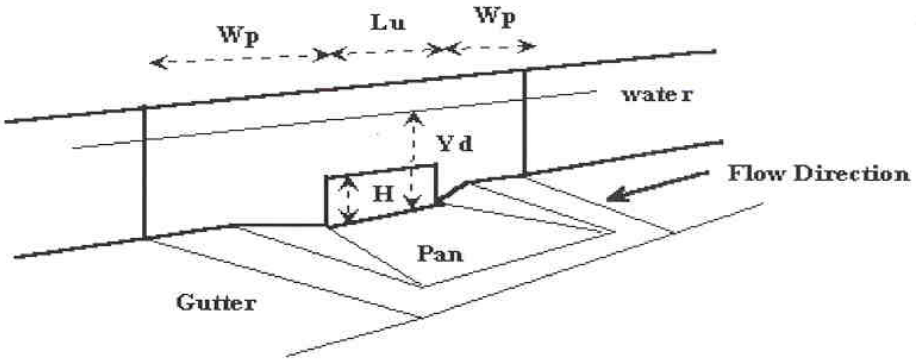
CURB OPENING INLET IN A SUMP

Project = Example 6.12 - Curb Opening Inlet in a Sump Condition
Inlet ID =



Design Information (Input)			
Design Discharge on the Street (from *Street Hy*)	**Qo =**	**2.5**	**cfs**
Length of a Unit Inlet	Lu =	6.00	ft
Side Width for Depression Pan	Wp =	3.00	ft
Clogging Factor for a Single Unit	Co =	0.00	
Height of Curb Opening in Inches	H =	3.60	inches
Orifice Coefficient	Cd =	0.67	
Weir Coefficient	Cw =	3.00	
Water Depth for the Design Condition	Yd =	0.51	ft
Angle of Throat (see USDCM Chapter 6, Figure ST-5)	Theta =	63.0	degrees
Number of Curb Opening Inlets	No =	1	

Curb Opening Inlet Capacity in a Sump			
As a Weir			
Total Length of Curb Opening Inlet	L =	6.00	ft
Capacity as a Weir without Clogging	Qwi =	12.5	cfs
Clogging Coefficient for Multiple Units	Clog-Coeff =	1.00	
Clogging Factor for Multiple Units	Clog =	0.00	
Capacity as a Weir with Clogging	Qwa =	12.5	cfs
As an Orifice			
Capacity as an Orifice without Clogging	Qoi =	5.9	cfs
Capacity as an Orifice with Clogging	Qoa =	5.9	cfs
Capacity for Design with Clogging	**Qa =**	**5.9**	**cfs**
Capture Percentage for this Inlet = Qa / Qo =	**C% =**	**100.00**	**%**

Note: Unless additional ponding depth or spilling over the curb is acceptable, a capture percentage of less than 100% in a sump may indicate the need for additional inlet units.

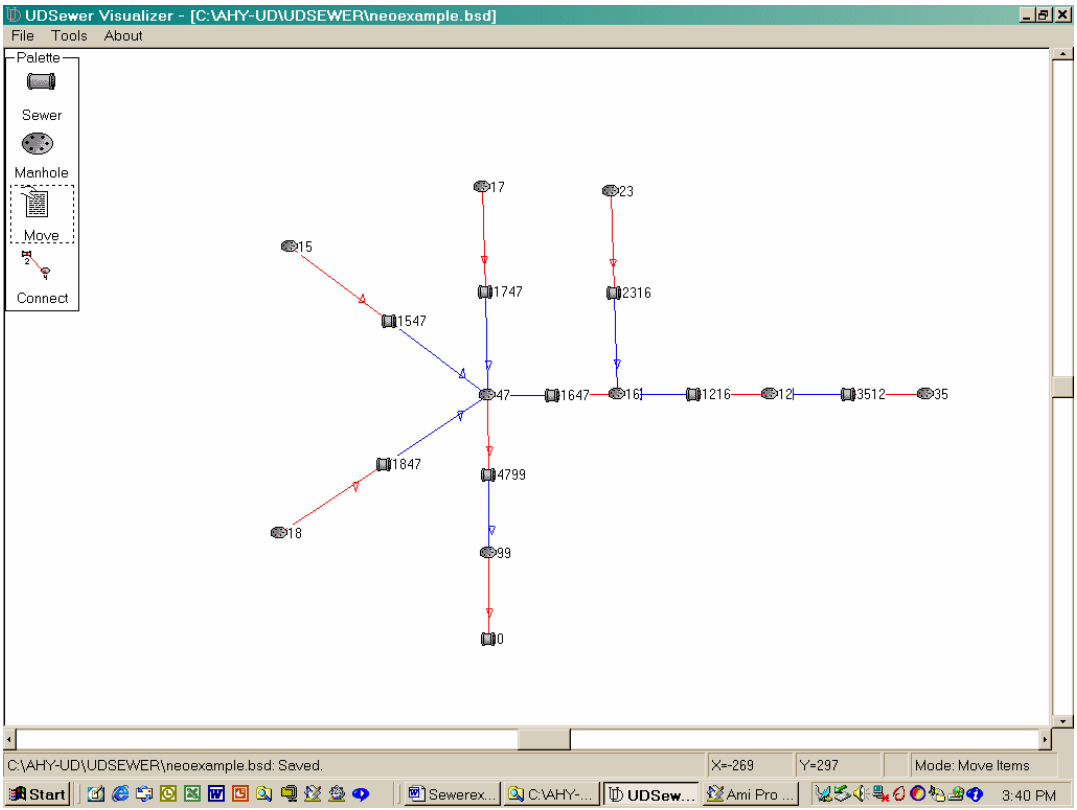
6.13 Example—Storm Sewer Hydrology

This example storm sewer system is based on the hydrology for the Denver, Colorado area. It is developed here to illustrate the solution using the NeoUDSEWER computer software. The storm sewer system is to be designed to fully convey the five-year runoff event. The following formula, taken from the Rainfall Chapter of this Manual, describes design rainfall intensity as a function of storm duration:

$$i = \frac{38.5}{(10 + T_d)^{0.768}}$$

in which i = rainfall intensity in inches per hour and T_d = rainstorm duration in minutes.

The illustration below depicts a layout of the storm sewer system. It is a copy of the input screen from the NeoUDSEWER software. An ID number is assigned to each manhole and to each sewer segment. The ID numbers have to be unique among the manholes in a system and cannot be duplicated, as is the case for sewer ID numbers among the sewers. At a manhole, NeoUDSEWER can accommodate one outgoing sewer and up to four incoming sewers.



Example Storm Sewer System Using Computer Model: NeoUDSEWER

NeoUDSEWER is a storm sewer system sizing and analysis software package. It calculates rainfall and runoff using the Rational Formula method and then sizes circular sewers using Manning's equation. It

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has a graphical interface for data entry and editing. NeoUDSEWER can handle a storm sewer system having up to 100 manholes and up to 100 sewers.

Data entry includes project title, rainfall statistics, manhole information, basin hydrology, and sewer network information. Rainfall IDF information can be entered as a table or calculated using the equation given above by entering only a value for the 1-hour depth, P1. The user needs to check all of the default design constraints and criteria and make all necessary changes to these values as needed.

The input parameters for each manhole include the manhole identification number, ground elevation, and incoming and outgoing sewer identification numbers. The hydrologic parameters for the tributary area at a manhole include tributary area, runoff coefficients, overland flow length and slope, local tributary gutter flow length, and gutter flow velocity.

When the local runoff flow rate at a manhole is known, it may be entered (along with non-zero values for local tributary area and local runoff coefficient) to override the flows calculated by the Rational Equation for the local area. NeoUDSEWER will combine the local flow with the upstream flow to calculate the design discharge at the manhole. When the design discharge at a manhole is known for the entire upstream area, the user must enter this discharge (along with total tributary area) and the weighted runoff coefficient to have the program then analyze the EGL and HGL for the system.

A storm sewer is described by its length, slope, upstream crown elevation, Manning's roughness coefficient, shape, bend loss coefficient, and lateral loss coefficient. An existing sewer is identified by the user-defined size and shape. Use of noncircular sewers such as box sewers and arch pipes can be achieved by prescribing their dimensions. However, all new sewers are sized using circular pipes. The program provides suggested commercial sewer sizes for both new and existing sewers. Sewers with flat or negative slope may be analyzed as existing sewers with user-defined sizes provided to the program, along with user-defined tailwater surface elevation at the outlet end. NeoUDSEWER applies open channel hydraulics, culvert hydraulics, and pressure flow hydraulics to calculate the EGL and HGL along the predefined sewer system.

For this example, Table ST-11 provides the watershed hydrologic parameters for the determination of peak design flow rates at the manholes in the system. The design flow can be changed only at a manhole. Sewers 3512, 1216, 1647, and 1547 are treated as existing sewer and their sizes are given in Table ST-12. Other sewer segments are new and will be sized by NeoUDSEWER using circular pipes. In a case that a box conduit is preferred, the sewer may be treated as an existing sewer with a known width. NeoUDSEWER will calculate the water depth and recommend the height for a box sewer. All manholes must have an outgoing pipe except the system outfall pipe (i.e., Manhole 99 in this example) whose outgoing sewer has a pre-assigned ID of zero. For this example, the global Manning's roughness coefficient n = 0.013 was used, and the tailwater surface elevation was set at an elevation of 87 feet.

Table ST-11—Hydrologic Parameters at Manholes

Manhole ID Number	Ground Elevation Feet	Tributary Area acres	Runoff Coeff.	Overland Slope percent	Overland Length Feet	Gutter Slope percent	Gutter Length Feet
35.00	111.00	3.00	0.90	0.15	250.00	0.49	150.00
12.00	109.00	6.45	0.85	0.25	180.00	1.00	450.00
23.00	110.00	5.00	0.90	1.00	275.00	1.00	450.00
16.00	101.50	0.00	0.00	0.00	0.00	0.00	0.00
15.00	104.00	5.00	0.85	0.50	285.00	2.25	450.00
47.00	99.00	3.00	0.80	0.40	250.00	1.56	255.00
99.00	97.50	0.00	0.00	0.00	0.00	0.00	0.00
17.00	99.90	1.00	0.65	0.10	200.00	0.36	300.00
18.00	99.75	1.20	0.45	0.40	300.00	0.00	0.00

Table ST-12—Vertical Profile Information of Sewers

Sewer ID	Length (feet)	Slope (percent)	Upstream Crown Elevation (feet)	Diameter (inches)	Height or Rise (inches)	Width or Span (inches)	Bend Loss Coef.	Lateral Loss Coef.
3512 (round)	450.00	0.50	104.50	24			0.05	
1216 (arch)	360.00	0.80	97.05		20.00	28.00	0.05	0.25
2316	460.00	1.20	105.50				1.00	
1647 (round)	380.00	- 0.10	94.25	27			0.05	0.25
1547 (round)	295.00	1.50	101.10	18			0.40	
4799 (box)	410.00	0.25	93.32		48.00	48.00	0.05	
1747	200.00	2.00	96.80				1.00	
1847	350.00	0.75	94.00				1.00	

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For the input parameters in Tables St-11 and ST-12, Neo-UDSEWER produced the following outputs:

NeoUDS Results Summary

Project Title: CASE STUDY : EXAMPLE ONE
Project Description: STORM SEWER SYSTEM DESIGN: NEW SEWERS WITH EXISTING SEWERS
Output Created On: 8/2/2002 at 9:08:16 AM
Using NeoUDSewer Version 1.1.
Rainfall Intensity Formula **Used.**
Return Period of Flood is 5 **Years.**

A. Sub Basin Information

		Time of Concentration				
Manhole ID #	**Basin Area * C**	**Overland (Minutes)**	**Gutter (Minutes)**	**Basin (Minutes)**	**Rain I (Inch/Hour)**	**Peak Flow (CFS)**
35	2.70	12.2	0.0	0.0	3.36	9.1
12	3.83	5.0	0.0	0.0	6.33	24.2
23	4.50	13.0	0.0	0.0	3.28	14.7
16	0.00	0.0	0.0	0.0	0.00	35.6
15	4.25	14.1	0.0	0.0	3.16	13.4
47	2.40	19.1	0.0	0.0	2.72	6.5
99	1.70	17.2	0.0	0.0	2.87	4.9
17	0.65	12.8	0.0	0.0	3.30	2.1
18	0.54	11.7	0.0	0.0	3.43	1.9

The shortest design rainfall duration is 5 minutes.
For rural areas, the catchment time of concentration is always => 10 minutes.
For urban areas, the catchment time of concentration is always => 5 minutes.
At the first design point, the time constant is <= (10+Total Length/180) in minutes.
When the weighted runoff coefficient => 0.2, then the basin is considered to be urbanized.
When the Overland Tc plus the Gutter Tc does not equal the catchment Tc, the above criteria supercedes the calculated values.

B. Summary of Manhole Hydraulics

Manhole ID #	Contributing Area * C	Rainfall Duration (Minutes)	Rainfall Intensity (Inch/Hour)	Design Peak Flow (CFS)	Ground Elevation (Feet)	Water Elevation (Feet)	Comments
35	2.7	12.2	3.36	9.1	111.00	106.60	
12	6.52	9.6	3.71	24.2	109.00	105.08	
23	4.5	13.0	3.28	14.7	110.00	105.17	
16	11.02	13.4	3.23	35.6	101.50	99.61	
15	4.25	14.1	3.16	13.4	104.00	101.46	
47	18.86	15.6	3.00	56.7	99.00	91.66	
99	0	0.0	0.00	0.0	97.50	87.00	
17	0.65	12.8	3.30	2.1	99.90	95.88	
18	0.54	11.7	3.43	1.9	99.75	93.03	

C. Summary of Sewer Hydraulics

Note: The given depth to flow ratio is 1.

	Manhole ID Number			Calculated	Suggested	Existing	
Sewer ID #	Upstream	Downstream	Sewer Shape	Diameter (Rise) (Inches) (FT)	Diameter (Rise) (Inches) (FT)	Diameter (Rise) (Inches) (FT)	Width (FT)
3512	35	12	Round	19.4	21	24	N/A
1216	12	16	Arch	25.7	27	20	28
2316	23	16	Round	19.8	21	21	N/A
1647	16	47	Round	27.0	27	27	N/A
1547	15	47	Round	18.3	21	18	N/A
4799	47	99	Box	2.3	2	4	4
1747	17	47	Round	8.7	18	18	N/A
1847	18	47	Round	9.9	18	18	N/A

Round and arch sewers are measured in inches.

Box sewers are measured in feet.

Calculated diameter was determined by sewer hydraulic capacity.

Suggested diameter was rounded up to the nearest commercially available size

All hydraulics where calculated using the existing parameters.

If sewer was sized mathematically, the suggested diameter was used for hydraulic calculations.

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Sewer ID	Design Flow (CFS)	Full Flow (CFS)	Normal Depth (Feet)	Normal Velocity (FPS)	Critical Depth (Feet)	Critical Velocity (FPS)	Full Velocity (FPS)	Froude Number	Comment
3512	9.1	16.0	1.08	5.3	1.08	5.2	2.9	1	
1216	24.2	20.3	2.00	7.7	1.73	8.4	7.7	N/A	
2316	14.7	17.4	1.24	8.1	1.42	7.0	6.1	1.34	
1647	35.6	35.6	2.25	8.9	2.00	9.5	8.9	N/A	
1547	13.4	12.9	1.50	7.6	1.35	8.0	7.6	N/A	
4799	56.7	91.7	2.34	6.0	1.84	7.7	3.5	0.7	
1747	2.1	14.9	0.38	6.0	0.58	3.4	1.2	2.02	
1847	1.9	9.1	0.46	4.0	0.53	3.3	1.0	1.24	

A Froude number = 0 indicated that a pressured flow occurs.

D. Summary of Sewer Design Information

		Invert Elevation		Buried Depth		
Sewer ID	Slope %	Upstream (Feet)	Downstream (Feet)	Upstream (Feet)	Downstream (Feet)	Comment
3512	0.50	102.50	100.25	6.50	6.75	
1216	0.80	95.37	92.49	11.96	7.34	
2316	1.20	103.75	98.23	4.50	1.52	Sewer Too Shallow
1647	-0.10	92.00	92.38	7.25	4.37	
1547	1.50	99.60	95.17	2.90	2.33	
4799	0.25	89.32	88.29	5.68	5.21	
1747	2.00	95.30	91.30	3.10	6.20	
1847	0.75	92.50	89.88	5.75	7.62	

E. Summary of Hydraulic Grade Line

			Invert Elevation		Water Elevation		
Sewer ID #	Sewer Length (Feet)	Surcharged Length (Feet)	Upstream (Feet)	Downstream (Feet)	Upstream (Feet)	Downstream (Feet)	Condition
3512	450	450	102.50	100.25	106.60	105.08	Pressured
1216	360	360	95.37	92.49	105.08	99.61	Pressured
2316	460	256.58	103.75	98.23	105.17	99.61	Jump
1647	380	380	92.00	92.38	99.61	91.66	Pressured
1547	295	295	99.60	95.17	101.46	91.66	Pressured
4799	410	0	89.32	88.29	91.66	87.00	Subcritical
1747	200	0	95.30	91.30	95.88	91.66	Jump
1847	350	118.29	92.50	89.88	93.03	91.66	Jump

F. Summary of Energy Grade Line

	Upstream Manhole			Juncture Losses				Downstream Manhole	
Sewer ID #	Manhole ID #	Energy Elevation (Feet)	Sewer Friction (Feet)	Bend K Coefficient	Bend Loss (Feet)	Lateral K Coefficient	Lateral Loss (Feet)	Manhole ID #	Energy Elevation (Feet)
3512	35	106.73	0.72	0.05	0.01	0.00	0.00	12	106.00
1216	12	106.00	4.10	0.05	0.05	0.25	1.01	16	100.85
2316	23	105.94	4.51	1.00	0.58	0.00	0.00	16	100.85
1647	16	100.85	8.51	0.05	0.06	0.25	0.05	47	92.23
1547	15	102.35	9.77	0.40	0.36	0.00	0.00	47	92.23
4799	47	92.23	5.23	0.05	0.00	0.00	0.00	99	87.00
1747	17	96.06	3.81	1.00	0.02	0.00	0.00	47	92.23
1847	18	93.20	0.96	1.00	0.02	0.00	0.00	47	92.23

Bend loss = Bend K * Flowing full vhead in sewer.
Lateral loss = Outflow full vhead - Junction Loss K * Inflow full vhead.
A friction loss of 0 means it was negligible or possible error due to jump.
Friction loss includes sewer invert drop at manhole.
Notice: Vhead denotes the velocity head of the full flow condition.
A minimum junction loss of 0.05 Feet would be introduced unless Lateral K is 0.
Friction loss was estimated by backwater curve computations.

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G. Summary of Earth Excavation Volume for Cost Estimate

The user given trench side slope is 1.

Manhole ID #	Rim Elevation (Feet)	Invert Elevation (Feet)	Manhole Height (Feet)
35	111.00	102.50	8.50
12	109.00	95.37	13.63
23	110.00	103.75	6.25
16	101.50	92.00	9.50
15	104.00	99.60	4.40
47	99.00	89.32	9.68
99	97.50	88.29	9.21
17	99.90	95.30	4.60
18	99.75	92.50	7.25

	Upstream Trench Width		Downstream Trench Width				
Sewer ID #	On Ground (Feet)	At Invert (Feet)	On Ground (Feet)	At Invert (Feet)	Trench Length (Feet)	Wall Thickness (Inches)	Earth Volume (Cubic Yards)
3512	16.5	4.5	17.0	4.5	450	3.00	1347
1216	27.8	4.8	18.5	4.8	360	3.00	1981
2316	12.3	4.2	6.3	4.2	460	2.75	562
1647	18.2	4.8	12.4	4.8	380	3.25	1031
1547	8.9	3.9	7.7	3.9	295	2.50	272
4799	16.4	6.9	15.5	6.9	410	5.51	1409
1747	9.3	3.9	15.5	3.9	200	2.50	358
1847	14.6	3.9	18.3	3.9	350	2.50	988

Total earth volume for sewer trenches = 7947.8 Cubic Yards. The earth volume was estimated to have a bottom width equal to the diameter (or width) of the sewer plus two times either 1 foot for diameters less than 48 inches or 2 feet for pipes larger than 48 inches.

If the bottom width is less than the minimum width, the minimum width was used.

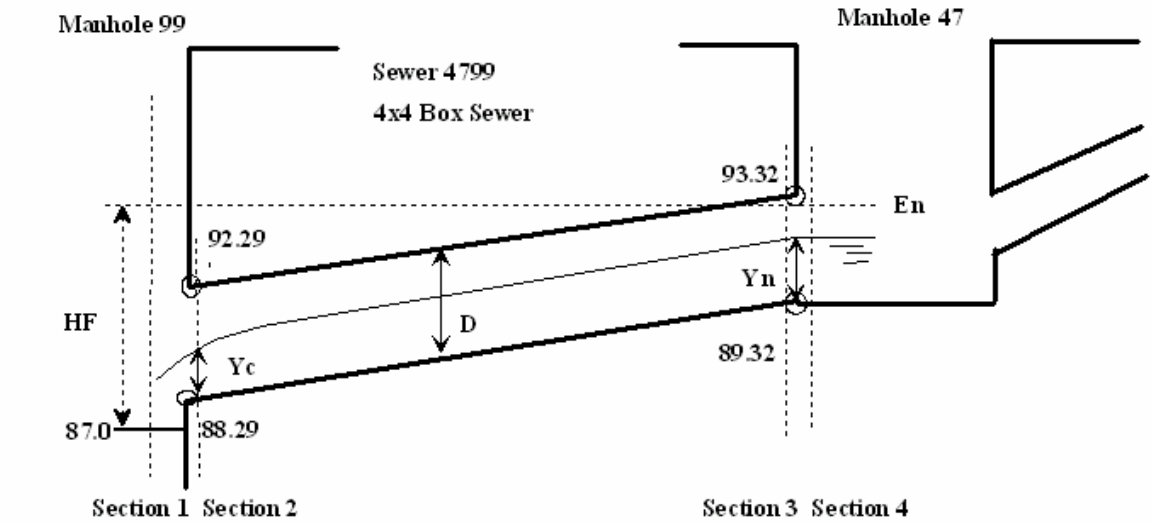
The backfill depth under the sewer was assumed to be 1 foot.

The sewer wall thickness is equal to: (equivalent diameter in inches/12)+1

The following two cases illustrate how the HGL and EGL were calculated by NeoUDSEWER:

Case 1. Energy Grade Line Calculation for Sewer 4799 in Example 6.13

The profile for Sewer 4799 is shown below:



Calculation of an EGL requires the knowledge of flow hydraulics in the sewer and in the downstream manhole. The following parameters are extracted from the NeoUDSEWER output:

Q cfs	*Yn* ft	*Vn* fps	*Ss* ft/ft	*Yc* ft	*Vc* fps	*Sc* ft/ft	*N*	*Fr*	*Ls* ft
56.70	2.34	6.04	0.25%	1.84	7.71	0.48%	0.013	0.70	410

in which:

Q = design flow

N = Manning's roughness coefficient

Fr = Froude number for normal flow

Ss = sewer slope

Ls = length of sewer

S = *energy slope*

V = flow velocity

Y = flow depth

The subscript of *n* represents the normal flow condition and *c* represents the critical flow condition.

The calculations of energy balance for this example include three ports: (A) juncture loss at the

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downstream manhole, (B) friction losses along Sewer 4799, and (C) energy balance between upstream and downstream manholes. They are conducted separately as follows:

A. Juncture Loss at Manhole 99

Manhole 99 is the system exit. There is no bend loss and lateral loss at Manhole 99. As a result, the known tailwater surface elevation of 87 feet serves for both the EGL and HGL at Manhole 99.

B. Along Sewer 4799

Sewer 4799 carries a discharge of 56.70 cfs. The water surface profile in Sewer 4799 is an M-2 curve produced by a subcritical flow with a Froude number of 0.70.

Section 1

With EGL = HGL= 87 feet at Manhole 99, the EGL and HGL at Section 1 are:

E_1 = 87 feet and W_1 = 87 feet

Section 2

With an unsubmerged condition at the sewer exit, an M-2 water surface profile is expected. Therefore, the EGL at Section 2 is dictated by the critical flow condition. Let $Y_2 = Yc$, $V_2 = Vc$. According to Equation ST-40, the EGL at Section 2 is:

$$E_2 = Max(\frac{7.71^2}{2*32.2} + 1.84 + 88.29,\ 87.0) = 91.05 \text{ feet}$$

and the HGL at Section 2 is:

W_2 = 1.82 + 88.29 = 90.13 feet

Section 3

The determination of the EGL from Section 2 to Section 3 is essentially the backwater profile calculation using the direct step method. Assuming that the flow depth at Section 3 is the normal flow depth, the energy equation is written as:

$E_c = E_n + h_f$

in which:

E_c = 92.23 feet which is the EGL of the critical flow at Section 2

E_n = 91.05 feet which is the EGL of the normal flow at Section 3

h_f = friction loss which is related to the critical energy slope, S_c

S_c = 0.0048

S_s = 0.0025 which is the normal flow energy slope

Both energy slopes can be calculated by Manning's equation. Using the direct step method, the length of the M-2 water surface profile, *X*, between the critical flow section and normal flow section is calculated as:

$$X = \frac{E_n - E_c}{0.5(S_n + S_c)} = \frac{92.23 - 91.05}{0.5(0.0025 + 0.0048)} = 322.45 \text{ feet}$$

Because the length of the M-2 curve is shorter than the length of Sewer 4799, the assumption of normal flow at Section 3 is acceptable. Therefore, the EGL and HGL at Section 3 are:

E_3 = 92.23 feet (normal flow condition)

W_3 = 2.34 + 89.23 = 91.66 feet

Section 4

Assuming that the loss at the entrance of Sewer 4799 is negligible, the EGL and HGL at Section 4 are the same as those at Section 3, namely:

E_4 = 92.23 feet

W_4 = 91.66 feet

C. Energy Balance Between Manholes.

The calculations of the EGL along Sewer 4799 and across Manhole 99 do not include manhole drop and possible losses due to hydraulic jump. Therefore, it is necessary to perform energy balancing between Manholes 47 and 99 as:

92.23 = 87.0 + H_b + H_m + H_f

H_f = 92.23 – 87.0 – 0 – 0 = 5.23 feet

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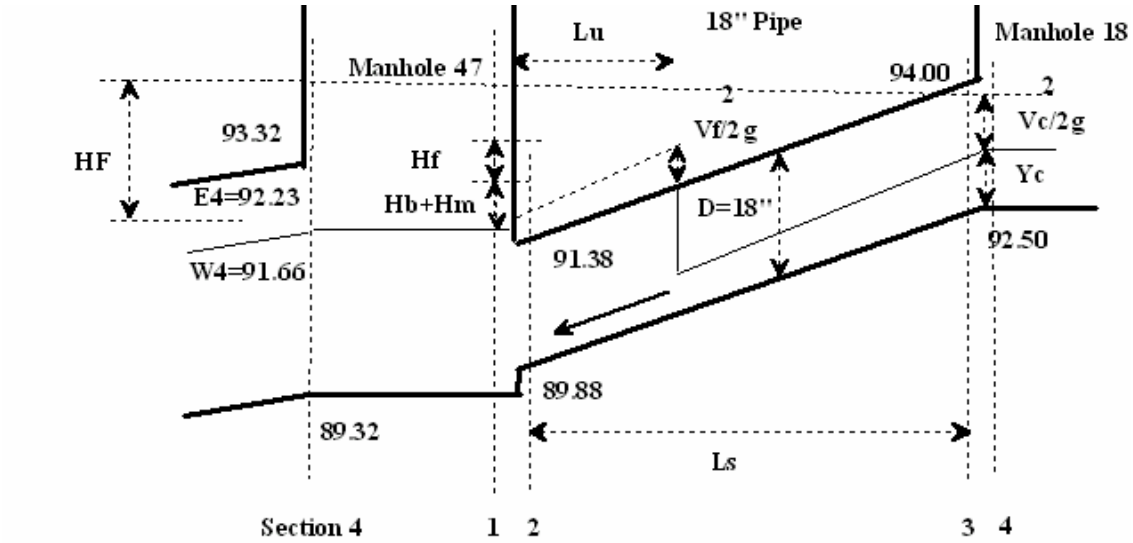
Case 2. Energy Grade Line for Sewer 1847 in Example 6.13



The flow parameters along Sewer 1847 and at Manhole 47 can be found in the NeoUDSEWER output file. They are summarized as follows:

Q	*Yn*	*Vn*	*Yc*	*Vc*	V_f	*N*	*Fr*	*Ss*	*Ls*	*Kb*
cfs	ft	fps	ft	fp	ft			ft/ft	ft	
1.85	0.46	4.05	0.53	3.33	1.05	0.01	1.05	.75%	350	1.00

in which V_f = full-flow velocity and the definitions of other flow parameters can be found in Example 12-1.

A. Juncture Loss at Manhole 47

Sewer 1847 carries a discharge of 1.85 cfs, which is a supercritical flow with a Froude number of 1.05. At Manhole 47, the EGL and HGL have been calculated as E_4 = 92.23 and W_4 = 91.66 feet.

To cross Manhole 47 (i.e., from Section 4 to Section 1) the bend loss is:

$$H_b = K_b \frac{V_f^{\,2}}{2g} = 1.0 \frac{1.05^2}{2*32.2} = 0.017 \text{ feet}$$

Because Sewer 1847 is not on the main line, it does not have a lateral loss (i.e., K_m = 0.0). Between Sections 4 and 1, the energy principle is written as:

$$E_1 = E_4 + H_b + H_m = 92.23 + 0.017 + 0 = 92.25 \text{ feet}$$

$$H_1 = E_1 - \frac{V_f^{\,2}}{2g} = 92.25 - \frac{1.05^2}{2*32.2} = 92.23 \text{ feet}$$

B. Friction Losses through Sewer 1847

Section 1

With EGL = 92.25 feet and HGL= 92.23 feet at Manhole 99, the EGL and HGL at Section 1 are:

E_1 = 92.25 feet and W_1 = 92.23 feet

The downstream end of Sewer 1847 is submerged.

Section 2

With a submerged exit, the EGL for the full-flow condition is:

$$E_F = \frac{1.05^2}{2 * 32.2} + 1.5 + 89.88 = 91.39 \text{ feet}$$

The EGL at Section 2 is chosen as the higher one between the one for the full-flow condition and the EGL at Section 1, thus:

$$E_2 = Max(E_F, E_1) = 92.25 \text{ feet}$$

and the resulting HGL at Section 2 is:

W_2 = 92.23 feet

Section 3

The lower portion of Sewer 1847 is surcharged because of the exit submergence. According to Manning's equation, the friction slope for the full flow condition in Sewer 1847 is 0.003 ft/ft. According to the direct step method, the surcharge length near the downstream end of Sewer 1847 can be approximated by W_2 and the sewer crown elevation, *Crown*, as:

$$L_u = \frac{W_2 - Crown}{(S_s - S_f)} = \frac{92.23 - 91.38}{(0.0075 - 0.003)} = 118.1 \text{ feet}$$

The friction loss through the surcharged length is:

$H_f = S_f * L_u$ = 0.003 * 118.1 = 0.35 feet

The EGL at Section 3 is controlled by either the friction loss through the surcharged length or the critical flow condition at the entrance. Considering the friction loss, we have:

$$E_{31} = E_1 + H_f = 92.25 + 0.35 = 92.6 \text{ feet}$$

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Considering the critical flow condition at the entrance, we have:

$$E_{32} = \frac{V_c^{\ 2}}{2g} + Y_c + 92.50 = 93.20 \text{ feet}$$

In comparison, the EGL at Section 3 is determined as:

$$E_3 = Max(E_{31}, E_{32}) = 93.20 \text{ feet}$$

This process is similar to the culvert hydraulics under a possible hydraulic jump. The headwater depth at the entrance of Sewer 1847 shall consider both inlet and outlet controls; whichever is higher dictates the answer. As a result, the HGL at Section 3 is:

$$W_3 = E_3 - \frac{V_c^{\ 2}}{2g} = 93.03 \text{ feet}$$

Section 4

Considering that the entrance loss is negligible for Sewer 1847, we have:

$E_4 = E_3$ and $W_4 = W_3$

C. Between Manholes 47 and 18

The energy balance between Manhole 18 and Manhole 47 is:

93.20 = 92.23 + H_b + H_m +H_f

H_f = 93.20 - 92.23 - 0.017 - 0 = 0.96 feet

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MAJOR DRAINAGE

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1.0 INTRODUCTION

1.1 General

Major drainage is the cornerstone of an urban storm runoff system. The major drainage system will exist whether or not it has been planned and designed, and whether or not urban development is wisely located in respect to it. Thus, major drainage must be given high priority when considering drainage improvements.

The major drainage system may include many features such as natural and artificial channels, culverts, long underground conduits and outfalls, streets, property line drainage easements, and others. It is closely allied to, but separate from, the initial drainage system consisting of storm sewers, curbs and gutters, swales, and minor drainageways. The two separate systems should generally be planned together. In many cases, a good major system can reduce or eliminate the need for an underground storm sewer system. An ill-conceived major system can make a storm sewer system very costly. The 2-, 5- or 10-year or other smaller runoff event can flow in the major system, but only a portion of the 100-year and larger runoff events will flow in the initial drainage system.



Photograph MD-1—An engineered wetland channel can serve as a filter for low flows and yet carry the major flood event without permanent damage.

While the primary function of a major drainageway is conveyance of runoff, many design decisions contribute to the role of the drainageway in the urban environment in terms of stability, multiple use benefits, social acceptance, aesthetics, resource management, and channel maintenance. It is important for the engineer to be involved from the very start of a land development project, so that the criteria in this *Manual* have bearing on the critical planning decisions involved in route selection for the major drainage system. The importance of route selection cannot be overstated since the route selected will influence every element of the major drainage project from the cost to the type of channel to use to the benefits derived to the community for years to come.

1.2 Types of Major Drainage Channels

The types of major drainage channels available to the designer are numerous, depending upon good hydraulic practice, environmental considerations, sociological/community impact and needs, permitting limitations, and basic project requirements. Section 3.3.1 describes in detail the following types of channels engineers can consider as potential major drainage channels in urban areas and then select the ones that address the considerations listed above the best:

- Natural channels
- Grass-lined channels
- Composite channels
- Concrete-lined channels
- Riprap-lined channels
- Bioengineered channels
- Channels with manufactured liners
- Boatable channels

As discussed in the rest of this chapter, the selection of the channel type for any given reach of a major drainageway is a complex function of hydraulic, hydrologic, structural, financial, environmental, sociological, public safety, and maintenance considerations and constraints.

1.3 Overview of Chapter

This chapter addresses the major topics related to major drainage design, beginning with essential background on the issues of major drainage planning and engineering (Section 1.4) and fluvial geomorphology (Section 1.5). Section 2.0 addresses planning for major drainage systems, including route selection and requirements for drainage master planning. General open channel hydraulics and

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preliminary design criteria are presented in Section 3.0. It is assumed that the designer is knowledgeable of open channel hydraulics, and, therefore, the key principles and equations are reviewed without extensive background of the subject matter, theoretical considerations, etc. Section 4.0 contains specific design criteria for a variety of channel types and includes example calculations, typical cross sections, and other representative design details. Sections 5.0 and 6.0 address rectangular conduits and large pipes, respectively, and Section 7.0 provides information on the use of riprap and boulders for major drainage applications. Section 8.0 addresses sediment.

1.4 Issues in Major Drainage Planning and Engineering

The planner and engineer have great opportunities when working on major channels to help provide a better urban environment for all citizens. The challenge is particularly great for those having the opportunity to plan and design works in the core areas of cities. The most fundamental function of a major drainageway is conveyance of the major storm runoff event, and an important characteristic is its stability during minor and major storms. Stability must be examined in the context of the future urbanized condition, in terms of both runoff events and altered base flow hydrology. Urbanization in the Denver metropolitan area commonly causes base flows to increase, and the planner and engineer must anticipate and design for this increase.

In addition to stability issues, there are many planning and engineering decisions that contribute to the role of the drainageway in the urban environment, in terms of multiple use benefits, social acceptance, aesthetics, and resource management. The choices of the type and layout of the major drainage system and the type of flow conveyance elements are of prime importance.

Types of major drainageways can generally be characterized as open (i.e., open channel) or closed (i.e., below-ground rectangular conduits and large pipes). Open channels for transporting major storm runoff are more desirable than underground conduits in urban areas, and use of such channels is encouraged. Open channels offer many opportunities for creation of multiple use benefits such as incorporation of parks and greenbelts along the channel and other aesthetic and recreational uses that closed-conveyance drainageway designs preclude. Channel layout affords many opportunities for creation of multiple uses in addition to the channel's fundamental function of conveyance of the major event. Photograph MD-2 illustrates some of the multiple uses/benefits of well-planned major drainageways. Open channels are also usually less costly than closed conduits and they provide a higher degree of flood routing storage.

The function of open channels does not depend on a limited number of inlet points. Getting storm flows into a closed coduit system can be problematic since blockage of inflow points can be problematic and has been observed to occur during larger runoff events. Public safety is a major concern with closed conduits and the record of life loss is well documented when individuals were swept into a conduit.

Disadvantages of open channels include higher right-of-way needs and maintenance costs; however, maintenance of failed or failing closed conduits can be much more expensive. Careful planning and design can minimize the disadvantages and increase the benefits of open channel drainageways.



Photograph MD-2—Well-planned major drainageways provide biological diversity, recreational opportunities, and aesthetic benefits in addition to flood conveyance.

The choice of the type of open channel is a critical decision in planning and design of major drainageways. The ideal channel is a stable natural one carved by nature over a long period of time that can remain stable after urbanization. The benefits of such a channel can often include any or all of the following:

1. Relatively low-flow velocities sometimes resulting in longer concentration times and lower downstream peak flows.
2. Channel storage that tends to decrease peak flows.
3. Reasonable maintenance needs when the channel is somewhat stabilized.
4. A desirable greenbelt, which can support urban wildlife and recreation, adding significant social and environmental benefits. The REVEGETATION chapter provides guidance on vegetation selection, design, planning and maintenance for wetland and upland settings along naturalized man-made or stabilized natural channels.

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5. Support of a variety of processes that preserve and/or enhance water quality, ranging from microbial activity in the bed and water column to the pollution prevention afforded by a stable channel's resistance to erosion.



Photograph MD-3—Integrating major drainageways into neighborhoods is critical for success.

Generally, the closer an artificial channel's character can be made to that of a natural channel, the more functional and attractive the artificial channel will be. In an urban area, however, it is rarely feasible to leave a natural channel untouched since urbanization alters the hydrology of the watershed. Consequently, some level of stabilization is usually necessary to prevent the channel from degrading and eroding.

Design of the major drainage system should consider the features and functions of the existing drainage system. Natural drainageways should be used for storm runoff waterways when feasible, and floodplains along drainageways should be preserved when feasible and practicable. Open channel planning and design objectives are often best met by using natural-like vegetated channels, which characteristically have slower velocities and large width-to-depth ratios. Efforts must be made to reduce peak flows and control erosion so that the natural channel regime is preserved, to the extent practical.

1.5 Fluvial Geomorphology

Any person who has witnessed the rise in stage of a river during spring snowmelt or who has observed the swelled banks of a river after an intense thunderstorm has a sense of the dynamic nature of waterways. Relatively simple hydraulic calculations can be performed to define flow conditions for a given set of specific, well-defined parameters; these techniques have been a highly effective basis of open channel design for many years. Walking along the bank of a channel, however, one quickly realizes that the actual behavior of the channel is far more complex than a simple, unchanging geometric cross section and a battery of design flow conditions. Fluvial geomorphology provides an approach to understanding the dynamic nature of a stream and the interactions between the water and the channel.

A drainage system within a watershed involves flowing water or movement of water, thus the term *fluvial.* When flowing water develops a drainage pattern or surface forms, the process is identified as *fluvial geomorphology*. Surface form characteristics represented by stream channels behave in a complex manner dependent on watershed factors such as geology, soils, ground cover, land use, topography, and hydrologic conditions. These same watershed factors contribute to the sediment eroded from the watershed and transported by the stream channel. The sediments moved by the flowing water also influence channel hydraulic characteristics. The natural-like channel and stabilization systems recommended in this *Manual* are based on fluvial geomorphology principles.

1.5.1 Stream Channel Characterization

At the start of the design process for on-site major drainageways, the designer should carefully characterize all existing channels on a reach-by-reach basis, documenting parameters including bank slope, bank cover, trees, bank line, sediment deposits, and scour areas in addition to geomorphic characteristics related to channel planform and hydraulics, such as sinuosity, riffle characteristics, cross-sectional geometry, and slope. For larger, complex channels, assistance from a specialist in stream channel behavior is recommended. Biologists can provide valuable input, as well, regarding existing wetland and upland vegetation, wildlife habitat, revegetation considerations, and other factors that indirectly relate to channel stability considerations.

Methods of channel assessment should utilize aerial photography, interviews with nearby residents, master plans, and other information available for the existing channel. Inspection of channels in areas of urbanization that, prior to development, had similar characteristics to the area planned for development can provide valuable foresight into channel changes likely to occur because of urbanization. By understanding channel behavior historically, currently, and in the future, the designer will focus on the optimal strategies for attaining channel stability. Detailed information regarding field data to collect for channel assessment is provided by Leopold (1994).

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1.5.2 Effects of Urbanization on Stream Channels

In response to urbanization, stream channels can undergo substantial changes, especially if channel stabilization measures are not instituted in the early stages of urbanization. Urbanization causes (1) significant increases in peak discharges, total runoff volume, and frequency of bank-full discharges; (2) the steepening of channel slopes if and where natural channels are straightened to accommodate new development (this practice is discouraged by the District); (3) reduction in sediment bed load from fully developed areas; and (4) eroding and degrading natural channels. These factors, in combination, create conditions that are conducive to channel instability—widening (erosion) and deepening (degradation) in most reaches and debris and sediment accumulation (aggradation) in others. Photograph MD-4 illustrates severe channel degradation in response to increased flows caused by urbanization.



Photograph MD-4—Channel degradation in an unstable channel.

To fully evaluate the proper channel morphological processes when undertaking a basic design or protective measure project, it is necessary to have some knowledge of channel stability concepts. The normal objective of channel stability evaluation is identification of principal channel hydraulic parameters influencing the stability of the channel. After identifying these parameters under existing channel conditions, the values of these parameters under future conditions are estimated. For areas undergoing urbanization, one of the most important changes is an increase in the volume, frequency, and flow rates of water in main channels. Stability analysis is then performed based on hydraulic parameters for anticipated future conditions, and stabilization measures are planned to minimize potential channel erosion under future conditions. There are a number of quantitative methods of channel stability analysis available to the designer including allowable velocity methods (Fortier and Scobey 1926), tractive force calculations, and Leopold channel configuration relationships (Leopold 1994), among others.

1.5.3 Stable Channel Balance

A stable channel is usually considered an alluvial channel in equilibrium with no significant change in channel cross section with time. This is a *dynamic equilibrium* in which the stream has adjusted its width,

depth, and slope so that the channel neither aggrades nor degrades. In this case, the sediment supply from upstream is equal to the sediment transport capacity of the channel. Under watershed conditions with normal hydrologic variations affecting runoff and sediment inflow, some adjustments in channel characteristics are inevitable.

An illustration, shown as Figure MD-1 (from USFISRWG 1998 [originally from Lane 1955a]), provides a visual depiction of a stable channel balance based on the relationship proposed by Lane (1955a) for the equilibrium concept whereby:

$$Q_w S \propto Q_s D_{50} \qquad \text{(MD-1)}$$

in which:

Q_w = water discharge (cfs)

S = channel slope (ft/ft)

Q_s = bed material load (tons/day)

D_{50} = size of bed material (mm)

For a stable channel, these four parameters are balanced, and, when one or more of the parameters changes, the others adjust to restore the state of equilibrium. For example, if the stream flow increased with no change in channel slope, there would be an adjustment on the sediment side of the balance, with an increase in either bed material size or sediment load, or both.

1.5.4 References for Additional Information

Copious information exists on fluvial geomorphology ranging from the pioneering works of Lane, Leopold, and others to more recent compendiums on channel geomorphology and stability. References that may be useful to the designer include:

- *The Importance of Fluvial Morphology in Hydraulic Engineering* (Lane 1955b).
- *Progress Report on Results of Studies on the Design of Stable Channels: A Guide for Planners, Policymakers and Citizens* (Lane 1955a).
- *A View of the River* (Leopold 1994).
- *Restoring Streams in Cities* (Riley 1998).
- *Applied River Morphology* (Rosgen 1996).
- *Stream Corridor Restoration: Principles, Processes, and Practices* (USFISRWG 1998).
- *Sedimentation Engineering* (Vanoni (ed.) 1975).

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- *Channel Rehabilitation: Process, Design, and Implementation* (Watson, Biedenharn, and Scott 1999).

Additional references can be found in the reference section of this chapter or in the extensive bibliographies of the references listed above.

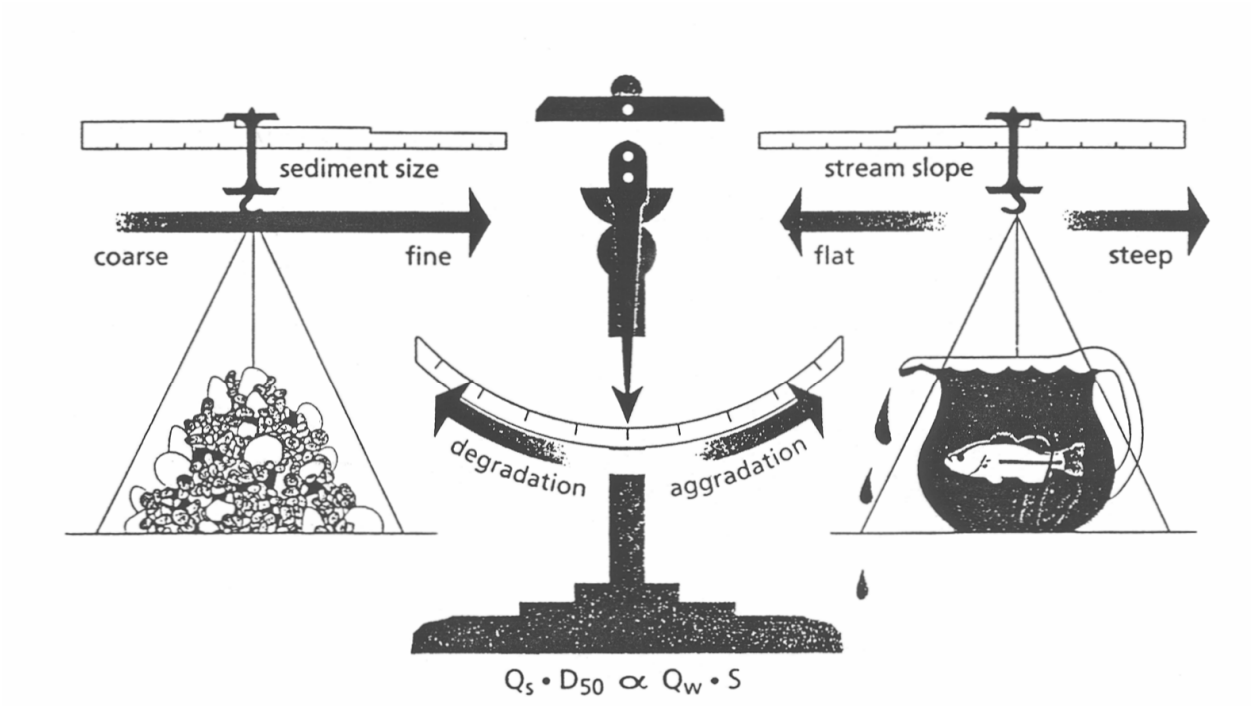

Figure MD-1—Illustration of the Stable Channel Balance Based on the Relationship Proposed by Lane (1955)

Note: This graphical interpretation of Lane's Equation was reprinted from *Applied River Hydrology*, with written permission from Mr. David Rosgen of Wildland Hydrology (and author of the book) in Pagosa Springs, Colorado.

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2.0 PLANNING

2.1 General

A major drainage system that is thoughtfully planned can provide adequate conveyance of the major runoff event in addition to other benefits to the urban area that it serves. A basic policy of the District is that the major drainage system, regardless of type, should be capable of conveying water without flooding buildings and remain relatively stable during the major runoff event (e.g., the 100-year flood). A study of the POLICY and PLANNING chapters is suggested to provide a foundation for understanding this section.

By respecting natural drainage patterns and existing floodplains in planning, appropriate major drainageway systems, including natural-like open-channel drainageways, can be created that provide flood capacity, that are stable, cost effective, and environmentally sensitive, and that offer multiple use benefits to surrounding urban areas.

2.2 Impacts of Urbanization and Associated Effects

The hallmark of urbanization is increased imperviousness. Planning of a major drainage system must account for changes in hydrology, hydraulics, and channel stability that urbanization produces. As a result, the design of the major drainage system must be based on fully urbanized conditions to assure adequate capacity for conveyance of the major (e.g., 100-year) flood event. It is also important to recognize that the higher sediment loads during the process of urbanization (during construction) may shift the channel toward an equilibrium state that is different from the desired stable channel balance for the urbanized basin.

2.3 Special Considerations for Semi-Arid Climates

Major drainage planning and design efforts along natural waterways in the Denver area must consider the region's semi-arid climate. Special considerations include:

1. Streams that have historically been ephemeral or intermittent often develop base flow because of the increased volume of water from impervious areas and infiltration of lawn and garden irrigation water, water line leakage, car-wash rinse water, and other factors. In addition, the increase in impervious area from urbanization can result in dramatic increases in the volume, discharge, and frequency of surface runoff, especially relative to base flow (if any), resulting in channel instability.

2. Availability of water for support of vegetation must be evaluated when considering types of major drainage channels utilizing vegetation including grass-lined channels, channels with wetland bottoms, and bioengineered channels. This is especially important for channel types using wetland vegetation since the high productivity of wetland plants

results in a high level of water consumption. See the REVEGETATION chapter for additional information on vegetation selection and water use.

2.4 Route Considerations

A preliminary estimate of the design rate of flow is necessary to roughly approximate the channel or conduit capacity and size. This estimate can be made by comparing to other similar watersheds where unit rates of discharge have been computed, or using the design flow rates published in master plans.

Routing of the outfall is usually a relatively straightforward matter of following the natural valley (thalweg) and defining it on a map. In many urbanized and agricultural areas, however, there is no thalweg, or the thalweg has been filled and/or built upon. For these cases, it is necessary to determine many factors before the route is chosen. Representative items to determine for routing the outfall are discussed below, many of which apply even when the thalweg is defined.

2.4.1 Present Flow Path

Fully examine topographic mapping to determine where the storm runoff would go without any further work or modification to the ground surface.

2.4.2 Historic Flow Path

Determine, by using old mapping and aerial photographs, where the water would have flowed prior to any man-made changes.

2.4.3 Permitting and Regulations

Major drainage planning and design along existing natural channels are multi-jurisdictional processes and, therefore, must comply with regulations and requirements ranging from local ordinances to federal laws. The concept of floodplain regulation recognizes, and is premised upon, governmental responsibility for administration of publicly owned rights-of-way and flood-related prescriptive easements. At the local level, floodplain management is accomplished through zoning ordinances and land use regulations and/or requirements. On a regional level, floodplain management and drainage policies are identified in the POLICY chapter of this Manual.

All construction within the 100-year floodplain must comply with the National Flood Insurance Program (NFIP) regulations. Permits for all development in the 100-year floodplain and the Special Flood Hazard Area (SFHA) must be acquired from local governments. The policy of the District is to encourage the preservation and enhancement of natural floodplains whenever feasible. Filling floodplain fringes is generally discouraged because discharge and flood stoorage capacity in the flood fringe is important and filling tends to increase water surface elevations, velocity of flow, and downstream peak flows. All filling in the floodplain fringe should be undertaken with caution and in accordance with Federal Emergency

Management Agency (FEMA) and local regulations. Modifications to the 100-year floodplain related to the major drainage system must be documented through the FEMA map revision process.

Wetland regulations and permitting issues are also relevant to the major drainage system. A permit under Section 404 of the federal Clean Water Act (CWA) is required for any activities impacting "waters of the U.S. and jurisdictional wetlands." Construction of major drainage improvements along existing natural drainageways typically requires a Section 404 permit from the U.S. Army Corps of Engineers (USACE). In addition, routine maintenance activities along established major drainage channels and in wetlands may also require a Section 404 permit. Always check with the USACE to determine if the proposed channel work or maintenance activities require a 404 permit. In addition to federal wetland regulations, construction of major drainage improvements along existing natural drainageways may be subject to the federal Endangered Species Act. Early and regular discussions and coordination with permitting authorities is encouraged from start through final mitigation activities. Refer to Section 3.3.3 for additional information on permitting.

2.4.4 Public Safety

Public safety is fundamental to the major drainage system. One purpose of the major drainage system is to protect an urban area from extensive property damage and loss of life from flooding. However, there are also "day-to-day" safety considerations in design such as the use of railings at vertical walls and avoiding vertical drops and use of steep side slopes adjacent to public trails.

2.4.5 Public Acceptance

Planning and design are of primary importance in gaining public acceptance. Public acceptance of the major drainage system depends on many factors such as public perception of flood protection, channel aesthetics, right-of-way, open space preservation, and channel maintenance. The use of open channels, especially those utilizing vegetation and other natural material and natural-like planform and morphology can create aesthetic and recreational amenities for the public and often are congruous with community open space goals. The general principle that the closer an artificial channel's character is to that of a natural channel, the better the artificial channel will be, often holds true for public acceptance, as well.

2.4.6 Alternate Routes

Choose various routes on maps and examine them in the field from engineering viewpoints. Also, determine social impacts on neighborhoods and general environmental design restraints.

2.4.7 Maintenance

Identify points of access along alternate routes based on existing and proposed roads and public rights-of-way. Adequate right-of-way is necessary to provide maintenance access for a major drainageway.

2.4.8 Route Costs

Prepare profiles of apparently satisfactory routes and make rough cost estimates of each, using

approximations as to character and location of channel or conduit. Include costs of bridges, culverts, drop structures, special structures and facilities, etc.

2.4.9 Recreational Use Potential

Identify areas with potential for recreational use. Factors to consider include proximity to residential areas, access to channel via roads and trails, areas suitable for creation of multi-use areas along channel, and location of potentially hazardous areas.

2.4.10 Environmental Considerations

Examine advantages and disadvantages of routes with an environmental design team normally consisting of an urban planner, biologist, and landscape architect, and, in some cases, an urban sociologist and drainage attorney. Include USACE regulatory personnel in these examinations to identify permitting issues that need to be addressed and to avoid 404 permitting problems later. Choose the best route based upon maximum total advantages and benefits.

2.4.11 Presentation of Choice

A meeting should be held between project sponsors and affected parties to discuss the routes studied and to select the final route. At the same time, the types of channel or conduit being considered should be presented and suggestions or concurrence should be obtained. A dialogue with citizen groups where various alternates are explained is encouraged.

2.4.12 Underground Conduits

Open channels for transporting major storm runoff are more desirable than underground conduits in urban areas because they are closer in character to natural drainageways and offer multiple use benefits. However, right-of-way constraints in urbanized areas (in the case of redevelopment, for example) may necessitate the use of underground conduits. District does not support the practice of putting major drainageways into underground conduits unless there is an overwhelming need to reduce flooding in already developed areas. The primary considerations when selecting underground conduits are public safety concerns of people being swept into them and the fact that underground conduits are extremely susceptible to having their inflow points clogged, especially when equipped with safety or trash racks. Once clogged, they fail to provide the intended flood protection. For this reason, overflow paths should be provided for to have little or no flood damage when the inlet end of a long conduit is clogged.

2.4.13 Two-Stage Channels

In some cases, it may be desirable to distribute the 100-year flow between a formal channel and the adjacent floodplain. These two-stage channels are acceptable as long as they are designed so that velocity and depth criteria stated in this chapter are satisfied for the 100-year event. Freeboard must still be provided between the 100-year water surface profile and the lowest point of building entry or first floor elevation, whichever is lower, and all applicable roadway overtopping criteria must be considered.

2.5 Layout

The approximate centerline should be laid out on topographic mapping and adjustments made for best fit. At a minimum, the following factors should be taken into consideration:

- Land form (including topography and historic and existing thalwegs)
- Right-of-way
- Curvature
- Existing or future streets
- Ability to drain adjacent land

2.5.1 Working Map

The outfall should be surveyed with adequate detail. An aerial photographic contour map with 2-foot contours at a scale of 1 inch to 50 feet or 100 feet is desirable. In the case of an outfall conduit, a centerline field survey often suffices if adequate adjacent conditions are reflected in the survey.

2.5.2 Preliminary Plan and Profile

The existing ground surface, street grades, conflicting utilities, and other pertinent data can be plotted in plan and profile. Grades should be noted and analyzed and thought should be given to hydraulic requirements. Adjustments to the centerline should be made where needed to alleviate problem areas when possible and to provide the maximum total benefits.

2.6 Master Planning or Preliminary Design

The preliminary design portion of the planning phase is second in importance only to route selection and the concept stage. Here major decisions are made as to design velocities, location of structures, means of accommodating conflicting utilities, and potential alternate uses in the case of an open channel. Decisions on the use of downstream detention storage or upstream storage also need to be made. The planning and preliminary design should include evaluation of the full spectrum of channel improvements for application in each major drainage management project.

2.6.1 Criteria for Final Hydrology

The characteristics of the outfall are defined after the master planning is underway. At this time, the final hydrological analyses should be performed for additional refinements and use as the proposed conveyance geometries can affect the peak flows in the total system.

2.7 The Master Plan

The master major drainage plan must both provide thorough attention to engineering detail and be

suitable for day-to-day use by local and regional governmental administrators. Drainage facility designers should check relevant major drainageway/outfall master plans to assure that the facilities they are designing are consistent with the intent of these master plans. The significant parts of a master plan are described below.

2.7.1 Report

The report shall include a description of the basin, the present and future ultimate development (both on-site and in the upstream drainage area), rainfall data, unit hydrograph derivations, major runoff quantities, engineering criteria used in planning, alternate plans, environmental design considerations, legal opinions, and recommendations. The ability of the major drainage system to serve the total tributary basin must be demonstrated.

2.7.2 Drawings

The drawings shall be prepared on full-size plan and profile sheets at a scale of 1 inch to 50, 100, 200, or even 400 feet, as appropriate for the plan being developed. Detail must be shown in regard to bottom elevations, the approximate hydraulic grade line, bridge and culvert opening criteria, and typical cross sections. Adequate information is needed to provide a guide to land acquisition.

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3.0 OPEN CHANNEL DESIGN PRINCIPLES

This section is intended to provide the designer with information necessary to perform open channel hydraulic analysis related to channel geometry, channel lining, and flow characteristics. This section includes preliminary design criteria and identifies considerations in selection of channel type.

3.1 General Open Channel Flow Hydraulics

Whether using a natural or constructed channel, hydraulic analyses must be performed to evaluate flow characteristics including flow regime, water surface elevations, velocities, depths, and hydraulic transitions for multiple flow conditions. Open channel flow analysis is also necessary for underground conduits to evaluate hydraulics for less-than-full conditions. Hydraulic grade lines and energy grade lines should be prepared on all design projects.

The purpose of this section is to provide the designer with an overview of open channel flow hydraulics principles and equations relevant to the design of open channels. Many excellent references address open channel hydraulics in great detail, including Chow (1959), Daugherty and Franzini (1977), and King and Brater (1963). Water surface profile computations are not addressed herein, and the reader is referred to these references for discussion of this topic.

3.1.1 Types of Flow in Open Channels

Open channel flow can be characterized in many ways. Types of flow are commonly characterized by variability with respect to time and space. The following terms are used to identify types of open channel flow:

- *Steady flow*—conditions at any point in a stream remain constant with respect to time (Daugherty and Franzini 1977).
- *Unsteady flow*—flow conditions (e.g., depth) vary with time.
- *Uniform flow*—the magnitude and direction of velocity in a stream are the same at all points in the stream at a given time (Daugherty and Franzini 1977). If a channel is uniform and resistance and gravity forces are in exact balance, the water surface will be parallel to the bottom of the channel for uniform flow.
- *Varied flow*—discharge, depth, or other characteristics of the flow change along the course of the stream. For a steady flow condition, flow is termed *rapidly varied* if these characteristics change over a short distance. If characteristics change over a longer stretch of the channel for steady flow conditions, flow is termed *gradually varied*.

For the purposes of open channel design, flow is usually considered steady and uniform. For a channel with a given roughness, discharge, and slope, there is only one possible depth for maintaining a uniform

flow. This depth is the *normal depth*. When roughness, depth, and slope are known at a channel section, there can only be one discharge for maintaining a uniform flow through the section. This discharge is the *normal discharge*.

Manning's Equation describes the relationship between channel geometry, slope, roughness, and discharge for uniform flow:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2} \qquad \text{(MD-2)}$$

in which:

Q = discharge (cfs)

n = roughness coefficient

A = area of channel cross section (ft^2)

R = hydraulic radius = Area/Wetted Perimeter, P (ft)

P = wetted perimeter (ft)

S = channel bottom slope (ft/ft)

Manning's Equation can also be expressed in terms of velocity by employing the continuity equation, $Q = VA$, as a substitution in Equation MD-2, where V is velocity (ft/sec).

For wide channels of uniform depth, where the width, b, is at least 25 times the depth, the hydraulic radius can be assumed to be equal to the depth, y, expressed in feet, and, therefore:

$$Q = \frac{1.49}{n} by^{5/3} S^{1/2} \qquad \text{(MD-3)}$$

$$y = \frac{Q^{0.6} n^{0.6}}{1.27 b^{0.6} S^{0.3}} \qquad \text{(MD-4)}$$

$$S = \frac{(Qn)^2}{2.2 b^2 y^{3.33}} \qquad \text{(MD-5)}$$

Since solution of Equation MD-2 for depth is iterative, a number of techniques are useful to quickly obtain the solution without having to perform iterations. Figure MD-2 can be used to determine normal depth graphically based on convenient dimensionless parameters. In addition, the ***UD-Channels*** spreadsheet available through the www.udfcd.org website can be used to perform normal flow calculations for trapezoidal channels and can help with the design of such channels. Example MD-1, provided at the end

of this chapter, illustrates application of this spreadsheet for finding the normal depth of a trapezoidal channel.

The designer should realize that uniform flow is more often a theoretical abstraction than an actuality (Calhoun, Compton, and Strohm 1971), namely, true uniform flow is difficult to find. Channels are sometimes designed on the assumption that they will carry uniform flow at the normal depth, but because of ignored conditions the flow actually has depths that can be considerably different. Uniform flow computation provides only an approximation of what will occur

3.1.2 Roughness Coefficients

When applying Manning's Equation, the choice of the roughness coefficient, n, is the most subjective parameter. Table MD-1 provides guidance on values of roughness coefficients to use for channel design. Both maximum and minimum roughness coefficients should be used for channel design to check for sufficient hydraulic capacity and channel lining stability, respectively. When using the retardance curves for grass-lined channels and swales, use Retardance C for finding Manning's n for finding the depth in a mature channel and Retardance D for finding the controlling velocity in a newly constructed channel.

The designer should be aware that roughness greater than that assumed will cause the same discharge to flow at a greater depth, or conversely that flow at the computed depth will result in less discharge. Obstructions in the channel will cause an increase in depth above normal depth and must be taken into account. Sediment and debris in channels increase roughness coefficients, as well, and should be accounted for.

For additional information on roughness coefficients, the reader is referred to the U.S. Geological Survey Water Supply Paper 1849 (Barnes, Jr. 1967).

3.1.3 Flow Regime

Another important characteristic of open channel flow is the state of the flow, often referred to as the flow regime. Flow regime is determined by the balance of the effects of viscosity and gravity relative to the inertia of the flow. The Froude number, F_r, is a dimensionless number that is the ratio of inertial forces to gravitational forces that defines the flow regime. The Froude number is given by:

$$F_r = \frac{V}{\sqrt{gd}} \qquad \text{(MD-6)}$$

in which:

V = mean velocity (ft/sec)

g = acceleration of gravity = 32.2 ft/sec²

d = hydraulic depth (ft) = A/T, cross-sectional area of water/width of free surface

Table MD-1—Roughness Coefficients ("*n*") for Channel Design

(After Chow 1959)

Channel Type	Roughness Coefficient (*n*)		
	Minimum	**Typical**	**Maximum**
I. Excavated or Dredged			
1. Earth, straight and uniform			
a. Gravel, uniform section, clean	0.022	0.025	0.030
b. With short grass, few weeds	0.022	0.027	0.033
2. Earth, winding and sluggish			
a. Grass, some weeds	0.025	0.030	0.033
b. Dense weeds or aquatic plants	0.030	0.035	0.040
c. Earthy bottom and rubble/riprap sides	0.028	0.030	0.035
3. Channels not maintained, weeds and brush uncut			
a. Dense weeds, high as flow depth	0.050	0.080	0.120
b. Clean bottom, brush on sides	0.040	0.050	0.080
II. Natural streams (top width at flood stage 100 ft)			
1. Streams on plain			
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Clean, winding, some pools and shoals, some weeds and stones	0.035	0.045	0.050
c. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
III. Lined or Built-Up Channels			
1. Concrete			
a. Trowel/float finish	0.011	0.015	0.016
b. Shotcrete	0.016	0.020	0.025
2. Gravel bottom with sides of:			
a. Formed concrete	0.017	0.020	0.025
b. Random stone in mortar	0.020	0.023	0.026
c. Dry rubble or riprap	0.023	0.033	0.036
3. Wetland Bottom Channels	See Figure MD-9a		
4. Grass-Lined Channels and Swales	See Figure MD-9b		

When F_r = 1.0, flow is in a *critical* state. When F_r < 1.0, flow is in a *subcritical* state. When F_r > 1.0, flow is in a *supercritical* state. The following sections describe these flow regimes and associated criteria for channel design.

The *specific energy* of flow in a channel section is defined as the energy per pound of water measured with respect to the channel bottom. Specific energy, E (expressed as head in feet), is given by:

$$E = y + \frac{V^2}{2g} = y + \frac{Q^2}{2gA^2} \qquad \text{(MD-7)}$$

in which:

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y = depth (ft)

V = mean velocity (ft/sec)

g = acceleration of gravity = 32.2 ft/sec^2

Q = discharge (cfs)

A = area of channel cross section (ft^2)

For all subcritical channels, check the Froude number using the *minimum* value of n. When performing hydraulic computations for grassed channels, the n values for the 0.1-foot to 1.5-feet flow depth range are generally suitable for calculating the wetted channel portion for the initial storm runoff. For major runoff computations, however, the greater than 3.0-feet depth values are more appropriate since flows will tend to lay the grass down to form a smoother bottom surface.

3.1.3.1 Critical Flow

Critical flow in an open channel or covered conduit with a free water surface is characterized by several conditions (Fletcher and Grace 1972):

1. The specific energy is a minimum for a given discharge.
2. The discharge is a maximum for a given specific energy.
3. The specific force is a minimum for a given discharge.
4. The velocity head is equal to half the hydraulic depth in a channel of small slope.
5. The Froude number is equal to 1.0 (see Equation MD-6.)
6. The velocity of flow in a channel of small slope is equal to the celerity of small gravity waves in shallow water.

If the critical state of flow exists throughout an entire reach, the channel flow is critical flow, and the channel slope is at critical slope, S_{cr}. A slope less than S_{cr} will cause subcritical flow, and a slope greater than S_{cr} will cause supercritical flow. A flow at or near the critical state may not be stable. In design, if the depth is found to be at or near critical, the shape or slope should be changed to achieve greater hydraulic stability.

To simplify the computation of critical flow, dimensionless curves have been given for rectangular, trapezoidal, and circular channels in Figure MD-3. Critical velocity, V_c, can be calculated from the critical hydraulic depth, d_c. For a rectangular channel, the flow depth is equal to hydraulic depth, ($y_c = d_c$), and the critical flow velocity is:

$$V_c = \sqrt{gy_c} \qquad \text{(MD-8)}$$

In addition, the **Critical** worksheet from the UD-Channels Spreadsheet performs critical depth calculations.

3.1.3.2 Subcritical Flow

Flows with a Froude number less than 1.0 are *subcritical* flows and have the following characteristics relative to critical flows (Maricopa County 2000):

1. Flow velocity is lower.
2. Flow depth is greater.
3. Hydraulic losses are lower.
4. Erosive power is less.
5. Behavior is easily described by relatively simple mathematical equations.
6. Surface waves can propagate upstream.

Most stable natural channels have *subcritical* flow regimes. Consistent with the District's philosophy that the most successful artificial channels utilize characteristics of stable natural channels, major drainage design should seek to create channels with *subcritical* flow regimes.

A concrete-lined channel should not be used for subcritical flows except in unusual circumstances where a narrow right-of-way exists. A stabilized natural channel, a wide grass-lined channel, a channel with a wetland bottom, or a bioengineered channel is normally preferable in the Denver region. Do not design a subcritical channel for a Froude number greater than 0.8 using the velocity and depth calculated with the lowest recommended range for Manning's n. When designing a concrete-lined channel for subcritical flow, use a Manning's n = 0.013 for capacity calculations and 0.011 to check whether the flow could go supercritical. If significant sediment deposition or sediment transport is likely, a Manning's n greater than 0.013 may be necessary for capacity calculations.

3.1.3.3 Supercritical Flow

Flows with a Froude number greater than 1.0 are supercritical flows and have the following characteristics relative to critical flows (Maricopa County 2000):

1. Flows have higher velocities.
2. Depth of flow is shallower.
3. Hydraulic losses are higher.
4. Erosive power is greater.
5. Surface waves propagate downstream only.

Supercritical flow in an open channel in an urban area creates hazards that the designer must consider.

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From a practical standpoint, it is generally not practical to have curvature in such a channel. Careful attention must be taken to prevent excessive oscillatory waves, which can extend down the entire length of the channel from only minor obstructions upstream. Imperfections at joints can cause rapid deterioration of the joints, which may cause a complete failure of the channel. In addition, high velocity flow at cracks or joints creates an uplift force by creating zones of flow separation with negative pressures and converts the velocity head to pressure head under the liner which can virtually tear out concrete slabs. It is evident that when designing a lined channel with supercritical flow, the designer must use utmost care and consider all relevant factors.

In the Denver region, all channels carrying supercritical flow shall be lined with continuously reinforced concrete linings, both longitudinally and laterally. There shall be no diminution of wetted area cross section at bridges or culverts. Freeboard shall be adequate to provide a suitable safety margin. Bridges or other structures crossing the channel must be anchored satisfactorily to withstand the full dynamic load that might be imposed upon the structure in the event of major trash plugging.

The concrete linings must be protected from hydrostatic uplift forces that are often created by a high water table or momentary inflow behind the lining from localized flooding. A perforated underdrain pipe, designed to be free draining, is required under the lining. For supercritical flow, minor downstream obstructions do not create any backwater effect. Backwater computation methods are applicable for computing the water surface profile or the energy gradient in channels having a supercritical flow; however, the computations must proceed in a downstream direction. The designer must take care to prevent the possibility of unanticipated hydraulic jumps forming in the channel. Flows at Froude numbers between 0.8 and 1.2 are unstable and unpredictable and should be avoided.

Roughness coefficients for lined channels are particularly important when dealing with supercritical flow. Once a particular roughness coefficient is chosen, the construction inspection must be carried out in a manner to insure that the particular roughness is obtained. Because of field construction limitations, the designer should use a Manning's n roughness coefficient equal to 0.013 for a wel-trowelled concrete finish. Other finishes should have proportionately larger n values assigned to them.

3.2 Preliminary Design Criteria

3.2.1 Design Velocity

Minimum and maximum velocities must be considered in the design of major drainage systems. From structural and stability standpoints, maximum velocities are of concern; however, minimum velocities should also be considered in design with respect to sediment accumulation and channel maintenance. For channels with high velocity flows, drop structures, suitable channel lining, check dams or other velocity controls will be necessary to control erosion and maintain channel stability. *Subcritical* flow is desirable since the velocity for *subcritical* flow is less than that of critical or *supercritical* flow for a given

discharge. Froude number criteria also restrict velocity.

The flow velocity during the major design storm (i.e., 100-year) must recognize the scour potential of the channel, whether natural, grassed, bioengineered, riprapped or concrete-lined. Average velocities need to be determined using backwater calculations, which account for water drawdowns at drops, expansions, contractions and other structural controls. Velocities must be kept sufficiently low to prevent excessive erosion in the channel. As preliminary design criteria, flow velocities should not exceed velocities and Froude numbers given in Table MD-2 for non-reinforced channel linings and, in general, should not exceed 18 ft/sec for reinforced channel linings. Channel-specific velocity criteria depend greatly on the channel lining and slope and are presented in more detail in Section 4.0 of this chapter for various types of open channels.

For estimating maximum velocities for erosive or hazard considerations or localized scour in a channel, relying only upon the HEC-2 or HEC-RAS (USACE 1991, 1995) outputs for the cross section is not acceptable. Instead, more detailed hydraulic analysis of the specific cross section, which accounts for variable velocities across the channel, is necessary.

3.2.2 Design Depths

The maximum design depths of flow should also recognize the scour potential of the channel lining and the bank materials. Scouring power of water increases in proportion to the third to fifth power of flow depth and is also a function of the length of time flow is occurring (USBR 1984). As criteria, the design depth of flow for the major storm runoff flow during a 100-year flood should not exceed 5.0 feet in areas of the channel cross section outside the low-flow channel area, and less depth is desirable for channel stability. Low-flow channel depth should be between 3.0 and 5.0 feet.

3.2.3 Design Slopes

3.2.3.1 Channel Slope

The slope of a channel affects flow velocity, depth, and regime and can have a significant impact on erosion and channel stability. Channel slope criteria vary based on the type of channel; however, the slope of a channel should not be so steep as to result in a Froude number greater than 0.5 or 0.8, depending on soil erodibility characteristics (see Table MD-2), for the 100-year event. Slopes for channels with vegetative linings should not exceed 0.6% and should be less than 1% for channels with reinforced concrete linings. For steep-gradient drainageways, drop structures are necessary to meet slope criteria. An important consideration in channel slope is sinuosity of the channel—straightening of a natural channel inevitably results in an increase in slope. Conversely, for a constructed channel, a design incorporating meanders can be used to satisfy slope criteria, potentially reducing the number of drop structures required.

3.2.3.2 Side Slopes

The flatter the side slopes, the more stable are the banks. For grassed channels, channels with wetland bottoms, and bioengineered channels, side slopes should not be steeper than 4H:1V. Under special conditions in areas of existing development (i.e., not new development) and where right-of-way is a problem, the slopes may be as steep as 3H:1V; however, the designer is cautioned that operation of mowing equipment may not be safe on side slopes that are steeper than 4H:1V. Channels that require minimal slope maintenance such as concrete channels may have side slopes as steep as 1.5H:1V, although public safety issues must be taken into account. For riprap-lined channels, side slopes should not be steeper than 2.5H:1V.

For vegetated channels with underlying riprap, slopes must accommodate maintenance. For example, a grassed channel with underlying riprap should have side slopes no steeper than 4H:1V, as required for a grassed channel.

Local standards or conditions may require flatter side slopes. Side slopes steeper than 3H:1V are not recommended in residential areas or areas with frequent foot traffic. Fencing or railings may need to be considered if side slopes will be steeper than 3H:1V in these areas.

3.2.4 Curvature and Transitions

Generally, the gentler the curves, the better the channel will function. Channel alignments should not be selected to maximize land-use opportunities for lot layout; instead, lot layouts should be selected based on channel alignment. The centerline curvature of the channel shall have a radius of at least twice the top width of the 100-year flow channel. The exception to this axiom is for concrete channels that may experience *supercritical* flow conditions. From a practical standpoint, it is generally not advisable to have any curvature in a channel conveying *supercritical* flow, since minor perturbations can be amplified as they move downstream.

Superelevation must also be considered with respect to curvature. Curves in a channel cause the flow velocity to be greater on the outside of the curve, and the depth of flow is also greater on the outside of a curve due to centrifugal force. This rise in water surface on the outside of a curve is referred to as superelevation. For *subcritical* flows, superelevation can be estimated by:

$$\Delta y = \frac{V^2 T}{2 g r_c} \qquad \text{(MD-9)}$$

in which:

Δy = increase in water surface elevation above average elevation due to superelevation (ft)

V = mean flow velocity (ft/sec)

T = top width of the channel under design flow conditions (ft)

g = gravitational constant = 32.2 ft/sec^2

r_c = radius of curvature (ft)

Transitions (expansions and contractions) are addressed in Section 4.4 (riprap-lined channels) and in Section 5.0 of the HYDRAULIC STRUCTURES chapter.

3.2.5 Design Discharge Freeboard

Residual discharge freeboard is necessary to ensure that a design developed using idealized equations will perform as desired under actual conditions. The amount of residual freeboard that must be allowed depends on the type of channel and the location and elevation of structures adjacent to the channel. Preserving existing floodplains maximizes "natural" freeboard. Freeboard requirements are addressed for a number of specific channel types in Section 4.0 of this chapter; however, in general, a minimum residual freeboard of 1 to 2 feet should be allowed between the water surface and top of bank.

3.2.6 Erosion Control

Erosion control pertains to major drainage channels on the watershed scale as well as the drainage corridor scale. On the watershed scale, erosion and sediment control is critical in areas of urbanization, especially active construction areas, to prevent loading of initial and major drainageways with excessive sediment from disturbed areas in the watershed. Poor control of erosion on the watershed scale can result in increased maintenance and decreased capacity of major drainageways. Watershed erosion and sediment control is beyond the scope of this *Manual* but is regulated at the federal, state, regional, and local levels. In the State of Colorado, the Colorado Department of Public Health and Environment administers the National Pollutant Discharge Elimination System (NPDES) of the CWA, which requires stormwater management measures including erosion and sediment controls for construction sites larger than 1 acre under the Stormwater Permitting Regulations. In addition, most localities in Colorado require erosion and sediment control measures for construction sites.

For major drainage channels, protection against erosion is key to maintaining channel stability. Unless hard-lined and vigilantly maintained, most major drainage channels are susceptible to at least some degree of erosion. The concave outer banks of stream bends are especially susceptible to erosion and may require armoring with riprap for grassed, bioengineered, or wetland bottom channels. While high sediment loads to a channel may occur as a result of active construction in the watershed, once an area is fully urbanized, the channel behavior changes. Flows increase significantly due to the increase in imperviousness in the watershed, and the runoff from these fully urbanized areas contains relatively low levels of sediment. As a result, the potential for erosion in the channel increases.

In the Denver area, most waterways will need the construction of drops and/or erosion cutoff check structures to control the channel slope. Typically, these grade control structures are spaced to limit channel degradation to what is expected to be the final stable longitudinal slope after full urbanization of

the tributary watershed. The designer should also be aware of the erosion potential created by constriction and poorly vegetated areas. An example is a bridge crossing over a grassed major drainage channel, where velocities increase as a result of the constriction created by the bridge, and bank cover is poor due to the inability of grass to grow in the shade of the bridge. In such a situation, structural stabilization, such as riprap, may be needed.

Another aspect of erosion control for major drainage channels is controlling erosion during and after construction of channel improvements. Construction of channel improvements during times in the year that are typically dryer can reduce the risk of erosion from storm runoff. Temporary stabilization measures including seeding and mulching and erosion controls such as installation and maintenance of silt fencing should be used during construction of major drainage improvements to minimize erosion.

3.2.7 Summary of Preliminary Design Guidance

Table MD-2 summarizes the guidance for the preliminary design of man-made channels discussed above. This guidance is for simple trapezoidal shapes to approximate alignment and geometry. Final design of man-made channels of a more complex nature will be discussed in Section 4.0.

Table MD-2—Trapezoidal Channel Design Guidance/Criteria

Design Item	Major Drainage Chapter Section	Criteria for Various Types of Channel Lining			
		Grass: Erosive Soils	Grass: Erosion Resistant Soils	Riprap	Concrete
Maximum 100-yr velocity	3.2.1	5.0 ft/sec	7.0 ft/sec	12.0 ft/sec	18.0 ft/sec
Minimum Manning's *n*—stability check	Table MD-3	0.03	0.03	0.03	0.011
Maximum Manning's *n*—capacity check	Table MD-3	0.035	0.035	0.04	0.013
Maximum Froude number	3.2.1	0.5	0.8	0.8	N/A
Maximum depth outside low-flow zone	3.2.2	5.0 ft	5.0 ft	n/a	N/A
Maximum channel longitudinal slope	3.2.3.1	0.6%	0.6%	1.0%	N/A
Maximum side slope	3.2.3.2	4H:1V	4H:1V	2.5H:1V	1.5H:1V [4]
Minimum centerline radius for a bend	3.2.4	2 x top width	2 x top width	2 x top width	2 x top width
Minimum freeboard [3]	3.2.5	1.0 ft [1]	1.0 ft [1]	2.0 ft [1]	2.0 ft [2]

[1] Suggested freeboard is 2.0 ft to the lowest adjacent habitable structure's lowest floor.

[2] For supercritical channels, use the freeboard recommended in Section 4.3.1.5 for final design.

[3] Add superelevation to the normal water surface to set freeboard at bends.

[4] Side slopes may be steeper if designed as a structurally reinforced wall to withstand soil and groundwater forces.

3.2.8 Maintenance Eligibility

The minimum design criteria requirements below must be satisfied as of June 2001 for a major drainage channel to be eligible for District maintenance assistance. Note that the District's *Maintenance Eligibility Guidelines* may change with time. The reader is directed to the District's Web site (www.UDFCD.org) for

the latest version of the *Maintenance Elegibility Guidelines*.

3.2.8.1 Natural Channels (Open Floodplain Design)

When a developer chooses to stay out of the 100-year floodplain, the following requirements must be met:

1. If the total flow of the channel and floodplain is confined to an incised channel and erosion can be expected to endanger adjacent structures, 100-year check structures are required to control erosion and degradation of the channel area. See the HYDRAULIC STRUCTURES chapter of this *Manual* for more information. In addition, sufficient right-of-way shall be reserved to install the equivalent of a trapezoidal grass-lined channel that satisfies the velocity criteria specified in Table MD-2. Extra width shall be reserved where drop structures are needed, in which locations a 20-foot-wide maintenance access bench shall be provided along one side of the channel.

2. If the floodplain is wide and the low-flow channel represents a small portion of the floodplain area, low-flow check structures are usually required, unless it can be demonstrated that the channel will remain stable as the watershed urbanizes.

3. Consult the applicable Urban Drainage and Flood Control District's master plan document for guidance on the design event and stable steam or waterway longitudinal slope.

4. For either of the above cases, a maintenance access trail shall be provided. It should be designed according to the guidelines for grass-lined channels in Section 3.2.8.3, below.

3.2.8.2 Open Floodway Design (Natural Channel With Floodplain Encroachment)

Although floodplain preservation is preferable, when the design involves preserving the floodway while filling and building on the fringe area, the developer must meet the requirements in Section 3.2.8.1, and the fill slopes must be adequately protected against erosion with:

1. Fill slopes of 4H:1V or flatter that are vegetated according to the criteria in the REVEGETATION chapter.

2. Fill slopes protected by rock (not broken concrete or asphalt) riprap meeting District criteria with up to 2.5H:1V slopes.

3. Retaining walls, no taller than 3.5 feet, with adequate foundation protection.

3.2.8.3 Grass-Lined Channel Design

The design for a grass-lined channel must meet the following criteria to be eligible for District maintenance:

1. Side slopes should be 4H:1V or flatter.

2. Continuous maintenance access, such as with a trail, must be provided. The stabilized trail surface must be at least 8 feet wide with a clear width of 12 feet. It shall be located above the minor event water surface elevation (usually 2- to 10-year event, as directed by local government), but never less than 2-feet (3-feet for streams with perennial flow). Trail profiles need to be shown for all critical facilities such as roadway crossings, stream crossings and drop structures. All access trails shall connect to public streets. Maintenance trials need not be paved, but must be of all-weather construction such as aggregate base course, crusher fines, recycled concrete course or Aggregate Turf Reinforced Grass Pavement (RGP) described in Volume 3 of this *Manual* and capable of sustaining loads associated with large maintenance equipment. Paved trails are encouraged to allow for recreational use of the trails. When paved, pavement should be 5-inches minimum thickness of concrete (not asphalt). Maximum longitudinal slope for maintenance-only trails is 10%, but less than 5% when used as multi-purpose recreational trails to meet the requirements of the *Americans with Disabilities Act*. The District may accept adjacent public local streets or parking lots in lieu of a trail.

3. A low-flow or trickle channel is desirable. See Section 4.1.5 of this chapter for criteria.

4. Wetland bottom and bioengineered channels are acceptable when designed according to District wetland bottom channel criteria in Section 4.2 of this chapter.

5. The channel bottom minimum cross slope for dry bottom channels shall be 1%.

6. Tributary inflow points shall be protected all the way to the low-flow channel or trickle channel to prevent erosion. Inflow facilities to wetland bottom channels shall have their inverts at least 2 feet above the channel bottom to allow for the deposition of sediment and shall be protected with energy dissipaters.

7. All roadway crossings of wetland bottom channels shall incorporate a minimum of a stblized 2-foot drop from the outlet to the bottom of the downstream channel in order to preserve hydraulic capacity as sediment deposition occurs ovcer time in the channel.

8. All drop structures shall be designed in accordance with the HYDRAULIC STRUCTURES chapter of this *Manual*. Underdrain and storm sewer outlets located below the stilling basin's end sills are not acceptable. Construction plans shall utilize District standard details.

9. Storm sewer outlets shall be designed in accordance with the criteria in Sections 5.0, 6.0, and 7.0 of this chapter. Alternatively, conduit outlet sstructures, including low tailwater riprap basins design described in Section 3.0 of the HYDRAULIC STRUCTURES chapter of the *Manual* shall be used when appropriate.

10. Grouted boulder rundowns and similar features shall be designed in accordance with Section 7.0

of the HYDRAULIC STRUCTURES chapter of the *Manual*.

11. Grass seeding specifications provided by the District (see the REVEGETATION chapter of this *Manual*) are recommended unless irrigated blue grass is used. The District will not maintain irrigated blue grass (due to cost constraints), but other elements of such a channel (i.e., drop structures, trickle channel) can still qualify for maintenance eligibility.

3.3 Choice of Channel Type and Alignment

3.3.1 Types of Channels for Major Drainageways

The types of major drainage channels available to the designer are almost infinite, depending only upon good hydraulic practice, environmental design, sociological impact, and basic project requirements. However, from a practical standpoint, it is useful to identify general types of channels that can be used by the designer as starting points in the design process. The following types of channels may serve as major drainage channels for the 100-year runoff event in urban areas:

Natural Channels—Natural channels are drainageways carved or shaped by nature before urbanization occurs. They often, but not always, have mild slopes and are reasonably stable. As the channel's tributary watershed urbanizes, natural channels often experience erosion and degrade. As a result, they require grade control checks and stabilization measures. Photograph MD-5 shows a natural channel serving as a major drainageway for an urbanized area.



Photograph MD-5—Natural channel (open floodplain design) serving as a major drainageway. Note the preservation of riparian vegetation, absence of floodplain encroachment and the use of grade control structures to arrest thalweg downcutting (i.e., channel incising/degradation)

Grass-Lined Channels—Among various types of constructed or modified drainageways, grass-lined channels are some of the most frequently used and desirable channel types. They provide channel storage, lower velocities, and various multiple use benefits. Grass-lined channels in urbanizing watersheds should be stabilized with grade control structures to prevent downcutting, depression of the water table, and degradation of natural vegetation. Low-flow areas may need to be armored or otherwise stabilized to guard against erosion. Photograph MD-6 shows a grass-lined major drainage channel.



Photograph MD-6—Engineered grass-lined major drainageway with low-flow channel with bioengineered components integrated into the design.

Composite Channels—Composite channels have a distinct low-flow channel that is vegetated with a mixture of wetland and riparian species. A monoculture of vegetation should be avoided. In composite channels, dry weather (base) flows are encouraged to meander from one side of the low-flow channel to the other. The low-flow channel banks need heavy-duty biostabilization that includes rock lining to protect against undermining and bank erosion. Photograph MD-6 shows a composite channel.

Concrete-Lined Channels—Concrete-lined channels are high velocity artificial drainageways that are not recommended for use in urban areas. However, in retrofit situations where existing flooding problems need to be solved and where right-of-way is limited, concrete channels may offer advantages over other types of open drainageways. A concrete-lined channel is shown in Photograph MD-8.



Photograph MD-7—Composite channel.



Photograph MD-8—Concrete-lined channel.

Riprap-Lined Channels—Riprap-lined channels offer a compromise between grass-lined channels and concrete-lined channels. Riprap-lined channels can somewhat reduce right-of-way needs relative to grass-lined channels and can handle higher velocities and greater depths than grass-lined channels. Relative to concrete-lined channels, velocities in riprap-lined channels are generally not as high. Riprap-lined channels are more difficult to keep clean and maintain than other types of channels and are recommended for consideration only in retrofit situations where existing urban flooding problems are being addressed. Riprap may also be useful for bank line protection along sections of channels susceptible to erosion such as outer banks of bends. Photograph MD-9 shows a riprap-lined major drainage channel.



Photograph MD-9—Riprap channel. Burying and revegetation of the rock (i.e., soil riprap) could make this site blend into the adjacent terrain very nicely.

Bioengineered Channels—Bioengineered channels utilize vegetative components and other natural materials in combination with structural measures to stabilize existing channels in existing urban areas, area undergoing urbanization and to construct natural-like channels that are stable and resistant to erosion. Bioengineered channels provide channel storage, slower velocities, and various multiple use benefits. Photographs MD-10 and 11 show examples of bioengineered major drainage channels. Wetland bottom channels are an example of one type of bioengineered channel.



Photograph MD-10—Bioengineered major drainage channel using low-grade control structure provides long-term structural integrity and diverse ecology.



Photograph MD-11—Bioengineered major drainageway with dense and diverse vegetation and energy dissipator.

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Channels with Manufactured Liners—A variety of artificial channel liners are on the market, intended to protect the channel banks and bottom from erosion at higher velocities. These include gabions, interlocked concrete blocks, concrete revetment mats formed by injecting concrete into double layer fabric forms, and various types of synthetic fiber liners. All of these types are best considered for helping to solve existing urban flooding problems and are not recommended for new developments. Each type of channel lining has to be scrutinized for its merits, applicability, ability to meet other community needs, long term integrity, maintenance needs and maintenance costs.

Boatable Channels—Larger, natural, perennial waterways such as the South Platte River, Clear Creek, and Boulder Creek in the Denver metropolitan area are regularly used for boating and, because of their size and capacity, are subject to more comprehensive hydraulic analyses and considerations. Unless there is evidence of erosion, suitable natural armoring of the channel should not be disturbed; however, boater-friendly drop structures and diversion structures are often necessary. Refer to the discussion on boatable channels in the HYDRAULIC STRUCTURES chapter of this *Manual*.

3.3.2 Factors to Consider in Selection of Channel Type and Alignment

The choice of channel type and alignment must be based upon a variety of multi-disciplinary factors and complex considerations that include, among others:

Hydraulic Considerations

- Slope of thalweg
- Right-of-way
- Capacity needs
- Basin sediment yield
- Topography
- Ability to drain adjacent lands

Structural Considerations

- Cost
- Availability of material
- Areas for wasting fill
- Seepage and uplift forces
- Shear stresses
- Pressures and pressure fluctuations
- Momentum transfer

Environmental Considerations

- Neighborhood character
- Neighborhood aesthetic requirements
- Street and traffic patterns
- Municipal or county policies
- Need for new green areas
- Wetland mitigation
- Character of existing channel
- Wildlife habitat
- Water quality enhancement

Sociological Considerations

- Neighborhood social patterns
- Neighborhood children population
- Public safety of proposed facilities for storm and non-storm conditions
- Pedestrian traffic
- Recreational needs
- Right-of-way corridor needs

Maintenance Considerations

- Life expectancy
- Repair and reconstruction needs
- Maintainability
- Proven performance
- Accessibility
- Regulatory constraints to maintenance

Prior to choosing the channel type, the planner should consult with experts in related fields in order to choose the channel that will create the greatest overall benefits. Whenever practical, the channel should have slow flow characteristics, be wide and shallow, and be natural in its appearance and functioning (Bohan 1970).

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3.3.3 Environmental Permitting Issues

Environmental permitting, in particular wetland permitting, must be considered in selection of the type of major drainage channel. To assist with the selection of type of channel or drainageway improvements to be used, a flow chart is presented in Figure MD-4. The flow chart contains a series of questions to be considered in light of the requirements in this *Manual* and the requirements of the CWA, Section 404 (dredge and fill in jurisdictional wetlands and "Waters of the United States").

Following along with the chart, the first step is to determine whether channelization is needed or desired. In many cases, a well-established natural drainageway and its associated floodplain can be preserved and protected from erosion damage. Therefore, before deciding to channelize, assess whether the value of reclaimed lands will justify the cost of channelization and whether a new channel will provide greater community and environmental benefits than the existing drainageway.

If the decision is to neither channelize nor re-channelize an existing drainageway, investigate the stability of the natural drainageway and its banks, design measures to stabilize the longitudinal grade and banks, if needed, in selected areas, and obtain, if necessary, Section 404 permits and other approvals for these improvements. However, it is suggested that the reader review the latest Maintenance Eligibility Guidelines available at the District's Web site before deciding what improvements to natural channels are needed to qualify for the District's maintenance eligibility.

If the decision is to channelize, then determine whether the existing natural drainageway has a perennial flow, evidence of wetland vegetation, or is a well-established ephemeral channel. This will often require the assistance of a biologist with wetland training. If any of these conditions exist, then the project is likely to be subject to individual or nationwide Section 404 permitting requirements. Regardless, it is suggest that the designer check with the local USACE office early to determine which permit will be needed. Keep in mind that it is the responsibility of the proponent to comply with all applicable federal and state laws and regulations. Approvals by the local authorities do not supercede or waive compliance with these federal laws.

3.3.4 Maintenance

All major drainage channels in urban areas will require maintenance to ensure that they are capable of conveying their design flow, such as the 100-year flow (as well as more frequently occurring flows) and to ensure that channels do not become a public nuisance and eyesore. Routine maintenance (i.e., mowing for weed control or annual or seasonal clean-outs), unscheduled maintenance (i.e., inspection and clean-out after large events) and restorative maintenance after some years of operation should be expected.

Native tall grasses may require mowing three to six times a year or on a less frequent schedule, depending on the type of channel and setting. Mowing cuts down the presence of "standing dead" grasses and place them on the ground where decomposition can take place. Often mowing of dry-land

native grasses during the growing season may not be necessary, except for weed control.

A maintenance access platform with a minimum passage width of 12 feet shall be provided along the entire length of all major drainageways except at drop structures, where a 20 foot maintenance platform is needed. The local government may require the road to be surfaced with 6-inches of Class 2 road base or a 5-inch-thick concrete slab.

Channels may be eligible for District maintenance assistance if they are designed and constructed in accordance with the criteria in this *Manual*, are under some form of public ownership, and meet the District Maintenance Eligibility Guidelines that are stated in Section 3.2.8 of this chapter (see District Web site for periodic updates).

3.4 Design Flows

The major drainage system, including residual floodplain, must be able to convey the flow from a fully urbanized watershed for the event with a 100-year recurrence interval without significant damage to the system. Methods for calculating this flow are described in the RAINFALL and RUNOFF chapters of this *Manual*. In addition to consideration of the 100-year event, the designer must also consider events of lesser magnitudes. For the low-flow channel, ⅓ to ½ of the 2-year flow for fully developed conditions, assuming no upstream detention, is recommended for design. Base flow must also be assessed, especially for grassed channels, channels with wetland bottoms, and bioengineered channels. Base flows are best estimated by examining already-urbanized watersheds that are similar to the planned urban area in terms of imperviousness, land use, and hydrology.

3.5 Choice of Channel Lining

Where the project requires a waterway for storm runoff to be lined because of either hydraulic, topographic, or right-of-way needs, there are a number of choices for linings including grass and other types of vegetation (see the REVEGETATION chapter), other natural materials, riprap, concrete, and manufactured lining materials. The major criterion for choosing a lining is that the lining selected must be designed to withstand the various forces and actions that tend to overtop the bank, damage the lining, and erode unlined areas.

Natural-like channel linings are encouraged; however, in some situations where right-of-way is limited within the constraints of an already-urbanized area, hard-lined channels (i.e., riprap or concrete) may be necessary to assure a stable drainageway. Hard-lined channels are most applicable in solving existing urban flooding problems and are not recommended for new developments.

Natural-like channel linings need to have gentle to mild slopes and are especially desirable for residential areas and areas with public access.

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Manufactured channel linings such as gabions, interlocked concrete blocks, synthetic linings, etc., are not recommended for new developments. As with concrete- and riprap-lined channels, all of these types are best considered for helping to solve existing urban flooding problems where right-of-way is very limited. Manufactured channel linings should be used with caution, and each type of channel lining must be scrutinized for its merits, applicability, ability to meet other community needs, long term integrity, and maintenance needs and costs.

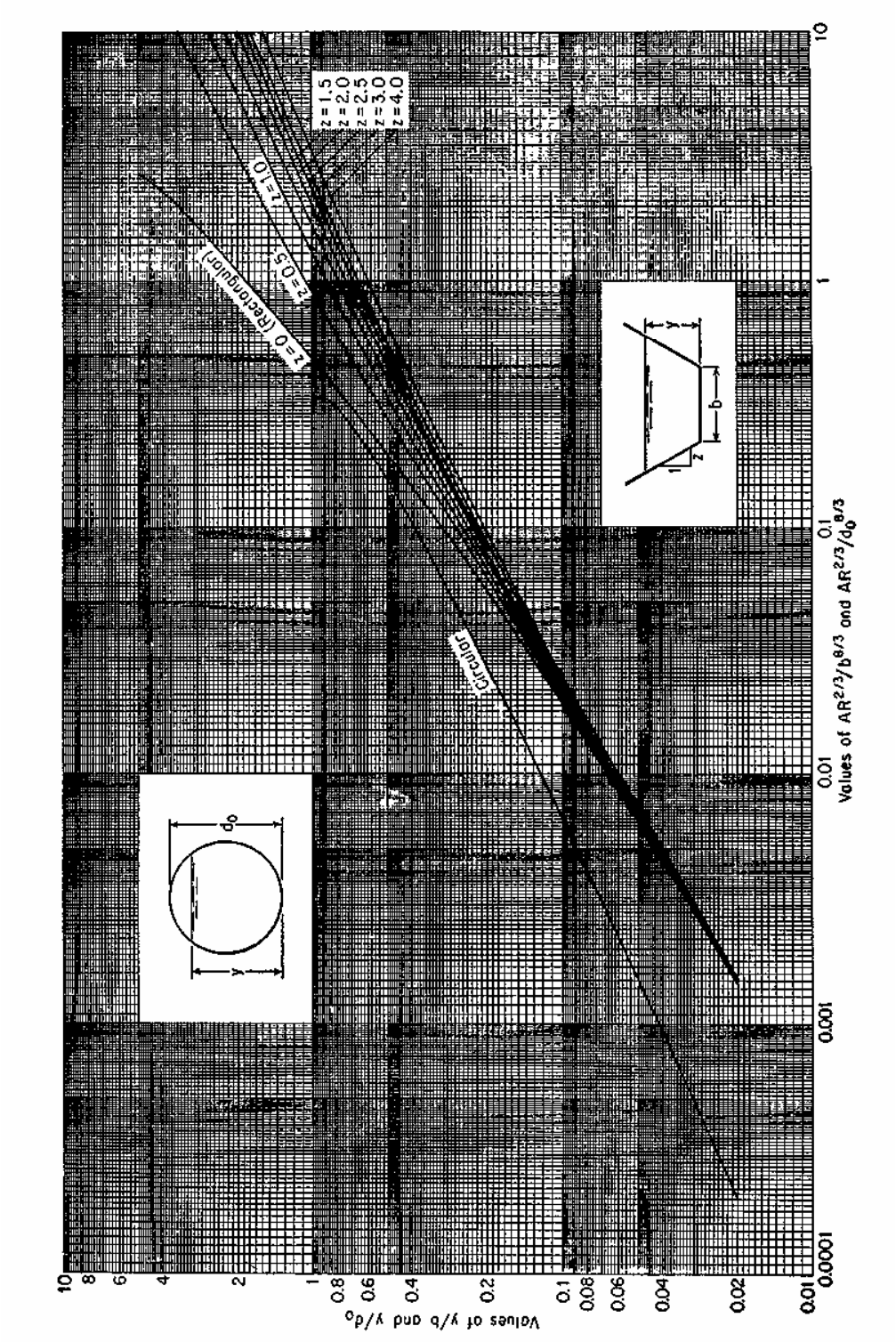

Figure MD-2—Normal Depth for Uniform Flow in Open Channels

(Fletcher and Grace 1972)

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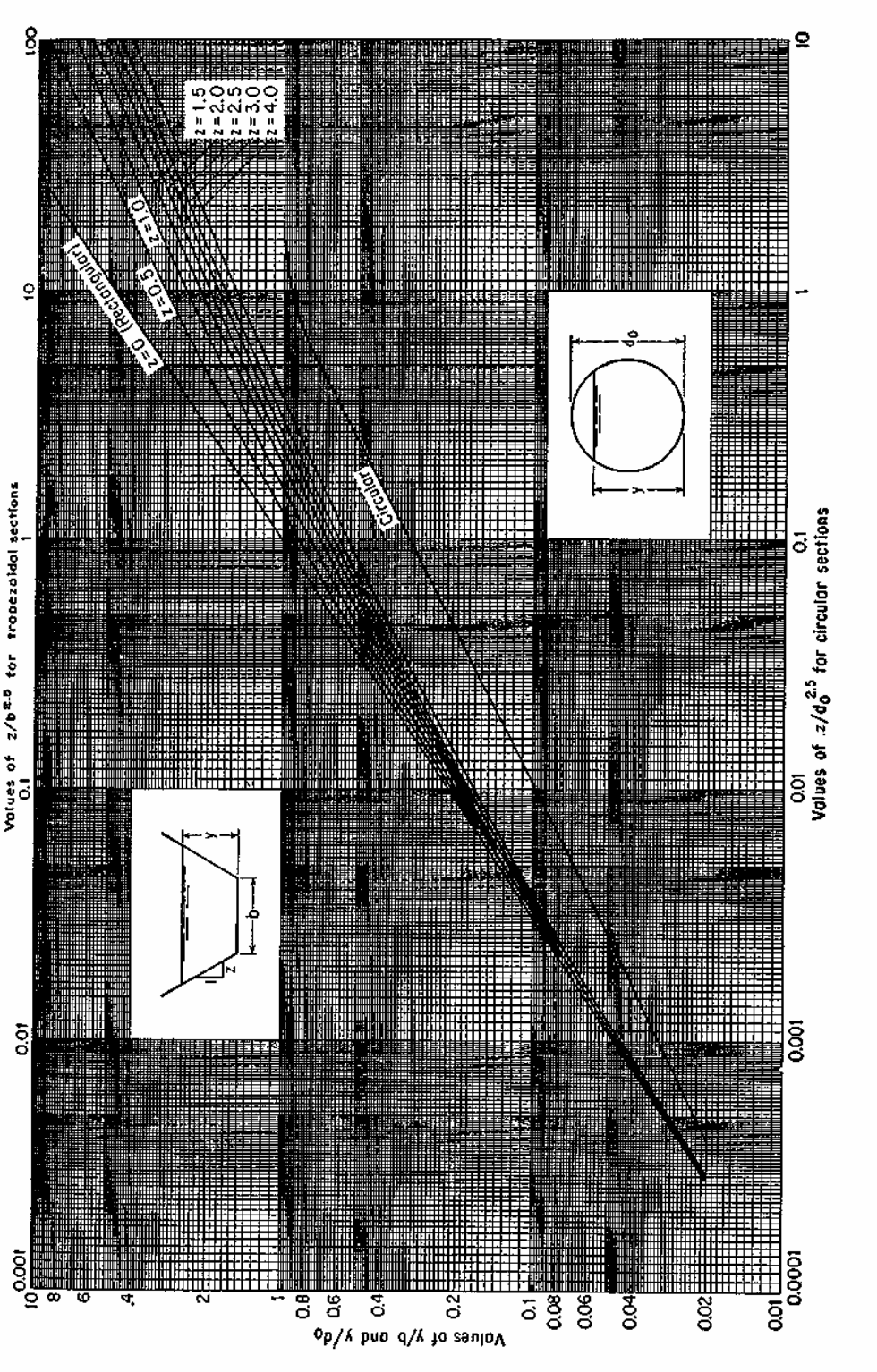

Figure MD-3—Curves for Determining the Critical Depth in Open Channels

(Fletcher and Grace 1972)

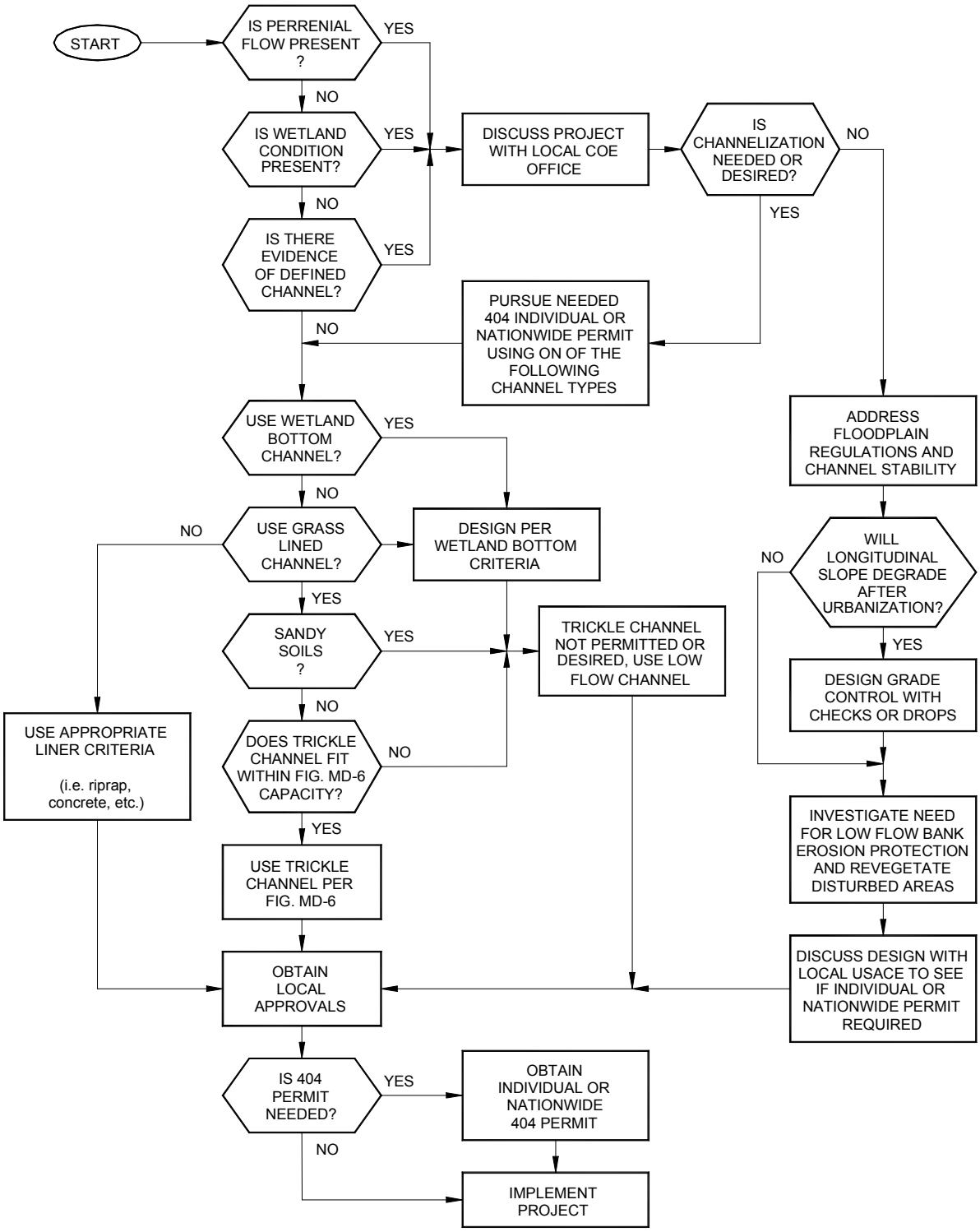

Figure MD-4—Flow Chart for Selecting Channel Type and Assessing Need for 404 Permit

4.0 OPEN-CHANNEL DESIGN CRITERIA

The purpose of this section is to provide design criteria for open channels, including grass-lined channels, composite channels, concrete-lined channels, riprap-lined channels, bioengineered channels, and natural channels. Open-channel hydraulic principles summarized in Section 3.0 can be applied using these design criteria to determine channel geometry and hydraulics.

4.1 Grass-Lined Channels

Grass-lined channels may be considered the most desirable type of artificial channels for new development where natural channels are absent or have limited environmental value. Channel storage, lower velocities, and wildlife, aesthetic, and recreational benefits create significant advantages over other types of channels. The design must fully consider aesthetics, sediment deposition, scouring, hydraulics, safety, and maintenance. Photograph MD-6 shows a grass-lined channel.

4.1.1 Design Criteria

These design criteria are particularly useful in preliminary design and layout work. Any final design that has parameters that vary significantly from those described below should be carefully reviewed for adequacy. Figures MD-5, MD-7, and MD-8 provide representative sketches for grass-lined channels.

4.1.1.1 Design Velocity and Froude number

In determining flow velocity during the major design storm (i.e., 100-year) the designer must recognize the scour potential of the soil-vegetative cover complex. Average velocities need to be determined using backwater calculations, which account for water draw-down at drops, expansions, contractions, and other structural controls. Velocities must be kept sufficiently low to prevent excessive erosion in the channel. The recommended maximum normal depth velocities and Froude numbers for 100-year flows are listed in Table MD-2.

4.1.1.2 Design Depths

The maximum design depths of flow should recognize the scour potential of the soil-vegetative cover complex. The scouring power of water increases in proportion to a third to a fifth power of depth of flow and is a function of the length of time flow is occurring. As preliminary criteria, the design depth of flow for the major storm runoff flow should not exceed 5.0 feet in areas of the channel cross section outside the low-flow or trickle channel area.

4.1.1.3 Design Slopes

To function without instability, grass-lined channels normally have longitudinal slopes ranging from 0.2 to 0.6%. Where the natural slope is steeper than desirable, drop structures should be utilized.

With respect to side slopes, the flatter the side slope, the more stable it is. For grassed channels, side slopes should not be steeper than 4H:1V. Under special conditions where development exists and right-

of-way is a problem, the slopes may be as steep as 3H:1V; however, the designer is cautioned that operation of mowing equipment may not be safe on side slopes that are steeper than 4H:1V.

4.1.1.4 Curvature

The more gentle the curve, the better the channel will function. At a minimum, centerline curves shall have a radius that is greater than two times the top width (i.e., $2 \cdot T$) of the 100-year design flow (or other major flow) in the channel.

4.1.1.5 Design Discharge Freeboard

Bridge deck bottoms and sanitary sewers often control the freeboard along the channel in urban areas. Where such constraints do not control the freeboard, the allowance for freeboard should be determined by the conditions adjacent to the channel. For instance, localized overflow in certain areas may be acceptable and may provide flow storage benefits. In general, a minimum freeboard of 1 to 2 feet should be allowed between the water surface and top of bank. Along major streams such as the South Platte River, Clear Creek, Boulder Creek, and others where potential for much timber and other debris exists during a flood, a 3-foot freeboard is recommended.

For curves in the channel, superelevation should be evaluated using Equation MD-9 in Section 3.2.4 and should be included in addition to freeboard.

4.1.2 Grass and Vegetation Selection and Use

Please refer to the REVEGETATION chapter.

4.1.3 Channel Cross Sections

The channel shape may be almost any type suitable to the location and environmental conditions. Often the shape can be chosen to suit open space and recreational needs, to create wildlife habitat, and/or to create additional sociological benefits (Murphy 1971). Typical cross sections suitable for grass-lined channels are shown in Figure MD-5.

4.1.3.1 Side Slopes

The flatter the side slopes, the better. Side slopes should not be steeper than specified in Section 4.1.1.3 of this chapter.

4.1.3.2 Depth

The maximum depth should not exceed the guidelines in Section 4.1.1.2 of this chapter. For known channel geometry and discharge, normal water depth can be calculated using Manning's Equation from Section 3.1.1 of this chapter.

4.1.3.3 Bottom Width

The bottom width should be designed to satisfy the hydraulic capacity of the cross section recognizing the limitations on velocity, depth, and Froude number. For a given discharge, the bottom width can be

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calculated using the depth, velocity, and Froude number constraints in Sections 4.1.1.1 and 4.1.1.2 using Manning's Equation from Section 3.1.1 of this chapter.

4.1.3.4 Trickle and Low-Flow Channels

When base flow is present or is anticipated as the drainage area develops, a trickle or low-flow channel is required. Steady base flow will affect the growth of grass in the bottom of the channel, create maintenance needs, and can cause erosion. A trickle channel with a porous bottom (i.e., unlined or riprapped) or a low-flow channel is required for all urban grass-lined channels. In some cases, a traditional concrete trickle channel may be necessary, but should be limited to headland tributary channels created in areas where no natural channel previously existed. However, low-flow/trickle channels with natural-like linings are preferable, especially for larger major drainageways, streams and rivers, or for channels located on sandy soils. Criteria for low-flow/trickle channels are presented in Section 4.1.5 of this chapter.

4.1.3.5 Outfalls Into Channel

Outfalls into grass-lined, major channels should be at least 1 foot (preferably 2 feet) above the channel invert with adequate erosion protection provided.

4.1.4 Roughness Coefficients

The hydraulic roughness of man-made grass-lined channels depends on the length of cutting (if any), the type of grass, and the depth of flow (Steven, Simons, and Lewis 1971). Table MD-1 summarizes typical roughness coefficients for grass-lined channels, and Table MD-2 provides guidance for the coefficients for simple trapezoidal channels.

4.1.5 Trickle and Low-Flow Channels

The low flows, and sometimes base flows, from urban areas must be given specific attention. Waterways which are normally dry prior to urbanization will often have a continuous base flow after urbanization because of lawn irrigation return flow and other sources, both overland and from groundwater inflow. Continuous flow over grass or what used to be ephemeral waterways will cause the channel profile to degrade, its cross-section to widen, its meanders to increase, destroy a healthy grass stand and may create boggy nuisance conditions.

These new perennial flows in previously ephemeral waterways change the composition of vegetation. However, it may be possible to plant species adapted to the new hydrologic regime. More mesic species could be planted as flows increase to establish a better-adapted native vegetation type. In some cases, namely in man-made channels, a concrete-lined trickle channel may guard against erosion; however, low-flow/trickle channels with natural-like linings are more attractive visually. Low-flow channels shall be used for larger major drainageways, streams, and rivers and for channels located on sandy soils. Trickle channels with natural-like linings offer and advantage over concrete-lined trickle channels because they

more closely mimic natural channels, have greater aesthetic appeal, and provide habitat benefits and vegetative diversity. These linings are best when porous and allow exchange of water with adjacent groundwater table and sub-irrigate vegetation along the channel. In addition, a vegetated low-flow channel provides a degree of water quality treatment, unlike concrete lined channels that tend to flush pollutants accumulated on the impervious lining downstream during runoff events. Low-flow channels with natural-like linings must be carefully designed to guard against erosion.

Low flows must be carried in a trickle channel, a low-flow channel, or an underdrain pipe. The capacity of a trickle channel should be approximately 2.0% of the major (i.e., 100-year) design flow for the fully developed condition assuming no upstream detention. If an underdrain pipe is used, it should be at least 24 inches in diameter, have access manholes at least every 200 feet, and have a slope so that a velocity of at least 3 ft/sec is maintained at ½ full pipe depth. Underdrains are subject to sediment deposition and are very expensive to maintain. As a result, the District does not recommend, nor will consider them for maintenance eligibility.

Figure MD-6 should be used to estimate the required capacity of a trickle flow channel based on the percent of impervious area, I_a. For flows exceeding the limits in Figure MD-6 or where a natural gulch or stream exists, a separate low-flow channel having stabilized banks should be used. A low-flow channel should have a minimum capacity of ⅓ to ½ of the 2-year peak flow under the fully developed watershed conditions. To the extent practicable, a low-flow channel should be gently sloped and shallow to promote flow through the channel's vegetation. See Figure MD-7 and MD-8 for typical details of grass-lined channels with trickle and low-flow channels.

Using a soil-riprap mix for the low-flow channel lining can provide a stable, vegetated low-flow channel for grass-lined wetland bottom and bioengineered channels. Soil and riprap should be mixed prior to placement for these low-flow channels. Soil-riprap low-flow channels should have a cross slope of 1% to 2% (they may be "dished out"). It's longitudinal slope should be consistent with the channel type used.

4.1.6 Erosion Control

Grassed channels are erodible to some degree. Experience has shown that it is uneconomical to design a grassed channel that is completely protected from erosion during a major storm. It is far better to provide reasonably erosion-resistant design with the recognition that additional erosion-control measures and corrective steps will be needed after a major runoff event. The use of drops and checks at regular intervals in a grassed channel is almost always needed to safeguard the channel from serious degradation and erosion by limiting velocities in the channel and dissipating excess energy at these structures. Take advantage of other infrastructure crossing the channel, such as a concrete-encased sewer crossing the channel that can be designed to also serve the function of a grade control structure or a drop structure. Erosion tends to occur at the edges and immediately upstream and downstream of a drop. Proper shaping of the crest and the use of riprap at all drops is necessary. Grade control

structures will also protect healthy and mature native vegetation (i.e., trees, shrubs, grasses, wetlands) and reduce long-term maintenance needs.

Under bridges, grass will not grow; therefore, the erosion tendency is larger. A cut-off wall at the downstream edge of a bridge is a good practice.

4.1.6.1 Erosion at Bends

Often special erosion control measures are often needed at bends, (see Section 4.1.1.4). An estimate of protection and velocity along the outside of the bend needs to be made using the following guidelines:
When $r_c/T \geq 8.0$, no riprap protection is needed for the bank on the outside of the bend for channels meeting the velocity and depth criteria specified in this *Manual* for grass-lined channels.
When $r_c/T < 8.0$, protect the bank on the outside of the bend with riprap sized per Section 4.4.2.3 using an adjusted channel velocity determined using Equation MD-10.

$$V_a = (-0.147 \frac{r_c}{T} + 2.176) V \qquad \text{(MD-10)}$$

in which:

V_a = adjusted channel velocity for riprap sizing along the outside of channel bends
V = mean channel velocity for the peak flow of the major design flood
r_c = channel centerline radius
T = Top width of water during the major design flood

Riprap should be applied to the outside ¼ of the channel bottom and to the channel side slope for the entire length of the bend plus a distance of $2 \cdot T$ downstream of the bend. As an alternative to lining the channel bottom, extend the riprap liner at the channel side slope to 5-feet below the channel's bottom.

Construction of channels, should be accomplished in a manner that retards erosion of bare soil areas. Downstream streams, channels, culverts and storm sewers experience severe silting problems if erosion is not controlled during construction by use of contour furrows and aggressive mulching during and after construction. In addition, to control erosion from construction site runoff all concentrated flows have be intercepted and conveyed across or around the construction site in a pipe or a lined open channel. Consult Volume 3 of this *Manual* for detailed guidance on erosion control.

4.1.6.2 Riprap Lining of Grass-lined Channels

For long-term maintenance needs, it is recommended that riprap channel linings be used only in the low-flow channel portion of a composite channel, but not on the banks above the low-flow channel section, nor on the banks of other grass-lined channels, with the exception of use of riprap at bends as discussed above. For this reason whenever soil-riprap linings are used above the low-flow section, a side-slope typically used for grass-line channels is recommended (i.e., 4H:1V), with certain exceptions in retrofit

situations in older urbanized areas with limited right of way, where a maximum steepness of 3H:1V may be used.

4.1.7 Water Surface Profile

Water surface profiles should be computed for all channels, typically for the 10-year and 100-year events. Computation of the water surface profile should include standard backwater methods, taking into consideration all losses due to changes in velocity, drops, bridge openings, and other obstructions. Computations should begin at a known point and extend in an upstream direction for subcritical flow. It is for this reason that the channel should be designed from a downstream direction to an upstream direction. It is necessary to show the hydraulic and energy grade lines on all preliminary drawings to help ensure against errors. Whether or not the energy grade line is shown on the final drawings is an option of the reviewing agency, although the District encourages this.

The designer must remember that open-channel flow in urban settings is usually non-uniform because of bridge openings, curves, and structures. This necessitates the use of backwater computations for all final channel design work.

4.1.8 Maintenance

Grass-lined channels must be designed with maintainability in mind. See Section 3.2.8 for the District's Maintenance Eligibility Guidelines, which also provide guidance for elements of design that permit good maintenance of these installations. A stable maintenance access road with a minimum passage width of 12 feet shall be provided along the entire length of all major drainageways. The local government may require the road to have an all weather surface such as a 5-inch-thick concrete pavement.

4.1.9 Calculation Tool

Calculations for sizing of a grass-lined channel using hydraulic equations from Section 3.0 and criteria from Section 4.1 can be performed using the **Grass Ch Worksheet** of the UD-Channels Spreadsheet. The **Composite Design Worksheet** of the UD-Channels Spreadsheet can be used for the design of a grass-lined channel with a low-flow channel. An example of this tool is provided in Example MD-2, which is located at the end of this chapter.

4.1.10 Design Submittal Checklist

Table MD-3 provides a design submittal checklist for a grass-lined channel.

Table MD-3—Design Submittal Checklist for Grass-Lined Channel

Criterion Requirements	✓
Maximum velocity for 100-year event: ≤ 5.0 ft/sec for erosive soils ≤ 7.0 ft/sec for erosion-resistant soils	
Manning's *n* ≥ 0.035 used to check capacity Froude Number	
Manning's *n* ≤ 0.030 used to check velocity and maximum Froude Number	
Froude number: < 0.5 for erosive soils and < 0.8 for non-erosive soils	
Maximum depth for 100-year event ≤ 5.0 ft outside of trickle channel	
Longitudinal channel slope ≥0.2% and ≤ 0.6%	
Side slopes no steeper than 4H:1V	
Channel bottom cross-slope 1% to 2%	
Centerline curve radius > 2 x top width for 100-year event	
Channel bends checked for needed erosion protection (see Section 4.1.6.1 Erosion Control" of the Major Drainage Chapter).	
Channel bend protection, use Type V or VL soil riprap lining extended below channel bottom, buried and vegetated when called for at bends (see Section 4.1.6.1).	
Outfalls into channel ≥ 1 foot above channel invert (use pipes, concrete-lined rundowns or grouted boulder rundowns)	
Adequate freeboard provided, including superelevation	
Grass species appropriate (drought resistant, sturdy, easily established, turf forming)	
Trickle channel (if any) sized for 2.0% of 100-year design flow for fully developed, undetained condition in u/s watershed.	
Underdrain pipe (if any) diameter ≥ 24 inches [**Note: not recommended or endorsed**.]	
Underdrain pipe (if any) includes manhole access every 200 ft	
Underdrain pipe (if any) velocity ≥ 3.0 ft/sec when one-half full	
Erosion protection measures included where necessary	
District Maintenance Eligibility Guidelines satisfied	
Continuous maintenance access road provided (minimum 8-foot stable surface with 12-foot clear width, 20-feet at drop structures)	
Energy and hydraulic grade lines calculated, plotted, design discharges annotated	

4.2 Composite Channels

When the trickle flow channel capacity limits are exceeded as discussed earlier, the use of a composite channel is required, namely a channel with a stabilized low-flow section and an overflow section above it to carry major flow. It is best to assume that wetland and other flow-retarding vegetation will develop in the los-flow section over time. A fact that needs to be accounted for when designing a composite channel. Under certain circumstances, such as when existing wetland areas are affected or natural channels are modified, the USACE's Section 404 permitting process may mandate the use of composite

channels that will have wetland vegetation in their bottoms (see Photograph MD-7 for representative example). In other cases, a composite channel with a wetland bottom low-flow channel may better suit individual site needs if used to mitigate wetland damages elsewhere or if used to enhance urban stormwater runoff quality. Composite channels can be closely related to bioengineered and natural channels. Composite channel can provide aesthetic benefits, habitat for aquatic, terrestrial and avian wildlife and water quality enhancement as base flows come in contact with vegetation.

Wetland bottom vegetation within a composite channel will trap sediment and, thereby, reduce the low-flow channel's flood carrying capacity over time. To compensate for this the channel roughness factor used for design must be higher than for a grass-lined channel. As a result, more right-of-way is required for composite channels that have the potential for developing wetlands in their bottom. In developed areas, where right-of-way is limited, mitigating flood damages should take precedence over other considerations during project design. In cases where existing wetlands are eliminated or otherwise impacted, off-site wetland mitigation may be required by the USACE's 404 Permit.

4.2.1 Design Criteria

The simplified design procedures in this *Manual* are based on assumptions that the flow depth is affected by the maturity of vegetation in the low-flow channel, affects the channel roughness, and the rate of sediment deposition on the bottom. These assumptions are based on state-of-the-art literature, observed sediment loads in stormwater (USEPA 1983, DRCOG 1983) and locally observed sediment buildup (District 1996) in several existing wetland bottom and composite channels in the Denver area.

The recommended criteria parallel the criteria for the design of grass-lined channels (Section 4.1), with several notable differences. Composite channels are, in essence, grass-lined channels in which more dense vegetation (including wetland-type) is encouraged to grow on the bottom and sides of the low-flow channel. From a design perspective, these types of channels are differentiated from smaller grass-lined channels by (1) the absence of an impermeable trickle channel, (2) gentler longitudinal slopes and wider bottom widths that encourage shallow, slow flows, (3) greater presence of hydrophytic vegetation along the channel's bottom and lower banks, and (4) non-applicability of the 1% to 2% cross-slope criterion. Another major difference is that a wetland bottom channel should be designed as a low-flow channel having a capacity to carry the 2-year flood peak, instead of the ⅓ to ½ of the 2-year peak required for low-flow channels. Figures MD-8 illustrates a representative wetland bottom composite channel. The use on an appropriate Manning's *n* in its design is critical and guidance for one can be found in Figure MD-9. More detailed design guidance for wetland bottom channels may be found in Volume 3 of this *Manual*.

In designing low-flow channels, the engineer must account for two flow roughness conditions. To ensure vertical stability, the longitudinal slope of the channel should be first calculated and fixed assuming there is no wetland vegetation on the bottom (i.e., "new channel"). Next, in order to ensure adequate flow capacity after the low-flow channel vegetation matures and some sedimentation occurs, the channel's

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bottom is widened to find the channel cross section needed to carry the design flow using roughness coefficients under the “mature channel” condition. To allow for the "mature channel" condition and potential sediment accumulation, outfalls into channels with low-flow channels should be at least 2 feet above the low-flow channel invert. Guidance for the design of a wetland bottom channel for water quality purposes is given in the STRUCTURAL BMPs chapter in Volume 3 of this *Manual*. A typical cross-sections for composite channels is shown in Figure MD-7.

4.2.2 Design Procedure

If a wetland bottom channel is to be used, the designer may utilize the *CWC Worksheet* from the *Design Forms Spreadsheet* provided for Volume 3 of this *Manual* to assist in these calculations. Otherwise use the *Open Channel Design* workbook. Both may be downloaded from the www.udfcd.org web site.

After the low-flow channel has been designed, complete the design by providing additional channel capacity for the major flows in accordance with the grass-lined channel design requirement. The final Manning’s n for the composite channel shall be determined using Equation MD-11.

$$n_c = \frac{P \cdot R^{5/3}}{\frac{P_L \cdot R_L^{5/3}}{n_L} + \frac{P_M \cdot R_M^{5/3}}{n_M} + \frac{P_R \cdot R_R^{5/3}}{n_R}} \qquad \text{(MD-11)}$$

In which:

n_c = Manning’s n for the composite channel

n_L = Manning’s n for the left overbank

n_R = Manning’s n for the right overbank

n_M = Manning’s n for the middle area (low-flow)

P_L = Wetted perimeter of the left overbank

P_R = Wetted perimeter of the right overbank

P_M = Wetted perimeter of the middle area

R_L = Hydraulic radius of the left overbank

R_R = Hydraulic radius of the right overbank

R_M = Hydraulic radius of the middle area

Figure MD-9 is provided to assist the designer in determining Manning's n for the low-flow section of a composite channel when the design water depth is known.

Whenever a composite bottom channel is crossed by a road, railroad, or a trail requiring a culvert or a bridge, a drop structure should be provided immediately downstream of such a crossing. This will help reduce sediment deposition in the crossing. A 1-foot to 2-foot drop is recommended (a larger drop may be preferred in larger systems) on the downstream side of each culvert and crossing of a wetland bottom

channel (see Figure MD-10).

Water surface profiles must be computed, typically for the 10- and 100-year events. Computation of the water surface profile should utilize standard backwater methods, taking into consideration all losses due to changes in velocity, drops, bridge openings, and other obstructions. Computations begin at a known point and extend in an upstream direction for subcritical flow. It is for this reason that the channel should be designed from a downstream direction to an upstream direction. It is necessary to show the energy gradient on all preliminary drawings to help prevent errors. Whether or not the energy gradient line is shown on the final drawings is the option of the reviewing agency but is encouraged by the District.

The designer must remember that open-channel flow in urban drainage is usually non-uniform because of bridge openings, curves, and structures. This necessitates the use of backwater computations for all final channel design work.

Guidance regarding vegetation selection, planting, and maintenance is provided in the REVEGETATION chapter.

4.2.3 Life Expectancy and Maintenance

The low-flow channel can serve as a productive ecosystem and can also be highly effective at trapping sediment. Wetland vegetation bottom channels are expected to fill with sediment over time. Some sediment accumulation is necessary for a wetland channel's success to provide organic matter and nutrients for growth of biological communities. The life expectancy of such a channel will depend primarily on the land use of the tributary watershed. However, life expectancy can be dramatically reduced to as little as 2 to 5 years, if land erosion in the tributary watershed is not controlled. Therefore, land erosion control practices need to be strictly enforced during land development and other construction within the watershed, and all facilities should be built to minimize soil erosion to maintain a reasonable economic life for the wetland bottom channel. In addition, sediment traps or forebays located at stormwater runoff points of entry can trap a significant portion of the sediment arising at the wetland channel and, if used, could decrease the frequency of major channel dredging.

A maintenance access road with a minimum passage width of 12 feet shall be provided along the entire length of all major drainageways. The local government may require the road to be surfaced with 6 inches of Class 2 roadbase or a 5-inch-thick concrete slab.

4.2.4 Calculation Example for Wetland Bottom Channel

See Volume 3 of this *Manual* for a design example.

4.2.5 Design Submittal Checklist

Table MD-4, below, provides a design checklist for a composite channel.

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Table MD-4—Design Submittal Checklist for Composite Channel

Criterion/Requirement	✓
Maximum velocity in main channel outside of the low-flow or wetland low-flow section for the 100-year event: ≤ 5.0 ft/sec for erosive soils ≤ 7.0 ft/sec for non-erosive soils	
"New channel" roughness condition used to set longitudinal slope	
"Mature channel" roughness condition used to evaluate capacity	
Composite Manning's n calculated for channel and used in hydraulic computations	
Froude number: < 0.5 for erosive soils; < 0.8 for non-erosive soils	
Maximum depth for 100-year event ≤ 5.0 ft outside of low-flow channel	
Side slopes in low-flow section, no steeper than 2.5H:1V for soil riprap lined (i.e., rock mixed with topsoil, covered with topsoil and revegetated)	
Side slopes above low-flow channel: no steeper than 4H:1V	
Centerline curve radius: > 2 x top width for 100-year event	
Channel bends: check for need for erosion protection in accordance with recommendation of section "4.1.6.1 Erosion at Bends" of the *USDCM*	
Channel bend protection, use Type V or VL soil riprap lining extended below channel or low-flow channel bottom, buried and vegetated if called for at bends (see Section 4.1.6.1).	
Outfalls into channel: ≥ 1 foot above channel invert (use pipes, concrete-lined rundowns or grouted boulder rundowns)	
Adequate freeboard provided, including superelevation	
Vegetation Species appropriate for anticipated hydroperiod, water levels, zonation on banks (see the REVEGETATION chapter)	
No impermeable lining present	
Drop downstream of each culvert or bridge crossing: 1-foot to 2-foot for wetland bottom channels	
Low-flow channel size: ⅓ to ½ of the 2-year flow for the fully developed watershed flows	
Low-flow channel depth: ≥ 3.0 ft and ≤ 5.0 ft	
Erosion protection measures included where necessary (at crossing, drops, bend, etc.)	
District Maintenance Eligibility Guidelines satisfied	
Continuous maintenance access road provided (minimum 8-foot stable surface with 12-foot clear width, 20-foot at drop structures)	
Energy and hydraulic grade lines calculated and plotted (min. 2- and 100-year flows)	

4.3 Concrete-Lined Channels

Although not recommended for general use because of safety and structural integrity and aesthetic reasons; hydraulic, topographic, or right-of-way constraints may necessitate the use of a concrete-lined channel in some instances. A common constraint requiring a concrete-lined channel is the need to convey high velocity, sometimes supercritical, flow. Whether the flow will be supercritical or subcritical,

the concrete lining must be designed to withstand the various forces and actions that cause overtopping of the bank, damage to the lining, and erosion of unlined areas. Concrete-lined channels will typically not be eligible for District's maintenance eligibility.

Concrete-lined channels can be used for conveyance of both subcritical and supercritical flows. In general, however, other types of channels such as grass-lined channels or channels with wetland bottoms are preferred for subcritical flows. The use of a concrete-lined channel for subcritical flows should not be used except in unusual circumstances where a narrow right-of-way exists. Vegetated channels are normally preferable in the Denver region because available thalweg slopes are generally steep enough.

Channels conveying supercritical flows must be carefully designed due to many potential hazards. Imperfections at joints can cause their rapid deterioration, in which case a complete failure of the channel can occur. In addition, high-velocity flow at cracks or joints creates an uplift force by creating zones of flow separation with negative pressures and conversion of the velocity head to pressure head under the liner, which can virtually tear out concrete slabs. When designing a lined channel with supercritical flow, the designer must use utmost care and consider all relevant factors.

In the Denver region, all channels carrying supercritical flow shall be lined with continuously reinforced concrete linings, both longitudinally and laterally. There shall be no diminution of wetted area cross sections at bridges or culverts. Adequate freeboard shall be provided to have a suitable safety margin. Bridges or other structures crossing the channel must be anchored satisfactorily to withstand the full dynamic load that might be imposed upon the structure in the event of major trash plugging.

The concrete linings must be protected from hydrostatic uplift forces, which are often created by a high water table or momentary inflow behind the lining from localized flooding. A perforated underdrain pipe is required under the lining, and the underdrain must be designed to be free draining. At supercritical flow, minor downstream obstructions do not create any backwater effect. Backwater computation methods are applicable for computing the water surface profile or the energy gradient in channels having a supercritical flow; however, the computations must proceed in a downstream direction.

Roughness coefficients for lined channels are particularly important when dealing with supercritical flow. Once a particular roughness coefficient is chosen, the construction inspection must be carried out in a manner to ensure that the particular roughness is obtained. Because of field construction limitations, the designer should use a Manning's n roughness coefficient equal to 0.013 for a well-trowelled concrete finish. Other finishes should have proportionately larger n values assigned to them. A value of n higher than 0.013 may be applicable for a concrete channel with subcritical flow if deposition of sediment or transport of sediment as bedload is expected.

Small concrete channels that function as rundowns are addressed in the HYDRAULIC STRUCTURES

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chapter.

4.3.1 Design Criteria

4.3.1.1 Design Velocity and Froude Number

Concrete channels can be designed to convey supercritical or subcritical flows; however, the designer must take care to prevent the possibility of unanticipated hydraulic jumps forming in the channel. For concrete channels, flows at *Froude Numbers* between 0.7 and 1.4 are unstable and unpredictable and should be avoided at all flow levels in the channel. When a concrete channel is unavoidable, the maximum velocity at the peak design flow shall not exceed 18 feet per second.

To calculate velocities, the designer should utilize Manning's Equation from Section 3.1.1 of this chapter with roughness values from Table MD-5. When designing a concrete-lined channel for subcritical flow, use a Manning's n = 0.013 for capacity calculations and 0.011 to check whether the flow could go supercritical. Do not design a subcritical channel for a Froude number greater than 0.7 using the velocity and depth calculated with a Manning's n = 0.011. Also, do not design supercritical channel with a Froude Number less than 1.4 when checking for it using a Manning's n = 0.013

Table MD-5—Roughness Values for Concrete-Lined Channels

Type of Concrete Finish	Roughness Coefficient (n)		
	Minimum	Typical	Maximum
Concrete			
Trowel finish*	0.011	0.013	0.015
Float finish*	0.013	0.015	0.016
Finished, with gravel on bottom*	0.015	0.017	0.020
Unfinished*	0.014	0.017	0.020
Shotcrete, trowelled, not wavy	0.016	0.018	0.023
Shotcrete, trowelled, wavy	0.018	0.020	0.025
Shotcrete, unfinished	0.020	0.022	0.027
On good excavated rock	0.017	0.020	0.023
On irregular excavated rock	0.022	0.027	0.030

* For a *subcritical* channel with these finishes, check the Froude number using n = 0.011

4.3.1.2 Design Depths

There are no specific limits set for depth for concrete-lined channels, except as required for low-flow channels of a composite section where the low-flow channel is concrete lined.

4.3.1.3 Curvature

Curvature is not allowed for channels with supercritical flow regimes. For concrete-lined channels with subcritical flow regimes, the centerline radius of curvature should be at least two times the top width, and superelevation should be evaluated for all bends using Equation MD-9 in Section 3.2.4 and included in

determining freeboard.

4.3.1.4 Design Discharge Freeboard

Freeboard above the design water surface shall not be less than that determined by the following:

$$H_{fb} = 2.0 + 0.025V(y_0)^{1/3} + \Delta y \qquad \text{(MD-12)}$$

in which:

H_{fb} = freeboard height (ft)

V = velocity of flow (ft/sec)

y_o = depth of flow (ft)

Δy = increase in water surface elevation due to superelevation at bends (see Equation MD-9) (no bends allowed in supercritical channels)

In addition to H_{fb}, add height of estimated standing waves, superelevation and/or other water surface disturbances to calculate the total freeboard. In all cases, the freeboard shall be no less than 2 feet and the concrete lining shall be extended above the flow depth to provide the required freeboard.

4.3.2 Concrete Lining Specifications

4.3.2.1 Concrete Lining Section

All concrete lining shall be designed to withstand the anticipated hydrodynamic and hydrostatic forces, and the minimum thickness shall be no less than 7 inches for supercritical channels and no less than 5 inches for subcritical channels. A free draining granular bedding shall be provided under the concrete liner and shall be no less than 6-inches thick for channels with Froude number ≤ 0.7 and 9-inches thick for channels with Froude number ≥ 1.4.

The side slopes shall be no steeper than 1.5V:1H unless designed to act as a structurally reinforced wall to withstand soil and groundwater forces. In some cases, a rectangular cross section may be required. Rectangular cross sections are acceptable, provided they are designed to withstand potential lateral loads. In addition, fencing along concrete channels should be used to restrict access for safety reasons.

4.3.2.2 Concrete Joints

Concrete joints must satisfy the following criteria:

1. Channels shall be constructed of continuously reinforced concrete without transverse joints.
2. Expansion/contraction joints shall be installed where new concrete lining is connected to a rigid structure or to existing concrete lining which is not continuously reinforced.
3. Longitudinal joints, where required, shall be constructed on the sidewalls at least 1 foot vertically

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above the channel invert.

4. All joints shall be designed to prevent differential movement.

5. Construction joints are required for all cold joints and where the lining thickness changes. Reinforcement shall be continuous through the joint.

4.3.2.3 Concrete Finish

The surface of the concrete lining may be finished in any of the finishes listed in Table MD-5, provided appropriate finishing technique is used. Check with local authorities to determine which finishes are acceptable.

4.3.2.4 Underdrain

Longitudinal underdrains shall be provided along the channel bottom on 10-foot centers within a free-draining bedding under the channel lining, be free draining, and daylight at check drops (when applicable). A check valve or flap valve shall be provided at the outlet to prevent backflow into the drain. Appropriate numbers of weep holes and one-way valves shall be provided in vertical wall sections of the channel to relieve hydrostatic pressure.

4.3.3 Channel Cross Section

4.3.3.1 Side Slopes

The side slopes shall be no steeper than 1.5H:1V unless designed to act as a structurally reinforced wall to withstand soil and groundwater forces.

4.3.3.2 Depth

Maximum depth shall be consistent with Section 4.3.1.2. For known channel geometry and discharge, normal water depth can be calculated using Manning's Equation recommended in Section 3.1.1.

4.3.3.3 Bottom Width

The bottom width should be designed to satisfy the hydraulic capacity of the cross section recognizing the limitations on velocity, depth, and Froude number. For a given discharge, the bottom width can be calculated from depth, velocity, slope, and Froude number constraints in Sections 4.3.1.1, 4.3.1.2, and 4.3.1.3 using Manning's Equation.

4.3.3.4 Trickle and Low-Flow Channels

For a well-designed concrete-lined channel, a trickle or low-flow channel is not necessary since the entire channel is hard-lined. However, if a small base flow is anticipated, it is a good idea to incorporate a trickle flow swale or section to reduce occurrence of bottom slime, noxious odors and mosquito breeding.

4.3.3.5 Outfalls Into Channel

Outfalls into concrete-lined channels should be at least 1 foot above the channel invert.

4.3.4 Safety Requirements

A 6-foot-high chain-link or comparable fence shall be installed to prevent access wherever the 100-year channel concrete section depth exceeds 3 feet. Appropriate numbers of gates, with top latch, shall be placed and staggered where a fence is required on both sides of the channel to permit good maintenance access.

In addition, ladder-type steps shall be installed not more than 200 feet apart on alternating sides of the channel. A bottom rung shall be placed approximately 12 inches vertically above the channel invert.

4.3.5 Calculation Tools

Calculations for sizing of a concrete-lined channel using hydraulic equations from Section 3.0 and criteria from Section 4.3 can be performed using the *Basis Worksheet* of UD-Channels Spreadsheet.

4.3.6 Maintenance

Concrete channels require periodic maintenance including debris and sediment removal, patching, joint repair, and other such activities. Their condition should be periodically monitored, especially to assure that flows cannot infiltrate beneath the concrete lining. A maintenance access road with a minimum passage width of 12 feet shall be provided along the entire length of all major drainageways. The local government may require the road to have an all weather surface such as 5-inch-thick concrete pavement.

4.3.7 Design Submittal Checklist

Table MD-6 provides a design checklist for a concrete-lined channel.

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Table MD-6—Design Submittal Checklist for Concrete-Lined Channel

Criterion/Requirement	✓
Maximum velocity for 100-year event ≤ 18 ft/sec	
Channel capacity and Froude Number ≥ 1.4: checked with Manning's n = 0.013	
Maximum velocity and Froude Number ≤ 0.7: checked using Manning's n = 0.011	
Froude number ≤ 0.7 and ≥ 1.4 under both Manning's n assumptions	
Side slopes no steeper than 1.5H:1V	
Centerline curve radius for subcritical channels: > 2 x top width for 100-year event	
Centerline curve radius for supercritical channels: NO CURVATURES PERMITTED	
Concrete lining designed to withstand hydrodynamic and hydrostatic forces (minimum thickness = 7.0 inches for supercritical channels, 5.0 inches for subcritical channels)	
Concrete joints meet Section 4.3.2.2 criteria	
Free draining granular bedding under concrete (6-inch minimum thickness for Fr ≤ 0.7, 9-inch minimum thickness for Fr ≥ 1.4	
Free draining longitudinal underdrains provided on 10-ft centers, including check or flap valve at outlet to prevent backflow	
Concrete finish from list in Table MD-5	
Outfalls into channel ≥ 1 ft above channel invert	
Adequate freeboard provided (see criteria in text)	
Standing waves included in freeboard for supercritical channels	
6-ft chain link fence (or comparable) provided when channel depth > 3.0 ft	
Ladder-type steps spaced no more than 200 ft apart on alternating sides of channel with lowest rung approximately 12 inches above channel invert	
District Maintenance Eligibility Guidelines satisfied	
Continuous maintenance access road provided (minimum 8-foot stable surface with 12-foot clear width, 20-foot at drops)	
Energy and hydraulic grade lines calculated and plotted for the channel and also annotate the design discharges	

4.4 Riprap-Lined Channels

Channel linings constructed from soil riprap, grouted boulders, or wire-encased rock to control channel erosion may be considered on a case-by-case basis, or may be required as the case may be, for the following situations:

1. Where major flows such as the 100-year flood are found to produce channel velocities in excess of allowable non-eroding values (5 ft/sec for sandy soil conditions and 7 ft/sec in erosion resistant soils) or when main channel depth is greater than 5 feet.

2. Where channel side slopes must be steeper than 3H:1V.

3. For low-flow channels.

4. Where rapid changes in channel geometry occur such as channel bends and transition s.

Design criteria applicable to these situations are presented in this section. Riprap-lined channels should only be used for subcritical flow conditions where the Froude number is 0.8 or less. When used, it is recommended that all riprap outside frequent flow zones have the voids filled with soil, the top of the rock covered with topsoil, and the surface revegetated with native grasses, namely, use soil riprap.

4.4.1 Types of Riprap

4.4.1.1 Ordinary and Soil Riprap

Ordinary riprap, or simply "riprap," refers to a protective blanket of large loose stones, which are usually placed by machine to achieve a desired configuration. The term ordinary riprap has been introduced to differentiate loose stones from grouted boulders and wire-enclosed rock. Photograph MD-9 shows a representative riprap-lined channel, while Figures MD-11 through MD-14 depict key design aspects of such channels.

Many factors govern the size of the rock necessary to resist the forces tending to move the riprap. For the riprap itself, this includes the size and weight of the individual rocks, shape of the stones, gradation of the particles, blanket thickness, type of bedding under the riprap, and slope of the riprap layer. Hydraulic factors affecting riprap include the velocity, current direction, eddy action, waves, and hydraulic uplift forces.

Experience has shown that riprap failures result from a variety of factors: undersized individual rocks in the maximum size range; improper gradation of the rock, which reduces the interlocking of individual particles; and improper bedding for the riprap, which allows leaching of channel particles through the riprap blanket.

Classification and gradation for riprap and boulders are given in Table MD-7, Table MD-8 and Figure MD-11 and are based on a minimum specific gravity of 2.50 for the rock. Because of its relatively small size and weight, riprap types VL, L and M must be mixed with native topsoil, covered with topsoil and revegetated. This practice also protects the rock from vandalism.

The type of riprap that is mixed with native soil as described above is called *soil riprap*. Soil Riprap consist of 35% by volume of native soil, taken from the banks of the channel, that is mixed in with 65% by volume of riprap on-site, before placement as channel liner. Soil riprap is recommended for all urban channels within District regardless of riprap size used. A typical section for soil riprap installation is illustrated in Figure MD-13b.

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Table MD-7—Classification and Gradation of Ordinary Riprap

Riprap Designation	% Smaller Than Given Size by Weight	Intermediate Rock Dimensions (inches)	d_{50} (inches)*
Type VL	70-100 50-70 35-50 2-10	12 9 6 2	6**
Type L	70-100 50-70 35-50 2-10	15 12 9 3	9**
Type M	70-100 50-70 35-50 2-10	21 18 12 4	12**
Type H	70-100 50-70 35-50 2-10	30 24 18 6	18
Type VH	70-100 50-70 35-50 2-10	42 33 24 9	24

* d_{50} = mean particle size (intermediate dimension) by weight.

** Mix VL, L and M riprap with 35% topsoil (by volume) and bury it with 4 to 6 inches of topsoil, all vibration compacted, and revegetate.

Basic requirements for riprap stone are as follows:

- Rock shall be hard, durable, angular in shape, and free from cracks, overburden, shale, and organic matter.
- Neither breadth nor thickness of a single stone should be less than one-third its length, and rounded stone should be avoided.
- The rock should sustain a loss of not more than 40% after 500 revolutions in an abrasion test (Los Angeles machine—ASTM C-535-69) and should sustain a loss of not more than 10% after 12 cycles of freezing and thawing (AASHTO test 103 for ledge rock procedure A).
- Rock having a minimum specific gravity of 2.65 is preferred; however, in no case should rock have a specific gravity less than 2.50.

4.4.1.2 Grouted Boulders

Table MD-8 provides the classification and size requirements for boulders. When grouted boulders are used, they provide a relatively impervious channel lining which is less subject to vandalism than ordinary riprap. Grouted boulders require less routine maintenance by reducing silt and trash accumulation and

are particularly useful for lining low-flow channels and steep banks. The appearance of grouted boulders is enhanced by exposing the tops of individual stones and by cleaning the projecting rocks with a wet broom right after the grouting operation. In addition, it is recommended that grouted boulders on channel banks and outside of frequent flow areas be buried with topsoil and revegetated with native grasses, with or without shrubs depending on the local setting. Boulders used for grouting should meet all the properties of rock for ordinary riprap, and rock of uniform size should be used. The boulder sizes are categorized in Table MD-8.

Table MD-8—Classification of Boulders

Boulder Classification	Nominal Size and [Range in Smallest Dimension of Individual Rock Boulders (inches)]	Maximum Ratio of Largest to Smallest Rock Dimension of Individual Boulders
B18	18 [17 – 20]	2.5
B24	24 [22 – 26]	2.0
B30	30 [28 – 32]	2.0
B36	36 [34 – 38]	1.75
B42	42 [40 – 44]	1.65
B48	48 [45 – 51]	1.50

Grouted boulders should be placed directly on subbase without granular bedding. The top one-half of the boulders shall be left ungrouted and exposed. Weep holes should be provided at the toe of channel slopes and channel drops to reduce uplift forces on the grouted channel lining. Underdrains should be provided if water is expected to be present beneath the liner. Grouted boulders on the banks should be buried and vegetated with dry-land grasses and shrubs. At least 18 inches of soil must be used to cover grouted riprap for establishing dry-land vegetation. Recommended seed mixtures for revegetation are provided in the REVEGETATION chapter of this *Manual*. Shrubs will not grow well over grouted boulders unless irrigated on side-slope areas where grout may be omitted. Shrubs can be used between boulders (rocks) to stabilize the soil between the boulders and adjacent soils.

Two types of grout are recommended for filling the voids for the grouted boulders. The technical specifications for two types of structural grout mix are given as a part of Figures HS-7a4 and HS-7b4 of the HYDRAULIC STRUCTURES chapter of this *Manual*. Type A can be injected using a low-pressure grout pump and can be used for the majority of applications. Type B has been designed for use in streams and rivers with significant perennial flows where scouring of Type A grout is a concern. It requires a concrete pump for injection.

Full penetration of grout around the lower one-half of the rock is essential for successful grouted boulder performance. Inject grout in a manner that ensures that no air voids between the grout, subbase, and boulders will exist. To accomplish this, inject the grout by lowering the grouting nozzle to the bottom of

the boulder layer and build up the grout from the bottom up, while using a vibrator or aggressive manual rodding. Inject the grout to a depth equal to one-half of the boulders being used and keep the upper one-half ungrouted and clean. Remove all grout splatters off the exposed boulder portion immediately after grout injection using wet brooms and brushes.

4.4.1.3 Wire-Enclosed Rock (Gabions)

Wire-enclosed rock, or gabions, refers to rocks that are bound together in a wire basket so that they act as a single unit. The durability of wire-enclosed rock is generally limited by the life of the galvanized binding wire that has been found to vary considerably under conditions along waterways. Water carrying sand or gravel will reduce the service life of the wire dramatically. Water that rolls or otherwise moves cobbles and large stones breaks the wire with a hammer-and-anvil action, considerably shortening the life of the wire. The wire has been found to be susceptible to corrosion by various chemical agents and is particularly affected by high-sulfate soils. Wire-enclosed rock installations have been found to attract vandalism, and flat mattress surfaces seem to be particularly susceptible to having wires cut and stones removed. For these reasons, the District discourages the use of wire-enclosed rock. If the designer chooses to utilize gabions, they should be placed above the low-flow channel or 2-year water surface elevation. All flat mattresses must be filled with topsoil and then covered with a 6-inch layer of topsoil.

4.4.2 Design Criteria

The following sections present design criteria for riprap-lined channels. Additional information on riprap can be found in Section 7.0 of this chapter.

4.4.2.1 Design Velocity

Riprap-lined channels should only be used for subcritical flow conditions where the Froude number is 0.8 or less.

4.4.2.2 Design Depths

There is no maximum depth criterion for riprap-lined channels. Wire-enclosed rock sections shall be used on banks only above the low-flow channel or 2-year flood water surface, placed on a stable foundation.

4.4.2.3 Riprap Sizing

The stone sizing for ordinary riprap can be related to the channel's longitudinal slope, flow velocity, and the specific gravity of the stone using the relationship:

$$\frac{VS^{0.17}}{d_{50}^{0.5}(G_s-1)^{0.66}} = 4.5 \qquad \text{(MD-13)}$$

in which:

V = mean channel velocity (ft/sec)

S = longitudinal channel slope (ft/ft)

d_{50} = mean rock size (ft)

G_s = specific gravity of stone (minimum = 2.50)

Note that Equation MD-13 is applicable for sizing riprap for channel lining. This equation is not intended for use in sizing riprap for rundowns or culvert outlet protection. Information on rundowns is provided in Section 7.0 of the HYDRAULIC STRUCTURES chapter of this *Manual*, and protection downstream of culverts is discussed in Section 7.0 of this chapter, as well as in the HYDRAULIC STRUCTURES chapter, Section 3.0.

Table MD-10 shall be used to determine the minimum size of rock type required. Note that rock types for ordinary riprap, including gradation, are presented in Table MD-7 and Figure MD-11.

Table MD-10—Riprap Requirements for Channel Linings*

$\frac{VS^{0.17}}{(G_s-1)^{0.66}}$ **	Rock Type
< 3.3	VL** (d_{50} = 6 inches)
≥ 3.3 to < 4.0	L** (d_{50} = 9 inches)
≥ 4.0 to < 4.6	M (d_{50} = 12 inches)
≥ 4.6 to < 5.6	H (d_{50} = 18 inches)
≥ 5.6 to 6.4	VH (d_{50} = 24 inches)

* Applicable only for a Froude number of < 0.8 and side slopes no steeper than 2H:1V.

** Use G_s = 2.5 unless the source of rock and its density are known at time of design.

Table MD-10 indicates that rock size does not need to be increased for steeper channel side slopes, provided the side slopes are no steeper than 2.5H:1V (District 1982). Rock-lined side slopes steeper than 2.5H:1V are considered unacceptable under any circumstances because of stability, safety, and maintenance considerations. Proper bedding is required both along the side slopes and the channel bottom for a stable lining. The riprap blanket thickness should be at least 1.75 times d_{50} (at least 2.0 times d_{50} in sandy soils) and should extend up the side slopes at least 1 foot above the design water surface. At the upstream and downstream termination of a riprap lining, the thickness should be increased 50% for at least 3 feet to prevent undercutting.

4.4.2.4 Riprap Toes

Where only the channel sides are to be lined and the channel bottom remains unlined, additional riprap is needed to protect such lining. In this case, the riprap blanket should extend at least 3 feet below the channel thalweg (invert) in erosion resistant soils, and the thickness of the blanket below the existing

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channel bed should be increased to at least 3 times d_{50} to accommodate possible channel scour during higher flows. The designer should compute the scour depth for the 100-year flow and, if this scour depth exceeds 3 feet, the depth of the riprap blanket should be increased accordingly (see Figure MD-12). As an alternative, a thinner layer of riprap (i.e., 1.75 to 2.0 d_{50}) may be used in the toe provided it is extended to 5.0 feet below the channel bottom. For sandy soils, it will be necessary to extend the riprap toe to even greater depths (5-foot minimum) and site-specific scour calculations are recommended.

4.4.2.5 Curves and Bends

The potential for erosion increases along the outside bank of a channel bend due to acceleration of flow velocities on the outside part of the bend. Thus, it is often necessary to provide erosion protection in channels that otherwise would not need protection; riprap is commonly used for this. The need for protection of the bank on the outside of the bend has been discussed in Section 4.1.6 for channel bends that have a radius less than 8 times the top width of the channel cross section.

Whenever an outside bend in a grass-lined channel needs protection, soil riprap should be used, then covered with native topsoil and revegetated to provide a grassed-line channel appearance. Note that buried soil riprap may lose its cover in a major event if vegetation has not fully matured, requiring re-burial and revegetation.

The minimum allowable radius for a riprap-lined bend is 2.0 times the top width of the design flow water surface. The riprap protection should be placed along the outside of the bank and should be extended downstream from the bend a distance of not less than 2.0 times the top width of the channel. The riprap does not need to be extended upstream of the point of curvature (start of the bend).

Where the mean channel velocity exceeds the allowable non-eroding velocity so that riprap protection is required for straight channel sections, increase the rock size using the adjusted flow velocity found using Equation MD-10. Use the adjusted velocity in Table MD-10 to select appropriate riprap size.

4.4.2.6 Transitions

Scour potential is amplified by turbulent eddies near rapid changes in channel geometry such as transitions and bridges. Table MD-10 may be used for selecting riprap protection for subcritical transitions (Froude numbers 0.8 or less) by using the maximum velocity in the transition and then increasing the velocity by 25%.

Protection should extend upstream from the transition entrance at least 5 feet and downstream from the transition exit for a distance equal to at least 5 times the design flow depth.

4.4.2.7 Design Discharge Freeboard

Freeboard above the design water surface shall not be less than that determined by Equation MD-12 in Section 4.3.1.5.

In addition to the freeboard height calculated using Equation MD-12, add the height of estimated standing waves and/or other water surface disturbances and calculate total freeboard. In all cases, the riprap lining shall be extended above the flow depth to provide freeboard.

4.4.3 Roughness Coefficient

The Manning's roughness coefficient, n, for a riprap-lined channel may be estimated for ordinary riprap using:

$$n = 0.0395 d_{50}^{1/6} \qquad \text{(MD-14)}$$

In which, d_{50} = the mean stone size in feet.

This equation does not apply to grouted boulders or to very shallow flow (where hydraulic radius is less than, or equal to 2.0 times the maximum rock size). In those cases the roughness coefficient will be greater than indicated by Equation MD-14.

4.4.4 Bedding Requirements

The long-term stability of riprap erosion protection is strongly influenced by proper bedding conditions. A large percentage of all riprap failures is directly attributable to bedding failures.

Properly designed bedding provides a buffer of intermediate-sized material between the channel bed and the riprap to prevent channel particles from leaching through the voids in the riprap. Two types of bedding are in common use: (1) a granular bedding filter and (2) filter fabric.

4.4.4.1 Granular Bedding

Two methods for establishing gradation requirements for granular bedding are described in this section. The first method, a single or two-layer bedding that uses Type I and II gradations, is shown in Table MD-11 and is adequate for most ordinary riprap and grouted riprap applications. The second utilizes a design procedure developed by Terzaghi, which is referred to as the T-V (Terzaghi-Vicksburg) design (Posey 1960, USACE 1970). The T-V filter criteria establish an optimum bedding gradation for a specific channel soil. The latter requires channel soil information, including a gradation curve, while the Type I and Type II bedding specifications given in Table MD-11 and Figure MD-13 are applicable whether or not soil information is available.

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Table MD-11—Gradation for Granular Bedding

U.S. Standard Sieve Size	Percent Weight by Passing Square-Mesh Sieves	
	Type I CDOT Sect. 703.01	Type II CDOT Sect. 703.09 Class A
3 inches	-----	90-100
1½ inches	-----	-----
¾ inches	-----	20-90
3/8 inches	100	-----
#4	95-100	0-20
#16	45-80	-----
#50	10-30	-----
#100	2-10	-----
#200	0-2	0-3

The Type I and Type II bedding specifications shown in Table MD-11 were developed using the T-V filter criteria and the fact that bedding which will protect an underlying non-cohesive soil with a mean grain size of 0.045 mm will protect anything finer. Since the T-V filter criterion provides some latitude in establishing bedding gradations, it is possible to make the Type I and Type II bedding specifications conform with Colorado Division of Highways' aggregate specifications. The Type I bedding in Table MD-11 is designed to be the lower layer in a two-layer filter for protecting fine-grained soils and has a gradation identical to Colorado Department of Transportation's (CDOT's) concrete sand specification AASHTO M-6 (CDOT Section 703.01). Type II bedding, the upper layer in a two-layer filter, is equivalent to Colorado Division of Highways' Class A filter material (Section 703.09 Class A) except that it permits a slightly larger maximum rock fraction. When the channel is excavated in coarse sand and gravel (50% or more of coarse sand and gravel retained on the #40 sieve by weight), only the Type II filter is required. Otherwise, a two-layer bedding (Type I topped by Type II) is required. Alternatively, a single 12-inch layer of Type II bedding can be used, except at drop structures. For required bedding thickness, see Table MD-12. At drop structures, a combination of filter fabric and Type II bedding is acceptable as an alternative to a two-layer filter.

Table MD-12—Thickness Requirements for Granular Bedding

Riprap Designation	Minimum Bedding Thickness (inches)		
	Fine-Grained Soils*		Coarse-Grained Soils**
	Type I	Type II	Type II
VL (d_{50} = 6 in), *L* (d_{50} = 9 in)	4	4	6
M (d_{50} = 12 in)	4	4	6
H (d_{50} = 18 in)	4	6	8
VH (d_{50} = 24 in)	4	6	8

* May substitute one 12-inch layer of Type II bedding. The substitution of one layer of Type II bedding shall not be permitted at drop structures. The use of a combination of filter fabric and Type II bedding at drop structures is acceptable.

** Fifty percent or more by weight retained on the # 40 sieve.

The specifications for the T-V reverse filter relate the gradation of the protective layer (filter) to that of the bed material (base) by the following inequalities:

$$D_{15(\ filter)} \leq 5d_{85(base)} \quad \text{(MD-15)}$$

$$4d_{15\,(base)} \leq D_{15(\ filter\ )} \leq 20d_{15(base)} \quad \text{(MD-16)}$$

$$D_{50(\ filter\ )} \leq 25d_{50\,(base\ )} \quad \text{(MD-17)}$$

in which, the capital "D" and lower case "d" refer to the filter and base grain sizes, respectively. The subscripts refer to the percent by weight, which is finer than the grain size denoted by either D or d. For example, 15% of the filter material is finer than $D_{15(filter)}$ and 85% of the base material is finer than $d_{85\,(base)}$. Application of the T-V filter criteria is best described using an example provided in Section 4.4.8.

4.4.4.2 Filter Fabric

Filter fabric is not a substitute for granular bedding. Filter fabric provides filtering action only perpendicular to the fabric and has only a single equivalent pore opening between the channel bed and the riprap. Filter fabric has a relatively smooth surface, which provides less resistance to stone movement. As a result, it is recommended that the use of filter fabric be restricted to slopes no steeper than 3H:1V. Tears in the fabric greatly reduce its effectiveness; therefore, direct dumping of riprap on the filter fabric is not allowed, and due care must be exercised during construction. Nonetheless, filter fabric has proven to be a workable supplement to granular bedding in many instances, provided it is properly selected, installed and not damaged during installation.

At drop structures and sloped channel drops, where seepage forces may run parallel to the fabric and cause piping along the bottom surface of the fabric, special care is required in the use of filter fabric. Seepage parallel with the fabric must be reduced by folding the edge of the fabric vertically downward about 2 feet (similar to a cutoff wall) at 12-foot intervals along the installation, particularly at the entrance and exit of the channel reach. Filter fabric has to be lapped a minimum of 12 inches at roll edges, with upstream fabric being placed on top of downstream fabric at the lap.

Fine silt and clay has been found to clog the openings in filter fabric. This prevents free drainage, increasing failure potential due to uplift. For this reason, a double granular filter is often more appropriate bedding for fine silt and clay channel beds. See Figure MD-14 for details on acceptable use of filter fabric as bedding.

4.4.5 Channel Cross Section

4.4.5.1 Side Slopes

For long-term maintenance needs, it is recommended that riprap channel linings be used only as toe protection in natural channel and in low-flow channel portion of an engineered channel, but not on the

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banks above the low-flow channel section. For this reason whenever soil-riprap linings are used above the low-flow section or above what is needed for toe protection, a slope typically used for grass-line channels is recommended (i.e., 4H:1V), with certain exceptions in retrofit situations with limited right of way, where a maximum steepness of 3H:1V may be used.

Riprap-lined and soil riprap-lined side slopes when used as described above that are steeper than 2.5H:1V are considered unacceptable because of stability, safety, and maintenance considerations. In some cases, such as under bridges and in retrofit situations where right-of-way is very limited, use of 2H:1V may be considered.

4.4.5.2 Depth

The maximum depth should be consistent with the guidelines in Section 4.4.2.2 of this chapter. For known channel geometry and discharge, normal water depth can be calculated using Manning's Equation from Section 3.1.1 of this chapter.

4.4.5.3 Bottom Width

The bottom width should be designed to satisfy the hydraulic capacity of the cross section, recognizing the limitations on velocity, depth, and Froude number. For a given discharge, the bottom width can be calculated from depth, velocity, slope, and Froude number constraints in Sections 4.4.2.1, 4.4.2.2, and 4.4.2.3 using Manning's Equation from Section 3.1.1 of this chapter.

4.4.5.4 Outfalls Into Channel

Outfalls into riprap-lined channels should be at least 1 foot (preferably 2 feet) above the channel invert.

4.4.6 Erosion Control

For a properly bedded and lined riprap channel section, in-channel erosion should not generally be a problem. As with concrete channels, the primary concern with erosion is control of erosion in the watershed tributary to the channel. Good erosion control practices in the watershed will reduce channel maintenance. In addition, accumulation of debris in the channel, especially after a large event, may be of concern due to the potential for movement of riprap and damming.

4.4.7 Maintenance

A maintenance access road with a minimum passage width of 12 feet shall be provided along the entire length of all major drainageways. The local government may require the road to have an all weather surface such as 5-inch-thick concrete pavement. Requirements for District maintenance eligibility are reviewed in Section 3.2.8 of this chapter. Of particular concern is the long-term loss of riprap, particularly due to the public removing rock. If grouted rock is used, follow the criteria for grouted boulders (i.e., use of grouted riprap is not an acceptable practice). Grout can deteriorate with time, and this should be monitored, as well. Improper grout installation creates long-term maintenance problems.

4.4.8 Calculation Example

Calculations for sizing a riprap-lined channel using hydraulic equations from Section 3.0 and criteria from Section 4.4 are shown in Example MD-3 using the **Riprap Worksheet** of the UD-Channels Spreadsheet. This example is located at the end of this chapter.

4.4.9 Design Submittal Checklist

Table MD-13 provides a design checklist for a riprap-lined channel.

Table MD-13—Design Submittal Checklist for Riprap-Line d Channel

Criterion Requirement	✓
Maximum normal depth velocity for 100-year event ≤12 ft/sec	
Channel capacity checked with Manning's n = 0.041	
Maximum velocity checked using Manning's n = 0.030	
Froude number ≤ 0.8	
Side slopes in low-flow channel and for toe protection in natural channel: no steeper than 2.5H:1V (see section 4.4.5.1).	
Use of soil riprap, buried with topsoil and revegetated, if type VL, L or M riprap in grass-lined channel is used. (Use of soil riprap is suggested for larger stones as well)	
Rock specific gravity ≥ 2.50 and meets other requirements in Section 4.1.1.1	
Riprap size determined using Equation MD-13 and Table MD-10	
Riprap blanket thickness ≥ 2.0 x d_{50}	
Blanket thickness increased at least 50% for ≥ 3 ft at upstream & downstream ends of lining	
Toe protection provided in accordance with Section 4.4.2.4	
Scour depth calculated for 100-yr flow to assure adequate toe thickness	
Outfalls into channel 1 to 2 ft above channel invert	
Riprap lined bend curve radius of the channel's centerline ≥ 2.0 x top width for 100-year event	
Channel bends size riprap using adjusted velocity in accordance with recommendations in section "4.1.6 Erosion Control" of the *USDCM*	
Riprap protection for outer bank of bend extended downstream at least 2 x 100-yr top width	
Minimum of 2.0 ft freeboard, including superelevation, for adjacent structures	
Riprap at transitions extended upstream by 5 ft and downstream by 5 x design flow depth	
Riprap sized for transitions using 1.25 times maximum transition velocity	
Appropriate gradation of granular bedding material per Section 4.4.4.1	
Adequate thickness for granular bedding Section 4.4.4.1	
District Maintenance Eligibility Guidelines satisfied	
Continuous maintenance access road provided (8-foot surface with 12-foot clear width, 20-foot at drop structures)	
Energy and hydraulic grade lines calculated and plotted for channel, with annotated design discharges shown	

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4.5 Bioengineered Channels

Bioengineered channels (see Photographs MD-10 and MD-11) emphasize the use of vegetative components in combination with structural measures to stabilize and protect stream banks from erosion. The District advocates the integration of bioengineering techniques into drainage planning, design, and construction when the use of such channels is consistent with the District's policies concerning flow carrying capacity, stability, maintenance, and enhancement of the urban environment and wildlife habitat. The following discussion on bioengineered channels interfaces closely with Section 4.2, Wetland Bottom Channels, and Section 4.6, Natural Channels; designers are encouraged to read Sections 4.2, 4.5 and 4.6, concurrently. In addition, because bioengineered channels require some structural assistance to maintain stability in urban settings, the designer is referred to guidance on drop structures in the HYDRAULIC STRUCTURES chapter.

4.5.1 Components

Vegetation is the basic component of what is known as "bioengineering" (Schiechtl 1980). Schiechtl (1980) states that, "bioengineering requires the skills of the engineer, the learning of the biologist and the artistry of the landscape architect."

It has been hypothesized that vegetation can function as either armor or indirect protection, and, in some applications, can function as both simultaneously (Biedenharn, Elliot, and Watson 1997 and Watson, Biedenharn, and Scott 1999). Grassy vegetation and the roots of woody vegetation may function as armor, while brushy and woody vegetation may function as indirect protection; the roots of the vegetation may also add a degree of geotechnical stability to a bank slope through reinforcing the soil (Biedenharn, Elliot, and Watson 1997 and Watson, Biedenharn, and Scott 1999), but these premises have not yet been technically substantiated through long-term field experience in urban settings. Each species of grass or shrub has differing ecological requirements for growth and differing characteristics such as root strength and density. Species should be selected based on each site's individual characteristics. Bioengineered channels must be designed with care and in full recognition of the physics and geomorphic processes at work in urban waterways and changing watersheds. Representative components of bioengineered channels include:

1. Planted riprap
2. Planted, grouted boulders
3. Brush layering
4. Fiber rolls
5. Fascines
6. Live willow stakes (with and without joint plantings in soil filled rock)
7. Live plantings in conjunction with geotextile mats
8. Wide ranges of planting of wetland and upland vegetation

9. Wrapped soil lifts for slope stability

See Photographs MD-10 and MD-13 and Figures MD-15 through MD-18 for more guidance.



Photograph MD-12—Willow plantings and vegetation along bioengineered channel.



Photograph MD-13—Integration of open water areas with major drainageways provides habitat and aesthetic benefits in addition to providing storage.

4.5.2 Applications

Bioengineered channels are applicable when channel designs are firmly grounded in engineering principles and the following conditions are met:

1. Hydrologic conditions are favorable for establishment and successful growth of vegetation.

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2. Designs are conservative in nature, and bioengineered features are used to provide redundancy.
3. Maintenance responsibilities are clearly defined.
4. Adequate structural elements are provided for stable conveyance of the major runoff flow.
5. Species are selected based on individual site characteristics.

4.5.3 Bioengineering Resources

The purpose of this section is to provide the designer with an overview of bioengineering and basic guidelines for the use of bioengineered channels on major drainage projects within the District. There are many sources of information on bioengineering that the designer should consult for additional information when planning and designing a bioengineered channel (Watson, Biedenharn, and Scott 1999; USFISRWG 1998; Riley 1998; and Biedenharn, Elliot, and Watson 1997).

4.5.4 Characteristics of Bioengineered Channels

The following characteristics are generally associated with bioengineered channels:

1. Their design must address the hydrologic changes associated with urbanization (increased peak discharges, increased runoff volume, increased base flow, and increased bank-full frequency). These changes typically necessitate the use of grade control structures. In the absence of grade control structures, especially in the semi-arid climate of the Denver area, purely bioengineered channels will normally be subject to bed and bank erosion, channel instability, and degradation.

2. In addition to grade controls, most bioengineered channels require some structural methods to assist the vegetation with maintaining channel stability. Examples include buried riprap at cannel toes and at outer channel banks (see Figures MD-16, MD-17 and MD-18).

3. The designer must ensure that there will be sufficient flow in the channel (or from other sources, such as locally high groundwater) to support the vegetation. A complicating factor is that, in newly developing areas, base flows will *not* be present; whereas, if the tributary drainage area is large enough, base flows will often materialize after substantial urbanization has occurred. Therefore, it is important to match the channel stabilization technique to the water available at the time of construction, whether naturally or from supplemental water sources.

4. The extent to which vegetative techniques for channel stabilization will need to be supplemented with structural measures is a function of several factors:

    a. Slope
    b. Maximum velocity during 5-year event
    c. Maximum velocity during 100-year event
    d. Froude number during 5-year event
    e. Froude number during 100-year event

f. Tractive force
g. Sinuosity
h. Timing of period of construction relative to the growing season
i. Other site-specific factors

In general, slight channel slopes, lower velocities, lower Froude numbers, lower tractive force values, and higher sinuosity are conducive to channel stabilization approaches that emphasize bioengineering. These factors indicate that park-like settings (areas of open space, parks, office parks, etc.) are often conducive to bioengineered projects because they provide space for the channel to have a meander pattern that increases flow length and decreases channel slope, velocities, and tractive forces.

A technique that can be utilized is stabilization of the outer banks of a defined low-flow channel to withstand the major storm. Within the defined low-flow channel, base flows and small storm flows can then assume their own flow path (meander pattern). This pattern can either be pre-established (with a "pilot" channel) or the flows can move freely from one side of the hardened low-flow channel to the other, thereby establishing their own pattern.

Figure MD-19 shows examples of details for boulder toe protection (grouted and ungrouted, for one- and two-boulder high toe walls) that can be used to define a hardened, low-flow channel within which base flows and small storm flows can freely meander. Boulders should be placed on a Type L riprap foundation, and boulders should be aligned so that they are wider than they are tall. Boulders should be placed so that the top of the toe protection wall is flat. If stacking is stable, grouting may not be necessary. In areas where the channel is easily accessible to the public, the top row of boulders may be grouted in place so that vandals cannot remove them.

4.5.5 Advantages of Bioengineered Channels

Public reaction to bioengineered channels is generally favorable, not only in metropolitan Denver, but also regionally and nationally. In contrast to major drainageway stabilization projects that focus on structural measures, such as concrete-lined or riprap-lined channels, bioengineered channels:

1. Appear more natural in character and, often, more like a channel prior to urbanization. When post-urbanization hydrology permits, riparian areas may be created where there previously was little vegetation. Also, wetlands can often be created in conjunction with bioengineered channels.
2. Have a "softer" appearance and are generally judged by most to be more aesthetic.
3. Are often found where space is not a limitation, such as in public parks and open space areas.
4. Generally, provide wildlife habitat.
5. Provide other benefits such as passive recreational opportunities for the public (like bird watching), open space creation/preservation, potentially water temperature moderation, and/or water quality enhancement.

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6. Create a living system that may strengthen over time.
7. Can facilitate obtaining 404 permits.

4.5.6 Technical Constraints

The following constraints are associated with bioengineered channels:

1. There is only limited experience to rely on for successful design of urban channels. The majority of the experience with bioengineering techniques relates to channels in nonurban settings.
2. The semi-arid conditions that characterize Denver can be at odds with the need for an adequate water supply for maintaining the vegetation. Careful species selection that reflects the site's soils and water availability characteristics is essential.
3. A basic design criterion within the District is to demonstrate channel stability during the major (100-year) storm, due to public safety and property protection concerns within urban areas. There is little evidence (locally, regionally, or nationally) as to whether purely bioengineered channels can withstand 100-year (or lesser) flood forces.
4. Significant space can be required for bioengineered channels, yet space is often at a premium in urban areas.
5. Bioengineered facilities can be more expensive than their traditional counterparts.
6. Bioengineered channels can be maintenance intensive, particularly in their early years.
7. During the early years while the vegetation is becoming established, if a significant storm occurs, the probability of significant damage to the facility and adjacent infrastructure and properties (i.e., economic loss) is high.

Additional potential constraints of vegetative stabilization methods are summarized by Biedenharn, Elliot, and Watson (1997), as follows:

- Even well executed vegetative protection cannot be planned and installed with the same degree of confidence, or with as high a safety factor, as structural protection. Vegetation is especially vulnerable to extremes of weather, disease, insects, and inundation before it becomes well established.
- Most vegetation has constraints on the season of the year that planting can be performed.
- Growth of vegetation can cause a reduction in flood conveyance or erosive increases in velocity in adjacent un-vegetated areas.
- Vegetation can deteriorate due to mismanagement by adjacent landowners or natural causes.
- Trunks of woody vegetation or clumps of brushy vegetation on armor revetments can cause local flow anomalies, which may damage the armor.
- Large trees can threaten the integrity of structural protection by root invasion, by toppling and damaging the protection works, by toppling and directing flow into an adjacent unprotected bank,

or by leaving voids in embankments due to decomposition.

- Roots can infiltrate and interfere with internal bank drainage systems or cause excess infiltration of water into the bank.
- Many of these problems may be avoided through selection of the appropriate type and species of vegetation. Such selections and expert advice must be obtained from qualified individuals in revegetation and bioengineering. Invasion by other species is quite likely over the years the bioengineered channel is in operation.

4.5.7 Design Guidelines

To provide the designer with guidelines for the applicability of bioengineered channels, a comparison of hydraulic characteristics is provided in Table MD-14 for four types of channels, ranging from a fully bioengineered channel to a structural channel. To allow for growth of vegetation and accumulation of sediment, outfalls into bioengineered channels should be 1 to 2 feet above the channel invert.

Table MD-14—Guidelines for Use of Various Types of Channels

(Note: All channel types typically require grade control structures.)

Design Parameter	Fully Bioengineered Channel	Bioengineered Channel Including Structural Elements	Structural Channel With Bioengineered Elements	Structural Channel
Maximum Slope	0.2%	0.5%	0.6%	1.0%
Is base flow necessary?	Yes	Yes	Yes	No
V_{max} for $Q_{5\text{-}year}$*	3.5 ft/sec (2.5)	4.0 ft/sec (3.0)	5.0 ft/sec (3.5)	**
V_{max} for $Q_{100\text{-}year}$*	5.0 ft/sec (3.5)	6.0 ft/sec (4.5)	7.0 ft/sec (5.0)	**
$F_{r5\text{-}year}$	0.4 (0.3)	0.6 (0.4)	0.7 (0.5)	**
$F_{r100\text{-}year}$	0.4 (0.3)	0.8 (0.5)	0.8 (0.5)	**
Maximum tractive force (100-year event)	0.30 lb/ft^2	0.60 lb/ft^2	1.00 lb/ft^2	1.30 lb/ft^2
Maximum sinuosity	1.6	1.2	1.2	1.0

* Values presented for both non-erosive and erosive soils. Erosive soil values are in parenthesis ( ).

** With a purely structural channel, such as a reinforced concrete channel, allowable velocities and allowable Froude numbers, F_r, are based on site-specific design calculations.

4.6 Natural Channels

Natural waterways in the Denver region are sometimes in the form of steep-banked gulches, which have eroding banks and bottoms. On the other hand, many natural waterways exist in urbanized and to-be-urbanized areas, which have mild slopes, are reasonably stable, and are not currently degrading. If the channel will be used to carry storm runoff from an urbanized area, it can be assumed that the changes in the runoff regime will increase channel erosion and instability. Careful hydraulic analysis is needed to

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address this projected erosion. In most cases, stabilization of the channel will be required. Stabilization using bioengineering techniques, described in Section 4.5 of this chapter, has the advantage of preserving and even enhancing the natural character and functions of the channel. Some structural stabilization measures will also be required in combination with the bioengineered stabilization measures.

In the Denver area, most natural waterways will need drops and/or erosion cutoff check structures to maintain a mild channel slope and to control channel erosion. Typically, these grade control structures are spaced to limit channel degradation to what is expected to be the final stable longitudinal slope after full urbanization of the tributary watershed. In the Denver area, this slope, depending on watershed size and channel soils, has been observed to range from 0.2 to 0.6%, with the South Platte River itself approaching a slope of 0.1%. Whenever feasible, natural channels should be kept in as near a natural condition as possible by limiting modifications to those necessary to protect against the destabilizing hydrologic forces caused by urbanization.

Investigations needed to ensure that the channel is stable will differ for each waterway; however, generally, it will be necessary to measure existing cross sections, investigate the bed and bank material, determine soil particle size distribution, and study the stability of the channel under future conditions of flow. At a minimum, the designer should consider the concept of the stable channel balance discussed in Section 1.5.3 of this chapter, complete tractive force analysis, and apply the Leopold equations to evaluate channel stability and changes in channel geometry. Oftentimes, more sophisticated analysis will be required. When performing stability and hydraulic analyses, keep in mind that supercritical flow normally does not exist in natural-earth channels. During backwater computations, check to ensure that the computations do not reflect the presence of consistent supercritical flow (Posey 1960).

Because of the many advantages of natural channels to the community (e.g., preservation of riparian habitat, diversity of vegetation, passive recreation, and aesthetics), the designer should consult with experts in related fields as to method of development. Nowhere in urban hydrology is it more important to convene an environmental design team to develop the best means for using a natural waterway. It may be concluded that park and greenbelt areas should be incorporated into the channel design. In these cases, the usual rules of freeboard, depth, curvature, and other rules applicable to artificial channels often will need to be modified to better suit the multipurpose objectives. For instance, there are advantages that may accrue if the formal channel is designed to overtop, resulting in localized flooding of adjacent floodplain areas that are laid out for the purpose of being inundated during larger (i.e., > 10-year) flood events. See the STORAGE chapter of this *Manual*.

The following design criteria are recommended when evaluating natural channels:

1. The channel and overbank floodplain should have adequate capacity for the 100-year flood.
2. A water surface profile should be defined in order to identify the 100-year floodplain, to control

earthwork, and to build structures in a manner consistent with the District's and local floodplain regulations and ordinances.

3. Use roughness factors (n) representative of un-maintained channel conditions for analysis of water surface profiles. Roughness factors for a variety of natural channel types are presented in Table MD-1.
4. Use roughness factors (n) representative of maintained channel conditions to analyze effects of velocities on channel stability. Roughness factors for a variety of natural channel types are presented in Table MD-1.
5. Prepare plan and profile drawings of the channel and floodplain.
6. Provide erosion-control structures, such as drop structures or grade-control checks, to control channel erosion and/or degradation as the tributary watershed urbanizes.
7. Outfalls into natural channels should be 2 feet above the channel invert to account for vegetation and sediment accumulation. The engineer should visit the site of any outfalls into natural drainageways to examine the actual ground surface condition.

4.7 Retrofitting Open-Channel Drainageways

Many projects involving major drainage system design will occur in areas that have already been developed, rather than in newly urbanizing areas. Design of major drainageways in these areas can be challenging due to limitations of the existing major drainage system, right-of-way constraints, community desires, and public acceptance. While underground conduits or hard-lined channels may be required in some situations, the designer should first consider the option of retrofitting a channel to provide flood conveyance and other recreational, aesthetic, environmental, and/or water quality benefits. Retrofitting a major drainage channel may be appropriate when:

1. The retrofitted channel will be capable of conveying the major flow event in a stable manner.
2. The retrofitted channel will provide recreational, aesthetic, environmental, and/or water quality benefits that other design options (i.e., an underground conduit or concrete channel) would not provide.
3. The retrofitted channel will not pose an increased public health or safety risk and, preferably, will be a safer alternative than other design options.

4.7.1 Opportunities for Retrofitting

Opportunities for retrofitting exist in many projects occurring in areas that have already been developed. Retrofitting is well suited to areas such as urban parks and designated open space areas where right-of-way is not too restricted by existing development. Retrofitting is especially favorable for redevelopment projects in urban areas that seek to incorporate the major drainageway as a feature of the development, providing aesthetic, recreational, and/or water quality benefits.

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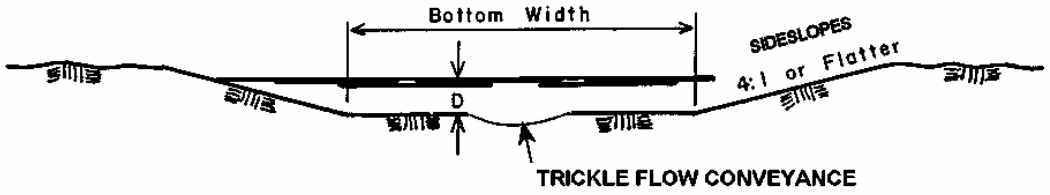
4.7.2 Objectives of Retrofitting

The foremost objective of retrofitting a drainageway must be to provide stable conveyance of the major flow event for the future developed condition of the watershed. Other objectives of retrofitting include:

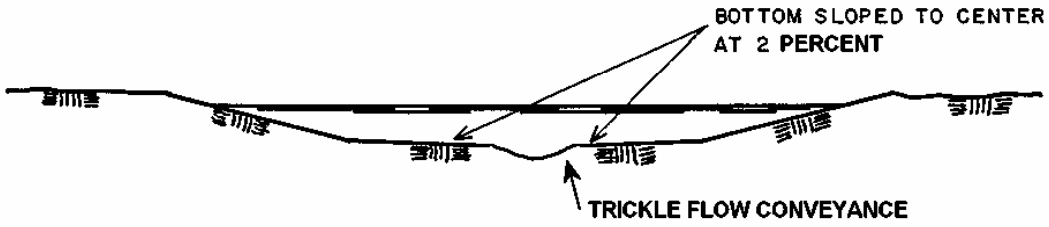
1. Creating multi-use areas. Uses that may be compatible with a well-designed retrofitted major drainageway include recreation, open space, parks and trails, wildlife corridors, restoration of vegetation for diversity and habitat, and others.
2. Enhancing channel aesthetics. Revegetation and landscaping can provide a riparian corridor that is attractive to the public as well as wildlife.
3. Enhancing water quality. Improved channel stabilization resulting from a major drainage channel retrofit has a direct benefit to water quality in reducing erosion and sediment transport. In addition, retrofitting can create aquatic habitat, and riparian vegetation and soil microorganisms can provide a degree of water quality treatment. Retrofitting can also be designed to limit access to some portions of the channel or to encourage access in specific areas that are more frequently maintained and/or equipped with trash cans.
4. Increasing benefit-to-cost ratio. For retrofitting to be acceptable, in most cases, it must be cost effective. Retrofitting an open channel may often be less expensive than constructing an underground conduit. Even when retrofitting costs are comparable to or higher than the costs of other design options, the multi-use potential for a retrofitted channel may justify the additional cost by providing benefits that otherwise would require separate facilities for each use.

4.7.3 Natural and Natural-Like Channel Creation and Restoration

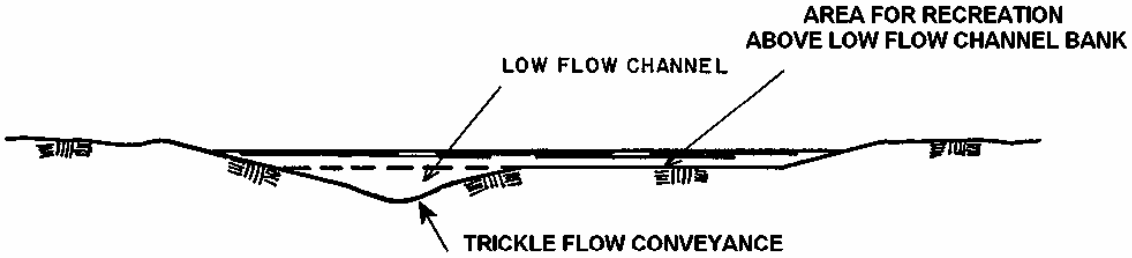
The designer should refer to Sections 4.1, 4.2, and 4.5 for guidance and criteria for creation of grass-lined channels, channels with wetland bottoms, and bioengineered channels, respectively.



CROSS SECTION WITH OVAL OR SLOPED BOTTOM WITH TRICKLE CHANNEL



CROSS SECTION WITH OVAL OR SLOPED BOTTOM WITH TRICKLE CHANNEL



CROSS SECTION WITH LOW FLOW CHANNEL WITH TRICKLE CHANNEL
AREA FOR MAJOR DRAINAGE RUNOFF



CROSS SECTION WITH LOW FLOW CHANNEL WITH
OVERFLOW AREA FOR MAJOR DRAINGAE RUNOFF

Figure MD-5—Typical Grassed Channels

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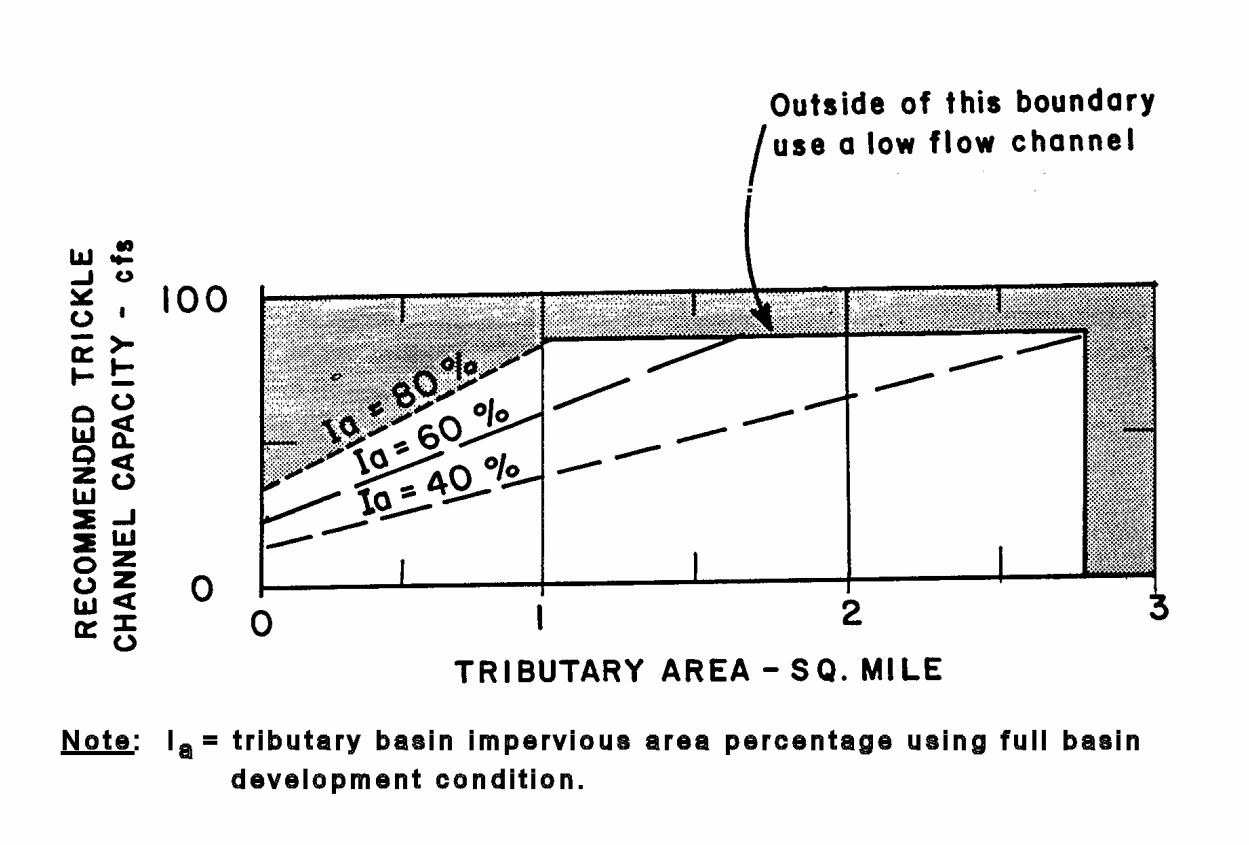
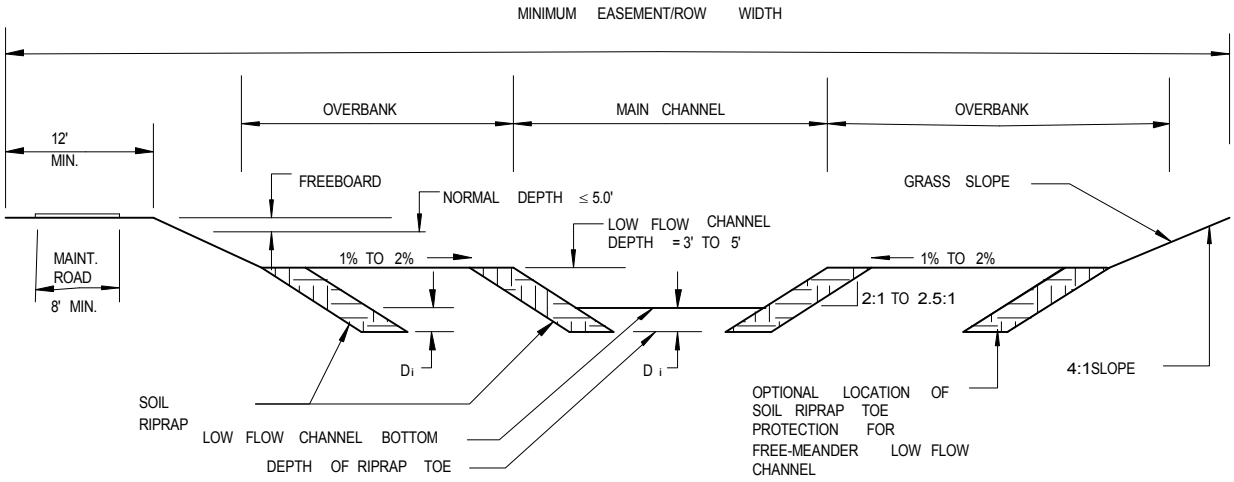


Note: I_a = tributary basin impervious area percentage using full basin development condition.

Figure MD-6—Minimum Capacity Requirements for Trickle Channels



NOTE:

1. LOW FLOW CHANNEL: CAPACITY TO BE THE EQUIVALENT OF $\frac{1}{3}$ TO $\frac{1}{2}$ OF THE 2-YEAR FLOW BASED ON FULLY DEVELOPED TRIBUTARY WATERSHED PEAK FLOW.
2. NORMAL DEPTH: FLOW DEPTH FOR 100-YEAR FLOW SHALL NOT EXCEED 5 FEET, NOT INCLUDING THE LOW FLOW CHANNEL DEPTH. 100-YEAR FLOW VELOCITY AT NORMAL DEPTH SHALL NOT EXCEED 7 FT/S FOR CHANNELS WITH EROSION RESISTANT SOILS OR 5 FT/S FOR CHANNELS WITH EROSIVE SOILS.
3. FREEBOARD: FREEBOARD TO BE A MINIMUM OF 1 FOOT.
4. MAINTENANCE ACCESS ROAD: MINIMUM STABLE WIDTH TO BE 8 FEET WITH A CLEAR WIDTH OF 12 FEET.
5. ROW WIDTH: MINIMUM WIDTH TO INCLUDE FREEBOARD AND MAINTENANCE ACCESS ROAD.
6. OVERBANK: FLOW IN EXCESS OF MAIN CHANNEL TO BE CARRIED IN THIS AREA. AREA MAY BE USED FOR RECREATION PURPOSES.
7. D_i = 3-FOOT MINIMUM FOR EROSION RESISTANT SOILS.
   D_i = 5-FOOT MINIMUM FOR SANDY SOILS
8. CHANNEL SIDESLOPE ABOVE LOW-FLOW CHANNEL 4H:1V OR FLATTER, EVEN IF LINED WITH SOIL RIPRAP.
9. FROUDE NUMBER FOR ALL FLOWS SHALL NOT EXCEED 0.8 FOR EROSION RESISTANT SOILS AND 0.5 FOR EROSIVE SOILS.
10. THE CHANNEL CAN BE DESIGNED TO HAVE THE LOW-FLOW SECTION TO HAVE A WETLAND BOTTOM.

Figure MD-7—Composite Grass-line Channel with a Low-Flow Channel, including a Wetland Bottom Low-Flow Channel

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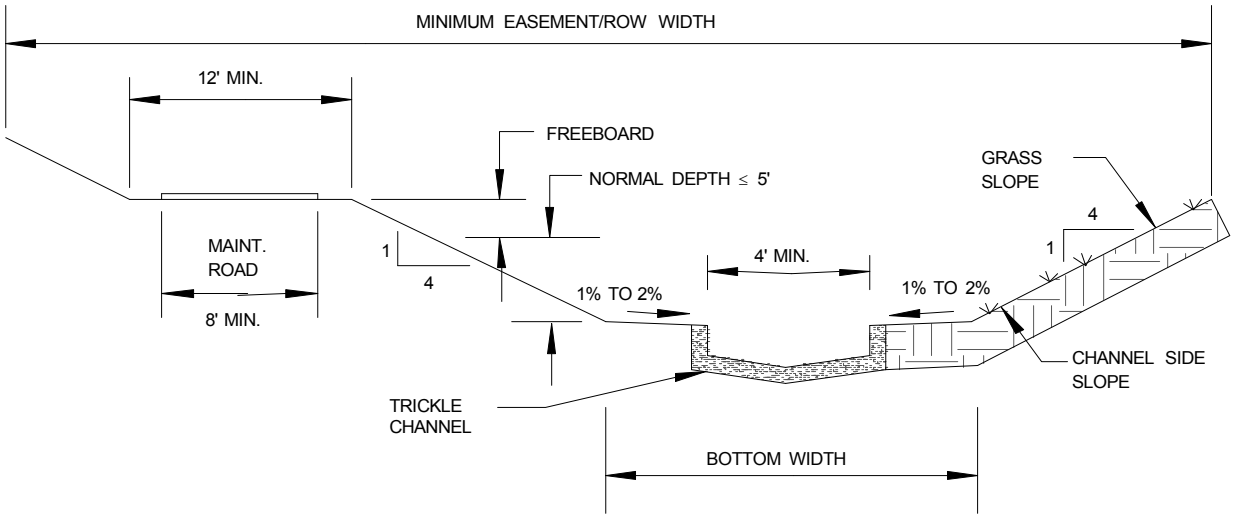

NOTES:

1. BOTTOM WIDTH: CONSISTENT WITH MAXIMUM ALLOWABLE DEPTH AND VELOCITY REQUIREMENTS, SHALL NOT BE LESS THAN TRICKLE CHANNEL WIDTH.

2. TRICKLE CHANNEL: CAPACITY TO BE APPROXIMATELY 2% OF 100-YEAR FLOW FOR THE FULLY DEVELOPED, UNDETAINED CONDITION TRIBUTARY WATERSHED PEAK FLOW. USE NATURAL LINING WHEN PRACTICAL.

3. NORMAL DEPTH: NORMAL DEPTH AT 100-YEAR FLOW SHALL NOT EXCEED 5 FEET. MAXIMUM 100-YEAR FLOW VELOCITY AT NORMAL DEPTH SHALL NOT EXCEED 7 FT/S FOR CHANNELS WITH EROSION RESISTANT SOILS OR 5 FT/S FOR CHANNELS WITH EROSIVE SOILS.

4. FREEBOARD: FREEBOARD TO BY A MINIMUM OF 1 FOOT.

5. MAINTENANCE ACCESS ROAD: MINIMUM STABLE WIDTH TO BE 8 FEET WITH CLEAR WIDTH OF 12 FEET.

6. EASEMENT/ROW WIDTH: MINIMUM WIDTH TO INCLUDE FREEBOARD AND MAINTENANCE ACCESS ROAD.

7. CHANNEL SIDE SLOPE: MAXIMUM SIDE SLOPE FOR GRASSED CHANNELS TO BE NO STEEPER THAN 4:1.

8. FROUDE NUMBER: MAXIMUM VALUE FOR MINOR AND MAJOR FLOODS SHALL NOT EXCEED 0.8 FOR CHANNELS WITH EROSION RESISTANT SOILS OR 0.5 FOR CHANNELS WITH EROSIVE SOILS.

Figure MD-8—Grass-lined Channel with a Trickle Channel

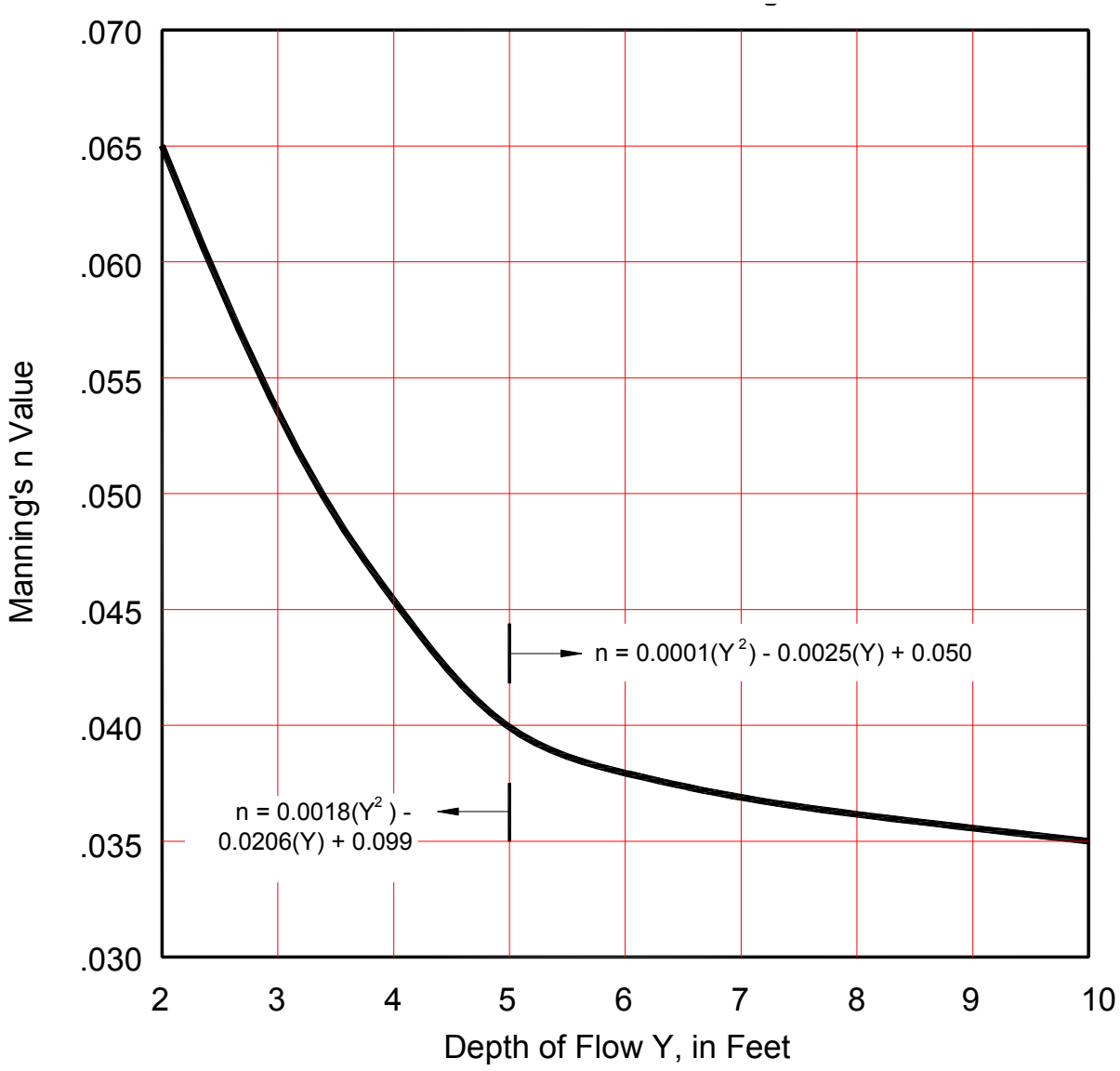

Figure MD-9a—Manning's *n* vs. Depth for Low-Flow Section in a Composite Channel.

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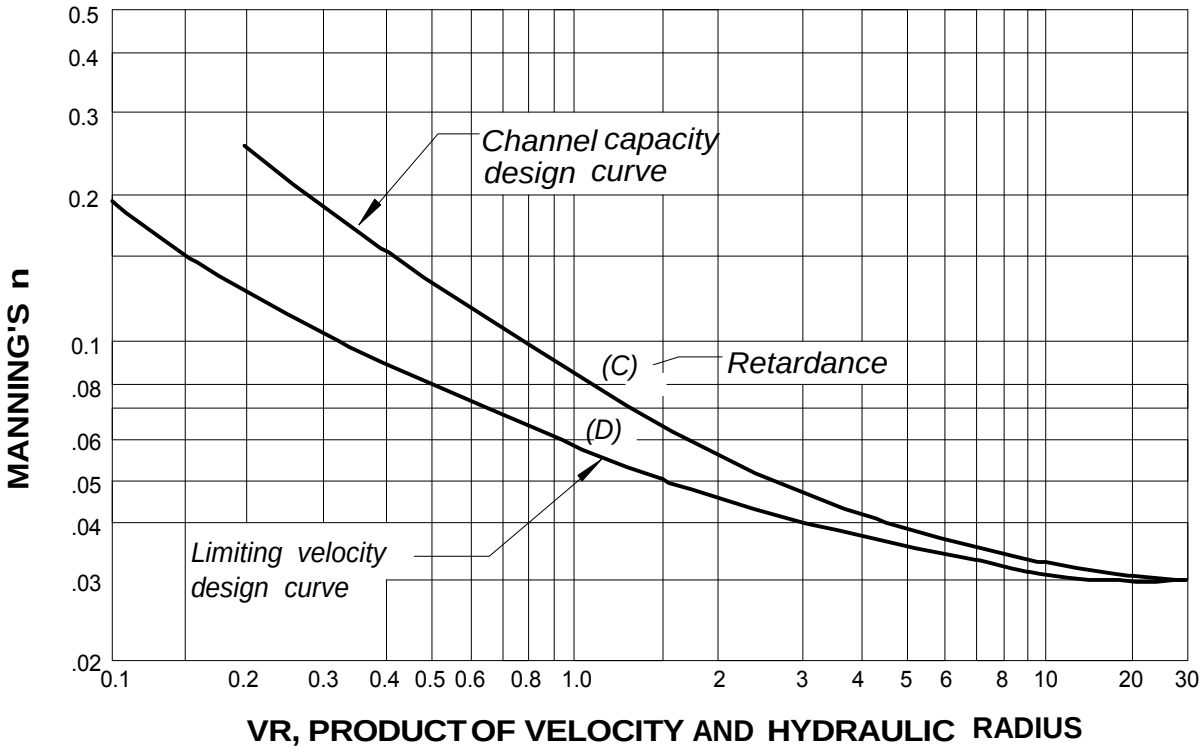

From "Handbook of Channel Design For Soil and Water Conservation,: U.S. Department of Agriculture, Soils Conservation Service, No. SCS-TP-61 March, 1947, Rev. June, 1954

Figure MD-9b—Manning's n vs. VR for Two Retardances in Grass-Lined Channels.

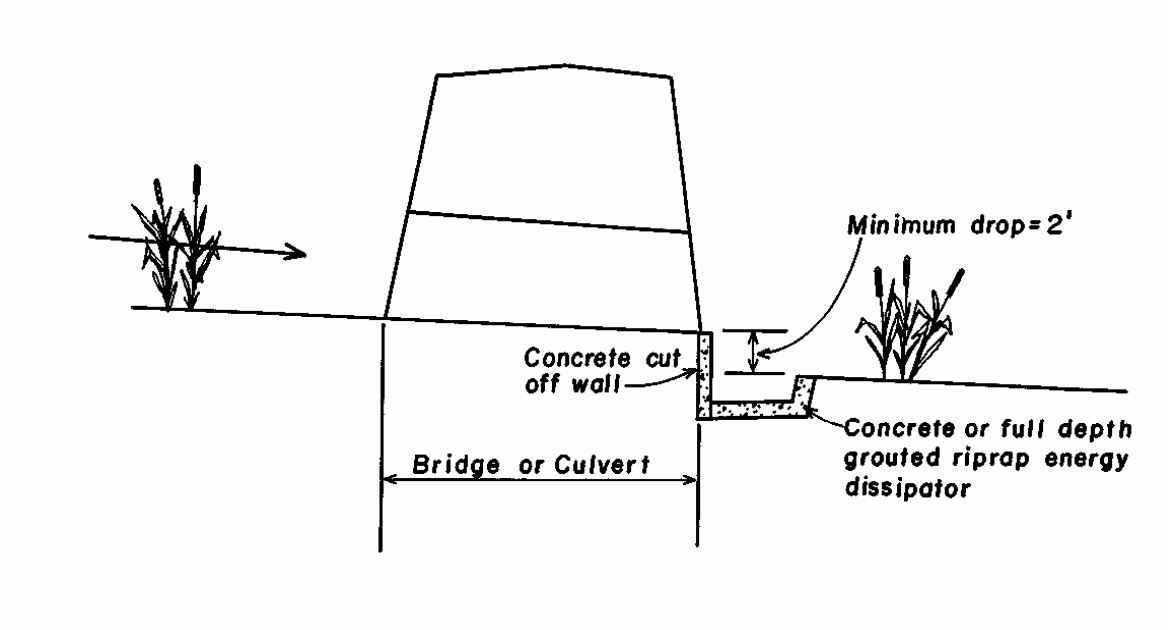

Figure MD-10—Composite (Wetland Bottom) Channel At Bridge or Culvert Crossing

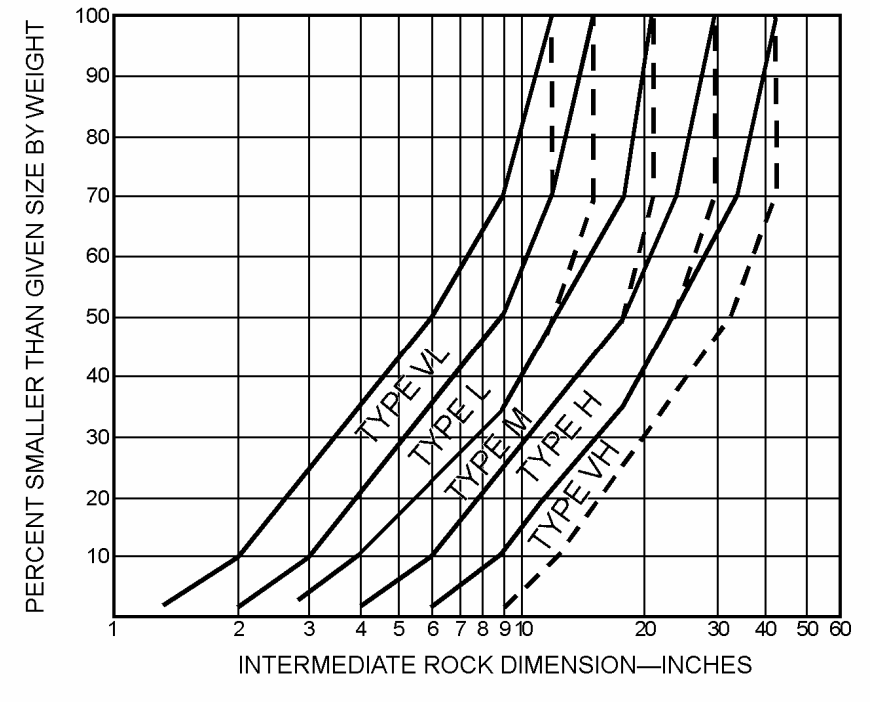

Figure MD-11—Gradation of Ordinary Riprap

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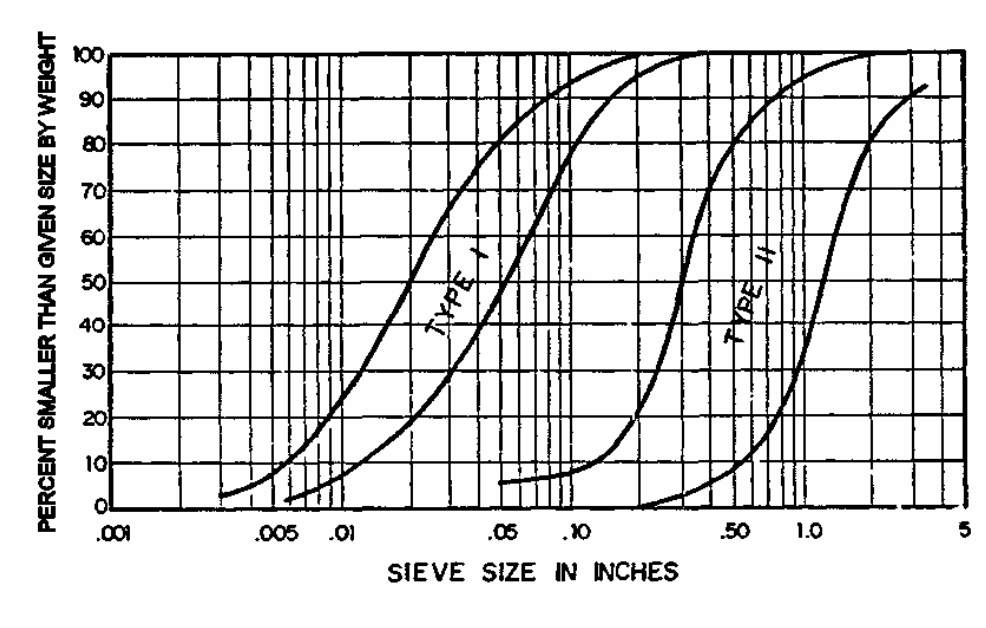
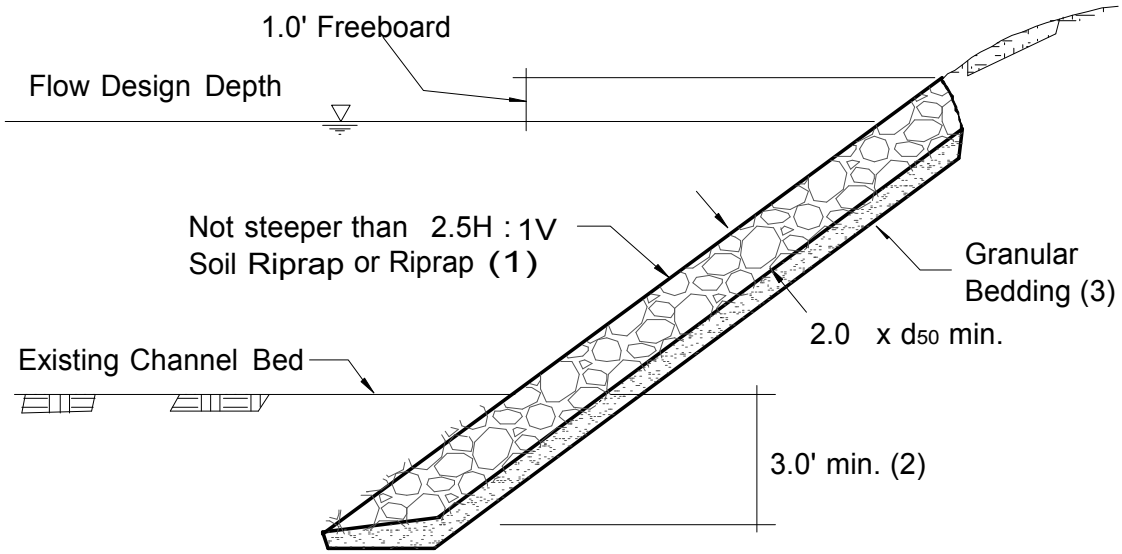


Figure MD-12—Gradation Curves for Granular Bedding

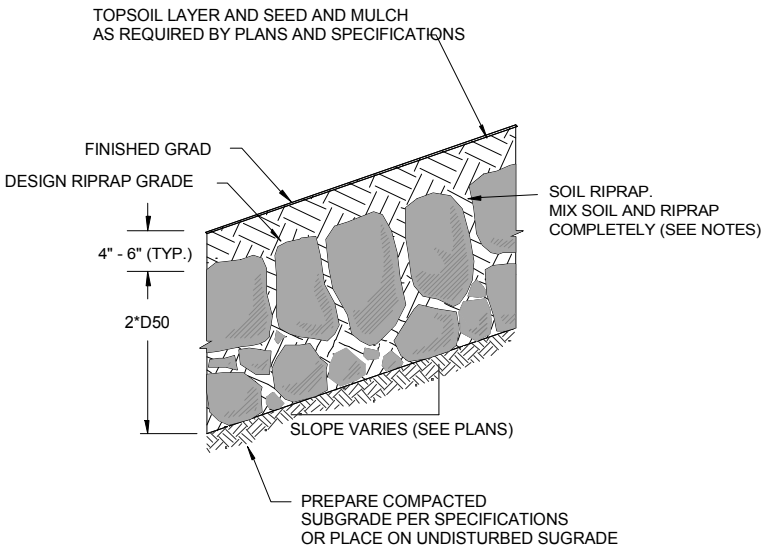


(1) Use Soil Riprap when d_{50} is less than or equal to Type M. (Suggest use of Soil Riprap for larger riprap sizes as well)

(2) 5 - feet minimum in sandy or erosive soils.

(3) Eliminate granular bedding when soil-riprap is used.

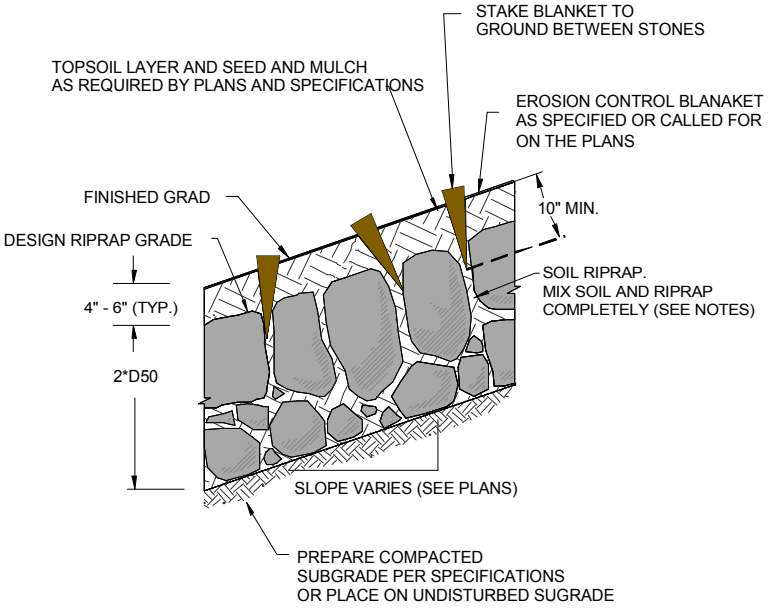
Figure MD-13a—Riprap Channel Bank Lining, Including Toe Protection

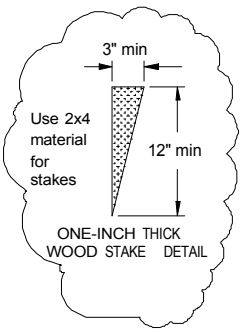


TYPICAL SECTION -
SOIL RIPRAP WITH MUCLH

NOTES:

1. SOIL RIPRAP DETAILS ARE APPLICABLE TO SLOPED AREAS. REFER TO THE SITE PLAN ACTUAL LOCATION AND LIMITS.
2. MIX UNIFORM ALLY 65% RIPRAP BY VOLUME WITH 35% OF APPROVED SOIL BY VOLUME PRIOR TO PLACEMENT.
3. PLACE STONE-SOIL MIX TO RESULT IN SECURELY INTERLOCKED ROCK AT THE DESIGN THICKNESS AND GRADE. COMPACT AND LEVEL TO ELIMINATE ALL VOIDS AND ROCKS PROJECTING ABOVE DESIGN RIPRAP TOP GRADE.
4. CRIMP OR TACKIFY MULCH OR USE APPROVED HYDROMULCH AS CALLED FOR IN THE PLANS AND SPECIFICATIONS.





TYPICAL SECTION -
SOIL RIPRAP WITH EROSION CONTROL FABRIC

Figure MD-13b—Soil Riprap Typical Details

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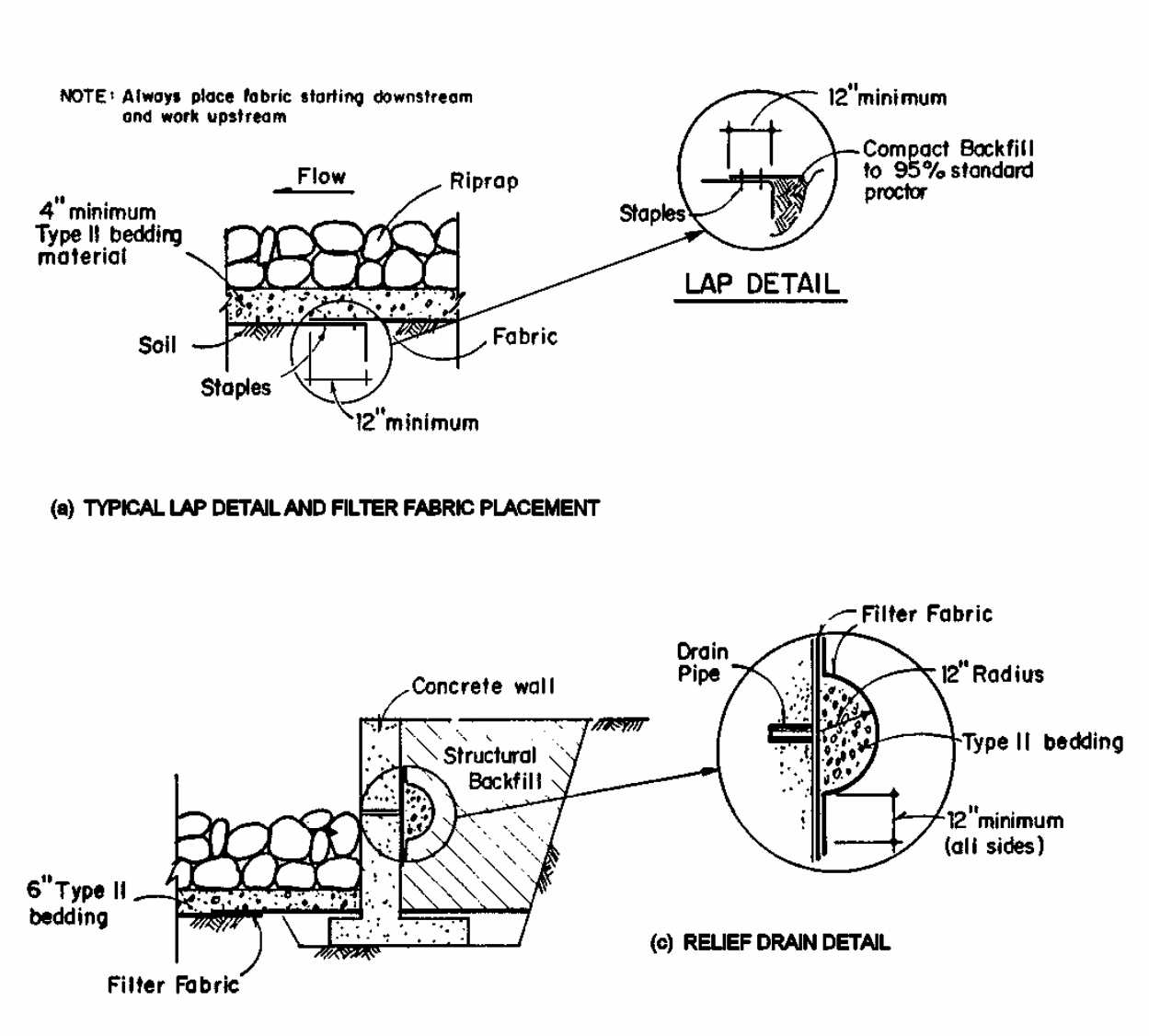

Figure MD-14—Filter Fabric Details

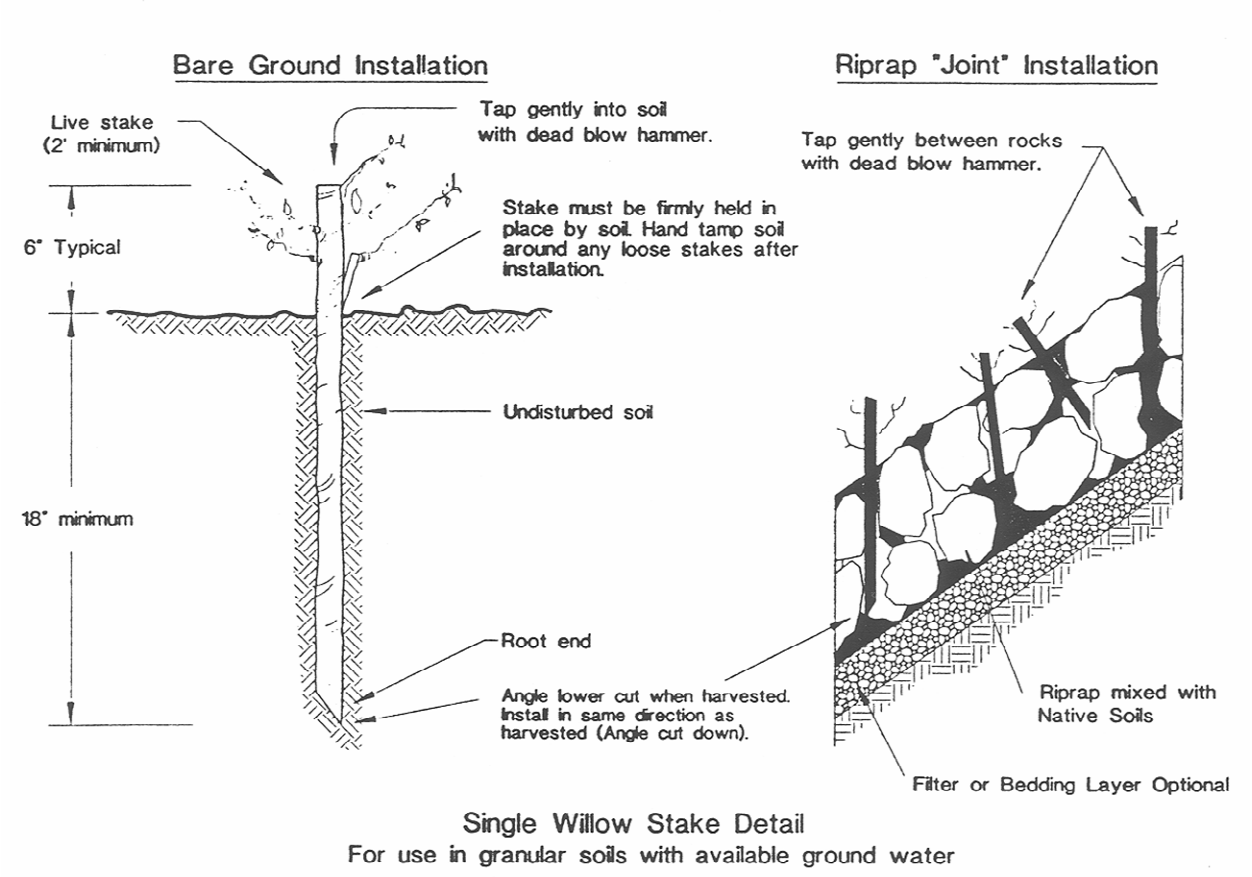

Figure MD-15—Live Willow Staking for Bare Ground and Joint Installation

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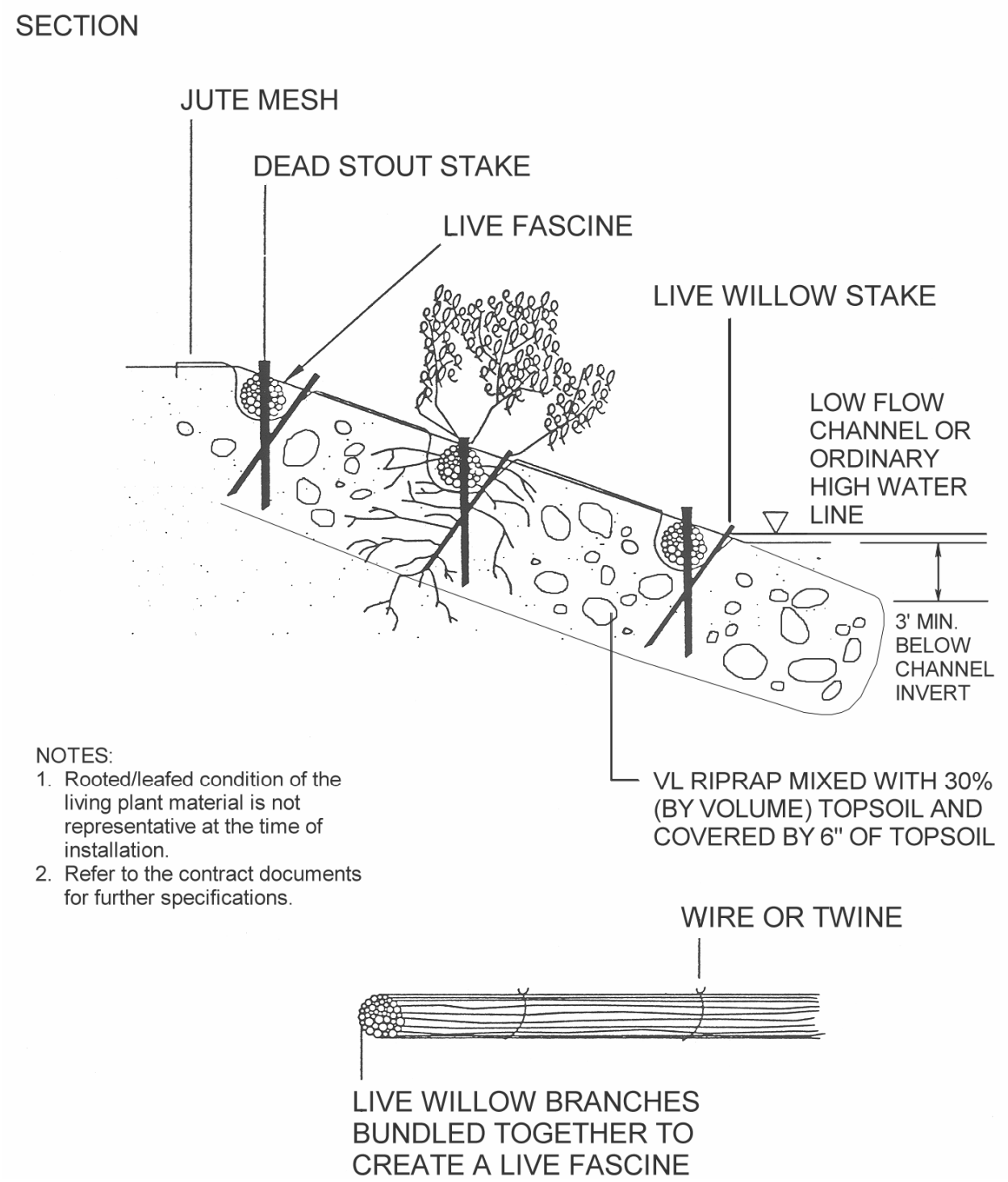
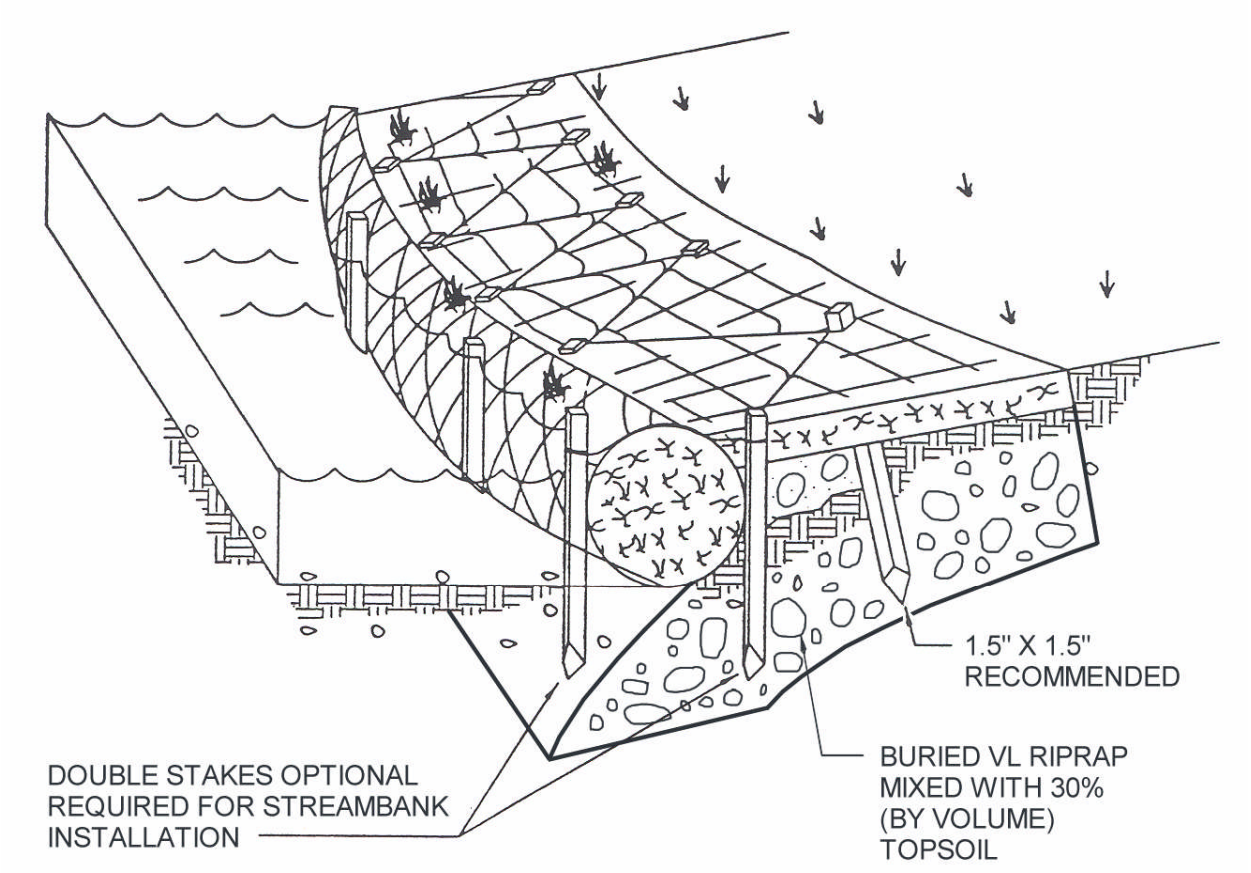


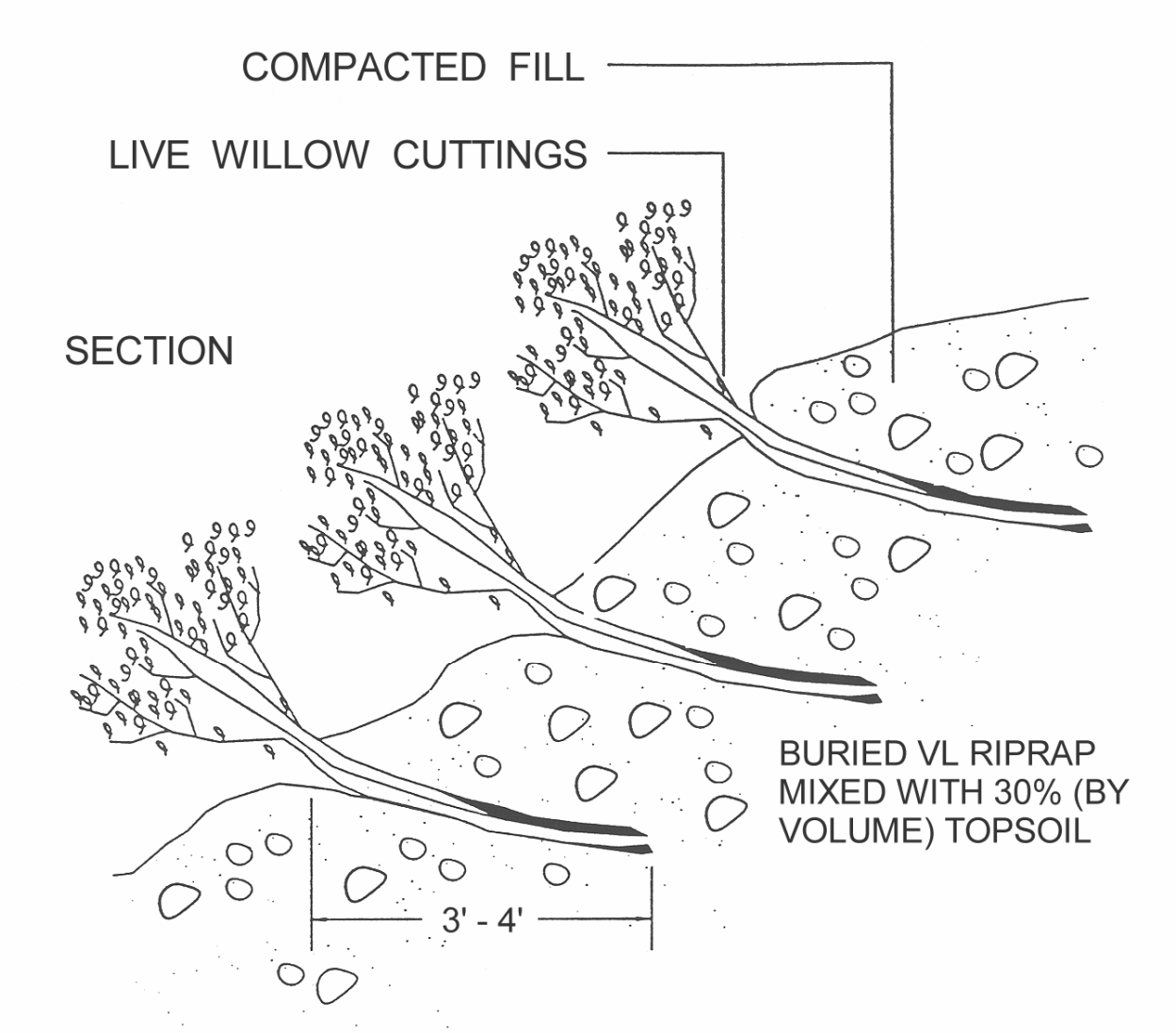
Figure MD-16—Fascine in Conjunction With Jute Mesh Mat



NOTES:
1. LENGTH OF STAKE DETERMINED BY THE SUBSTRATE.
2. REFER TO CONTRACT DOCUMENTS FOR FURTHER DETAILS.

Reprinted from Salix Applied Earthcare, Erosion Draw 2.0, 1996

Figure MD-17—Fiber Roll

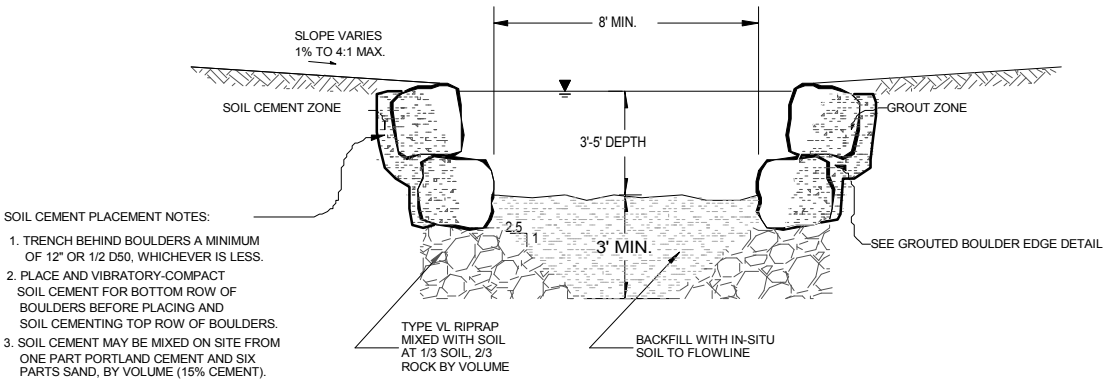


NOTES:

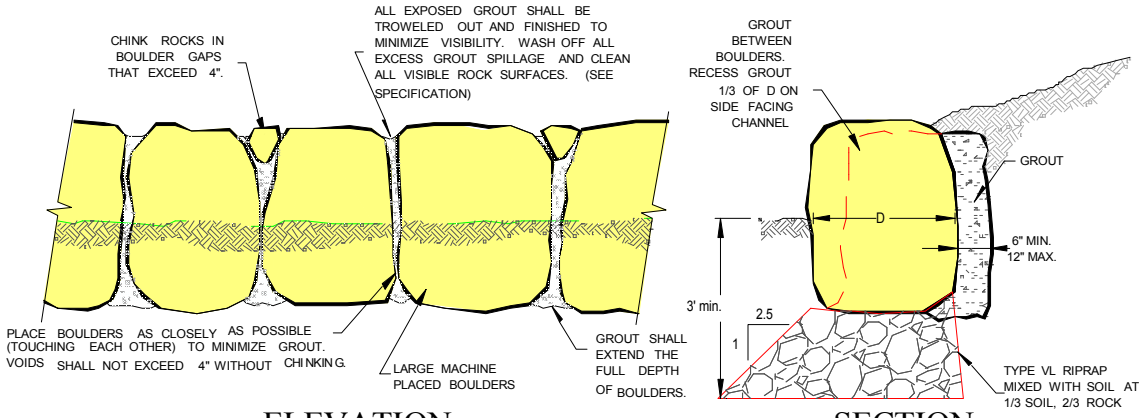
1. Rooted/leafed condition of the living plant material is not representative at the time of installation.

2. Refer to the contract documents for further details.

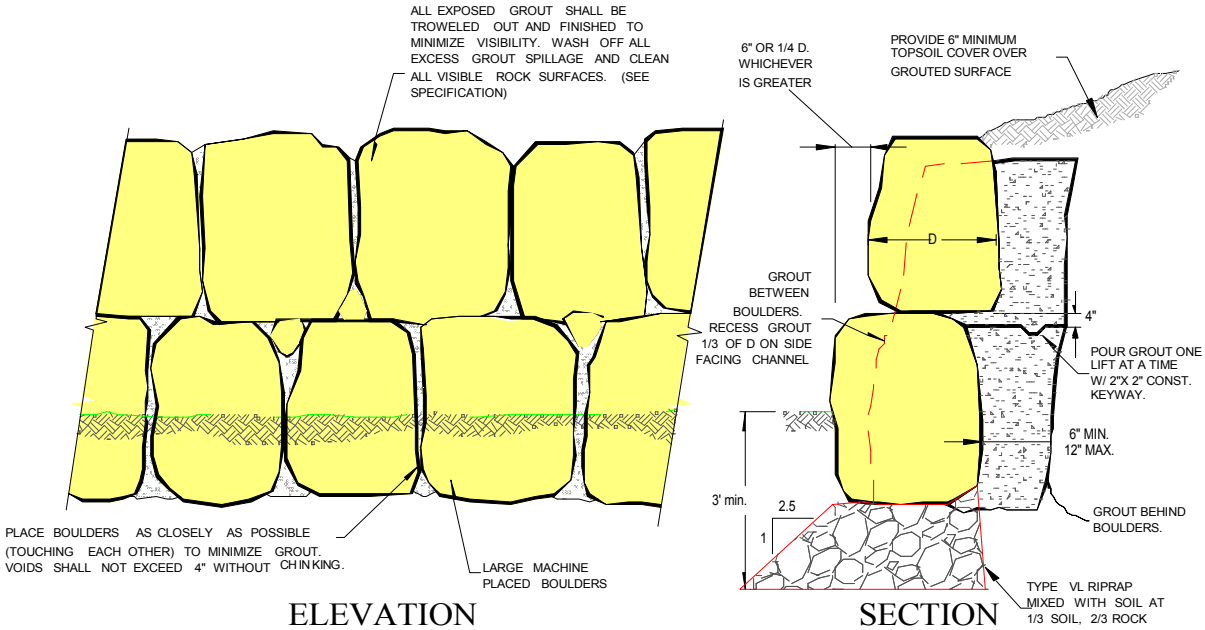
Figure MD-18—Brush Layering with Willow Cuttings



BOULDER EDGED LOW FLOW CHANNEL CROSS-SECTION



GROUTED BOULDER EDGE DETAIL



GROUTED BOULDER STACKED WALL EDGE

Figure MD-19—Details for Boulder Edge Treatment of a Low-Flow Channel

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5.0 RECTANGULAR CONDUITS

The use of rectangular conduits of larger capacity can sometimes have cost advantages over large-diameter pipe. Furthermore, because they can be poured in place, advantages accrue in being able to incorporate conflicting utilities into the floor and roof of the structure.

Major disadvantages of rectangular conduits as storm sewers are:

1. The conduit's capacity drops significantly when the water surface reaches its roof since the wetted perimeter dramatically increases. The drop is 20% for a square cross section and more for a rectangular cross section where the width is greater than the height.

2. Normal structural design, because of economics, usually does not permit any significant interior pressures, meaning that if the conduit reached a full condition and the capacity dropped, there could be a failure due to interior pressures caused by a choking of the capacity (Murphy 1971).

It is apparent that the use of long rectangular conduits for outfall purposes requires a high standard of planning and design involving complex hydraulic considerations.

The chapters on CULVERTS and HYDRAULIC STRUCTURES in this *Manual* contain information that should be used to supplement this section in development of designs.

5.1 Hydraulic Design

Rectangular conduits are often considered as a covered free-flow conduit. They are open channels with a cover (Smith 1974). Computational procedures for flow in rectangular conduits are essentially the same as for canals and lined channels, except that special consideration is needed in regard to rapidly increasing flow resistance when a long conduit becomes full. The reader is referred to the chapters on CULVERTS and HYDRAULIC STRUCTURES for additional information.

An obstruction, or even a confluence with another conduit, may cause the flow in a near-full rectangular conduit to strike the roof and choke the capacity. The capacity reduction may then cause the entire upstream reach of the conduit to flow full, with a resulting surge and pressure head increase of sufficient magnitude to cause a structural failure. Thorough design is required to overcome this inherent potential problem. Structural design must account for internal pressure if pressure will exist.

Structural requirements and efficiency for sustaining external loads, rather than hydraulic efficiency, usually control the shape of the rectangular conduit. In urban drainage use, a rectangular conduit should usually have a straight alignment and should not decrease in size or slope in a downstream direction. It is desirable to have a slope that increases in a downstream direction as an added safety factor against it flowing full. This is particularly important for supercritical velocities that often exist in long conduits. For flatter-sloped conduits, the sediment deposition problem must be considered to prevent loss of capacity.

Roughness coefficients from Table MD-15 should be chosen carefully because of their effect on proper operation of the conduit. Quality control is important during construction; attention must be paid to grinding off projections and keeping good wall alignment. When using precast box sections, joint alignment, sealing and grouting are especially important.

Bedding and cover on conduits are structural considerations, and specifications for bedding and cover are closely allied to the loads and forces used in the structural design.

Table MD-15—Roughness Coefficients for Large Concrete Conduits

Type of Concrete Conduit	Roughness Coefficient
Precast concrete pipe, excellent joint alignment	0.012
Precast concrete pipe, ordinary joint alignment	0.013
Poured-in-place steel forms, projections 1/8” or less	0.013
Poured-in-place smooth wood forms, projections 1/8” or less	0.013
Poured-in-place ordinary work with steel forms	0.014
Poured-in-place ordinary work with wood forms	0.015

5.1.1 Entrance

Because a long rectangular conduit is costly, as well as for other reasons, the hydraulic characteristics at the entrance are particularly important. A conduit that cannot flow at the design discharge because of an inadequate or clogged inlet represents wasted investment and can result in flooding of homes, buildings, structures, and other urban infrastructure.

The entrances take on a special degree of importance for rectangular conduits, however, because the flow must be limited to an extent to ensure against overcharging the conduit. Special maximum-flow limiting entrances are often used with rectangular conduits. These special entrances should reject flow over the design discharge so that, if a runoff larger than the design flow occurs, the excess water will flow via other routes, often overland. A combined weir-orifice design is useful for this purpose. Model tests are needed for dependable design (Murphy 1971).

A second function of the entrance should be to accelerate the flow to the design velocity of the conduit, usually to meet the velocity requirements for normal depth of flow in the upstream reach of the conduit.

Air vents are needed at regular intervals to obviate both positive and negative pressures and to permit released entrained air to readily escape from the conduit.

5.1.2 Internal Pressure

The allowable internal pressure in a rectangular conduit is limited by structural design. Often, internal pressures are limited to no more than 2 to 4 feet of head before structural failure will commence, if structural design has not been based on internal pressure. Surges or conduit capacity choking cannot

normally be tolerated.

5.1.3 Curves and Bends

The analysis of curves in rectangular conduits is critical to insure its hydraulic capacity. When water surface (normal, standing or reflecting waves) reaches the roof of the conduit hydraulic losses increase significantly and the capacity drops. Superelevation of the water surface must also be investigated, and allowances must be made for a changing hydraulic radius, particularly in high-velocity flow. Dynamic loads created by the curves must be analyzed to assure structural integrity for the maximum flows. See the HYDRAULIC STRUCTURES chapter of this *Manual*.

5.1.4 Transitions

Transitions provide complex hydraulic problems and require specialized analyses. Transitions, either contracting or expanding, are important with most large outfall conduits because of high-velocity flow. The development of shock waves that continue downstream can create significant problems in regard to proper conduit functioning. The best way to study transitions is through model tests (Fletcher and Grace 1972). Analytical procedures can only give approximate results. Poor transitions can cause upstream problems with both subcritical and supercritical flow, and can cause unnecessary flooding. Criteria given in the HYDRAULIC STRUCTURES chapter of this *Manual* may be used as a guide to certain limitations.

5.1.5 Air Entrainment

Entrained air causes a swell in the volume of water and an increase in depth than can cause flow in the conduit to reach the height of the roof with resulting loss of capacity; therefore, hydraulic design must account for entrained air. In rectangular conduits and circular pipes, flowing water will entrain air at velocities of about 20 ft/sec and higher. Additionally, other factors such as entrance condition, channel roughness, distance traveled, channel cross section, and volume of discharge all have some bearing on air entrainment. Volume swell can be as high as 20% (Hipschman 1970).

5.1.6 Major Inlets

Major inlets to a rectangular conduit at junctions or large storm inlets should receive a rigorous hydraulic analysis to assure against mainstream conduit flow striking the top of the rectangular conduit due to momentum changes in the main flow body as a result of the introduction of additional flow. Model tests may be necessary.

5.1.7 Sedimentation

The conduit must be designed to obviate sediment deposition problems during storm runoff events that have a frequency of occurrence of about twice each year. That is, at least twice per year, on average, the storm runoff velocity should be adequate to scour deposited sediment from the box section.

5.2 Appurtenances

The appurtenances to a long rectangular conduit are dictated by the individual needs of the particular project. Most appurtenances have some effect upon the overall operation of the system; the designer must consider all of these effects.

5.2.1 Energy Dissipators

Long conduits usually have high exit velocities that must be slowed to avoid downstream problems and damage. Energy dissipators are nearly always required. See the HYDRAULIC STRUCTURES chapter of this *Manual*.

5.2.2 Access Manholes

A long rectangular conduit should be easy to inspect, and, therefore, access manholes are desirable at various locations. If a rectangular conduit is situated under a curb, the access manholes may be combined with the storm sewer system inlets. Manholes should be aligned with the vertical wall of the box to allow rungs in the riser and box to be aligned.

Access manholes and storm inlets are useful for permitting air to flow in and out of a rectangular conduit as filling and emptying of the conduit occurs. They might also be considered safety water ejection ports should the conduit ever inadvertently flow full and cause a pileup of water upstream. The availability of such ejection ports could very well save a rectangular conduit from serious structural damage.

5.2.3 Vehicle Access Points

A large rectangular conduit with a special entrance and an energy dissipater at the exit may need an access hole for vehicle use in case major repair work becomes necessary. A vehicle access point might be a large, grated opening just downstream from the entrance. This grated opening can also serve as an effective air breather for the conduit. Vehicles may be lowered into the conduit by a crane or A-frame.

5.2.4 Safety

See discussion on public safety design consideration in the CULVERTS chapter.

5.2.5 Air Venting

Whenever it is suspected the conduit could operate at Froude Number higher than 0.7 during any flow that is at the design flow and flows lower than the design flow, or when the headwater at the conduits entrance is above the top of the conduit, the engineer has to consider installation of adequate air vents along the conduit. These are necessary to minimize major pressure fluctuations that can occur should the flow becomes unstable. When instabilities occur, air is trapped and less-than-atmospheric pressures have been shown to occur intermittently which air vents can mitigate and reduce structural loads and fluctuating hydraulic capacity in the conduit.

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6.0 LARGE PIPES

Large pipes are often used as underground outfall conduits. An advantage of using pipes (circular conduits) rather than rectangular conduits is that pipes can withstand internal pressure to a greater degree than rectangular conduits can. Thus, the hydraulic design is not as critical, and a greater safety factor exists from the structural standpoint. Unless the designer is competent, experienced in open-channel hydraulics, and prepared to utilize laboratory model tests as a design aid, large pipes should be used rather than rectangular conduits. Cost differentials for the project should be carefully weighed before choosing the type of outfall conduit.

Disadvantages may include the fact that large pipes are less adaptable to an existing urban street where conflicts may exist with sanitary sewer pipes and other utilities.

6.1 Hydraulic Design

Large pipes are also considered as covered free-flow conduits; they are open channels with a cover (Steven, Simons, and Lewis 1971). Computational procedures for flow in large pipes are essentially the same as for canals and lined channels, except that consideration is given to diminishing capacity as the pipe flow nears the full depth.

Large pipes lend themselves to bends and slope changes more readily than do rectangular conduits. In a situation with a large pipe with the slope increasing in a downstream direction, there is no reason that the downstream pipe cannot be made smaller than the upstream pipe. However, the required transitional structure may rule out the smaller pipe from an economic standpoint. Improper necking down of large pipes has been a contributing factor in significant flooding of urban areas.

To aid in the solution of uniform flow computations for large pipes, see Table MD-16. The background and use of the table are similar to that given in Section 3.1.1 for open channels. Figures MD-2 and MD-3 are also useful aids for flow computations in pipes. Figure MD-20 is given as an additional design aid example. Curves presented in the STREETS/INLETS/STORM SEWERS and CULVERTS chapters of this *Manual* are also helpful in studying flow in large pipes.

Table MD-16—Uniform Flow in Circular Sections Flowing Partially Full

(Hipschman 1970)

y_0 = depth of flow
D = diameter of pipe
A = area of flow
R = hydraulic radius
Q = discharge in cfs by Manning formula
n = Manning coefficient
S_0 = slope of channel bottom and of the water surface

y_0/D	A/D^2	R/D	$Qn/(D^{8/3}S_0^{1/2})$	$Qn/(y_0^{8/3}S_0^{1/2})$	y_0/D	A/D^2	R/D	$Qn/(D^{8/3}S_0^{1/2})$	$Qn/(y_0^{8/3}S_0^{1/2})$
0.01	0.0013	0.0066	0.00007	15.040	0.51	0.4027	0.2531	0.23900	1.442
0.02	0.0037	0.0132	0.00031	10.570	0.52	0.4127	0.2562	0.24700	1.415
0.03	0.0069	0.0197	0.00074	8.560	0.53	0.4227	0.2592	0.25500	1.388
0.04	0.0105	0.0262	0.00138	7.380	0.54	0.4327	0.2621	0.26300	1.362
0.05	0.0147	0.0325	0.00222	6.550	0.55	0.4426	0.2649	0.27100	1.336
0.06	0.0192	0.0389	0.00328	5.950	0.56	0.4526	0.2676	0.27900	1.311
0.07	0.0242	0.0451	0.00455	5.470	0.57	0.4625	0.2703	0.28700	1.286
0.08	0.0294	0.0513	0.00604	5.090	0.58	0.4724	0.2728	0.29500	1.262
0.09	0.0350	0.0575	0.00775	4.760	0.59	0.4822	0.2753	0.30300	1.238
0.10	0.0409	0.0635	0.00967	4.490	0.60	0.4920	0.2776	0.31100	1.215
0.11	0.0470	0.0695	0.01181	4.250	0.61	0.5018	0.2799	0.31900	1.192
0.12	0.0534	0.0755	0.01417	4.040	0.62	0.5115	0.2821	0.32700	1.170
0.13	0.0600	0.0813	0.01674	3.860	0.63	0.5212	0.2842	0.33500	1.148
0.14	0.0668	0.0871	0.01952	3.690	0.64	0.5308	0.2862	0.34300	1.126
0.15	0.0739	0.0929	0.02250	3.540	0.65	0.5404	0.2882	0.35000	1.105
0.16	0.0811	0.0985	0.02570	3.410	0.66	0.5499	0.2900	0.35800	1.084
0.17	0.0885	0.1042	0.02910	3.280	0.67	0.5594	0.2917	0.36600	1.064
0.18	0.0961	0.1097	0.03270	3.170	0.68	0.5687	0.2933	0.37300	1.044
0.19	0.1039	0.1152	0.03650	3.060	0.69	0.5780	0.2948	0.38000	1.024
0.20	0.1118	0.1206	0.04060	2.960	0.70	0.5872	0.2962	0.38800	1.004
0.21	0.1199	0.1259	0.04480	2.870	0.71	0.5964	0.2975	0.39500	0.985
0.22	0.1281	0.1312	0.04920	2.790	0.72	0.6054	0.2987	0.40200	0.965
0.23	0.1365	0.1364	0.05370	2.710	0.73	0.6143	0.2998	0.40900	0.947
0.24	0.1449	0.1416	0.05850	2.630	0.74	0.6231	0.3008	0.41600	0.928
0.25	0.1535	0.1466	0.06340	2.560	0.75	0.6319	0.3017	0.42200	0.910
0.26	0.1623	0.1516	0.06860	2.490	0.76	0.6405	0.3024	0.42900	0.891
0.27	0.1711	0.1566	0.07390	2.420	0.77	0.6489	0.3031	0.43500	0.873
0.28	0.1800	0.1614	0.07930	2.360	0.78	0.6573	0.3036	0.44100	0.856
0.29	0.1890	0.1662	0.08490	2.300	0.79	0.6655	0.3039	0.44700	0.838
0.30	0.1982	0.1709	0.09070	2.250	0.80	0.6736	0.3042	0.45300	0.821
0.31	0.2074	0.1756	0.09660	2.200	0.81	0.6815	0.3043	0.45800	0.804
0.32	0.2167	0.1802	0.10270	2.140	0.82	0.6893	0.3043	0.46300	0.787
0.33	0.2260	0.1847	0.10890	2.090	0.83	0.6969	0.3041	0.46800	0.770
0.34	0.2355	0.1891	0.11530	2.050	0.84	0.7043	0.3038	0.47300	0.753
0.35	0.2450	0.1935	0.12180	2.000	0.85	0.7115	0.3033	0.47700	0.736
0.36	0.2546	0.1978	0.12840	1.958	0.86	0.7186	0.3026	0.48100	0.720
0.37	0.2642	0.2020	0.13510	1.915	0.87	0.7254	0.3018	0.48500	0.703
0.38	0.2739	0.2062	0.14200	1.875	0.88	0.7320	0.3007	0.48800	0.687
0.39	0.2836	0.2102	0.14900	1.835	0.89	0.7384	0.2995	0.49100	0.670
0.40	0.2934	0.2142	0.15610	1.797	0.90	0.7445	0.2980	0.49400	0.654
0.41	0.3032	0.2182	0.16330	1.760	0.91	0.7504	0.2963	0.49600	0.637
0.42	0.3130	0.2220	0.17050	1.724	0.92	0.7560	0.2944	0.49700	0.621
0.43	0.3229	0.2258	0.17790	1.689	0.93	0.7612	0.2921	0.49800	0.604
0.44	0.3328	0.2295	0.18540	1.655	0.94	0.7662	0.2895	0.49800	0.588
0.45	0.3428	0.2331	0.19290	1.622	0.95	0.7707	0.2865	0.49800	0.571
0.46	0.3527	0.2366	0.20100	1.590	0.96	0.7749	0.2829	0.49600	0.553
0.47	0.3627	0.2401	0.20800	1.559	0.97	0.7785	0.2787	0.49400	0.535
0.48	0.3727	0.2435	0.21600	1.530	0.98	0.7817	0.2735	0.49800	0.517
0.49	0.3827	0.2468	0.22400	1.500	0.99	0.7841	0.2666	0.48300	0.496
0.50	0.3927	0.2500	0.23200	1.471	1.00	0.7854	0.2500	0.46300	0.463

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6.1.1 Entrance

The longer a pipe is, the more important is design of the entrance. A large pipe unable to flow at the design capacity represents wasted investment. Acceleration of flow, typically to the design velocity of the pipe reach immediately downstream, is often an important characteristic of the entrance. Typically air vents are necessary immediately downstream of the entrance to allow entrained air to escape and to act as breathers should less-than-atmospheric pressures develop in the pipe. Long pipes that depend on flow entering at upstream points other than street inlets need to be equipped with adequately sized safety/trash racks at the entrances. For guidance on sizing safety/trash racks, see guidance in the CULVERTS chapter.

6.1.2 Internal Pressure

The allowable internal pressure is limited by the structural design of the pipe; however, it is not as critical as with rectangular conduits, with up to perhaps 25 feet of head being permissible in some pipe designs before failure commences. It is evident, however, that large pipe outfalls cannot be designed for flow under any significant pressure because then inflow from other lines could not enter, and water would flow out of storm inlets rather than into these inlets. The internal pressure aspect is important only as a safety factor in the event of a choking of capacity or an inadvertent flow surcharge.

6.1.3 Curves and Bends

Curves and bends are permitted, but detailed analysis is required to ensure structural integrity and proper hydraulic functioning of the conduit. Maintenance access should be provided in the proximity of all bends. Hydraulic analyses are important at locations where hydraulic jumps may occur.

6.1.4 Transitions

Transitions are discussed in the HYDRAULIC STRUCTURES chapter of this *Manual*.

6.1.5 Air Entrainment and Venting

The reader is referred to Sections 5.1.5 and 5.2.5 of this chapter.

6.1.6 Major Inlets

Inflow to the conduit can cause unanticipated hydraulic variations; however, the analytical approach need not be as rigorous as with rectangular conduits.

6.2 Appurtenances

The reader is referred to Section 5.2 of this chapter.

6.3 Safety

See guidance in the CULVERTS chapter.

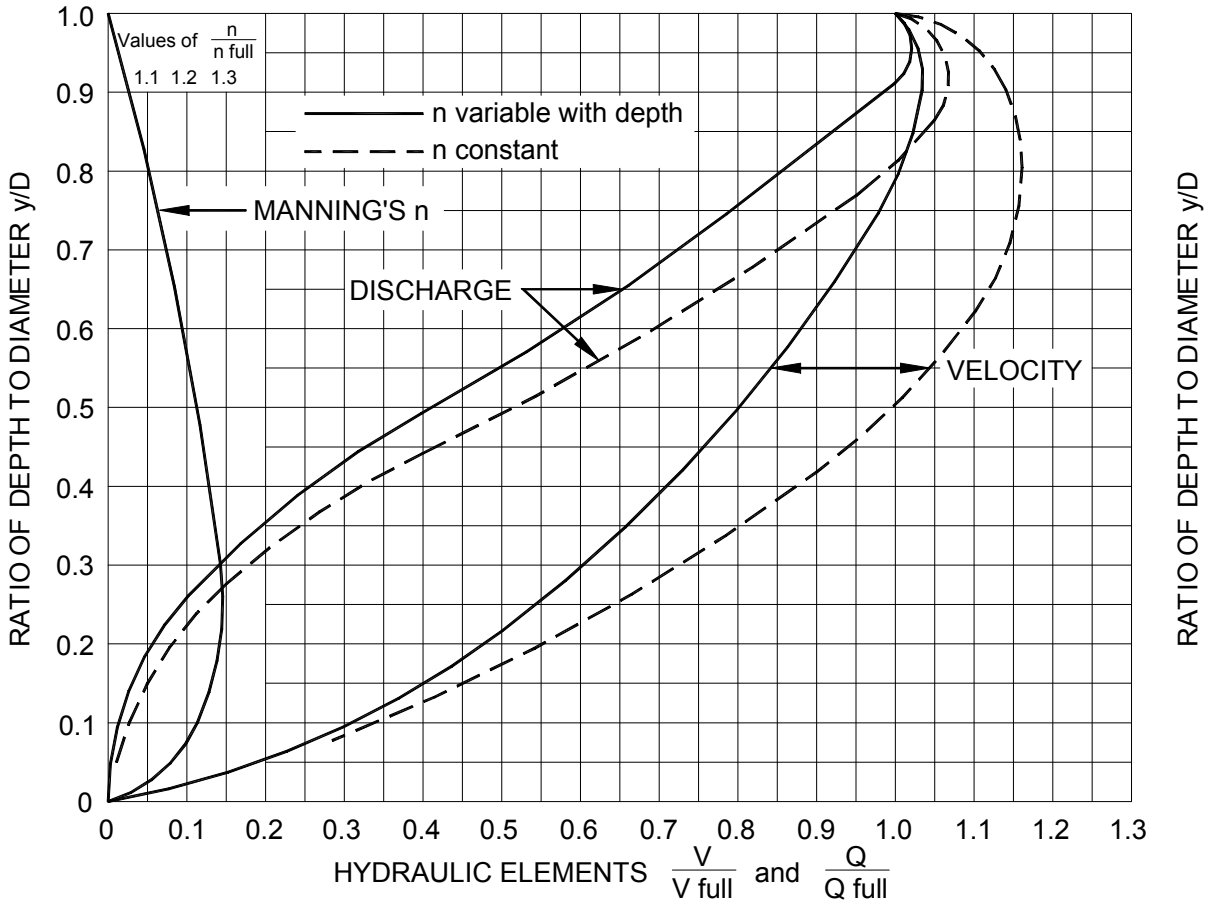

Figure MD-20—Hydraulic Properties of Pipes

(Steven, Simons, and Lewis 1976)

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7.0 PROTECTION DOWNSTREAM OF PIPE OUTLETS

This section is intended to address the use of riprap for erosion protection downstream of conduit and culvert outlets that are in-line with major drainageway channels. Inadequate protection at conduit and culvert outlets has long been a major problem. The designer should refer to Section 4.4 for additional information on major drainage applications utilizing riprap. In addition, the criteria and guidance in Section 4.4 may be useful in design of erosion protection for conduit outlets. The reader is referred to Section 7.0 of the HYDRAULIC STRUCTURES chapter of this *Manual* for information on rundowns, and to Section 3.0 of the HYDRAULIC STRUCTURES chapter for additional discussion on culvert outfall protection.

Scour resulting from highly turbulent, rapidly decelerating flow is a common problem at conduit outlets. The riprap protection design protocol is suggested for conduit and culvert outlet Froude numbers up to 2.5 (i.e., Froude parameters $Q/d_0^{2.5}$ or $Q/WH^{1.5}$ up to 14 $ft^{0.5}$/sec) where the channel and conduit slopes are parallel with the channel gradient and the conduit outlet invert is flush with the riprap channel protection. Here, Q is the discharge in cfs, d_0 is the diameter of a circular conduit in feet and W and H are the width and height, respectively, of a rectangular conduit in feet.

7.1 Configuration of Riprap Protection

Figure MD-25 illustrates typical riprap protection of culverts and major drainageway conduit outlets. The additional thickness of the riprap just downstream from the outlet is to assure protection from flow conditions that might precipitate rock movement in this region.

7.2 Required Rock Size

The required rock size may be selected from Figure MD-21 for circular conduits and from Figure MD-22 for rectangular conduits. Figure MD-21 is valid for $Q/D_c^{2.5}$ of 6 or less and Figure MD-22 is valid for $Q/WH^{1.5}$ of 8.0 or less. The parameters in these two figures are:

1. $Q/D^{1.5}$ or $Q/WH^{0.5}$ in which Q is the design discharge in cfs, D_c is the diameter of a circular conduit in feet, and W and H are the width and height of a rectangular conduit in feet.

2. Y_t/D_c or Y_t/H in which Y_t is the tailwater depth in feet, D_c is the diameter of a circular conduit in feet, and H is the height of a rectangular conduit in feet. In cases where Y_t is unknown or a hydraulic jump is suspected downstream of the outlet, use $Y_t/D_t = Y_t/H = 0.40$ when using Figures MD-21 and MD-22.

3. The riprap size requirements in Figures MD-21 and MD-22 are based on the non-dimensional parametric Equations MD-18 and MD-19 (Steven, Simons, and Lewis 1971 and Smith 1975).

   Circular culvert:

$$\frac{\left(\frac{d_{50}}{D_c}\right)\left(\frac{Y_t}{D_c}\right)^{1.2}}{\left(\frac{Q}{D_c^{2.5}}\right)} = 0.023 \qquad \text{(MD-18)}$$

   Rectangular culvert:

$$\frac{\left(\frac{d_{50}}{H}\right)\left(\frac{Y_t}{H}\right)}{\left(\frac{Q}{WH^{1.5}}\right)} = 0.014 \qquad \text{(MD-19)}$$

The rock size requirements were determined assuming that the flow in the culvert barrel is not supercritical. It is possible to use Equations MD-18 and MD-19 when the flow in the culvert is supercritical (and less than full) if the value of D_c or H is modified for use in Figures MD-21 and MD-22. Whenever the flow is supercritical in the culvert, substitute D_a for D_c and H_a for H, in which D_a is defined as:

$$D_a = \frac{(D_c + Y_n)}{2} \qquad \text{(MD-20)}$$

in which the maximum value of D_a shall not exceed D, and

$$H_a = \frac{(H + Y_n)}{2} \qquad \text{(MD-21)}$$

in which the maximum value of H_a shall not exceed H, and:

D_a = parameter to use in place of D in Figure MD-21 when flow is supercritical

D_c = diameter of circular culvert (ft)

H_a = parameter to use in place of H in Figure MD-22 when flow is supercritical

H = height of rectangular culvert (ft)

Y_n = normal depth of supercritical flow in the culvert

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7.3 Extent of Protection

The length of the riprap protection downstream from the outlet depends on the degree of protection desired. If it is necessary to prevent all erosion, the riprap must be continued until the velocity has been reduced to an acceptable value. For purposes of outlet protection during major floods, the acceptable velocity is set at 5.5 ft/sec for very erosive soils and at 7.7 ft/sec for erosion resistant soils. The rate at which the velocity of a jet from a conduit outlet decreases is not well known. For the procedure recommended here, it is assumed to be related to the angle of lateral expansion, θ, of the jet. The velocity is related to the expansion factor, $(1/(2\tan\theta))$, which can be determined directly using Figure MD-23 or Figure MD-24, assuming that the expanding jet has a rectangular shape:

$$L_p = \left(\frac{1}{2\tan\theta}\right)\left(\frac{A_t}{Y_t} - W\right) \qquad \text{(MD-22)}$$

where:

L_p = length of protection (ft)

W = width of the conduit in (ft) (use diameter for circular conduits)

Y_t = tailwater depth (ft)

θ = the expansion angle of the culvert flow

and:

$$A_t = \frac{Q}{V} \qquad \text{(MD-23)}$$

where:

Q = design discharge (cfs)

V = the allowable non-eroding velocity in the downstream channel (ft/sec)

A_t = required area of flow at allowable velocity (ft²)

In certain circumstances, Equation MD-22 may yield unreasonable results. Therefore, in no case should L_p be less than $3H$ or $3D$, nor does L_p need to be greater than $10H$ or $10D$ whenever the Froude parameter, $Q/WH^{1.5}$ or $Q/D^{2.5}$, is less than 8.0 or 6.0, respectively. Whenever the Froude parameter is greater than these maximums, increase the maximum L_p required by ¼ D_c or ¼ H for circular or rectangular culverts, respectively, for each whole number by which the Froude parameter is greater than 8.0 or 6.0, respectively.

7.4 Multiple Conduit Installations

The procedures outlined in Sections 7.1, 7.2, and 7.3 can be used to design outlet erosion protection for multi-barrel culvert installations by hypothetically replacing the multiple barrels with a single hydraulically equivalent rectangular conduit. The dimensions of the equivalent conduit may be established as follows:

1. Distribute the total discharge, Q, among the individual conduits. Where all the conduits are hydraulically similar and identically situated, the flow can be assumed to be equally distributed; otherwise, the flow through each barrel must be computed.

2. Compute the Froude parameter $Q_i/D_{ci}^{2.5}$ (circular conduit) or $Q_i/W_iH_i^{1.5}$ (rectangular conduit), where the subscript i indicates the discharge and dimensions associated with an individual conduit.

3. If the installation includes dissimilar conduits, select the conduit with the largest value of the Froude parameter to determine the dimensions of the equivalent conduit.

4. Make the height of the equivalent conduit, H_{eq}, equal to the height, or diameter, of the selected individual conduit.

5. The width of the equivalent conduit, W_{eq}, is determined by equating the Froude parameter from the selected individual conduit with the Froude parameter associated with the equivalent conduit, $Q/W_iH_{eq}^{1.5}$.

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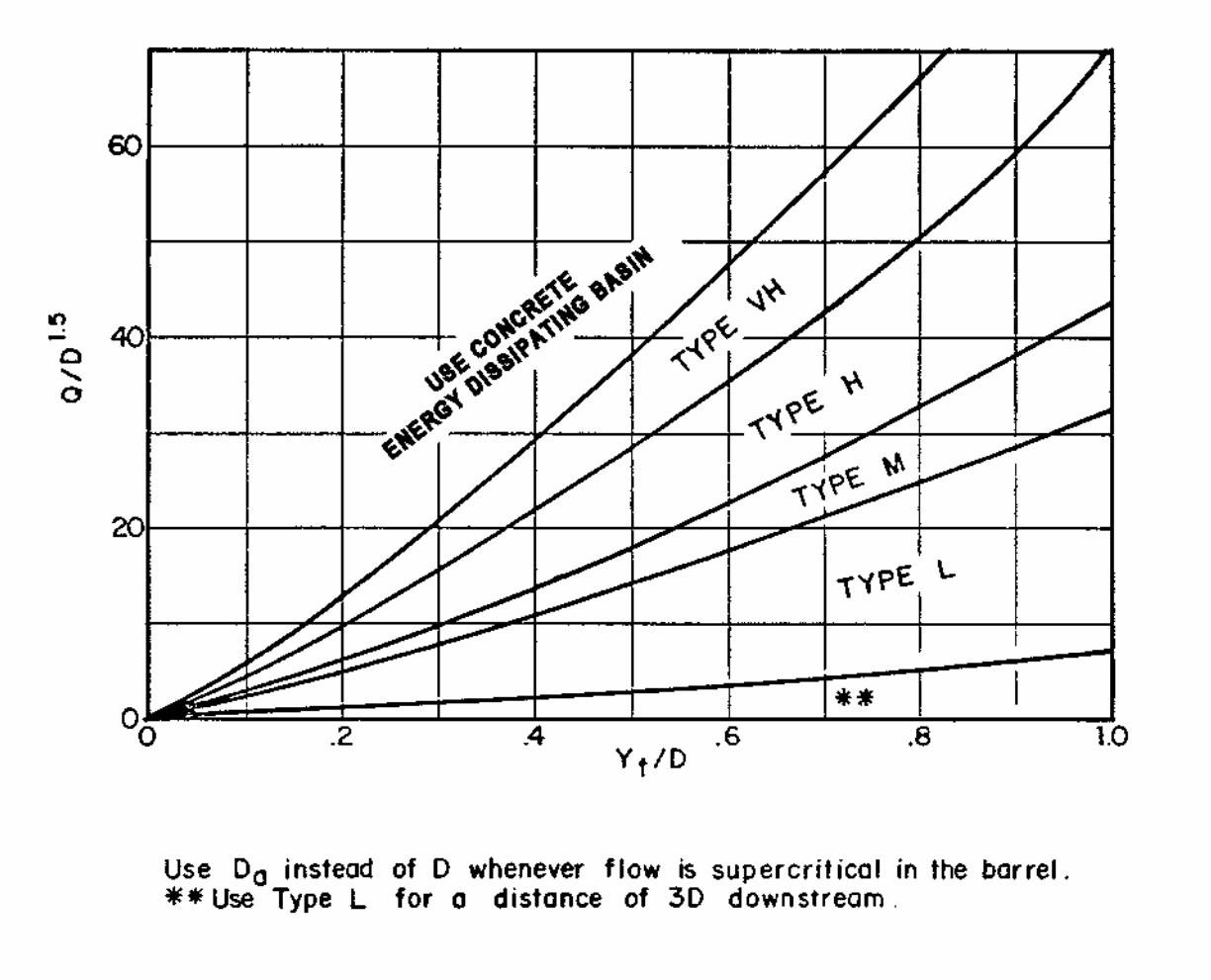

Figure MD-21—Riprap Erosion Protection at Circular Conduit Outlet Valid for $Q/D^{2.5} \leq 6.0$

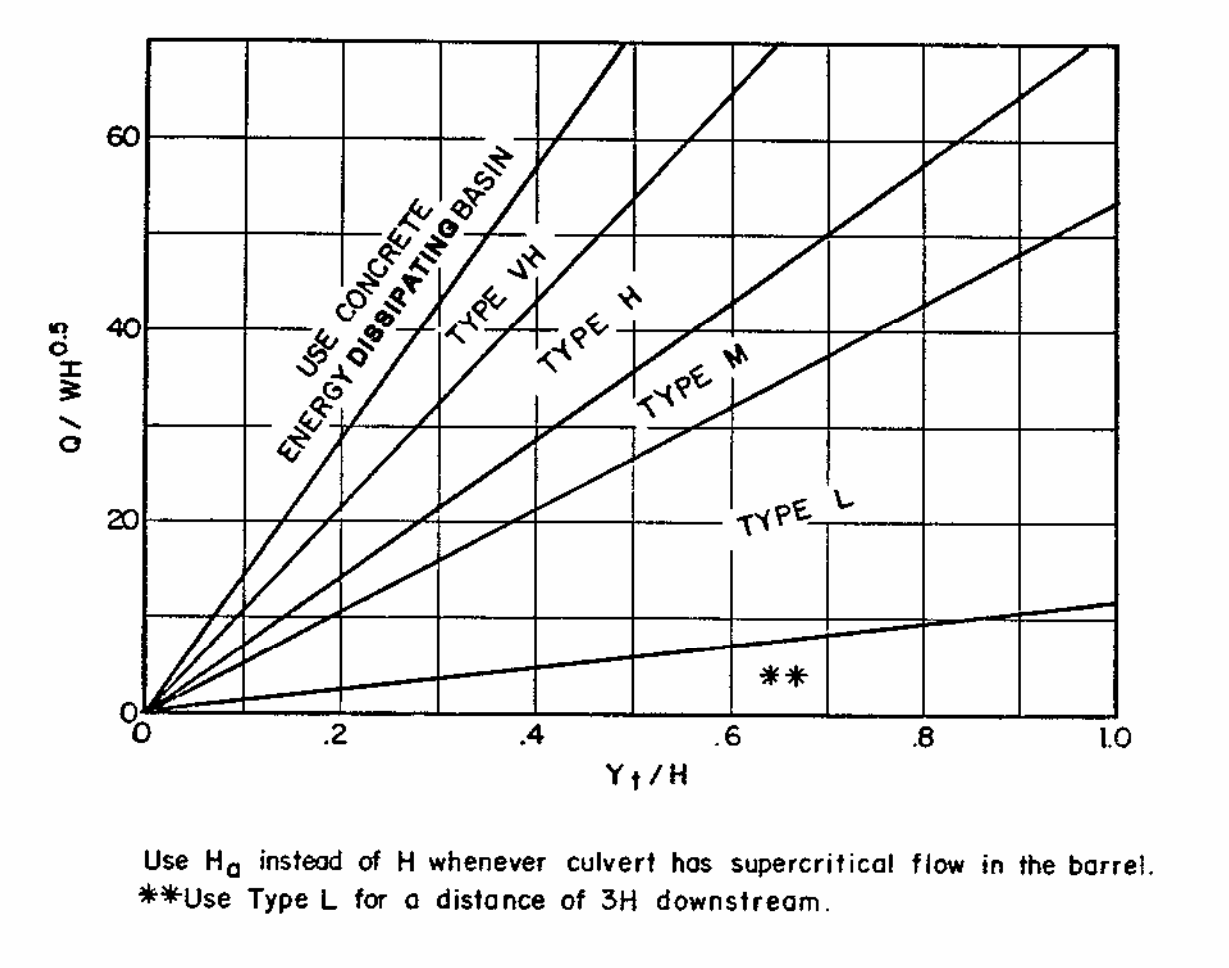

Figure MD-22—Riprap Erosion Protection at Rectangular Conduit Outlet Valid for $Q/WH^{1.5} \leq 8.0$

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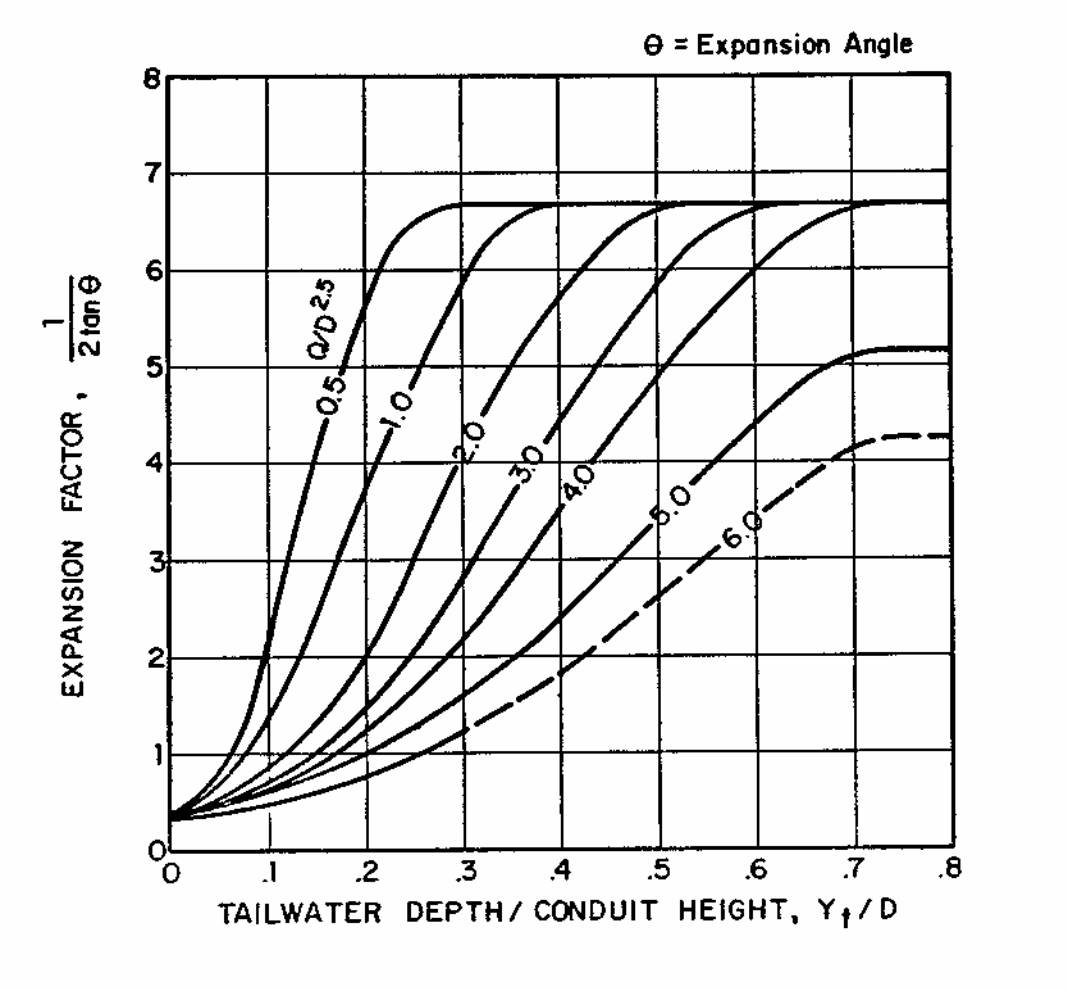

Figure MD-23—Expansion Factor for Circular Conduits

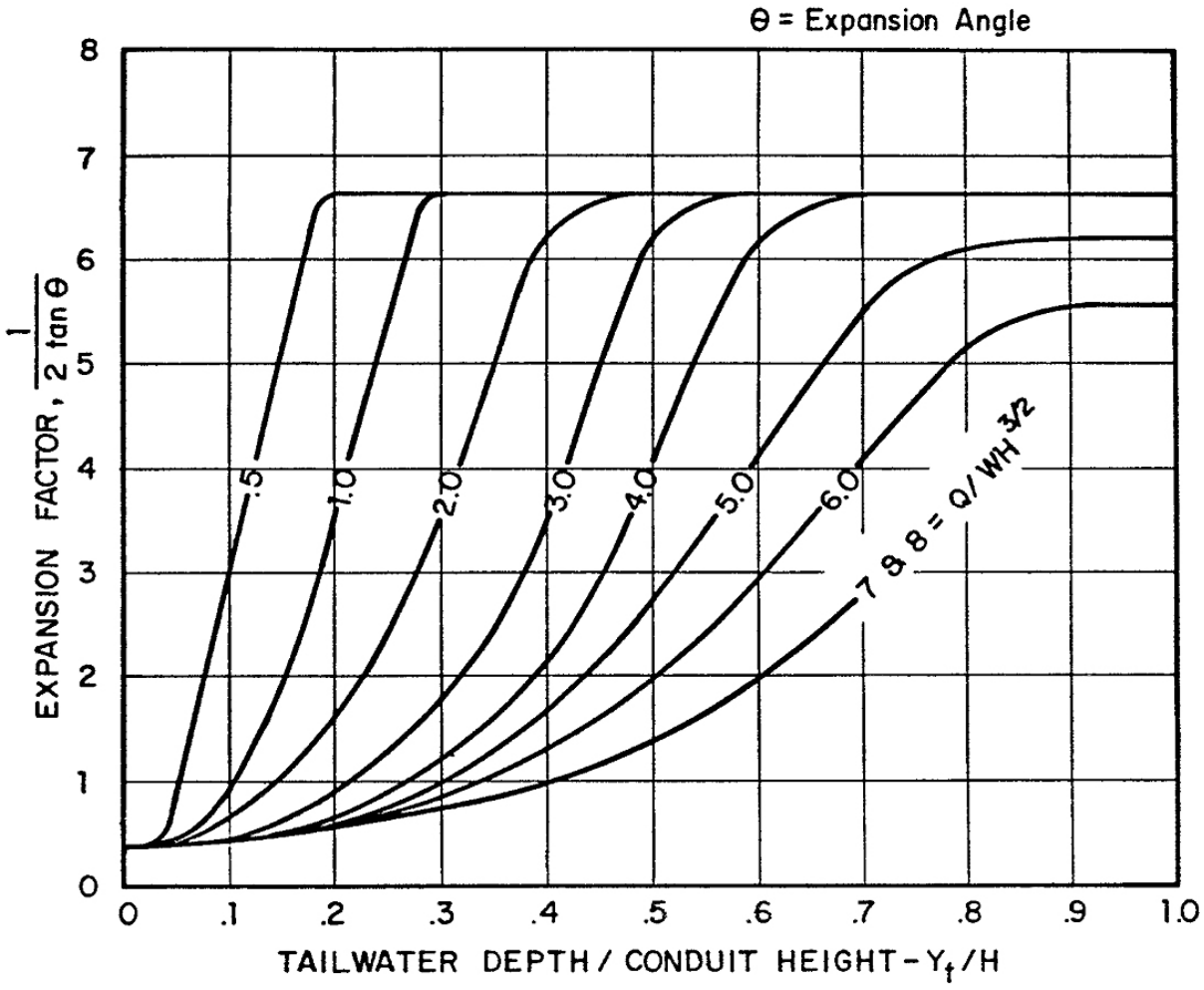

Figure MD-24—Expansion Factor for Rectangular Conduits

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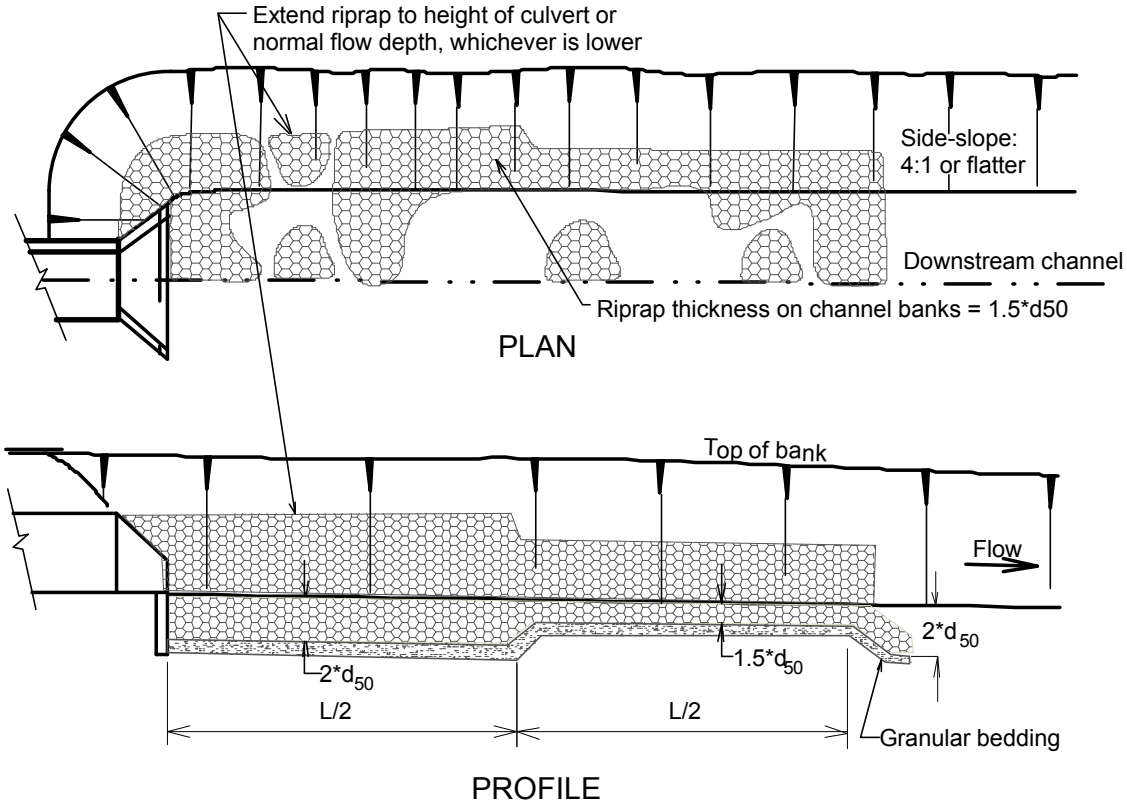


NOTES: 1. Headwall with wingwalls or flared end section required at all culvert outlets.
2. Cutoff wall required at end of wingwall aprons and end section.
Minimum depth of cutoff wall = 2*d50 or 3-feet, whichever is deeper.
3. Provide joint fasteners for flared end sections.

Figure MD-25—Culvert and Pipe Outlet Erosion Protection

8.0 SEDIMENT

Well-established urban areas are not significant sediment producers. However, winter sanding operations, new construction areas, and usual residential storm runoff will provide some sediment to the drainage system, which must be acknowledged. One of the greatest sedimentation problems occurs, however, when an area is undergoing urbanization. Furthermore, in a grass-lined channel or a natural channel, erosion will typically occur in some reaches of the channel and sediment will generally deposit in other reaches. Sedimentation is a problem in urban drainage hydrology in that, if the channel is made steep enough to transport all sediment, the velocities will also be high enough to cause erosion that would not otherwise occur if the channel was flatter. Often the designer must make the choice to have a well-planned and designed channel which will transport the minimal sediment yield in the future, realizing that the initial operation of the channel will result in sediment deposition during the process of urbanization.

The designer would be well advised to give full consideration to the sediment deposition problem and to utilize sediment deposition basins at selected locations along channels and at stormwater runoff entry points into channels for periodic sediment removal when it is obvious that there will be substantial sediment inflow, at least initially. In addition, the designer can include sediment storage and trap areas within flood detention basins and retention ponds to great advantage. See the chapter on STORAGE in this *Manual*.

In a grass-lined channel, particularly after the grass has obtained maturity, fine sediment will settle out regularly on top of the sod. Over a period of years, there will be a gradual buildup of the channel bottom, many times imperceptible, but nonetheless occurring. Because of the frequent use of drops in grass-lined channels as well as natural channels, the build-up rate will decrease with time. However, if aggradation tends to reduce the capacity of the channel, periodic restorative maintenance work will need to be performed to re-establish the design depth.

The subject of sedimentation design cannot be completely covered in this *Manual* because of its complexity. Volume 3 of the *Manual* addresses suspended sediment in greater detail, but little guidance is given for bedload since its presence is dependant on many factors (i.e., construction activities upstream, channel bank line erosion, channel bed degradation, use of erosion control practices, etc.). As a rule of thumb, velocities of 3.0 ft/sec will transport sediments up to the size of fine sands. However, being able to achieve these velocities during minor runoff events throughout the channel's cross section may not be feasible.

9.0 EXAMPLES

9.1 Example MD-1: Normal Depth Calculation with Normal Worksheet

This example involves determination of channel capacity and other relevant hydraulic parameters for a grass-lined trapezoidal channel flowing at normal depth, given the following channel characteristics and constraints:

Channel Characteristics:

So = channel bottom slope (longitudinal slope) = 0.3%

Z = Z1 = Z2 = channel side slopes (left and right) = 4H:1V

n = Manning's n (grass-lined channel) = 0.035

B = bottom width = 10 ft

Constraints:

Y = maximum allowable depth of flow in channel = 5.0 ft

F = freeboard required = 2.0 ft

A sketch of the channel cross section, which defines these parameters, is included as a part of the worksheet and is illustrated for this example on the calculation sheet on the following page.

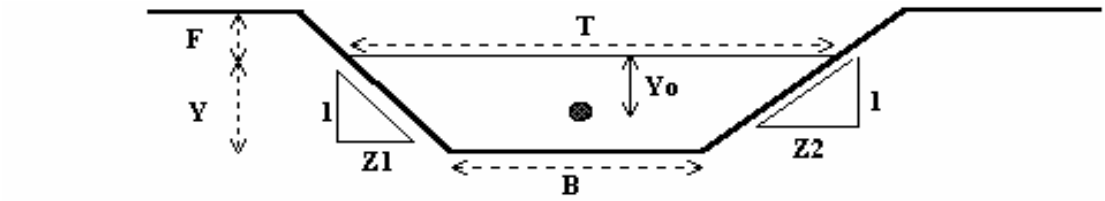
These channel characteristics and sizing constraints are entered into the input section of the *Basic* worksheet of the UD-Channels Spreadsheet to determine discharge using normal depth calculations. A worksheet demonstrating application of the *Basic Worksheet* titled "Normal Flow Analysis—Trapezoidal Channel" for "Project = Example MD-1" and "Channel ID = Normal Depth Example" is provided as an example of normal depth analysis.

Based on this analysis, the channel would be capable of carrying a flow of approximately 700 cfs, given a total bank height of 7 ft to allow for the required freeboard. In addition, the calculations indicate that flow will be subcritical under these conditions. Since the velocity is close to the 5.0 ft/sec maximum allowable 100-year velocity for grass-lined channels with erosive soils, the spreadsheet should be reapplied using a lower Manning's n value to see if the maximum velocity criterion is exceeded.

Normal Flow Analysis - Trapezoidal Channel

Project: Example MD-1

Channel ID: Normal Depth Exampl



Design Information (Input)			
Channel Invert Slope	So =	0.003	ft/ft
Manning's n	n =	0.035	
Bottom Width	B =	10	ft
Left Side Slope	Z1 =	4	ft/ft
Right Side Slope	Z2 =	4	ft/ft
Freeboard Height	F =	2	ft
Design Water Depth	Y =	5	ft

Normal Flow Condtion (Calculated)			
Discharge	**Q =**	**715.83**	cfs
Froude Number	**Fr =**	**0.49**	
Flow Velocity	**V =**	**4.77**	fps
Flow Area	A =	150.00	sq ft
Top Width	T =	50.00	ft
Wetted Perimeter	P =	51.23	ft
Hydraulic Radius	R =	2.93	ft
Hydraulic Depth	D =	3.00	ft
Specific Energy	Es =	5.35	ft
Centroid of Flow Area	Yo =	1.93	ft
Specific Force	Fs =	24.72	kip

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9.2 Example MD-2: Composite Section Calculations Using Composite Design Worksheet

This example involves calculation of channel cross-section geometry parameters for a composite channel consisting of a low-flow channel with side slope protection for conveyance of frequent flows (up to 2-year) and vegetated overbanks to accommodate larger runoff events (up to the 100-year event). In this case, criteria for a grass-lined composite channel with side slope protection for the low-flow channel are applied for sizing. The channel sizing is based on hydraulic design parameters including:

Q-2yr = 2-year discharge = 600 cfs

Q-100yr = 100-year discharge (fully-developed, un-detained condition) = 3000 cfs

Qlf = design discharge for low flow channel = 300 cfs

Z1 = low flow channel left side slope = 3H:1V

Z2 = low flow channel right side slope = 3H:1V

Ym = low flow channel bank-full depth = 3 ft

ZL = left overbank side slope = 4H:1V

N-left = left overbank Manning's n = 0.040

ZR = right overbank side slope = 4H:1V

N-right = right overbank Manning's n = 0.040

Yob = overbank flow depth = 3.0 ft

Soil type = sandy

Left overbank width as a percentage of total overbank width = 50%

A sketch of the channel cross section, which defines these parameters, is included as a part of the worksheet and is illustrated for this example on the calculation sheet on the following page.

These hydraulic parameters are entered into the input section of the **Composite Design Worksheet** of the UD-Channels Spreadsheet to determine low flow, overbank, and composite channel characteristics for the low-flow design discharge and the 100-year discharge. A worksheet demonstrating application of the **Composite Design Worksheet** titled "Design of Composite Channel" for "Project = Example MD-2" and "Channel ID = Composite Channel Example" is provided as an example of this calculation tool.

The analysis demonstrates that a channel with the characteristics specified above, an invert slope of 0.49%, a 3-foot-deep low-flow channel with a bottom width of 20.7 ft, evenly distributed overbank benches to the left and right of the low-flow channel with width = 38.6 ft, and a total top width of 139.9 ft will meet the following design criteria:

1. The low-flow channel has the capacity to convey between ⅓ to ½ of the 2-year flow at a depth not exceeding 3 ft.
2. Flow is subcritical for all flow conditions evaluated, and Fr < 0.8, thereby satisfying Froude number criterion for non-erosive soils.
3. Longitudinal channel slope ≥ 0.2% and ≤ 0.6%.
4. Maximum depth of flow outside of low flow channel < 5.0 ft.
5. Composite cross section 100-year velocity < 7.0 ft/sec (non-erosive soils).
6. 4H:1V side slopes permit maintenance of vegetated banks.

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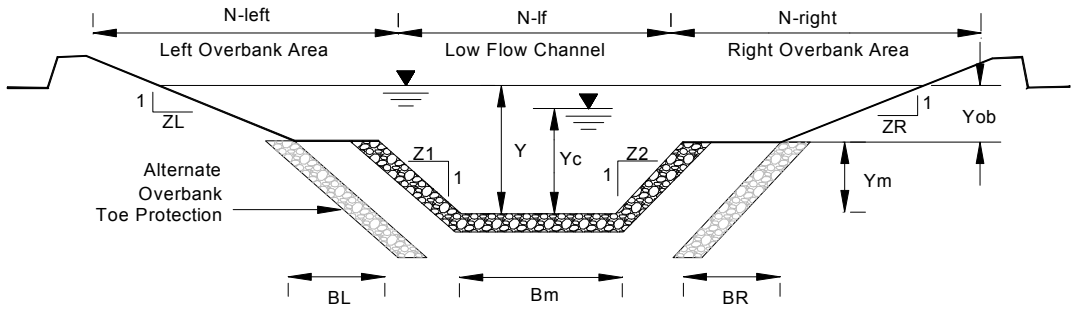
Design of Composite Channel

Project: Example MD-2

Channel ID: Composite Section Calculations Using Composite Design Worksheet



Design Information (Input)

2-Year Discharge - Total	Q-2yr =	600	cfs		
100-Year Discharge - Total	Q-100yr =	3,000	cfs	**Check one of the following toe protection types**	
Design Discharge - Low Flow Channel	Qlf =	300	cfs	Low Flow Channel Sideslope Protection	X check, OR
Low Flow Channel Left Side Slope	Z1 =	3.0	ft/ft	Overbank Toe Protection	check
Low Flow Channel Right Side Slope	Z2 =	3.0	ft/ft		
Low Flow Channel Bank-full depth	Ym =	3.00	ft	Left overbank width as a	
Left Overbank Side Slope	ZL =	4.0	ft/ft	percentage of total overbank width	50 %
Left Overbank Manning's n	n-left =	0.0400			
Right Overbank Side Slope	ZR =	4.0	ft/ft	**Check one of the following soil types**	
Right Overbank Manning's n	n-right =	0.0400		Sandy Soil	X check, OR
Overbank Flow Depth Yob (Y - Ym)	Yob =	3.00	ft	Non-Sandy Soil	check

Flow Condition (Calculated)

Channel Invert Slope **So = 0.0049 ft/ft**

Low Flow Channel Condition for Qd				**Low Flow Channel Flow Condition for Q100**		
Channel Bottom Width	Blf =	20.7	ft	Low Flow Channel Bottom Width	Bm =	20.7 ft
Channel Normal Flow Depth	Ylf =	3.00	ft	Top width	Tm =	38.7 ft
Top width	Tlf =	38.7	ft	Flow area	Am =	204.9 sq ft
Flow area	Alf =	89.0	sq ft	Wetted perimeter	Pm =	39.6 ft
Wetted perimeter	Plf =	39.6	ft	Manning's n (Calculated)	n-m =	0.0386
Manning's n (Calculated)	n-lf =	0.0534		**Discharge**	**Qm =**	**1,667 cfs**
Discharge (Calculated)	**Qlf =**	**300**	**cfs**	Velocity	Vm =	8.1 fps
Velocity	Vlf =	3.4	fps	**Froude number**	**Frm =**	**0.62**
Froude number	Fr-lf =	0.39		100-Yr. Critical Velocity	Vmc =	11.2 fps
				100-Yr. Critical Depth	Ymc =	4.6 ft

Left Overbank Flow Condition for Q100				**Right Overbank Flow Condition for Q100**		
Overbank Bench Width	BL =	38.6	ft	Overbank Bench Width	BR =	38.6 ft
Normal Depth in Overbanks	YLob =	3.0	ft	Normal Depth in Overbanks	YRob =	3.0 ft
Top width	TL =	50.6	ft	Top width	TR =	50.6 ft
Flow area	AL =	133.7	sq ft	Flow area	AR =	133.7 sq ft
Wetted perimeter	PL =	50.9	ft	Wetted perimeter	PR =	50.9 ft
Discharge	**QL =**	**668**	**cfs**	**Discharge**	**QR =**	**668 cfs**
Velocity	**VL =**	**5.0**	**fps**	**Velocity**	**VR =**	**5.0 fps**
Froude number	**FrL =**	**0.54**		**Froude number**	**FrR =**	**0.54**
100-Yr. Critical Velocity	VLc =	7.7	fps	100-Yr. Critical Velocity	VRc =	7.7 fps
100-Yr. Critical Depth in Overbanks	YLc =	2.0	ft	100-Yr. Critical Depth in Overbanks	YRc =	2.0 ft

Composite Cross-Section Flow Condition for Q100

Top width	**T =**	**139.8**	**ft**	**Discharge**	**Q = 3,002 cfs**
Channel Depth Y	**Y =**	**6.00**	**ft**	**Velocity (average)**	**V = 6.4 fps**
Flow area	A =	472.2	sq ft	Froude number	Fr = 0.61
Wetted perimeter	P =	141.5	ft	100-Yr. Critical Velocity	Vc = 9.0 fps
Cross-Sectional Manning's n (Calculated)	n =	0.0392		100-Yr. Critical Depth in Overbanks	Yc = 1.97 ft

NOTE:

The sum of QL + QR + Qm will slightly overestimate the total composite channel discharge, and will not equal Q. These element values are used, however, to estimate critical velocity and critical depth for design purposes.

9.3 Example MD-3: Riprap Lined Channel Calculations Using Riprap Channel Worksheet

This example demonstrates application of the **Riprap Worksheet** of the UD-Channels Spreadsheet to determine riprap sizing for a trapezoidal channel. The worksheet calculates a riprap sizing parameter based on Equation MD-13, with adjustments for channel curvature, to determine the riprap type required for the channel lining. Calculations are based on the following channel characteristics provided by the user:

So = channel invert slope = 0.010 ft/ft

B = bottom width = 30.0 ft

Z1 = left side slope = 2.5H:1V

Z2 = right side slope = 2.5H:1V

Ss = specific gravity of rock = 2.5

Ccr = radius of channel centerline = 200 ft

Q = design discharge = 2500 cfs

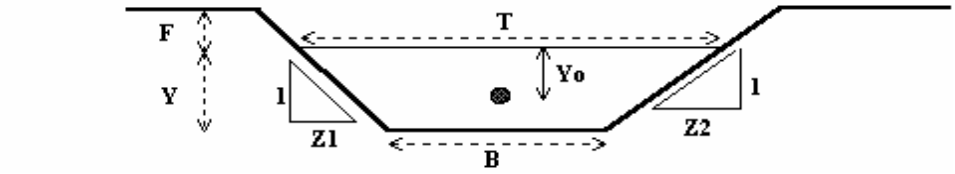
A sketch of the channel cross section, which defines these parameters, is included as a part of the worksheet and is illustrated for this example on the calculation sheet on the following page.

These parameters are entered into the input section of the **Riprap Worksheet** of the UD-Channels Spreadsheet to determine riprap type and channel hydraulic characteristics including Manning's *n*, the Froude number, velocity, and superelevation. A worksheet demonstrating application of the **Riprap Worksheet** titled "Design of Riprap Channel Cross Section" for "Project = Example MD-3" and "Channel ID = Riprap Channel Example" is provided as an example of this calculation tool.

Based on this analysis, Type H riprap is suitable for straight and curved sections of the channel and will meet the minimum K factor requirements. Calculations indicate that flow will be subcritical for the design discharge and that the Froude number is less than the maximum Froude number criterion for riprap channels of 0.8. Calculations also indicate that superelevation is not expected as a result of the channel curvature.

Design of Riprap Channel Cross Section

Project: Example MD-3
Channel ID: Rirap Channel Example



Design Information (Input)			
Channel Invert Slope	So =	0.0100	ft/ft
Bottom Width	B =	30.0	ft
Left Side Slope	Z1 =	2.5	ft/ft
Right Side Slope	Z2 =	2.5	ft/ft
Specific Gravity of Rock	Ss =	2.50	
Radius of Channel Centerline	Ccr =	200.0	ft
Design Disharge	**Q =**	**2,500.0**	**cfs**

Flow Condition (Calculated)			
Riprap Type (Straight Channel)	**Type =**	**H**	
Intermediate Rock Diameter (Straight Channel)	**D50 =**	**18**	**inches**
Calculated Manning's n (Straight Channel)	**n =**	**0.0423**	
Riprap Type (Outside Bend of Curved Channel)	**Type =**	**H**	
Intermediate Rock Dia. (O.B. of Curved Channel)	**D50 =**	**18**	**inches**
Calculated Manning's N (Curved Channel)	**n =**	**0.0423**	
Water Depth	Y =	5.97	ft
Top Width of Flow	T =	59.8	ft
Flow Area	A =	268.2	sq ft
Wetted Perimeter	P =	62.1	ft
Hydraulic Radius (A/P)	R =	4.3	ft
Average Flow Velocity (Q/A)	V =	9.3	fps
Hydraulic Depth (A/T)	D =	4.5	ft
Froude Number (max. = 0.8)	Fr =	0.78	
Channel Radius / Top Width	Ccr/T =	3.34	
Riprap Design Velocity Factor For Curved Channel	Kv =	1.69	
Riprap Sizing Velocity For Curved Channel	V_{Kv} =	15.8	fps
Riprap Sizing Paramenter for Straight Channel	**K =**	**3.27**	
Riprap Sizing Paramenter for Outside Bend of Curve	**K_{curve} =**	**5.51**	
*** Superelevation (dh)	dh =	0.41	ft
Discharge (Check)	**Q =**	**2,506.4**	**cfs**

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URBAN STORM DRAINAGE

CRITERIA MANUAL

Volume 2



Urban Drainage and Flood Control District
Denver, Colorado June 2001
Revised January 2007

- Hydraulic Structures
- Culverts
- Storage
- Flood Proofing
- Revegetation
- Design Examples

Urban Storm Drainage Criteria Manual

Volume 2

June 2001

Revised:
January 2007

SARB_009002

Drainage Criteria Manual (Volume 2)

June 2001

Revised January 2007



Urban Drainage and Flood Control District

SARB_009003

SUMMARY OF CHANGES TO VOLUME 2
of the
URBAN STORM DRAINAGE CRITERIA MANUAL
and
DISCLAIMER

2001 Edition vs. 1969 Edition

GENERAL

- All chapters edited; some totally rewritten.
- Many design aids added, including figures, nomographs, spreadsheets, etc.
- New chapters on Revegetation and Design Examples added.
- Emphasis on maintenance, public safety, aesthetics and multidisciplinary design approaches.
- Design checklists added to many chapters.
- Stronger emphasis on "designing with nature" principles such as "bioengineering."

HYDRAULIC STRUCTURES CHAPTER

- Revises drop structure design criteria and details.
- Provides guidance on safety considerations for boatable channels.
- Includes section on "rundowns" to convey flows into major drainageways and storage facilities.
- Also includes section on design of low tailwater basins at storm sewer discharge locations.
- Emphasizes public safety.

CULVERTS CHAPTER

- Contains significant changes.
- Emphasizes public safety through appropriate use of trash/safety racks at culvert entrances.
- Provides minimum trash rack size guidance.
- Discourages use of grates or racks at pipe outlets.

STORAGE CHAPTER

- Contents totally rewritten.
- Emphasizes designing for maintainability, aesthetics and safety.
- Addresses protecting against catastrophic failures due to overtopping embankments.
- Gives alternative techniques for preliminary and final design sizing of facilities.
- Presents guidance on sizing and use of retention facilities.
- Includes spreadsheets for aid in preliminary and final design.
- Provides for consistency with Volume 3 of the *Manual*.

FLOODPROOFING CHAPTER

- Contents completely rewritten.
- Draws heavily from Federal Emergency Management Agency guidance.

REVEGETATION CHAPTER

- Introduces a new chapter.
- Provides guidance on preparation of a planting plan.
- Provides grass and wildflower seed mixes for different soil and moisture conditions.
- Lists recommended shrubs, trees and planting techniques.
- Gives details on bioengineered elements including live staking, poling and willow bundles.
- Discusses soil amendments.
- Includes a revegetation process guidance chart.

DESIGN EXAMPLES CHAPTER

- Provides a variety of design examples from around the Denver metropolitan area.

2001 through 2005 Revisions to 2001 Edition of Volume 2

ENTIRE VOLUME 2

2005-03: Reformat entire Volume 2 to facilitate future updates. (Significant Revision)

HYDRAULIC STRUCTURES CHAPTER

2002-06: Correct Tables HS-4 and HS-7a4 and Figure HS-8. (Significant Revision)

CULVERT CHAPTER

2001-07: Rewritten *Trash Rack* Section. (Major Revision)

January 2007 Update to 2001 Edition

HYDRAULIC STRUCTURES CHAPTER

- Revised Manning's *n* and Boulder sizing recommendations for grouted boulders.
- Revised simplified Grouted Sloping Boulder (GSB) drop design recommendations and increased the allowable maximum drop for the simplified design from 5-feet to 6-feet.
- Added details for a smaller Impact Energy Dissipating Basin that is recommended for use with pipe outlets from 18- to 48-inches in diameter.
- Added details for the design of an impact basin for pipe outlets 18" and smaller in diameter.
- Modified the guidance on pipe outlet rundowns.
- Added details for a Grouted Boulder Rundown
- Added details for a GSB drop for use in channels with sandy/erosive soils.
- Modified concrete check structure details
- Added details and design guidance for a sheet-pile check structure.
- Clarifies some point in the *Detailed Hydraulic Analysis* section including guidance for Manning's *n* for Concrete, Boulders and Grouted Boulders.
- Clarified guidance on the design of low tailwater riprap basins at pipe outlets.

STORAGE CHAPTER

- Clarifies a number of topics covered in the *Design Storms for Sizing Storage Volumes* section, including issues dealing with drainage and flood control, spillway sizing, retention facilities, outlet works design (including guidance for triangular weirs) and other miscellaneous items.
- Claries the uses Rational Formula-Based Modified FAA Procedure as being applicable only for the sizing of single return period control on-site detention basins.
- Added Full Spectrum Detention procedure for the design of on-site detention facilities for tributary areas of one square mile and less.
    - Added guidance for simplified sizing detention volumes.
    - Added guidance for simplified perforated outlet design.
- Added a section titled: *On-Site Detention and UDFCD 100-year Floodplain Management Policy*.
- Expanded on the discussion on use of vegetation in detention basins.
- Revised the submittal checklist.

DISCLAIMER

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URBAN STORM DRAINAGE CRITERIA MANUAL

SUMMAY OF CHANGES TO VOLUME 2 AND DISCLAIMER

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1.0 USE OF STRUCTURES IN DRAINAGE
2.0 CHANNEL GRADE CONTROL STRUCTURES (CHECK AND DROP STRUCTURES)
3.0 CONDUIT OUTLET STRUCTURES
4.0 BRIDGES
5.0 TRANSITIONS AND CONSTRICTIONS
6.0 BENDS AND CONFLUENCES
7.0 RUNDOWNS
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1.0 USE OF STRUCTURES IN DRAINAGE

1.1 Introduction

Hydraulic structures are used to guide and control water flow velocities, directions and depths, the elevation and slope of the streambed, the general configuration of the waterway, and its stability and maintenance characteristics.

Careful and thorough hydraulic engineering is justified for hydraulic structures. Consideration of environmental, ecological, and public safety objectives should be integrated with hydraulic engineering design. The proper application of hydraulic structures can reduce initial and future maintenance costs by managing the character of the flow to fit the environmental and project needs.



Photograph HS-1—Denver's Harvard Gulch Flood Control Project introduced the baffle chute drop structure to urban flood control in 1966. Vegetation and time have made the structure part of the city's urban poetry.

Hydraulic structures include transitions, constrictions, channel drops, low-flow checks, energy dissipators, bridges, bends, and confluences. Their shape, size, and other features vary widely for different projects, depending upon the discharge and the function to be accomplished. Hydraulic design procedures must govern the final design of all structures. These may include model testing for larger structures when the proposed design requires a configuration that differs significantly from known documented guidelines or when questions arise over the character of the structure being considered.

This chapter deals with structures for drainage and flood control channels, in contrast to dam spillways or specialized conveyance systems. Specific guidance is given on drop structures for channels that match the District's guidelines for grass-lined and riprap-lined channels as given in the MAJOR DRAINAGE chapter of this *Manual*. In addition, guidance is provided for the design of energy dissipaters at conduit outlets. Sections on bridges, transitions, and constrictions primarily refer to other sources for more extensive design information.



Photograph HS-2—The Clear Creek I-25 vertical concrete drop structure was a "drowning machine" until it was retrofitted by CDOT with a 10:1 downstream face. (Photograph taken before retrofit.)

1.2 Channels Used for Boating

There are streams in the District in which rafting, canoeing, kayaking, and other water-based recreational activities occur. Design and construction of hydraulic structures in these waterways require a standard of care consistent with common sense safety concerns for the public that uses them. The ultimate responsibility for individual safety still resides with the boating public and their prudent use of urban waterways.

It is reasonable to retain a whitewater boating specialist to assist in the design criteria for a hydraulic structure on a boatable stream. In particular, reverse rollers are to be avoided (USACE 1985).

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1.3 Channel Grade Control Structures

Grade control structures, such as check structures and drop structures, provide for energy dissipation and thereby result in a mild slope in the upstream channel reaches. The geometry at the crest of these structures can effectively control the upstream channel stability and, to an extent, its ultimate configuration.

A drop structure traverses the entire waterway, including the portion that carries the major flood. A check structure is similar, but is constructed to stabilize the low-flow channel (i.e., one carrying the minor or lesser flood) in artificial or natural drainageways. It crosses only the low-flow portion of the waterway or floodplain. During a major flood, portions of the flow will circumvent the check. Overall channel stability is maintained because degradation of the low-flow channel is prevented. Typically, the 2-year flows are contained in the protected zone so that the low-flow channel does not degrade downward, potentially undermining the entire waterway.

1.4 Wetland Channel Grade Control

Wetland channels, whether low-flow channels or from bank to bank, require modest slopes not exceeding about 0.3%. Grade control structures are often required for stability. Due to the environmental nature of the wetlands, the grade control structures are planned and designed to be compatible with a wetland environment. Wetland channels do not need a trickle channel, but where used, the trickle channel should not lower the wetland water table more than 12 inches.

1.5 Conduit Outlet Structures

Design criteria given in this chapter are for structures specifically designed to dissipate flow energy at conduit outlets to the open waterway. These types of structures are typically located at storm sewer outlets. Design criteria for culverts and storm sewers that discharge in-line with the receiving channel are described in the MAJOR DRAINAGE chapter of this *Manual*.

1.6 Bridges

Bridges have the advantage of being able to cross the waterway without disturbing the flow. However, for practical, economic, and structural reasons, abutment encroachments and piers are often located within the waterway. Consequently, the bridge structure can cause adverse hydraulic effects and scour potential that must be evaluated and addressed as part of each design project.

1.7 Transitions and Constrictions

Channel transitions are typically used to alter the cross-sectional geometry, to allow the waterway to fit within a more confined right-of-way, or to purposely accelerate the flow to be carried by a specialized high velocity conveyance. Constrictions can appreciably restrict and reduce the conveyance in a manner that is either detrimental or beneficial. For example, a bridge, box culvert, or constriction may increase the upstream flooding by encroaching too far into the floodplain conveyance, whereas in another situation a

hydraulic control structure can be employed to purposely induce an upstream spill into an off-stream storage facility.

1.8 Bends and Confluences

General considerations for lined channels and conduits are discussed in the MAJOR DRAINAGE chapter of this *Manual*. Additional emphasis is added herein for certain situations. Channels and conduits that produce supercritical flow may require special structural or design considerations. This discussion is limited since these types of structures are generally associated with hydraulic performance exceeding the recommended criteria for grass-lined channels. Extensive study, specialized modeling and/or analysis may be required for these situations.

On the other hand, confluences are commonly encountered in design. Relative flow rates can vary disproportionately with time so that high flows from either upstream channel can discharge into the downstream channel when it is at high or low level. Depending on the geometry of the confluence, either condition can have important consequences, such as supercritical flow and hydraulic jump conditions, and result in the need for structures

1.9 Rundowns

A rundown is used to convey storm runoff from high on the bank of an open channel to the low-flow channel of the drainageway or into a detention facility. The purpose is to control erosion and head cutting from concentrated flow. Without such rundowns, the concentrated flow will create erosion.

1.10 Energy Dissipation

The energy of moving water is known as kinetic energy, while the stored energy due to elevation is potential energy. A properly sloped open channel will use up the potential energy in a uniform manner through channel roughness without the flow being accelerated. A grade control structure (i.e., drop and check) converts potential energy to kinetic energy under controlled conditions. Selection of the optimum spacing and vertical drop is the work of the hydraulic engineer. Many hydraulic structures deal with managing kinetic energy—to dissipate it in a reasonable manner, to conserve it at structures such as transitions and bridges, or occasionally to convert kinetic to potential energy using a hydraulic jump. Thus, managing energy involves understanding and managing the total energy grade line of flowing water.

1.11 Maintenance

Urban drainage facilities should not be built if they cannot be properly maintained on a long-term basis. This means that suitable access must be provided, a maintenance plan must be developed and funded, and the drainage facilities must be maintained in accordance with public works standards.

1.12 Structure Safety and Aesthetics

The design of structures must consider safety of flood control workers and the general public, especially

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when multiple uses are intended. Regulations and interpretations vary from community to community and may change with time. There are some inherent safety risks in any waterway that have to be recognized by the public, designers, and government officials. General suggestions are given in regard to safety; however, the designer must use a reasonable standard of care for the particular structure being designed or retrofitted that includes evaluation of present or likely future public access and uses such as recreation. The designer should give special consideration to structures located in waterways where boating is likely to occur. These structures need to be designed to avoid known hazards, such as reverse rollers (Leutheusser and Birk 1991), often referred to by some as "keepers."

Aesthetic appearance of structures in urban areas is also important. Structures can be designed with various configurations, different materials, and incorporation of adjacent landscaping to produce a pleasing appearance and good hydraulic function and to enhance the environmental and ecological character of the channel and floodplain. The incorporation of wetland vegetation, native grasses, and shrubs into the design adds to their aesthetics and provides erosion control and water quality functions.



Photograph HS-3—Stepped grouted sloping boulder drop structures such as in Denver's Bible Park can be safe, aesthetic, and provide improved aquatic habitat besides performing their primary hydraulic function of energy dissipation.

2.0 CHANNEL GRADE CONTROL STRUCTURES (CHECK AND DROP STRUCTURES)

2.1 Planning for the Future

Channel grade control structures (typically check structures and drop structures) should be designed for future fully developed basin conditions. In the use of a natural channel, the effects of future hydrology and potential down cutting must be included so that the natural channel is properly stabilized. Urbanization will create a base flow that, over time, will cause down cutting if not managed with grade control structures.

"Drop structures" are broadly defined. They establish a stable stream grade and hydraulic condition. Included are structures built to restore damaged channels, those that prevent accelerated erosion caused by increased runoff, and grade control drops in new channels. Drop structures provide special hydraulic conditions that allow a drop in water surface and/or channel grade. The supercritical flow may go through a hydraulic jump and then return to subcritical flow.

The focus of these criteria is on channel drops with primary emphasis on grass-lined channels. Check structures may be used to stabilize the natural low-flow channel in an unmodified floodplain. Thus, check structures also require additional consideration of the wider major flood path extending around the structure abutments.

Specific design guidance is presented for the following basic categories of drop structures: baffle chute drops (BCD), grouted sloping boulder drops (GSB), and vertical hard basin drops (VHB).

All drop structures should be evaluated after construction. Bank and bottom protection and adjustments may be needed when secondary erosion tendencies are revealed. It is advisable to establish construction contracts and budgets with this in mind. Use of standardized design methods for the types of drops suggested herein will reduce the need for secondary design refinements.

The design of the drop structure crest and provisions for the trickle or low-flow channel directly affect the ultimate configuration of the upstream channel. A shallow and/or dispersed trickle configuration will tend to result in some aggradation and a wetter channel bottom than might be associated with a wetland channel bottom. However, the wetland channel design would not contain a trickle channel because the low flows would be spread out uniformly across the entire channel bottom.

A higher unit flow will pass through the trickle or low-flow area than will pass through other portions of the channel cross section. This situation must be considered in design to avoid destabilization of the drop and the channel.

2.1.1 Outline of Section

The following section provides guidelines to aid in the selection of alternate types of drops, particularly those used for grass-lined channels. Drops for boatable channels are described separately.

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Much of the section is oriented toward hydraulic design and criteria for drop structures. There are two levels of analysis given. One level of hydraulic analysis is "detailed." All steps that are important are described, along with design aids. The other level is "simplified." Layouts of typical drops, particularly the crest configuration and related channel, are given which result in grass-lined channel hydraulic performance at the maximum depths and velocities normally allowed by the District for these types of channels. The use of these charts allows a quicker start, but certain steps from the "detailed" analysis will still be necessary, particularly the effects of greater unit flows in the low-flow or trickle channel area.

Hydraulic analysis sections are followed by further details appropriate to each of the types of drops that are recommended for grass-lined channels and boatable channel drops. Then, further information on seepage analysis, construction concerns, and low-flow channel structures is given.



Photograph HS-4—This grade control structure on the South Platte River was a hazard to the boating public until it was retrofitted by the CDOT. Here, a rescue is supervised by Colorado Governor Richard Lamm who was enjoying a rafting trip with friends and the Denver Water Rescue Team.

2.1.2 Boatable Channels

Channels that are known to be boatable, either now or that will be in the future, and those others that are classified by the Colorado Water Quality Control Commission for Class 1 or 2 Recreation, but are not presently judged to be boatable, should have hydraulic structures designed with public safety as a special consideration. The designer should not set the stage for hazardous hydraulics that would trap a boater,

such as at a drop structure having a reverse roller that may develop as the hydraulic jump becomes submerged.

Designs for boatable channels, grade control structures, and low-head dams have to prevent the development of submerged hydraulic jumps, have a gently sloped or stepped downstream face, and not have a deep stilling basin that would encourage the creation of a submerged hydraulic jump. One design approach is to direct the hydraulic momentum at the bottom of the drop at a relatively flat angle to help prevent a reverse roller. A downstream face on a drop having large grouted boulders and high roughness that is sloped at 10(H) to 1(V) has been used successfully on several projects along the South Platte River and on Clear Creek, permitting safe passage of boaters as the move over them.

Drop structures or low-head dams in boatable channels should incorporate a boat chute designed in accordance with carefully planned components that are consistent with recreational requirements for boater safety. Often, physical model studies are used to verify the efficacy of the proposed design.

Hydraulic structures on boatable channels should not create obstructions that would pin a canoe, raft or kayak, and sharp edges should be avoided.

2.1.3 Grass and Wetland Bottom Channels

Structures for grass and wetland bottom (i.e., non boatable) channels are described in detail on the following pages and are represented by a variety of choices and shapes to suit the particular site and related hydraulics.

Based on experience, the sloped drop has been found to be more desirable than the vertical wall drop with a hardened energy dissipation basin. Vertical drops can create a reverse roller and backflow eddies that have been know to trap boaters. Because of boater and public safety concerns, vertical drops are less desirable than sloping drops in urban areas. Other disadvantages of a vertical drop include the turbulence and erosive effect of the falling water on the drop structure, necessitating high maintenance.

It is desirable to limit the height of most drops to 3 to 5 feet to avoid excessive kinetic energy and to avoid the appearance of a massive structure, keeping in mind that the velocity of falling water increases geometrically with the vertical fall distance. If vertical drops are use, it is best to limit their height to 3 feet.

2.1.4 Basic Approach to Drop Structure Design

The basic approach to design of drop structures includes the following steps:

1. Determine if the channel is, or will be, a boatable channel. If boatable, the drop or check structure should use a standard of care consistent with adequate public safety to provide for boater passage.

2. Define the representative maximum channel design discharge (often the 100-year) and other discharges appropriate for analysis, (e.g., low or trickle flows and other discharges expected to

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occur on a more frequent basis) which may behave differently. All channels need to be designed for stability by limiting their erosion and degradation potential and for longevity by analyzing all the effects on channel stability at levels of flow, including the 100-year flood.

3. Approximate the channel dimensions and flow parameters including longitudinal slope. Identify the probable range of drop choices and heights with the aid of Figure HS-1.

4. Select drop structure alternatives to be considered for grass-lined or other channel types (see Section 2.2).

5. Decide if channel performance at maximum allowable criteria (i.e., velocity, depths, etc.) for grass-lined channels is practical or desirable. If not, or if the design flow is over 7,500 cfs, go to step 6; otherwise, the simplified design charts in Section 2.3.3 may be used to size the basic configuration of the crest. The designer should review the precautions given and the limits of application with respect to site conditions. Then the crest section and upstream channel transition will need to be refined for incorporation of the trickle or low-flow channel. This requires review of the upstream water surface profile and the supercritical flow downstream of the crest through the dissipation zone of the drop. Under conditions of a submerged jump due to a high tailwater elevation, steps to mitigate the reverse roller should be evaluated. If measures are taken to provide baffles or large boulders to break up the jet, then extensive analysis of the trickle zone hydraulics is not necessary. The steps involved are discussed in Section 2.3. Then go to step 7.

6. For refined analysis and optimal design of grass-lined channel drop structures, use the “detailed” hydraulic analysis in Section 2.3.2.

7. Perform soils and seepage analyses as necessary to obtain foundation design information.

8. In the case of drops for grass-lined channels, comply with the minimum specific criteria and follow the guidelines for the recommended types of drops (baffle chute, vertical hard basin, and grouted sloping boulder) presented in Section 2.3.4. Otherwise, provide a complete hydraulic analysis documenting the performance and design for the type of drop or other type of channel being considered. For channels with alluvial beds that present an erosion/degradation risk, a complete stability and scour analysis should be completed, accompanied by a geotechnical investigation and seepage analysis.

9. Use specific design criteria and guidelines to determine the final drop structure flow characteristics, dimensions, material requirements, and construction methods.

10. Obtain necessary environmental permits, such as a Section 404 permit.

2.2 Drop Selection

The primary concerns in selection of the type of drop structure should be functional hydraulic performance and public safety. Other considerations include land uses, cost, ecology, aesthetics, and maintenance, and environmental permitting.

Table HS-1 presents information to assist in the selection of appropriate drop structures applicable for various situations. Generally, the drops in any group are shown in order of preference. Comparative costs are often close. However, on-site conditions, such as public safety, and aesthetics may weight the selection of a drop structure type. Whenever public access is likely to occur, fencing not withstanding, the use of sloping drops is preferred for safety reasons over the use of vertical ones.

Table HS-1—Non-Boatable Drop Structure Selection
for 3- to 5-Foot High Drops and Flows of 0 to 15,000 cfs

1. Easy or limited public access; downstream degradation likely. a) Grouted sloping boulder drop with toe imbedded in the stream bed b) Baffle chute drop
2. Limited public access; downstream degradation not likely. a) Grouted sloping boulder drop b) Vertical hard basin drop c) Baffle chute drop
3. Easy public access; downstream degradation not likely. a) Grouted sloping boulder drop b) Baffle chute drop

From an engineering design standpoint, there are two fundamental systems of a drop structure: the hydraulic surface-drop system and the foundation and seepage control system. The material components that can be used for the foundation and seepage control system are a function of on-site soils and groundwater conditions. The selection of the best components for design of the surface drop system is essentially independent of seepage considerations and is based on project objectives, channel stability, approach hydraulics, downstream tailwater conditions, height of drop, public safety, aesthetics, and maintenance considerations. Thus, foundation and seepage control system considerations are discussed separately. One factor that influences both systems is the extent of future downstream channel degradation that is anticipated. Such degradation can destroy a drop structure if adequate precautions are not provided.

2.3 Detailed Hydraulic Analysis

2.3.1 Introduction

Analysis guidelines are discussed in this section to assist the engineer in addressing critical hydraulic and seepage design factors. For a given discharge, there is a balance between the crest base width,

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upstream and downstream flow velocities, the Froude number in the drop basin, and the location of the jump. These parameters must be optimized for each specific application.

There are two levels of analysis possible. The first involves detailed analysis of all hydraulic conditions and leads to an optimal design for each structure. The concepts involved are described herein, and numerous references are available for more detailed information. The second level of analysis is a simpler approach that is based on configurations that will be adequate at the limits of permissible grass-lined channel criteria as described in Section 2.4.

There are two general categories of drops: sloping and vertical. For safety reasons, vertical drops should be avoided under urban conditions for public safety reasons. Performance of vertical or smooth sloping drops into a hard basin is relatively well documented. Their hydraulic analysis is briefly described herein. The design criteria for other drops such as vertical plunge pools and baffle chutes is based on empirical data and model studies.

2.3.2 Crest and Upstream Hydraulics

After preliminary channel layout has indicated probable drop location and heights (see the MAJOR DRAINAGE chapter for guidance, including the design spreadsheet UD-Channels), analysis and design begins with review of the crest section at the top of the drop. As flow passes through critical depth near the crest, upstream hydraulics are separated from downstream. Usually, the key task here is to determine critical depth at the crest based on the entire section. The critical flow state needs to be verified to ascertain that the downstream tailwater does not submerge the crest and effectively controls the hydraulics above the crest. If the downstream tailwater controls, then the structure must still be evaluated as a check for the peak discharge and as a drop at lower flows, if appropriate.

With control at the drop crest, water surface profile computations are used to establish the upstream abutment and bank heights. Computations should include a transition head loss, typically ranging from 0.3 (modest transitions in grass-lined channels) to 0.5 (channels approaching abrupt constrictions) times the change in velocity head across the transition (see Section 5.2), and allowance for the end contraction where the flow may effectively separate from the abutment end walls. Refer to Section 5.0 and standard hydraulic references for guidance (Chow 1959, Rouse 1949, and USACE 1994).

2.3.3 Water Surface Profile Downstream of the Crest

2.3.7.1 Critical Depth Along a Drop Structure.

Although this discussion concerns the hydraulics below the crest of a drop structure, the fundamental analysis of this hydraulics is established by the crest conditions. Main, low-flow and trickle channel regions are considered separately. Although the actual location of critical depth can vary according to the channel, transition, and drop geometry, the assumption is made that critical depth occurs at the crest, in a horizontal straight line across the crest section.

The assumption of critical flow conditions across the crest is illustrated conceptually by the diagrams in Figures HS-2 and the corresponding energy level across the section. At any point across the crest, the velocity is a function of the critical depth at that point. This causes a higher unit discharge applied to the trickle channel zone than across the main channel flow area. Figure HS-2 also illustrates that the water surface and energy grade line profiles will be different at the trickle (or low-flow) portions of the section than in the main channel flow zones and the forces exerted by flow on individual boulders on the sloping face of the drop.

2.3.7.2 Hydraulic Analysis.

After review of the crest and upstream hydraulics, the analysis proceeds to the supercritical flow and the hydraulic jump downstream. It is here that the designer should give special consideration to the potential of reverse rollers and avoid them in boatable channels and, where practicable, in grass-lined channels. Little flow dispersal from the trickle or low-flow zone to the main zone occurs through the supercritical portion of the drop. (Flow expansion is more likely downstream of the jump.) Therefore, unit discharge determined at the crest for either the trickle channel or the main portion of the drop is assumed to remain constant. The required basin length varies between these zones. Baffle chutes are the only type of drop where this distinction is not significant because the baffles break up the flow patterns and spread the flow more evenly over the width of the channel.

With the exception of baffle chute drops, separate analysis should be performed to evaluate the main drop and trickle or low-flow channel zones, as follows:

Critical depth, Y_c, is determined for the entire section area. The subscript ($_t$) or ($_m$) is added to refer to the trickle or low-flow zone or main channel zone, respectively. For example, in the main channel zone:

$$Y_{cm} = El_c - El_m \qquad \text{(HS-1)}$$

Similarly, in the trickle or low-flow channel zone:

$$Y_{ct} = El_c - El_t \qquad \text{(HS-2)}$$

in which:

El_c = critical water surface elevation

El_m = elevation of the main channel at the drop crest

El_t = elevation of the trickle or low-flow channel at the drop crest

The remaining hydraulic parameters, such as critical velocity, V_c (ft/sec), energy grade line, *EGL*, and unit discharge, q (cfs/ft), are determined separately for the main and trickle or low-flow channel zones by equations of the form:

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$$V_c = \left(gY_c\right)^{1/2} \quad \text{(HS-3)}$$

$$EGL = Y_c + \frac{V_c^2}{2g} + El_m\left(or\ El_t\right) \text{ at the drop crest} \quad \text{(HS-4)}$$

$$q = Y_c^{3/2} g^{1/2} \quad \text{(HS-5)}$$

where g is the acceleration of gravity, and each parameter would have the subscript ($_m$) or ($_t$) as appropriate for the main, trickle, or low-flow channel zone.

Water surface profiles for the drawdown along the slope of a sloping drop and through the basin may be calculated using the "Standard Step Method" (Chow 1959), or any equivalent method suitable for unit discharge computations. For baffle chutes and vertical drops, individual methods are given in later subsections. It is necessary to plot the energy grade line to assure calculations are reasonable.

2.3.7.3 Manning's *n* for Concrete, Boulders and Grouted Boulders.

Depending on the type of materials and the relative depth, the appropriate roughness parameters should be used in computations. Table HS-2 and Figure HS-3 it refers to for grouted boulders, give the recommended Manning's roughness values and are based on Chow (1959), Oliver (1967), Anderson et. al. (1973), Henderson (1966), Barnes (1967), Smith and Murray (1975), Stevens et. al. (1976), Bathurst, Li and Simons (1979) and Stevens (1984). Normal equations typically used for riprap do not apply to boulders and grouted boulders because of their near-uniform size and because the voids may be completely or only partially filled with grout. The roughness coefficient taken from Figure HS-3 varies with the depth of flow relative to the size of the boulders and the depth of grout used to lock them in place. Stepped grouted rock placement is another method that can be used to increase roughness and reduce velocities over the face of the drop.

Table HS-2—Suggested Approximate Manning's Roughness Parameter at Design Discharge for Sloping Drops

Smooth concrete	0.011 to 0.013
Stepped concrete where step heights equal 25% of nape depth	0.025*
Grouted Boulders	See Fig. HS-3

* This assumes an approach channel depth of at least 5 feet. Values would be higher at lesser flow depths

2.3.7.4 Avoid Low Froude Number Jumps in Grass-Lined Channels.

Low Froude number hydraulic jumps with longer areas of hydraulic instability are common in grass-lined channel applications. Baffles and rock placements that create turbulence and dissipate energy along the face of the drop are recommended to help counteract the adverse effects of low Froude number jumps and the associated tendency to carry residual energy and waves for extended distances downstream.

2.3.4 Hydraulic Jump Location

The water surface profile analysis starts at the crest and works downstream to analyze supercritical flow. Separate analysis for the low-flow, trickle, and main channels includes the review of hydraulic jumps. In the case of a baffle chute, no jump will occur because the baffles are constantly breaking up the flow, preventing supercritical flow. Examination of tailwater conditions is still important for a baffle chute to evaluate riprap and basin layout.

To determine the location of the hydraulic jump, a tailwater elevation has to be established by water surface profile analysis that starts from a downstream control point and works upstream to the drop basin. This backwater analysis is based upon entire cross sections for the downstream waterway. The hydraulic jump, in either the low-flow, trickle channel, or the main drop, will begin to form where the unit specific force of the downstream tailwater is greater than the specific force of the supercritical flow below the drop. Special consideration must be given to submerged hydraulic jumps because it is here that reverse rollers are most common. For submerged jumps, the resulting downstream hydraulics should be evaluated (Cotton 1995).

The determination of the jump location is usually accomplished through the comparison of specific force between supercritical inflow and the downstream subcritical flow (i.e., tailwater) conditions:

$$F = \left(\frac{q^2}{gy}\right) + \left(\frac{y^2}{2}\right) \qquad \text{(HS-6)}$$

in which:

F = specific force (ft^2)

q = unit discharge (determined at crest, for low-flow, trickle, and main channel zones) (cfs/ft)

y = depth at analysis point (ft)

g = acceleration of gravity = 32.2 ft/sec^2

The depth, y, for downstream specific energy determination is the tailwater water surface elevation minus the ground elevation at the point of interest, which is typically the main basin elevation or the trickle channel invert (if the jump is to occur in the basin). The depth, for the upstream specific energy (supercritical flow), is the supercritical flow depth at the point in question.

Note that on low drops, the jump may routinely submerge the crest or may occur on the face of the drop. Refer to Little and Daniel (1981), Little and Murphey (1982), Chow (1959), USACE (1994), and Peterka (1984) for these cases.

The jump at sloping drops typically begins no further downstream than the drop toe. In vertical drops, the jump should begin where the jet hits the floor of the basin. This is generally accomplished in the main

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drop zone by depressing the basin to a depth nearly as low as the downstream trickle channel elevation. This will provide drainage for the basin.

2.3.5 Jump and Basin Length

The un-submerged jump length is typically between 3.6 and 6 times the tailwater depth, depending on the Froude number. For most cases, a basin length of 5 to 6 times the tailwater depth is the most advisable. A longer basin length is advisable for erosive soils or depending on the nature of the jump. Typically, at least 60% of the jump length is rock lined or otherwise reinforced. For baffle chute drops and vertical drops, basin dimensions are empirically derived.

In the trickle or low-flow channel alignment, the jump will tend to wash further downstream of the toe, and additional mitigation is recommended such as extending the basin length and/or providing baffles or large boulders that will break up the jet and dissipate energy.

2.3.6 Seepage Analysis

Subgrade erosion caused by seepage and structure failures caused by high seepage pressures or inadequate mass are of critical concern. These factors are important in the design and must be analyzed; otherwise, the structure might fail.

Seepage analysis can range from hand-drawn flow nets to computerized groundwater flow modeling. Advanced geotechnical field and laboratory testing techniques may be used to confirm the accepted permeability values where complicated seepage problems are anticipated. Several flow net analysis programs are currently available that are suitable for this purpose.

A minimal approach is Lane's Weighted Creep method. It can be used to determine dimensions or cutoff improvements that would provide an adequate seepage length. It should only be used as a guideline and, when marginal conditions or complicated geological conditions exist, a more precise analysis should be used. The involvement of a geotechnical engineer will often be necessary. Lane's method is given later in this section.

2.3.7 Force Analysis

Each component of a drop has forces acting upon it that require evaluation. This subsection describes the general forces, except forces on riprap for which the reader is referred to Isbash (1936), Oliver (1967), Smith (1975), Smith and Strung (1967), Stevens (1976), Taggart (1984), Abt (1986 and 1987), Wittler and Abt (1988), Maynord and Ruff (1987), Richardson (1988), and LSA (1986 and 1989). It is worth noting that the boulders are subject to all of the usual forces plus the hydrodynamic forces of interflow through voids and related pressure fluctuations. A complete presentation of forces acting on riprap and boulders is not presented herein. Forces are described here, as they would apply to sloping grouted boulder and reinforced concrete drops. Additional information on forces on baffle blocks is presented in the baffle chute subsection, and this information may also be useful to extrapolate for large boulders used as

baffles in grouted boulder drops.

The various criteria for structural slab thicknesses given for each type of drop have generally taken these forces into consideration. It is the user's responsibility to determine the forces involved.

Figure HS-3 illustrates the forces involved for a grouted sloping boulder drop, which is similar to other sloping concrete drops or baffle chutes. Five location points are of concern. Point 1 is downstream of the toe, at a location far enough downstream to be beyond the point where the deflection (turning) force of the surface flow occurs. Point 2 is at the toe where the turning force is encountered. Point 3 is variable in location to reflect alternative drain locations. When a horizontal drain is used, Point 3 is at a location where the drain intercepts the subgrade of the structure. Point 4 is approximately 50% of the distance along the drop slope. Point 5 is at a point underneath the grout layer at the crest and downstream of the cutoff wall.

Point 3 is usually the critical pressure location, regardless of the drain orientation. In some cases, Point 1 may also experience a low safety factor when shallow supercritical flow occurs, such as when the jump washes downstream.

Seepage uplift is often an important force controlling structure stability. Weep drains, the weight of the structure, and the water on top of the structure counteract uplift. The weight of water is a function of the depth of flow. Thus, the greater the roughness, the deeper the flow condition and the greater the weight.

2.3.7.1 Shear Stress

The normal shear stress equation is transformed for unit width and the actual water surface profile by substituting S_e, the energy grade line slope for S_o, and the drop slope.

$$\tau = \gamma y S_e \qquad \text{(HS-7)}$$

in which:

τ = shear stress (lbs/ft^2)

γ = specific weight of water (lbs/ft^3)

y = depth of water at analysis point (ft)

2.3.7.2 Buoyant Weight of Structure

Each design should take into consideration the volume of grout and rock or reinforced concrete and the density of each. In the case of reinforced concrete, 150 pounds per cubic foot can be used as the specific weight (or 88 pounds per cubic foot net buoyant weight). Specific weight of rock is variable depending on the nature of the material.

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2.3.7.3 Impact, Drag and Hydrodynamic Lift Forces

Water flowing down the drop will directly impact any abrupt rock faces or concrete structure projections into the flow. Technically, this is considered as a type of drag force, which can be estimated by equations found in various references. One should compare calculated drag force results with the forces shown later for baffle chute blocks (Section 2.5). Impact force caused by debris or rock is more difficult to estimate because of the unknown size, mass, and time elapsed while contact is made. Therefore, it is recommended that a conservative approach be taken with regard to calculating water impact (drag force), which generally will cover other types of impact force. Specialty situations, where impact force may be significant, must be considered on an individual basis. In addition, boulders and riprap are subject to hydrodynamic lift forces (Urbonas, 1968) that are caused by high velocities over the top of the stones and the zones of separation they create, resulting in significant reduction in pressure on the top while hydrostatic pressure remains unchanged at the stone's bottom.

2.3.7.4 Tur ning Force

A turning force impacts the basin as a function of slope change. Essentially, this is a positive force countering uplift and causes no great stress in the grouted rock or reinforced concrete. This force can be estimated as the momentum force of the projected jet area of water flowing down the slope onto the horizontal base and calculating the force required to turn the jet.

2.3.7.5 Friction

With net vertical weight, it follows that there would be a horizontal force resisting motion. If a friction coefficient of 0.5 is used and multiplied by the net weight, the friction force to resist sliding can be estimated.

2.3.7.6 Frost Heave

This value is not typically computed for the smaller drops anticipated herein. However, the designer should not allow frost heave to damage the structure, and, therefore, frost heave should be avoided and/or mitigated. In reinforced concrete, frost blankets, structural reinforcing, and anchors are sometimes utilized for cases where frost heave is a problem. If gravel blankets are used, then the seepage and transmission of pressure fluctuations from the hydraulic jump are critical.

2.3.7.7 Seepage Uplift Pressure

As explained previously, uplift pressure and seepage relief considerations are extremely important to structural stability and usually of greater concern than the forces described above. There can be troublesome pressure differentials from either the upstream or downstream direction when there is shallow supercritical flow on the drop slope or in the basin. One may consider an upstream cutoff to mitigate this problem. Weep locations with proper seepage control may be provided. For high drops (i.e., > 6 feet), more than one row of weep holes may be necessary.

A prudent approach is to use a flow net or other type of computerized seepage analysis to estimate

seepage pressures and flows under a structure.

2.3.7.8 Dynamic Pressure Fluctuations

Laboratory testing (Toso 1986; Bowers and Toso 1988) has documented that the severe turbulence in a hydraulic jump can pose special problems often ignored in hydraulic structures. This turbulence can cause significant positive and negative pressure fluctuations along a structure.

A good example of the problem can be envisioned by a situation in which the entire sloping face of the drop is underlain by a gravel seepage blanket. The gravel could be drained to the bottom of the basin or other locations where the jump will occur. In such a case, the positive pressure fluctuations could be transmitted directly to the area under the sloping face, which then could destabilize the structure since there would not be sufficient weight of water over the structure in the area of shallow supercritical flow.

The key parameter is the coefficient of maximum pressure fluctuation, $C_{p\text{-}max,}$ which is in terms of the velocity head of the supercritical flow just upstream of the jump:

$$C_{p-\max} = \frac{\Delta P}{\left(\frac{V_u^2}{2g}\right)} \qquad \text{(HS-8)}$$

in which:

ΔP = pressure deviation (fluctuation) from mean (ft)

V_u = incident velocity (just upstream of jump) (ft/sec)

g = acceleration of gravity (ft/sec^2)

Effectively, C_P is a function of the Froude number of the supercritical flow. The parameter varies as a function of X, which is the downstream distance from the beginning of the jump to the point of interest.

Table HS-3 presents recommended $C_{p\text{-}max}$ positive pressure values for various configurations. When the Froude number for the design case is lower than those indicated, the lowest value indicated should be used (do not reduce on a linear relationship) for any quick calculations. The values can be tempered by reviewing the C_p graphs, a few of which are given in Figures HS-4 through HS-6. Note that the graphs are not maximum values but are the mean fluctuation of pressure. The standard deviation of the fluctuations is also indicated, from which the recommended $C_{p\text{-}max}$ values were derived.

Figure HS-4 illustrates positive and negative pressure fluctuations in the coefficient, C_p, with respect to the location where the jump begins at the toe. Figure HS-5 presents the positive pressure fluctuation coefficient where the jump begins on the face. Figure HS-6 illustrates how the pressure fluctuations vary in a U.S. Bureau of Reclamation (USBR) Type II or III basin.

For the typical basin layouts given and where the drains are at the toe and connect directly to the

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supercritical flow, these pressure fluctuations should not be of great concern. However, when drains discharge to the jump zone and could transfer pressure fluctuations to areas under supercritical flow, pressure fluctuations are of concern.

Table HS-3—Nominal Limit of Maximum Pressure Fluctuations within the Hydraulic Jump (Toso, 1986)

Jump Condition	Froude Number	Suggested Maximum C_p
0° slope, developed inflow (boundary layer has reached surface)	3.0	1.0
30° slope, toe of jump at base of chute*	3.8	0.7
30° slope, toe of jump on chute*	3.3	0.8
30° slope, with Type II basin (USBR)	5.0	0.7
30° slope with Type III basin (USBR)	5.0	1.0

* Velocity head increased by elevation difference between toe of jump and basin floor, namely, depth at the drop toe.

2.3.7.9 Overall Analysis

All of the above forces can be resolved into vertical and horizontal components. The horizontal components are generally small (generally less than 1 psi) and capable of being resisted by the weight of the grout, rock, and reinforced concrete. When problems occur, they are generally the result of a net vertical instability.

The overall (detailed) analysis should include reviews of the specific points along the drop and the overall drop structure geotechnical and structural stability. All steps of this detailed analysis are not necessary for design of drops along modest capacity grass-lined channels, provided that the design is developed using the guidelines and configurations presented in the following simplified analysis approach section and that other District criteria are met. The critical design factors are seepage cutoff and relief and pressure fluctuations associated with the hydraulic jump that can create upward forces greater than the weight of water and structure over the point of interest. Underflow can easily lift a major slab of rock and grout and, depending upon the exposure, the surface flow could cause further weakening, undermining, or displacement. Generally, a 30-pound net downward safety allowance should be provided, and 60 pounds is preferred. An underdrain is generally needed as shown in detail 2 of Figure HS-7D to prevent hydrostatic uplift on the stones.

2.4 Simplified Drop Structure Designs for District's Grass-Lined Channels

2.4.1 Introduction and Cautions

As previously mentioned, there is a balance between the crest shape chosen, upstream channel stability, and the configuration of the drop downstream which will result in reasonable or optimal energy dissipation. Further, there is usually a single configuration of drop crest, upstream channel slope, and base width that will result in an acceptable drop structure performance for grass-lined channels designed

using the District's criteria described in the MAJOR DRAINAGE chapter.

This subsection presents simplified relationships that provide basic configuration and drop-sizing parameters that may be used when the District's maximum allowable velocity and depth criteria for grass-lined channels are used.

Design guidance presented in this section is developed for channels that operate at the brink of maximum criteria (i.e., approximately having unit discharge of 25 cfs/ft for erosive soil and 35 cfs/ft for erosion resistant soils and Froude Number $\leq$ 0.8). They do not consider channel curvature, effects of other hydraulic structures, or unstable beds, all of which require detailed analysis. They do provide guidelines for initial sizing and reasonableness checking, but are not a substitute for comprehensive hydraulic analysis in the context of the entire waterway.

2.4.2 Applicability of Simplified Channel Drop Designs

This section presents guidelines and analysis steps and specific minimum design criteria for two types of drops. Grouted sloping boulder drops and vertical hard basin drops are the only two types of drops for which these simplified design procedures may be utilized when used in grass-lined channels. Other designs are available, but they are more limited in application and require an individual analysis. Regardless of the type of drop used, it should never be located within or immediately downstream of a curve in a channel. Namely, locate all drops on a tangent and not on a curve of a channel.



Photograph HS-5—Example of stepped downstream face for a sloping boulder drop structure. Note dissipation of energy at each step for low flow.

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2.4.3 Simplified Grouted Sloping Boulder Drop Design

This type of structure has gained acceptance in the Rocky Mountain region due to close proximity to high-quality rock sources, design aesthetics, and successful applications. The quality of rock used and proper grouting procedure are very important to the structural integrity. There is no maximum height limit; however, the rock sizing procedure is more complex than the simplified procedures and details provided by Figures HS-7A, HS-7B and HS-7C for GSB drops 6-feet or less in height.

For typical channels the drop is designed with a hydraulic jump dissipator basin, although some energy loss is incurred due to the roughness of the grouted rock slope. In sandy soil channels the design provides for a scour at the toe and does not require an energy-dissipating basin. Structure integrity and containment of the erosive turbulence within the basin area are the main design objectives.



Photograph HS-6—Detail of the grouted sloping boulder drop with a trickle channel section creating the sight and sound of cascading water.

Construct boulder drops using uniform-height boulders with a minimum height specified in Table HS-4. Grout all boulders to a depth of 1/2 or 1/3 of their height through the approach, sloping face, and basin areas, except at the upstream crest where it needs to extend the full depth of the rock in order to provide stability of the approach channel. Figures HS-7A, HS-7B and HS-7C illustrate the general configuration of three types of GSB drops; one for a channel with a trickle channel (Figure HS-7A), one for one with a low-flow channel (Figure HS-7B) and one for channels in erosive soils or unstable conditions. (Figure HS-7C). Requirements for the grout, riprap and boulders are specified in the MAJOR DRAINAGE chapter of this *Manual*. Adequate seepage control with underdrains is important for a successful design whenever drop height exceeds 5-feet.

The following outlines the fundamental design steps and guidelines.

1. Hydraulics should be completed as described in Section 2.3 whenever the drop height exceeds 6 feet. Otherwise, use critical depth to size the boulders, using the boulder sizing procedure described below.
2. Grouted boulders must cover the crest and cutoff and extend downstream through the energy-dissipating basin when there is one, or through the imbedded toe of the drop when not present.
3. The vertical cutoff should be located at the upstream face of the crest, at a minimum depth of $0.8H_d$ or 4 feet, whichever is deeper. Evaluate specific site soils for use in seepage analysis and foundation suitability.



Photograph HS-7—An overall view of the drop structure from the previous page is illustrated here to emphasize the opportunities available for creating an attractive urban hydraulic setting for the riparian corridor.

4. The trickle or low-flow channel should extend through the drop crest section. Downstream, the trickle or low-flow channel protection should extend past the main channel protection, or large boulders and curves in the trickle or low-flow channel can be used in the basin area to help dissipate the energy.
5. Grout thickness, D_g, and rock thickness, D_r, should be determined based upon a minimum safety surplus net downward force of 30 pounds. The rocks must be carefully placed to create a stepped appearance, which helps to increase roughness. Minimum criteria for the simplified design process are referred to in step 8, below.
6. The main stilling basin should be depressed 1 to 2 feet deep in order to stabilize the jump. A row

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of boulders should be located at the basin end to create a sill transition to the downstream invert elevation. It is advisable to bury riprap for a distance of 10 feet downstream of the sill to minimize any erosion that may occur due to secondary currents.

When the drop is located in sandy soils and in channels with lesser stability, the stilling basin is eliminated and the sloping face extended to where the top of the boulders are five feet (5') below the projected (i.e., after accounting for downstream degradation) downstream channel's invert.

7. Do not use longitudinal slopes steeper than 4:1. Longitudinal slopes flatter than 4:1 improve appearance and safety while steeper slopes reduce structural stability. With high public usage, very flat longitudinal slopes (i.e., flatter than 8H:1V) help to mitigate reverse roller formation at higher tailwater depths that can cause submerged hydraulic jump formation and create "keepers".
8. Simplified design criteria are provided in Table HS-4 for grouted sloping boulder drops. These criteria are valid only where the channel flow conditions meet the minimum criteria recommended in the MAJOR DRAINAGE chapter.

Table HS-4—Grouted Sloping Boulder Drops: Minimum Design Criteria for Grass-Lined Channels Meeting the District's Maximum Depth and Velocity Criteria

Design Parameter	Drop Height (H_d) 6 Feet or Less	Drop Height (H_d) Greater Than 6 Feet
Maximum longitudinal slope	4H to 1V	4H to 1V
Minimum boulder depth	Use V_c to size*	Use V_n to size***
Grout thickness—D_g	½ to $^1/_3$ D_r except at the upstream crest of the structure where full grout depth is needed	½ D_r to $^1/_3$ D_r except at the upstream crest of the structure where full grout depth is needed
Basin depression	1 to 2 feet (*see Step 6 above for sandy/unstable channels*)	Do sequential depth analysis
Grouted boulder approach—L_a	5 feet (min.)	8 feet
Basin length—L_b** Erosive (sandy channel) Non-erosive	20 feet (*see Step 6 above for sandy/unstable channels*) 15 feet	20 feet (*also see Step 6 above for sandy/unstable channels*) 15 feet
Basin width—B	Same as crest width (*see Step 6 above for sandy/unstable channels*)	
Trickle and low-flow zone provisions	Install large boulders in center basin zone to break up high flow stream (*see Step 6 above for sandy/unstable channels*)	
Trickle zone protection width below drop	$3b_1$ or b^2 (whichever is smaller; see Figure HS-7)	
Other provisions	A buried riprap zone should be installed for $2H_d$ (10 feet minimum) downstream of the basin (*see Step 6 above for sandy channel*s) Do not locate a drop within a channel curve or immediately downstream of one.	

* Use critical velocity in low-flow and main channels to size boulders.

** Use drawdown velocity at H_d to size low-flow and main channel section boulders.

Sizing of boulders for the simplified grouted sloping boulder procedure is based on the following:

1. This procedure can be used only for channels designed using the specified maximum velocities and depths for grass-lined channels in this *Manual* (see the MAJOR DRAINAGE chapter).
2. For drops of 6-feet or less in height, one can use UD-Channels Spreadsheet to find the 100-year critical velocities in the low-flow and the main channels to size boulders for each section.

For drops greater than 6-feet in height, a detailed design procedure has to be used consisting of the following:

1. Determine the critical velocities using drawdown calculations to establish the 100-year flow depth at the toe of the drop.
   a. For a composite channel, find critical velocity, V_c, for the channel cross-section segment outside the low-flow section.
   b. For a composite channel, find critical velocity, V_{mc}, for the low-flow channel cross-section segment.
   c. For a simple trapezoidal or wetland bottom channel, find critical velocity, V_c, for the channel cross section.
2. Calculate rock-sizing parameter, R_p, for the channel cross-section segment outside the low-flow section or for a simple trapezoidal channel section using the critical velocity estimated for this segment of the cross section:

$$R_p = \frac{V_c S^{0.17}}{(S_s - 1)^{0.66}}$$

   in which: S = longitudinal slope along direction of flow in ft/ft

   S_s = Specific gravity of the rock. Assume 2.55 unless the quarry certifies higher specific gravity.

3. Calculate rock-sizing parameter, R_{pL}, for the channel cross-section segment within the low-flow section using the critical velocity for drops 6-feet in height (the draw-down velocity estimates at bottom of the drop for taller structures):

$$R_{pL} = \frac{V_{mc} S^{0.17}}{(S_s - 1)^{0.66}} \qquad \text{(HS-9)}$$

4. Select minimum boulder sizes for the cross-section segments within and outside the low-flow channel cross-section from Table HS-5. If the boulder sizes for the low-flow channel and the

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overbank segments differ, decide to use only the larger sized boulders throughout the entire structure, or to specify two sizes, namely, one for the low-flow channel and the other for the overbank segments of the cross section. Consider the complexity of specifying two different sizes on the design drawings and in the construction of the structure before deciding.

Regardless of the design procedure used above, all boulders shall be grouted in accordance with the specifications Figure HS-8. All grouted boulders outside of the low-flow channel shall be buried with topsoil to a depth of no less than 4 inches (6 inches or more preferred for successful grass growth) above the top of the highest boulder and the surface vegetated with native grasses on the overbank bench and native grasses and dry-land shrubs on the overbank channel's side slopes.

Table HS-5—Boulder Sizes for Various Rock Sizing Parameters

Rock Sizing Parameter, R_p	Ungrouted Boulders		Grouted Boulders *	
	Minimum Dimensions of Boulder, D_r	Boulder Classification	Minimum Dimensions of Boulder, D_r	Boulder Classification
Less than 4.50	18 inches	B18	18 inches	B18
4.50 to 4.99	24 inches	B24	18 inches	B18
5.00 to 5.59	30 inches	B30	24 inches	B24
5.60 to 6.39	36 inches	B36	30 inches	B30
6.40 to 6.99	42 inches	B42	36 inches	B36
7.00 to 7.49	48 inches	B48	42 inches	B42
7.50 to 8.00	n/a	n/a	48 inches	B48

* Grouted to no less than ½ the height (+1"/- 0"), no more than $^1/_3$ (+0"/- 1") of boulder height.

2.4.4 Vertical Hard Basin Drops

The vertical hard basin drops include a wide variety of structure designs, but they are not generally recommended for use in urban areas because of concerns for public safety, during wet and dry weather periods. In addition, vertical hard basin drops are to be avoided due to impingement energy, related maintenance and turbulent hydraulic potential (ASCE and WEF 1992). Whenever used, it is recommended their drop height, upstream invert to downstream channel invert, be limited to 3-feet.

The hydraulic phenomenon provided by this type of drop is a jet of water that overflows the crest wall into the basin below. The jet hits the hard basin and is redirected horizontally. With sufficient tailwater, a hydraulic jump is initiated. Otherwise, the flow continues horizontally in a supercritical mode until the specific force of the tailwater is sufficient to force the jump. Energy is dissipated through turbulence in the hydraulic jump. The basin is sized to contain the supercritical flow and the erosive turbulent zone. Figure HS-9 shows a vertical drop with a grouted boulder basin. The rock-lined approach length ends abruptly at a structural retaining crest wall that has trickle channel section.



Photograph HS-8—A vertical hard basin drop structure can be an effective tool for controlling grade, but its use in urban areas is not generally not recommended because of public safety concerns and aesthetics.

Basic design steps are as follows:

1. The design approach uses the unit discharge in the main and trickle channel to determine separately the water surface profile and jump location in these zones. The overall jump hydraulic problems are the same as previously described.

   Chow (1959) presents the hydraulic analysis for the "Straight Drop Spillway." Add subscript ($_t$) for the trickle channel area and subscript ($_m$) for the main channel area in the following equations. The drop number, D_n, is defined as:

$$D_n = \frac{q^2}{\left(gY_f^3\right)} \qquad \text{(HS-10)}$$

   in which:

   q = unit discharge (cfs/ft)

   Y_f = effective fall height from the crest to the basin floor (ft)

   g = acceleration of gravity = 32.2 ft/sec^2

   For hydraulic conditions at a point immediately downstream of where the nappe hits the basin

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floor, the following variables are defined as illustrated in Figure HS-10:

$$\frac{L_d}{Y_f} = 4.3D_n^{0.27}$$

$$\frac{Y_p}{Y_f} = 1.0D_n^{0.22}$$

$$\frac{Y_l}{Y_f} = 0.54D_n^{0.425}$$

$$\frac{Y_2}{Y_f} = 1.66D_n^{0.27}$$

in which:

Y_f = effective fall height from the crest to the basin floor (ft)

L_d = length from the crest wall to the point of impingement of the jet on the floor or the nappe length (ft)

Y_p = pool depth under the nappe just downstream of the crest (ft)

Y_l = flow depth on the basin floor just below where the nappe contacts the basin (ft)

Y_2 = tailwater depth (sequent depth) required to cause the jump to form at the point evaluated (ft)

In the case where the tailwater does not provide a depth equivalent to or greater than Y_2, the jet will wash downstream as supercritical flow until its specific force is sufficiently reduced to allow the jump to occur. Determination of the distance to the hydraulic jump, D_j, requires a separate water surface profile analysis for the main and low-flow zones as described herein for sloping drops. Any change in tailwater affects the stability of the jump in both locations.

2. The hydraulic jump length, L_j, is approximated as 6 times the sequent depth, Y_2. The design basin length, L_b, includes nappe length, L_d, the distance to the jump, D_j, and 60% of the jump length, L_j. (The subscripts "m" and "t" in Equations HS-11 and HS-12 refer to the main and trickle channel zones, respectively.)

   At the main channel zone:

$$L_{bm} = L_{dm} + D_{jm} + 60\%\left(6Y_{2m}\right) \qquad \text{(HS-11)}$$

   At the trickle channel flow zone, without baffles or boulders to break up the jet:

$$L_{bt} = L_{dt} + D_{jt} + 60\% \left(6Y_{2t}\right) \quad \text{(HS-12)}$$

3. Caution is advised regarding the higher unit flow condition in the low-flow zone. Large boulders and meanders in the trickle zone of the basin may help dissipate the jet and may reduce downstream if riprap extended downstream along the low-flow channel. When large boulders are used as baffles in the impingement area of the low-flow zone, the low-flow basin length L_{bt}, may be reduced, but not less than L_{bm}. Boulders should project into the flow 0.6 to 0.8 times the critical depth. They should be located between the point where the nape hits the basin and no closer than 10 feet from the basin end.

4. The basin floor elevation should be depressed in depth, and variable with drop height. Note that the basin depth adds to the effective tailwater depth for jump control. The basin can be constructed of concrete or grouted rock. Use of either material must be evaluated for hydraulic forces and seepage uplift.

   There should be a sill at the basin end to bring the invert elevation to that of the downstream channel and sidewalls extending from the crest wall to the sill. The sill is important in causing the hydraulic jump to form in the basin. Buried riprap should be used downstream of the sill to minimize any local scour caused by the lift over the sill.

5. Caution is advised to avoid flow impinging on the channel side slopes of the basin.

6. Crest wall and footer dimensions should be determined by conventional structural methods. Underdrain requirements should be determined from seepage analysis.

7. Seepage uplift conditions require evaluations for each use. Thus, seepage analysis should be completed to provide for control and weight/size of components (see Section 2.6).

8. Simplified design criteria are provided in Table HS-6 for vertical hard basin (grouted boulder) drops. These criteria are valid only where the channel flow conditions meet the criteria in the MAJOR DRAINAGE chapter of this *Manual* and the drop does not exceed 3-feet in height.

9. Drops with reinforced concrete basins will have slab thickness and drop lengths that vary somewhat from the simplified design in Item 8 above, depending upon hydraulic and seepage considerations.

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Table HS-6—Vertical Drops With Grouted Boulder Basin: Simplified Design Criteria for Small Vertical Drops in Grass-Lined Channels Meeting District Criteria

Design Parameter	Criterion
Maximum Drop Height	3 feet, invert to invert
Boulder size—D_r*	18 inch minimum dimension
Grout thickness—D_g	10 inches**
Basin depression—B (see Figure HS-10)	1.5 ft
Basin length—L_b (see Figure HS-10)	25 ft
Approach length—L_a	10 ft buried riprap
Trickle flow zone provisions	Install large boulder or baffles in center zone to break up high flow stream, or apply separate water surface analysis
Other provisions	A buried riprap zone should be installed for 10 ft minimum downstream of the drop basin Consider the possible hazard to public when selecting this type of drop for use in urban areas.

* Boulder size refers to the minimum dimension of all boulders measured in any direction.

** Bury all grouted boulders on side slopes by filling all gaps and depressions to top of boulders with lightly compacted topsoil and capping with at least 4 inches of top soil; however, capping it with 6 to 12 inches of topsoil will insure a much more robust conditions the native grasses to be seeded on the soil cap.

2.5 Baffle Chute Drops

The USBR has developed design standards for a reinforced concrete chute with baffle blocks on the sloping face of the drop, commonly referred to as baffled apron or baffle chute drops. There are references such as *Hydraulic Design of Stilling Basins and Energy Dissipators* (Peterka 1984) and *Design of Small Canal Structures* (Aisenbrey, et al. 1978) that should be used for the design of these structures. A baffle chute drop was constructed on Harvard Gulch that can be inspected for long-term performance (Wright 1967).

The hydraulic concept involves flow repeatedly encountering obstructions (baffle blocks) that are of a nominal height equivalent to critical depth. The excess energy is dissipated through the drop by the momentum loss associated with reorientation of the flow. A minimum of four rows of baffle blocks is recommended to achieve control of the flow and maximum dissipation of energy. Guidelines are given for sizing and spacing the blocks. Designing for proper approach velocities is critical to structure performance. One advantage of this type of drop is that it does not require tailwater control. However, the designer does need to consider local flow and scour patterns in the transition back to the channel.

Optimal performance occurs for a unit discharge of 35 to 60 cfs/ft of chute width, which happens to be a well-matched design for the District's grass-lined channel criteria. Refer to Rhone (1977) for guidance on higher unit discharge and entrance modifications to address backwater effects.



Photograph HS-9—Close-up of the inside workings of a baffle chute drop after more than three decades of service.

The typical design consists of upstream transition walls, a rectangular approach chute, a sloping apron of 2:1 or flatter slope that has multiple rows of baffle blocks and downstream transition walls. The toe of the chute extends below grade and is backfilled with loose rock to prevent undermining of the structure by eddy currents or minor degradation of the downstream channel. This rock will rearrange to establish a stable bed condition and produce additional stilling action. The structure is effective without tailwater; however, tailwater reduces scour at the toe. Grouted and concrete basins have been used at the transition to the downstream trickle and main channels. The structure also lends itself to a variety of soils and foundation conditions.

There are fixed costs associated with the upstream transition walls, crest approach section, downstream transition walls and a minimum length of sloping apron (for four baffle rows). Consequently, the baffle chute becomes more economical with increasing drop height.

The potential for debris accumulation and subsequent maintenance must be considered. Caution is advised regarding streams with heavy debris flow because the baffles can become clogged, resulting in overflow, low energy dissipation, and direct impingement of the erosive stream jet on the downstream channel. Baffle chute drops are best suited for grass-lined channels and should not be used for boatable streams.

The basic design criteria and details are given in Figure HS-11 (adapted from Peterka 1984). Remaining structural design parameters must be determined for specific site conditions. Recommended design

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procedures are as follows:

1. Determine the maximum inflow rate and the design unit discharge, $q = \frac{Q}{W}$.

2. An upstream channel transition section with vertical wingwalls constructed 45 degrees to the flow direction causes flow approaching the rectangular chute section to contract. It is also feasible to use walls constructed at 90 degrees to the flow direction. In either configuration, it is important to analyze the approach hydraulics and water surface profile. Often, the effective flow width at the critical cross section is narrower than the width of the chute opening due to flow separation at the corners of the abutment (see Section 5.0).

3. The entrance transition should be followed by a rectangular flow alignment apron, typically 5 feet in length. The upstream approach channel velocity, V, should be as low as practical and less than critical velocity at the control section of the crest. Figure HS-11 gives the USBR-recommended chute entrance velocity. In a typical grass-lined channel, the entrance transition to the rectangular chute section will produce the desired upstream channel velocity reduction. The chute elevation (shown in Figure HS-11) should only be above the channel elevation when approach velocities cannot be controlled by the transition. Extra measures to prevent upstream aggradation are required with the raised crest configuration.

4. Normally, the baffles should be sized at height, H, equal to 0.8 times critical depth at peak flow. The chute face slope should be 2:1 for most cases but may be reduced for low drops or where a flatter slope is desirable. For unit discharge applications greater than 60 cfs/ft, the baffle height may be based on two-thirds of the peak flow; however, the chute sidewalls should be designed for peak flow (see Step 8 below).

   Baffle block widths and spaces should equal approximately $1.5H$ but not less than H. Other baffle block dimensions are not critical hydraulically. The spacing between the rows of baffle block should be H times the slope ratio. For example, a 2:1 slope makes the row spacing equal to $2H$ parallel to the chute floor. The baffle blocks should be constructed with the upstream face normal to the chute floor.

5. Four rows of baffle blocks are required to establish full control of the flow. At least 1½ rows of baffles should be buried in riprap where the chute extends below the downstream channel grade. Rock protection, assumed here as Type M riprap, should continue from the chute outlet to a minimum distance of approximately $4H$ at a riprap layer depth of 2.0 feet to prevent eddy currents from undermining the walls. Additional rows of baffles may need to be buried below grade to allow for downstream channel degradation. Determine if the downstream channel grade has been stabilized to determine how many rows of baffles may need to be buried.

6. The baffle chute wall height (measured normal to the floor slope) should be 2.4 times the critical depth based on peak discharge. The wall height will contain the main flow and most of the splash. The designer of the area behind the wall should consider that some splash may occur, but extensive protection measures are not required.

7. Determine upstream transition and apron sidewall height as required by backwater analysis. Lower basin wingwalls generally should be constructed normal to the chute sidewalls at the chute outlet to prevent eddy current erosion at the drop toe. These transition walls should be of a height equal to the channel normal depth in the downstream channel plus 1 foot and length sufficient to inhibit eddy current erosion.

8. The trickle flow channel should be maintained through the entrance transition apron, approach, and crest sections. It may be routed between the first row of baffle piers. The trickle channel should start again at the basin rock zone that should be slightly depressed and then graded up to transition into the downstream channel to focus the low flows into the trickle channel. Figure HS-12 illustrates one method of designing the trickle channel through the crest.

9. The conventional design shown in Figure HS-11 results in the top elevation of the baffles being higher than the crest, which causes a backwater effect upstream. Figure HS-12 may be used to estimate the extent of the effect and to determine corrective measures such as increasing the upstream freeboard or widening the chute. Note that blocks projecting above the crest will tend to produce upstream sediment aggradation. Channel aggradation can be minimized by the trickle channel treatment suggested in Step 8.

   Another means of alleviating these problems is by using the Fujimoto entrance developed by the USBR and illustrated in Figure HS-12. The upper rows of baffles are moved one row increment downstream. The important advantage of this entrance is that there is not a backwater effect of the baffles. The serrated treatment of the modified crest begins disrupting the flow entering the chute without increasing the headwater. More importantly, this configuration provides a level crest control. The designer may either bring the invert of the upstream trickle channel into this crest elevation, widening the trickle channel as it approaches the crest, or he or she may have a lower trickle channel and bring it through the serrated crest similar to Step 8.

10. Concrete walls and footer dimensions should be determined by conventional structural methods. Cutoffs and underdrain requirements should be determined by seepage analysis discussed earlier in this chapter.

11. The hydraulic impact forces on the baffles should be determined to allow the structural engineer to size adequate reinforcing steel. Figure HS-12 may be used as a guideline. The structural engineer should apply a conservative safety factor.

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2.6 Seepage Control

2.6.1 Seepage Analysis Methods

The **preferred deterministic methodology** for seepage analysis is the use of manual and computerized flow net analyses. It is used to quantify groundwater flows, pressures, and critical gradients under hydraulic structures. Flow net analysis can quantify the effects of multiple strata of different soil media and complex geometries and situations. Full decryption of flow net analysis is beyond the scope of this *Manual* and the user is referred to Cedergren (1967), USBR (1987) and Taylor (1967) for more information and instruction in the use of flow net analysis techniques.

At an absolute minimum and as a first order of estimation, Lane's Weighted Creep Method (CWM) can be used to identify probable seepage problems, evaluate the need for control measures, and roughly estimate uplift forces. It is not as definitive as the above-mentioned flow net analysis. The CWM technique was originally proposed by E.W. Lane in 1935. This method has been deleted, however, in the 1987 revision of *Design of Small Dams* (USBR 1987), possibly indicating greater use of flow net and computer modeling methods or for other reasons that we do not know about. Although Lane's method is relatively well founded, it should be used as a guideline, and when marginal conditions or complicated geological conditions exist, the more sophisticated flow-net analysis should be used. The essential elements of Lane's method are as follows:

1. The weighted-creep distance through a cross section of a structure is the sum of the vertical creep distances, L_v (along contact surfaces steeper than 45 degrees), plus one-third of the horizontal creep distances, L_H (along contact surfaces less than 45 degrees).

2. The weighted-creep head ratio is defined as:

$$C_W = \frac{\left(\frac{L_H}{3} + L_V\right)}{H_S} \qquad \text{(HS-13)}$$

   in which:

   C_W = creep ratio

   H_S = differential head between analysis points (ft)

3. Reverse filter drains, weep holes, and pipe drains help to reduce seepage problems, and recommended creep head ratios may be reduced as much as 10% if they are used.

4. In the case where two vertical cutoffs are used, then Equation HS-13 should be used along with Equation HS-14 to check the short path between the bottom of the vertical cutoffs.

$$C_{W2} = \frac{\left(L_{V-US} + \quad 2L_{H-C} + L_{V-DS}\right)}{H_S} \qquad \text{(HS-14)}$$

in which:

C_{W2} = creep ratio where two vertical cutoffs are used

$L_{V\text{-}US}$ = vertical distance on the upstream side of the upstream cutoff (ft)

$L_{V\text{-}DS}$ = vertical distance on the downstream side of the downstream cutoff (ft)

$L_{H\text{-}C}$ = horizontal distance between the two vertical cutoffs (ft)

5. If there are seepage lengths upstream or downstream of the cutoffs, they should be treated in the numerator of Equation HS-14 similar to Equation HS-13. Seepage is controlled by increasing the total seepage length such that C_W or C_{W2} is raised to the value listed in Table HS-7. Soils tests must be conducted during design and confirmed during construction.

6. The upward pressure to be used in design may be estimated by assuming that the drop in uplift pressure from headwater to tailwater along the contact line of the dam and foundation is proportional to the weighted-creep distance.

Table HS-7—Lane's Weighted Creep: Recommended Ratios

Material	Ratio
Very fine sand or silt	8.5
Fine sand	7.0
Medium sand	6.0
Coarse sand	5.0
Fine gravel	4.0
Medium gravel	3.0
Coarse gravel including cobbles	3.0
Boulders with some cobbles and gravel	3.0
Soft clay	3.0
Medium clay	2.0
Hard clay	1.8
Very hard clay or hardpan	1.6

2.6.2 Foundation/Seepage Control Systems

Table HS-8 presents some typical foundation conditions and systems that are often used for various drop heights. For each condition, cutoff types are listed in general order of preference for guidance purposes only. As a general rule, it is not recommended that groundwater flow cutoffs not be installed at the downstream ends of drop structures. Their presence can cause greater hydraulic uplift forces than would exist without a downstream cutoff. The design goal is to relieve the hydrostatic pressures along the

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structure and not to block the groundwater flow and cause higher pressures to build up.

The hydraulic engineer must calculate hydraulic loadings that can occur for a variety of conditions such as during construction, during dominant low flows, during flood flows, during design flows and other critical loading scenarios. The soils/foundation engineer combines this information with the on-site soils information to determine foundation requirements. Both engineers should work with a structural engineer to establish final loading diagrams and in selection and sizing of structural components.

Table HS-8—General Cutoff Technique Suitability

	Drop Height (ft)			
Soil Conditions	2	4	8	12
Sands and gravel over bedrock with sufficient depth of material to provide support—groundwater prevalent	SP[1] CTc CTf	SP[1] CTc/ST CTf/CTI	Sp/SwB[1] ST	Sp/SwB[1] ST
Sands and gravel with shallow depth to bedrock—groundwater prevalent	CTc CW SP[2]	CTc/ST CW SP[2]	ST CW SP[2]	ST CW SwB[2]
Sands and gravel with large depths to bedrock—groundwater prevalent	SP CTc	SP CTc/ST	SP ST	SP/SwB ST
Sands and gravel, no groundwater, or water table normally below requirement (for variation caused by depth to bedrock, see first case)	SP CTf/CTI CW	SP CTI CW	SP CTI	SP/SwB CTI
Clay (and silts)—medium to hard	CTc	CT	CT	CT
	CW	Reduce length for difficult backfill conditions		
	CTI/CTf	Only for local seepage zones/silts		
	ST	Expensive—for special problems		
Clays (and silts)—soft to medium with lenses of permeable material—groundwater present	CP CTc	SP CTc	SP CTc/ST	SP/SwB ST
Clay (and silts)—soft to medium with lenses of permeable material (may be moist but not significant groundwater source)	SP CTc CTf CW	SP CTc CTI CW	SP CTc/ST CTI CW	SP/SwB ST CTI CW

[1] Consider scour in sheet pile support.

[2] Excavate into bedrock and set into concrete.

Legend:

- SP Sheet pile
- SwB Sheet pile with bracing and extra measures
- CTc Cutoff trench backfilled with concrete
- ST Slurry trench; similar to CTc, but trench walls are supported with slurry and then later replaced with concrete or additives that provide cutoff
- CW Cutoff wall; conventional wall, possibly with footer, backfilled; note that the effective seepage length should generally be decreased because of backfill
- CTI Cutoff trench with synthetic liner and fill
- CTf Cutoff trench with clay fill



Photograph HS-10—Boatable channels of the District waterways provide enjoyment to a wide variety of citizens. The South Platte River example in this photograph provides an easily accessible boating experience.

2.7 Simplified Minimum Design Approach for Boatable Channels

Due to the fact that a special standard of care for the design of drops and low-head dams on boatable channels is required, the following design approach for boatable channels is limited to suggestions for the experienced hydraulic structure designer once the channel has been determined to be a boatable one.

1. Contact reliable whitewater boating experts to discuss general design objectives and boater safety concerns.

2. Select maximum height of individual drops—generally 4 feet. If they are more than 4 feet, a physical hydraulic model may be necessary.

3. Determine basic drop characteristics to be compatible with public safety and recreational boating. Suggestions are as follows:

   - Use a Froude number, F_r, less than 1.5 at the toe of the drop.
   - Avoid reverse rollers under all conditions of flow.
   - Assess stability of the structure taking into account expected downstream channel degradation.
   - Consider the slope of the downstream face of a sloping drop; 10(H) to 1(V) is common.

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Photograph HS-11—Unprotected urban channels can experience bank erosion and degradation when established design criteria are not used. The invert of pipe used to be at invert of channel before degradation occurred.

- Provide boat chute with pilot rocks for routine boat passage of drop.
- Do not use an energy dissipating basin; instead, continue the sloping surface at least 5 feet below the downstream thalweg of the stream.
- Provide adequate warning signs and portage area.
- Use grouted sloping boulder or appropriately sized large ungraded sloping boulder structure.
- Consider vertical cutoff walls at the upstream end for seepage control.

4. Obtain peer review on the preliminary design.
5. Allow for follow-up rock adjustment after completion, especially for boat chutes.

2.8 Construction Concerns: Grass-Lined Channels

The selection of a drop or a grade control check and its foundation may be tempered by construction difficulty, access, material delivery, etc. Some of the important concerns are discussed below, although this is by no means an exhaustive list of the concerns possible for every site and situation.

2.8.1 Foundation/Seepage Control

Initial items that are especially important are site water control and foundation conditions. A common problem is destabilization of the foundation soils by rapid local dewatering of fine-grained, erosive soils, or soils with limited hydraulic conductivity. Often the preferred method is continuous pumping rates at perimeter locations (or well points) that allow the entire construction area to remain stable. Appropriate

water control techniques for use during construction of a drop structure should be presented to the contractor. Diversion berms should be designed with planned berm failure points to avoid flooding of drop-structure sites during construction.

The actual subgrade condition with respect to seepage control assumptions must be inspected and field verified. The engineer who established the design assumptions and calculated the required cutoffs should inspect the cutoff for each drop and adjust the cutoff for the actual conditions encountered. For example, if the inspection of a cutoff trench reveals a sandy substrate rather than clay, then the cutoff trench may need to be deepened, or a different cutoff type may need to be implemented. Obviously, soil testing is an advisable precaution to minimize changes and avoid failures.

2.8.2 Baffle Chute Construction

There are numerous steps necessary in the construction of a baffle chute, but a contractor usually easily controls them. For quality control and inspection there are consistent, measurable, and repeatable standards to apply.

Baffle chutes are highly successful as far as hydraulic performance is concerned and are straightforward to construct. Steel, formwork, concrete placement and finish, and backfill generally require periodic inspection. Potential problems include foundation integrity, riprap quality control, water control, and the finish work with regard to architectural and landscape treatments. Formwork, form ties, and seal coatings can leave a poor appearance if not done properly.

2.8.3 Vertical Hard Basin Construction

Foundation and seepage concerns are critical with regard to the vertical wall. Poor construction and seepage control can result in sudden failure. The use of caissons or piles can mitigate this effect. Put in comparative terms with the baffle chute, seepage problems can result in displacement of the vertical wall with no warning, where the box-like structure of the baffle chute may experience some movement or cracking, but not total failure, and thus allow time for repairs.

The quality control concerns and measures for vertical basins are the same as for baffle chutes. The subsoil condition beneath the basin is important to insure that the stilling basin concrete or grouted rock bottom is stable against uplift pressures.

2.8.4 Sloping Grouted Boulder Construction

The sloping grouted boulder drops require significant construction control efforts in the field. Seepage analysis is required to determine a compatible combination of cutoff depth, location of weep and toe drains, and the thickness of grouted rock layer. The greatest danger lies with a “sugar-coated” grout job, where the grout does not penetrate the voids fully between the rock and the subgrade and leaves voids below the grout that act as a direct piping route for water, guaranteeing early failure.

Individual boulders should be larger in diameter than the grout layer so that the contractor and the

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inspector can verify the grout depth and have grout placed directly to the subgrade. The best balance appears to have the grout thickness set at 1/2 the boulder height, but no more than 2/3 boulder height, and to have an overall mass sufficient to offset uplift, plus a safety factor. Limiting grout thickness also improves the overall appearance of the grouted boulder structure.

The condition of the subgrade, adequate seepage control, and sub-drainage of the seepage flow are all critical. There is a tendency to disturb the subgrade during rock placement, leaving a potential piping route. This should be controlled by good subgrade preparation, careful rock placement, and removal of loose materials. Absolutely no granular bedding or subgrade fill using granular materials should be used to prevent conditions that will cause piping. Problems with rock density, durability and hardness are of concern and can vary widely for different locations. The rock should be inspected at regular intervals to meet minimum physical dimensions, strengths, durability and weights as defined in the specifications.

For aesthetic reasons, it is recommended that the grouted boulders above the low flow section and on the banks be covered with local soils, topsoil and revegetated.

2.9 Low-Flow Check and Wetland Structures

Urbanization causes more frequent and sustained flows, and therefore the trickle/low-flow channel and wetlands become more susceptible to erosion even though the overall floodplain may remain stable and able to resist major flood events. Erosion of the low-flow channel, if left uncontrolled, can cause degradation and destabilization of the entire channel. Low-flow grade-control check structures are designed to provide control points and establish stable bed slopes within the base flow channel. They should be used to limit longitudinal slope of the channel to about 0.3% to 0.5% and as described in the MAJOR DRAINAGE chapter. Low-flow check structures are not appropriate along incised floodplains and may not be economical for very steep channels, where higher drop structures may be needed.

Grouted sloping boulder and vertical hard basin designs can be adapted for use as check structures after considering (1) stable bed slopes for the unlined trickle or low-flow channel and (2) potential overflow erosion during submergence of the check structure and where flow converges back from the main channel sides or below the check structure.

The basic design steps for low-flow grade-control check structures include the following:

1. Determine a stable slope and configuration for the low-flow zone. For unlined channels, discharges from full floodplain flow to the dominant discharge should first be considered. The dominant discharge is more fully explained in sediment transport texts (Richardson 1988; Shen 1971; Simons 1977; Simons, Li and Associates 1982; and Muessetter 1983). It is generally defined as the flow that represents the average or equilibrium conditions controlling the channel bed. In the Denver region, the dominant discharge is typically the 2-year flood. Numerous references (Chow 1959; SCS 1977; and above references) cite information on permissible

velocities. The range of stable longitudinal slopes for non-rock lined major drainageways in the Denver area is between 0.003 ft/t and 0.005 ft/ft. Two exceptions to this range exist, one is for larger streams and the South Platte River, where it can be much flatter, and the other is for steep waterways with small tributary catchments of relatively low imperviousness, where the final stable slopes can be steeper.

2. The configuration of the low-flow zone and number and placement of the check structures must be reviewed. A good rule is to have the check structures spaced so the drop does not exceed 3-feet after the downstream channel has degraded to the projected stable longitudinal slope.

One type of check structure that can be used to stabilize low-flow channels within relatively stable channels is the control check (see Figure HS-13a and Figure HS-13b). This type of a check structure can be constructed by filling an excavated narrow trench (12' minimum) with concrete if soil and groundwater conditions permit trenching to a depth of 6 feet, or by driving a concrete capped sheet piles to 10 foot depth when trenching is not possible.

Extend the cutoff walls into the main channel banks a minimum of 10 feet and make sure it rises sufficiently to contain the 5- to 10-year flow (depending on local criteria), but no less than 2-feet above the approach channel (outside the trickle flow section) to avoid side cutting.

Wetland channel check structures will typically do not have a trickle channel. When building check structures for wetland bottom channels, place riprap downstream of the cutoff wall to dissipate the kinetic energy when downstream backwater is low so as to avoid deep scour hole downstream.

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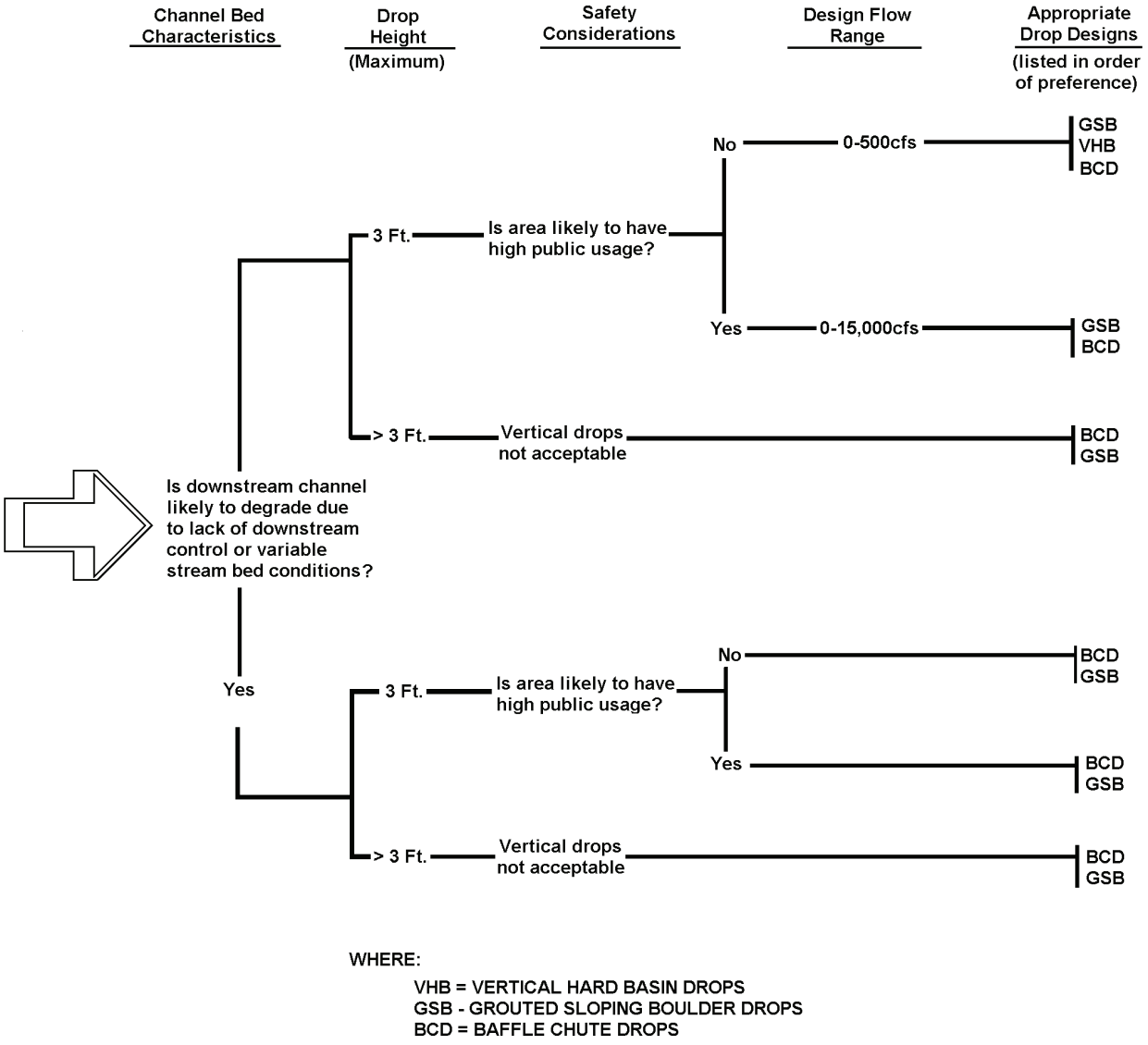
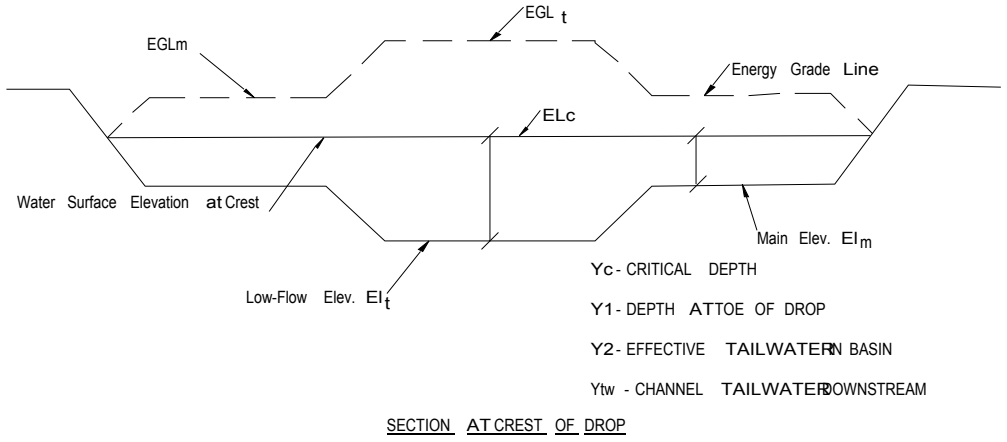
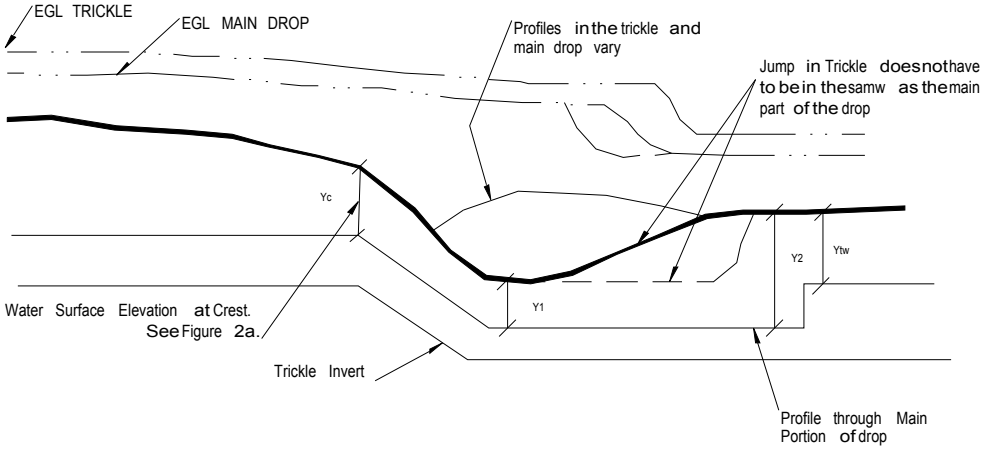


Figure HS-1—Probable Range of Drop Choices and Heights



SECTION AT CREST OF DROP



PROFILE FOR SLOPING DROP

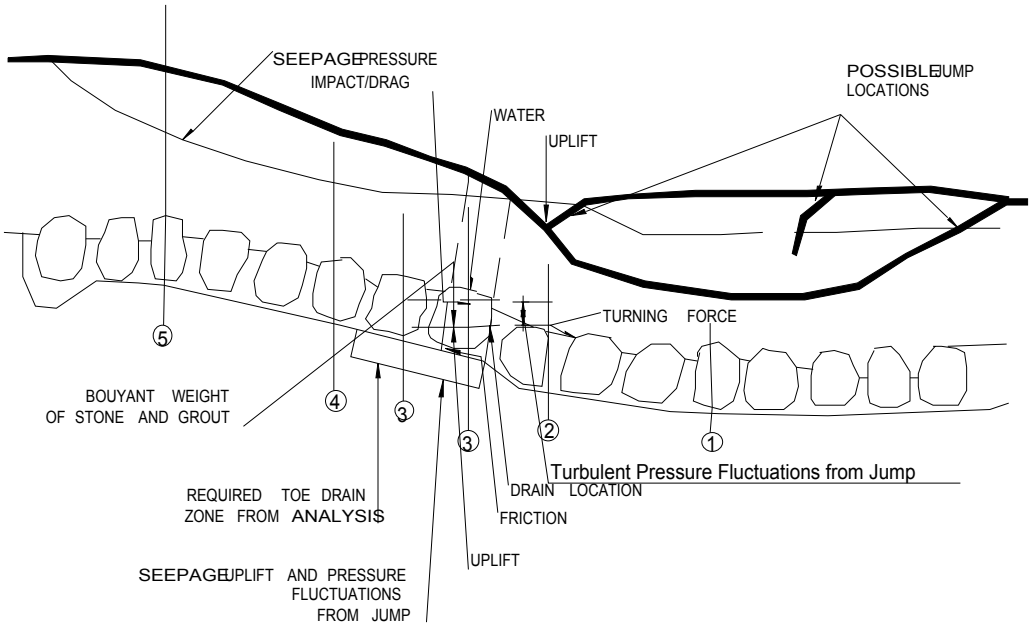


Figure HS-2—Hydraulic Analysis and Typical Forces at Sloping Boulder Drops

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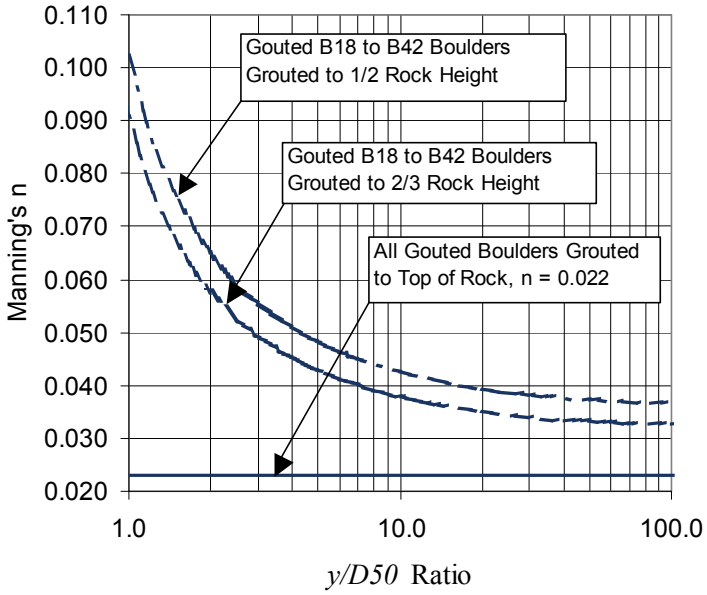

The following equations may be used to find the recommended Manning's n as a function of flow depth over height of the boulders, $y/D50$ represented by the above two curves:

When the upper one-half (+/- 1") of the rock depth (height) is left ungrouted, the equation for n is:

$$n_{18"-42"(1/2)} = \frac{0.086 \cdot y^{0.17}}{\ln(1.64 \cdot y)}$$

Upper limit: $n \leq 0.15$ for above equation

When the upper one-third (+/- 1") of the rock depth (height) is left ungrouted, the equation for n is:

$$n_{18"-42"(2/3)} = \frac{0.086 \cdot y^{0.17}}{\ln(2.46 \cdot y)}$$

Upper limit: $n \leq 0.12$ for above equation

In both, y = depth of flow above top of rock, in feet

When rock is grouted to the top of the rock, Manning's is a constant n = 0.022.

Note that grouting only the lower ½ of the rock on the sloping face of the drop has a significantly higher Manning's n roughness coefficient and, as a result, greater flow depth and lower velocity, reducing the boulder size needed to have a stable structure.

Figure HS-3—Recommended Manning's n for Flow Over B18 to B42 Grouted Boulders

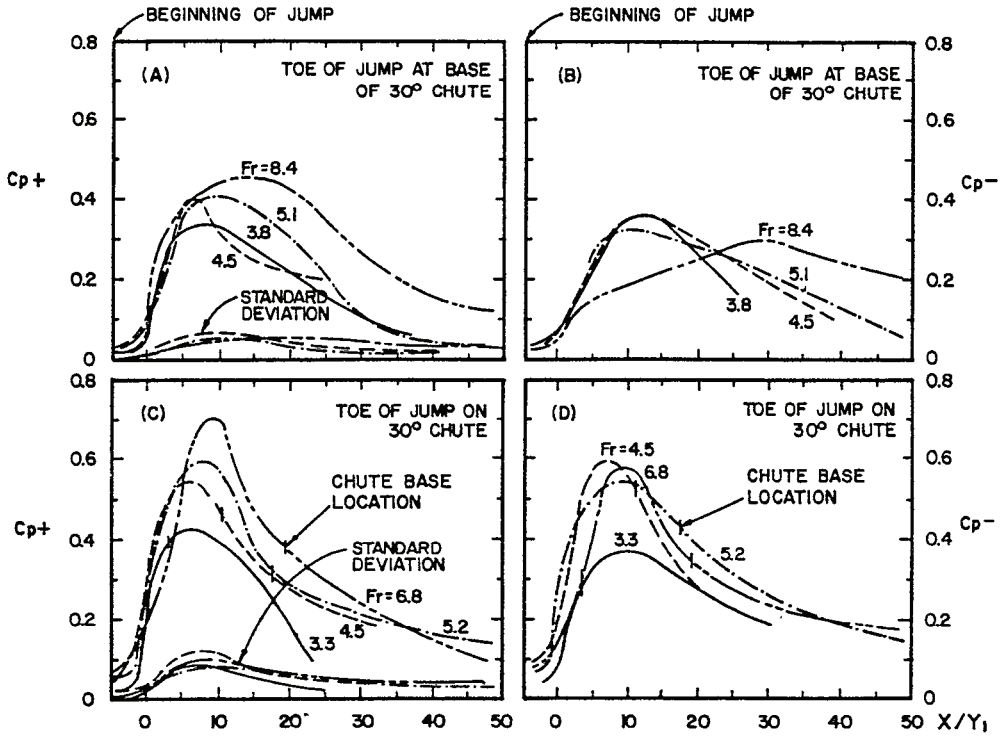

Figure HS-4—Coefficient of Pressure Fluctuation, C_p, at a Hydraulic Jump

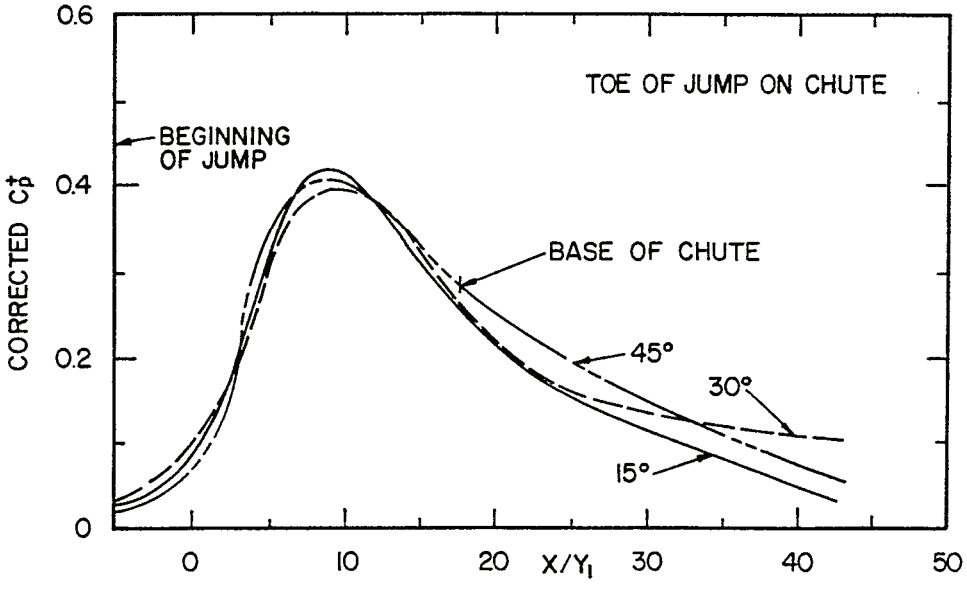

Figure HS-5—Pressure Fluctuation Coefficient, C_p, Normalized for Consideration of Slope and Jump Beginning on Slope

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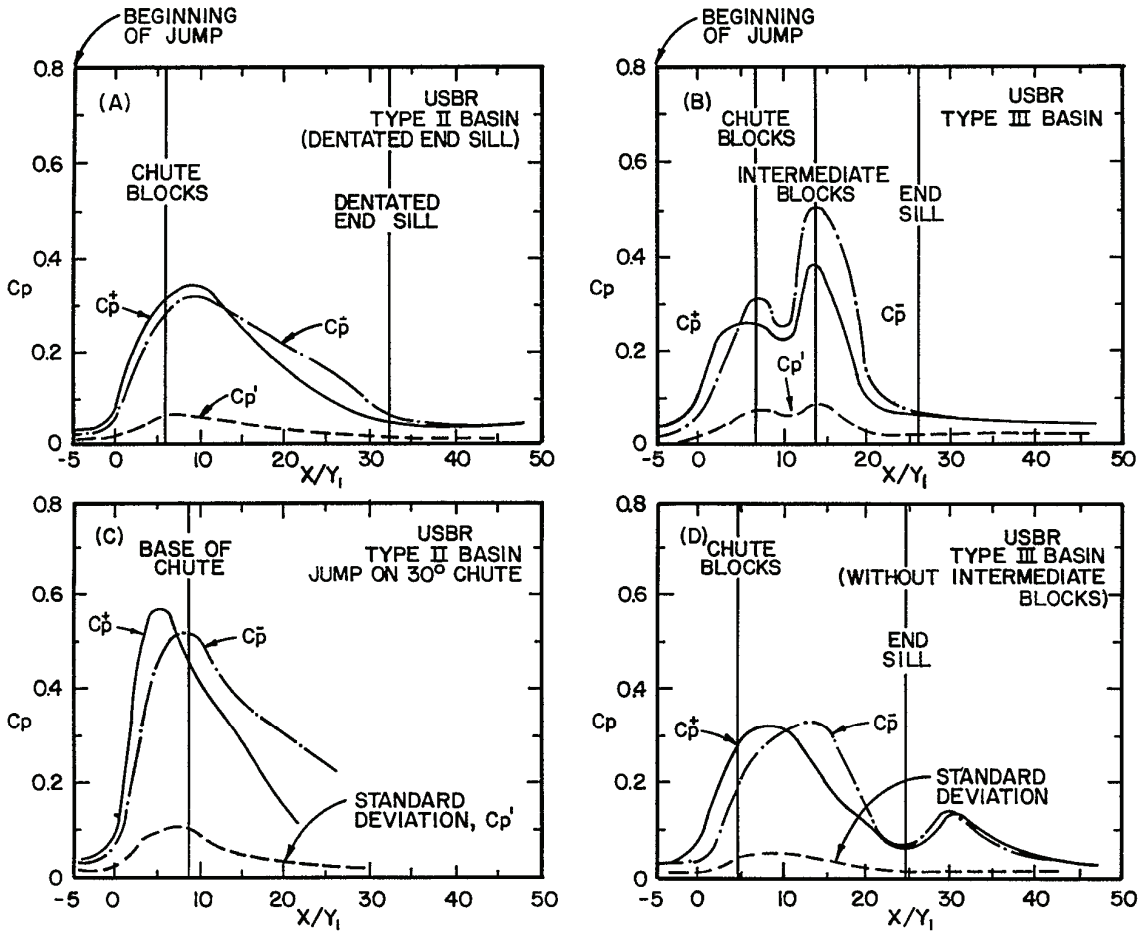

Figure HS-6—Coefficient of Pressure Fluctuation, C_p, in a Jump on a USBR II or III Basin

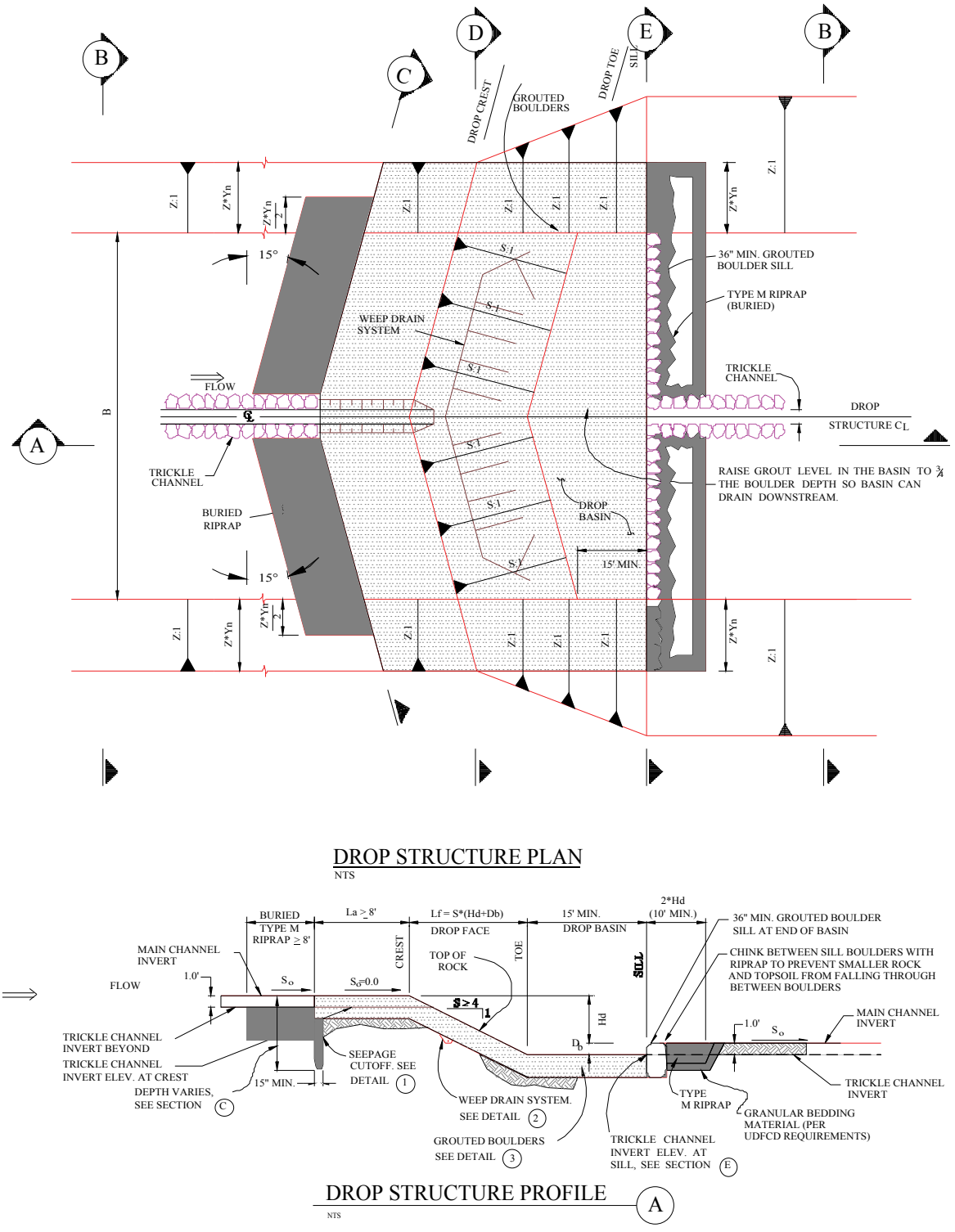

Figure HS-7A—Grouted Sloping Boulder Drop with Trickle Channel for Stabilized Channels in Erosion Resistant Soils (Figure 1 of 2)

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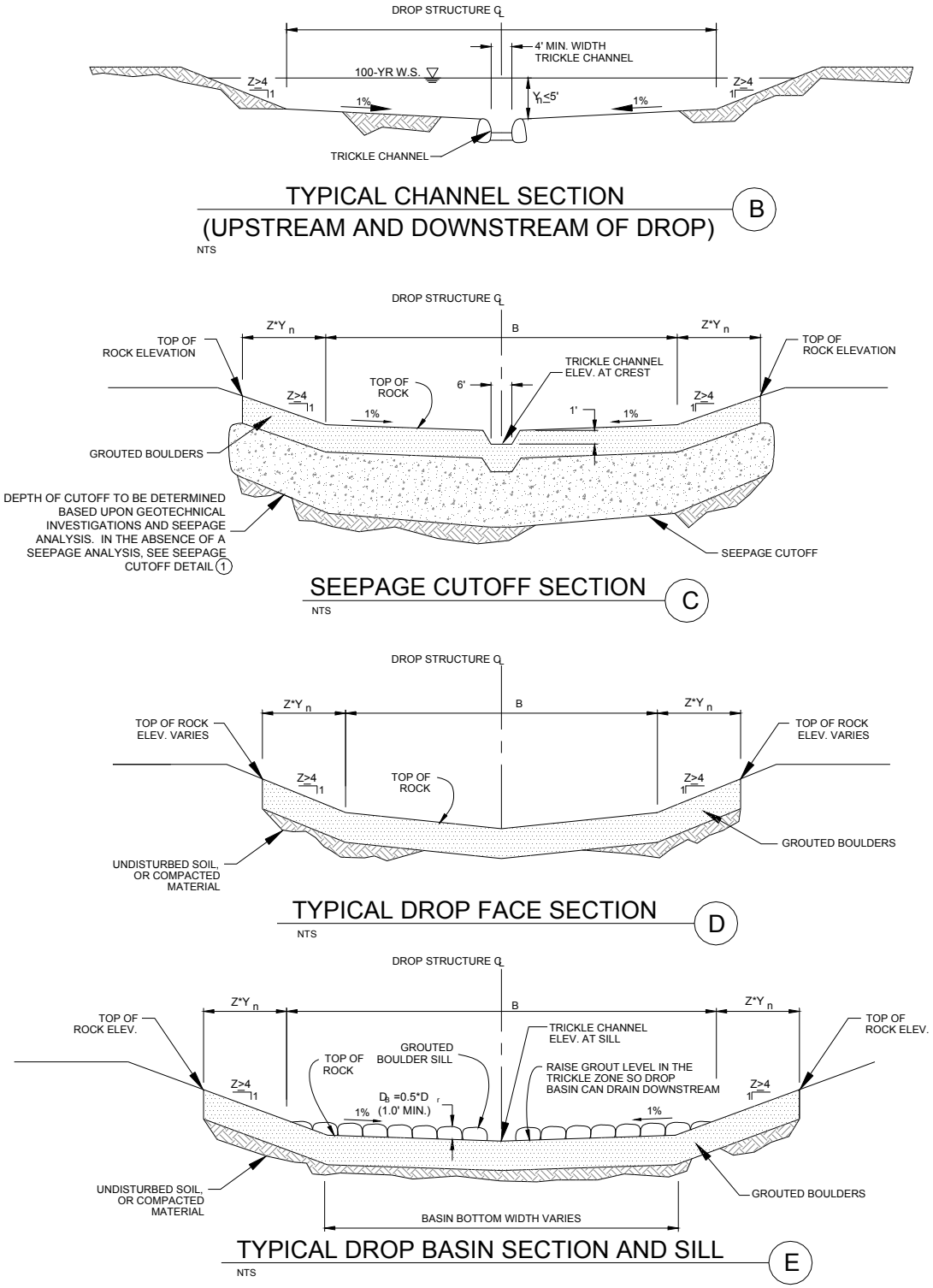

Figure HS-7A— Grouted Sloping Boulder Drop with Trickle Channel for Stabilized Channels and Erosion Resistant Soils (Figure 2 of 2)

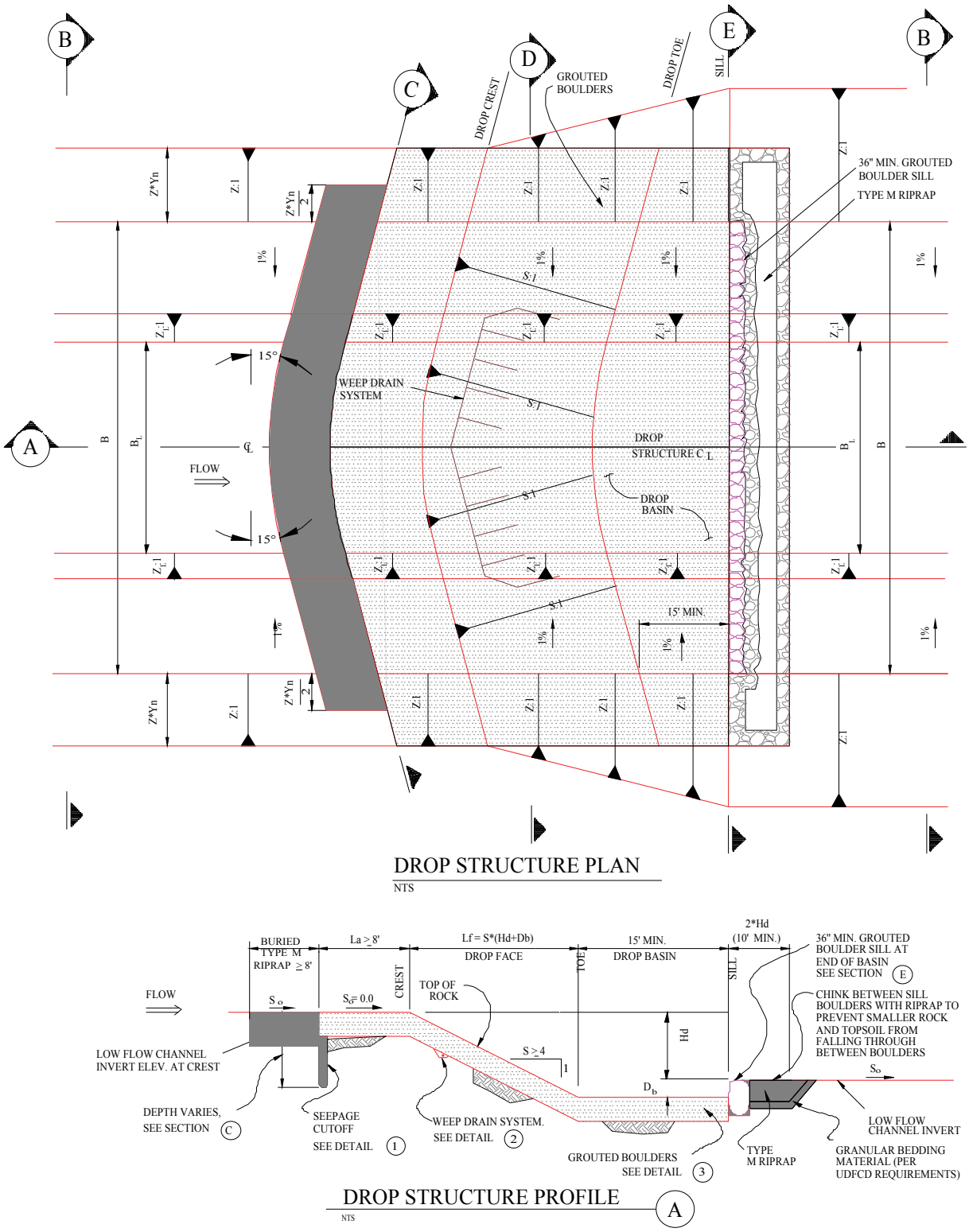

Figure HS-7B—Grouted Sloping Boulder Drop With Low-Flow Channel for Stabilized Channels in Erosion Resistant Soils (Figure 1 of 2)

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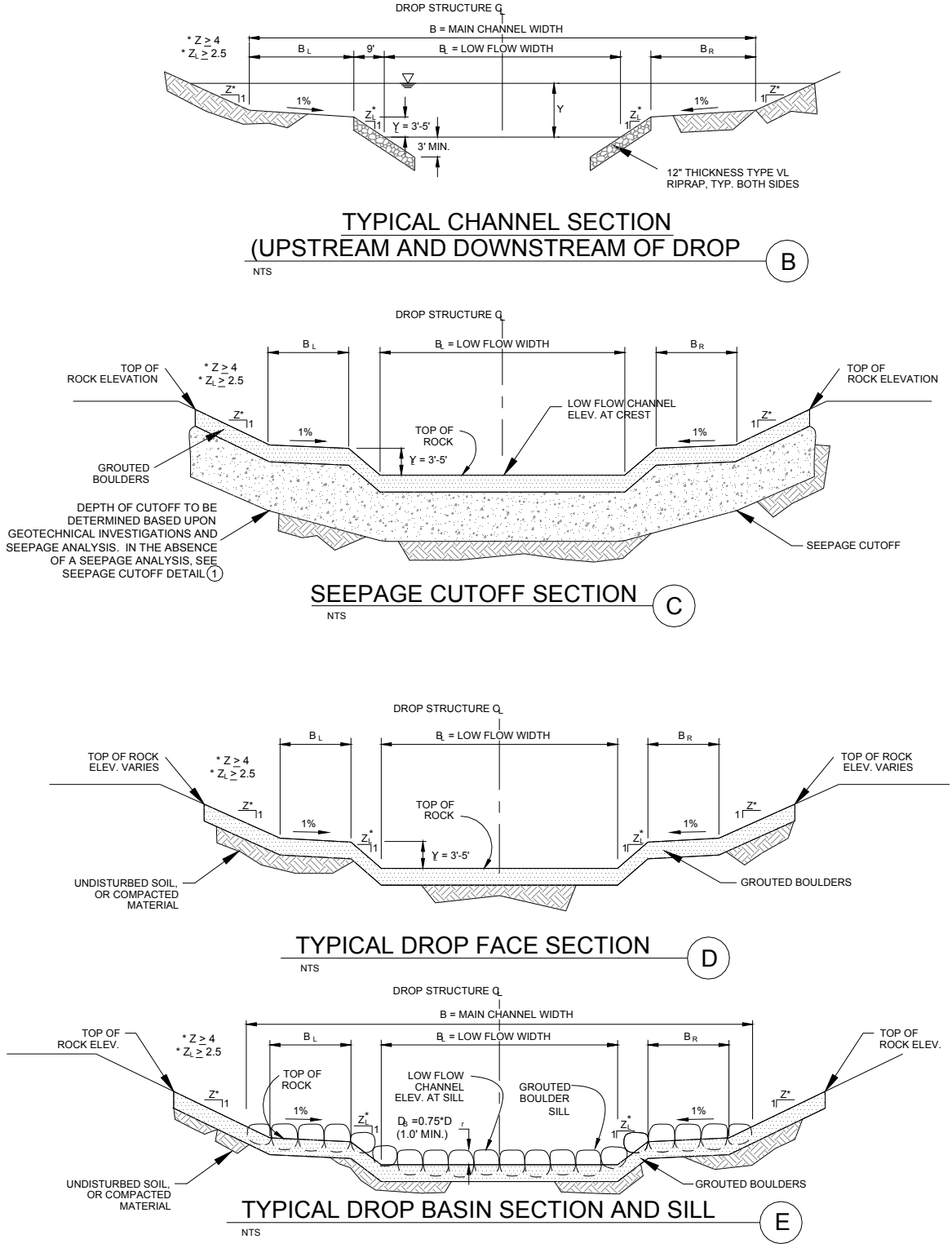

Figure HS-7B— Grouted Sloping Boulder Drop With Low-Flow Channel For Stabilized Channels and Erosion Resistant Soils (Figure 2 of 2)

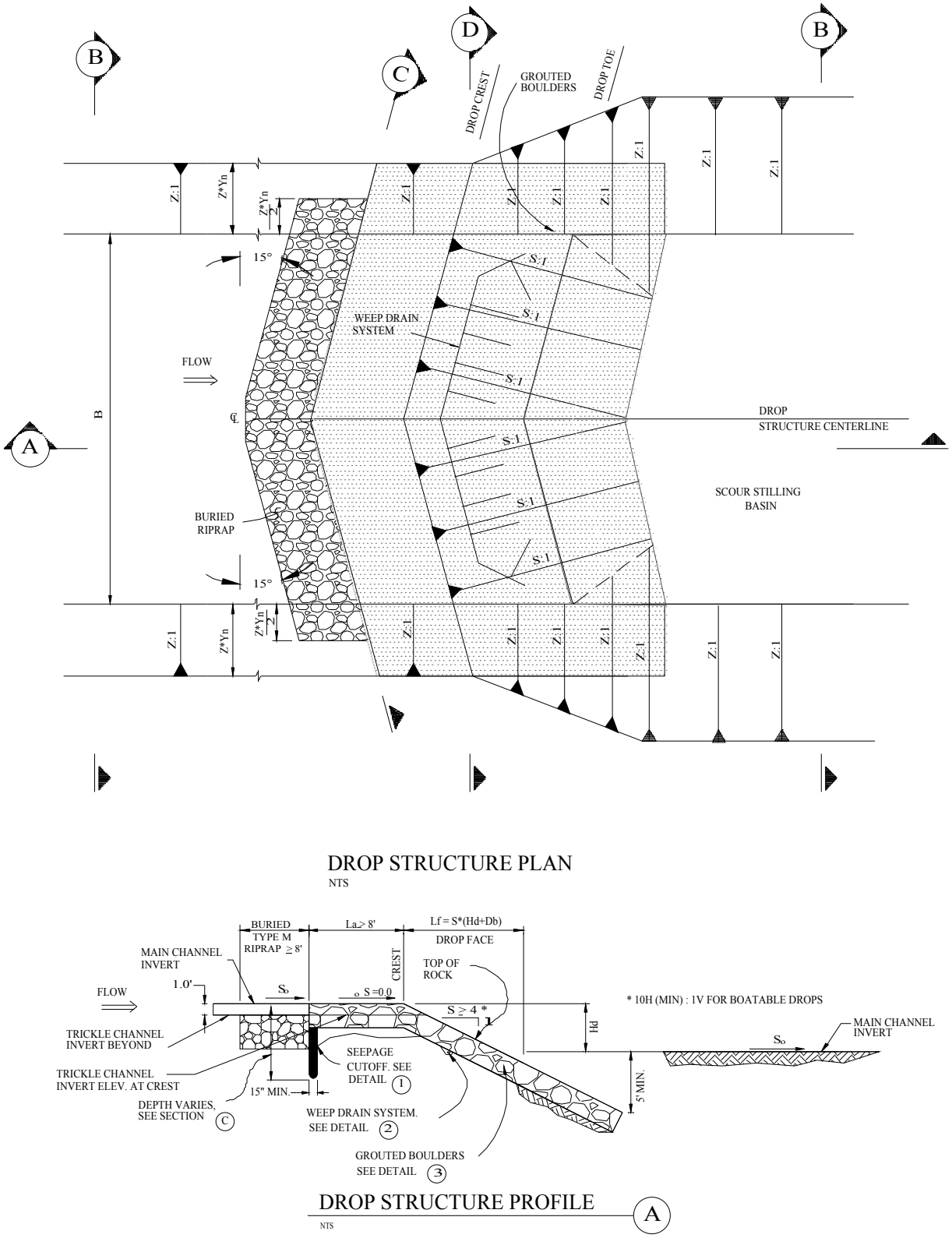

Figure HS-7C—Grouted Sloping Boulder Drop for Unstable Channels in Erosive Soils (Figure 1 of 2)

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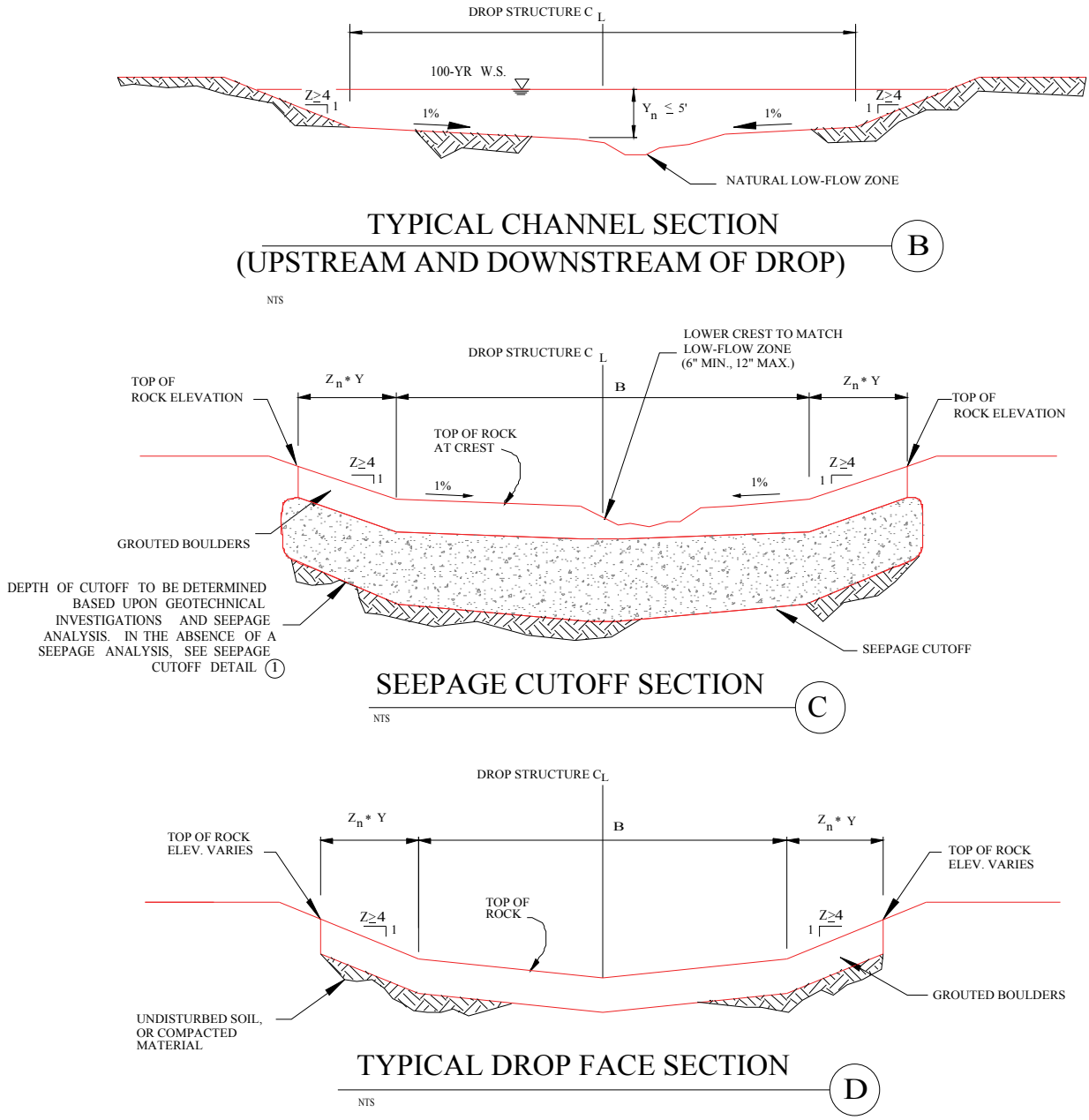
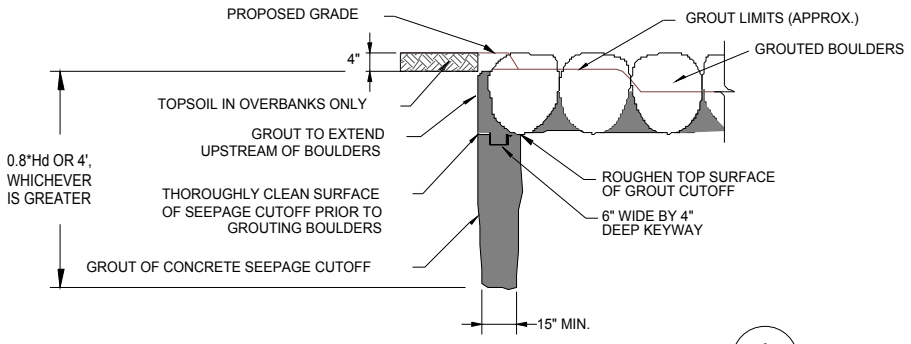
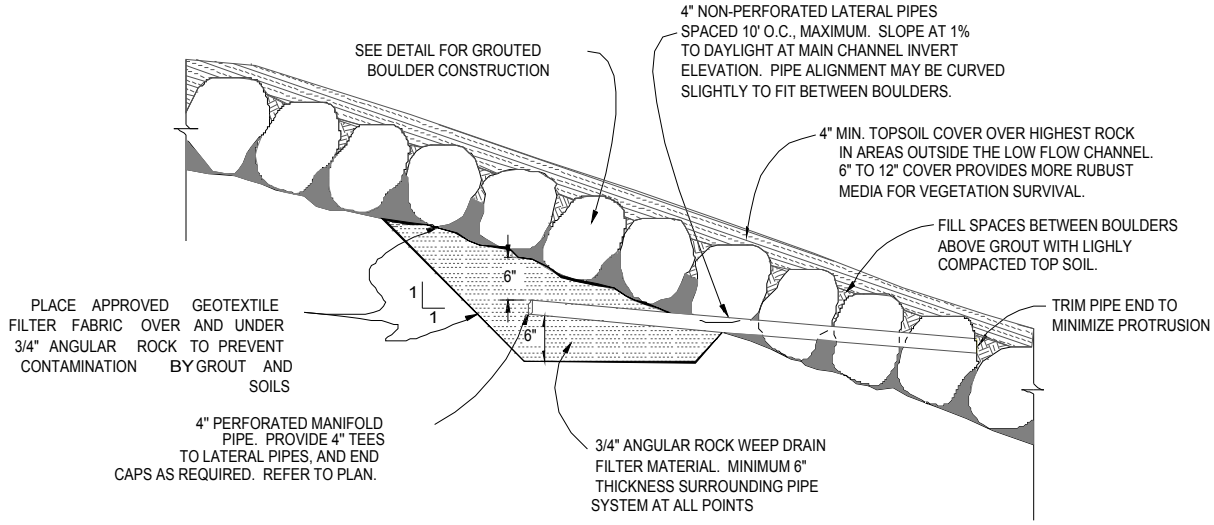


Figure HS-7C— Grouted Sloping Boulder Drop for Unstable Channels in Erosive Sandy Soils. (Figure 2 of 2)



SEEPAGE CUTOFF DETAIL 1

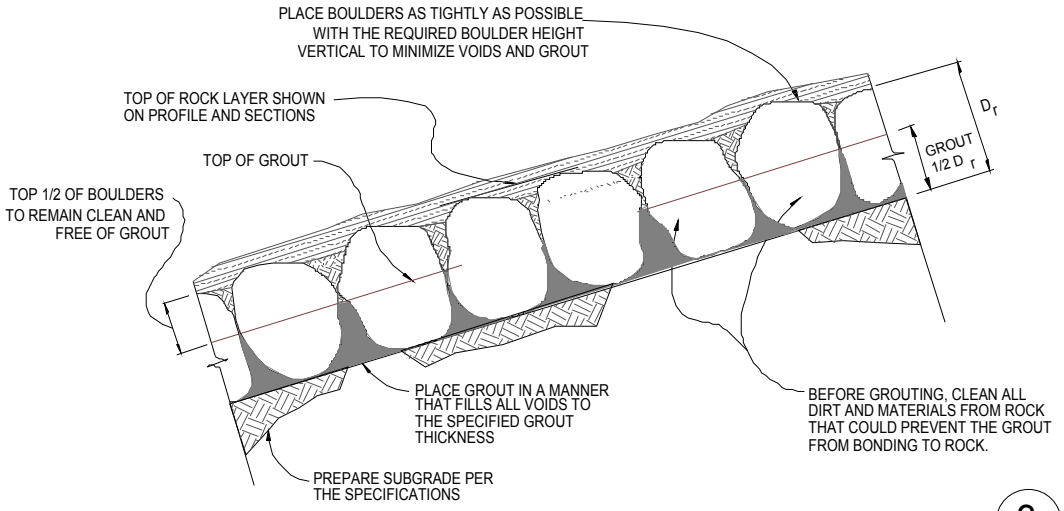
NTS



NTS

WEEP DRAIN SYSTEM DETAILS 2

USE ONLY IN DROPS HIGHER THAN 5 FEET



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GROUTED BOULDER PLACEMENT DETAIL 3

Figure HS-7D— Grouted Sloping Boulder Drop Details.

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GROUT NOTES

Material Specifications

1. All grout shall have a minimum 28-day compressive strength equal to 3200 psi.
2. One cubic yard of grout shall have a minimum of six (6) sacks of Type II Portland cement.
3. A maximum of 25% Type F Fly Ash may be substituted for the Portland cement.
4. For Type A grout, the aggregate shall be comprised of 70% natural sand (fines) and 30% $\frac{3}{8}$ -inch rock (coarse).
5. For Type B grout, the aggregate shall be comprised of $\frac{3}{4}$ -inch maximum gravel, structural concrete aggregate.
6. Type B grout shall be used in streams with significant perennial flows.
7. The grout slump shall be 4-inches to 6-inches.
8. Air entrainment shall be 5.5%-7.5%.
9. To control shrinkage and cracking, 1.5 pounds of Fibermesh, or equivalent, shall be used per cubic yard of grout.
10. Color additive in required amounts shall be used when so specified by contract.

Placement Specifications

1. All Type A grout shall be delivered by means of a low pressure (less than 10 psi) grout pump using a 2-inch diameter nozzle.
2. All Type B grout shall be delivered by means of a low pressure (less than 10 psi) concrete pump using a 3-inch diameter nozzle
3. Full depth penetration of the grout into the boulder voids shall be achieved by injecting grout starting with the nozzle near the bottom and raising it as grout fills, while vibrating grout into place using a pencil vibrator.
4. After grout placement, exposed boulder faces shall be cleaned with a wet broom.
5. All grout between boulders shall be treated with a broom finish.
6. All finished grout surfaces shall be sprayed with a clear liquid membrane curing compound as specified in ASTM C-309.
7. Special procedures shall be required for grout placement when the air temperatures are less than 40°F or greater than 90°F. Contractor shall obtain prior approval from the design engineer of the procedures to be used for protecting the grout.
8. Clean Boulders by brushing and washing before grouting.

Figure HS-8—Specifications and Placement Instructions for Grout in Sloping Boulder Drops.

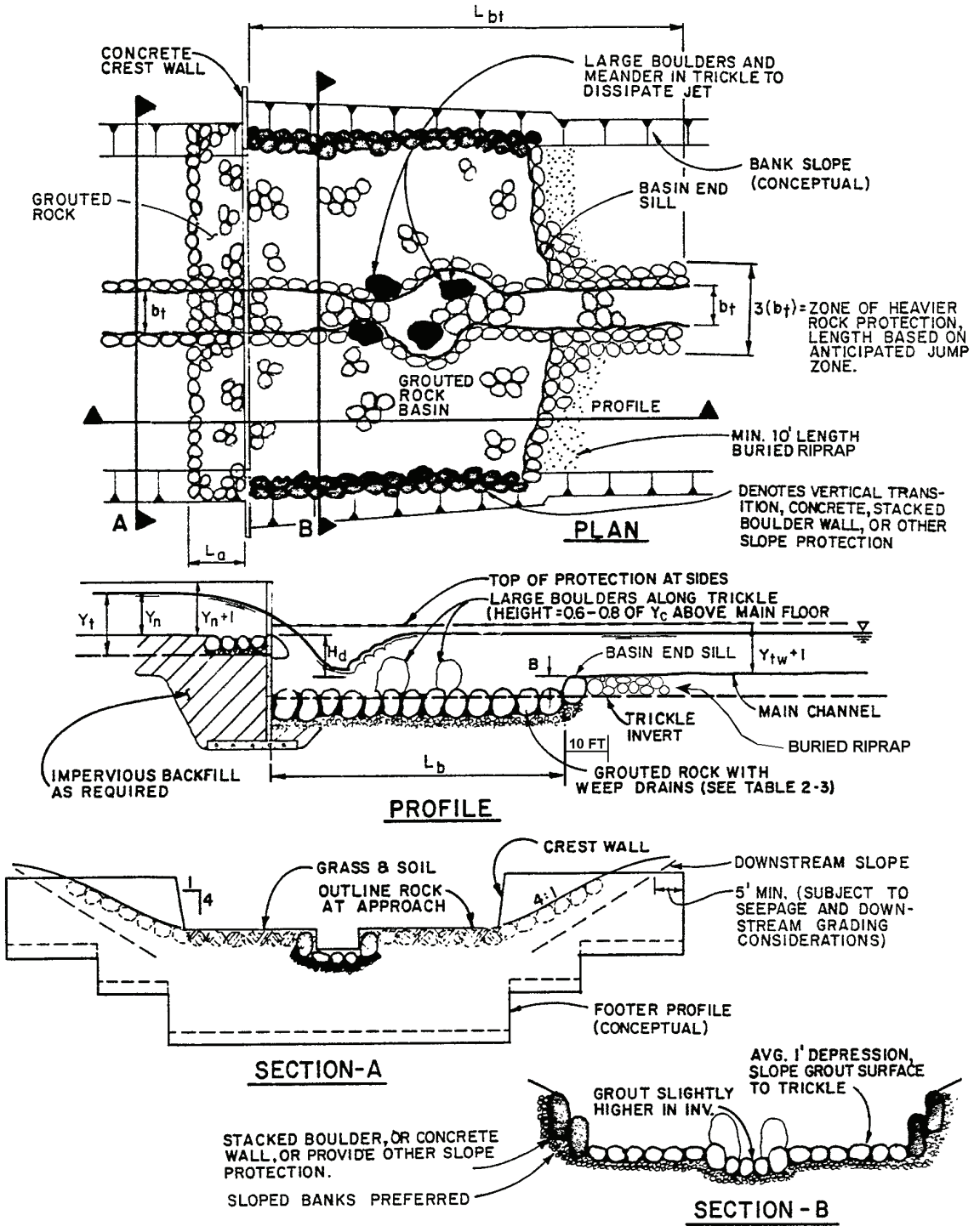

Figure HS-9—Vertical Hard Basin Drop

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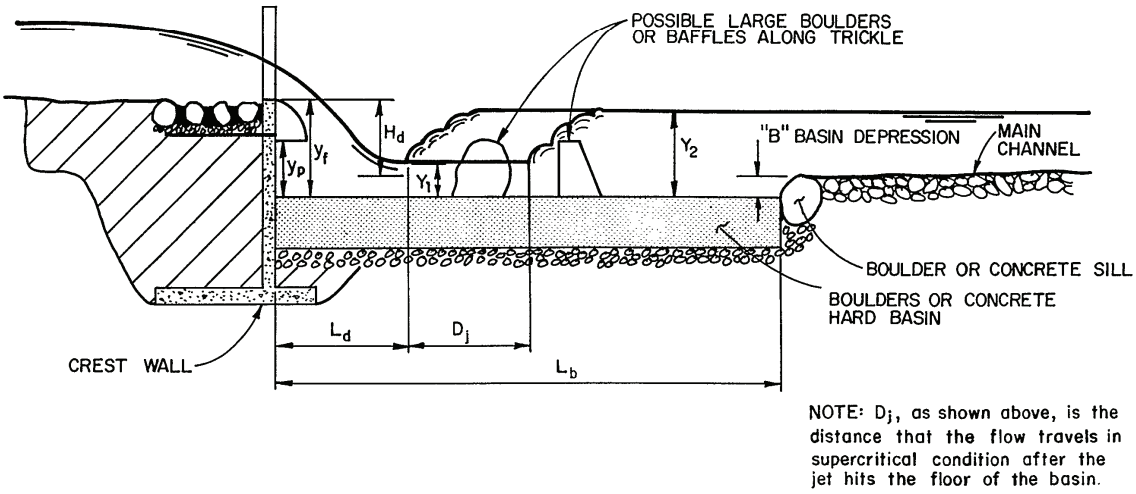
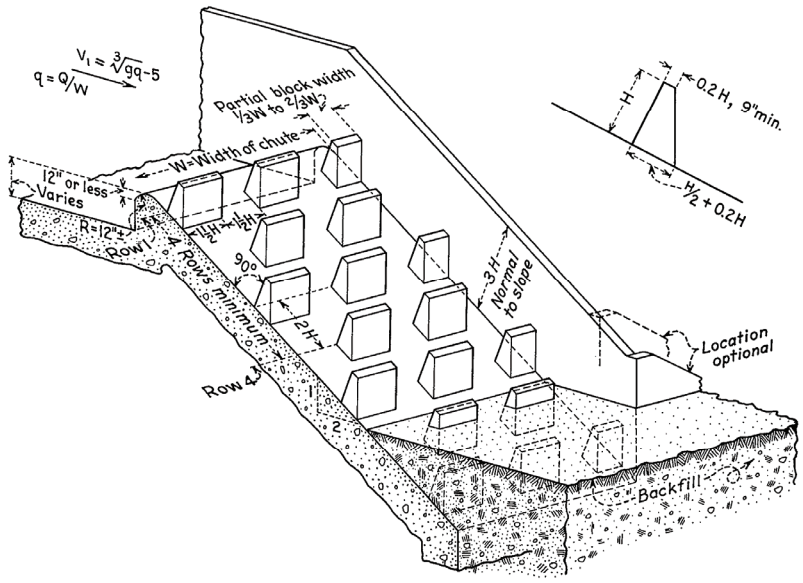
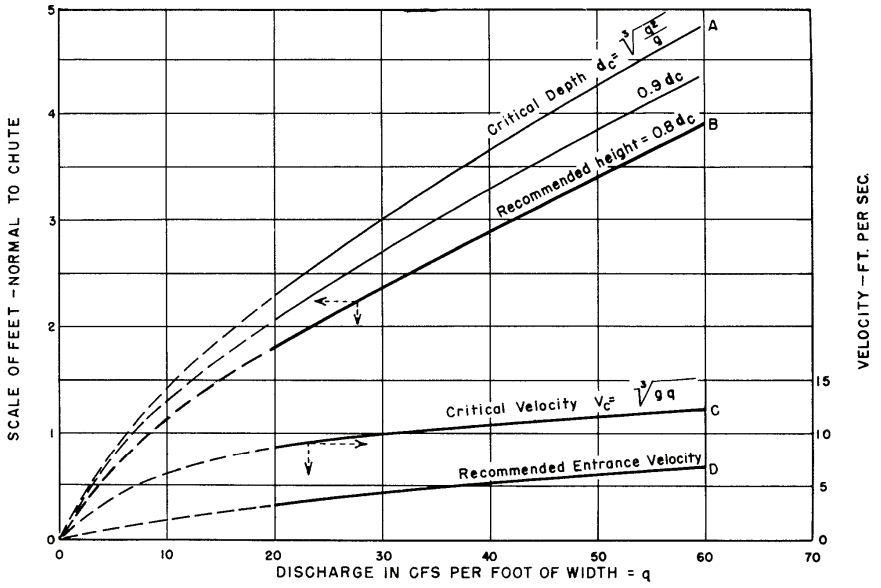


Figure HS-10—Vertical Drop Hydraulic System



(A) USBR ISOMETRIC



(B) DESIGN CRITERIA

Figure HS-11—Baffle Chute Drop Standard USBR Entrance

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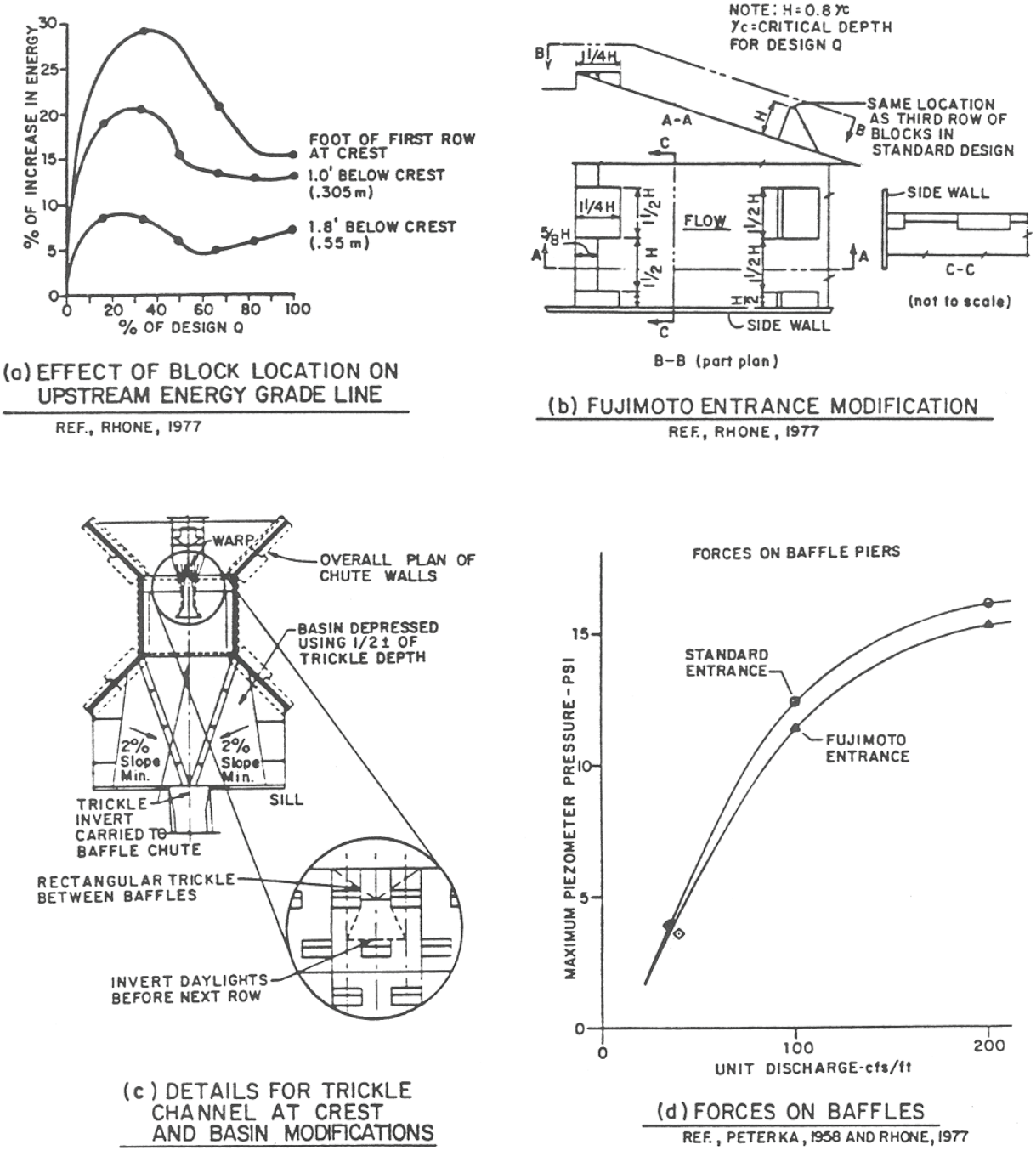
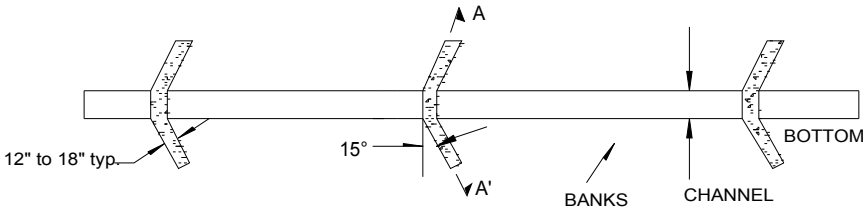
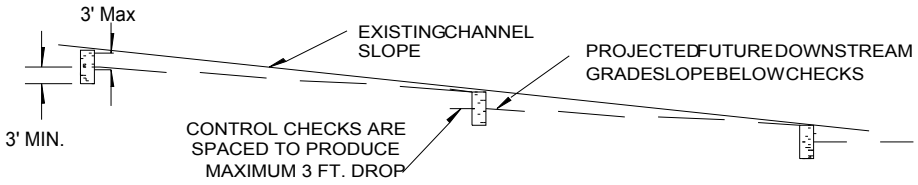


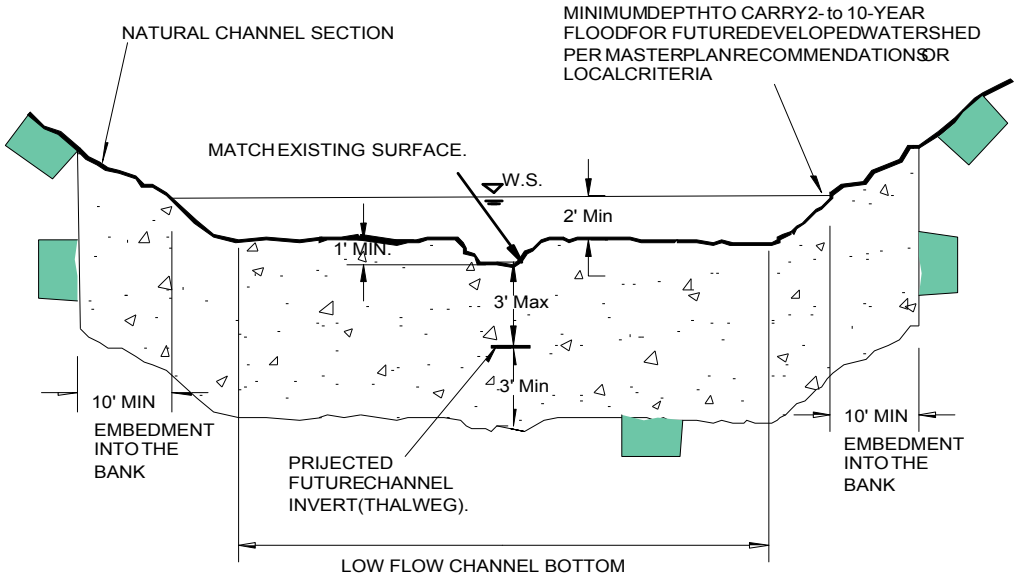
Figure HS-12—Baffle Chute Crest Modifications and Forces



PLAN VIEW



PROFILE



SECTION A-A'

NOTES:
1. TRENCH IN UNDISTURBED SOIL. DO NOT EXCAVATE TO FORM WALLS.
2. POUR AND VIBRATE CONCRETE INTO TRENCH.
3. IF SOIL CANNOT BE TRENCHED WITHOUT WALLS COLLAPSING, USE SHEET PILE CHECKS SHOWN IN FIGURE HS-13b.

Figure HS-13a—Control Check for Stable Floodplain – Concrete Wall

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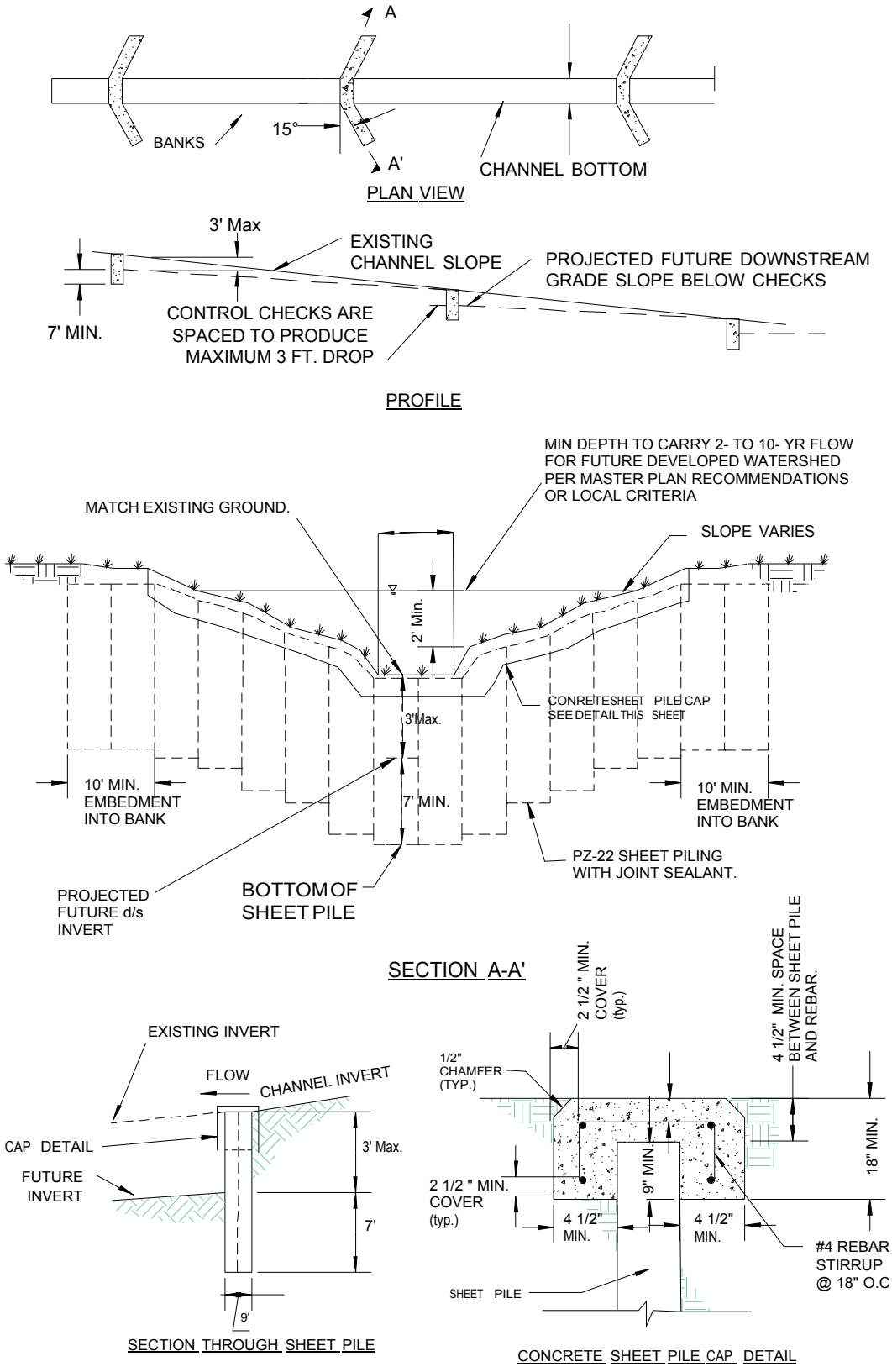

Figure HS-13b—Control Check for Stable Floodplain – Sheet Piling Type

3.0 CONDUIT OUTLET STRUCTURES

3.1 General

Energy dissipation or stilling basin structures are required to minimize scour damages caused by high exit velocities and turbulence at conduit outlets. Similarly, culverts nearly always require special consideration at their outlets. Outlet structures can provide a high degree of energy dissipation and are generally effective even with relatively low tailwater control. Rock protection at conduit outlets (see the MAJOR DRAINAGE chapter) is appropriate where moderate outlet conditions exist; however, there are many situations where rock basins are impractical. Reinforced concrete outlet structures are suitable for a wide variety of site conditions. In some cases, they are more economical than larger rock basins, particularly when long-term costs are considered.

Any outlet structure must be designed to match the receiving stream conditions. The following steps include an analysis of the probable range of tailwater and bed conditions that can be anticipated including degradation, aggradation, and local scour.

Hydraulic concepts and design criteria are provided in this section for an impact stilling basin and adaptation of a baffle chute to conduit outlets. Use of concrete is often more economical due to structure size or local availability of materials. Initial design selection should include consideration of a conduit outlet structure if any of the following situations exist: (1) high-energy dissipation efficiency is required, where hydraulic conditions approach or exceed the limits for alternate designs (see the MAJOR DRAINAGE chapter); (2) low tailwater control is anticipated; or (3) site conditions, such as public use areas, where plunge pools and standing water are unacceptable because of safety and appearance, or at locations where space limitations direct the use of a concrete structure.

Longer conduits with large cross-sectional areas are designed for significant discharges and often with high velocities requiring special hydraulic design at their outlets. Here, dam outlet and spillway terminal structure technology is appropriate (USBR 1987). Type II, III or IV stilling basins, submerged bucket with plunge basin energy dissipators and slotted-grating dissipators can be considered when appropriate to the site conditions. For instance, a plunge basin may have applicability where discharge is to a wet detention pond or a lake. Alternate designs of pipe exit energy dissipators are provided in this *Manual* that can be matched to a variety of pipe sizes and pipe outlet physical and hydraulic settings.

3.2 Impact Stilling Basin

Most design standards for an impact stilling basin are based on the USBR Type VI basin, often called “impact dissipator” or conduit “outlet stilling basin”. This basin is a relatively small structure that is very efficient energy in dissipating energy without the need of tailwater. The original hydraulic design reference by Biechley (1971) is based on model studies. Additional structural design details are provided by Aisenbrey, et al. (1974) and Peterka (1984).

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The Type VI basin was originally designed to operate continuously at the design flow rate. However, it is applicable for use under the varied flow conditions of stormwater runoff. The use of this outlet basin is limited only by structural and economic considerations.

Energy dissipation is accomplished through the turbulence created by the loss of momentum as flow entering the basin impacts a large overhanging baffle. At high flow, further dissipation is produced as water builds up behind the baffle to form a highly turbulent backwater zone. Flow is then redirected under the baffle to the open basin and out to the receiving channel. A check at the basin end reduces exit velocities by breaking up the flow across the basin floor and improves the stilling action at low to moderate flow rates.

The generalized, slightly modified, USBR Type IV Impact Basin design configuration is shown in Figure HS-14, which consists of an open concrete box attached directly to the conduit outlet. The width, W, is a function of the Froude number and can be determined using Figure HS-15. The sidewalls are high enough to contain most of the splashing during high flows and slope down to form a transition to the receiving channel. The inlet pipe is vertically aligned with an overhanging L-shaped baffle such that the pipe invert is not lower than the bottom of the baffle. The end check height is equal to the height under the baffle to produce tailwater in the basin. The alternate end transition (at 45 degrees) is recommended for grass-lined channels to reduce the downstream scour potential.

The impact basin can also be adapted to multiple pipe installations. Such modifications are discussed later, but it should be noted that modifications to the design may affect the hydraulic performance of the structure. Model testing of designs that vary significantly from the standard is recommended.

3.2.1 Modified Impact Basins for Smaller Outlets

For smaller pipe outlets a modified version of the USBR Type IV Impact Basin is suggested in this *Manual*. Figure HS-16a provides a design layout for circular outlets ranging in size from 18-inches to 48-inches in diameter and Figure HS-16b for pipes 18-inches in diameter and smaller. The latter was added for primary use as an outlet energy dissipator upstream of forebays of small extended detention basins, sand filters and other structural best management practices requiring energy dissipation at the end of the pipe delivering water to the BMP facility.

Unlike the Type IV impact basin, the modified basins do not require sizing for flow under normal stormwater discharge velocities recommended for storm sewers in this *Manual*. However, their use is limited to exit velocities of 18 feet per second or less. For larger conduits and higher exit velocities, it is recommended that the standard Type IV impact basin be used instead.

3.2.2 Low-flow Modifications

The standard design will retain a standing pool of water in the basin bottom that is generally undesirable from an environmental and maintenance standpoint. As a result, the standard USBR design has been

modified herein for urban applications to allow drainage of the basin bottom during dry periods. This situation should be alleviated where practical by matching the receiving channel low-flow invert to the basin invert. A low-flow gap is extended through the basin end check wall. The gap in the check should be as narrow as possible to minimize effects on the check hydraulics. This implies that a narrow and deeper (1½- to 2-foot) low-flow channel will work better than a shallow and wide gap section.

For the modified impact basin illustrated in Figure HS-16a, the downstream geometry recognizes the need for a trickle channel and also provides for a modification when this structure is used upstream of a forebay in an Extended Detention Basin or other BMP requiring energy dissipation at the entrance.

Low-flow modifications have not been fully tested to date. Caution is advised to avoid compromising the overall hydraulic performance of the structure. Other ideas are possible including locating the low-flow gap at one side (off center) to prevent a high velocity jet from flowing from the pipe straight down the low-flow channel. The optimal configuration results in continuous drainage of the basin area and helps to reduce the amount of siltation.

3.2.3 Multiple Conduit Installations

Where two or more conduits of different sizes outlet in proximity, a composite structure can be constructed to eliminate common walls. This can be somewhat awkward since each basin "cell" must be designed as an individual basin with different height, width, etc. Where possible, a more economical approach is to combine storm sewers underground, at a manhole or vault, and bring a single, combined pipe to the outlet structure.

When using a Type IV impact basin shown in Figure HS-14 for two side-by-side pipes of the same size, the two pipes may discharge into a single basin. If the basin's design width for each pipe is W, the combined basin width for two pipes would be $1.5W$. When the flow is different for the two conduits, the design width W is based on the pipe carrying the higher flow. For the modified impact basin shown in Figure HS-16, add 1/2 D space between the pipes and to each outside pipe edge when two pipes discharge into the basin to determine the width of the headwall and extent the width of the impact wall to match the outside edges of the two pipes. The effect of mixing and turbulence of the combined flows in the basin has not been model tested to date.

Remaining structure dimensions are based on the design width of a separate basin W. If the two pipes have different flow, the combined structure is based on the higher Froude number when designing the Type IV basins. Use of a handrail is suggested around the open basin areas where safety is a concern. Access control screens or grating where necessary are a separate design consideration. A hinged rack has been used on a few projects in the District.

3.2.4 General Design Procedure for Type IV Impact Basin

1. Determine the design hydraulic cross-sectional area just inside the pipe, at the outlet. Determine

the effective flow velocity, V, at the same location in the pipe. Assume depth $D = \left(A_{\sec t}\right)^{1/2}$ and compute the Froude number = $\dfrac{V}{(gD)^{1/2}}$

2. The entrance pipe should be turned horizontally at least one pipe diameter equivalent length upstream from the outlet. For pipe slopes greater than 15 degrees, the horizontal length should be a minimum of two pipe diameters.

3. Determine the basin width, W, by entering the Froude number and effective flow depth into Figure HS-15. The remaining dimensions are proportional to the basin width according to Figure HS-14. The basin width should not be oversized since the basin is inherently oversized for less than design flows. Larger basins become less effective as the inflow can pass under the baffle.

4. Structure wall thickness, steel reinforcement, and anchor walls (underneath the floor) should be designed using accepted structural engineering methods. Note that the baffle thickness, t_b, is a suggested minimum. It is not a hydraulic parameter and is not a substitute for structural analysis. Hydraulic forces on the overhanging baffle may be approximated by determination of the hydraulic jet force at the outlet:

   F_j = 1.94 $V_{out} Q_{des}$ (force in pounds) (HS-15)

   Q_{des} = maximum design discharge (cfs)

   V_{out} = velocity of the outlet jet (ft/sec)

5. Type “M” rock riprap should be provided in the receiving channel from the end check to a minimum distance equal to the basin width. The depth of rock should be equal to the check height or at least 2.0 feet. Rock may be buried to finished grades and planted as desired.

6. The alternate end check and wingwall shown in Figure HS-14 are recommended for all grass-lined channel applications to reduce the scour potential below the check wall.

7. Ideally, the low-flow invert matches the floor invert at the basin end and the main channel elevation is equal to the top of the check. For large basins where the check height, d, becomes greater than the low-flow depth, dimension d in Figure HS-14 may be reduced by no more than one-third. It should not be reduced to less than 2 feet. This implies that a deeper low-flow channel (1.5 to 2.0 feet) will be advantageous for these installations. The alternate when d exceeds the trickle flow depth is that the basin area will not drain completely.

8. A check section should be constructed directly in front of the low-flow notch to break up bottom flow velocities. The length of this check section should overlap the width of the low flow and its dimension is shown in Figure HS-14.

3.3 Pipe Outlet Rundowns

3.3.1 Baffle Chute Rundown

The baffle chute developed by the USBR (1958) has also been adapted to use at pipe outlets. This structure is well suited to situations with large conduit outfalls and at outfalls to channels in which some future degradation is anticipated. As mentioned previously, the apron can be extended at a later time to account for channel degradation. This type of structure is only cost effective if a grade drop is necessary below the outfall elevation.

Figure HS-17 illustrates a general configuration for a baffled outlet application for a double box culvert outlet. In this case, an expansion zone occurs just upstream of the approach depression. The depression depth is designed as required to reduce the flow velocity at the chute entrance. The remaining hydraulic design is the same as for a standard baffle chute using conditions at the crest to establish the design. The same crest modifications are applicable to allow drainage of the approach depression, to reduce the upstream backwater effects of the baffles, and to reduce the problems of debris accumulation and standing water at the upstream row of baffles.

Flow entering the chute should be well distributed laterally across the width of the chute. The velocity should be below critical velocity at the crest of the chute. To insure low velocities at the upstream end, it may be necessary to provide a short energy dissipating pool. The sequent or conjugate depth in the approach basin should be sized to prevent jump sweep-out, but the basin length may be considerably less than a conventional hydraulic jump basin since its primary purpose is only to reduce the average entrance velocity. A basin length of twice the sequent depth will usually provide ample basin length. The end check of the pool may be used as the crest of the chute as shown in Figure HS-17.

3.3.2 Grouted Boulder Chute Rundown

Another option for rundowns at outlets of larger pipes is to use a grouted boulder rundown illustrated in Figure 18. This type of rundown has been used successfully for several large storm sewers entering the South Platte River. It is critical that the details shown in Figure 18 be strictly followed and the grout and the actual filling of spaces between the boulders with grout closely adhere to the recommendations for grouted boulders provided in the Major Drainage Chapter of this *Manual*.

If the exit velocities of the pipe exceeds 12 feet per second, an approach chute for the baffle chute rundown described above should be considered and provided. If this approach chute is lined with grouted boulders in a manner called for in the Major Drainage Chapter, the stilling basin sill can be eliminated.

3.4 Low Tailwater Riprap Basins at Pipe Outlets

3.4.1 General

The design of low tailwater riprap basins for storm sewer pipe outlets and at some culvert outlets is

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necessary when the receiving or downstream channel may have little or no flow or tailwater at time when the pipe or culvert is in operation. Design criteria are provided in Figures HS-19a through HS-20c.

3.4.2 Objective

By providing a low tailwater basin at the end of a storm sewer conduit or culvert, the kinetic energy of the discharge is dissipated under controlled conditions without causing scour at the channel bottom. Photograph HS-12 shows a fairly large low tailwater basin.

3.4.3 Low Tailwater Basin Design

Low tailwater is defined as being equal to or less than ⅓ of the height of the storm sewer, that is:

$$y_t \le \frac{D}{3} \quad \text{or} \quad y_t \le \frac{H}{3}$$

in which:

y_t = tailwater depth at design

D = diameter of circular pipe (ft)

H = height of rectangular pipe (ft)

3.4.3.1 Finding Flow Depth and Velocity of Storm Sewer Outlet Pipe

The first step in the design of a scour protection basin at the outlet of a storm sewer is to find the depth and velocity of flow at the outlet. Pipe-full flow can be found using Manning's equation.

$$Q_{full} = \frac{1.49}{n} A_{full} \left(R_{full}\right)^{2/3} S_o^{1/2} \qquad \text{(HS-16a)}$$

Then and the pipe-full velocity can be found using the continuity equation.

$$V_{full} = Q_{full} / A_{full} \qquad \text{(HS-16a)}$$

The normal depth of flow, d, and the velocity in a conduit can be found with the aid of Figure HS-20a and Figure HS-20b. Using the known design discharge, Q, and the calculated pipe-full discharge, Q_{full}, enter Figure HS-20a with the value of Q/Q_{full} and find d/D for a circular pipe of d/H for a rectangular pipe.

Compare the value of d/D (or d/H) with the one obtained from Figure HS-20b using the Froude parameter.

$$Q/D^{2.5} \quad \text{or} \quad Q/\left(wH^{1/5}\right) \qquad \text{(HS-16a)}$$

Choose the smaller of the two (d/D or d/H) ratios to calculate the flow depth at the end of the pipe.

$$d = D\left(d/D\right) \quad \text{or} \quad d = H\left(d/H\right) \qquad \text{(HS-16b)}$$

Again, enter Figure HS-19a using the smaller d/D (or d/H) ratio to find the A/A_{full} ratio. Then,

$$A = \left(A / A_{full}\right) A_{full} \qquad \text{(HS-16c)}$$

Finally,

$$V = Q / A \qquad \text{(HS-16d)}$$

In which for Equations 16a through 16d above:

A_{full} = cross-sectional area of the pipe (ft^2)

A = area of the design flow in the end of the pipe (ft^2)

n = Manning's n for the pipe full depth

Q_{full} = pipe full discharge at its slope (cfs)

R = hydraulic radius of the pipe flowing full, ft [$R_{full} = D/4$ for circular pipes, $R_{full} = A_{full}/(2H + 2w)$ for rectangular pipes, where D = diameter of a circular conduit, H = height of a rectangular conduit, and w = width of a rectangular conduit (ft)]

S_o = longitudinal slope of the pipe (ft/ft)

V = design flow velocity at the pipe outlet (ft/sec)

V_{full} = flow velocity of the pipe flowing full (ft/sec)

3.4.3.2 Riprap Size

For the design velocity, use Figure HS-20c to find the size and type of the riprap to use in the scour protection basin downstream of the pipe outlet (i.e., B18, H, M or L). First, calculate the riprap sizing design parameter, P_d , namely,

$$P_d = \left(V^2 + gd\right)^{1/2} \qquad \text{(HS-16e)}$$

in which:

V = design flow velocity at pipe outlet (ft/sec)

g = acceleration due to gravity = 32.2 ft/sec^2

d = design depth of flow at pipe outlet (ft)



Photograph HS-12—Upstream and downstream views of a low tailwater basin in Douglas County protecting downstream wetland area. Burying and revegetation of the rock would blend the structure better with the adjacent terrain.

When the riprap sizing design parameter indicates conditions that place the design above the Type H riprap line in Figure HS-20, use B18, or larger, grouted boulders. An alternative to a grouted boulder or loose riprap basin is to use the standard USBR Impact Basin VI or one of its modified versions, described earlier in this Chapter of the *Manual*.

After the riprap size has been selected, the minimum thickness of the riprap layer, T, in feet, in the basin is set at:

$$T = 1.75 D_{50} \qquad \text{(HS-17)}$$

in which:

D_{50} = the median size of the riprap (see Table HS-9.)

Table HS-9—Median (i.e., D_{50}) Size of District's Riprap/Boulder

Riprap Type	D_{50}—Median Rock Size (inches)
L	9
M	12
H	18
B18	18 (minimum dimension of grouted boulders)

3.4.3.3 Basin Length

The minimum length of the basin, L, in Figure HS-19, is defined as being the greater of the following:

for circular pipe: $L = 4D$ or $L = (D)^{1/2}\left(\frac{V}{2}\right)$ (HS-18)

for rectangular pipe: $L = 4H$ or $L = (H)^{1/2}\left(\frac{V}{2}\right)$ (HS-19)

in which:

L = basin length

H = height of rectangular conduit

V = design flow velocity at outlet

D = diameter of circular conduit

3.4.3.4 Basin Width

The minimum width, W, of the basin downstream of the pipe's flared end section is set as follows:

for circular pipes: $W = 4D$ (HS-20)

for rectangular pipe: $W = w + 4H$ (HS-21)

in which,

W = basin width (Figure HS-19)

D = diameter of circular conduit

w = width of rectangular conduit

3.4.3.5 Other Design Requirements

All slopes in the pre-shaped riprapped basin are 2H to 1V.

Provide pipe joint fasteners and a structural concrete cutoff wall at the end of the flared end section for a circular pipe or a headwall with wingwalls and a paved bottom between the walls, both with a cutoff wall that extends down to a depth of:

$B = \frac{D}{2} + T$ or $B = \frac{H}{2} + T$ (HS-22)

in which,

B = cutoff wall depth

D = diameter of circular conduit

T = Equation HS-17

The riprap must be extended up the outlet embankment's slope to the mid-pipe level.

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3.5 Culvert Outlets



Photograph HS-13—Culvert outlets when left unprotected cause downstream erosion. The designer's job is not complete until provisions are made to protect the outlet. Use of vegetated soil-riprap would blend this structure better into the natural landscape.

Culvert outlets represent a persistent problem because of concentrated discharges and turbulence that are not fully controlled prior to the flow reaching the standard downstream channel configuration described in the Major Drainage Chapter of this *Manual*. Too often the designer's efforts are focused on the culvert inlet and its sizing with outlet hydraulics receiving only passing attention. Culvert design is not complete until adequate attention is paid to the outlet hydraulics and proper stilling of the discharge flows.

Culvert outlet energy dissipator and flow spreading may require special structures downstream of the culvert outlet to limit local scour, general stream degradation, and troublesome head cutting. Some of the techniques described in Sections 3.2, 3.3 and 3.4 may be applied at culver outlets as well if the downstream channel and/or tailwater conditions so indicate.

Local scour is typified by a scour hole at the pipe's outlet. High exit velocities cause this, and the effects extend only a limited distance downstream. Coarse material scoured from the hole is deposited immediately downstream, often forming a low bar. Finer material is transported further downstream. The dimensions of the scour hole change due to sedimentation during low flows and the varying erosive effects of storm events. The scour hole is generally deepest during passage of the flow when there is minimal tailwater depth at the outlet and not necessarily when the flow is highest. Methods for predicting scour hole dimensions are found in HEC No. 14 (Corry, et al. 1975) and need to be applied using a range of possible tailwater depth conditions during different design storms or floows.

General storm degradation, or head cutting, is a phenomenon independent of culvert performance. Natural causes produce a lowering of the streambed over time. The identification of a degrading stream is an essential part of the original site investigation. However, high-energy discharges from a culvert can often cause stream degradation for a limited in distance downstream. Both scour and steam degradation can occur simultaneously at a culvert outlet.

Various measures described in HEC No. *14* and in this *Manual* listed below need to be considered to protect the downstream channel or stream and control culvert outlet flow. It is beyond the scope of this *Manual* to provide detailed information about all available controls in HEC No. 14, but the District encourages the proper application and design as appropriate for the specific site.

1. Colorado State University rigid boundary basin
2. Tumbling flow rectangular section
3. Increased resistance—box culverts
4. Roughness elements—circular culverts
5. USBR Type II
6. USBR Type III
7. USBR Type IV
8. Contra Costa
9. Hook-type energy dissipator
10. Straight drop structure
11. Riprap basins
12. Channel check and drop structures and other energy dissipating and control structures described earlier in this Chapter
13. Use of properly anchored flared end sections – see Figure HS-19a

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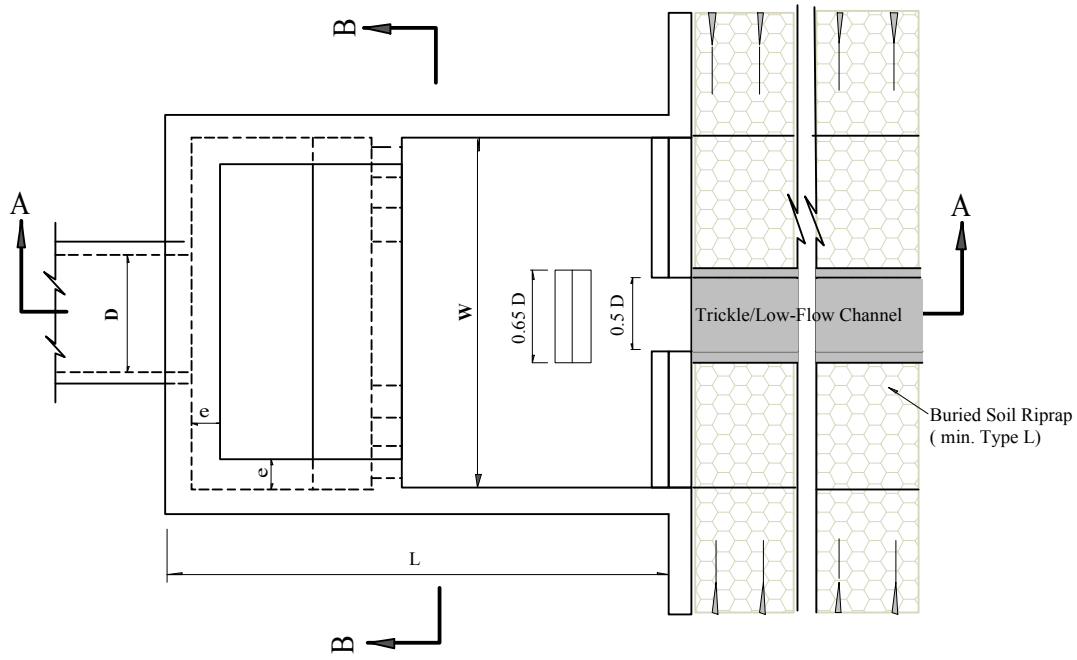


$W = 2.94D[V/gD]^{0.556}$

$V = Velocity, ft/s$

$D = \sqrt{A}$

$A = Area\ of\ flow, sq.ft.$

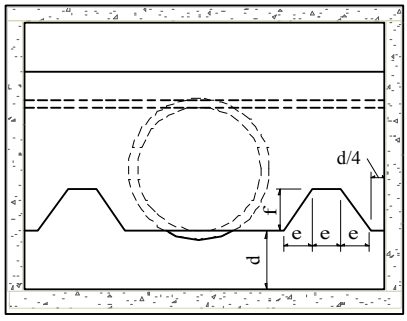
H = 3/4 W *c = 1/2 W*

L = 4/3 W *d = 1/6 W*

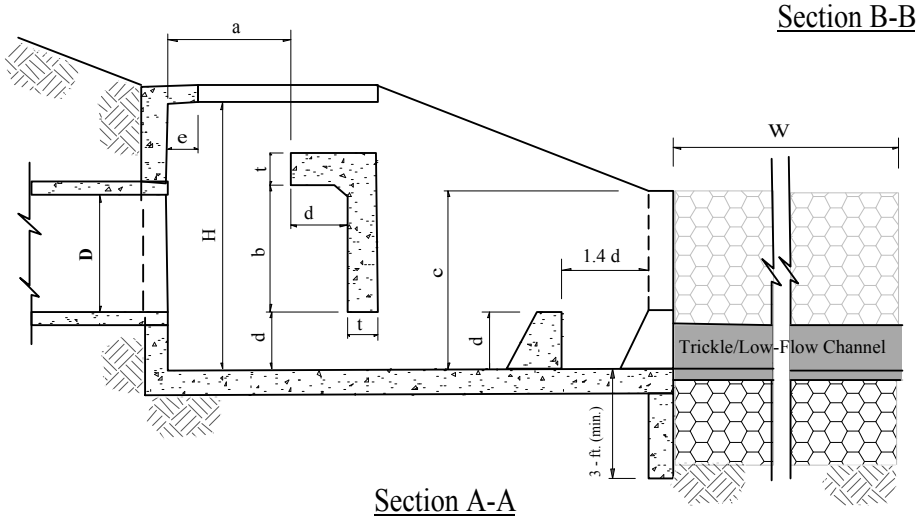
a = 1/2 W *e = 1/12 W*

b = 3/8 W *f = 1/8 W*

t = 1/12 W (suggested min.)



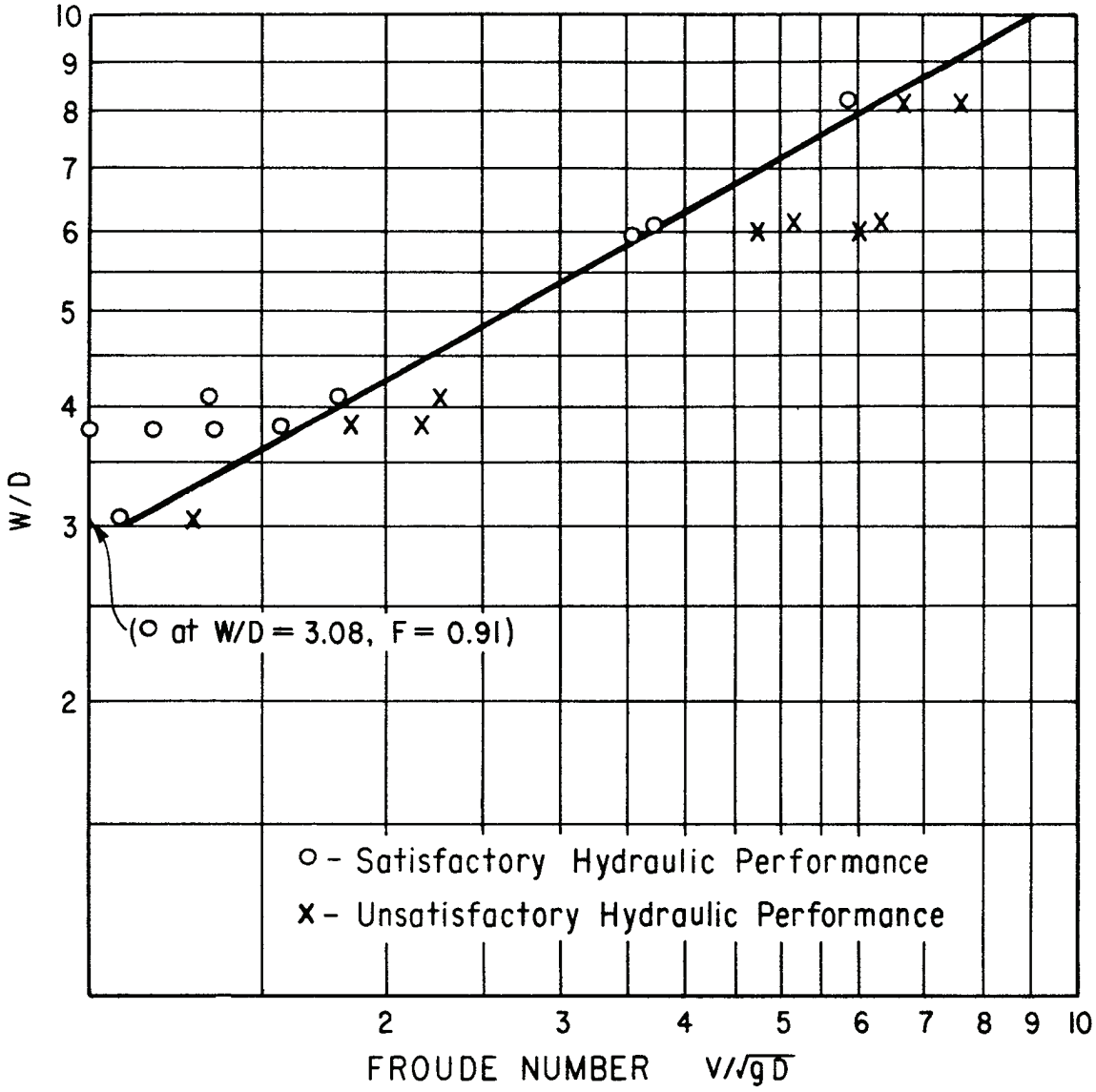
Section B-B



Section A-A

USGS Impact Stilling Basin Modified by UDFCD February 2004

Figure HS-14—General Design Dimensions for a USBR Type VI Impact Stilling Basin



"W" is the inside width of the basin.
"D" represents the depth of flow entering the basin and is the square root of the flow area at the conduit outlet.
"V" is the velocity of the incoming flow.
The tailwater depth is uncontrolled.

Figure HS-15—Basin Width Diagram for the USBR Type VI Impact Stilling Basin)

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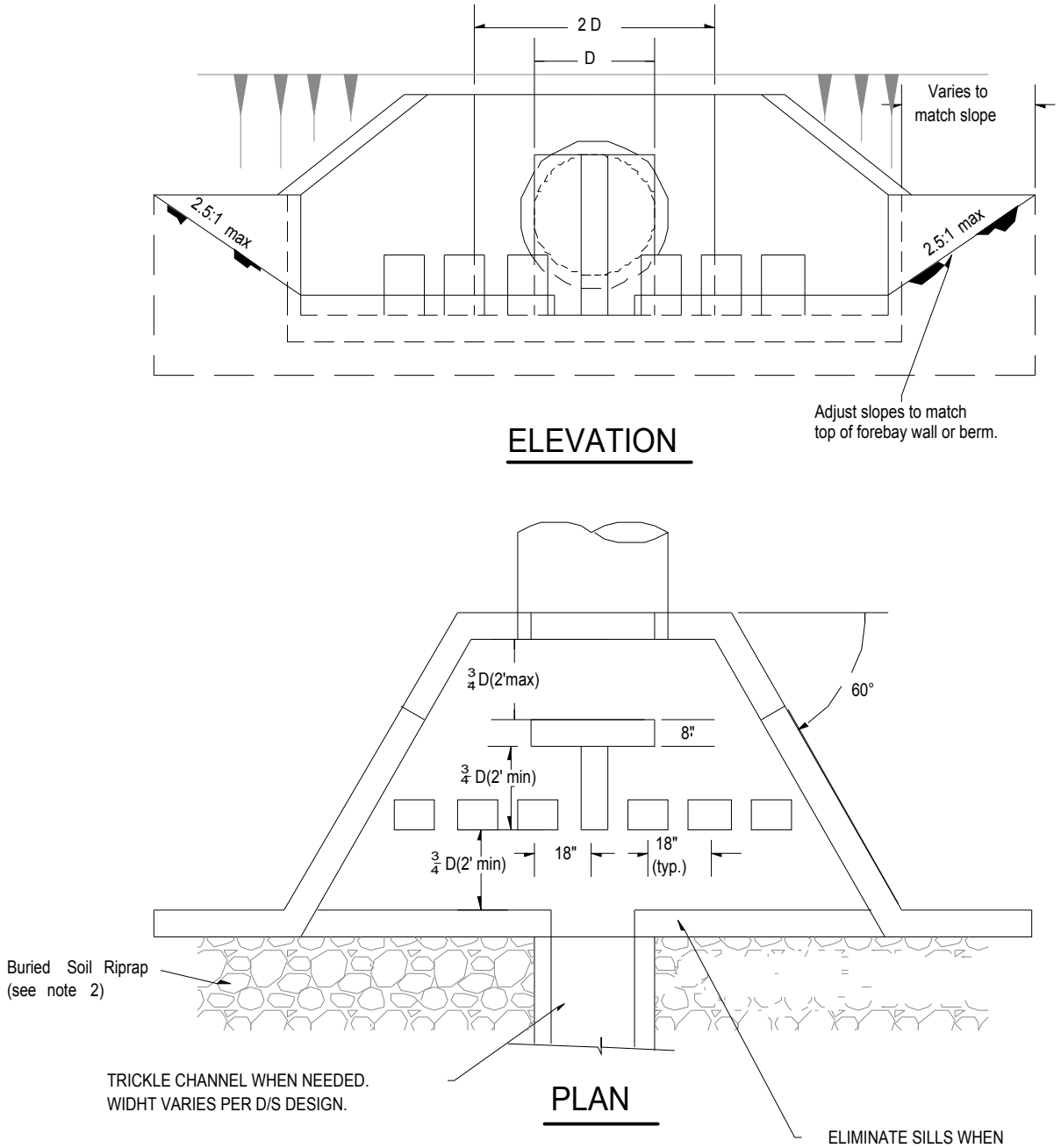
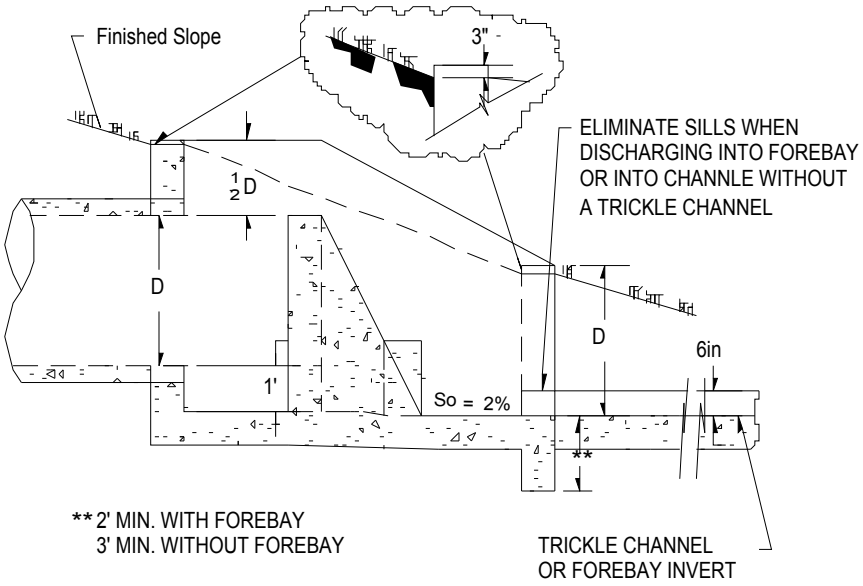


Notes: 1) Design of reinforcing steel is the responsibility of the desing engineer. Reinforce to withstand water earh pressueres.

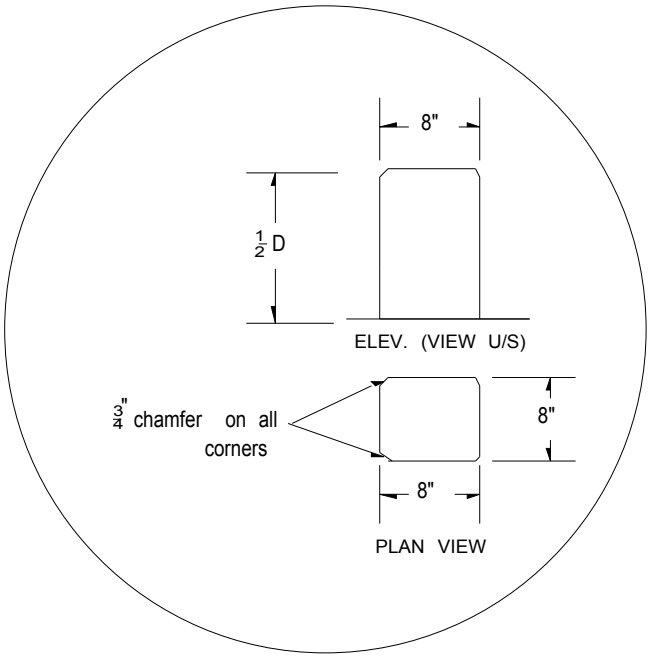
2) When dischargning into channel and not forebay install Type M buried soil riprap for a distance of 3*D downstream of structure.

Figure HS-16a Modified Impact Stilling Basin for Conduits 18" to 48" in Diameter

(Sheet 1 of 2)



PROFILE



BAFFLE BLOCK GEOMETRY

Figure HS-16a. Modified Impact Stilling Basin for Conduits 18" to 48" in Diameter

(Sheet 2 of 2)

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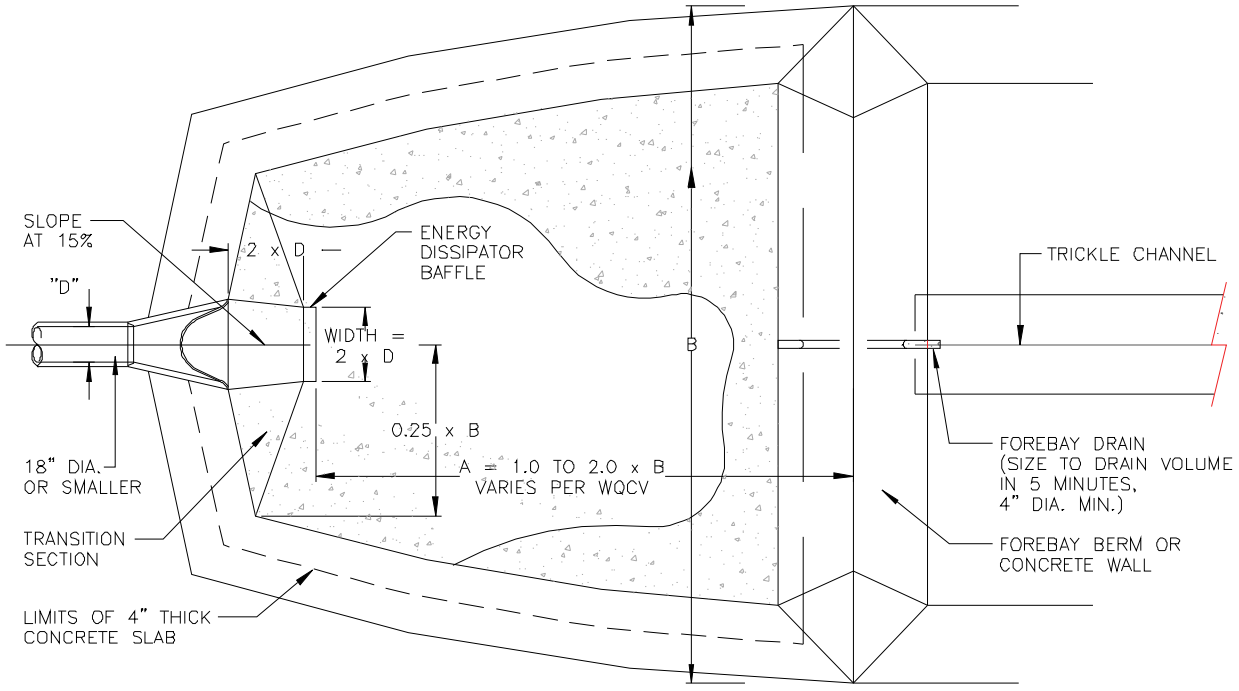
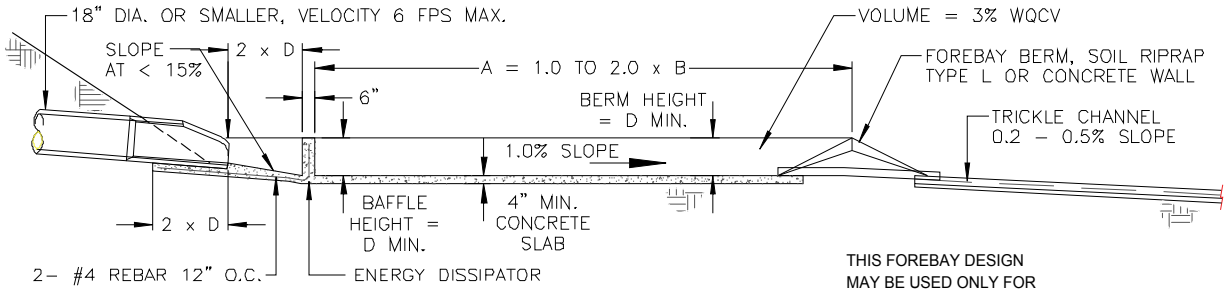


PLAN
NOT TO SCALE



PROFILE
NOT TO SCALE

This figure courtesy of the City and County of Denve

Figure HS-16b. Impact Stilling Basin for Pipes Smaller than 18" in Diameter Upstream of Forebays.

(Courtesy: Technical and Design Criteria, City and County of Denver, 2006)

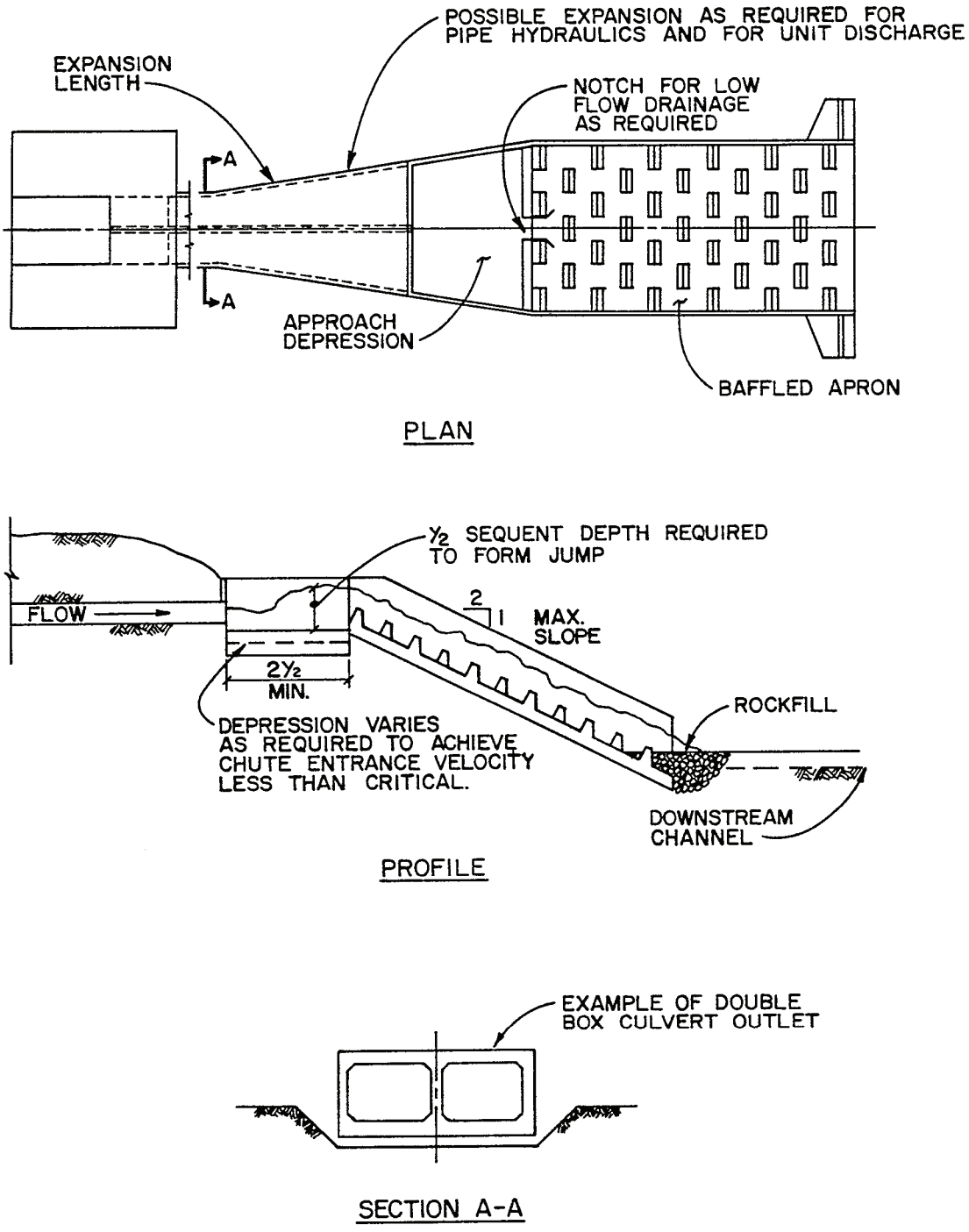


Figure HS-17—Baffle Chute Pipe Outlet

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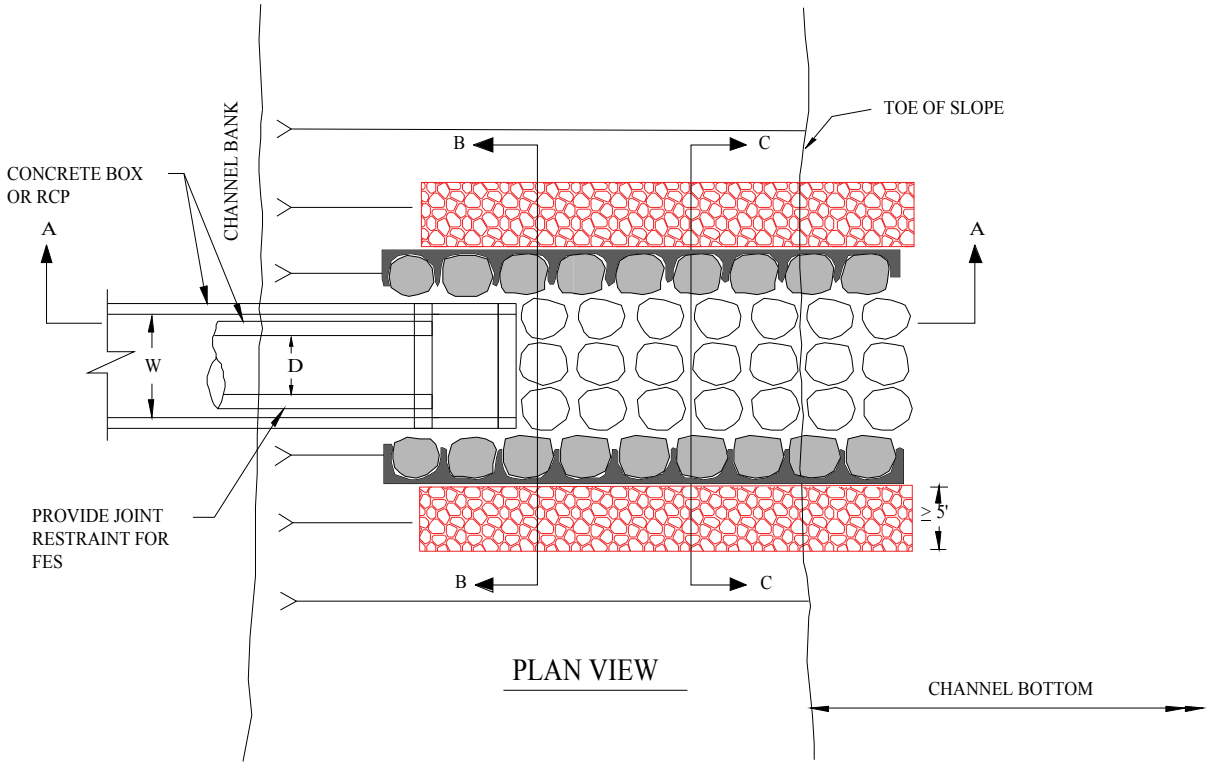
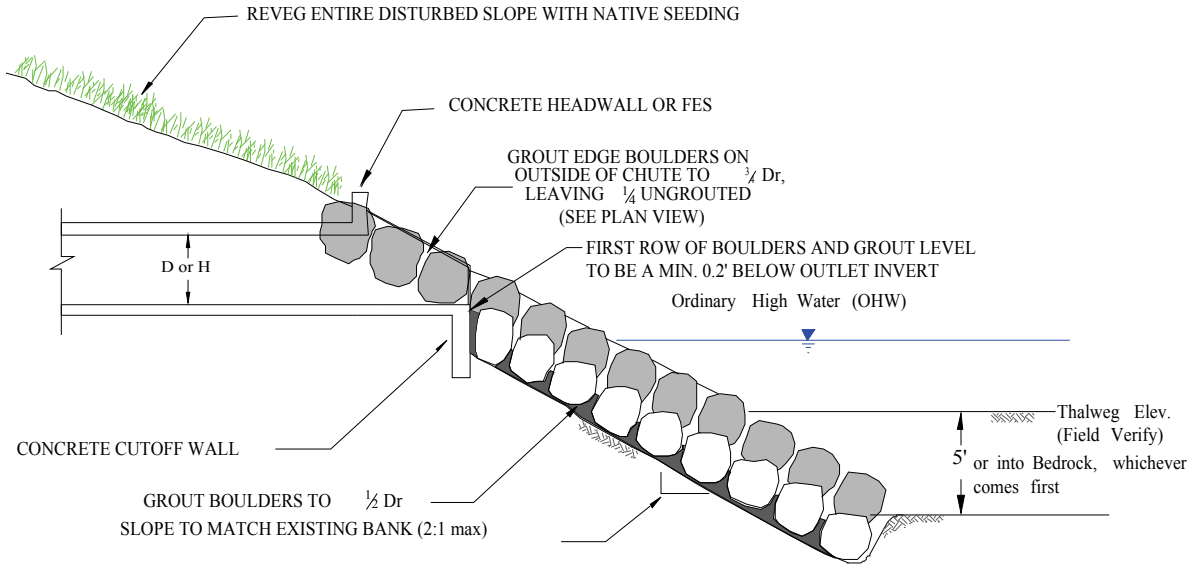


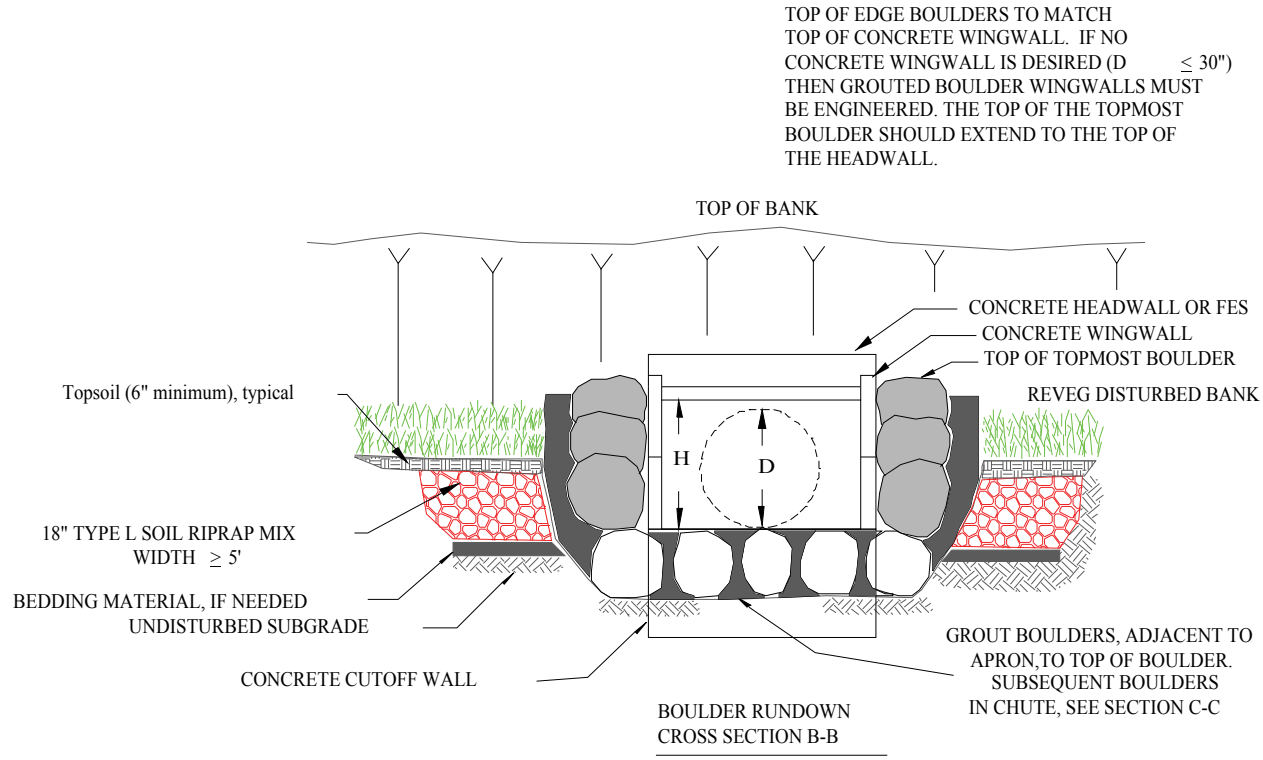


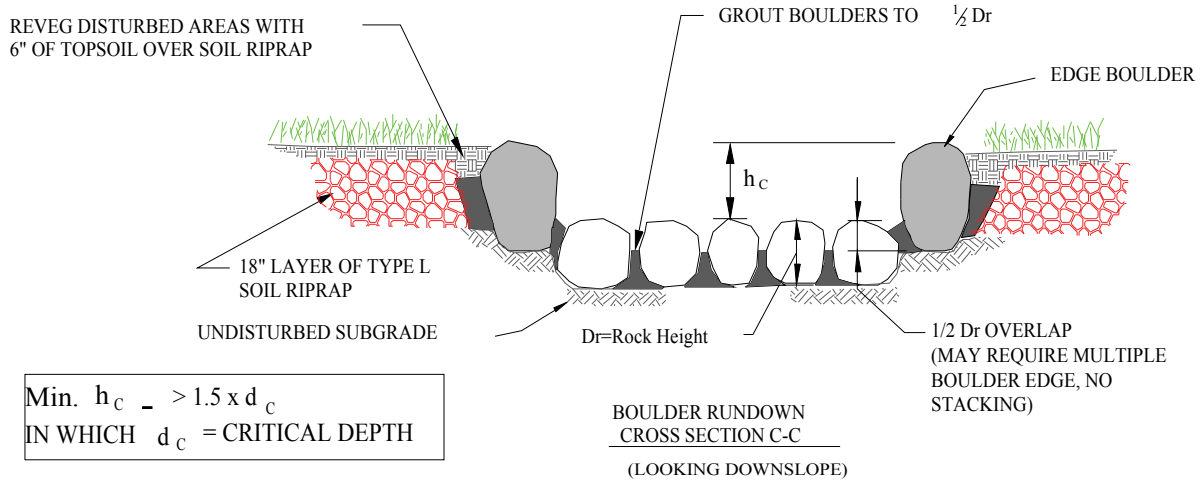
CROSS SECTION A-A

Sheet 1 of 2

Figure HS-18—Grouted Boulder Rundown

(Sheet 1 of 2)





Sheet 2 of 2

Figure HS-18a—Grouted Boulder Rundown

(Sheet 2 of 2)

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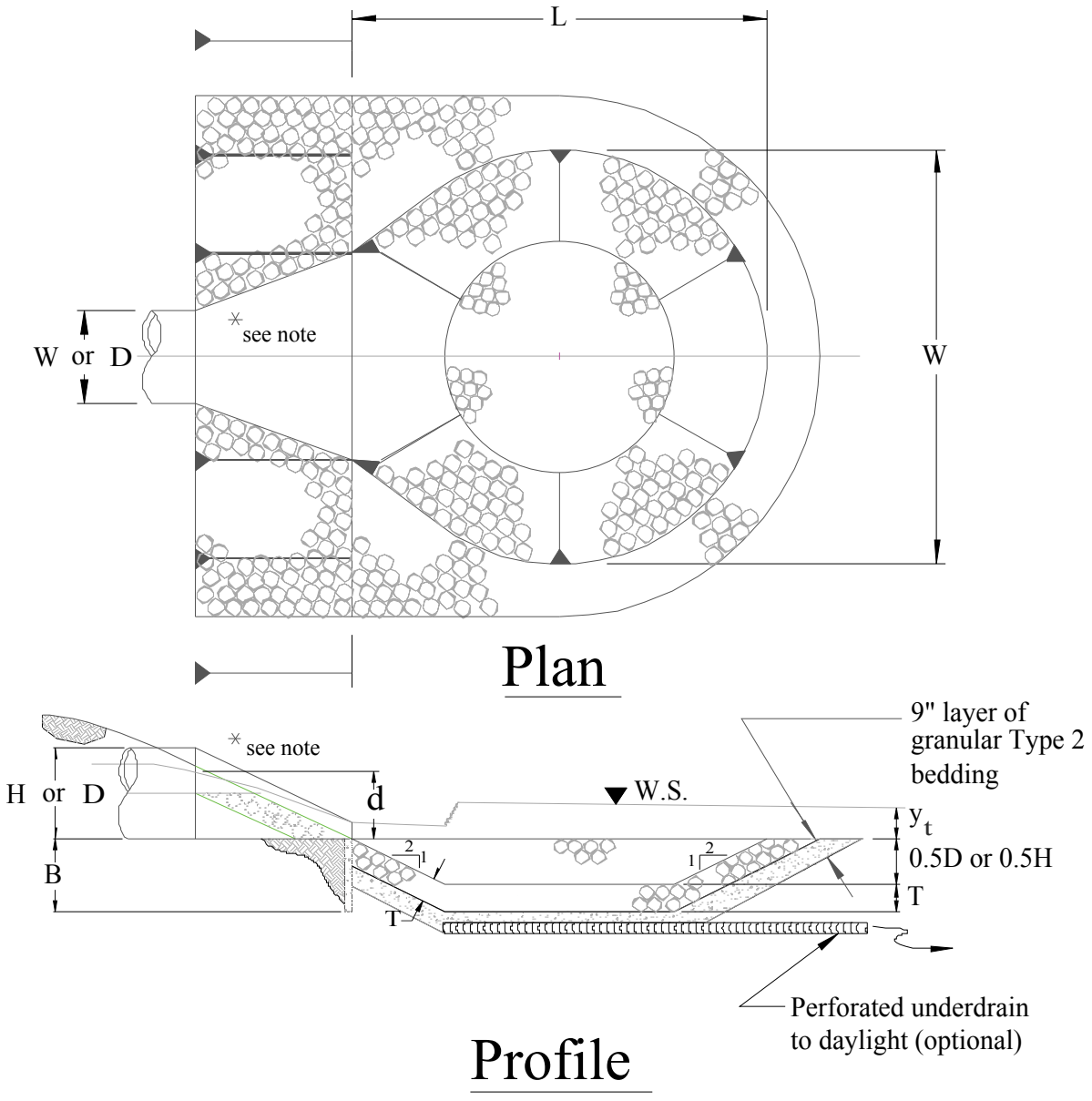

* Note: For rectangular conduits use a standard design for a headwall with wingwalls, paved bottom between the wingwalls, with an end cutoff wall extending to a minimum depth equal to B

Figure HS-19—Low Tailwater Riprap Basins for Storm Sewer Pipe Outlets—Low Tailwater Basin at Pipe Outlets
(Stevens and Urbonas 1996)

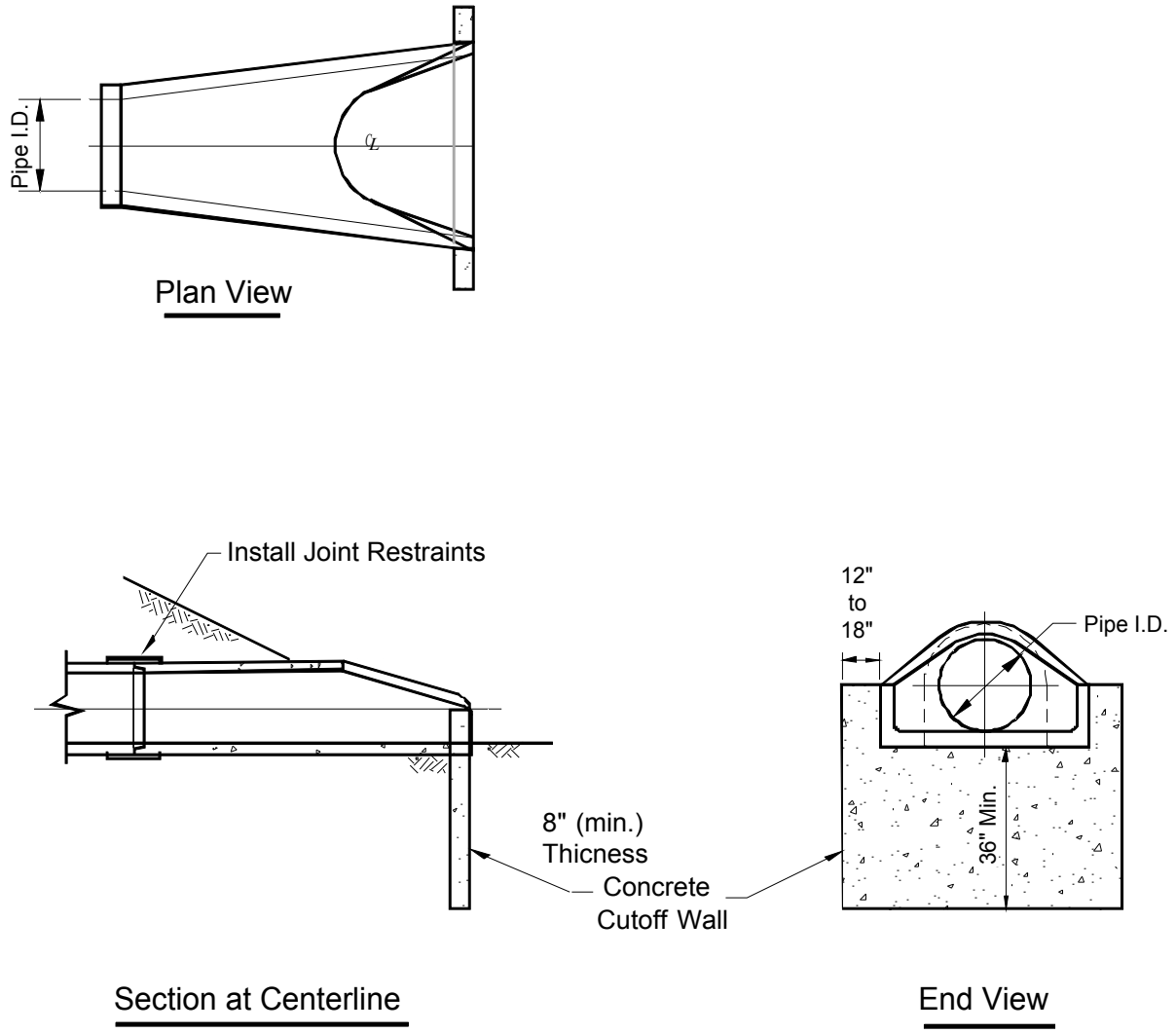

Figure HS-19a—Concrete Flared End Section with Cutoff Wall for all Pipe Outlets

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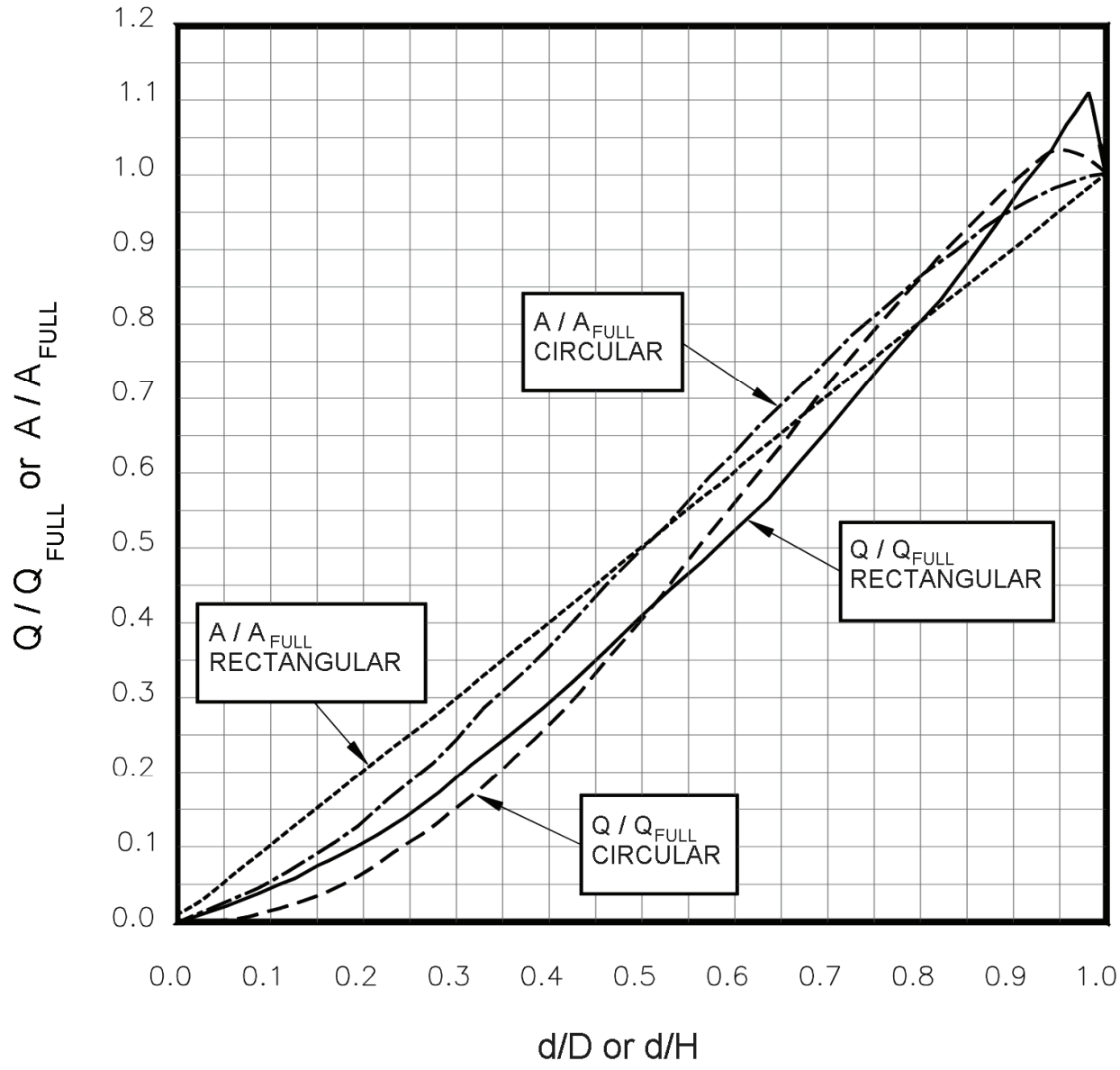

Figure HS-20a—Low Tailwater Riprap Basins for Storm Sewer Pipe Outlets—Discharge and Flow Area Relationships for Circular and Rectangular Pipes
(Ratios for Flow Based on Manning's *n* Varying With Depth)
(Stevens and Urbonas 1996)

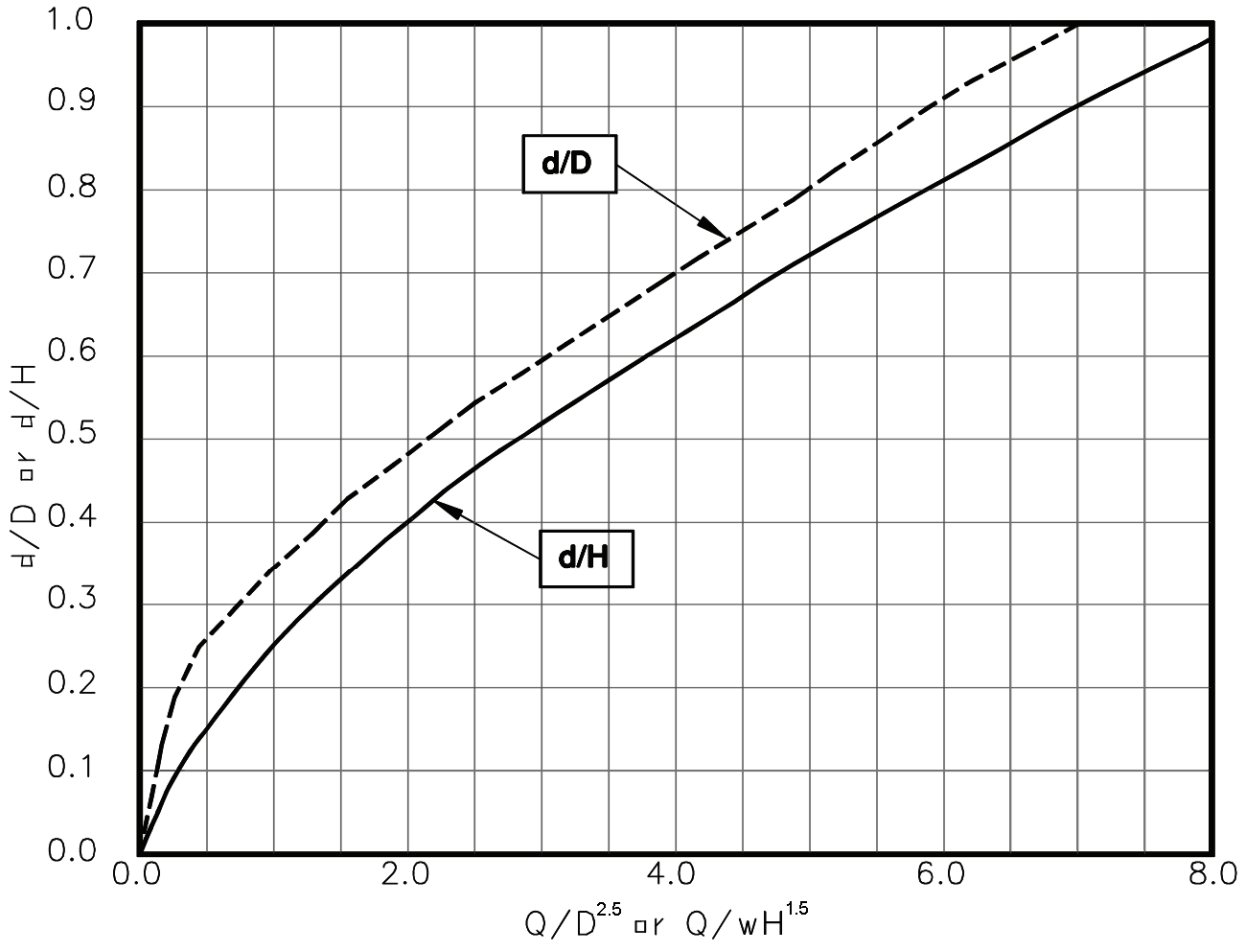

Figure HS-20b—Low Tailwater Riprap Basins for Storm Sewer Pipe Outlets—Brink Depth for Horizontal Pipe Outlets

(Stevens and Urbonas 1996)

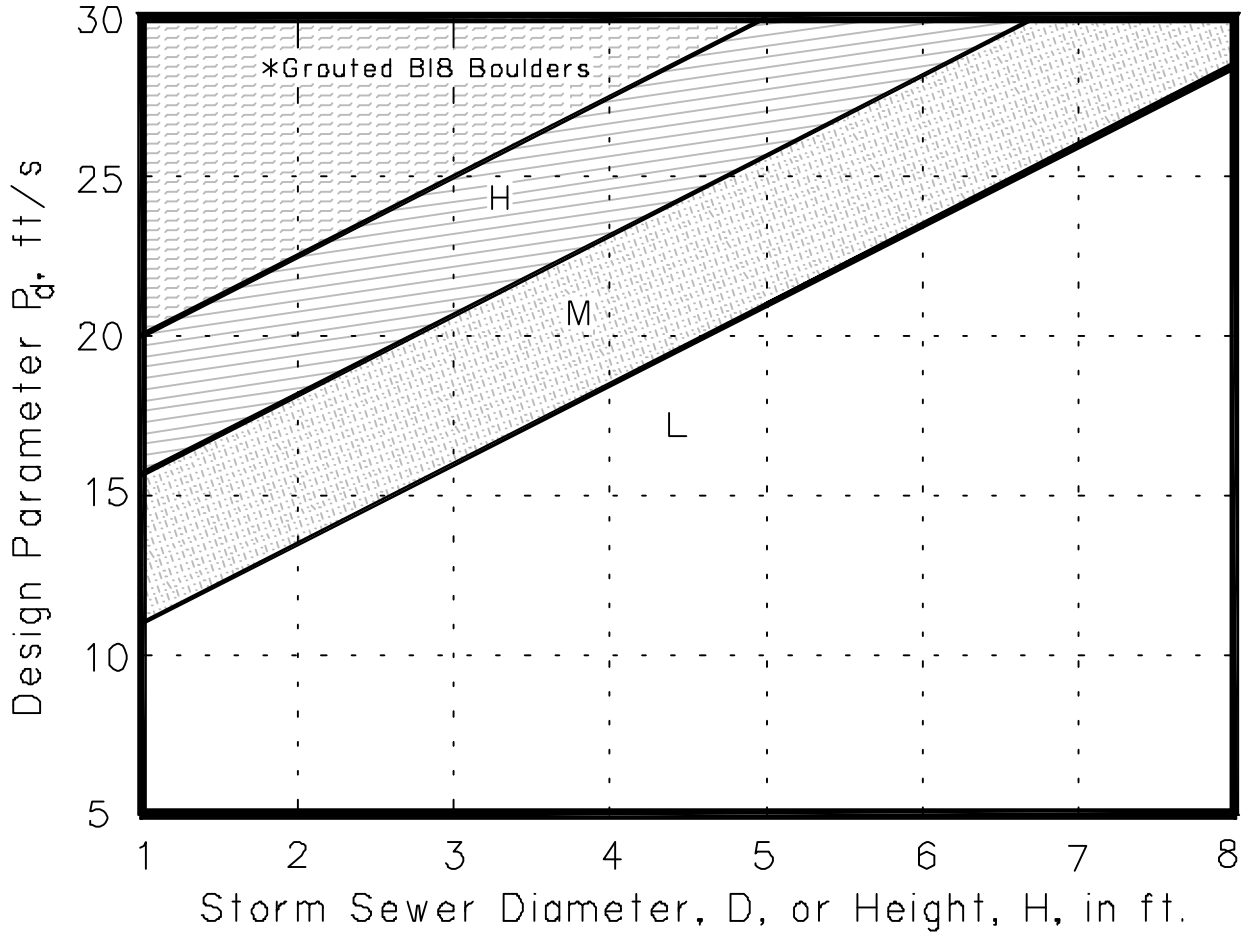

Figure HS-20c—Low Tailwater Riprap Basins for Storm Sewer Pipe Outlets—
Riprap Selection Chart for Low Tailwater Basin at Pipe Outlet
(Stevens and Urbonas 1996)

4.0 BRIDGES

There are extensive manuals on bridges that are available and should be used in bridge hydraulic studies and river stability analysis. Some of the best include:

1. *Hydraulics of Bridge Waterways* Hydraulic Design Series No. 1 (FHWA 1978). This is a good basic reference.
2. *Highway in the River Environment* (Richardson 1988 draft with appendices and 1974). This is particularly good for hydraulics, geomorphology, scour, and degradation.
3. *Design Manual for Engineering Analysis of Fluvial Systems for the Arizona Department of Water Resources* (LSA 1985). This is a prime reference on hydraulics and the three-level sediment transport analysis, with examples.



Photograph HS-14—A stable channel at bridges is important and includes caring for the stream downstream of the bridge as shown here on Cherry Creek.

4. *Hydraulic Analysis Location and Design of Bridges* Volume 7 (AASHTO 1987). This is a good overview document.
5. *Technical Advisory on Scour at Bridges* (FHWA 1988). This presents information similar to references 2, 3, and 4 above, but in a workbook format, and perhaps oversimplified.

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Bridges are required across nearly all open urban channels sooner or later and, therefore, sizing the bridge openings is of paramount importance. Open channels with improperly designed bridges will either have excessive scour or deposition or not be able to carry the design flow.

4.1 Basic Criteria

Bridge openings should be designed to have as little effect on the flow characteristics as reasonable, consistent with good bridge design and economics. However, in regard to supercritical flow with a lined channel, the bridge should not affect the flow at all—that is, there should be no projections into the design water prism that could create a hydraulic jump or flow instability in form of reflecting and standing waves.

4.1.1 Design Approach

The method of planning for bridge openings must include water surface profiles and hydraulic gradient analyses of the channel for the major storm runoff. Once this hydraulic gradient is established without the bridge, the maximum reasonable effect on the channel flow by the bridge should be determined. In urban cases this should not exceed a backwater effect of more than 6 to 12 inches.

Velocities through the bridge and downstream of the bridge must receive consideration in choosing the bridge opening. Velocities exceeding those permissible will require special protection of the bottom and banks.

For supercritical flow, the clear bridge opening should permit the flow to pass under unimpeded and unchanged in cross section.

4.1.2 Bridge Opening Freeboard

The distance between the design flow water surface and the bottom of the bridge deck will vary from case to case. However, the debris that may be expected must receive full consideration in setting the freeboard. Freeboard may vary from several feet to minus several feet. There are no general rules. Each case must be studied separately. In larger waterways, streams and on rivers where large floating debris is likely, at least a 3-foot freeboard during a 100-year flood should be considered.

Bridges that are securely anchored to foundations and designed to withstand the dynamic forces of the flowing water might, in some cases, be designed without freeboard.

4.2 Hydraulic Analysis

The hydraulic analysis procedures described below are suitable, although alternative methods such as FHWA HY-4 or HEC-RAS are acceptable, as well.

The design of a bridge opening generally determines the overall length of the bridge. The length affects the final cost of the bridge. The hydraulic engineering in the design of bridges has more impact on the bridge cost than does the structural design. Good hydraulic engineering is necessary for good bridge design (FHWA 1978, Richardson 1974 and 1988).

The reader is referred to *Hydraulics of Bridge Waterways* (U.S. Bureau of Public Roads 1978) for more guidance on the preliminary assessment approach described below. In working with bridge openings, the designer may use the designation shown in Figure HS-21.

4.2.1 Expression for Backwater

A practical expression for backwater has been formulated by applying the principle of conservation of energy between the point of maximum backwater upstream from the bridge and a point downstream from the bridge at which normal stage has been reestablished, as shown in Sections 1 and 4, respectively, of Figure HS-21. The expression is reasonably valid if the channel in the vicinity of the bridge is reasonably uniform, the gradient of the bottom is approximately constant between Sections 1 and 4, there is no appreciable erosion of the bed in the constriction due to scour, and the flow is subcritical.

The expression for computation of backwater upstream from a bridge constricting the flow is as follows:

$$h_1^* = (K^*)\left(\frac{(V_{n2})^2}{2g}\right) + \propto 1 \left[\left(\frac{A_{n2}}{A_4}\right)^2 - \left(\frac{A_{n2}}{A_1}\right)^2\right] \frac{V_{n2}{}^2}{2g} \qquad \text{(HS-23)}$$

in which:

h_1^* = total backwater (ft)

K^* = total backwater coefficient

$\propto 1 = \dfrac{qv^2}{QV_1^2}$ = kinetic energy coefficient

A_{n2} = gross water area in constriction measured below normal stage (ft^2)

V_{n2} = average velocity in constriction or Q/A_{n2} (ft/sec). The velocity V_{n2} is not an actual measurable velocity but represents a reference velocity readily computed for both model and field structures.

A_4 = water area at Section 4 where normal stage is reestablished (ft^2)

A_1 = total water area at Section 1 including that produced by the backwater (ft^2)

g = acceleration of gravity (32.2 ft/sec^2)

To compute backwater by Equation HS-23, it is necessary to obtain the approximate value of h_1^* by using the first part of the equation:

$$h_1^* = (K^*)\left(\frac{V_{n2}^2}{2g}\right) \qquad \text{(HS-24)}$$

The value of A_1 in the second part of Equation HS-23, which depends on h_1^*, can then be determined.

This part of the expression represents the difference in kinetic energy between Sections 4 and 1, expressed in terms of the velocity head $\frac{V_{n2}^2}{2g}$. Equation HS-24 may appear cumbersome, but it was set up as shown to permit omission of the second part when the difference in kinetic energy between Sections 4 and 1 is small enough to be insignificant in the final result.

To permit the designer to readily recognize cases in which the kinetic energy term may be ignored, the following guides are provided:

$M > 0.7$, where M = bridge opening ratio

$V_{n2} < 7$ ft/sec

$(K^*)\left(\frac{V_{n2}^2}{2g}\right) < 0.5$ ft

If values meet all three conditions, the backwater obtained from Equation HS-24 can be considered sufficiently accurate. Should one or more of the values not meet the conditions set forth, it is advisable to use Equation HS-23 in its entirety. The use of the guides is further demonstrated in the examples given in FHWA (1978) that should be used in all bridge design work.

4.2.2 Backwater Coefficient

The value of the overall backwater coefficient K^*, which was determined experimentally, varies with:

1. Stream constriction as measured by bridge opening ratio, M.
2. Type of bridge abutment: wingwall, spill through, etc.
3. Number, size, shape, and orientation of piers in the constriction.
4. Eccentricity, or asymmetric position of bridge with the floodplains.
5. Skew (bridge crosses floodplain at other than 90 degree angle).

The overall backwater coefficient K^* consists of a base curve coefficient, K_b, to which are added incremental coefficients to account for the effect of piers, eccentricity, and skew. The value of K^* is primarily dependent on the degree of constriction of the flow but also changes to a limited degree with the other factors.

4.2.3 Effect of M and Abutment Shape (Base Curves)

Figure HS-22 shows the base curve for backwater coefficient, K_b, plotted with respect to the opening ratio, M, for several wingwall abutments and a vertical wall type. Note how the coefficient K_b increases with

channel constriction. The several curves represent different angles of wingwalls as can be identified by the accompanying sketches; the lower curves represent the better hydraulic shapes.

Figure HS-23 shows the relation between the backwater coefficient, K_b, and M for spill-through abutments for three embankment slopes. A comparison of the three curves indicates that the coefficient is little affected by embankment slope. Figures HS-22 and HS-23 are "base curves" and K_b is referred to as the "base curve coefficient." The base curve coefficients apply to normal crossings for specific abutment shapes but do not include the effect of piers, eccentricity, or skew.

4.2.4 Effect of Piers (Normal Crossings)

The effect on the backwater from introduction of piers in a bridge constriction has been treated as an incremental backwater coefficient designated ΔK_p, which is added to the base curve coefficient when piers are a factor. The value of the incremental backwater coefficient, ΔK_p, is dependent on the ratio that the area of the piers bears to the gross area of the bridge opening, the type of piers (or piling in the case of pile bents), the value of the bridge opening ratio, M, and the angularity of the piers with the direction of flood flow. The ratio of the water area occupied by piers, A_p, to the gross water area of the constriction, A_{n2}, both based on the normal water surface, has been assigned the letter J. In computing the gross water area, A_{n2}, the presence of piers in the constriction is ignored. The incremental backwater coefficient for the more common types of piers and pile bents can be obtained from Figure HS-24. The procedure is to enter Chart A, Figure HS-24, with the proper value of J and read ΔK and obtain the correction factor σ from Chart B, Figure HS-24, for opening ratios other than unity. The incremental backwater coefficient is then

$$\Delta K_p = \Delta K \sigma \qquad \text{(HS-25)}$$

The incremental backwater coefficients for piers can, for all practical purposes, be considered independent of diameter, width, or spacing but should be increased if there are more than 5 piles in a bent. A bent with 10 piles should be given a value of ΔK_p about 20% higher than those shown for bents with 5 piles. If there is a good possibility of trash collecting on the piers, it is advisable to use a value greater than the pier width to include the trash. For a normal crossing with piers, the total backwater coefficient becomes:

$$K^* = K_b \text{ (Figures HS-22 or HS-23)} + \Delta K_p \text{ (Figure HS-24)} \qquad \text{(HS-26)}$$

4.3 Design Procedure

The following is a brief step-by-step outline for determination of backwater produced by a bridge constriction:

1. Determine the magnitude and frequency of the discharge for which the bridge is to be designed.

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2. Determine the stage of the stream at the bridge site for the design discharge.
3. Plot representative cross section of stream for design discharge at Section 1, if not already done under Step 2. If the stream channel is essentially straight and the cross section substantially uniform in the vicinity of the bridge, the natural cross section of the stream at the bridge site may be used for this purpose.
4. Subdivide the above cross section according to marked changes in depth of flow and roughness. Assign values of Manning's roughness coefficient, n, to each subsection. Careful judgment is necessary in selecting these values.
5. Compute conveyance and then discharge in each subsection.
6. Determine the value of the kinetic energy coefficient.
7. Plot the natural cross section under the proposed bridge based on normal water surface for design discharge and compute the gross water area (including area occupied by piers).
8. Compute the bridge opening ratio, M, observing modified procedure for skewed crossings.
9. Obtain the value of K_b from the appropriate base curve.
10. If piers are involved, compute the value of J and obtain the incremental coefficient, ΔK_p.
11. If eccentricity is severe, compute the value of eccentricity and obtain the incremental coefficient, ΔK_e (FHWA 1978).
12. If a skewed crossing is involved, observe proper procedure in previous steps, then obtain the incremental coefficient, ΔK_s, for proper abutment type.
13. Determine the total backwater coefficient, K*, by adding incremental coefficients to the base curve coefficient, K_b.
14. Compute the backwater by Equation HS-23.
15. Determine the distance upstream to where the backwater effect is negligible.

Detailed steps illustrated by examples are presented in *Hydraulics of Bridge Waterways* (FHWA 1978).

4.4 Inadequate Openings

The engineer will often encounter existing bridges and culverts that have been designed for storms having return periods less than 100 years. In addition, bridges will be encountered which have been improperly designed. Often the use of the orifice formula will provide a quick determination of the adequacy or inadequacy of a bridge opening:

$$Q_m = C_b A_b \sqrt{2gH_{br}} \quad \text{(HS-27)}$$

or

$$H_{br} = 0.04\left(\frac{Q_m}{A_b}\right)^2 \quad \text{(HS-28)}$$

in which:

Q_m = the major storm discharge (cfs)

C_b = the bridge opening coefficient (0.6 assumed in Equation HS-27)

A_b = the area of the bridge opening (ft^2)

g = acceleration of gravity (32.2 ft/sec^2)

H_{br} = the head, that is the vertical distance from the bridge opening center point to the upstream water surface about $10H$ upstream from the bridge, where H is the height of the bridge, in feet. It is approximately the difference between the upstream and downstream water surfaces where the lower end of the bridge is submerged.

These expressions are valid when the water surface is above the top of the bridge opening.

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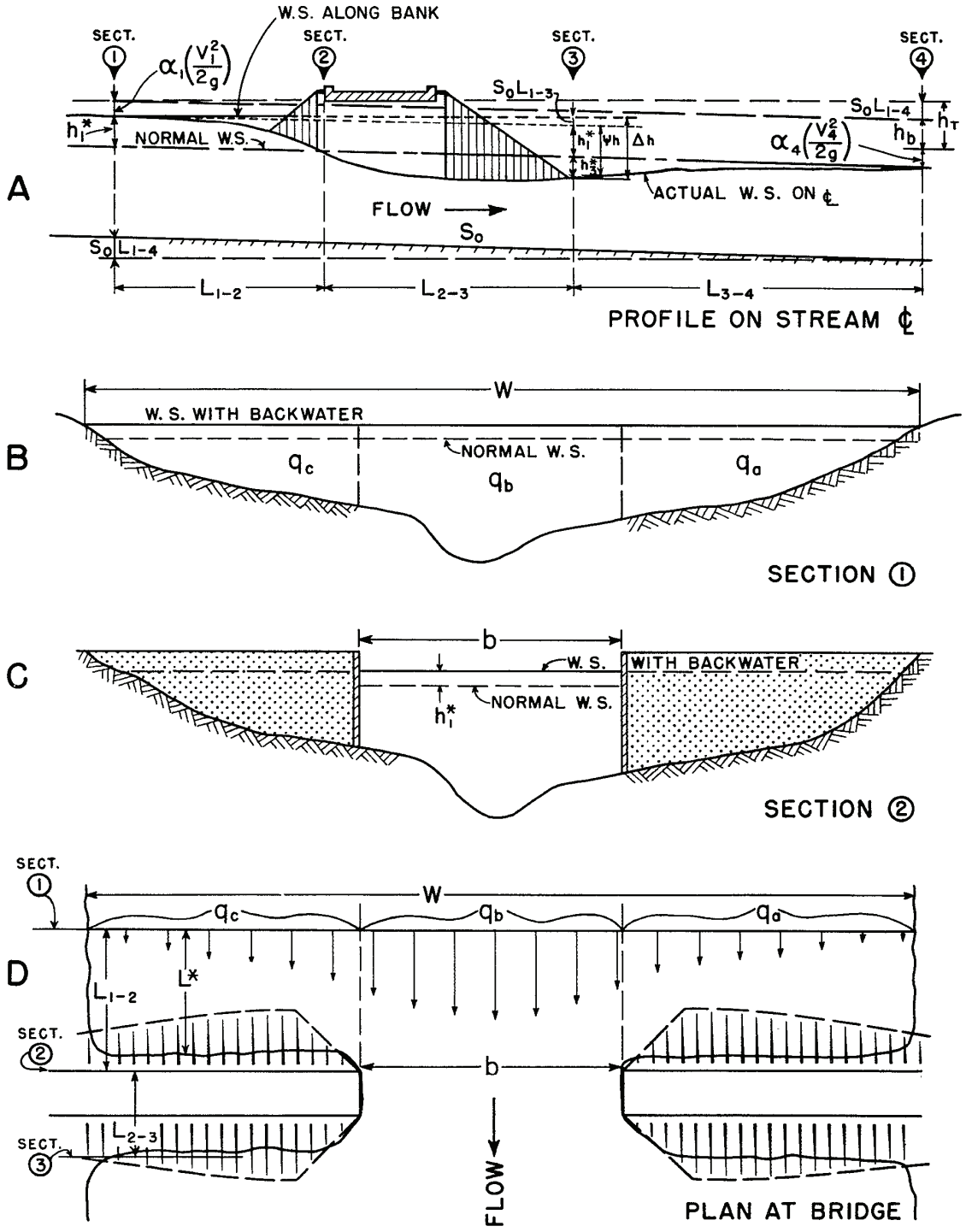

Figure HS-21—Normal Bridge Crossing Designation

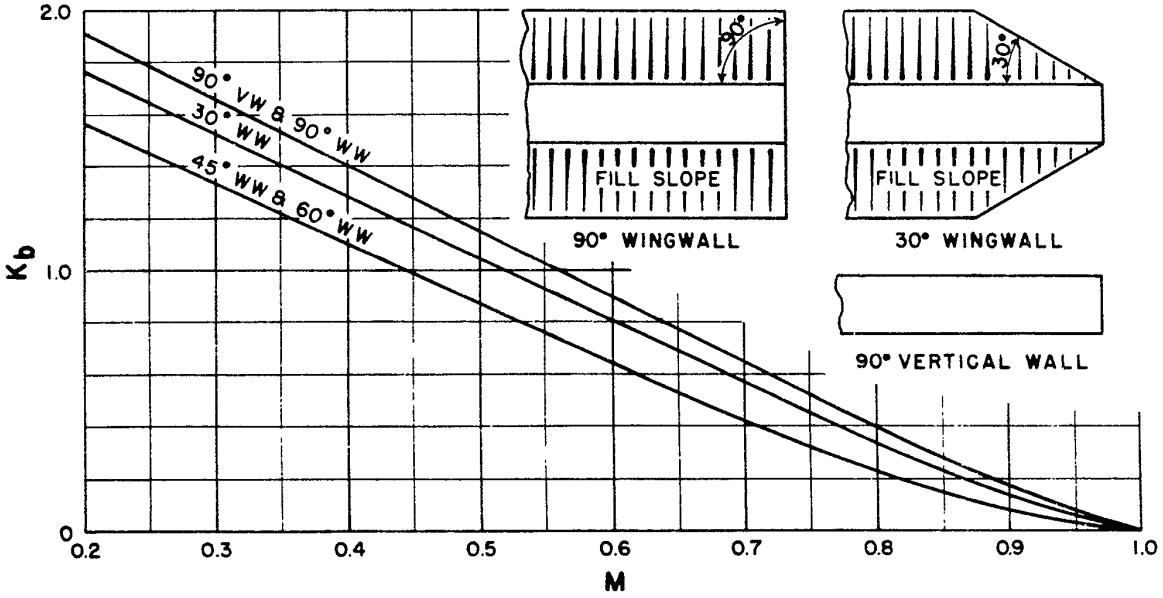

Figure HS-22—Base Curves for Wingwall Abutments

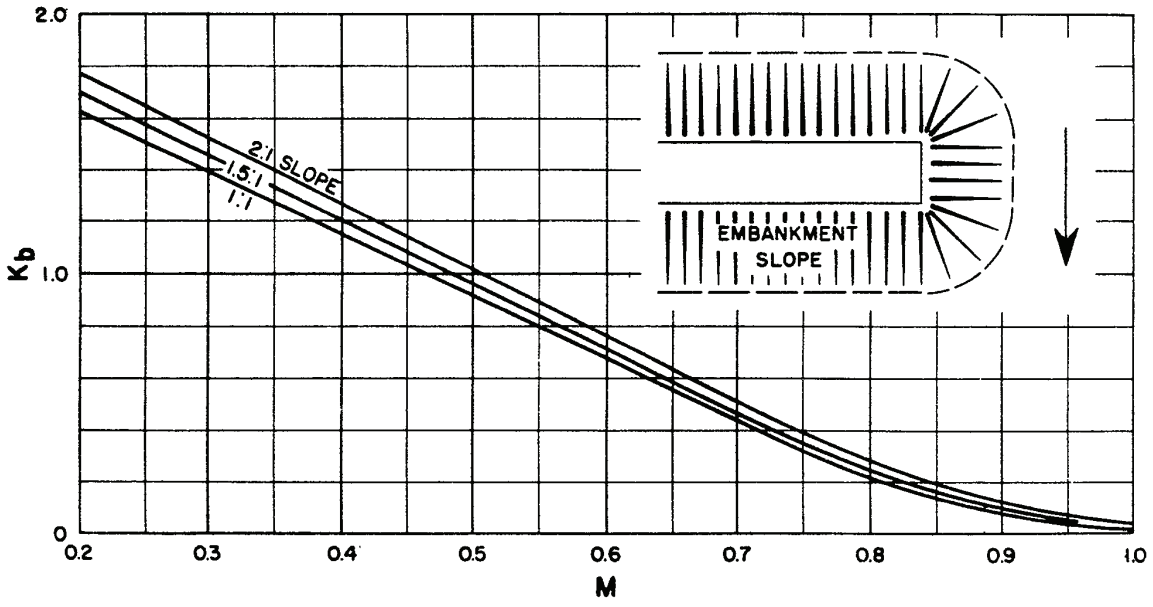

Figure HS-23—Base Curves for Spillthrough Abutments

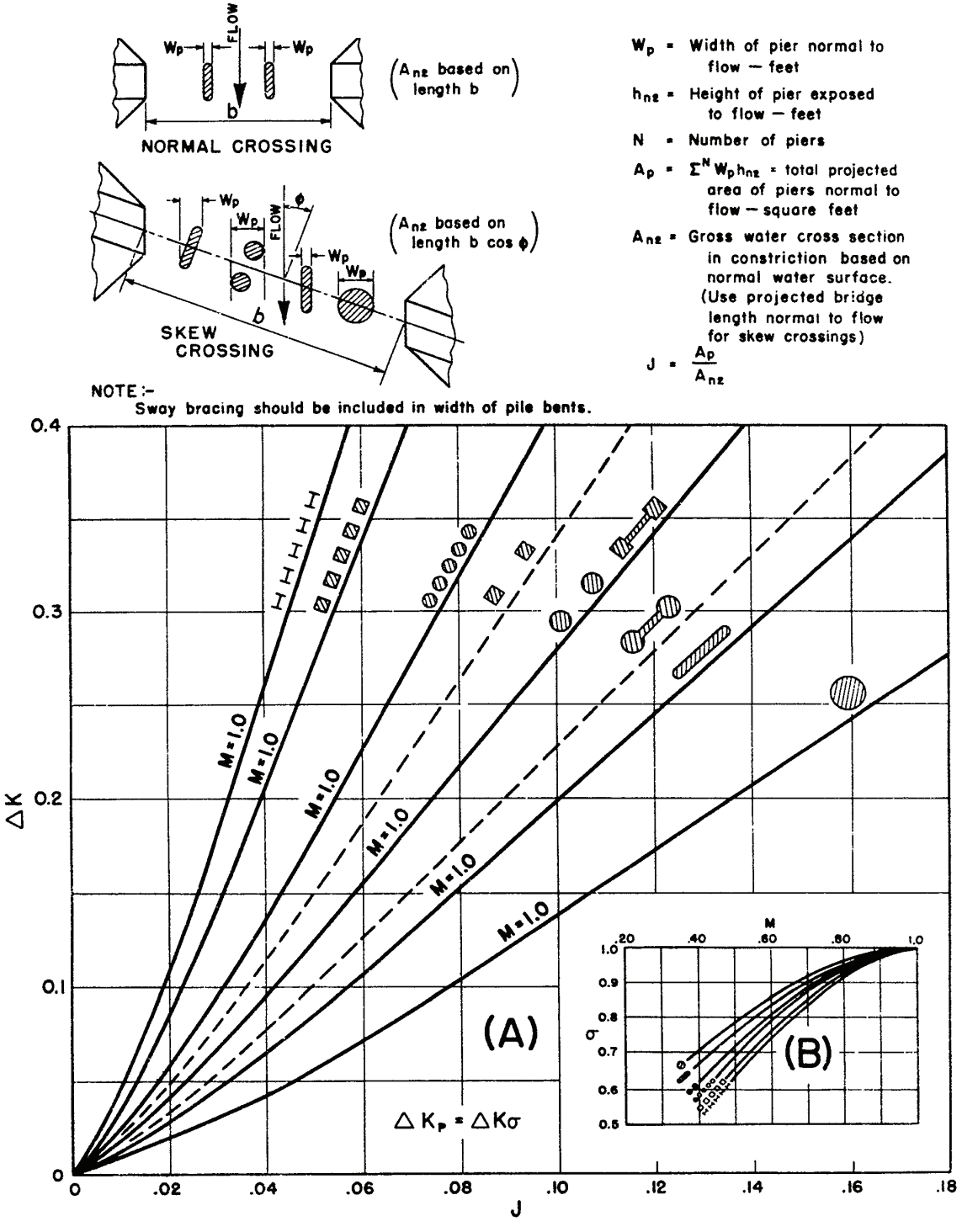

Figure HS-24—Incremental Backwater Coefficient for Pier

5.0 TRANSITIONS AND CONSTRICTIONS

5.1 Introduction

The purpose of this section is to outline typical design procedures for transition and constriction structures that are commonly encountered in the District's flood control and drainage projects. There are numerous references that can be useful for detailed analysis of different project objectives or site conditions (Rouse 1949, Chow 1959, USACE 1970 and 1982, FHWA 2000, SCS 1977). This topic is also addressed in MAJOR DRAINAGE, under riprap-lined channels.

5.2 Transition Analysis

5.2.1 Subcritical Transitions

Transitions for subcritical flow frequently involve localized structures or bank lining configurations that allow change in the cross section and produce a water surface profile based on gradually varied flow. The energy lost through a transition is a function of the friction, eddy currents and turbulence. The intent is often to minimize friction losses and/or erosional tendencies. Examples include transitions between trapezoidal and rectangular sections, modest transitions at bridges where little change takes place in the cross section, or slight encroachments into a channel to allow for utilities. Transitions can be handled with various structures, including concrete facilities (Figure HS-25) and riprap-lined channel reaches (see MAJOR DRAINAGE).

Standard water surface profile analysis is applied, with the addition of an energy loss at the transition. The loss is expressed as a function of the change in velocity head occurring across the contraction or expansion transition (from upstream to downstream locations). Figure HS-25 illustrates some of these transitions with basic design guidelines. Loss coefficients shown in Table HS-10 are applied to the difference in velocity head, as shown in Equation HS-29.

Analysis of transitions requires careful water surface profile analysis including verification of effective channel hydraulic controls. It is not uncommon to have a transition that is first thought to be performing in a subcritical mode, subsequently found to produce a supercritical profile with a hydraulic jump.

Energy Loss (ft) = Coefficient ($h_{v1} - h_{v2}$)

in which:

$$\left(h_{v1} - h_{v2}\right) = \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) \qquad \text{(HS-29)}$$

V_1 = flow velocity upstream of transition

V_2 = flow velocity downstream of transition

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Table HS-10—Subcritical Transition Energy Loss Coefficients

	Contraction	Expansion
Less than 4 inches between centerline and tangent lines	0.00	0.00
Less than 12.5 degrees between centerline and tangent lines	0 to 0.10	0 to 0.10
Warped type	0.10	0.20
Cylindrical quadrant type	0.15	0.25
Modest transitions	0.30	0.50
Straight line type	0.30	0.50
Square ended type	0.30+	0.75

5.2.2 Supercritical Transition Analysis

Supercritical transitions are beyond the scope of this *Manual* and require special analysis when used. The configuration of a supercritical transition is entirely different than subcritical transitions. Improperly designed and configured supercritical transitions can produce shock wave patterns which result in channel overtopping and other hydraulic and structural problems.

5.3 Constriction Analysis

5.3.1 Constrictions With Upstream Subcritical Flow

There are a variety of structures that are constrictions. They can include bridges, culverts, drop structures, and flow measurement devices. Constrictions of various types are used intentionally to control bed stability and upstream water surface profiles. For example, a constriction may be used to cause water to back up into or overflow into a flood storage pond.

The hydraulic distinction of constrictions is that they can cause rapidly varied flow. The upstream transition loss coefficients in Table HS-10 apply, but other factors come into play. Significant eddies can form upstream and downstream of the constriction depending upon the geometry. Flow separation will start at the upstream edge of the constriction, then the flow contracts to be narrower than the opening width. Typically, the width of contraction is 10% of the depth at the constriction for each side boundary. For example, at a typical drop with an abrupt crest contraction and assuming critical depth of 3.5 feet, the constriction on each side would be 0.35 feet or 0.7 feet total contraction from the opening width. Based on this contracted width and an assumption of critical conditions at that location, the upstream water surface profile may be computed.

In certain cases the flow regime will remain subcritical through the constriction. Chow (1959) presents guidelines developed by the U.S. Geological Survey for constrictions where the Froude number in the contracted section does not exceed 0.8. These cases are considered to be mild constrictions.

A consequence of abrupt contractions (and abrupt expansions) is that the velocities can be much higher in the center and change significantly across the constriction throat section. This results in a large energy coefficient and a further drop in water surface over what is first anticipated. This condition can produce

strong eddy currents with high erosion potential. A constriction in an open channel needs to be carefully evaluated for velocity, scour, water surface, and related problems.

Constrictions used for flow depth control or flow measurement devices require a high degree of accuracy. The design information available that can be used for insuring a high degree of accuracy is limited. It is advisable to use model-tested or proven prototype layouts. As a secondary option, adjustable edge plates or other components can be provided to allow later changes at minimal cost if the constructed facilities should need refinement.

5.3.2 Constrictions With Upstream Supercritical Flow

This situation is highly complex and goes beyond the scope of this *Manual*. Possible shock waves or choked flow causing high upstream backwater or a hydraulic jump are distinct possibilities and are should be of major concern to designers. The situation is best avoided in urban channels and settings.

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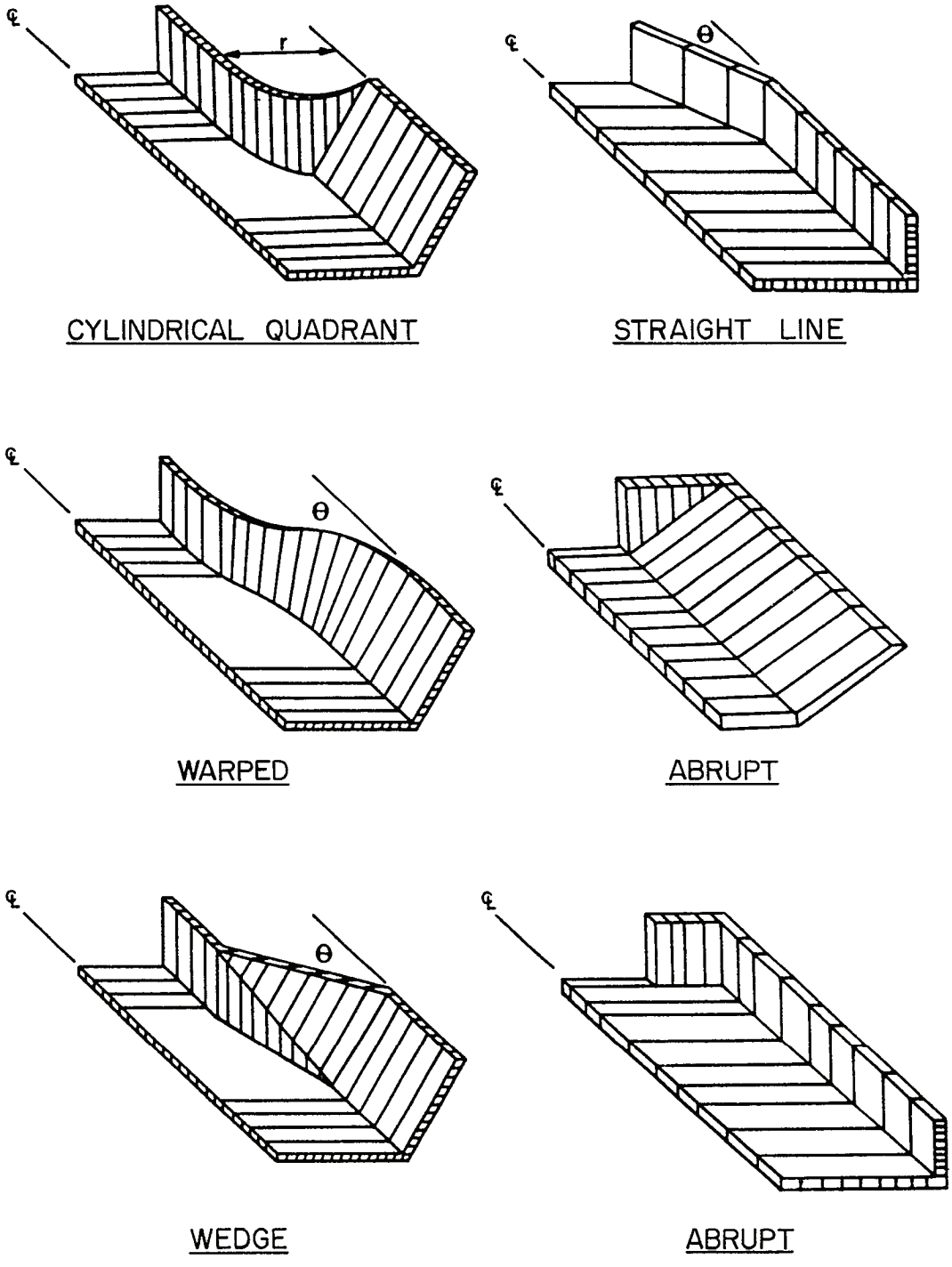

Figure HS-25—Transition Types

6.0 BENDS AND CONFLUENCES

6.1 Introduction

This section focuses on subcritical flow conditions. Because supercritical conditions can occur in various situations, a few supercritical conditions are also generally reviewed; however, supercritical flow analysis is not described in detail.

6.2 Bends

6.2.1 Subcritical Bends

Subcritical bends are required to have certain minimum curvatures described in the MAJOR DRAINAGE chapter. It is important that the engineer recognize the consequence of approaching and exceeding these criteria. Chow (1959), Rouse (1949) (see chapter by Ippen), and others illustrate flow patterns, superelevation, and backwater or flow resistance characteristics. Superelevation refers to a rise in water surface on the outer side of the bend. Effectively, the bend can behave like a contraction, causing backwater upstream and accelerated velocity zones, with high possibility of erosion on the outside of the bend and other locations. Significant eddy currents, scour, sedimentation, and loss of effective conveyance can occur on the inside of the bend.

Concrete-lined channels can be significantly affected by superelevation of the water surface. The designer should always add superelevation to the design freeboard of the channel. The equation for the amount of superelevation of the water surface, Δy that takes place is given as:

$$\Delta y = C_{se}\left(\frac{V^2 W_t}{g r_c}\right) \qquad \text{(HS-30)}$$

in which:

C_{se} = coefficient, generally 0.5 for subcritical flow (see references for higher coefficients for supercritical)

V = mean channel velocity

W_t = channel top width of water surface

g = acceleration of gravity (32.2 ft/sec^2)

r_c = radius of the channel centerline curvature

6.2.2 Supercritical Bends

As with supercritical transitions, supercritical bend hydraulics are completely different than subcritical. Supercritical channels are not desirable in urban drainage; however, special situations occur where supercritical flows enter a curved channel. Some examples include at confluences where one channel is empty and the entering flow expands and becomes supercritical, at a sharp bend in a conduit with a slope

that inherently leads to supercritical conditions, or at a channel drop that unavoidably ends up on a curve.

The main phenomenon to be aware of is shock waves, of which there are two types: positive and negative. On the outside of an angular bend, a positive shock wave will occur that results in a rise in water surface. The wave is stationary and crosses to the inside of the channel and then can continue to reflect back and forth. Where the flow passes the inside angular bend, a separation will occur, and a negative shock wave or drop in water surface will occur. This stationary negative shock wave will cross to the outside of the channel. Both shock waves will continue to reflect off the walls, resulting in a very disturbed flow pattern.

A basic control technique is to set up bend geometry to cause the positive shock wave to intersect the point where the negative wave is propagated. A bend usually requires two deflections on the outside and one bend on the inside. A beneficial aspect of the shock wave is that it turns the flow in a predictable pattern; thus, the channel walls have no more force imposed on them than that caused by the increased (or decreased) depths. This technique is described in Rouse (1949), USACE (1970), and Chow (1959).

Other control techniques include very gradual bends, super elevated floors and control sills, but these methods are generally less efficient. There is limited data on channels with sloping side banks, but it is clear there is a great tendency for shock waves to propagate up side slopes and divert flow out of the channel. Chow (1959) shows several good photographs of these problems. The SCS (1976) presents a documental report of a curved spillway on a modest flood control storage facility. During an overflow event, a shock wave pattern was produced that resulted in no flow on one side of a spillway, and great depths on the opposite.

Another problem observed at bends when channels operate under supercritical conditions is flow jumping out of the channel at the bend. When this happens, the downstream channel no longer carries the design flow and major damages to prosperities in line with the flows jumping out of the channel can and have occurred.

A special problem with long conduits used for flood control, particularly large box culverts, is that they will have an inherent tendency toward supercritical flow conditions at less than full capacity. When supercritical flow encounters bends or transitions, standing and reflective waves can occur which hit the ceiling of the culvert and can cause pressurized conditions or unstable conditions where the flow fluctuates between supercritical free surface flow and pressurized pipe flow conditions, often exacerbated by pressure variations in the pipe that can range from less than atmospheric to pressures approaching full velocity head. It is recommended that there be no bends or very gradual bends in conduits, along with air venting be provided when supercritical flows are expected in conduits, especially rectangular ones.

Use extreme caution in design anytime supercritical flow may occur and may encounter a bend or a transition.

6.3 Confluences

Some of the most difficult problems to deal with are confluences where the difference in flow characteristics may be great. When the flow enters the combined channel, the flow can diverge and drop in level if the flow capacity is suddenly increased. This can result in high velocity or unstable supercritical flow conditions with high erosion potential. When significant sediment flows exist, aggradation can occur at the confluence, resulting in loss of capacity in one or both upstream channels. The following material is adapted from *Hydraulic Design of Flood Control Channels* (USACE 1970).

6.3.1 Subcritical Flow Confluence Design

The design of channel junctions is complicated by variables such as the angle of intersection, shape and width of the channels, flow rates, and type of flow. The design of large complex junctions should be verified by model tests. The momentum equation design approach has been verified for small angles by Taylor (1944) and Webber and Greated (1966).

Figure HS-26 illustrates two types of junctions. The following assumptions are made for combining subcritical flows.

1. The side channel cross section is the same shape as the main channel cross section.
2. The bottom slopes are equal for the main channel and the side channel.
3. Flows are parallel to the channel walls immediately above and below the junction.
4. The depths are equal immediately above the junction in both the side and main channel.
5. The velocity is uniform over the cross sections immediately above and below the junction.

Assumption number 3 implies that hydrostatic pressure distributions can be assumed, and assumption number 5 suggests that the momentum correction factors are equal to each other at the reference sections.

The equation governing flow conditions for a vertical walled channel with the main channel width constant is shown in Figure HS-26(a) and the following equation:

$$\frac{Q_3^2}{gA_3} + \frac{by_3^2}{2} = \frac{Q_1^2}{gA_1} + \frac{(\cos\theta)Q_2^2}{gA_2} + \frac{by_1^2}{2} \qquad \text{(HS-31)}$$

Or, for a vertical walled channel with the main channel width variable, Figure HS-26(b):

$$\frac{Q_3^2}{gA_3} + \frac{b_3y_3^2}{2} = \frac{Q_1^2}{gA_1} + \frac{(\cos\theta)Q_2^2}{gA_2} + \frac{b_3y_1^2}{2} \qquad \text{(HS-32)}$$

Or, for a trapezoidal channel with the main channel width constant, Figure HS-26(a):

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$$\frac{Q_3^2}{gA_3}+\left(\frac{b_1}{2}+\frac{Zy_3}{3}\right)y_3^2=\frac{Q_1^2}{gA_1}+\frac{(\cos\theta)Q_2^2}{gA_2}+\left(\frac{b_1}{2}+\frac{Zy_1}{2}\right)y_1^2 \quad \text{(HS-33)}$$

Or, for trapezoidal channels with the main channel width variable, Figure HS-26(b):

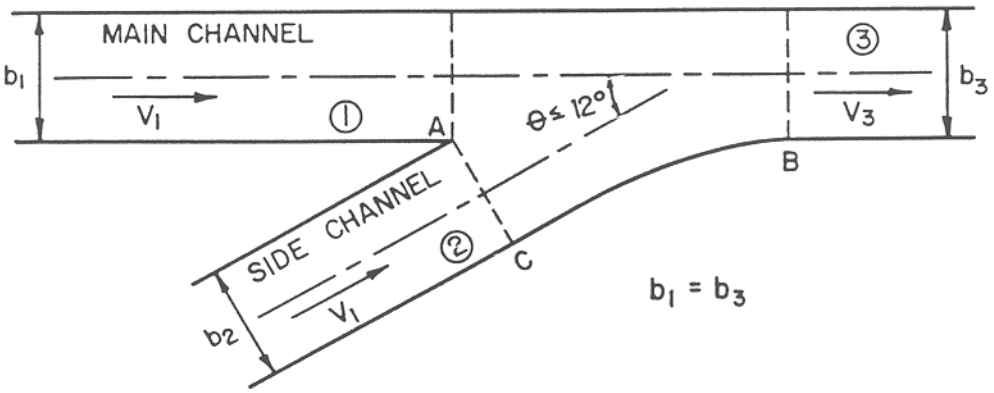
$$\frac{Q_3^2}{gA_3}+\left(\frac{b_3}{2}+\frac{Zy_3}{3}\right)y_3^2=\frac{Q_1^2}{gA_1}+\frac{(\cos\theta)Q_2^2}{gA_2}+\left(\frac{b_3}{2}+\frac{Zy_1}{3}\right)y_1^2 \quad \text{(HS-34)}$$

In which:

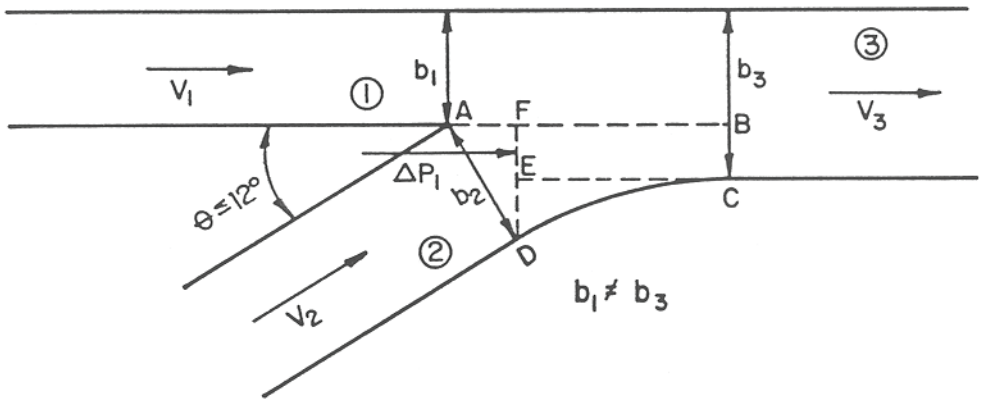
b = bottom width of the trapezoidal cross section

Z = side slope, horizontal to vertical

Momentum computations for a confluence involve a trial and error process. Starting with a known depth above or below the confluence, one iterates with an assumed depth on the unknown side of the confluence until the momentum has been balanced upstream to downstream.



(a) PLAN–CONSTANT WIDTH



(b) PLAN–UNEQUAL WIDTH

Figure HS-26—Channel Junction Definition Sketches

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7.0 RUNDOWNS

A channel rundown is used to convey storm runoff from the bank of a channel to the invert of an open channel or drainageway. Rundowns can also convey runoff from streets and parking lots into channels or storage facilities. The purpose of these structures is to minimize channel bank erosion from concentrated overland flow. All too frequently, rundowns are treated as an afterthought, and receive little, if any, design attention. As a result, failure is common, resulting in unsightliness and a maintenance burden.

7.1 Cross Sections

Typical types of channel rundowns are presented in Figure HS-17, Figure HS-18 and Figure HS-27.

7.2 Design Flow

The channel rundown should be designed to carry the full design flow of the channel or storm sewer upstream of it (see the RUNOFF chapter) or 1 cfs, whichever is greater.



Photograph HS-15—A failed rundown that relied upon a geotextile membrane for stability.

7.3 Flow Depth

The maximum depth at the design flow should be equal to the calculated flow depth using drawdown calculations for the design flow plus 6 inches of freeboard. Due to the typical profile of a channel rundown beginning with a flat slope and then dropping steeply into the channel or storage facility, the design depth of flow should be the computed critical depth for the design flow.

7.4 Outlet Configuration for Trickle Channel

The channel rundown outlet should enter the drainageway at the trickle channel flow line. Erosion protection of the opposite channel bank should be provided by a layer of buried, grouted, Type B18 boulders. The width of this riprap erosion protection should be at least three times the channel rundown width or pipe diameter. Riprap protection should extend up the opposite bank to the minor storm flow depth in the drainageway or 2 feet, whichever is greater. Rundowns discharging into storage facilities should have comparable scour protection at the outlet, typically in the form of buried, grouted, Type B18 boulders. A forebay upstream of a trickle channel sized in accordance with Volume 3 recommendations of this *Manual* can provide this energy dissipation.

7.5 Outlet Configuration for Wetland Channel

For a wetland channel or low-flow channel, the rundown must be carried to the edge of the wetland where grouted rock is placed to dissipate the kinetic energy so that rundown discharge velocities do not cause erosion of the wetland. A low tailwater basin is also suitable for this purpose.

7.6 Grouted Boulder Rundowns

Instead of a concrete rundown, a grouted boulder rundown illustrated in Figure HS-18 can be provided. At a minimum, the width of a grouted boulder rundown should equal the width of the upstream storm sewer. The rundown depth should start at about ¾ of the height of the upstream pipe at the pipe and taper down to a depth equal to the calculated drawdown depth of water along the rundown plus 9 inches of freeboard. To find the depth of flow use Manning's n from Figure HS-3b. This will require iteration to find the value n that matches the depth of flow. Use boulders equal to at least 1/2 the height of the pipe (see boulder classifications in Table MD-8 of the MAJOR DRAINAGE chapter) grouted in accordance with the recommendations of Section 4.2.1.2 of the MAJOR DRAINAGE chapter.

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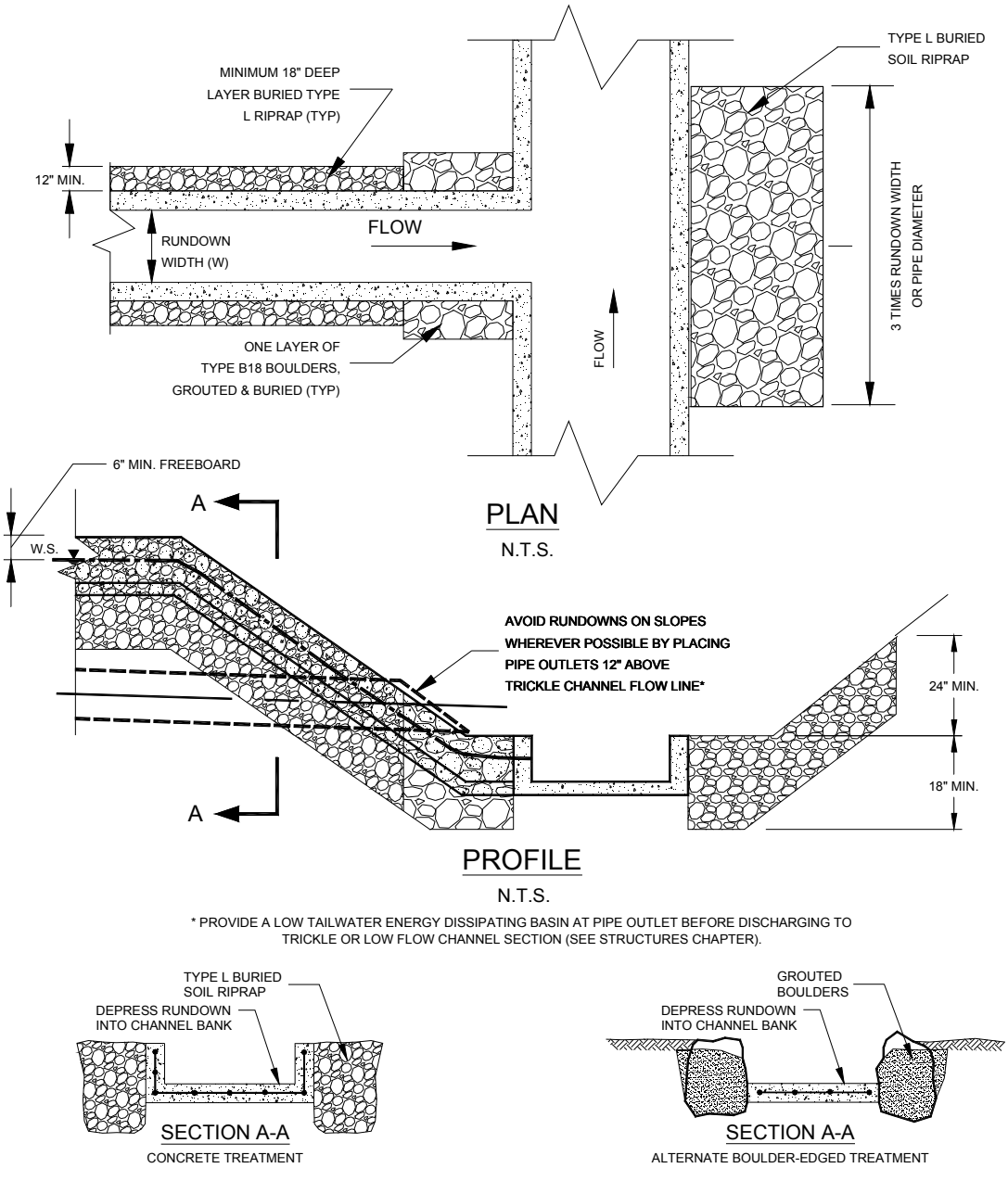

* Provide a low tailwater energy dissipating basin at end of pipe before discharging to trickle or low-flow channel section.

Figure HS-27—Rundown

8.0 MAINTENANCE

8.1 General

Maintenance of structures includes removing debris, excessive vegetation and excessive sediment. Replacing or realigning stones, repairing grout and concrete, and replacing warning signs are also items of maintenance that cannot be avoided under normal conditions. Refer to the District's Maintenance Eligibility Guidelines as contained on the CD version of this *Manual* for specific guidance on maintenance provisions for many of the structures addressed in this chapter. See the District's Web site (www.udfcd.org) for the latest updates to these guidelines.

8.2 Access

During the design process, attention must be given to providing for adequate maintenance access from one or both banks in accordance with current District regulations and guidelines.

8.3 Maintenance Optimization

Structures should be designed in accordance with public works policies related to minimizing operation and maintenance requirements.

9.0 BOATABLE DROPS

9.1 Introduction

Low-head dams or drop structures on a stream that includes boating should not present undue hydraulic hazards to boaters, maintenance workers or to the public. This is why some low-head dams and drop structures are retrofitted. This section outlines the approach for use in improving recreational boater safety.

9.2 Retrofitting Existing Structures

Retrofitting low-head dams and drop structures generally includes installing a stepped or sloped downstream structure face and suitable boat chute with upstream pilot rocks; eliminating sharp edges; and providing appropriate barriers, signing and accessible portages with take-out and put-in landings. A structure that is too high for the site may be replaced with two or more structures to reduce the drop at a single location.

Retrofitting boatable low-head dams or drop structures requires specific care to insure that the retrofit meets the objective of enhancing public safety. Hydraulic model tests are common for retrofitting of low-head dams and drop structures.

9.2.1 Downstream Face

A vertical or steep downstream face of a structure to be retrofitted may be corrected with a rock face having a slope of 10(H) to 1(V). Large rock or derrick stone is often used. The engineer may select a stepped face of either concrete or stone.

9.2.2 Boat Chute

Installing a boat chute to provide passage around or over the low-head dam or drop is desirable for boatable streams, even where the total drop may be only 3 feet or less. The boat chute may be combined with a relatively flat, sloping downstream face in many instances. Pilot rocks planted upstream of the boat chute signal the entrance to the boat chute.

9.2.3 Sharp Edges

Exposed sheet piling edges, sharp concrete edges, sharp rock protuberances, and angle-iron ends should be avoided in boatable stream structures.

9.2.4 Barriers and Signing

A range of barriers may be considered for use at structures to help keep watercraft from crests, intakes, and areas of highly turbulent flow. Barriers often include buoy lines. Warning signs should be placed upstream of structures at easily visible locations.



Photograph HS-16—The unsightly and hazardous 8-foot-high Brown Ditch weir was replaced with three low-head drop structures having a 10:1 downstream slope and a boat chute. The resulting improvement by the USACE has provided for safe, enjoyable recreational boating.

9.2.5 Portages

At many hydraulic structures, portages are provided to permit beginning boaters to bypass a boat chute or to avoid a more challenging hydraulic structure. Portages have take-outs and put-ins at appropriate locations combined with suitable signing.

9.3 Safety

Retrofitting hydraulic structures on boatable streams should be undertaken with an adequate standard of care related to public safety for boating. A retrofit often includes installation of anchor points and suitable access for use by rescue personnel (Wright, et al. 1995).

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10.0 STRUCTURE AESTHETICS, SAFETY AND ENVIRONMENTAL IMPACT

10.1 Introduction

Aesthetics, safety, overall integration with nearby land uses, and minimizing adverse environmental impacts are important aspects in the design of hydraulic structures. The planning, design, construction, and maintenance of hydraulic structures in an urban setting must include consideration of aesthetics, safety, and effects on the environment. Maximizing functional uses while improving visual quality and safety require good planning from the onset of the project and the coordinated efforts of owner/client, engineer, landscape architect, biologist, and planner.

10.2 Aesthetics and Environmental Impact

The combination and diversity of forms, lines, colors, and textures creates the visual experience. Material selection and placement of vegetation can provide visual character and create interesting spaces in and around hydraulic structures.



Photograph HS-17—Grouted sloping boulder drops can be built in series to create pleasing amenities and to provide stable and long-lived grade control structures.

Good planning may offer opportunities to minimize potentially adverse environmental impacts and maintain the natural habitat characteristics of the drainageway while fulfilling hydraulic, open space, and

recreation requirements. As discussed in detail in the POLICY, PLANNING, and MAJOR DRAINAGE chapters, multiple uses of flood control structures, open space, and parks have proven to be an effective land use combination. Such structures as channels, overflow structures, grade controls, energy dissipators, maintenance roads, and others can blend in with the park environment.

In natural and urbanized areas, the use of vegetation for bank protection and landscape treatment is effective. Bioengineering strategies that incorporate vegetation and natural materials can improve habitat for fish and wildlife, and create a pleasant environment, as discussed in the MAJOR DRAINAGE chapter.

Plant selection and placement around structures and channel features and use of planting that reduces erosion, dissipates residual energy, and does not create debris or local scour problems are fundamental to good aesthetics and environmental quality, as well as hydraulic function. Inclusion of high-maintenance plantings and spaces with planting that are inaccessible or require extensive care are not advisable, since they may end up poorly maintained, become a nuisance, and be unattractive.

In highly developed streamside areas, concrete plazas and edge treatment can be combined to increase channel efficiencies while providing reasonable access to the waterway area. Geometric and architectural forms, hard edges, and formal arrangements of materials are generally associated with urban settings. However, all of these features require sound engineering and evaluation of the structure stability and the effects on the hydraulic characteristics of the channel. Such facilities are usually well received by the public.

A variety of materials and finishes are available for use in hydraulic structures. Concrete color additives, exposed aggregates and form liners can be used to create visual interest to otherwise stark walls. The location of expansion and control joints in combination with edges can be used to help create attractive design detailing of headwalls and abutments.

Natural materials, rock, and vegetation can be used for bank stability and erosion protection while providing unusual interest, spatial character, and diversity. The placement and type of the rock can provide poor or pleasing appearance. A stepped boulder arrangement for drops, where there is a larger top horizontal surface, is usually an appealing placement that also improves hydraulics.

10.3 Safety

Design and construction of urban drainage facilities must account for potential public safety hazards. When planning and providing for recreation within public parks and open space, safety must always be considered, and safety for the public and maintenance workers should be incorporated. The design engineer must consider the variations in hydraulic jumps as they relate to the tailwater elevation as illustrated in Figure HS-28. Some hydraulic structures and drainage features offer an invitation to play; therefore, what is constructed should be made safe and attractive. While safety, to a reasonable extent, becomes the responsibility of the user, appropriate warning signage must be used. In some instances,

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fencing and emergency access and egress should be provided.

Safety requirements are usually defined by local government agencies. However, case-made law may define the responsibilities of involved parties. Risk and liability are important with respect to including signs, handrails, or barriers at steep slopes or vertical drop-offs as well as other safety related features. Signage should be provided at locations where public use is intended near hydraulic structures and where hazards are not obvious to the average person. For boatable waterways the standard of care should include avoidance of hazardous hydraulics such as reverse rollers and reverse flow eddies associated with hydraulic structures. When bicycle paths are incorporated with the construction of structures, there should be adequate directional and warning signs, sight distance, and avoidance of unannounced sharp turns and dropoffs.



Photograph HS-18—Warning signs can be used to help achieve public boating safety, but signs cannot in themselves serve as a substitute for an appropriate standard of care in the design of a reasonable grade control structures on a boatable waterway.

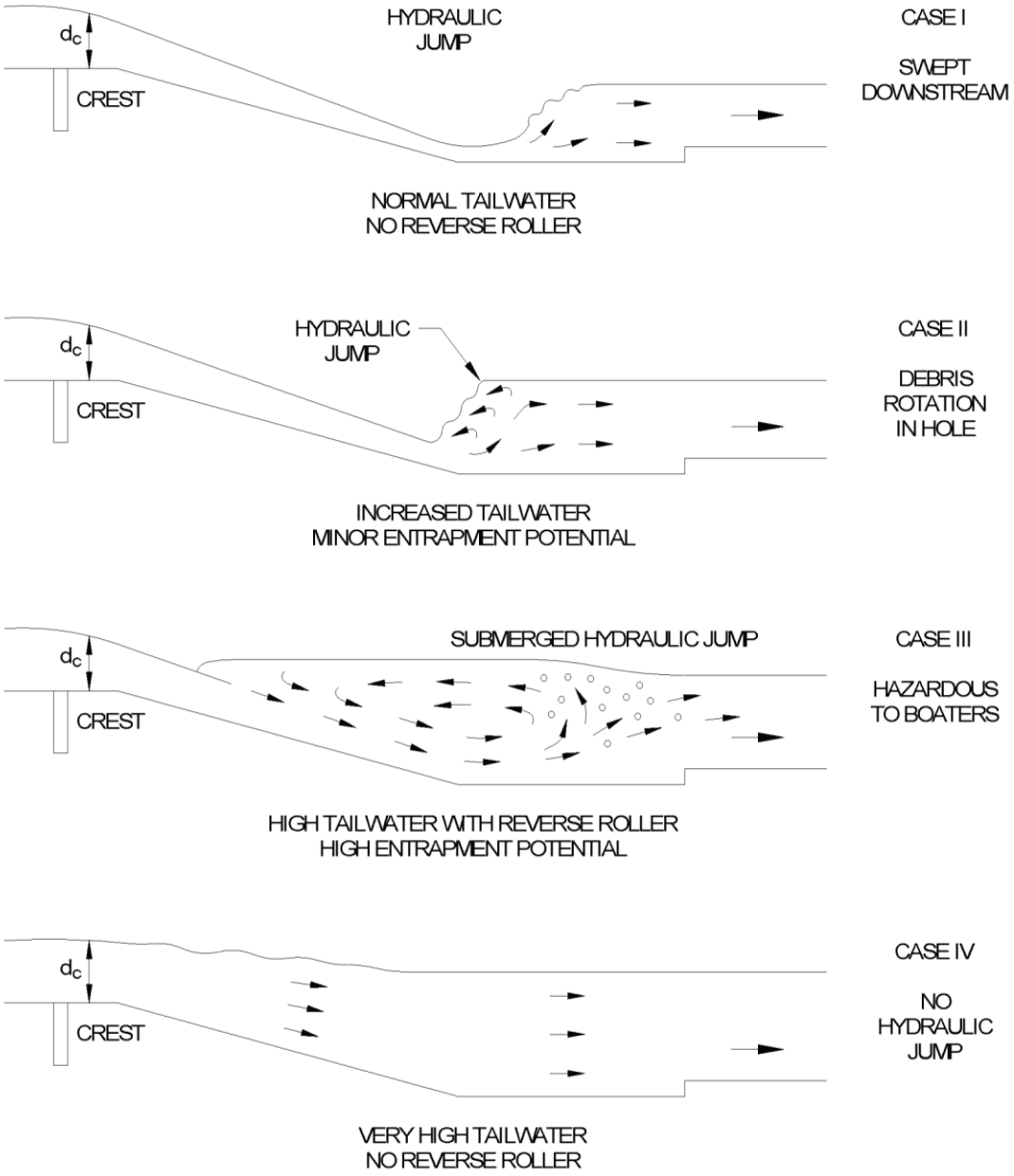

Figure HS-28—Hydraulic Jump Tailwater Stages as Related to Boating Hazards

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11.0 CHECKLIST

Criterion/Requirement (Note: Before work begins in a floodplain, obtain a floodplain development permit form local jurisdiction)	✓
Drop Structures (All Types)	
Simplified design or detailed hydraulic analysis	
Soils and seepage analysis	
Environmental permits	
High public usage or low public usage	
Likely downstream degradation or no likely downstream degradation	
Critical depth at crest	
Transition head loss	
Hydraulic roughness	
Hydraulic jump length and location	
Basin length	
Seepage control (need detailed analysis or provisions for drops taller than 5 feet)	
Individual force analysis	
Trickle and low-flow zone provisions	
Sloping Drop Height > 6 feet, Use Special Design	
Sloping Drop Height $\leq$ 6 feet, Used Simplified Design	
Vertical Drop	
Rock sizing	
Boatable channel, or not	
Froude number at toe	
Reverse roller evaluation	
Portages and warning signs, with peer review	
Non-Boatable Grouted Sloping Boulder Drops	
Waterway is not boatable	
Maximum design discharge less than 7,500 cfs	
Uniform size boulders as per Table HS-4	
Drop height less than 5 feet	
Vertical cutoff minimum depth at crest of 0.8 H_d or 4 feet	
Trickle or low-flow channel through crest	
Net downward force of 30 PSF	
Stilling basin depressed 1 to 2 feet	
Drop face slope at 4:1, or flatter	
Grouted rock approach of 8 feet	
Basin length of 25 feet for erosive soils, and 20 feet for non-erosive soils	
Large boulders in center basin	
Buried downstream riprap zone 2 H_d or 10 feet	
If drop height exceeds 5 feet, detailed hydraulic analysis used (see Section 2.3)	
Vertical Hard Basin Drops	
Waterway is not boatable	
Maximum drop height of 3 feet	
Low probability for public access (public safety concern for vertical drops)	
Drop number D_n defined	
Hydraulic jump length is 6 times Y_2	
Basin floor depressed minimum 1.5 feet	
Minimum boulder size of 1.5 feet	
Grout thickness minimum 10 inches	
Basin length of 25 feet minimum	
Riprap approach length of 10 feet	

Criterion/Requirement	✓
Baffle Chute Drops	
Waterway is not debris-prone	
Waterway is not boatable	
Minimum of 4 baffle rows	
Unit discharge maximum of 60 cfs/ft	
Sloping apron of 2:1 or less	
Buried and protected toe with 1.5 baffle rows	
Baffle height of $0.8D_c$	
Wall height $2.4D_c$	
Boatable Channel Drops	
Maximum drop height of 4 feet	
Froude number at toe < 1.5	
Reverse rollers avoided	
Downstream face slope 10:1	
Pilot rocks and signing	
Suitable portage facilities	
Peer review	
Low-Flow Check and Wetland Structures	
Dominant discharge computed	
Trickle channel maximum depth of 3 feet, or 5 feet downstream of check	
Lateral overflow protection	
Trickle channel cutoff extension of 5 to 10 feet into bank	
Wetland checks extended 10 feet into bank	
Maintain upstream wetland water table	
Impact Stilling Basin Outlet Structures	
Horizontal entrance pipe	
Basin width as per Figure HS-15	
Calculate hydraulic force	
Type M riprap downstream	
Sill wall minimum of 2 feet	
Low Tailwater Basin Outlet Structures	
Riprap size as per Figure HS-20	
Minimum riprap thickness of 1.75 D_{50}	
Minimum basin length as per Equations HS-18 or HS-19	
Minimum basin width of $4D$ or $W + 4H$	
Riprap slopes of 2H to 1V	
Pipe fasteners and cutoff wall	
Culvert Outlet Energy Dissipator (Outlet Structures)	
Scour and degradation control	
Tailwater depth adequacy	
Bridges (Preliminary Assessment Only)	
Avoid scour and deposition	
Minimize hydraulic interferences	
Water surface profiles and hydraulic gradients determined	
Backwater effect less than 1 foot	
Banks and bottom protected from higher velocity flows	
Check for supercritical flow	
Adequate freeboard if debris prone	
Backwater coefficient K	
Procedure 4.3 followed for design	

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Criterion/Requirement	✓
Boatable Drop Structures	
Downstream face at reasonable slope (e.g., 10H to 1V)	
Stepped face, or derrick stone	
Boat chute	
No sharp protrusions	
Pilot rocks	
Barriers if desirable	
Signing, informational and warning	
Portage with adequate signing	
Anchor points suitable for emergency rescue	
Peer review by whitewater expert	
General Items for Hydraulic Structures	
Visual quality	
Forms and lines	
Colors	
Vegetation	
Accessibility for maintenance; long-term maintenance assured	
Safety	
Public access	
Maintenance workers	
Hydraulic jump analysis with various tailwater elevations	
Signage	
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1.0 INTRODUCTION AND OVERVIEW

The function of a culvert is to convey surface water across a highway, railroad, or other embankment. In addition to the hydraulic function, the culvert must carry construction, highway, railroad, or other traffic and earth loads. Therefore, culvert design involves both hydraulic and structural design considerations. The hydraulic aspects of culvert design are set forth in this chapter.

Culverts are available in a variety of sizes, shapes, and materials. These factors, along with several others, affect their capacity and overall performance. Sizes and shapes may vary from small circular pipes to extremely large arch sections that are sometimes used in place of bridges.

The most commonly used culvert shape is circular, but arches, boxes, and elliptical shapes are used, as well. Pipe arch, elliptical, and rectangular shapes are generally used in lieu of circular pipe where there is limited cover. Arch culverts have application in locations where less obstruction to a waterway is a desirable feature, and where foundations are adequate for structural support. Box culverts can be designed to pass large flows and to fit nearly any site condition. A box or rectangular culvert lends itself more readily than other shapes to low allowable headwater situations since the height may be decreased and the span increased to satisfy the location requirements.

The material selected for a culvert is dependent upon various factors, such as durability, structural strength, roughness, bedding condition, abrasion and corrosion resistance, and water tightness. The more common culvert materials used are concrete and steel (smooth and corrugated).

Another factor that significantly affects the performance of a culvert is its inlet configuration. The culvert inlet may consist of a culvert barrel projecting from the roadway fill or mitered to the embankment slope. Other inlets have headwalls, wingwalls, and apron slabs or standard end sections of concrete or metal.

A careful approach to culvert design is essential, both in new land development and retrofit situations, because culverts often significantly influence upstream and downstream flood risks, floodplain management and public safety (Photograph CU-1). Culverts can be designed to provide beneficial upstream conditions (Photograph CU-2) and to avoid negative visual impact (Photograph CU-3).



Photograph CU-1—Public safety considerations for long culverts should be accounted for with culvert designs such as with this collapsible trash rack at a park-like location.



Photograph CU-2—Culverts can be designed to provide compatible upstream conditions for desirable wetland growth.



Photograph CU-3—Culverts can be integrated into the urban landscape without negative visual impact.

The information and references necessary to design culverts according to the procedure given in this chapter can be found in *Hydraulic Design of Highway Culverts*, Hydraulic Design Series No. 5 (FHWA 1985). Some of the charts and nomographs from that publication covering the more common requirements are given in this chapter. Nomographs and charts covering the range of applications

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commonly encountered in urban drainage are contained in Section 11.0. For special cases and larger sizes, the FHWA publication should be used.

1.1 Required Design Information

The hydraulic design of a culvert essentially consists of an analysis of the required performance of the culvert to convey flow from one side of the roadway (or other kind of embankment, such as a railroad) to the other. The designer must select a design flood frequency, estimate the design discharge for that frequency, and set an allowable headwater elevation based on the selected design flood and headwater considerations. These criteria are typically dictated by local requirements although state and federal standards will apply to relevant highway projects. The culvert size and type can be selected after the design discharge, controlling design headwater, slope, tailwater, and allowable outlet velocity have been determined.

The design of a culvert includes a determination of the following:

- Impacts of various culvert sizes and dimensions on upstream and downstream flood risks, including the implications of embankment overtopping.
- How will the proposed culvert/embankment fit into the relevant major drainageway master plan, and are there multipurpose objectives that should be satisfied?
- Alignment, grade, and length of culvert.
- Size, type, end treatment, headwater, and outlet velocity.
- Amount and type of cover.
- Public safety issues, including the key question of whether or not to include a safety/debris rack (Photograph CU-4).
- Pipe material.
- Type of coating (if required).
- Need for fish passage measures, in specialized cases.
- Need for protective measures against abrasion and corrosion.
- Need for specially designed inlets or outlets.
- Structural and geotechnical considerations, which are beyond the scope of this chapter.



Photograph CU-4—Public safety features such as the rack at the entrance to an irrigation ditch and the railing on the wingwalls must be considered.

1.1.1 Discharge

The discharge used in culvert design is usually estimated on the basis of a preselected storm recurrence interval, and the culvert is designed to operate within acceptable limits of risk at that flow rate. The design recurrence interval should be based on the criteria set forth in the POLICY chapter of this *Manual*. Specifically, refer to Tables DP-1 through DP-3 for street overtopping criteria.

1.1.2 Headwater

Culverts generally constrict the natural stream flow, which causes a rise in the upstream water surface. The elevation of this water surface is termed *headwater elevation*, and the total flow depth in the stream measured from the culvert inlet invert is termed *headwater depth*.

In selecting the design headwater elevation, the designer should consider the following:

- Anticipated upstream and downstream flood risks, for a range of return frequency events.
- Damage to the culvert and the roadway.
- Traffic interruption.
- Hazard to human life and safety.
- Headwater/Culvert Depth (HW/D) ratio.
- Low point in the roadway grade line.
- Roadway elevation above the structure.
- Elevation at which water will flow to the next cross drainage.

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- Relationship to stability of embankment that culvert passes through.

The headwater elevation for the design discharge should be consistent with the freeboard and overtopping criteria in the POLICY chapter of this *Manual* (Tables DP1 through DP-3). The designer should verify that the watershed divides are higher than the design headwater elevations. In flat terrain, drainage divides are often undefined or nonexistent and culverts should be located and designed for the least disruption of the existing flow distribution.

1.1.3 Tailwater

Tailwater is the flow depth in the downstream channel measured from the invert at the culvert outlet. It can be an important factor in culvert hydraulic design because a submerged outlet may cause the culvert to flow full rather than partially full.

A field inspection of the downstream channel should be made to determine whether there are obstructions that will influence the tailwater depth. Tailwater depth may be controlled by the stage in a contributing stream, headwater from structures downstream of the culvert, reservoir water surface elevations, or other downstream features.

1.1.4 Outlet Velocity

The outlet velocity of a highway culvert is the velocity measured at the downstream end of the culvert, and it is usually higher than the maximum natural stream velocity. This higher velocity can cause streambed scour and bank erosion for a limited distance downstream from the culvert outlet. Permissible velocities at the outlet will depend upon streambed type, and the kind of energy dissipation (outlet protection) that is provided.

If the outlet velocity of a culvert is too high, it may be reduced by changing the barrel roughness. If this does not give a satisfactory reduction, it may be necessary to use some type of outlet protection or energy dissipation device. Most culverts require adequate outlet protection, and this is a frequently overlooked issue during design.

Variations in shape and size of a culvert seldom have a significant effect on the outlet velocity. Slope and roughness of the culvert barrel are the principal factors affecting the outlet velocity.

2.0 CULVERT HYDRAULICS

2.1 Key Hydraulic Principles

For purposes of the following review, it is assumed that the reader has a basic working knowledge of hydraulics and is familiar with the Manning's, continuity and energy equations, which were presented in the MAJOR DRAINAGE chapter (terms are defined in that chapter):

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2} \quad \text{(CU-1)}$$

$$Q = v_1 A_1 = v_2 A_2 \quad \text{(CU-2)}$$

$$\frac{v^2}{2g} + \frac{p}{\gamma} + z + \text{losses} = \text{constant} \quad \text{(CU-3)}$$

2.1.1 Energy and Hydraulic Grade Lines

Figures CU-1 and CU-2 illustrate the energy grade line (EGL) and hydraulic grade line (HGL) and related terms.

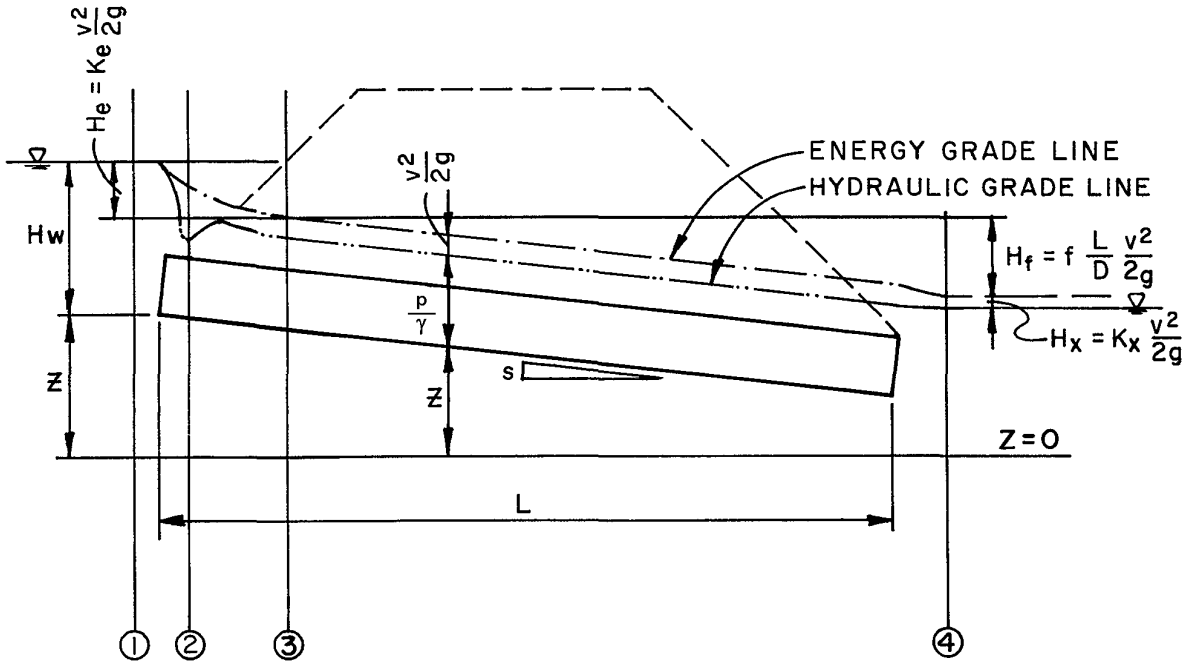

Figure CU-1—Definition of Terms for Closed Conduit Flow

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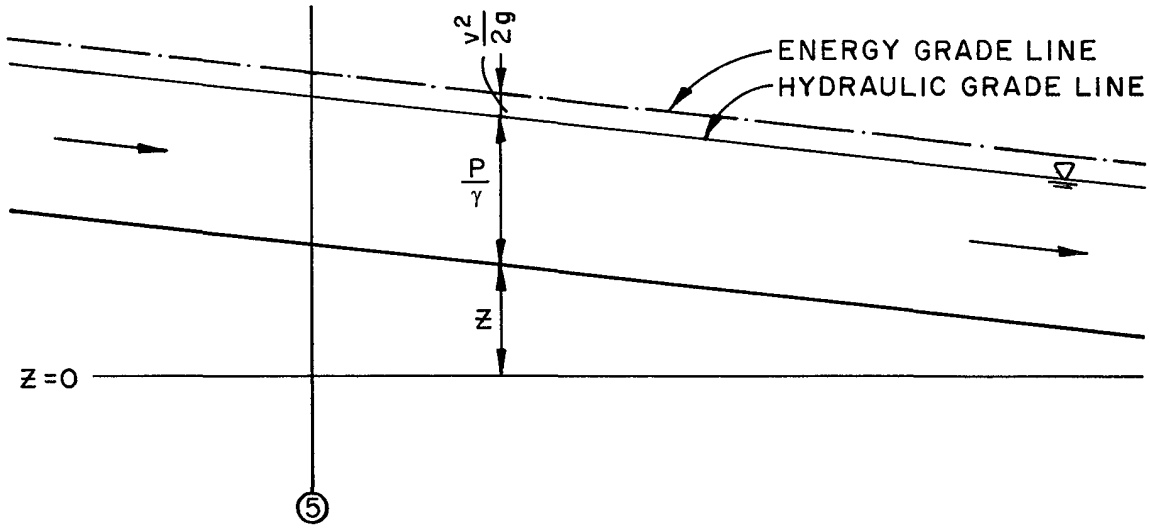

Figure CU-2—Definition of Terms for Open Channel Flow

The energy grade line, also known as the line of total head, is the sum of velocity head $v^2/2g$, the depth of flow or pressure head p/γ, and elevation above an arbitrary datum represented by the distance z. The energy grade line slopes downward in the direction of flow by an amount equal to the energy gradient H_L/L, where H_L equals the total energy loss over the distance L.

The hydraulic grade line, also known as the line of piezometric head, is the sum of the elevation z and the depth of flow or pressure head p/γ.

For open channel flow, the term p/γ is equivalent to the depth of flow and the hydraulic grade line is the same as the water surface. For pressure flow in conduits, p/γ is the pressure head and the hydraulic grade line falls above the top of the conduit as long as the pressure relative to atmospheric pressure is positive.

Approaching the entrance to a culvert as at Point 1 of Figure CU-1, the flow is essentially uniform and the hydraulic grade line and energy grade lines are almost the same. As water enters the culvert at the inlet, the flow is first contracted and then expanded by the inlet geometry causing a loss of energy at Point 2. As normal turbulent velocity distribution is reestablished downstream of the entrance at Point 3, a loss of energy is incurred through friction or form resistance. In short culverts, the entrance losses are likely to be high relative to the friction loss. At the exit, Point 4, an additional loss is incurred through turbulence as the flow expands and is retarded by the water in the downstream channel. At Point 5 of Figure CU-2 open channel flow is established and the hydraulic grade line is the same as the water surface.

There are two major types of flow conditions in culverts: (1) *inlet control* and (2) *outlet control*. For each

type of control, a different combination of factors is used to determine the hydraulic capacity of a culvert. The determination of actual flow conditions can be difficult; therefore, the designer must check for both types of control and design for the most adverse condition.

2.1.2 Inlet Control

A culvert operates with inlet control when the flow capacity is controlled at the entrance by these factors:

- Depth of headwater
- Cross-sectional area
- Inlet edge configuration
- Barrel shape

When a culvert operates under inlet control, headwater depth and the inlet edge configuration determine the culvert capacity with the culvert barrel usually flowing only partially full.

Inlet control for culverts may occur in two ways. The least common occurs when the headwater depth is not sufficient to submerge the top of the culvert and the culvert invert slope is supercritical as shown in Figure CU-3.

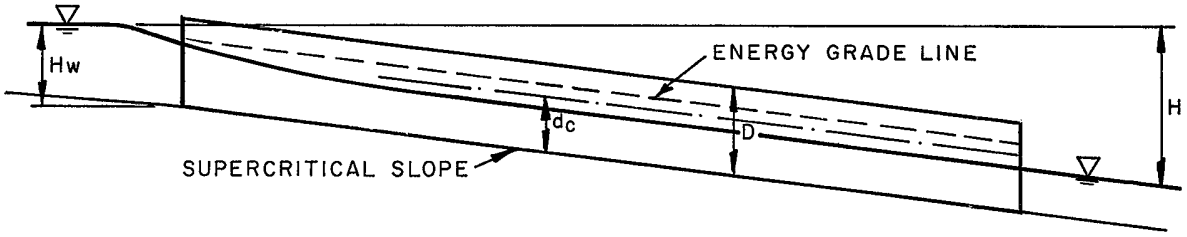

Figure CU-3—Inlet Control—Unsubmerged Inlet

The most common occurrence of inlet control is when the headwater submerges the top of the culvert (Figure CU-4), and the pipe does not flow full. A culvert flowing under inlet control is defined as a hydraulically short culvert.

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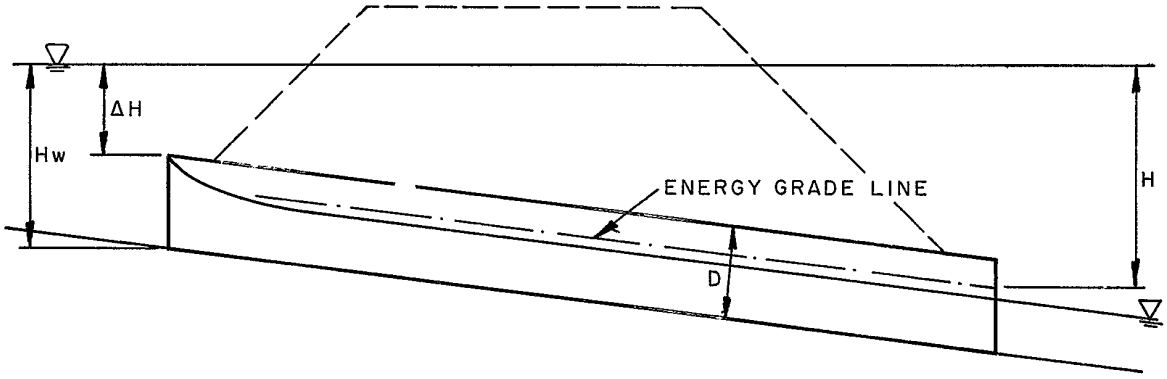

Figure CU-4—Inlet Control—Submerged Inlet

For a culvert operating with inlet control, the roughness, slope, and length of the culvert barrel and outlet conditions (including tailwater) are not factors in determining culvert hydraulic performance.

2.1.3 Outlet Control

If the headwater is high enough, the culvert slope sufficiently flat, and the culvert sufficiently long, the control will shift to the outlet. In outlet control, the discharge is a function of the inlet losses, the headwater depth, the culvert roughness, the culvert length, the barrel diameter, the culvert slope, and sometimes the tailwater elevation.

In outlet control, culvert hydraulic performance is determined by these factors:

- Depth of headwater
- Cross-sectional area
- Inlet edge configuration
- Culvert shape
- Barrel slope
- Barrel length
- Barrel roughness
- Depth of tailwater

Outlet control will exist under two conditions. The first and least common is that where the headwater is insufficient to submerge the top of the culvert, and the culvert slope is subcritical (Figure CU-5). The most common condition exists when the culvert is flowing full (Figure CU-6). A culvert flowing under outlet control is defined as a hydraulically long culvert.

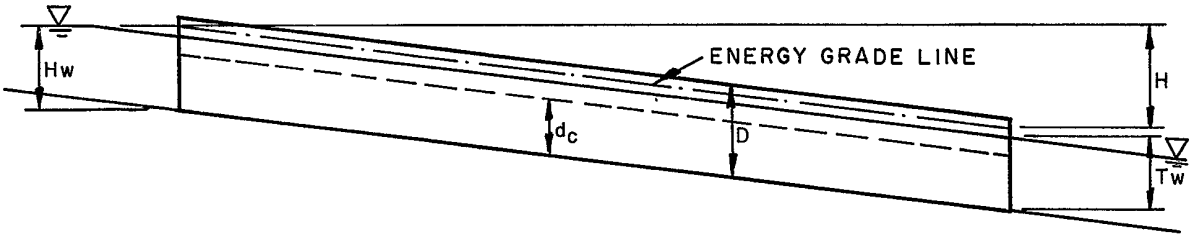

Figure CU-5—Outlet Control—Partially Full Conduit

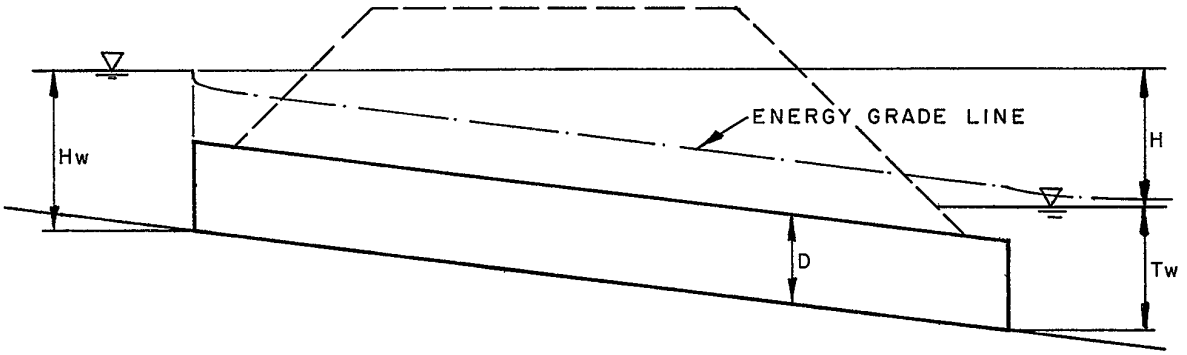

Figure CU-6—Outlet Control—Full Conduit

Culverts operating under outlet control may flow full or partly full depending on various combinations of the above factors. In outlet control, factors that may affect performance appreciably for a given culvert size and headwater are barrel length and roughness, and tailwater depth.

2.2 Energy Losses

In short conduits, such as culverts, the form losses due to the entrance can be as important as the friction losses through the conduit. The losses that must be evaluated to determine the carrying capacity of the culverts consist of inlet (or entrance) losses, friction losses and outlet (or exit) losses.

2.2.1 Inlet Losses

For inlet losses, the governing equations are:

$$Q = CA\sqrt{2gH} \quad \text{(CU-4)}$$

$$H_e = K_e \frac{v^2}{2g} \quad \text{(CU-5)}$$

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where:

Q = flow rate or discharge (cfs)

C = contraction coefficient (dimensionless)

A = cross-sectional area (ft^2)

g = acceleration due to gravity, 32.2 (ft/sec^2)

H = total head (ft)

H_e = head loss at entrance (ft)

K_e = entrance loss coefficient

v = average velocity (ft/sec)

2.2.2 Outlet Losses

For outlet losses, the governing equations are related to the difference in velocity head between the pipe flow and that in the downstream channel at the end of the pipe.

2.2.3 Friction Losses

Friction head loss for turbulent flow in pipes flowing full can be determined from the Darcy-Weisbach equation.

$$H_f = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right) \qquad \text{(CU-6)}$$

where:

H_f = frictional head loss (ft)

f = friction factor (dimensionless)

L = length of culvert (ft)

D = Diameter of culvert (ft)

v = average velocity (ft/sec)

g = acceleration due to gravity, 32.2 (ft/sec^2)

The friction factor has been determined empirically and is dependent on relative roughness, velocity, and barrel diameter. Moody diagrams can be used to determine the friction factor. The friction losses for culverts are often expressed in terms of Manning's n, which is independent of the size of pipe and depth of flow. Another common formula for pipe flow is the Hazen-Williams formula. Standard hydraulic texts should be consulted for limitations of these formulas.

3.0 CULVERT SIZING AND DESIGN

FHWA (1985) Hydraulic Design Series No. 5, *Hydraulic Design of Highway Culverts*, provides valuable guidance for the design and selection of drainage culverts. This circular explains inlet and outlet control and the procedure for designing culverts. Culvert design basically involves the trial and error method:

1. Select a culvert shape, type, and size with a particular inlet end treatment.
2. Determine a headwater depth from the relevant charts for both inlet and outlet control for the design discharge, the grade and length of culvert, and the depth of water at the outlet (tailwater).
3. Compare the largest depth of headwater (as determined from either inlet or outlet control) to the design criteria. If the design criteria are not met, continue trying other culvert configurations until one or more configurations are found to satisfy the design parameters.
4. Estimate the culvert outlet velocity and determine if there is a need for any special features such as energy dissipators, riprap protection, fish passage, trash/safety rack, etc.

3.1 Description of Capacity Charts

Figure CU-7 is an example of a capacity chart used to determine culvert size. Refer to this figure in the following discussion.

Each chart contains a series of curves, which show the discharge capacity per barrel in cfs for each of several sizes of similar culvert types for various headwater depths in feet above the invert of the culvert at the inlet. The invert of the culvert is defined as the low point of its cross section.

Each size is described by two lines, one solid and one dashed. The numbers associated with each line are the ratio of the length, L, in feet, to 100 times the slope, s, in feet per foot (ft/ft) ($100s$). The dashed lines represent the maximum $L/(100s)$ ratio for which the curves may be used without modification. The solid line represents the division between outlet and inlet control. For values of $L/(100s)$ less than that shown on the solid line, the culvert is operating under inlet control and the headwater depth is determined from the $L/(100s)$ value given on the solid line. The solid-line inlet-control curves are plotted from model test data. The dashed-line outlet-control curves were computed for culverts of various lengths with relatively flat slopes. Free outfall at the outlet was assumed; therefore, tailwater depth is assumed not to influence the culvert performance.

For culverts flowing under outlet control, the head loss at the entrance was computed using the loss coefficients previously given, and the hydraulic roughness of the various materials used in culvert construction was taken into account in computing resistance loss for full or part-full flow. The Manning's n values used for each culvert type ranged from 0.012 to 0.032.

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Except for large pipe sizes, headwater depths on the charts extend to 3 times the culvert height. Pipe arches and oval pipe show headwater up to 2.5 times their height since they are used in low fills. The dotted line, stepped across the charts, shows headwater depths of about twice the barrel height and indicates the upper limit of restricted use of the charts. Above this line the headwater elevation should be checked with the nomographs, which are described in Section 3.3.

The headwater depth given by the charts is actually the difference in elevation between the culvert invert at the entrance and the total head; that is, depth plus velocity head for flow in the approach channel. In most cases, the water surface upstream from the inlet is so close to this same level that the chart determination may be used as headwater depth for practical design purposes. Where the approach velocity is in excess of 3.0 ft/sec, the velocity head must be subtracted from the curve determination of headwater to obtain the actual headwater depth.

3.2 Use of Capacity Charts

1. The procedure for sizing the culvert is summarized below. Data can be tabulated in the Design Computation Form shown in Figure CU-8.
2. List design data: Q = flow or discharge rate (cfs), L = length of culvert (ft), allowable Hw = headwater depth (ft), s = slope of culvert (ft/ft), type of culvert barrel, and entrance.
3. Compute $L/(100s)$.
4. Enter the appropriate capacity chart in Section 11.0 with the design discharge, Q.
5. Find the $L/(100s)$ value for the smallest pipe that will pass the design discharge. If this value is above the dotted line in Figure CU-7, use the nomographs to check headwater conditions.
6. If $L/(100s)$ is less than the value of $L/(100s)$ given for the solid line, then the value of Hw is the value obtained from the solid line curve. If $L/(100s)$ is larger than the value for the dashed outlet control curve, then special measures must be taken, and the reader is referred to *Hydraulic Design of Highway Culverts* (FHWA 1985).
7. Check the Hw value obtained from the charts with the allowable Hw. If the indicated Hw is greater than the allowable Hw, then try the Hw elevation from the next largest pipe size.

3.3 Use of Nomographs

Examples of two nomographs for designing culverts are presented in Figures CU-9 and CU-10. The use of these nomographs is limited to cases where tailwater depth is higher than the critical depth in the culvert. The advantage of the capacity charts over the nomographs is that the capacity charts are direct where the nomographs are trial and error. The capacity charts can be used only when the flow passes

through critical depth at the outlet. When the critical depth at the outlet is less than the tailwater depth, the nomographs must be used; however, both give the same results where either of the two methods may be used. The procedure for design requires the use of both nomographs and is as follows (refer to Figures CU-9 and CU-10):

1. List design data: Q (cfs), L (ft), invert elevations in and out (ft), allowable Hw (ft), mean and maximum flood velocities in natural stream (ft/sec), culvert type and entrance type for first selection.

2. Determine a trial size by assuming a maximum average velocity based on channel considerations to compute the area, $A = Q/V$.

3. Find Hw for trial size culvert for inlet control and outlet control. For inlet control, Figure CU-9, connect a straight line through D and Q to scale (1) of the Hw/D scales and project horizontally to the proper scale, compute Hw and, if too large or too small, try another size before computing Hw for outlet control.

4. Next, compute the Hw for outlet control, Figure CU-10. Enter the graph with the length, the entrance coefficient for the entrance type, and the trial size. Connect the length scale and the culvert size scale with a straight line, pivot on the turning line, and draw a straight line from the design discharge on the discharge scale through the turning point to the head scale (head loss, H). Compute Hw from the equation:

$$Hw = H + h_o - Ls \qquad \text{(CU-7)}$$

where:

Hw = headwater depth (ft)

H = head loss (ft)

h_o = tailwater depth or elevation at the outlet of a depth equivalent to the location of the hydraulic grade line (ft)

L = length of culvert (ft)

s = slope of culvert (ft/ft)

For Tw greater than or equal to the top of the culvert, $h_o = Tw$, and for Tw less than the top of the culvert:

$$h_o = \frac{(d_c + D)}{2} \text{ or } T_w \text{ (whichever is greater)} \qquad \text{(CU-8)}$$

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where:

d_c = critical depth (ft)

Tw = tailwater depth (ft)

If Tw is less than d_c, the nomographs cannot be used, see *Hydraulic Design of Highway Culverts* (FHWA 1985) for critical depth charts.

5. Compare the computed headwaters and use the higher Hw to determine if the culvert is under inlet or outlet control. If outlet control governs and the Hw is unacceptable, select a larger trial size and find another Hw with the outlet control nomographs. Since the smaller size of culvert had been selected for allowable Hw by the inlet control nomographs, the inlet control for the larger pipe need not be checked.

3.4 Computer Applications, Including Design Spreadsheet

Although the nomographs discussed in this chapter are still used, engineers are increasingly designing culverts using computer applications. Among these applications are the FHWA's HY8 Culvert Analysis (Ginsberg 1987) and numerous proprietary applications. In addition, the District has developed spreadsheets to aid in the sizing and design of culverts. Both the UD-Culvert Spreadsheet application and FHWA's HY8 Culvert Analysis (Version 6.1) are located on the CD-ROM version of this *Manual*.

3.5 Design Considerations

Due to problems arising from topography and other considerations, the actual design of a culvert installation is more difficult than the simple process of sizing culverts. The information in the procedure for design that will be given is a guide to design since the problems encountered are too varied and too numerous to be generalized. However, the actual process presented should be followed to insure that some special problem is not overlooked. Several combinations of entrance types, invert elevations, and pipe diameters should be tried to determine the most economic design that will meet the conditions imposed by topography and engineering.

3.5.1 Design Computation Forms

The use of design computation forms is a convenient method to use to obtain consistent designs and promote cost-effectiveness. An example of such a form is Figure CU-8.

3.5.2 Invert Elevations

After determining the allowable headwater elevation, the tailwater elevation, and the approximate length, invert elevations must be assumed. Scour is not likely in an artificial channel such as a roadside ditch or a major drainage channel when the culvert has the same slope as the channel. To reduce the chance of failure due to scour, invert elevations corresponding to the natural grade should be used as a first trial.

For natural channels, the flow conditions in the channel upstream from the culvert should be investigated to determine if scour will occur.

3.5.3 Culvert Diameter

After the invert elevations have been assumed and using the design computation forms (e.g., Figure CU-8), the capacity charts (e.g., Figure CU-7), and the nomographs, the diameter of pipe that will meet the headwater requirements should be determined. Since small diameter pipes are often plugged by sediment and debris, it is recommended that pipe smaller than 18 inches not be used for any drainage where this *Manual* applies. Since the pipe roughness influences the culvert diameter, both concrete and corrugated metal pipe should be considered in design, if both will satisfy the headwater requirements.

3.5.4 Limited Headwater

If there is insufficient headwater elevation to obtain the required discharge, it is necessary to oversize the culvert barrel, lower the inlet invert, use an irregular cross section, or use any combination of the preceding.

If the inlet invert is lowered, special consideration must be given to scour. The use of gabions or concrete drop structures, riprap, and headwalls with apron and toe walls should be investigated and compared to obtain the proper design.

3.6 Culvert Outlet

The outlet velocity must be checked to determine if significant scour will occur downstream during the major storm. If scour is indicated (and this will normally be the case), refer to Section 7.0 of the MAJOR DRAINAGE chapter (“Protection Downstream of Culverts”) and to the HYDRAULIC STRUCTURES chapter for guidance on outfall protection. District maintenance staff have observed that inadequate culvert outlet protection is one of the more common problems within the District. Short-changing outlet protection is no place to economize during design and construction because downstream channel degradation can be significant and the culvert outlet can be undermined.

3.7 Minimum Slope

To minimize sediment deposition in the culvert, the culvert slope must be equal to or greater than the slope required to maintain a minimum velocity as described in the MAJOR DRAINAGE and STREETS/INLETS/STORM SEWERS chapters. The slope should be checked for each design, and if the proper minimum velocity is not obtained, the pipe diameter may be decreased, the slope steepened, a smoother pipe used, or a combination of these may be used.

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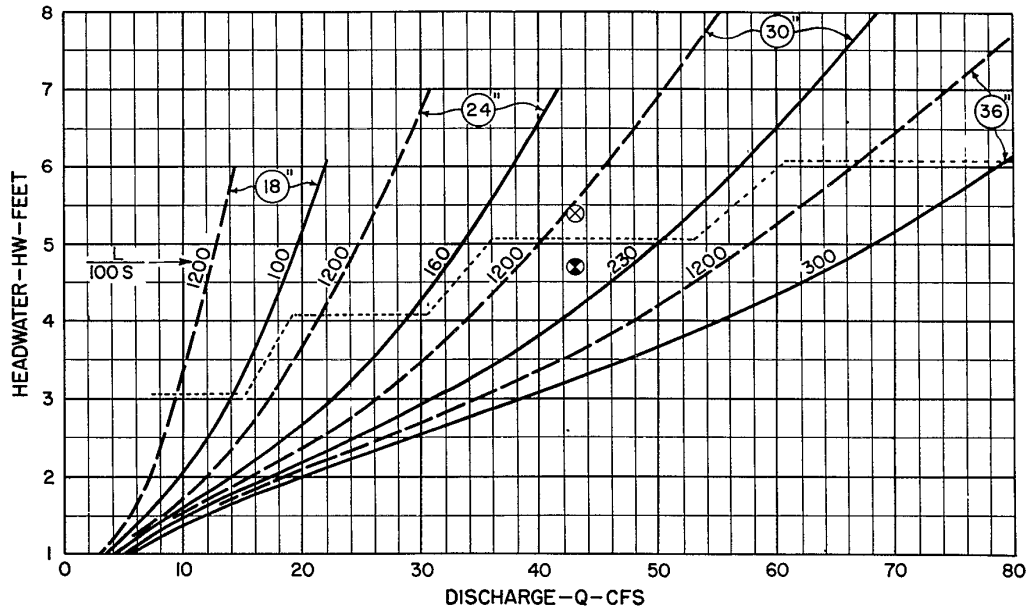

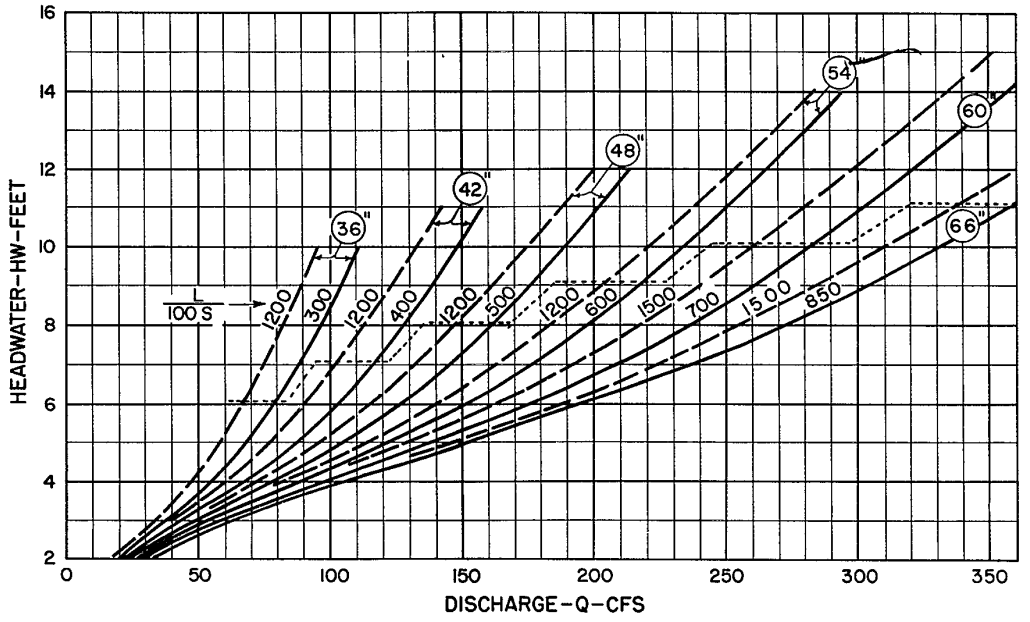

From BPR
EXAMPLE
⊗ GIVEN:
43 CFS ; AHW = 5.4 FT.
L = 120 FT.; S_o = 0.002

⊠ SELECT 30"
HW = 4.7 FT.

Figure CU-7—Culvert Capacity Chart—Example

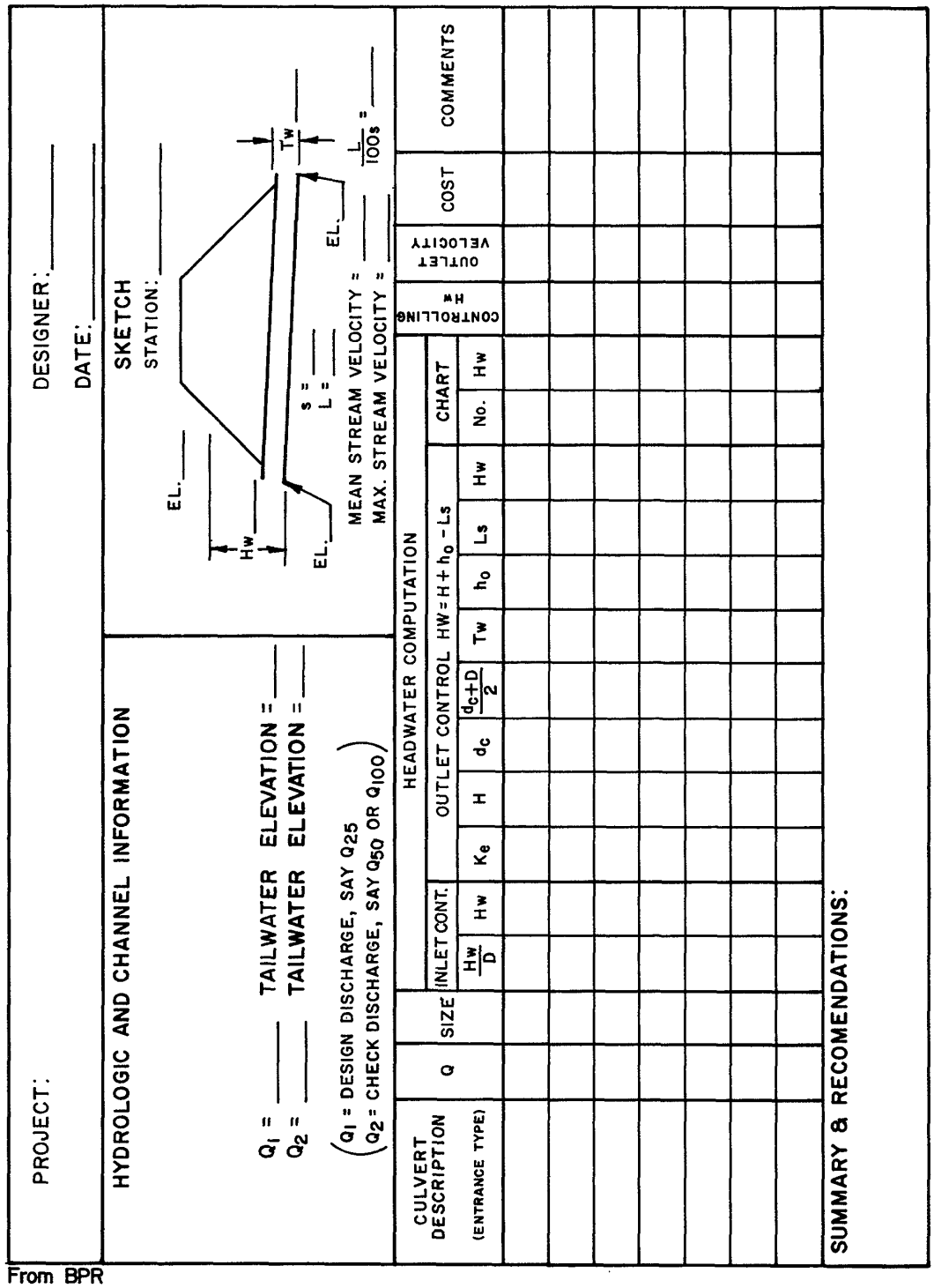

Figure CU-8—Design Computation for Culverts—Blank Form

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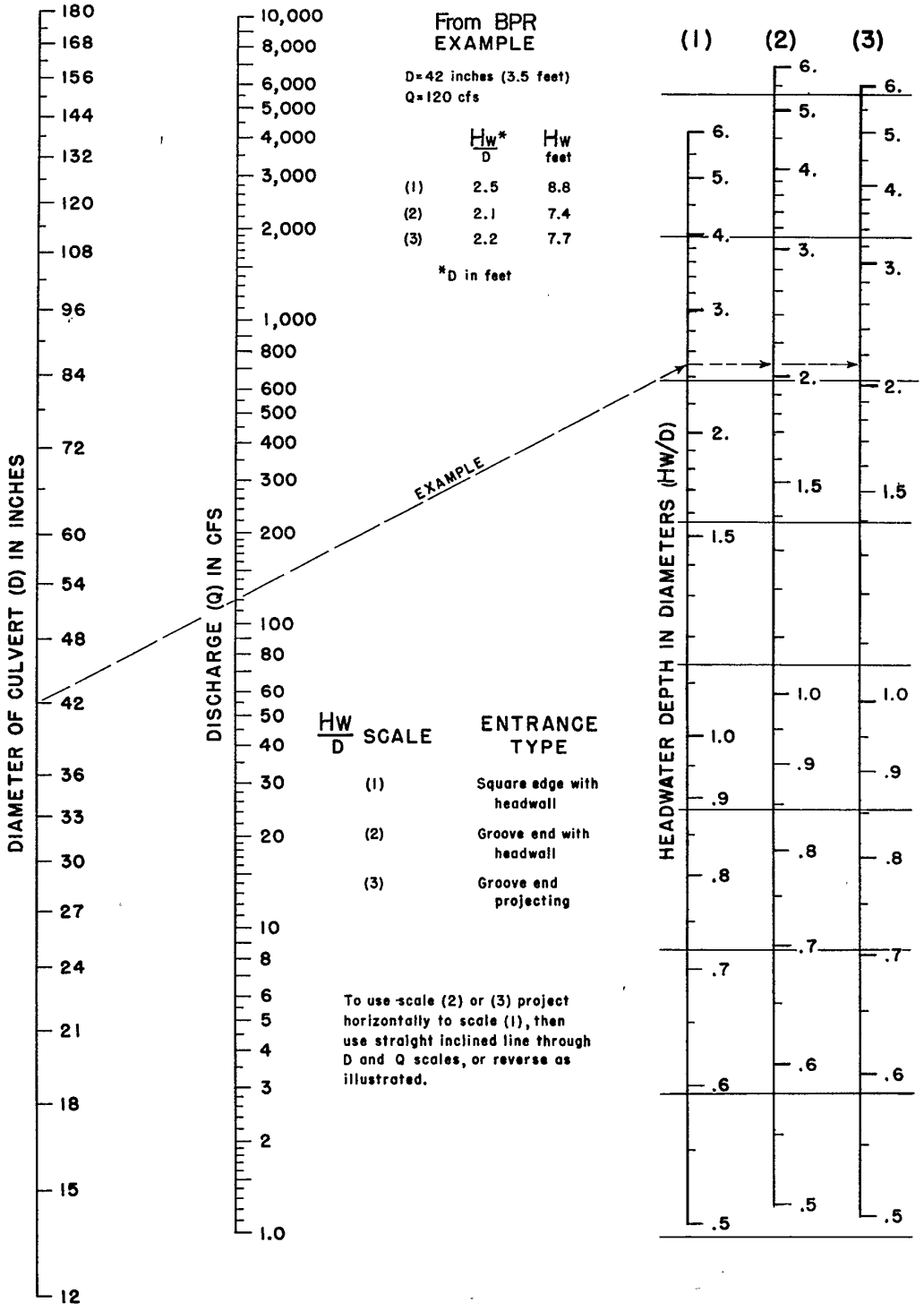

Figure CU-9—Inlet Control Nomograph—Example

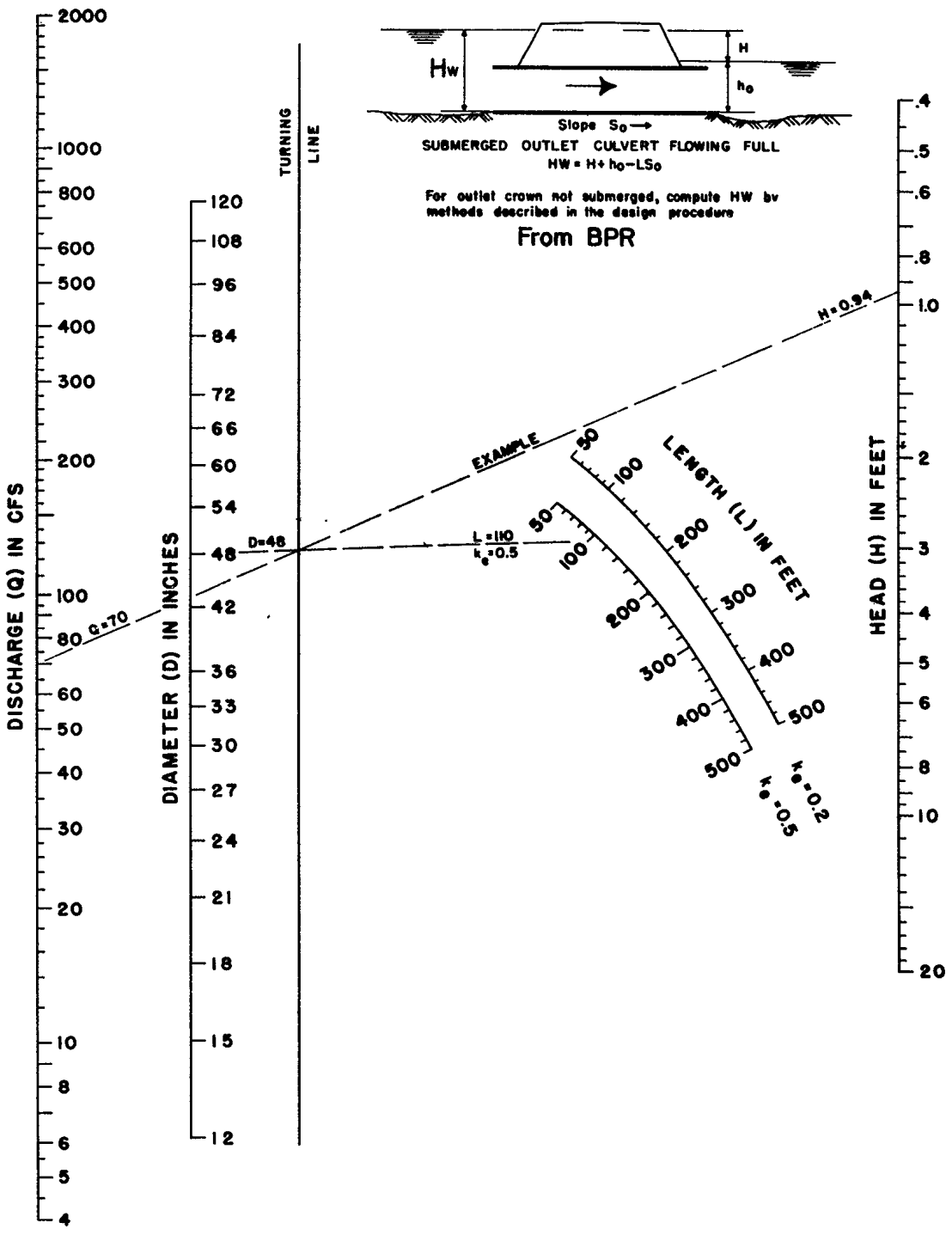

Figure CU-10—Outlet Control Nomograph—Example

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4.0 CULVERT INLETS

A fact often overlooked is that a culvert cannot carry any more water than can enter the inlet. Frequently culverts and open channels are carefully designed with full consideration given to slope, cross section, and hydraulic roughness, but without regard to the inlet limitations. Culvert designs using uniform flow equations rarely carry their design capacity due to limitations imposed by the inlet.

The design of a culvert, including the inlet and the outlet, requires a balance between cost, hydraulic efficiency, purpose, and topography at the proposed culvert site. Where there is sufficient allowable headwater depth, a choice of inlets may not be critical, but where headwater depth is limited, where erosion is a problem, or where sedimentation is likely, a more efficient inlet may be required to obtain the necessary discharge for the culvert.

The primary purpose of a culvert is to convey flows. A culvert may also be used to restrict flow, that is, to discharge a controlled amount of water while the area upstream from the culvert is used for detention storage to reduce a storm runoff peak. For this case, an inefficient inlet may be the most desirable choice.

The inlet types described in this chapter may be selected to fulfill either of the above requirements depending on the topography or conditions imposed by the designer. The entrance coefficient, K_e, as defined by Equation CU-5, is a measure of the hydraulic efficiency at the inlet, with lower valves indicating greater efficiency. Inlet coefficients recommended for use are given in Table CU-1.

Table CU-1—Inlet Coefficients For Outlet Control

Type of Entrance	Entrance Coefficient, K_e
1. Pipe entrance with headwall	
Grooved edge	0.20
Rounded edge (0.15D radius)	0.15
Rounded edge (0.25D radius)	0.10
Square edge (cut concrete and CMP)	0.40
2. Pipe entrance with headwall & 45° wingwall	
Grooved edge	0.20
Square edge	0.35
3. Headwall with parallel wingwalls spaced 1.25D apart	
Grooved edge	0.30
Square edge	0.40
4. Special inlets—see Section 4.3	
5. Projecting Entrance	
Grooved edge	0.25
Square edge	0.50
Sharp edge, thin wall	0.90

4.1 Projecting Inlets

Projecting inlets vary greatly in hydraulic efficiency and adaptability to requirements with the type of pipe material used. Figure CU-11 illustrates this type of inlet.

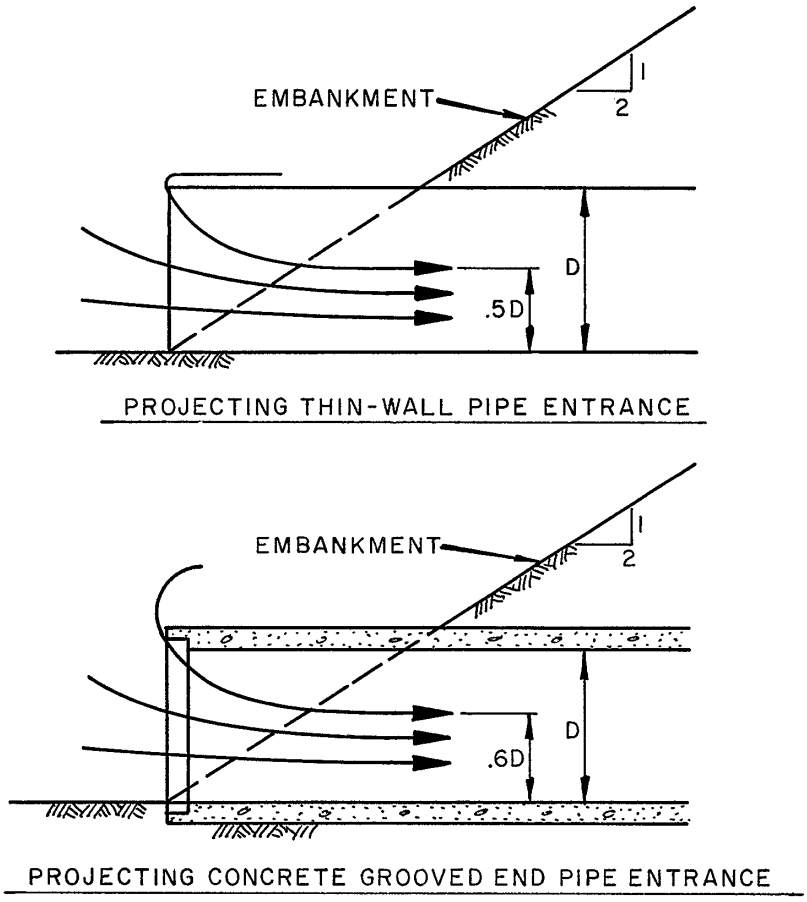

Figure CU-11—Common Projecting Culvert Inlets

The primary advantage of projecting inlets is relatively low cost. Because projecting inlets are susceptible to damage due to maintenance of embankment and roadways and due to accidents, the adaptability of this type of entrance to meet the engineering and topographical demands varies with the type of material used.

Corrugated metal pipe projecting inlets have limitations which include low efficiency, damage which may result from maintenance of the channel and the area adjacent to the inlet, and restrictions on the ability of maintenance crews to work around the inlet. The hydraulic efficiency of concrete-grooved or bell-end pipe is good and, therefore, the only restriction placed on the use of concrete pipe for projecting inlets is

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the requirement for maintenance of the channel and the embankment surrounding the inlet. Where equipment will be used to maintain the embankment around the inlet, it is not recommended that a projecting inlet of any type be used.

4.1.1 Corrugated Metal Pipe

A projecting entrance of corrugated metal pipe is equivalent to a sharp-edged entrance with a thin wall and has an entrance coefficient of about 0.9.

4.1.2 Concrete Pipe

Bell-and-spigot concrete pipe or tongue-and-groove concrete pipe with the bell end or grooved end used as the inlet section are quite efficient hydraulically, having an entrance coefficient of about 0.25. For concrete pipe that has been cut, the entrance is square edged, and the entrance coefficient is about 0.5.

4.2 Inlets with Headwalls

Headwalls may be used for a variety of reasons, including increasing the efficiency of the inlet, providing embankment stability, and providing embankment protection against erosion. The relative efficiency of the inlet varies with the pipe material used. Figure CU-12 illustrates a headwall with wingwalls.

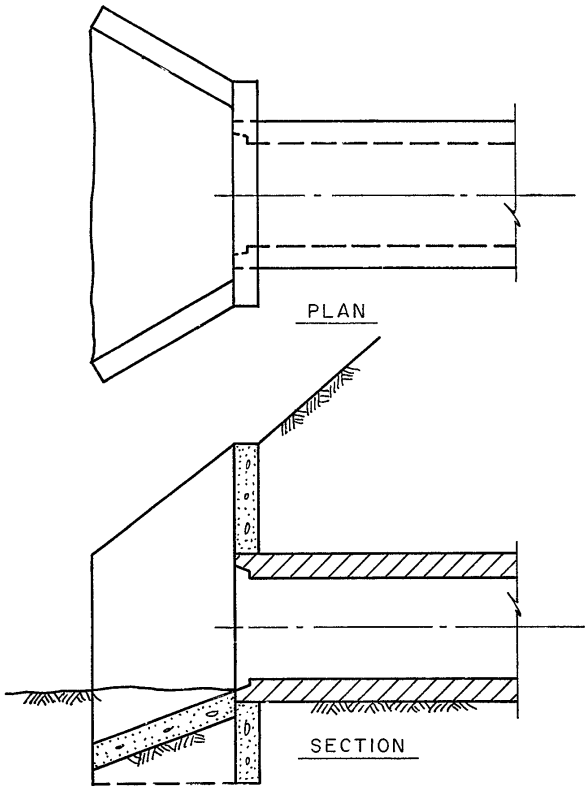

Figure CU-12—Inlet With Headwall and Wingwalls

4.2.1 Corrugated Metal Pipe

Corrugated metal pipe in a headwall is essentially a square-edged entrance with an entrance coefficient of about 0.4. The entrance losses may be reduced by rounding the entrance. The entrance coefficient may be reduced to 0.15 for a rounded edge with a radius equal to 0.15 times the culvert diameter, and to 0.10 for rounded edge with a radius equal to 0.25 times the diameter of the culvert.

4.2.2 Concrete Pipe

For tongue-and-groove or bell-end concrete pipe, little increase in hydraulic efficiency is realized by adding a headwall. The primary reason for using headwalls is for embankment protection and for ease of maintenance. The entrance coefficient is equal to about 0.2 for grooved and bell-end pipe, and equal to 0.4 for cut concrete pipe.

4.2.3 Wingwalls

Wingwalls are used where the side slopes of the channel adjacent to the entrance are unstable and where the culvert is skewed to the normal channel flow. Little increase in hydraulic efficiency is realized with the use of wingwalls, regardless of the pipe material used and, therefore, the use should be justified for reasons other than an increase in hydraulic efficiency. Figure CU-13 illustrates several cases where wingwalls are used. For parallel wingwalls, the minimum distance between wingwalls should be at least 1.25 times the diameter of the culvert pipe.

4.2.4 Aprons

If high headwater depths are to be encountered, or if the approach velocity of the channel will cause scour, a short channel apron should be provided at the toe of the headwall. This apron should extend at least one pipe diameter upstream from the entrance, and the top of the apron should not protrude above the normal streambed elevation.

Culverts with wingwalls should be designed with a concrete apron extending between the walls. Aprons must be re

inforced to control cracking. As illustrated in Figure CU-13, the actual configuration of the wingwalls varies according to the direction of flow and will also vary according to the topographical requirement placed upon them.

For conditions where scour may be a problem due to high approach velocities and special soil conditions, such as alluvial soils, a toe wall is often desirable for apron construction.

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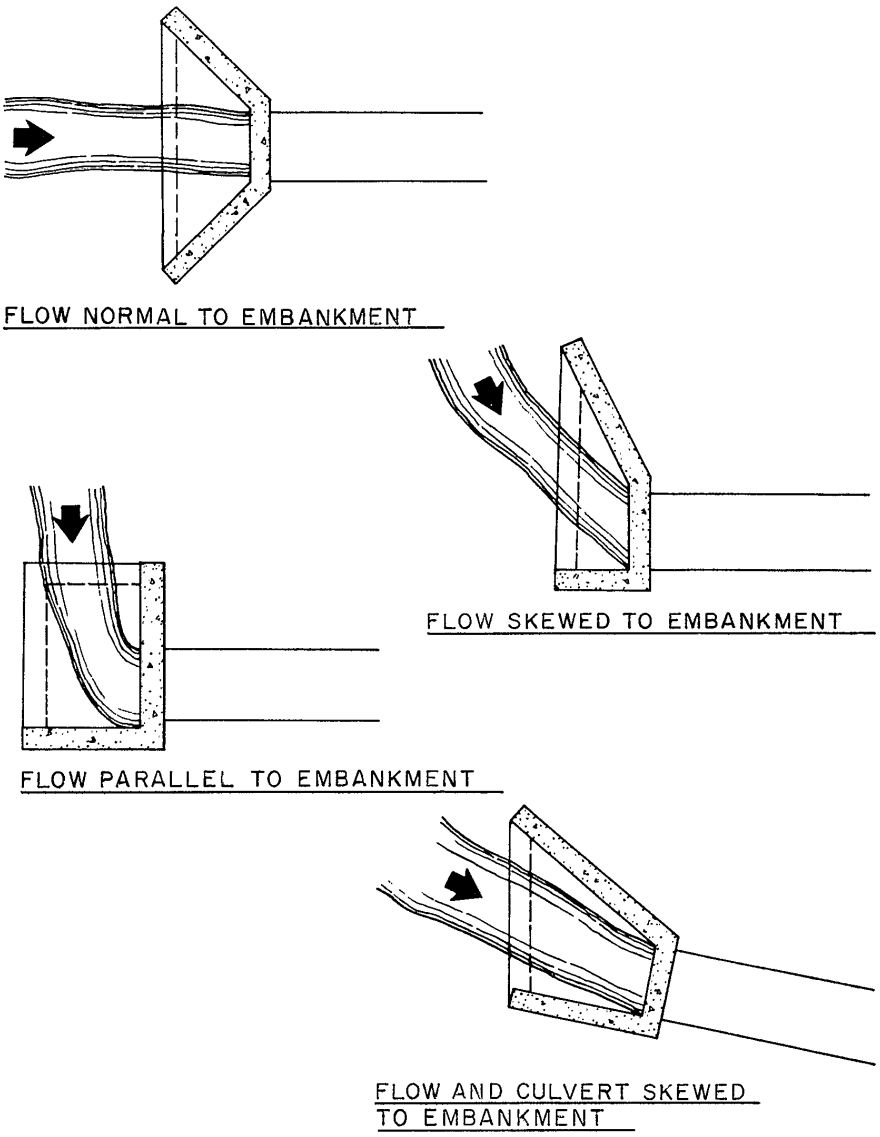

Figure CU-13—Typical Headwall-Wingwall Configurations

4.3 Special Inlets

There is a great variety of inlets other than the common ones described. Among these are special end-sections, which serve as both outlets and inlets and are available for both corrugated metal pipe and concrete pipe. Because of the difference in requirements due to pipe materials, the special end-sections will be discussed independently according to pipe material, and mitered inlets will also be considered.

4.3.1 Corrugated Metal Pipe

Special end-sections for corrugated metal pipe add little to the overall cost of the culvert and have the following advantages:

1. Less maintenance around the inlet.
2. Less damage from maintenance work and from accidents compared to a projecting entrance.
3. Increased hydraulic efficiency. When using design charts, as discussed in Section 3.0, charts for a square-edged opening for corrugated metal pipe with a headwall may be used.

4.3.2 Concrete Pipe

As in the case of corrugated metal pipe, these special end-sections may aid in increasing the embankment stability or in retarding erosion at the inlet. They should be used where maintenance equipment must be used near the inlet or where, for aesthetic reasons, a projecting entrance is considered too unsightly.

The hydraulic efficiency of this type of inlet is dependent on the geometry of the end-section to be used. Where the full contraction to the culvert diameter takes place at the first pipe section, the entrance coefficient, K_e, is equal to 0.5, and where the full contraction to the culvert diameter takes place in the throat of the end-section, the entrance coefficient, K_e, is equal to 0.25.

4.3.3 Mitered Inlets

The use of this entrance type is predominantly with corrugated metal pipe and its hydraulic efficiency is dependent on the construction procedure used. If the embankment is not paved, the entrance, in practice, usually does not conform to the side slopes, giving essentially a projecting entrance with K_e = 0.9. If the embankment is paved, a sloping headwall is obtained with K_e = 0.60 and, by beveling the edges, K_e = 0.50.

Uplift is an important factor for this type entrance. It is not good practice to use unpaved embankment slopes where a mitered entrance may be submerged to an elevation one-half the diameter of the culvert above the top of the pipe.

4.3.4 Long Conduit Inlets

Inlets are important in the design of culverts for road crossings and other short sections of conduit; however, they are even more significant in the economical design of long culverts and pipes. Unused capacity in a long conduit will result in wasted investment. Long conduits are costly and require detailed engineering, planning, and design work. The inlets to such conduits are extremely important to the functioning of the conduit and must receive special attention.

Most long conduits require special inlet considerations to meet the particular hydraulic characteristics of

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the conduit. Generally, on larger conduits, hydraulic model testing will result in better and less costly inlet construction.

4.4 Improved Inlets

Inlet edge configuration is one of the prime factors influencing the performance of a culvert operating under inlet control. Inlet edges can cause a severe contraction of the flow, as in the case of a thin edge, projecting inlet. In a flow contraction, the effective cross-sectional area of the barrel may be reduced to about one-half of the actual available barrel area. As the inlet configuration is improved, the flow contraction is reduced, thus improving the performance of the culvert.

A tapered inlet is a flared culvert inlet with an enlarged face section and a hydraulically efficient throat section. Tapered inlets improve culvert performance by providing a more efficient control section (the throat). However, tapered inlets are not recommended for use on culverts flowing under outlet control because the simple beveled edge is of equal benefit. The two most common improved inlets are the side-tapered inlet and the slope-tapered inlet (Figure CU-14). FHWA (1985) *Hydraulic Design of Highway Culverts* provides guidance on the design of improved inlets.

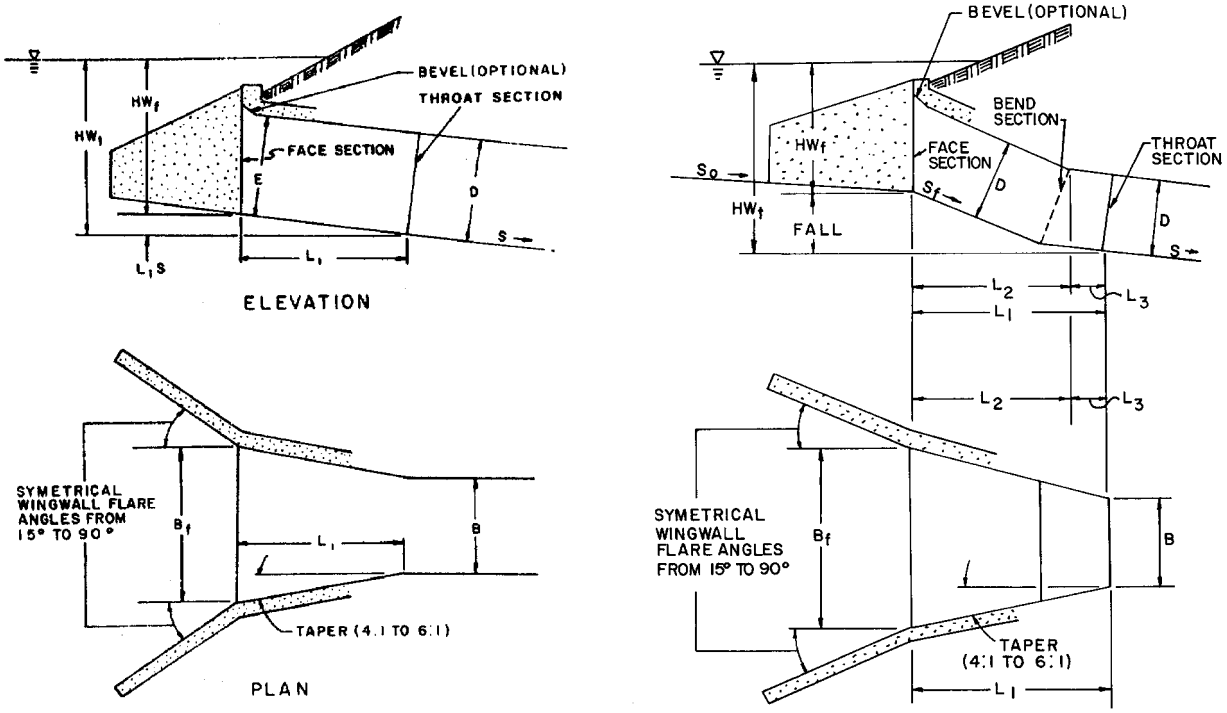

Figure CU-14—Side-Tapered and Slope-Tapered Improved Inlets

5.0 INLET PROTECTION

Inlets on culverts, especially on culverts to be installed in live streams, should be evaluated relative to debris control and buoyancy. These topics are addressed in this section, while broader discussion of the advantages and disadvantages of trash/safety racks is provided in Section 8.0.

5.1 Debris Control

Accumulation of debris at a culvert inlet can result in the culvert not performing as designed. The consequences may be damages from inundation of the road and upstream property. The designer has three options for coping with the debris problem:

1. Retain the debris upstream of the culvert.
2. Attempt to pass the debris through the culvert.
3. Install a bridge.

If the debris is to be retained by an upstream structure or at the culvert inlet, frequent maintenance may be required. The design of a debris control structure should include a thorough study of the debris problem.

The following are among the factors to be considered in a debris study:

- Type of debris
- Quantity of debris
- Expected changes in type and quantity of debris due to future land use
- Stream flow velocity in the vicinity of culvert entrance
- Maintenance access requirements
- Availability of storage
- Maintenance plan for debris removal
- Assessment of damage due to debris clogging, if protection is not provided

Hydraulic Engineering Circular No. 9, *Debris Control Structure*s (FHWA 1971), should be used when designing debris control structures.

5.2 Buoyancy

The forces acting on a culvert inlet during flows are variable and indeterminate. When a culvert is

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functioning with inlet control, an air pocket begins just inside the inlet that creates a buoyant effect when the inlet is submerged. The buoyancy forces increase with an increase in headwater depth under inlet control conditions. These forces, along with vortexes and eddy currents, can cause scour, undermine culvert inlets, and erode embankment slopes, thereby making the inlet vulnerable to failure, especially with deep headwater.

In general, installing a culvert in a natural stream channel constricts the normal flow. The constriction is accentuated when the capacity of the culvert is impaired by debris or damage.

The large unequal pressures resulting from inlet constriction are in effect buoyant forces that can cause entrance failures, particularly on corrugated metal pipe with mitered, skewed, or projecting ends. The failure potential will increase with steepness of the culvert slope, depth of the potential headwater, flatness of the fill slope over the upstream end of the culvert, and the depth of the fill over the pipe.

Anchorage at the culvert entrance helps to protect against these failures by increasing the deadload on the end of the culvert, protecting against bending damage, and by protecting the fill slope from the scouring action of the flow. Providing a standard concrete headwall or endwall helps to counteract the hydrostatic uplift and to prevent failure due to buoyancy.

Because of a combination of high head on the outside of the inlet and the large region of low pressure on the inside of the inlet due to separation, a large bending moment is exerted on the end of the culvert, which may result in failure. This problem has been noted in the case of culverts under high fills, on steep slopes, and with projecting inlets. Where upstream detention storage requires headwater depth in excess of 20 feet, reducing the culvert size is recommended rather than using the inefficient projecting inlet to reduce discharge.

6.0 OUTLET PROTECTION

Scour at culvert outlets is a common occurrence. It must be accounted for, as discussed below and in the HYDRAULIC STRUCTURES and MAJOR DRAINAGE chapters. The natural channel flow is usually confined to a lesser width and greater depth as it passes through a culvert barrel. An increased velocity results with potentially erosive capabilities as it exits the barrel. Turbulence and erosive eddies form as the flow expands to conform to the natural channel. However, the velocity and depth of flow at the culvert outlet and the velocity distribution upon reentering the natural channel are not the only factors that need consideration.

The characteristics of the channel bed and bank material, velocity, and depth of flow in the channel at the culvert outlet, and the amount of sediment and other debris in the flow are all contributing factors to scour potential. Due to the variation in expected flows and the difficulty in evaluating some of these factors, scour prediction is not a very exact science.

Scour in the vicinity of a culvert outlet can be classified into two separate types called local scour and general stream degradation.

6.1 Local Scour

Local scour is typified by a scour hole produced at the culvert outlet. This is the result of high exit velocities, and the effects extend only a limited distance downstream.

Coarse material scoured from the circular or elongated hole is deposited immediately downstream, often forming a low bar. Finer material is transported further downstream. The dimensions of the scour hole change due to sedimentation during low flows and the varying erosive effects of storm events. The scour hole is generally deepest during passage of the peak flow. Methods for predicting scour hole dimensions are found in *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA 1983 and 2000).

6.2 General Stream Degradation

General stream degradation is a phenomenon that is independent of culvert performance. Natural causes produce a lowering of the streambed over time. The identification of a degrading stream is an essential part of the original site investigation. This subject is discussed in the MAJOR DRAINAGE chapter.

Both local and general scour can occur simultaneously at a culvert outlet. Protection against scour at culvert outlets varies from limited riprap placement to complex and expensive energy dissipation devices (Photograph CU-5). At some locations, use of a rougher culvert material may alleviate the need for a special outlet protection device. Pre-formed scour holes (approximating the configuration of naturally formed holes) dissipate energy while providing a protective lining to the streambed.

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Photograph CU-5—Energy dissipation and outlet protection are essential to promote channel stability.

As discussed in the HYDRAULIC STRUCTURES chapter and in Section 7.0 of the MAJOR DRAINAGE chapter, riprapped channel expansions and concrete aprons protect the channel and redistribute or spread the flow. Barrel outlet expansions operate in a similar manner. Headwalls and cutoff walls protect the integrity of the fill. When outlet velocities are high enough to create excessive downstream problems, consideration should be given to more complex energy dissipation devices. These include hydraulic jump basins, impact basins, drop structures, and stilling wells. Design information for the general types of energy dissipators is provided in the MAJOR DRAINAGE and HYDRAULIC STRUCTURES chapters of this *Manual* and in *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA 1983 and 2000).

7.0 GENERAL CONSIDERATIONS

7.1 Culvert Location

Culvert location is an integral part of the total design. The main purpose of a culvert is to convey drainage water across the roadway section expeditiously and effectively. The designer should identify all live stream crossings, springs, low areas, gullies, and impoundment areas created by the new roadway embankment for possible culvert locations. Note that environmental permitting constraints will often apply for new culverts or retrofits, such as a Section 404 permit that regulates construction activities in jurisdictional wetlands and "Waters of the United States."

Culverts should be located on existing stream alignments and aligned to give the stream a direct entrance and a direct exit. Abrupt changes in direction at either end may retard the flow and make a larger structure necessary. If necessary, a direct inlet and outlet may be obtained by means of a channel change, skewing the culvert, or a combination of these. The choice of alignment should be based on economics, environmental concerns, hydraulic performance, and/or maintenance considerations.

If possible, a culvert should have the same alignment as its channel. Often this is not practical and where the water must be turned into the culvert, headwalls, wingwalls, and aprons with configurations similar to those in Figure CU-13 should be used as protection against scour and to provide an efficient inlet.

7.2 Sedimentation

Deposits usually occur within the culvert barrels at flow rates smaller than the design flow. The deposits may be removed during larger floods dependent upon the relative transport capacity of flow in the stream and in the culvert, compaction and composition of the deposits, flow duration, ponding depth above the culvert, and other factors.

Culvert location in both plan and profile is of particular importance to the maintenance of sediment-free culvert barrels. Deposits occur in culverts because the sediment transport capacity of flow within the culvert is often less than in the stream.

Deposits in culverts may also occur due to the following conditions:

- At moderate flow rates the culvert cross section is larger than that of the stream, so the flow depth and sediment transport capacity is reduced.
- Point bars form on the inside of stream bends. Culvert inlets placed at bends in the stream will be subject to deposition in the same manner. This effect is most pronounced in multiple-barrel culverts with the barrel on the inside of the curve often becoming almost totally plugged with sediment deposits.

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- Abrupt changes to a flatter grade in the culvert or in the channel adjacent to the culvert will induce sedimentation. Gravel and cobble deposits are common downstream from the break in grade because of the reduced transport capacity in the flatter section.

7.3 Fish Passage

At some culvert locations, the ability of the structure to accommodate migrating fish is an important design consideration. For such sites, state fish and wildlife agencies (such as the Colorado Division of Wildlife) should be consulted early in the roadway planning process. Some situations may require the construction of a bridge to span the natural stream. However, culvert modifications can often be constructed to meet the design criteria established by the fish and wildlife agencies.

7.4 Open Channel Inlets

Entrances to open channels often require the same careful planning and design as is needed for culverts and long conduits if the necessary hydraulic balance is to be achieved. The energy grade line should be analyzed by the designer to insure proper provision for balanced energy conversion, velocity control, energy loss, and other factors controlling the downstream flow. Channel confluences, in particular, require careful hydraulic design to eliminate scour, reduce oscillating waves, and minimize upstream backwater effects.

7.5 Transitions

Transitions from pipe flow to open channels, between different rigid channels, and from slow flow to supercritical flow must be designed using the concepts of conservation of energy and open channel hydraulics. Primarily, a transition is necessary to change the shape or cross section of flowing water.

Normally, the designer will have as an objective the avoidance of excessive energy losses, cross waves, and turbulence. It is also necessary to provide against scour and overtopping.

Supercritical flow transitions must receive more attention than is usually due subcritical flow transitions. Care must be taken to insure against unwanted hydraulic jumps or velocities causing critical depth. Froude numbers between 0.9 and 1.1 should be avoided.

In general, the rate at which the flow prism may be changed should not exceed perhaps 5 to 12½ degrees, depending upon velocity. Sharp angles should be avoided. The water surface hydraulic grade line should normally be smooth. Transition structure drawings are provided in the HYDRAULIC STRUCTURES chapter.

7.6 Large Stormwater Inlets

The functioning of large stormwater inlets, which collect major storm surface runoff at points of

concentration, is dependent upon careful planning and design. Due regard must be given to debris, hail, and safety hazards.

7.6.1 Gratings

The design of gratings should focus on (1) public safety, (2) hydraulic function and (3) debris control. See Section 8.0 of this chapter for further discussion.

7.6.2 Openings

The hydraulic openings for large storm inlets need to be designed in general accordance with the guides given in Section 4.0. Inadequate openings are easily plugged when needed most, and give a false sense of security. Clear vertical openings should be at least 6 inches. For greater inlet flows, the length of opening needed may be so large that special design approaches are needed for shape and function.

7.6.3 Headwater

The required headwater over large inlets must be computed and kept within acceptable limits to avoid excessive ponding on streets and damage to adjacent property.

7.7 Culvert Replacements

When installing or replacing an existing culvert, careful consideration should be taken to ensure that upstream and downstream property owners are not adversely affected by the new hydraulic conditions. The potential upstream flooding impacts associated with the backwater from the calculated headwater depth must be considered and the determination of the available headwater should take into account the area inundated at the projected water surface elevation. If a culvert is replaced by one with more capacity, the downstream effects of the additional flow must be factored into the analysis. Assuring consistency with existing major drainageway master plans and/or outfall studies is important.

7.8 Fencing for Public Safety

Culverts are frequently located at the base of steep slopes. Large box culverts, in particular, can create conditions where there is a significant drop, which poses risk to the public. In such cases, fencing (guardrails) is recommended for public safety.

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8.0 TRASH/SAFETY RACKS

The use of trash/safety racks at inlets to culverts and long underground pipes should be considered on a case-by-case basis. While there is a sound argument for the use of racks for safety reasons, field experience has clearly shown that when the culvert is needed the most, that is, during the heavy runoff, trash racks often become clogged and the culvert is rendered ineffective. A general rule of thumb is that a trash/safety rack will not be needed if one can clearly "see daylight" from one side of the culvert to the other, if the culvert is of sufficient size to pass a 48" diameter object and if the outlet is not likely to trap or injure a person. By contrast, at entrances to longer culverts and long underground pipes and for culverts not meeting the above-stated tests, a trash/safety rack is necessary.

The trash/safety rack design process is a matter of fully considering the safety hazard aspects of the problem, defining them clearly, and then taking reasonable steps to minimize these hazards while protecting the integrity of the water carrying capability of the culvert (see Photograph CU-6 for an example of how not to do it).



Photograph CU-6—Small trash racks at culvert entrance will increase the risk of entrance plugging.

In reviewing potential hazards to the public of a possibility of a person being swept into the culvert, it is also necessary to consider depth and velocity of upstream flow, the local currents in the vicinity of the culvert entrance, the general character of the neighborhood and whether it has residential population nearby, the length and size of the culvert, and other factors affecting safety and culvert capacity. Furthermore, in the event that someone was carried to the culvert with the storm runoff, the exposure hazard may in some cases be even greater if the person is pinned to the grating by the hydraulic pressures of the water rather than being carried through the culvert. Large, oversized racks positioned well in front of the culvert entrance can reduce the risk of pinning.

Where debris potential and/or public safety indicate that a rack is required, if the pipe diameter is more than 24 inches, the rack's open surface area must be, at the absolute minimum, at least four times larger. For smaller pipes, the factor increases significantly as suggested by Figure 7 in the "Typical Structural BMP Details" chapter of Volume 3 of this *Manual*. For culverts larger than 24 inches (i.e., in the smallest dimension), in addition to the trash rack having an open area larger than four times the culvert entrance, the average velocities at the rack's face shall be less than 2.0 feet per second at every stage of flow entering the culvert. The rack needs to be sloped no steeper than 3H:IV (the flatter the better) and have a clear opening at the bottom of 9 to 12 inches to permit debris at lower flows to go through. The bars on the face of the rack should be generally paralleling the flow and be spaced to provide 4½- to 5-inch clear openings between them. Transverse support bars need to be as few as possible, but sufficient to keep the rack from collapsing under full hydrostatic loads.

The District strongly recommends against the installation of trash racks at culvert outlets, because debris or a person carried into the culvert will impinge against the rack, thus leading to pressurized conditions within the culvert, virtually destroying its flow capacity and creating a greater hazard to the public or a person trapped in the culvert than not having one.

8.1 Collapsible Gratings

The District does not recommend the use of collapsible gratings. On larger culverts where a collapsible grating is deemed necessary by a local jurisdiction or an engineer, such gratings must be carefully designed from the structural standpoint so that collapse is achieved with a hydrostatic load of perhaps one-half of the maximum backwater head allowable. Collapse of the trash rack should be such that it clears the waterway opening adequately to permit the inlet to function properly without itself contributing to potential plugging of the culvert.

8.2 Upstream Trash Collectors

Where a safety hazard exists, a large trash rack situated diagonally across a stream a reasonable distance upstream from the culvert inlet offers an alternative. This type of rack may consist of a series of vertical pipes or posts embedded in the approach channel bottom with horizontal bars to deflect the debris to one side. If partial blocking of a properly designed rack occurs, it should be designed so that the backwater flow over the top of the rack is minimal. The rack must not cause the water to rise higher than the maximum allowable flood elevation. A trash rack at the culvert entrance can then provide a backup for safety.

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9.0 DESIGN EXAMPLE

The following example problem illustrates the culvert design procedures using the FHWA nomographs and using UD-Culvert Spreadsheet application.

9.1 Culvert Under an Embankment

Given: $Q_{5\text{-yr}}$ = 20 cfs, $Q_{100\text{-yr}}$ = 35 cfs, L = 95 feet

The maximum allowable headwater elevation is 5288.5. The natural channel invert elevations are 5283.5 at the inlet and 5281.5 at the outlet. The tailwater depth is computed as 2.5 feet for the 5-year storm, and 3.0 feet for the 100-year storm.

Solution:

Step 1. Fill in basic data (Figure CU-15)

$Q_{5\text{-yr}}$ = discharge for 5-year storm

$Q_{100\text{-yr}}$ = discharge for 100-year storm

Headwater and tailwater elevations

Step 2. Set invert elevations at natural channel invert elevations to avoid scour. Compute s and $L/(100s)$.

Step 3. Start with an assumed culvert size for the 5-year storm by adopting a velocity of 6.5 ft/sec. In this case, first size is estimated by adopting a velocity of 6.5 ft/sec and computing A = 20/6.5 = 3.1 ft², giving a culvert diameter, D = 24 inches.

Step 4. For this example, two inlets are considered: square edge with headwall (K_e = 0.4) and groove end with headwall (K_e = 0.2). Also, assume concrete pipe will be used with a Manning's n of 0.012 (Note: the District recommends a minimum n of 0.013; however, 0.012 is used in this example to correspond to the FHWA nomograph.)

Step 5. Using the inlet control nomograph (Figure CU-16), the ratio of the headwater depth to the culvert diameter (Hw/D) is 1.47 for the square edge and 1.32 for the groove end. Thus, the inlet control headwater depths are 2.94 feet and 2.64 feet, respectively.

Step 6. The outlet control headwater depth is determined using the method described in Section 3.0. The head is determined from the nomograph (Figure CU-17). The resulting outlet control headwater depths are 2.13 feet for the square edge and 1.90 feet for the grove end inlet.

Step 7. Comparing the headwater depths for inlet control (2.94 feet and 2.64 feet) and outlet

control (2.13 feet and 1.90 feet) shows that the culvert is inlet controlled with either inlet configuration. Furthermore, the calculated headwater depths are less than the allowable headwater depth. These results can also be determined using the UD-Culvert Spreadsheet.

Step 8. The next step is to evaluate the culvert for the 100-year flow of 35 cfs and tailwater depth of 3.0 feet. Using the same procedure, the culvert continues to be inlet controlled with the square-edge inlet and switches to outlet control with the more efficient groove-end inlet. However, both of the calculated headwater depths exceed the allowable headwater depth and, consequently, are not viable alternatives.

Step 9. Increase the pipe diameter to 27 inches and repeat the process. The resulting headwater depths are less than the allowable.

Step 10. Compute outlet velocities for each acceptable alternate.

Step 11. Compute cost for each alternate.

Step 12. Make recommendations.

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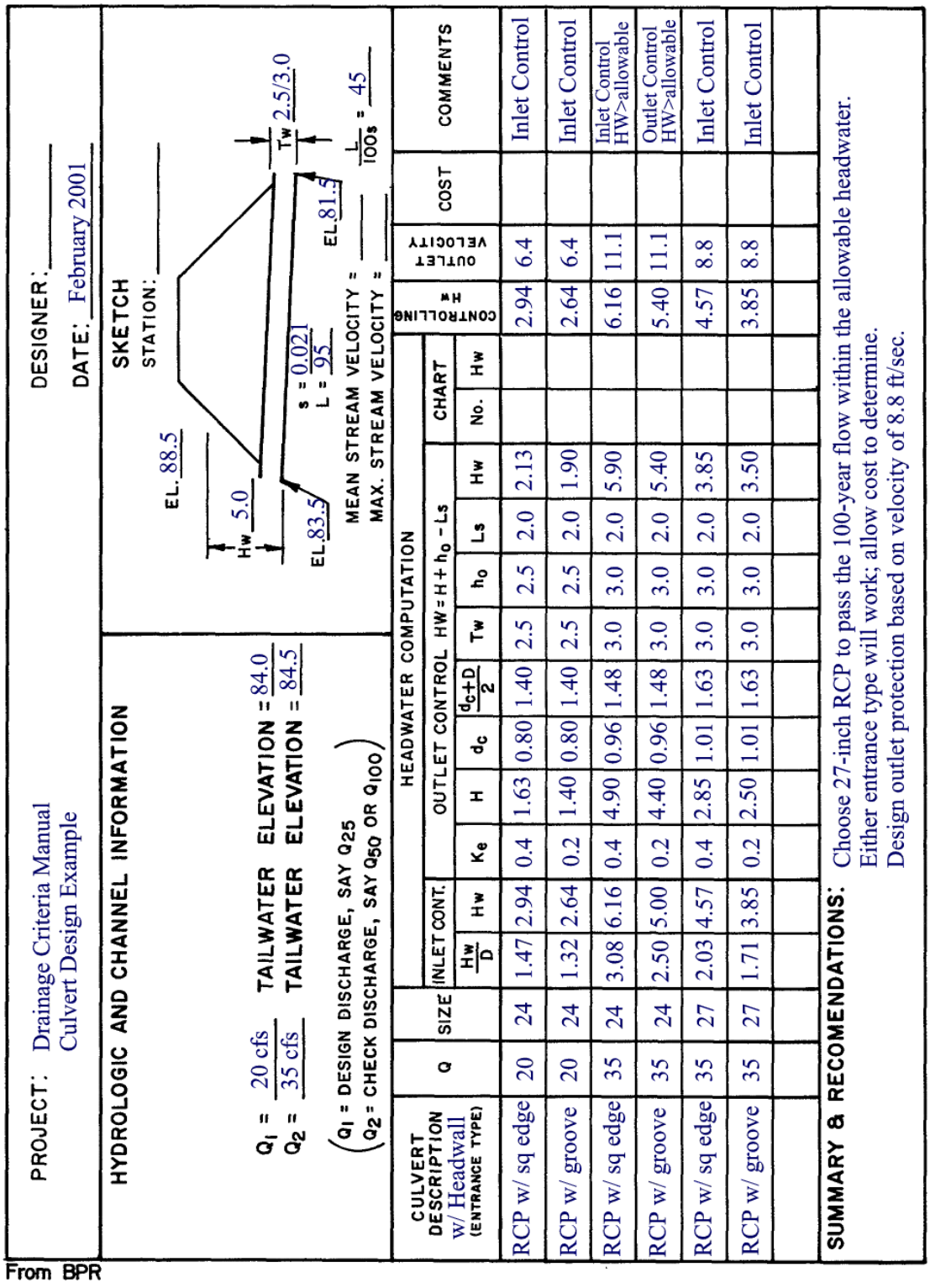

PROJECT: Drainage Criteria Manual Culvert Design Example

DESIGNER: _____

DATE: February 2001

HYDROLOGIC AND CHANNEL INFORMATION

Q_1 = 20 cfs TAILWATER ELEVATION = 84.0

Q_2 = 35 cfs TAILWATER ELEVATION = 84.5

(Q_1 = DESIGN DISCHARGE, SAY Q_{25}; Q_2 = CHECK DISCHARGE, SAY Q_{50} OR Q_{100})

SKETCH

STATION: _____

MEAN STREAM VELOCITY = _____

MAX. STREAM VELOCITY = _____

$\frac{L}{100s}$ = 45

CULVERT DESCRIPTION w/ Headwall (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION													CONTROLLING H_w	OUTLET VELOCITY	COST	COMMENTS
			INLET CONT.		OUTLET CONTROL $HW = H + h_o - Ls$								CHART						
			$\frac{Hw}{D}$	Hw	K_e	H	d_c	$\frac{d_c+D}{2}$	Tw	h_o	Ls	Hw	No.	Hw					
RCP w/ sq edge	20	24	1.47	2.94	0.4	1.63	0.80	1.40	2.5	2.5	2.0	2.13			2.94	6.4		Inlet Control
RCP w/ groove	20	24	1.32	2.64	0.2	1.40	0.80	1.40	2.5	2.5	2.0	1.90			2.64	6.4		Inlet Control
RCP w/ sq edge	35	24	3.08	6.16	0.4	4.90	0.96	1.48	3.0	3.0	2.0	5.90			6.16	11.1		Inlet Control HW>allowable
RCP w/ groove	35	24	2.50	5.00	0.2	4.40	0.96	1.48	3.0	3.0	2.0	5.40			5.40	11.1		Outlet Control HW>allowable
RCP w/ sq edge	35	27	2.03	4.57	0.4	2.85	1.01	1.63	3.0	3.0	2.0	3.85			4.57	8.8		Inlet Control
RCP w/ groove	35	27	1.71	3.85	0.2	2.50	1.01	1.63	3.0	3.0	2.0	3.50			3.85	8.8		Inlet Control

SUMMARY & RECOMENDATIONS: Choose 27-inch RCP to pass the 100-year flow within the allowable headwater. Either entrance type will work; allow cost to determine. Design outlet protection based on velocity of 8.8 ft/sec.

From BPR

Figure CU-15—Design Computation Form for Culverts—Example 9.1

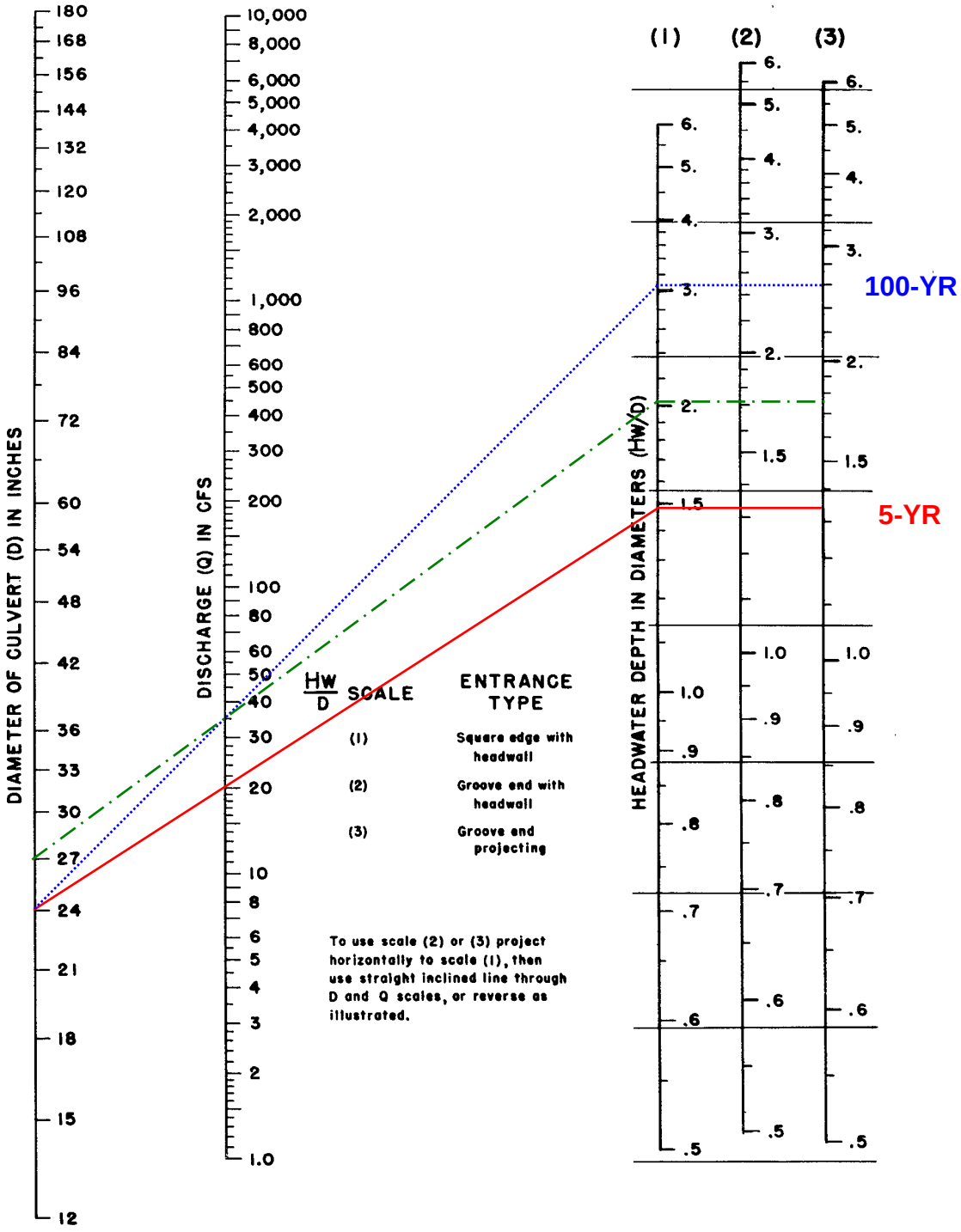

Figure CU-16—Headwater Depth for Concrete Pipe Culverts with Inlet Control—Example 9.1

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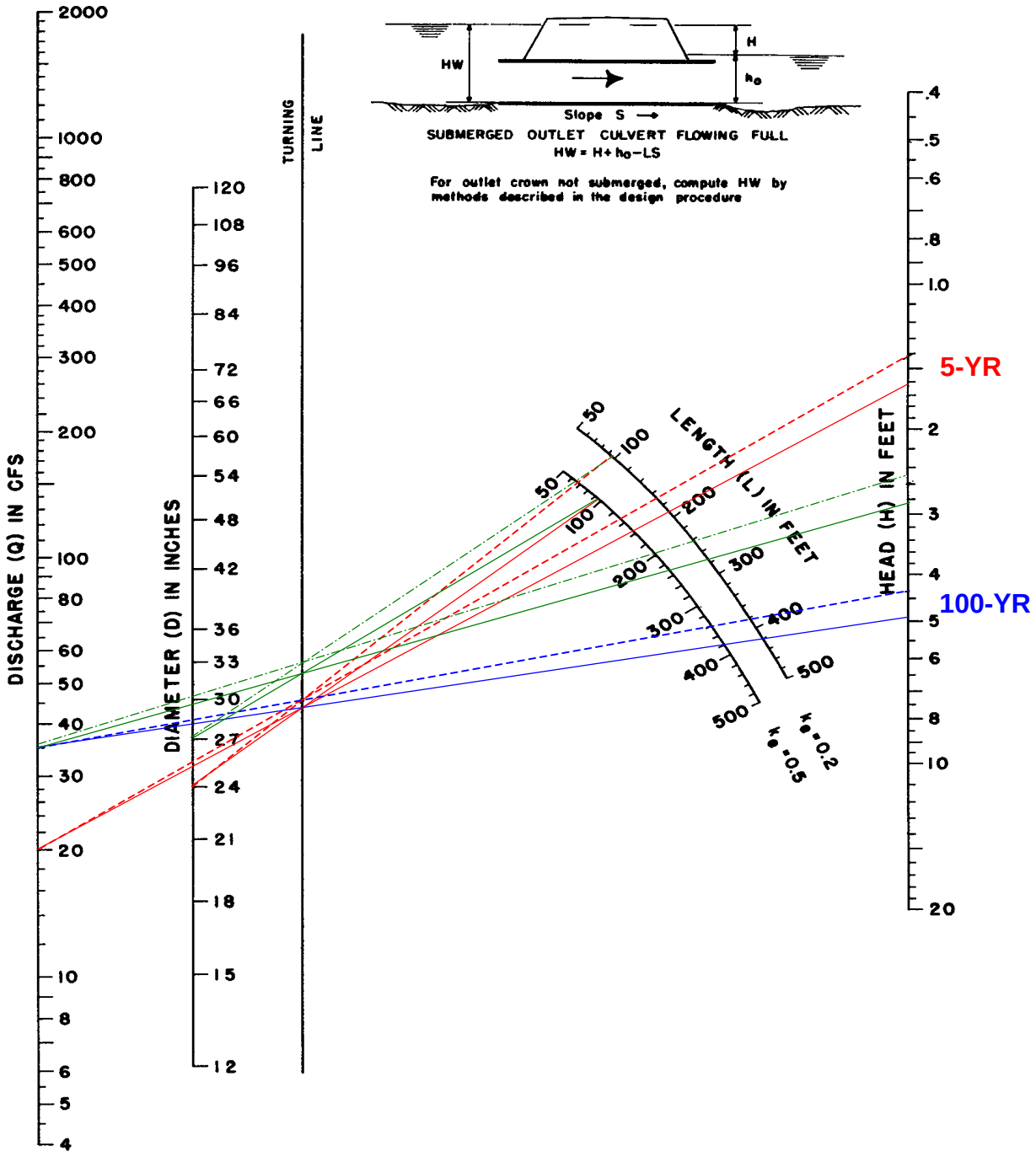
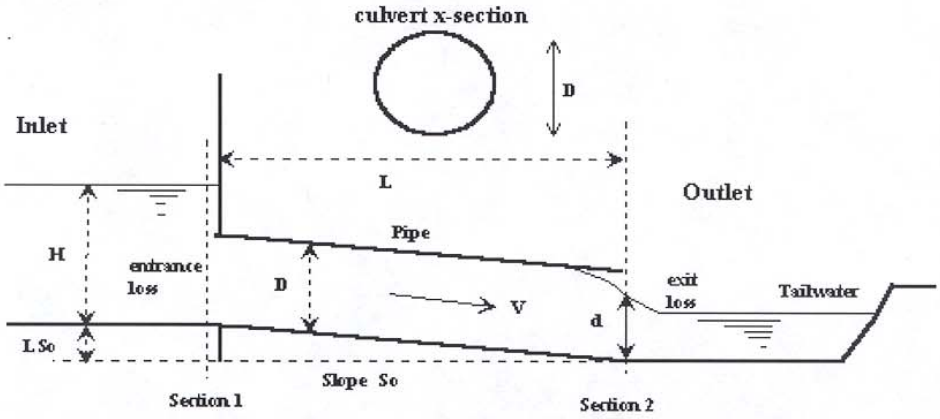


Figure CU-17—Head for Concrete Pipe Culverts Flowing Full (n = 0.012)—Example 9.1

Headwater Depth For Circular Culvert

Project: Drainage Criteria Manual
Pipe ID: Example 9.1



Design Information (input)

Design Discharge	**Q =**	20.0	**cfs**
Pipe Diameter	D =	2.00	ft
Inlet Edge Type (choose from pull-down list)	Inlet Type =	Square End with Headwall	
Inlet Invert Elevation	I_e =	83.50	ft
Outlet Invert Elevation	O_e =	81.50	ft
Pipe Length	L =	95.0	ft
Manning's Roughness N-Value	N =	0.012	*
Bend Loss Coefficient	K_b =	0.00	
Exit Loss Coefficient	K_x =	0.00	
Tailwater Water Surface Elevation	El. Y_t =	84.00	ft

Calculations (output)

Pipe Cross Sectional Area	A_o =	3.14	sq ft
Culvert Slope	S_o =	0.0211	ft/ft
Normal Flow Depth	Y_n =	0.54	ft
Critical Flow Depth	Y_c =	0.80	ft
Headwater Depth by Inlet Control			
Headwater Depth by Inlet Control	**HW-inlet=**	2.92	**ft**
Headwater Depth by Outlet Control			
Tailwater Depth for Design	d =	2.50	ft
Friction Loss Coefficient over Culvert Length	K_f =	1.00	
Sum of All Loss Coefficients	K'_s =	1.50	
Headwater Depth by Outlet Control	**HW-outlet=**	2.07	**ft**
Design Headwater Depth	**HW=**	2.92	**ft**
HW/D Ratio =	**HW/D=**	1.46	

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10.0 CHECKLIST

Criterion/Requirement	✓
Culvert diameter should be at least 18 inches.	
Evaluate the effects of the proposed culvert on upstream and downstream water surface elevations.	
When retrofitting or replacing a culvert, evaluate the changes in the upstream and downstream flood hazard.	
Review any proposed changes with local, state, and federal regulators.	
When a culvert is sized such that the overlying roadway overtops during large storms, check the depth of cross flow with Table DP-3 in the POLICY chapter.	
Provide adequate outlet protection in accordance with the energy dissipator discussion in the MAJOR DRAINAGE and HYDRAULIC STRUCTURES chapters.	

11.0 CAPACITY CHARTS AND NOMOGRAPHS

Capacity charts and nomographs covering the range of applications commonly encountered in urban drainage are contained in this section. These charts are from the FHWA Hydraulic Design Series No. 5 (FHWA 1985), which also contains detailed instructions for their use. For situations beyond the range covered by these charts, reference should be made to the original publications.

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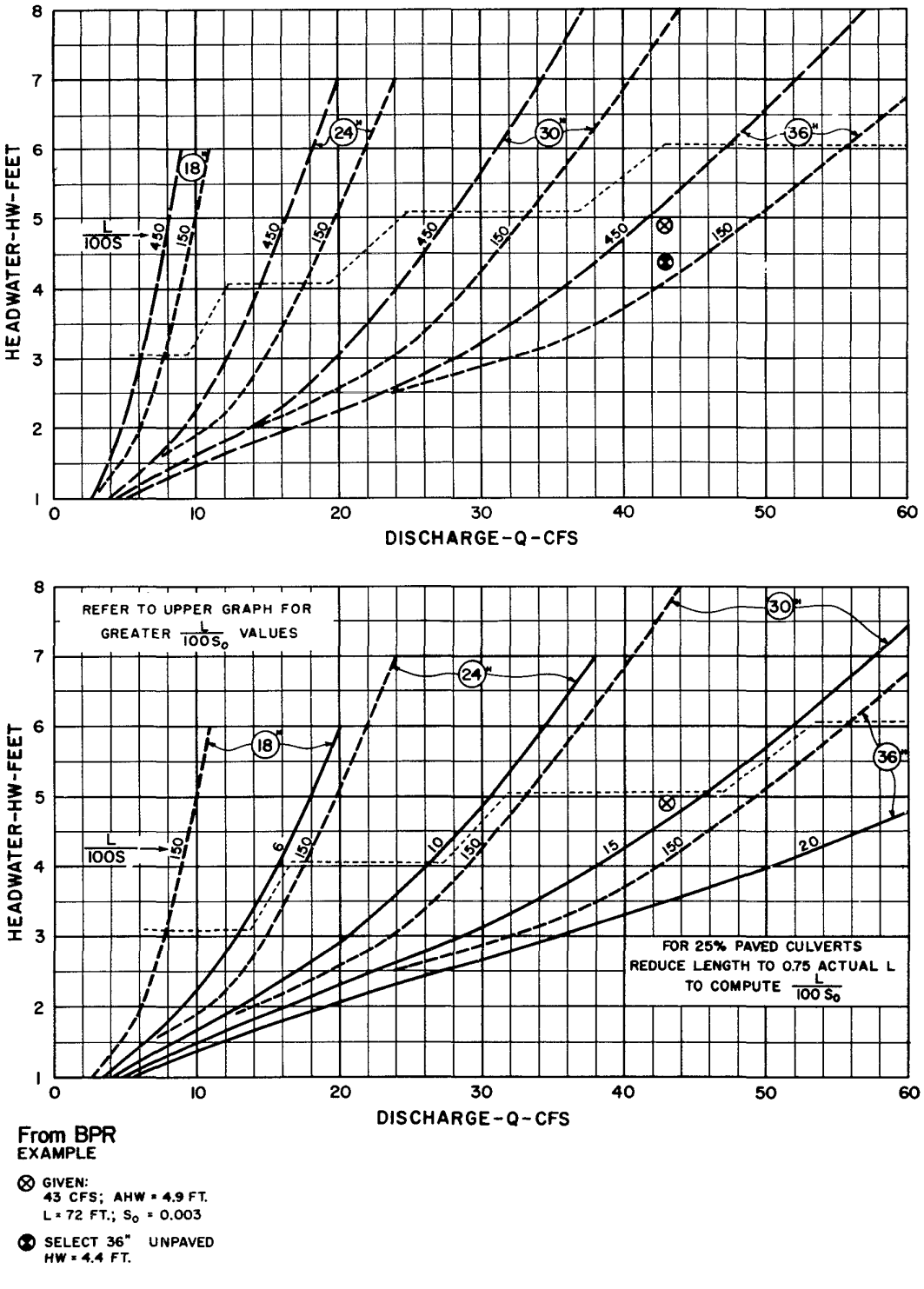


Figure CU-18—Culvert Capacity Standard Circular Corrugated Metal Pipe Headwall Entrance 18" to 36"

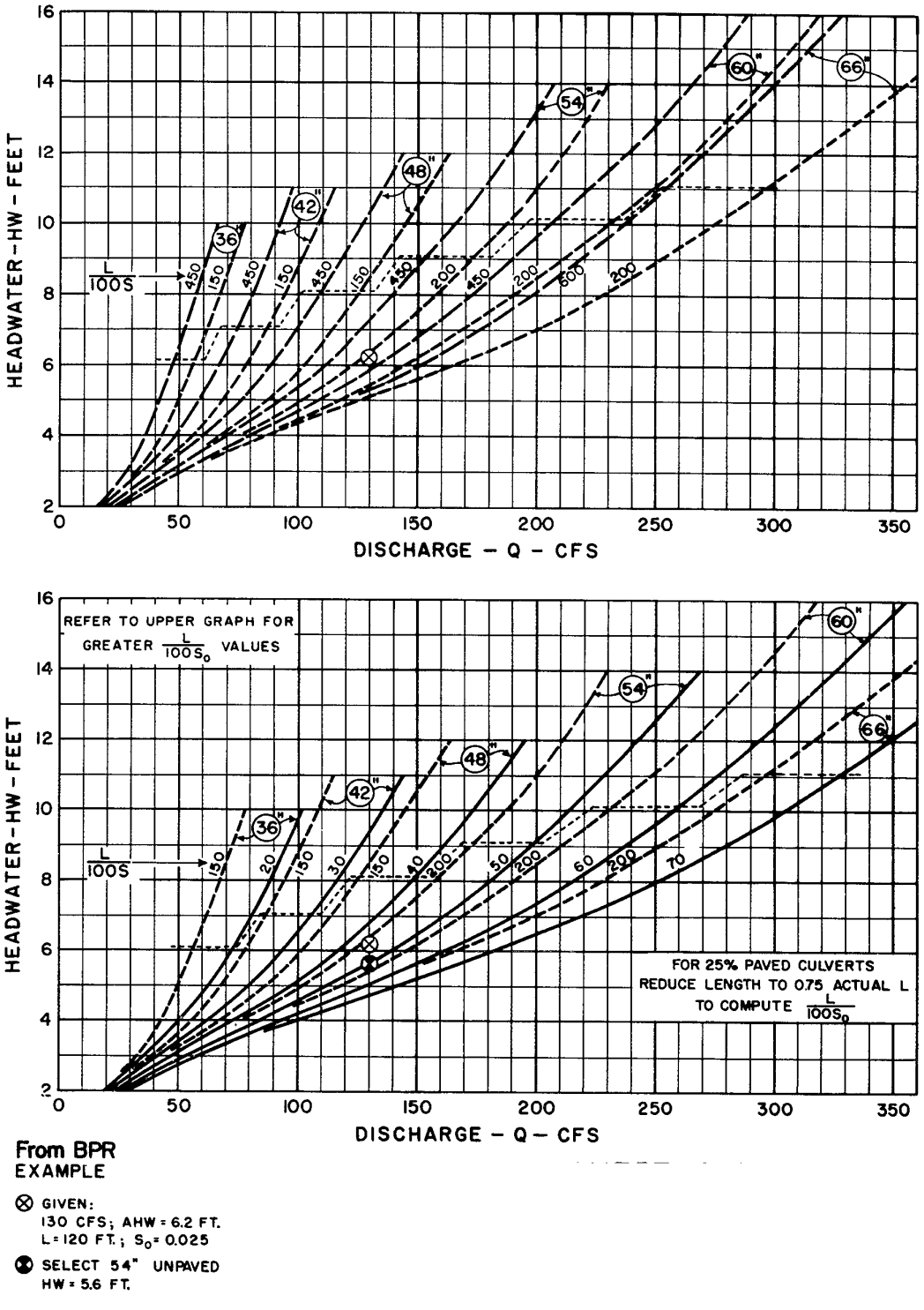


Figure CU-19—Culvert Capacity Standard Circular Corrugated Metal Pipe

Headwall Entrance 36” to 66”

SARB_009189

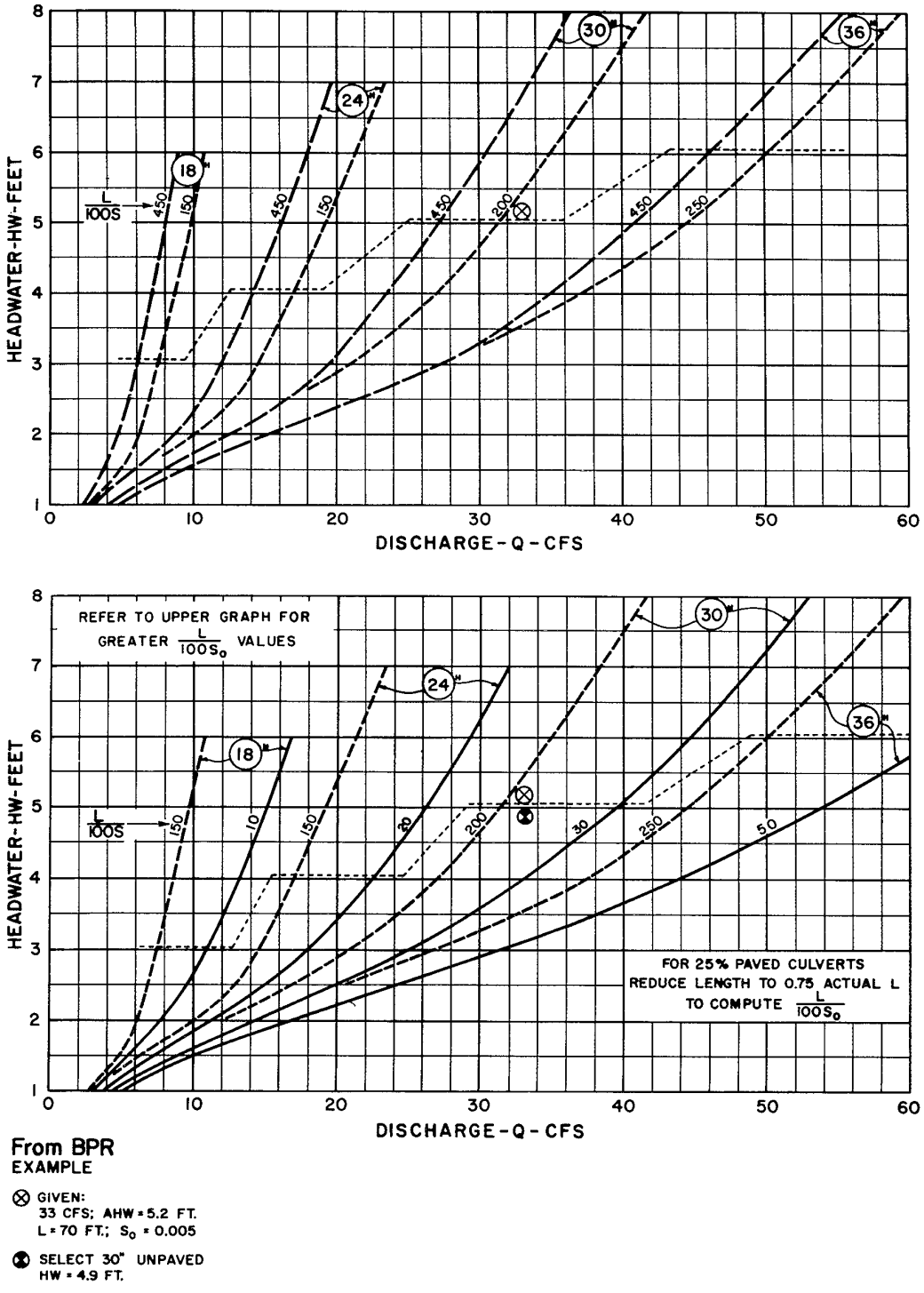
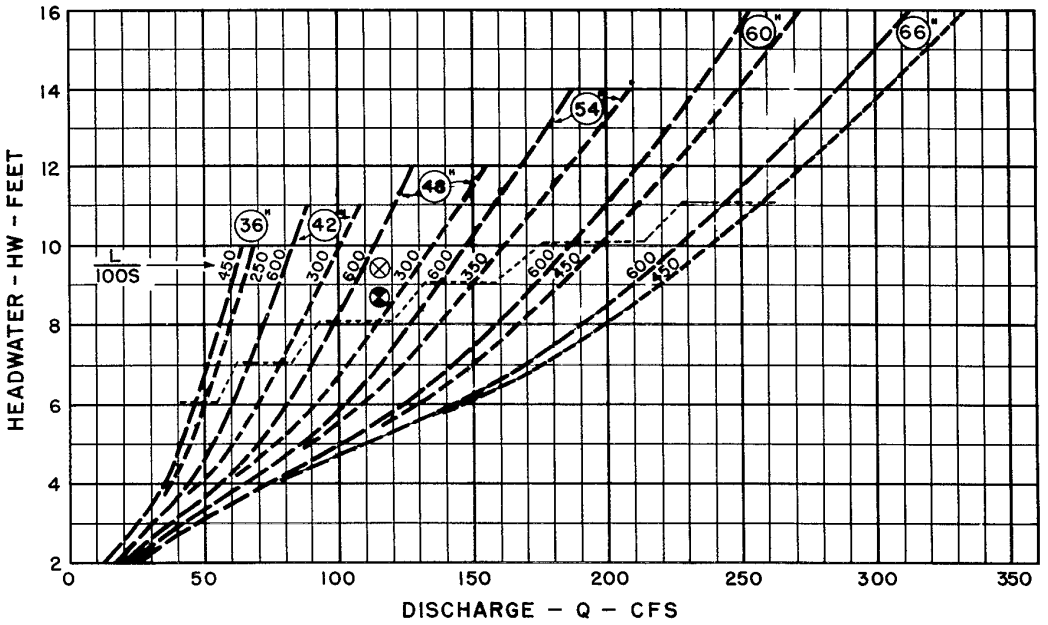
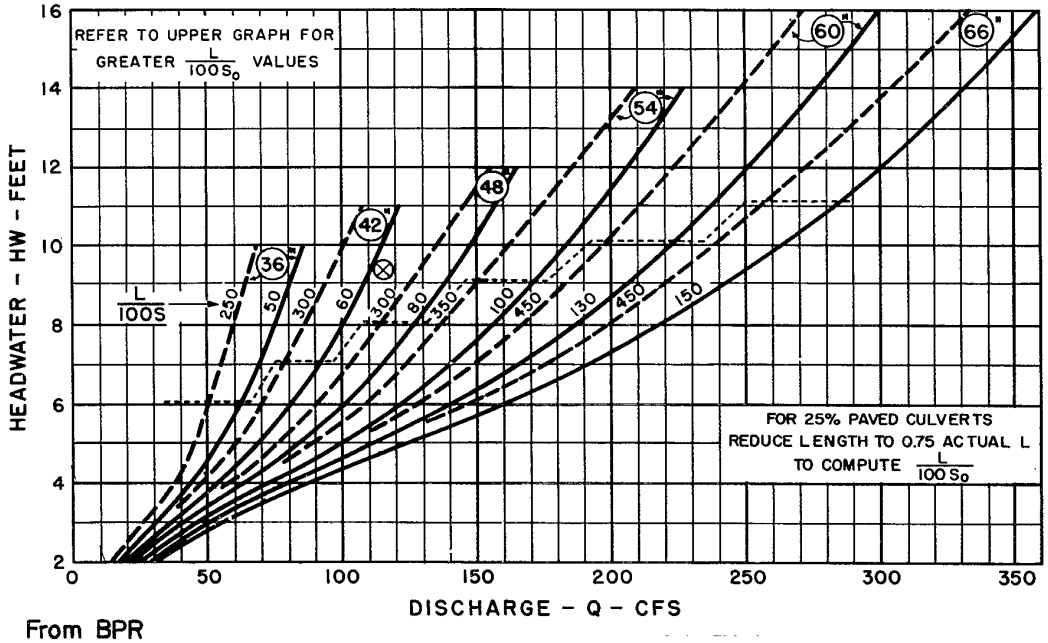


Figure CU-20—Culvert Capacity Standard Circular Corrugated Metal Pipe Projecting Entrance 18" to 36"





From BPR
EXAMPLE

⊗ GIVEN:
115 CFS; AHW = 9.4 FT.
L = 135 FT.; S_0 = 0.0034

SELECT 48" UNPAVED
HW = 8.6 FT.

Figure CU-21—Culvert Capacity Standard Circular Corrugated Metal Pipe Projecting Entrance 36” to 66”

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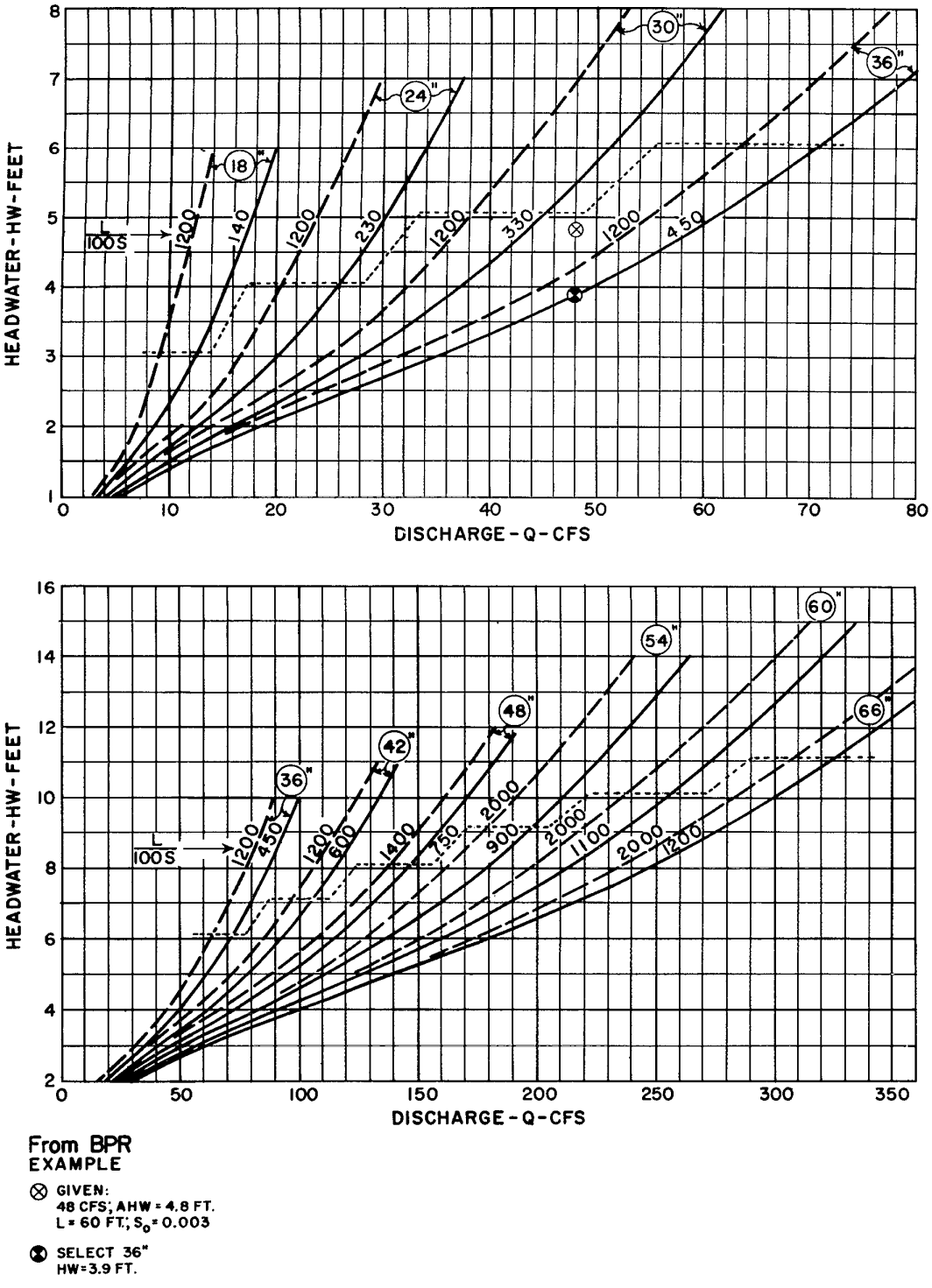

Figure CU-22—Culvert Capacity Circular Concrete Pipe Square-Edged Entrance 18" to 66"

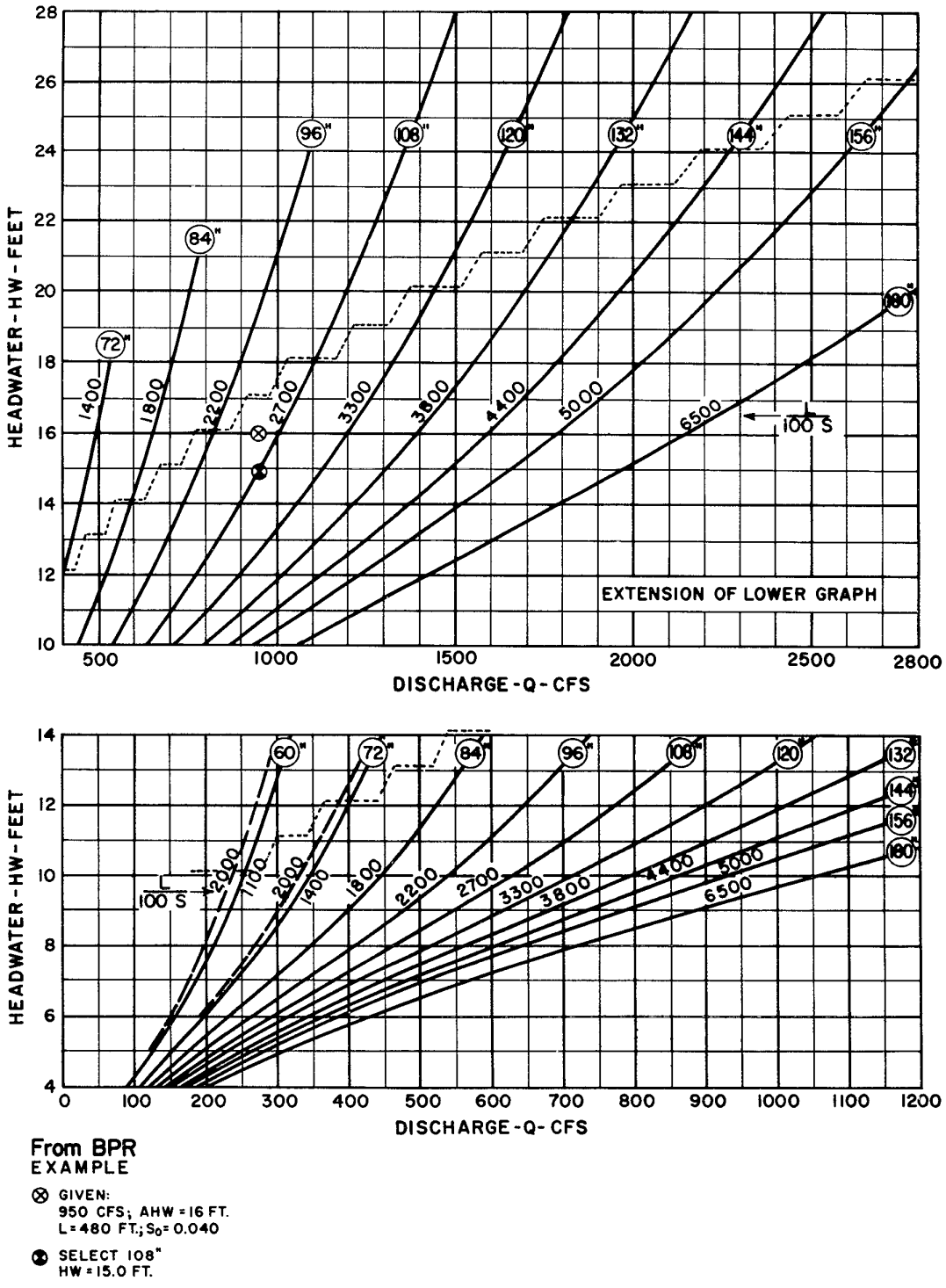

Figure CU-23—Culvert Capacity Circular Concrete Pipe Square-Edged Entrance 60” to 180”

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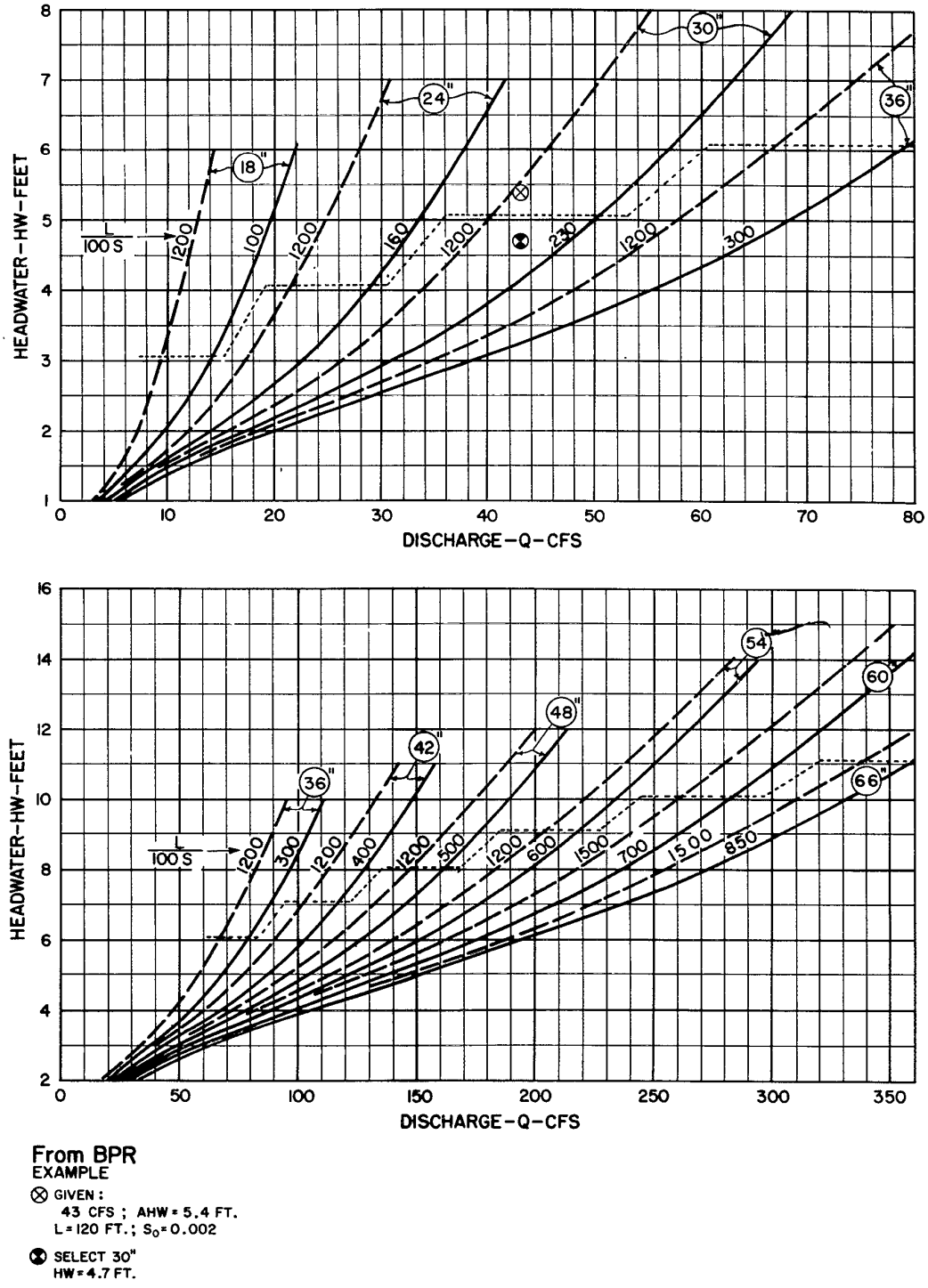

Figure CU-24—Culvert Capacity Circular Concrete Pipe Groove-Edged Entrance 18" to 66"

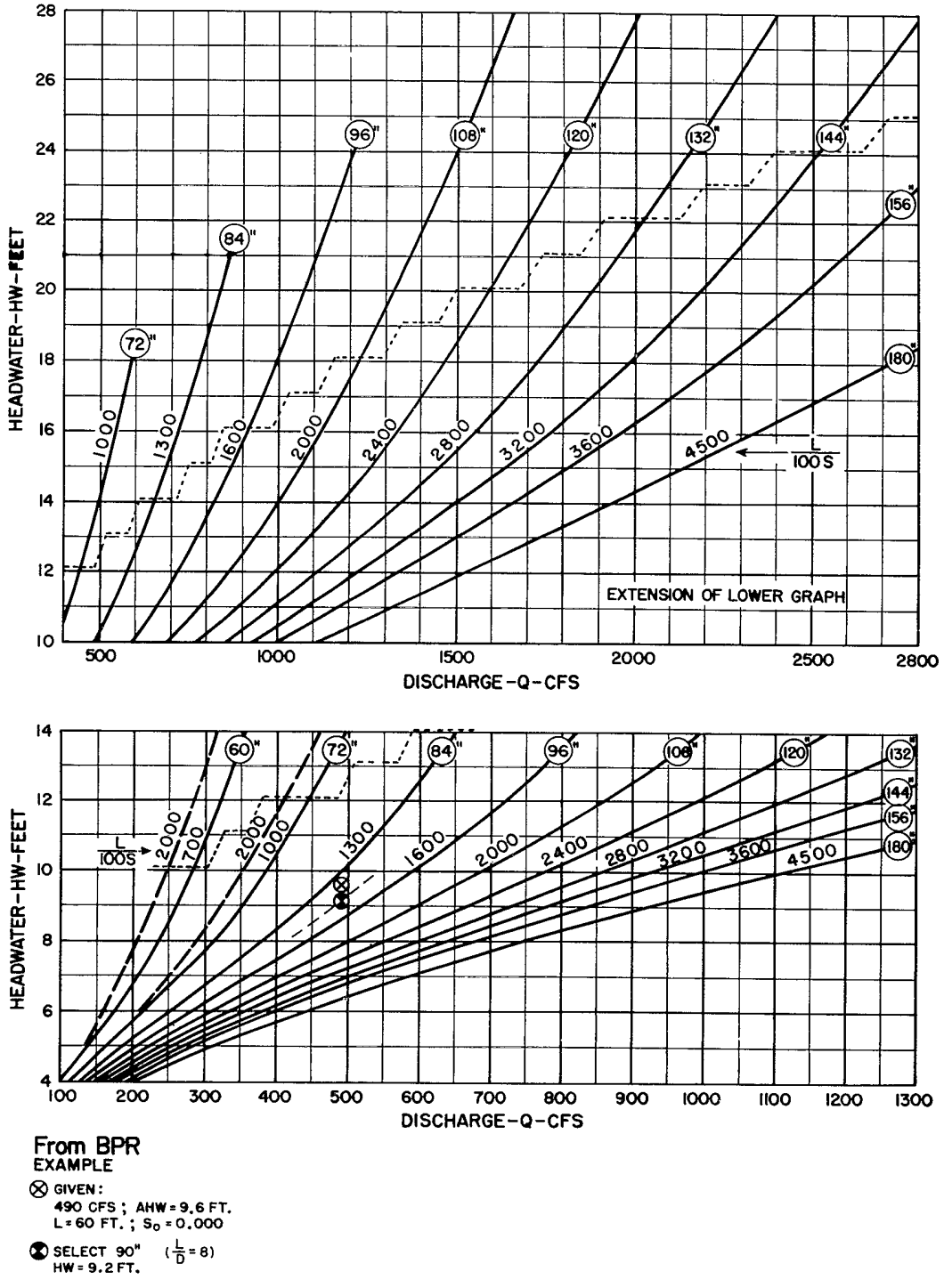

Figure CU-25—Culvert Capacity Circular Concrete Pipe Groove-Edged Entrance 60” to 180”

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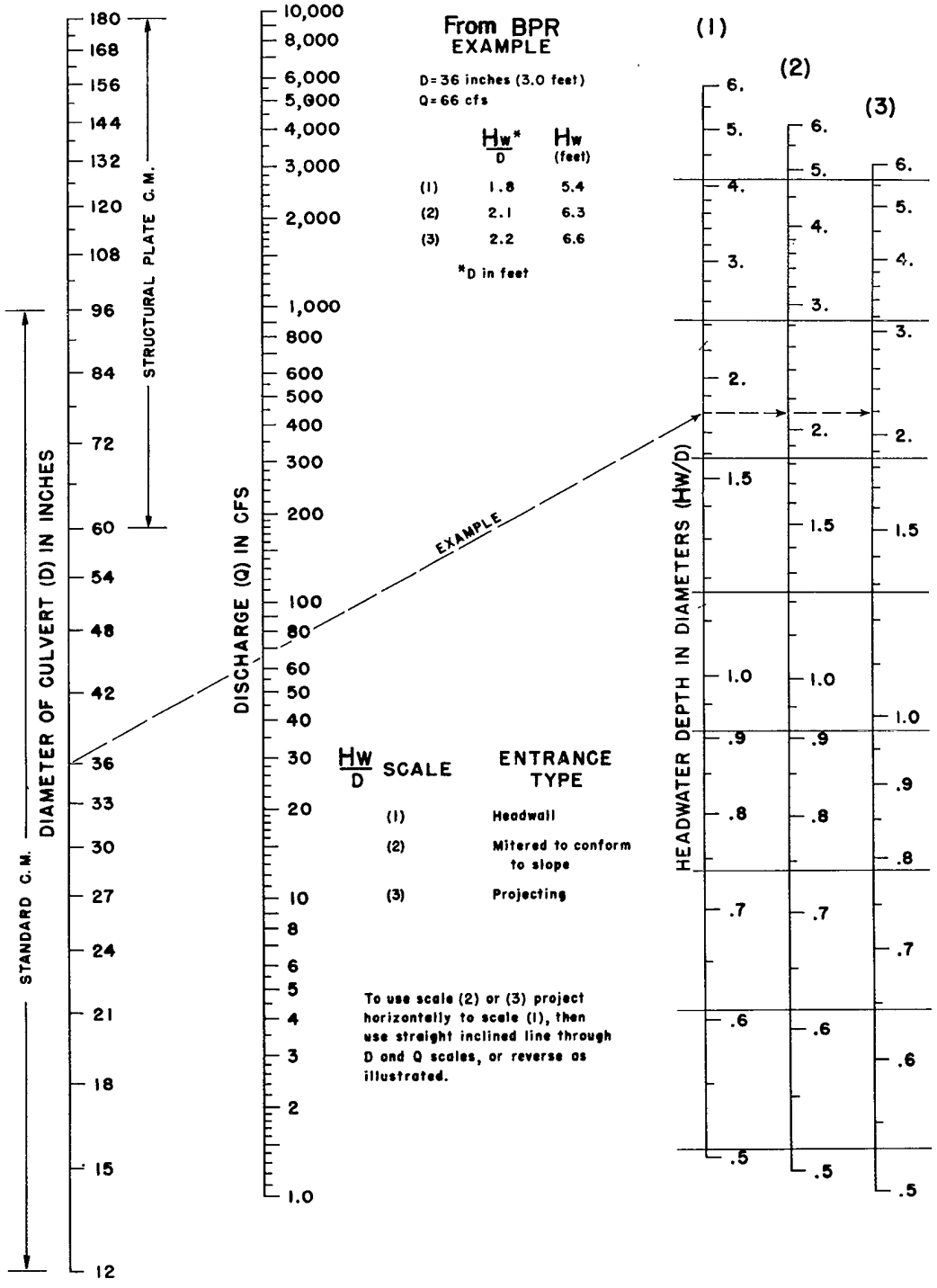

Figure CU-26—Headwater Depth for Corrugated Metal Pipe Culverts With Inlet Control

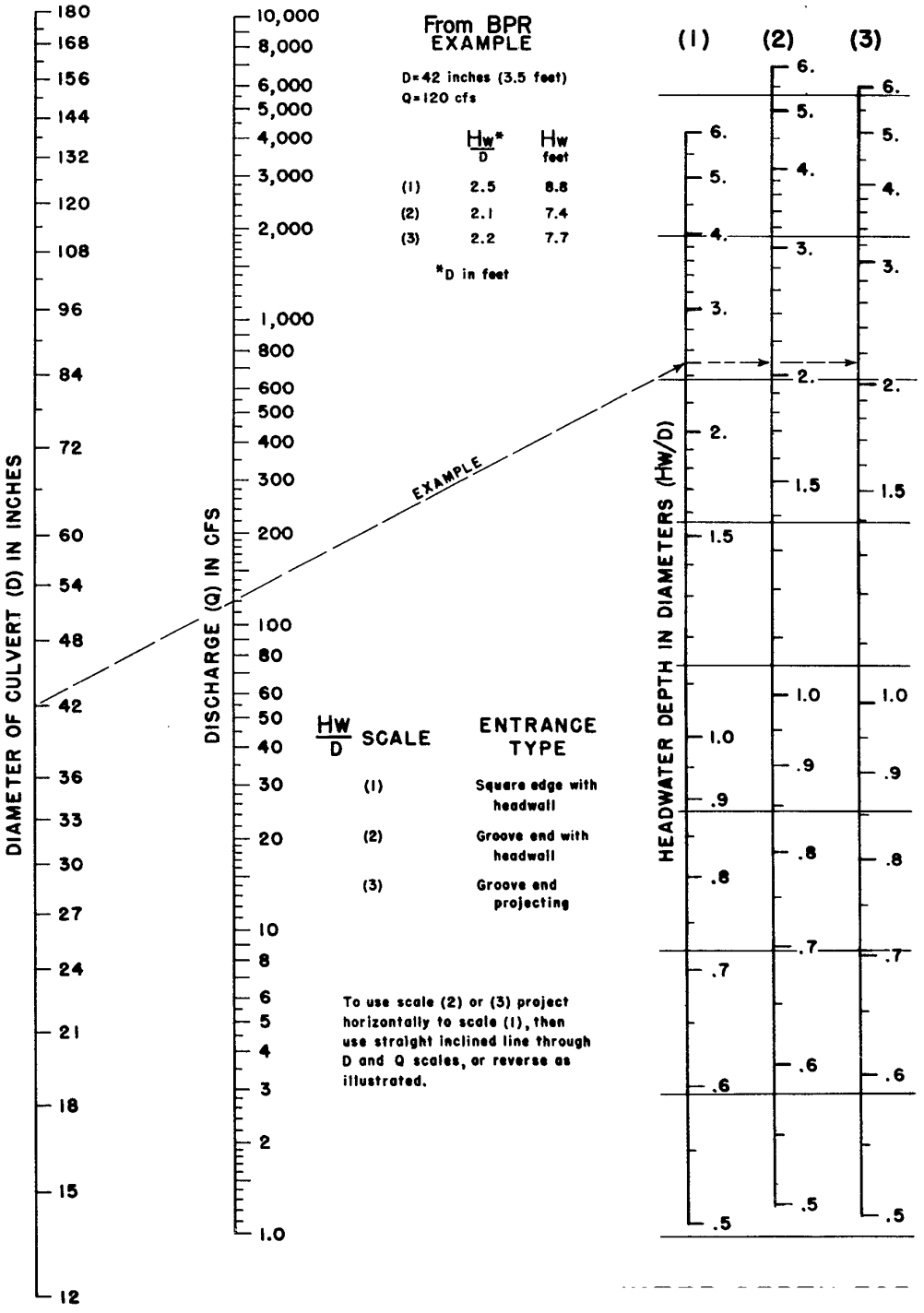

Figure CU-27—Headwater Depth for Concrete Pipe Culverts With Inlet Control

SARB_009197

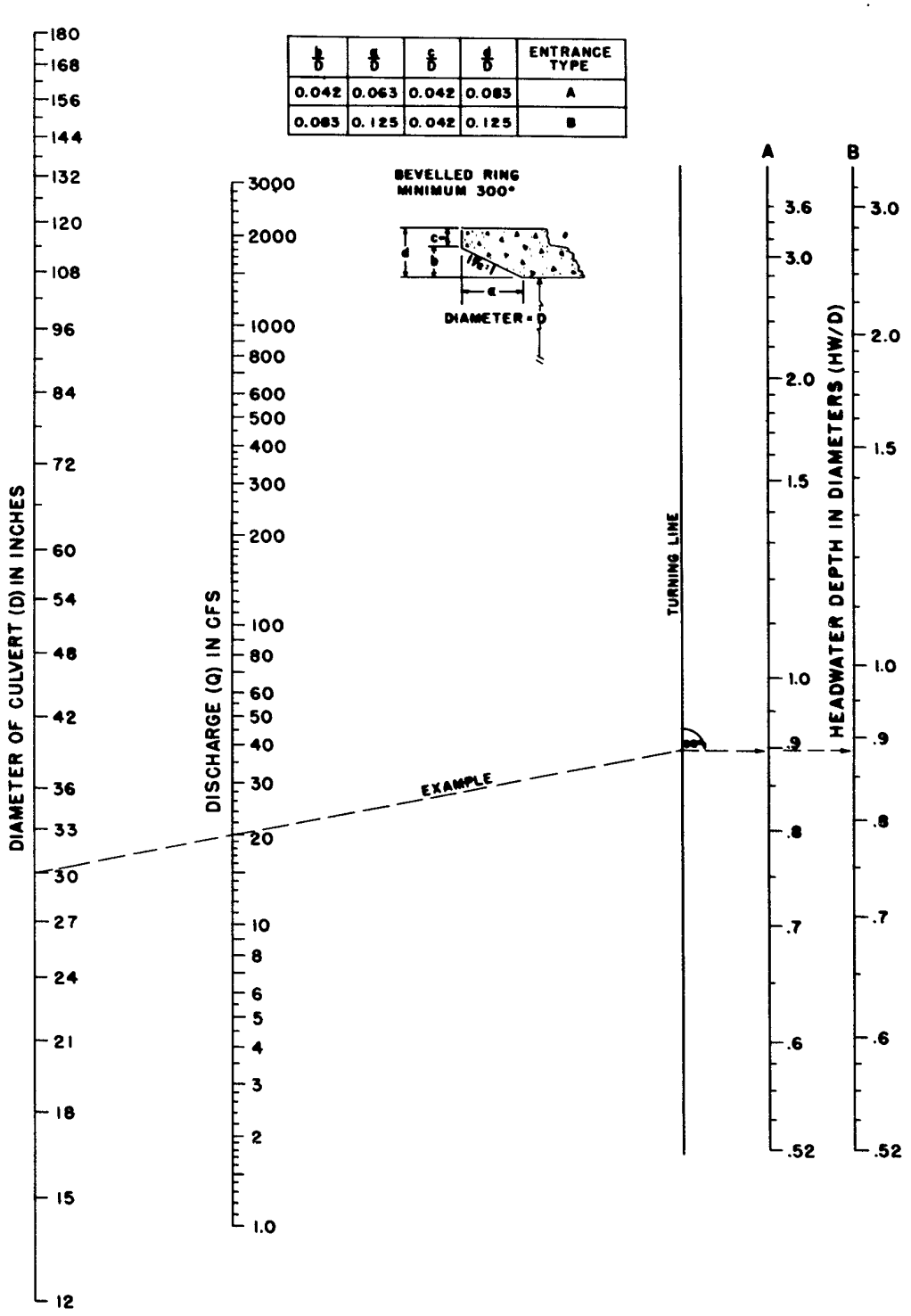

Figure CU-28—Headwater Depth for Circular Pipe Culverts With Beveled Ring Inlet Control

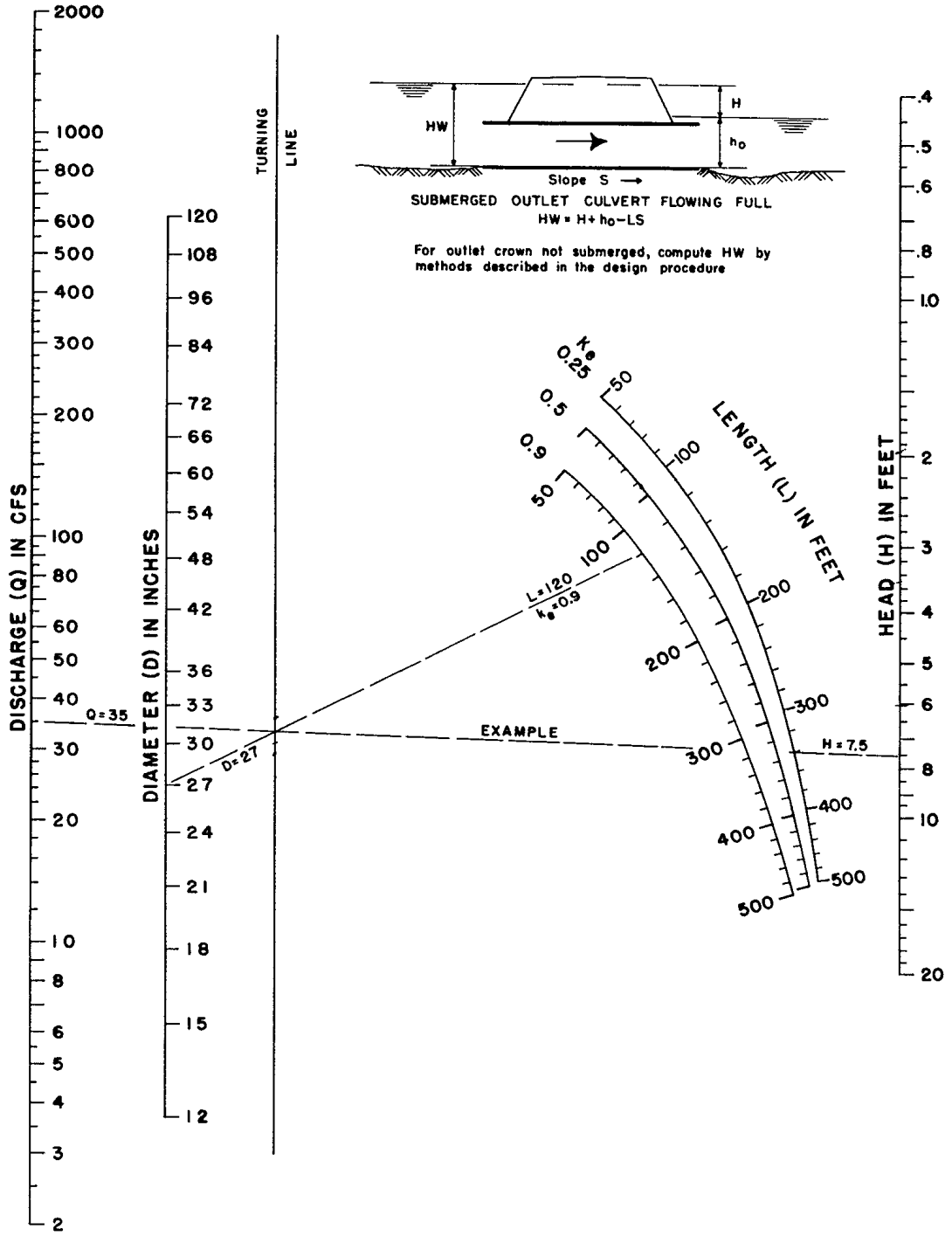

Figure CU-29—Head for Standard Corrugated Metal Pipe Culverts Flowing Full n = 0.024

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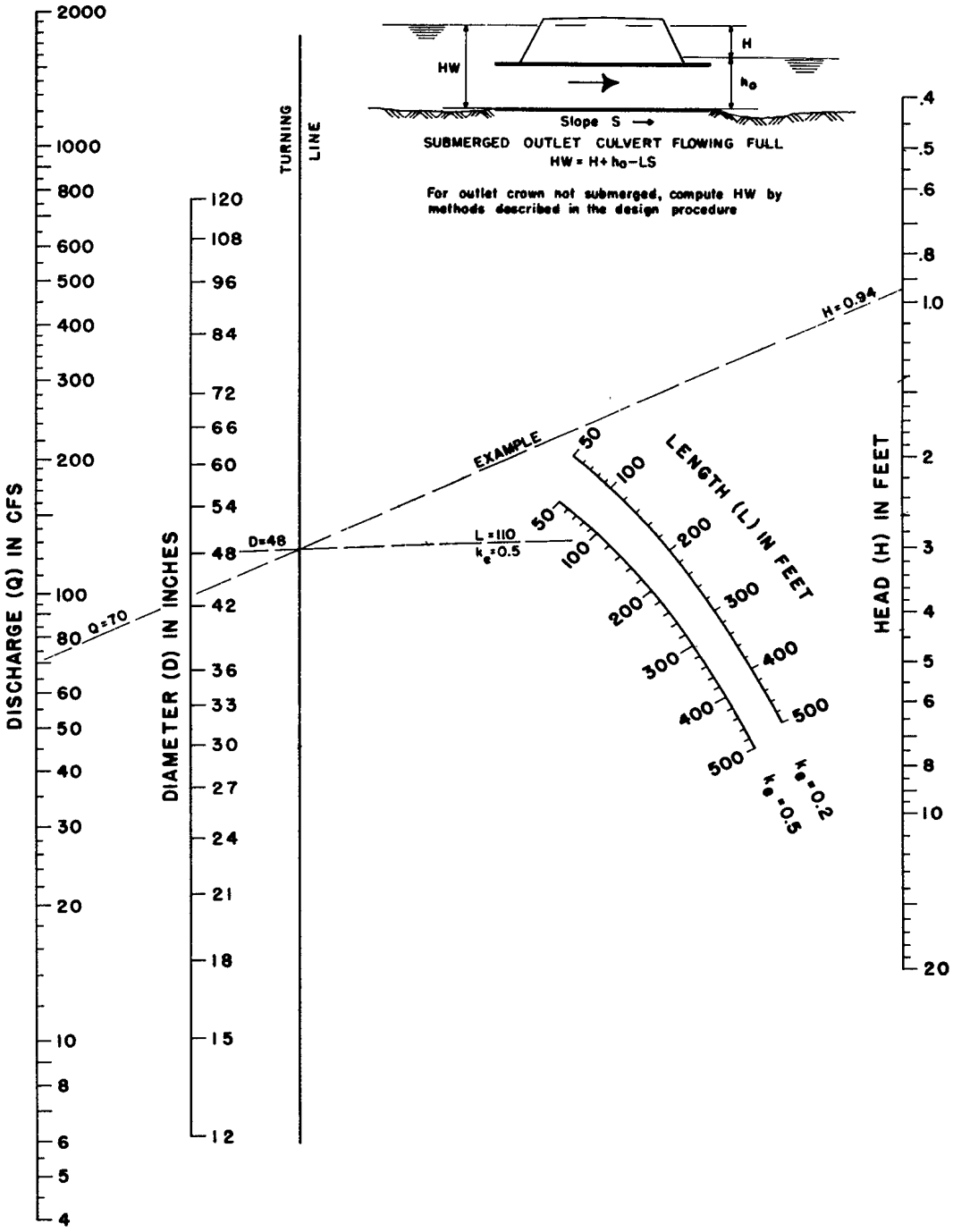

Figure CU-30—Head for Concrete Pipe Culverts Flowing Full *n* = 0.012

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STORAGE

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Photograph SO-8—Maintenance considerations must be carefully accounted for during design, with sediment accumulation a particular concern. 33

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1.0 OVERVIEW

This chapter provides guidance for the analysis and design of stormwater *quantity* detention facilities. Detention facilities for the management of stormwater *quality* (i.e., extended detention basins, retention ponds, wetland basins, etc.) are described in Volume 3 of this *Manual*. Detention and retention basins are used for stormwater runoff quantity control to mitigate the effects of urbanization on runoff flood peaks. If there is a need to design a storage facility for both water quality and quantity control purposes, this chapter should be used in conjunction with Volume 3 of this *Manual*.

Topics discussed in this chapter include design storms used for detention, the application of different types of storage facilities, basis for hydrologic and hydraulic design, and various other design considerations. As is the case with major drainageways, the Urban Drainage and Flood Control District (District) strongly encourages the development of multipurpose, attractive detention facilities that are safe, maintainable and viewed as community assets rather than liabilities.



Photograph SO-1—Attractive wet and dry detention facilities in commercial settings have been shown to increase property value.



Photograph SO-2—Dry and extended dry detention facilities can blend into the landscape, especially with the assistance of experienced landscape architects.

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2.0 APPLICATION OF DIFFERENT TYPES OF STORAGE

There are two basic approaches to designing storage facilities. When runoff storage facilities are planned on an individual-site basis, they are referred to as “on-site.” Larger facilities that have been identified and sized as a part of some overall regional plan are categorized as “regional” facilities. The regional definition can also be applied to detention facilities that encompass multiple land development projects.

On-site storage facilities usually are designed to control runoff from a specific land development site and are not typically located or designed with the idea of reducing downstream flood peaks along major drainageways for small and/or large storm runoff events. The total volume of runoff detained in the individual on-site facility is quite small, and the detention time for flood control purposes is relatively short. Therefore, unless design (i.e., sizing and flow release) criteria and implementation are applied uniformly throughout the urbanizing or redeveloping watershed, their effectiveness diminishes rapidly along the downstream reaches of waterways. The application of consistent design and implementation criteria and assurance of their continued maintenance and existence is of paramount importance if large numbers of on-site detention facilities are to be effective in controlling peak flow rates along major drainageways (Glidden 1981; Urbonas and Glidden 1983).

The principal advantage of on-site facilities is that developers can be required to build them as a condition of site approval. Major disadvantages include the need for a larger total land area for multiple smaller on-site facilities as compared to larger regional facility(ies) serving the same tributary catchment area. If the individual on-site facilities are not properly maintained, they can become a nuisance to the community and a basis for many complaints to municipal officials. It is also difficult to ensure adequate maintenance and long-term performance at levels they were design to provide. Prommesberger (1984) inspected approximately 100 on-site facilities built, or required by municipalities to be built, as a part of land developments over about a 10-year period. He concluded that a lack of adequate maintenance and implementation contributed to a loss of continued function or even presence of these facilities. He also concluded that a lack of institutional structures at the local government level was the major contributor to any of these facilities no longer being in existence or in original operational mode after their initial construction.



Photograph SO-3—On-site storage facility serving town home development (in background) coupled with park.

Facilities designed as part of a watershed planning process, in which the stormwater management needs for the watershed as a whole are developed in a staged regional plan, are called regional facilities. These are often planned and located as part of the District's master planning process. They are typically much larger than on-site facilities. The main disadvantage of the regional facilities is the lack of an institutional structure to fund their implementation early in the development process. Another disadvantage of regional facilities is that they can leave substantial portions of the stream network susceptible to increased flood peaks, and plans must be developed to take this condition into account. In addition, to promote water quality benefits, some form of on-site stormwater management is necessary upstream of the regional facilities. Examples include minimized directly connected impervious areas (MDCIA) that promote flow across vegetated surfaces utilizing "slow-flow" grassed swales and a number of other techniques described in Volume 3 of this *Manual* that reduce stormwater surface runoff volumes.

More economical and hydrologically reliable results can be achieved through stormwater management planning for an entire watershed that incorporates the use of regional facilities. Regional facilities also potentially offer greater opportunities in achieving multi-objective goals such as recreation, wildlife habitat, enhanced property value, open space, and others.

There are several types of stormwater storage facilities, whether they are classified as on-site or regional, namely:

1. Detention—Detention facilities provide temporary storage of stormwater that is released through an outlet that controls flows to pre-set levels. Detention facilities typically flatten and spread the

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inflow hydrograph, lowering the peak to the desired (i.e., master plan, pre-development, existing, etc.) flow rate. Often these facilities also incorporate features designed to meet water quality goals.

2. Retention—Retention facilities, as defined this chapter, store stormwater runoff without a positive outlet, or with an outlet that releases water at very slow rates over a prolonged period. These differ in nature and design from "retention ponds" described in Volume 3 of this *Manual* that are used for water quality purposes.

3. Conveyance (Channel) Storage—Conveyance, or channel routing, is an often-neglected form of storage because it is dynamic and requires channel storage routing analysis. Slow-flow and shallow conveyance channels and broad floodplains can markedly retard the build up of flood peaks and alter the time response of the tributaries in a watershed.

4. Infiltration Facilities—Infiltration facilities resemble retention facilities in most respects. They retain stormwater runoff for a prolonged period of time to encourage infiltration into the groundwater. These facilities are difficult to design and implement because so many variables come into play.

5. Other Storage Facilities—Storage can occur at many locations in urban areas for which special considerations typically apply to the use and reliance upon such conditions. Stormwater detention may occur at:

   a) *Random depressions*. Depressions can be filled in during development and cannot be relied upon as permanent.

   b) *Upstream of railroad and highway embankments*. If the designer intends to utilize roadway, railroad, or other embankments for detention storage, some form of ownership of the flood storage pool and some form of control of the outlet must be acquired. An agreement with the roadway, railroad, or other agency that insures the continued existence of the facility over time has to be reached before relying on the facility. In addition, it is necessary to demonstrate that (1) roadway, railroad or other embankment stability will not be compromised, (2) embankment overtopping during larger storms will not impact upstream or downstream properties, and (3) the storage facility will remain in place as a detention facility in perpetuity. Storage behind road, railroad, and other embankments can also be lost due to site grading and fill changes and/or the installation of larger culverts or bridges.

   c) *Water storage reservoirs.* Colorado State law specifically exempts the reliance of water storage reservoirs for flood control by downstream properties. If the designer or project developers want to utilize them for detention storage, some form of ownership of the flood

storage pool and outlet function must be acquired from the reservoir owner. An agreement with the reservoir owner that insures the continued existence of the facility or its detention function over time has to be reached before relying on such reservoirs. In addition, it is necessary to demonstrate that embankment and spillway are safe and stable to insure public safety.

It is beyond the scope of this *Manual* to address these kinds of specialized storage facilities in more detail, but readers are cautioned that the above-mentioned considerations must be taken into account before proposing their use as formal detention facilities.

Detention and retention facilities can be further subdivided into:

1. In-Line Storage—A facility that is located in-line with the drainageway and captures and routes the entire flood hydrograph. A major disadvantage with in-line storage is that it must be large enough to handle the total flood volume of the entire tributary catchment, including off-site runoff, if any.

2. Off-Line Storage—A facility that is located off-line from the drainageway and depends on the diversion of some portion of flood flows out of the waterway into the storage facility. These facilities can be smaller and potentially store water less frequently than in-line facilities.

Irrespective of which type of storage facility is utilized, the designer is encouraged to create an attractive, multipurpose facility that is readily maintainable and safe for the public, under both “dry” (i.e., dry weather) and “wet” (i.e., when runoff is occurring) conditions. Designers are also encouraged to consult with other specialists such as urban planners, landscape architects, and biologists during planning and design.

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3.0 HYDROLOGIC AND HYDRAULIC DESIGN BASIS

3.1 Procedures for the Sizing of Storage Volumes

Three procedures for the sizing of detention storage volumes and one for the sizing of retention storage volumes are described in this *Manual*. For detention facilities, two of the procedures may be applied to on-site facilities and facilities serving relatively small tributary areas. For detention facilities serving larger catchments or ones classified as regional, the *Manual* recommends only one design protocol for use within the District, as described below.

3.1.1 Use of Simplified On-Site Detention Sizing Procedures

The three simplified procedures for the sizing of on-site detention volumes described here are "empirical equations" (Section 3.2.2), the modified "Rational Formula-based FAA Method" (Section 3.2.3) and "Full-Spectrum Detention" (Section 3.2.4). The uses of empirical equations by themselves are only applicable for small catchments not exceeding 90 acres. The Rational Formula-based FAA procedure may be applied to tributary catchments up to 160 acres in size, but the District suggests that it is best to limit ther use to tributary areas of 90 acres or less.

The Excess Urban Runoff Control, called *Full Spectrum Detention*, method may be applied to catchments of up to one-square mile in size; however, the simplified approach described in this chapter, including the use of the spreadsheet for this method, is best limited to areas of 160 acres or less.

3.1.2 Use of Hydrograph Routing Detention Sizing Procedure

Whenever the area limits described above in Section 3.1.1. are exceeded (for tributary catchments larger than 90 acres for empirical equations and FAA Method and 160 acres for the *Full Spectrum Detention* method), the District recommends the use of hydrograph flood routing procedures (e.g., using CUHP-generated hydrographs and reservoir routing calculations). In addition, if there are upstream detention facilities in the watershed that catch and route runoff for portions of the upstream tributary area, hydrograph routing methods should be employed.

To be considered as a sub-regional or regional facility by the District, namely part of the major drainageway system, the detention basin has to have a tributary area of 130 acres or more.

If off-site tributary areas contribute runoff to an on-site detention facility, the total tributary area, assuming fully developed off-site land uses, must be included in the sizing of the on-site storage volumes in order to account for the total runoff volume in the watershed.

3.1.3 Water Quality Capture Volume in Sizing Detention Storage

When detention storage volume is sized for a site that also incorporates a water quality capture volume (WQCV) defined in Volume 3 of this *Manual*, check with the local jurisdiction to determine how to account for this volume. Some municipalities within the District will permit partial or full use of the WQCV within

the calculated 100-year volume. Others require that the 100-year volume be added to the WQCV. All jurisdictions require the WQCV be added to the 5- or 10-year volume. When clear written local criteria on this matter are absent, the District recommends that no less than 50% of the WQCV be added to the calculated 100-year volume for 100-year volumes obtained using empirical equations and the FAA Method. However, unless the local jurisdiction requires adding all or part of the WQCV to the 100-year volume obtained using the simplified *Full Spectrum Detention* design; District does not recommend adding any part of the WQCV to the 100-year volume. When the analysis is done using hydrograph routing methods, each level of controls needs to be accounted for and the resultant 100-year control volume used in final design.

3.2 Sizing of On-Site Detention Facilities

3.2.1 Maximum Allowable Unit Release Rates for On-Site Facilities

The maximum allowable unit release rates in the Denver area per acre of tributary catchment for on-site detention facilities for various design return periods are listed in Table SO-1. These maximum releases rates will apply for all on-site detention facilities unless other rates are recommended in a District-approved master plan. For regional facilities see Section 3.2.5.

Allowable unit release rates in Table SO-1 for each a soil group in the tributary catchment shall be area-weighted to composite the allowable unit release rate for the total catchment. Multiply this rate by the total tributary catchment's area to obtain the design release rates in cubic feet per second (cfs). Whenever Natural Resources Conservation Service (NRCS) soil surveys are not available, approximate their equivalent types using results of detailed soil investigations at the site.

Table SO-1—Maximum Unit Flow Release Rates (cfs/acre) from On-Site Detention Facilities

Design Return Period (Years)	NRCS Hydrologic Soil Group		
	A	B	C & D
2	0.02	0.03	0.04
5	0.07	0.13	0.17
10	0.13	0.23	0.30
25	0.24	0.41	0.52
50	0.33	0.56	0.68
100	0.50	0.85	1.00

3.2.2 Empirical Equations for the Sizing of On-Site Detention Storage Volumes

Urbonas and Glidden (1983), as part of the District's ongoing hydrologic research, conducted studies that evaluated peak storm runoff flows along major drainageways. The following set of empirical equations provided preliminary estimates of on-site detention facility sizing for areas within the District. They are

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intended for single return period control and not for use when off-site inflows are present or when multi-stage controls are to be used (e.g., 10- and 100-year peak control). In addition, these equations are not intended to replace detailed hydrologic and flood routing analysis, or even the analysis using the Rational Formula-based FAA method for the sizing of detention storage volumes. The District does not promote the use of these empirical equations. It does not object, however, to their use by local governments who have adopted them or want to adopt them as minimum requirements for the sizing of on-site detention for small catchments within their jurisdiction. If the District has a master plan that contains specific guidance for detention storage or sizing of on-site detention facilities, those guidelines should be followed instead. The empirical equations for NRCS Soil types B, C and D are as follows:

$$V_i = K_i A \qquad \text{(SO-1)}$$

for the 100-year:

$$K_{100} = \frac{(1.78I - 0.002I^2 - 3.56)}{900} \qquad \text{(SO-2)}$$

for the 10-year:

$$K_{10} = \frac{(0.95I - 1.90)}{1{,}000} \qquad \text{(SO-3)}$$

for the 5-year:

$$K_5 = \frac{(0.77I - 2.65)}{1{,}000} \qquad \text{(SO-4)}$$

For Soil Type A, Equations SO-1 and SO-2 tend to underestimate the needed 100-year detention volume. Instead, Equation SO-5 needs to be used to estimate the 100-year detention volume for Type A Soils (i.e., V_{100A}):

$$V_{100A} = \left(-0.00005501 \cdot I^2 + 0.030148 \cdot I - 0.12\right) \cdot \frac{A}{12} \qquad \text{(SO-5)}$$

in which:

V_i = required volume where subscript *i* = 100-, 10- or 5-year storm, as appropriate (acre-feet)

K_i = empirical volume coefficient where subscript *i* = 100-, 10- or 5-year storm, as appropriate

I = fully developed tributary catchment imperviousness (%)

A = tributary catchment area (acres)

Design Example 6.1 shows calculations of allowable release rate and storage requirement using empirical equations.

3.2.3 Rational Formula-Based Modified FAA Procedure

The Rational Formula-based Federal Aviation Administration (FAA) (1966) detention sizing method (sometimes referred to as the "FAA Procedure"), as modified by Guo (1999a), provides a reasonable estimate of storage volume requirements for on-site detention facilities. Again, this method provides sizing for one level of peak control only and not for multi-stage control facilities.

The input required for this Rational Formula-based FAA volume calculation procedure includes:

A = the area of the catchment tributary to the storage facility (acres)

C = the runoff coefficient

Q_{po} = the allowable maximum release rate from the detention facility based on Table SO-1 (cfs)

T_c = the time of concentration for the tributary catchment (see the RUNOFF chapter) (minutes)

P_1 = the 1-hour design rainfall depth (inches) at the site taken from the RAINFALL chapter for the relevant return frequency storms

The calculations are best set up in a tabular (spreadsheet) form with each 5-minute increment in duration being entered in rows and the following variables being entered, or calculated, in each column:

1. Storm Duration Time, *T* (minutes), up to 180 minutes.
2. Rainfall Intensity, *I* (inches per hour), calculated using Equation RA-3 from the RAINFALL chapter.
3. Inflow volume, V_i (cubic feet), calculated as the cumulative volume at the given storm duration using the equation:

$$V_i = CIA\left(60T\right) \qquad \text{(SO-6)}$$

4. Outflow adjustment factor *m* (Guo 1999a):

$$m = \frac{1}{2}\left(1 + \frac{T_c}{T}\right) \qquad 0.5 \le m \le 1 \text{ and } T \ge T_c \qquad \text{(SO-7)}$$

5. The calculated average outflow rate, Q_{av} (cfs), over the duration T:

$$Q_{av} = mQ_{po} \qquad \text{(SO-8)}$$

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6. The calculated outflow volume, V_o, (cubic feet), during the given duration and the adjustment factor at that duration calculated using the equation:

$$V_o = Q_{av}\left(60T\right) \quad \text{(SO-9)}$$

7. The required storage volume, V_S (cubic feet), calculated using the equation:

$$V_s = V_i - V_o \quad \text{(SO-10)}$$

The value of V_s increases with time, reaches a maximum value, and then starts to decrease. The maximum value of V_s is the required storage volume for the detention facility. Sample calculations using this procedure are presented in Design Example 6.2. The modified *FAA Worksheet* of the UD-Detention Spreadsheet performs these calculations.

3.2.4 Simplified Full-Spectrum Detention Sizing (Excess Urban Runoff Flow Control)

With urbanization, the runoff volume increases. Percentage-wise, this increase is much more noticeable for the smaller storm events than for the very big ones, such as the 100-year storm. Wulliman and Urbonas (2005) suggested a concept they termed *Full Spectrum Detention*. This concept was studied using extensive modeling, including continuous simulations of a calibrated watershed. Based on this modeling the original set of equations was slightly modified to increase the EURV by 10%. The protocol that resulted and that is described below reduced runoff peak flows from urbanized areas to more closely approximate the runoff peaks along major drainageways before urbanization occurred.

This concept captures a volume of runoff defined as the *Excess Urban Runoff Volume*" (EURV) and then releases it over approximately 72-hours. EURV is larger than the Water Quality Capture Volume (WQCV) defined in Volume 3 of this *Manual* and varies with the type of NRCS soil group upon which urbanization occurs. EURV includes within its volume the WQCV, which then makes it unnecessary to deal with it separately when the *Full Spectrum Detention* design is used. *Full Spectrum Detention* Equations SO-11, -12 and -13 may by used to find the EURV depths in watershed inches. They were developed using the hydrologic methods described in this *Manual*.

NRCS Soil Group A: $$EURV_A = 1.1 \cdot \left(2.0491 \cdot i - 0.1113\right) \quad \text{(SO-11)}$$

NRCS Soil Group B: $$EURV_B = 1.1 \cdot \left(1.2846 \cdot i - 0.0461\right) \quad \text{(SO-12)}$$

NRCS Soil Group C/D: $$EURV_{CD} = 1.1 \cdot \left(1.1381 \cdot i - 0.0339\right) \quad \text{(SO-13)}$$

in which, $EURV_K$ = Excess Urban Runoff Volume in watershed inches ($K = A, B$ or CD),

i = Imperviousness ratio (I/100)

By combining the capture and slow release of the EURV with the 100-year control volumes for Soil Types B, C and D recommended by Equations SO-1 and SO-2 or for Soil Type A recommended by Equation SO-5 with the 100-year release rates based on recommendations in Table SO-1, this concept was found to be more effective in controlling peak flow along major drainageways for almost all levels of storms than provided by the simplified equations or the FAA Method, even for relatively large urban catchments.

The EURV is found using volumes obtained for each soil type, which are then area weighted in proportion to the total catchment's area. The watershed inches of EURV are then converted to cubic feet or acre-feet. The total 100-year detention basin volume is found using Equations SO-1 and SO-2 for Type B, C and D soils or Equation SO-5 for Type A soils, which are also area-weighted by soil types and converted to cubic feet or acre feet. The outlet is designed to empty the EURV in approximately 72 hours. Volumes exceeding EURV are controlled by an outlet designed for a composite maximum 100-year release rate based on unit rates recommended in Table SO-1.

Equation 13a was developed to assist in the sizing of the openings of the perforated plate outlet to drain the EURV in 72 hours, provided the outlet follows the standardized design developed originally with the WQCV outlet for an Extended Detention Basin (EDB) described in Volume 3, namely the perforations are spaced vertically on 4" centers. Figure SO-8 depicts the results of this equation in graphical form. The equation and the figure are only applicable for water depths in the basin between one and eight feet and designers should not extrapolate beyond this range. Outlets needing greater or lesser depths than these need to be designed individually using ether EPA SWMM, UD-Detention spreadsheet or other appropriate software. The *Full-Spectrum Worksheet* of the UD-Detention Spreadsheet performs all of these calculations for the standardized designs, including adjustments for imperviousness due to Level 1 and 2 of MDCIA, accounts for the effects of various soil type distributions in the tributary catchment and has a provision for selecting the local government's policy in how the WQCV is treated as part of the 100-year volume, although the District does not recommend adding any portion of the WQCV to the 100-year volume calculated using this spreadsheet.

$$A = \left[\frac{EURV}{0.0166 \cdot H^2 + 0.2055 \cdot H + 0.1543} \right]^{\frac{1}{-0.0018 \cdot H^2 - 0.0068 \cdot H + 1.0015}} \qquad \text{SO-13a}$$

In which, A = open area per row of perforations, in square inches
H = maximum water depth in basin above the bottom of lowest perforation, in feet
$EURV$ = excess urban runoff volume, in acre feet

Whenever possible, it is suggested that circular orifice openings be used, beveled on the downstream side. The goal is to find a commonly available drill-bit size that will match the needed area with as few columns of perforations as possible. To achieve this, the designer should seek a drill bit size that will deliver an area within +5% and -10% of the one calculated using Equation SO-13a or Figure SO-8.

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3.2.5 Excess Urban Runoff Flow Control at Regional Facilities

The simplified full-spectrum detention concept described above is appropriate for volume and outlet sizing of detention facilities serving on-site watersheds of up to 160 acres. For full-spectrum basins serving larger watersheds, the EURV portion of the basin still needs to be sized using Equations SO-10 through SO-12 and the outlet designed to empty this volume in approximately 72-hours. The 100-year peak flow control volume above the EURV has to be sized, and its outlet designed, using full hydrograph routing protocols. The hydrograph routing option is also available for smaller sub-watersheds as well. Regardless of which 100-year sizing and outlet design option is used for regional facilities, the maximum 100-year release rates cannot exceed the release rates based on unit discharges recommended in Table SO-1 or pre-developed peak 100-year flow rates for the tributary watershed, whichever are less, or those recommended in a District accepted master plan.

3.2.6 Multi-Level Control

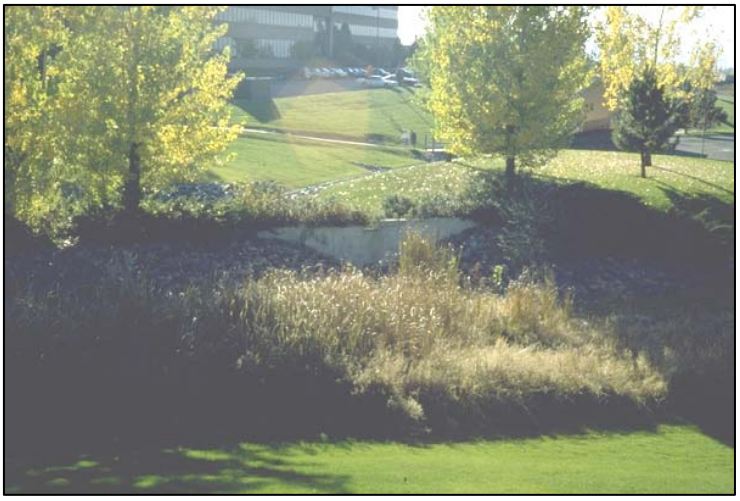
The District recommends that no more than two levels of controls, in addition to the WQCV controls, be used for on-site detention facilities. These levels can be the 10- or 100-year storm, in combination with the 2-, 5- or the 10-year storm, as appropriate. More levels of control may appear to provide increased protection, but the added complexity of design and the questionable accuracy of results rarely justifies it. As an alternative to this three-level control recommended above, one can chose the two-level control offered by Sections 3.2.4 and 3.2.5 above to achieve broader levels of peak runoff control and possibly less expensive outlet design.

3.2.7 On-Site Detention and UDFCD 100-year Floodplain Management Policy

While UDFCD has confidence in the ability of many on-site detention basins to control peak flow rates to predevelopment level for small urban catchments, this is not the case for larger watersheds. The complexities of predicting where each on-site detention basin is going to be installed as areas urbanize, how each is going to be designed and built, and then applying the detention routing technology on an evolving and diffuse system of control facilities is beyond anyone's ability to assess or predict. In addition, the UDFCD has no ability or power to insure that all on-site detention facilities will continue to be maintained and their function will not deteriorate over time. In fact, evidence suggests to the contrary (Prommersberger, 1984) that many on-site detention facilities do not receive needed maintenance and do not provide the original design function over time. Prommersberger (1984) found that many, in fact, have never been built as designed. In response to these complexities of implementation and future maintenance uncertaities, the UDFCD adheres to the following policies when developing hydrology for the delineation and regulation of the 100-year flood hazard zones within its boundaries:

1. Hydrology has to be based on fully developed watershed condition as estimated to occur, at a minimum, over the next 50 years.
2. No on-site detention basin will be recognized in the development of hydrology unless:

a. It serves a watershed that is larger than 130-acres, and
b. It provides a regional function, and
c. It is owned and maintained by a public agency, and
d. The public agency has committed itself to maintain the detention facility so that it continues to operate in perpetuity as designed and built.



Photograph SO-4—This on-site dry detention facility (note short concrete dam) promotes pollutant removal in smaller runoff events.

These policies are for the definition and administration of the 100-year floodplain and floodway zones and the design of facilities along major drainageways. They are not intended to discourage communities from using on-site detention, including the EURV control (i.e., Full-Spectrum Detention) discussed above. On-site detention can be very beneficial for stormwater quality and quantity management, reducing the sizes of local storm sewers and other conveyances, and providing a liability shield (defense) when needing to address the issue of keeping stormwater-related damages from increasing to downstream properties as lands are developed. However, unless detention is regional in nature with a government having property rights to operate and maintain it in perpetuity, and is designed in accordance with an approved master plan, it will not be considered eligible for District's maintenance assistance program (see Chapter 5 for maintenance eligibility discussion). Furthermore, Colorado law requires detention be provided to control the 100-year peak flow for all new development in the unincorporated portions of all counties.

3.3 Design Storms for Sizing Storage Volumes

Typically, more than one design storm usually is controlled when designing detention or retention facilities. Water quality storage and release is based on the recommendations in Volume 3 of this *Manual*. For drainage and flood control design, the 2-, 5-, 10-, 25- and 100-year design storms are often considered and used, as required by local municipality. Sizing may sometimes be driven by downstream conveyance system capacities and public safety concerns in addition to standard local detention sizing

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requirements. Sizing of emergency spillways may also require the use of design storms larger than the 100-year storm. What follows is a thumbnail description of the factors to consider for each.



Photograph SO-5—Multipurpose detention facilities are strongly encouraged, as they often become community focal points.

3.3.1 Water Quality Capture Volume

This was discussed in detail under Sections 3.1.3 and 3.2.4 for facilities that include quantity and quality storage, and the reader is referred to them. The specific recommendations for the sizing of the WQCV are given in Volume 3 of this *Manual*.

3.3.2 Drainage and Flood Control

Sizing of storage facilities and outlet works for flood control purposes is generally based on whether the facility is on-site or regional. For an individual development sites, local municipalities will dictate which design storms need to be addressed. On a watershed level, full system master planning studies are needed to identify the appropriate release rates for various design storms. Whenever a District-approved master plan recommends detention sites and release rates, or on-site detention/retention storage and release rates, this sizing and rates should be used in final design of detention/retention facilities. Other considerations that have to be taken into account include downstream system stability, the drainageway's capacity to convey discharges from the detention/retention facility in combination with the downstream runoff contributions, potential for flood damages to downstream properties, and other factors that may be specific to each situation.

3.3.3 Spillway Sizing

The overflow spillway of a storage facility should be designed to pass flows in excess of the design flow of the outlet works. When the storage facility falls under the jurisdiction of the Colorado State Engineer's Office (SEO), the spillway's design storm is prescribed by the SEO (SEO 1988). If the storage facility is not a jurisdictional structure, the size of the spillway design storm should be based upon the risk and

consequences of a facility failure. Generally, embankments should be fortified against and/or have spillways that, at a minimum, are capable of conveying the total not-routed peak 100-year storm discharge from a fully developed total tributary catchment, including all off-site areas, if any. Detailed analysis, however, of downstream hazards should be performed and may indicate that the embankment protection and/or spillway design needs to be for events much larger than the 100-year design storm.

3.3.4 Retention Facilities

A retention facility (a basin with a zero release rate or a very slow release rate) is used when there is no available formal downstream drainageway, or one that is grossly inadequate. When designing a retention facility, the hydrologic basis of design is difficult to describe because of the stochastic nature of rainfall events. Thus, sizing for a given set of assumptions does not ensure that another scenario produced by nature (e.g., a series of small storms that add up to large volumes over a week or two) will not overwhelm the intended design. For this reason, retention basins are not recommended as a permanent solution for drainage problems. They have been used in some instances as temporary measures until a formal system is developed downstream. When used, they can become a major nuisance to the community duo to problems that may include mosquito breeding, safety concerns, odors, etc.

When a retention basin is proposed as a temporary solution, the District recommends that it be sized to capture, as a minimum, the runoff equal to 1.5 times the 24-hour, 100-year storm plus 1-foot of freeboard. The facility also has to be situated and designed so that when it overtops, no human-occupied or critical structures (e.g., electrical vaults, homes, etc.) will be flooded, and no catastrophic failure at the facility (e.g., loss of dam embankment) will occur. It is also recommended that retention facilities be as shallow as possible to encourage infiltration and other losses of the captured urban runoff. When a trickle outflow can be accepted downstream or a small conduit can be built, provided and sized it in accordance with the locally approved release rates, preferably capable of emptying the full volume in 14 days or less.

3.4 Reservoir Routing of Storm Hydrographs for Sizing of Storage Volumes

The reservoir routing procedure for the sizing of detention storage volumes is more complex and time consuming than the use of empirical equations, FAA procedure or the simplified *Full Spectrum Detention* protocol. Its use requires the designer to develop an inflow hydrograph for the facility. This is generally accomplished using CUHP and UDSWM computer models as described in the RUNOFF chapter of this *Manual*. The hydrograph routing sizing method is an iterative procedure that follows the steps detailed below (Guo 1999b).

1. Select Location: The detention facility's location should be based upon criteria developed for the specific project. Regional storage facilities are normally placed where they provide the greatest overall benefit. Multi-use objectives such as the use of the detention facility as a park or for open space, preserving or providing wetlands and/or wildlife habitat, or others uses and community

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needs influence the location, geometry, and nature of these facilities.



Photograph SO-6—Public safety is an important design consideration for detention facilities, including the potential need for safety/debris racks on outfall structures, as shown in this dry pond.

2. Determine Hydrology: Determine the inflow hydrograph to the storage basin and the allowable peak discharge from the basin for the design storm events. The hydrograph may be available in published district outfall system planning or a major drainageway master plan report. The allowable peak discharge is limited by the local criteria or by the requirements spelled out in a District-approved master plan.

3. Initial Storage Volume Sizing: It is recommended that the initial size of the detention storage volume be estimated using the modified FAA method described in Section 3.2.3, the Full Spectrum Detention protocols in Section 3.2.4 or the hydrograph volumetric method detailed in Section 3.4.1.

4. Initial Shaping of the Facility: The initial shape of the facility should be based upon site constraints and other goals for its use discussed under item 1, above. This initial shaping is needed to develop a stage-storage-discharge relationship for the facility. The design spreadsheets provided on the CD version of this *Manual* are useful for initial sizing.

5. Outlet Works Preliminary Design: The initial design of the outlet works entails balancing the initial geometry of the facility against the allowable release rates and available volumes for each stage of hydrologic control. This step requires the sizing of outlet elements such as a perforated plate for controlling the releases of the WQCV, orifices, weirs, outlet pipe, spillways, etc.

6. Preliminary Design: A preliminary design of the overall detention storage facility should be completed using the results of steps 3, 4 and 5, above. The preliminary design phase is an

iterative procedure where the size and shape of the basin and the outlet works are checked using a reservoir routing procedure and then modified as needed to meet the design goals. The modified design is then checked again using the reservoir routing and further modified if needed. Though termed "preliminary design," the storage volume and nature and sizes of the outlet works are essentially in final form after completing this stage of the design. They may be modified, if necessary, during the final design phase.

7. Final Design: The final design phase of the storage facility is completed after the hydraulic design has been finalized. This phase includes structural design of the outlet structure, embankment design, site grading, a vegetation plan, accounting for public safety, spillway sizing and assessment of dam safety issues, etc.



Photograph SO-7—This retention pond has an embankment with upstream and downstream gentle sideslopes, which promotes dam safety and multipurpose use.

3.4.1 Initial Sizing

The intent of initial sizing of the facility is only to determine a starting point for the reservoir routing procedure that will be used to prepare the preliminary design for the facility. The initial sizing methods are not adequate for final design of the facility. Two methods for initial sizing are discussed below.

The Rational Formula-based modified FAA method may be used to find an initial storage volume for any size catchment. This technique for initial sizing yields best results when the tributary catchment area is less than 320 acres. The designer needs to understand that the design volumes may need to be adjusted significantly regardless of the tributary area once full hydrograph routing is performed.

It is also possible to use the inflow hydrograph, along with desired maximum release rates, to make an initial estimate of the required storage volume. This technique assumes that the required detention volume is equal to the difference in volume between the inflow hydrograph and the simplified outflow

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hydrograph. It is represented by the area between these two hydrographs from the beginning of a runoff event until the time that the allowable release occurs on the recession limb of the inflow hydrograph (Guo 1999b) (see Figure SO-1). The inflow hydrograph is generally obtained using CUHP/SWMM computer model computations. The outflow hydrograph can be approximated using a straight line between zero at the start of the runoff to a point where the allowable discharge is on the descending limb of the inflow hydrograph, T_p. The volume are calculated by setting up tabular calculations with the following columns:

1. The time T (in minutes) from 0 to T_p in 5-minute increments. T_p is the time (in minutes) where the descending limb of the inflow hydrograph is equal to the allowable release rate.

2. The inflow rate Q_i (cfs) to the detention basin corresponding to the time T. The inflow rate is an input value that is generally obtained from a CUHP/SWMM hydrologic analysis.

3. The outflow rate Q_o (cfs) calculated as:

$$Q_O = \frac{T}{T_p} Q_{po} \qquad \text{(SO-14)}$$

   in which, Q_{po} is the peak outflow rate, where allowable peak outflow rate is determined from a District master plan, local ordinance, or other considerations described in Section 3.3.2.

4. The incremental storage volume = (column 2 – column 3) · 300 seconds.

5. The total storage volume calculated as the sum of the values in column 4.

Design Example 6.3 illustrates this procedure.

The **Hydrograph Worksheet** of the UD-Detention Spreadsheet performs these computations.

3.4.2 Initial Shaping

The initial shaping of the storage basin provides a starting point for defining the stage-storage relationship. The stage-storage relationship has to be refined during preliminary design phase of the project. The initial shaping is easiest when regular geometry (such as a triangle, rectangle, or elliptical) is used for approximation. The detention volume needed for any specific design storm is combined with site constraints (e.g., size or depth limitations, number of control stages, etc.) and the simplified formulas describing the basin geometry in order to develop an initial depth, length, and width for the basin. Design spreadsheets can be used to assist in preliminary shaping of the basin. This does not mean that the District encourages the use of storage facilities with uniform geometric properties. To the contrary, the District encourages designers to collaborate with landscape architects to develop storage facilities that are visually attractive, fit into the fabric of the landscape, and enhance the overall character of an area. However, using regular geometries can speed up initial sizing of a non-uniformly shaped facility.

3.4.3 Outlet Works Design

Outlet works are structures that control the release rates from storage facilities. Figure SO-2 illustrates three concepts for detention basin outlets. Two are from Volume 3 of the *Manual* that provides for a three-level flow control including the control of the Water Quality Capture Volume (WQCV). The other is for a two-level control designed for release of the *Excess Urban Runoff Volume* (EURV) over 72-hours and control of the 100-year peak flow to a specified maximum rate. Both include an orifice plate for release of the WQCV or the EURV. The first concept also provides for the 2- to 10-year (or other return period) storm controls through drop boxes and orifices at the bottom of the boxes. The other provides and orifice at the bottom of one drop box to control the 100-year (or other return period) release rate. The weir length of the drop box is best oversized after reducing its length by the trash rack bars so as not to become the primary control when the trash rack has some clogging. The goal is to have the orifice at the bottom of the box and in front of the outlet pipe exercise the desired flow control at the maximum stage in the basin.

The hydraulic capacity of the various components of the outlet works (orifices, weirs, pipes) can be determined using standard hydraulic equations. The discharge pipe of the outlet works functions as a culvert. See the CULVERTS chapter of the *Manual* for guidance regarding the calculation of the hydraulic capacity of outlet pipes. The following discussion regarding weirs and orifices is adapted from *Urban Drainage Design Manual*, Hydraulic Engineering Circular No. 22 (Brown, Stein, and Warner 1996). A rating curve for the entire outlet can be developed by combining the rating curves developed for each of the components of the outlet and then selecting the most restrictive element that controls a given stage for determining the composite total outlet rating curve.

Design aids for the design of basins and outlet works are provided on several of the worksheets in the UD-Detention Spreadsheet available for downloading from the District's web site.

3.4.3.1 Orifices

Multiple orifices may be used in a detention facility, and the hydraulics of each can be superimposed to develop the outlet-rating curve. For a single orifice or a group of orifices, as illustrated in Figure SO-3a, orifice flow can be determined using Equation SO-15.

$$Q = C_o A_o (2gH_o)^{0.5} \qquad \text{(SO-15)}$$

in which:

Q = the orifice flow rate through a given orifice (cfs)

C_o = discharge coefficient (0.40 – 0.65)

A_o = area of orifice (ft^2)

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H_o = effective head on each orifice opening (ft)

g = gravitational acceleration (32.2 ft/sec^2)

If the orifice discharges as a free outfall, the effective head is measured from the centroid of the orifice to the upstream water surface elevation. If the downstream jet of the orifice is submerged, then the effective head is the difference in elevation between the upstream and downstream water surfaces.

For square-edged, uniform orifice entrance conditions, a discharge coefficient of 0.61 should be used. For ragged edged orifices, such as those resulting from the use of an acetylene torch to cut orifice openings in corrugated pipe, a value of 0.4 should be used.

3.4.3.2 Weirs

Relationships for sharp-crested, broad-crested, V-notch, and proportional weirs are provided below:

Sharp-Crested Weirs: Typical sharp-crested weirs are illustrated in Figures SO-4a through SO-4d. Equation SO-16 provides the discharge relationship for sharp-crested weirs with no end contractions (illustrated in Figure SO-4a):

$$Q = C_{scw} L H^{1.5} \qquad \text{(SO-16)}$$

in which:

Q = discharge (cfs)

L = horizontal weir length (ft)

H = head above weir crest excluding velocity head (ft)

H_c = height of weir crest above the approach channel bottom (ft)

C_{scw} = 3.27 + 0.4 (H/H_c)

The value of the coefficient C_{SCW} varies with the ratio H/H_c (see Figure SO-4c for definition of terms). When the ratio H/H_c less than 0.3, a constant C_{SCW} of 3.33 is often used.

Equation SO-17 provides the discharge equation for sharp-crested weirs with end contractions (illustrated in Figure SO-4b). As stated above, the value of the coefficient C_{SCW} varies with the ratio H/H_c and becomes a constant 3.33 when H/H_c is less than 0.3.

$$Q = C_{scw}(L - 0.2H) H^{1.5} \qquad \text{(SO-17)}$$

Another form of sharp crested weir is the *Cipoletti* weir. It is a trapezoidal weir with sides slope at 1-horizontal to 4-vertical. The equation for this weir is:

$$Q = 3.367 \cdot L \cdot H^{1.5} \qquad \text{(SO-17a)}$$

Sharp-crested weirs will be affected by submergence when the tailwater rises above the weir crest elevation, as shown in Figure SO-4d. The result will be that the discharge over the weir will be reduced.

The discharge equation for a submerged sharp-crested weir is:

$$Q_s = Q_r \left[1 - \left(\frac{H_2}{H_1} \right)^{1.5} \right]^{0.385} \qquad \text{(SO-18)}$$

in which:

Q_s = submerged flow (cfs)

Q_r = un-submerged weir flow from Equation SO-15 or SO-16 (cfs)

H_1 = upstream head above crest (ft)

H_2 = downstream head above crest (ft)

Flow over the top edge of the riser pipe can initially be treated, until the throat of the pipe takes over the hydraulic control, as flow over a sharp-crested weir with no end constrictions. Equation SO-17 should be used for this case.

Broad-Crested Weir: The equation typically used for a broad-crested weir is:

$$Q = C_{BCW} L H^{1.5} \qquad \text{(SO-18)}$$

in which:

Q = discharge (cfs)

C_{BCW} = broad-crested weir coefficient (This ranges from 2.38 to 3.32 as per Brater and King (1976). A value of 3.0 is often used in practice.)

L = broad-crested weir length (ft)

H = head above weir crest (ft)

V-Notch Weir: The discharge through a V-notch or triangular weir is shown in Figure SO-5 and can be calculated from the following equation:

$$Q = C_t \tan\left(\frac{\theta}{2}\right) H^{2.5} \qquad \text{(SO-20)}$$

in which:

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C_t = Coefficient for Triangular Weir taken from the table below

Q = discharge (cfs)

θ = angle of V-notch in degrees

H = head above the apex of V-notch (ft)

Depth H in feet	Coefficient C_t for V-Notch Angle θ			
	20°	45°	60°	90°
0.2	2.81	2.66	2.62	2.57
0.4	2.68	2.57	2.53	2.51
0.6	2.62	2.53	2.51	2.49
0.8	2.60	2.52	2.50	2.48

3.4.4 Preliminary Design

The preliminary design stage consists of refining the design of the basin (size, shape and elevation) and outlet structure (type, size, configuration). At this time, the basin's bottom may be sloped as needed to provide drainage to the outlet and/or trickle channel to prevent the bottom from becoming boggy and habitat for mosquito breeding. Preliminary design is an iterative process that determines the detention basin's outflow characteristics given the stage-storage-discharge parameters of the basin and the inflow hydrograph(s). The stage-storage-discharge characteristics are modified as needed after each model run until the outflow from the basin meets the specified flow limit. No description of the theory of reservoir routing is provided in this *Manual*. The subject is well described in many hydrology reference books (Viessman and Lewis 1996; Guo 1999b).

Reservoir modeling can be carried out in a number of different ways. The EPA SWMM model provides for reservoir routing. The modeler provides a stage-discharge relationship for a reservoir outlet junction and the stage-surface area relationship for the storage junction of the model or the detention facility. The stage-surface area relationship is determined by finding the water surface areas of the basin at different depths or elevations, which are then used by the model to calculate the incremental volumes used as the stage rises and falls. If the storage facility is modeled as part of a larger system being addressed through a master planning effort, the SWMM model must be used. For the design of individual detention sites that goes into greater detail than used in watershed master planning model, the District's UD POND software provides a reliable and relatively easy tool to facilitate detention basin design.

3.4.5 Final Design

The final design of the storage facility entails detailed hydraulic, structural, geotechnical, and civil design. This includes detailed grading of the site, embankment design, spillway design, outlet works hydraulic and structural design, trash rack design, consideration of sedimentation and erosion potential within and

downstream of the facility, liner design (if needed), etc. Collaboration between geotechnical engineers, structural engineers, hydrologic and hydraulic engineers, land planners, landscape architects, biologists, and/or other disciplines is encouraged during the preliminary and final design phases.

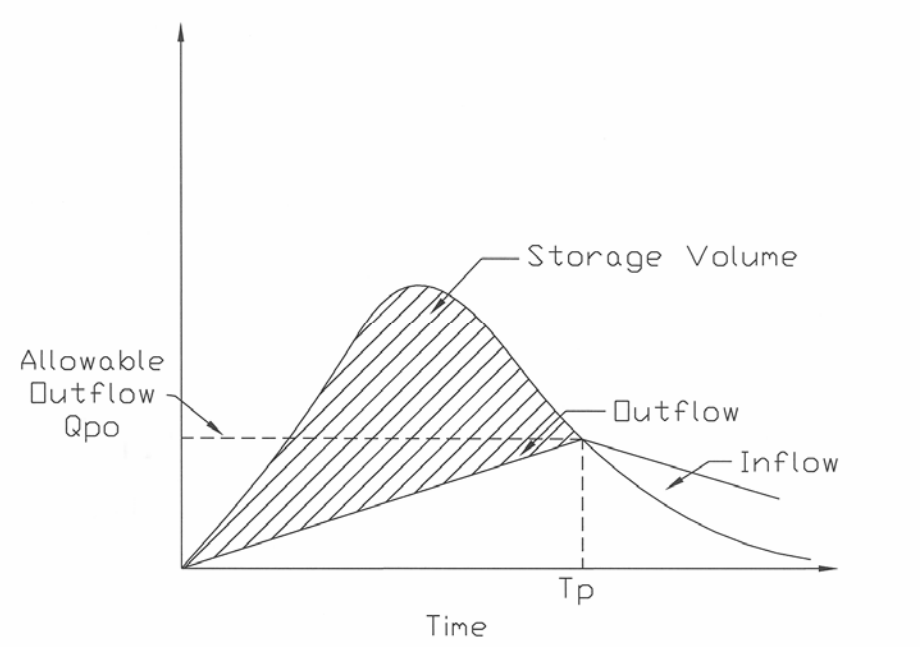

Figure SO-1—Hydrograph Volumetric Method for Initial Basin Pre-Sizing

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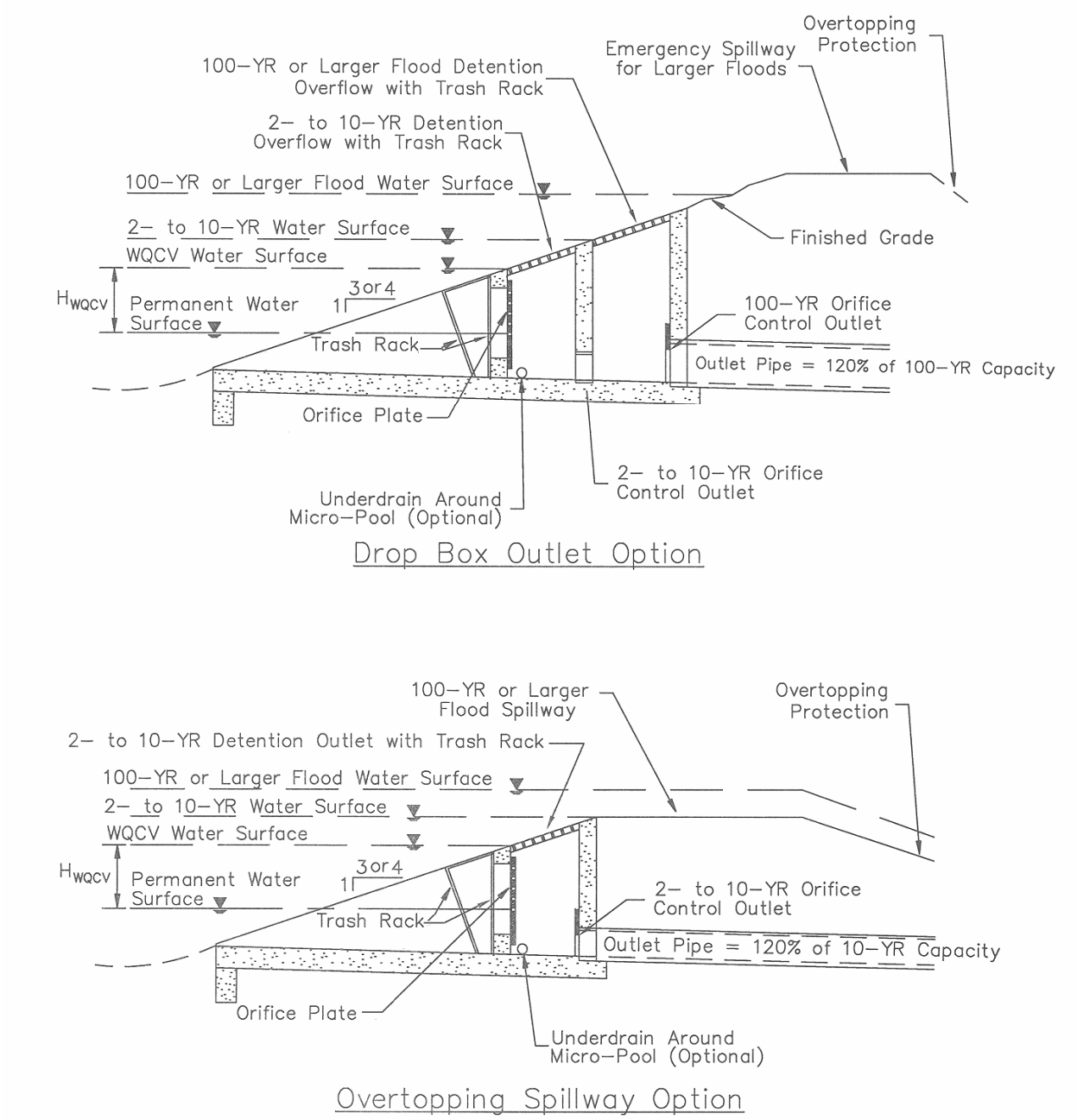
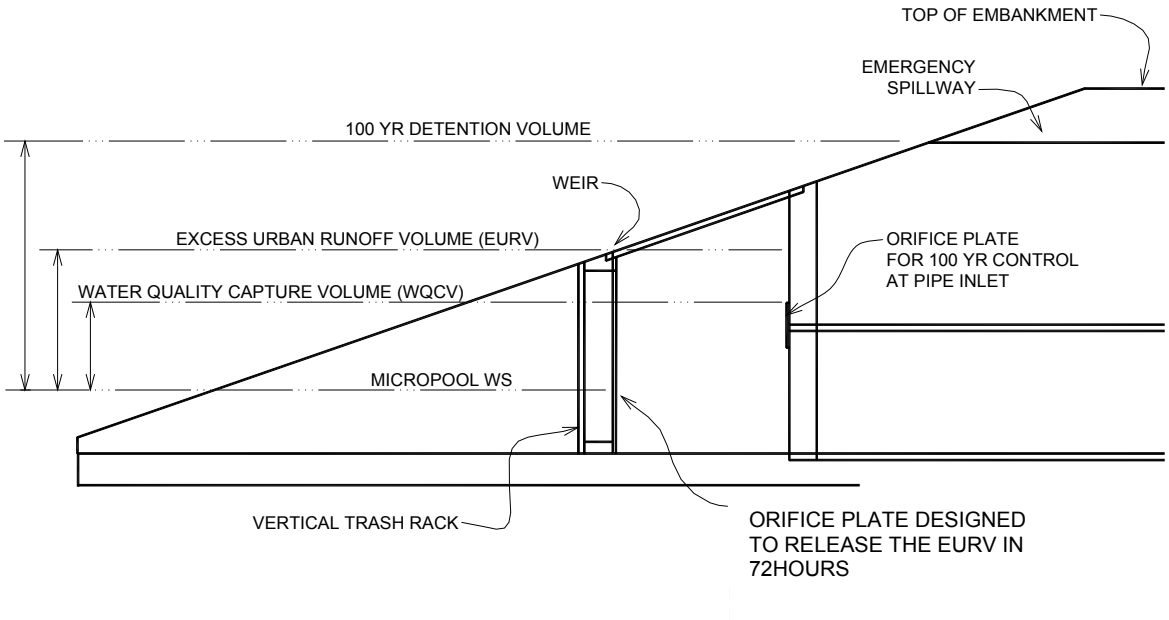


Figure SO-2—Typical Outlet Structure Profiles
(Sheet 1 of 2: Three-Level Peak Flow Control Case)



EXAMPLE OUTLET STRUCTURE

Figure SO-2—Typical Outlet Structure Profiles
(Sheet 2 of 2: Full Spectrum Detention Two-Level Flow Control Case)

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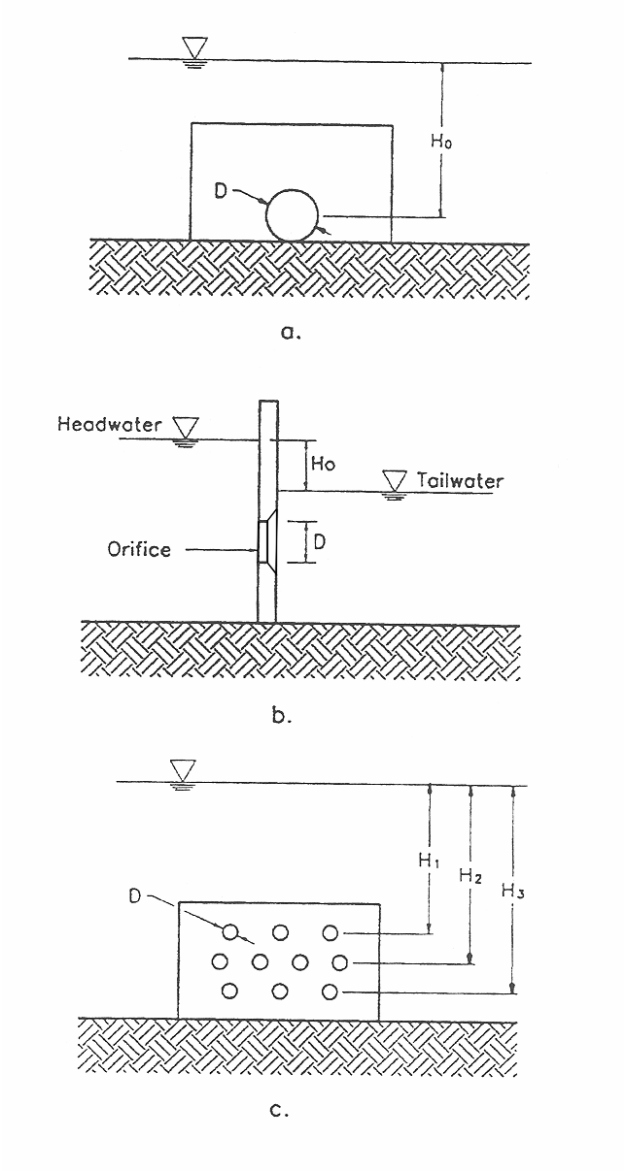

Figure SO-3—Illustration Defining Hydraulic Head for Flow through Orifice(s)

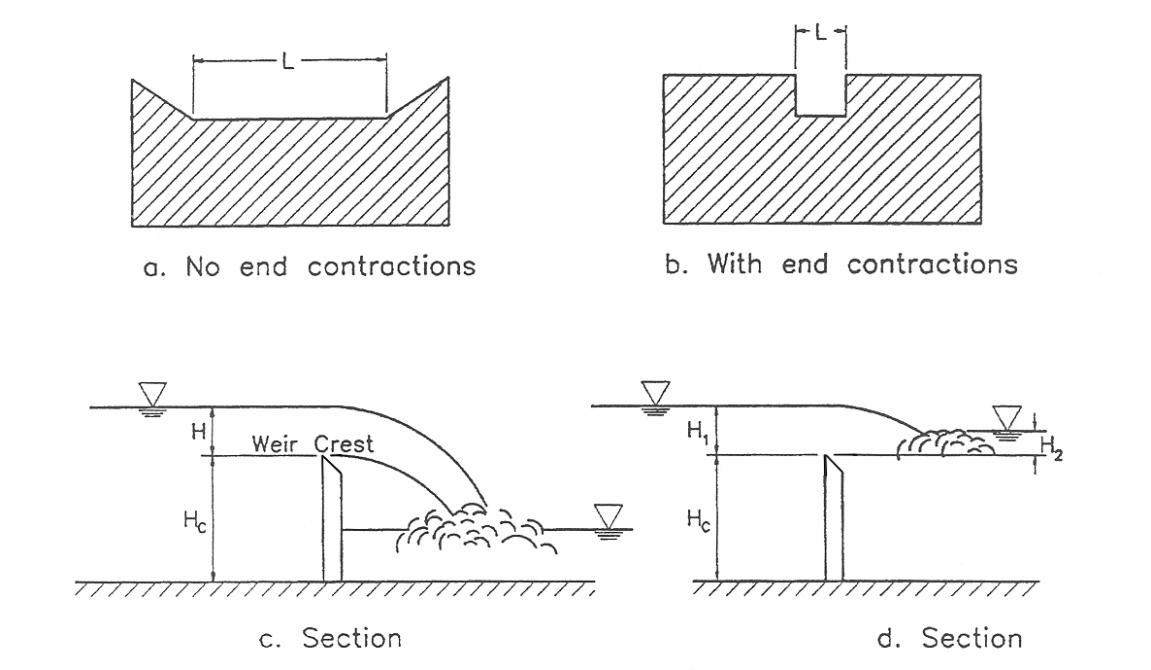

Figure SO-4—Sharp-Crested Weirs

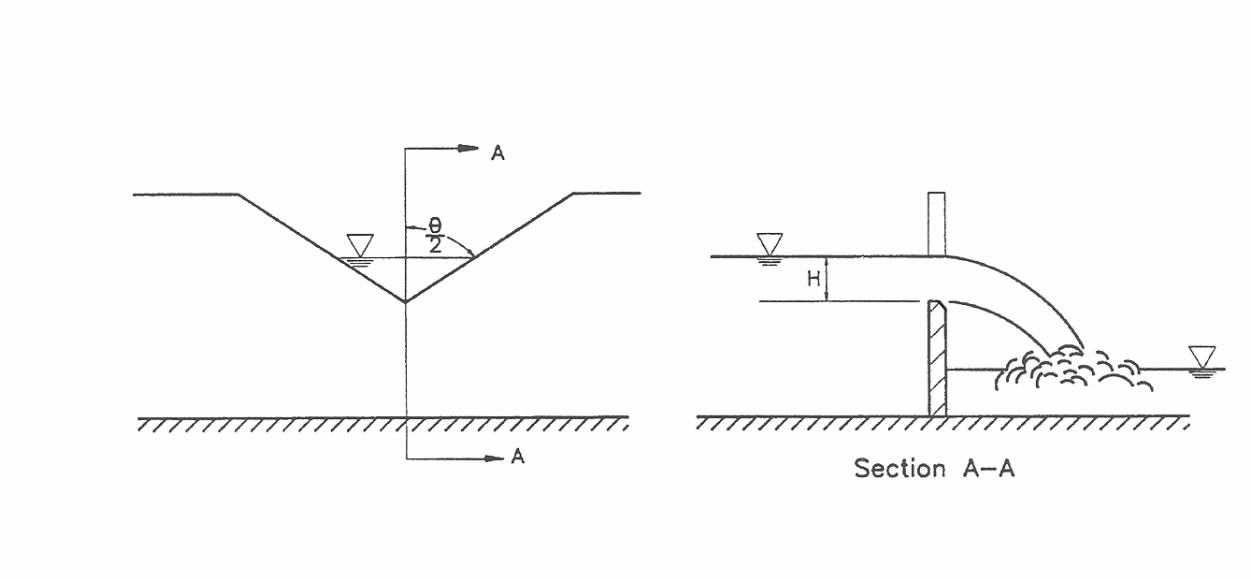

Figure SO-5—V-Notch Weir

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4.0 FINAL DESIGN CONSIDERATIONS

Final design of a storage facility should recognize the kinds of considerations described in this section. It is beyond the scope of this *Manual* to provide detailed dam design guidance. There are many excellent references in this regard such as *Design of Small Dams* (U.S. Bureau of Reclamation 1987). The District urges all designers to review and adhere to the guidance in such references because the failure of even small embankments can have serious consequences for the public and the municipalities downstream of the embankment. General guidelines for the final design phase of detention or retention facilities follows.

4.1 Storage Volume

The determination of storage volume for quantity control is described earlier in this chapter. If the storage facility includes a WQCV, the appropriate flood storage volume should be provided, one that is in addition to the WQCV, as discussed under Sections 3.1.3 and 3.2.4. Determination of the WQCV is described in Volume 3 of the *Manual*. In the case of on-site detention, if the Excess Urban Runoff Volume is to be provided (i.e., Full Spectrum Detention) in conjunction with the 100-year volume obtained using empirical equations, no additional volume for WQCV needs to be provided within the 100-year basin. When using the Full Spectrum Detention concept with regional detention, the flood control volume has to be calculated using full hydrograph routing procedures.

4.2 Potential for Multiple Uses

Whenever desirable and feasible, incorporate water quality detention into a larger flood control facility. Also, when feasible, provide for other urban uses such as active or passive recreation and wildlife habitat. If multiple uses are being contemplated, use the multiple-stage detention basin to limit inundation of passive recreational areas to one or two occurrences a year and active recreation areas to once every two years. Generally, the area within the WQCV is not well suited for active or passive recreation facilities such as ballparks, playing fields, picnic areas, wildlife habitat, or hiking trails. These are best located above the water quality storage level.

4.3 Geometry of Storage Facilities

The geometry of a storage facility depends on specific site conditions such as adjoining land uses, topography, geology, preserving/creating wildlife habitat, volume requirements, etc. Several key features should be incorporated in all storage facilities located within the District (see Figure SO-6). These include (a) 4:1 or flatter side slopes of all banks, (b) low-flow or trickle-flow channel unless a permanent pool takes its place, (c) forebay, (d) pond bottom sloped at least 1.0 percent to drain toward the low-flow or trickle-flow channel or the outlet, (e) micro pool at the outlet for Extended Detention Basins in Volume 3 of this *Manual*, and (f) emergency spillway or fortification of the embankment to prevent catastrophic failure when overtopped.

It is desirable to shape the water quality portion of the facility with a gradual expansion from the inlet and a gradual contraction toward the outlet, thereby minimizing short-circuiting. Storage facility geometry and layout are best developed in concert with a land planner/landscape architect.

4.4 Embankments and Cut Slopes

If the storage facility is "jurisdictional," namely, subject to regulation by the Colorado State Engineer's Office (SEO), the embankment shall be designed, constructed and maintained to meet SEO most-current criteria for jurisdictional structures. The design for an embankment of a stormwater detention or retention storage facility should be based upon a site-specific engineering evaluation. In general, the embankment should be designed to not catastrophically fail during the 100-year and larger storms that the facility may encounter. The following criteria apply in many situations (ASCE and WEF 1992):

1. Side Slopes—For ease of maintenance, the side slopes of the embankment should not be steeper than 3H:1V, with 4H:1V preferred. The embankment's side slopes should be well vegetated, and soil-riprap protection (or the equivalent) may be necessary to protect it from wave action on the upstream face, especially in retention ponds.

2. Freeboard—The elevation of the top of the embankment shall be a minimum of 1 foot above the water surface elevation when the emergency spillway is conveying the maximum design or emergency flow. When the embankment is designed to survive its overtopping without failure, freeboard requirements may be waived. When relevant, all SEO dam safety criteria must be carefully considered when determining the freeboard capacity of an impoundment.

3. Settlement—The design height of the embankment should be increased by roughly 5 percent to account for settlement. All earth fill should be free from unsuitable materials and all organic materials such as grass, turf, brush, roots, and other organic material subject to decomposition. The fill material in all earth dams and embankments should be compacted to at least 95 percent of the maximum density based on the Modified Proctor method of ASTM D698 testing.

4. Emergency Spillway—An emergency spillway will often be needed to convey flows that exceed the primary outlet capacity, unless the embankment is designed to convey overtopped flows without failure (e.g., buried soil cement, grouted boulders, concrete walls with splash pads, etc.).

4.5 Linings

A storage facility may require an impermeable clay or synthetic liner for a number of reasons. Stormwater detention and retention facilities have the potential to raise the groundwater level in the vicinity of the basin. If the basin is close to structures or other facilities that could be damaged by raising the groundwater level, consider lining the basin with an impermeable liner. An impermeable liner may also be warranted in a retention pond where the designer seeks to limit seepage from a permanent pool.

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Alternatively, there are situations where the designer may seek to encourage infiltration of stormwater into the ground. In this situation, a layer of permeable material may be warranted.

4.6 Inlets

Inlets to the detention facility should incorporate energy dissipation to limit erosion. They should be designed in accordance with drop structure or impact stilling basin criteria in the HYDRAULIC STRUCTURES chapter of this *Manual*, or using other approved energy dissipation structures. In addition, incorporate forebays or sediment traps at all inflow points to detention facilities to deposit coarse sediment being delivered by stormwater to the facility. These forebays will need regular maintenance to lessen the sediment being transported and deposited on the storage basin's bottom.

4.7 Outlet Works

Outlet works should be sized and structurally designed to release at the specified flow rates without structural or hydraulic failure. The design guidance for outlet works used for water quality purposes is included in Volume 3 of the *Manual* and for full-spectrum detention earlier in this chapter.

4.8 Trash Racks

Provide trash racks of sufficient size that do not interfere with the hydraulic capacity of the outlet. See Figure SO-7 for minimum trash rack sizes.

4.9 Vegetation

The type of grass used in vegetating a newly constructed storage facility is a function of the frequency and duration of inundation of the area, soil types, whether native or non-native grasses are desired, and the other potential uses (park, open space, etc.) of the area. A planting plan should be developed for new facilities to meet their intended use and setting in the urban landscape. Generally, trees and shrubs are not recommended on dams or fill embankments (see the REVEGETATION chapter). However, use of trees on the sides of detention basins will not interfere with their flood control operation of increase maintenance need significantly. Also, sparse planting of tree on bottoms of larger regional detention basins may also be acceptable as long as they are not located near inlets and outlet or on the emergency spillway(s) and will not interfere significantly with maintenance. At the same time use of shrubs on the banks and bottom, while not affecting the flood routing, can increase maintenance significantly by providing traps for debris that are difficult to clean and obstructions for the mowing of grasses.

4.10 Operation and Maintenance

Maintenance considerations during design include the following (ASCE and WEF 1992).

1. Use of flat side slopes along the banks and the installation of landscaping that will discourage

entry (thick, thorny shrubs) along the periphery near the outlets and steeper embankment sections are advisable. Also, use of safety railings at vertical or very steep structural faces is needed to public safety. If the impoundment is situated at a lower grade than and adjacent to a highway, installation of a guardrail is in order. Providing features to discourage public access to the inlet and outlet areas of the facility should be considered.

2. The facility should be accessible to maintenance equipment for removal of silt and debris and for repair of damages that may occur over time. Easements and/or rights-of-way are required to allow access to the impoundment by the owner or agency responsible for maintenance.

3. Bank slopes, bank protection needs, and vegetation types are important design considerations for site aesthetics and maintainability.

4. Permanent ponds should have provisions for complete drainage for sediment removal or other maintenance. The frequency of sediment removal will vary among facilities, depending on the original volume set aside for sediment, the rate of accumulation, rate of growth of vegetation, drainage area erosion control measures, and the desired aesthetic appearance of the pond.

5. For facilities designed for multipurpose use, especially those intended for active recreation, the play area might need special consideration during design to minimize the frequency and periods of inundation and wet conditions. It may be advisable to provide an underground tile drainage system if active recreation is contemplated.

6. Adequate dissolved oxygen supply in ponds (to minimize odors and other nuisances) can be maintained by artificial aeration. Use of fertilizer and EPA approved pesticides and herbicides adjacent to the permanent pool pond and within the detention basin should be controlled.

7. Secondary uses that would be incompatible with sediment deposits should not be planned unless a high level of maintenance will be provided.

8. French drains or the equivalent are almost impossible to maintain, and should be used with discretion where sediment loads are apt to be high.

9. Underground tanks or conduits designed for detention should be sized and designed to permit pumping or multiple entrance points to remove accumulated sediment and trash.

10. All detention facilities should be designed with sufficient depth to allow accumulation of sediment for several years prior to its removal.

11. Permanent pools should be of sufficient depth to discourage excessive aquatic vegetation on the bottom of the basin, unless specifically provided for water quality purposes.

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12. Often designers use trash racks and/or fences to minimize hazards. These may become trap debris, impede flows, hinder maintenance, and, ironically, fail to prevent access to the outlet. On the other hand, desirable conditions can be achieved through careful design and positioning of the structure, as well as through landscaping that will discourage access (e.g., positioning the outlet away from the embankment when the permanent pool is present, etc.). Creative designs, integrated with innovative landscaping, can be safe and can also enhance the appearance of the outlet and pond. Such designs often are less expensive initially.

13. To reduce maintenance and avoid operational problems, outlet structures should be designed with no moving parts (i.e., use only pipes, orifices, and weirs). Manually and/or electrically operated gates should be avoided. To reduce maintenance, outlets should be designed with openings as large as possible, compatible with the depth-discharge relationships desired and with water quality, safety, and aesthetic objectives in mind. One way of doing this is to use a larger outlet pipe and to construct orifice(s) in the headwall to reduce outflow rates. Outlets should be robustly designed to lessen the chances of damage from debris or vandalism. The use of thin steel plates as sharp-crested weirs is best avoided because of potential accidents, especially with children. Trash/safety racks must protect all outlets.

14. Clean out all forebays and sediment traps on a regular basis or when routine inspection shows them to be ¼ to ½ full.

See Volume 3 of this *Manual* for additional recommendations regarding operation and maintenance of water quality related facilities, some of which also apply to detention facilities designed to meet other objectives.



Photograph SO-8—Maintenance considerations must be carefully accounted for during design, with sediment accumulation a particular concern.

4.11 Access

All weather stable access to the bottom, inflow, forebay, and outlet works areas shall be provided for maintenance equipment. Maximum grades should be no steeper than 10 percent, and a solid driving surface of gravel, rock, concrete, or gravel-stabilized turf should be provided.

4.12 Geotechnical Considerations

The designer must take into full account the geotechnical conditions of the site. These considerations may include issues related to embankment stability, geologic hazards, seepage, and other site-specific issues.

It may be necessary to confer with a qualified geotechnical engineer during both design and construction, especially for the larger detention and retention storage facilities.

4.13 Environmental Permitting and Other Considerations

The designer must take into account environmental considerations surrounding the facility and the site during its selection, design and construction. These can include regulatory issues such as (a) whether the facility will be located on a jurisdictional wetland, (b) whether the facility is to be located on a waterway that is regulated by the U.S. Army Corps of Engineers as a “Waters of the U.S.”, and (c) whether there are threatened and endangered species or habitat in the area.

There are also non-regulatory environmental issues that should be taken into account. Detention facilities can become breeding grounds for mosquitoes unless they are properly designed, constructed and maintained. Area residents may view riparian habitat destruction necessary for construction of the facility objectionably. Considerations of this kind must be carefully taken into account and early discussions with relevant federal, state and local regulators are recommended.

In addition, under Colorado Water Law, storage impoundments can be subject to regulation from a water rights perspective by the SEO. For larger facilities, particularly those with permanent pools, the designer is encouraged to check with the SEO or a qualified water rights attorney to determine which water rights regulations apply.

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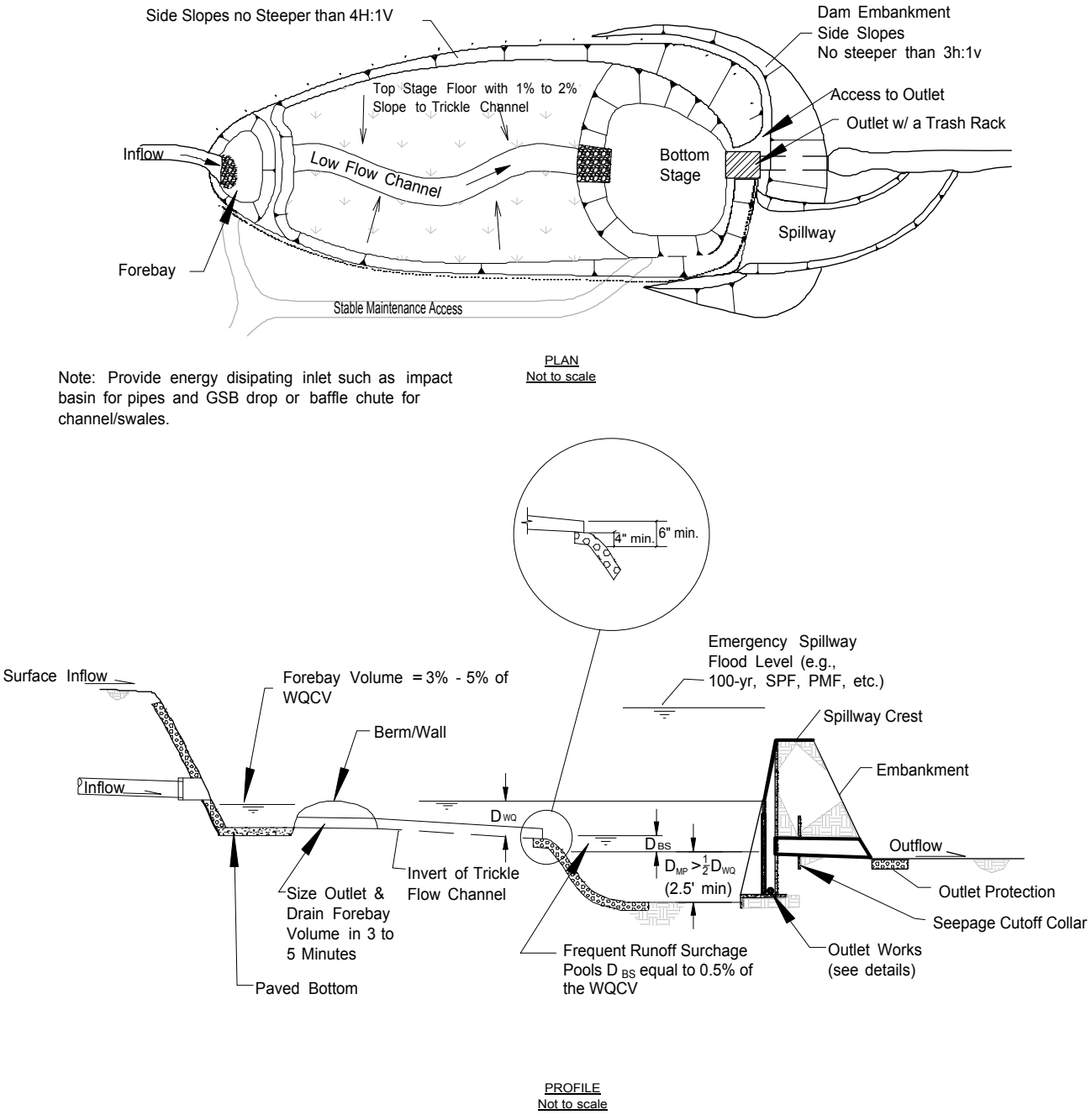

Figure SO-6—Plan and Profile of an Extended Detention Basin in a Flood Control Detention Basin

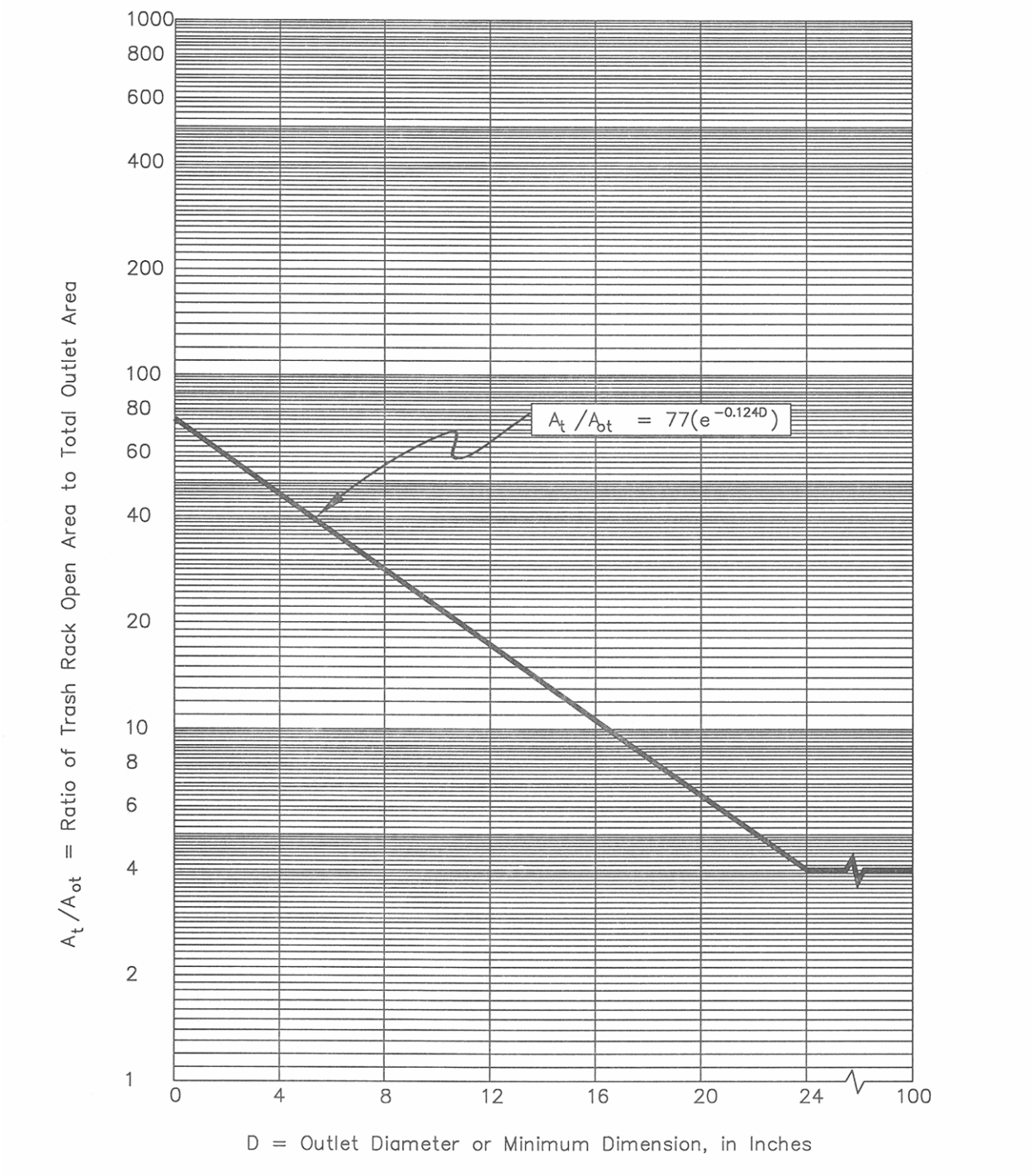

Figure SO-7—Minimum Trash Rack Open Area—Extended Range

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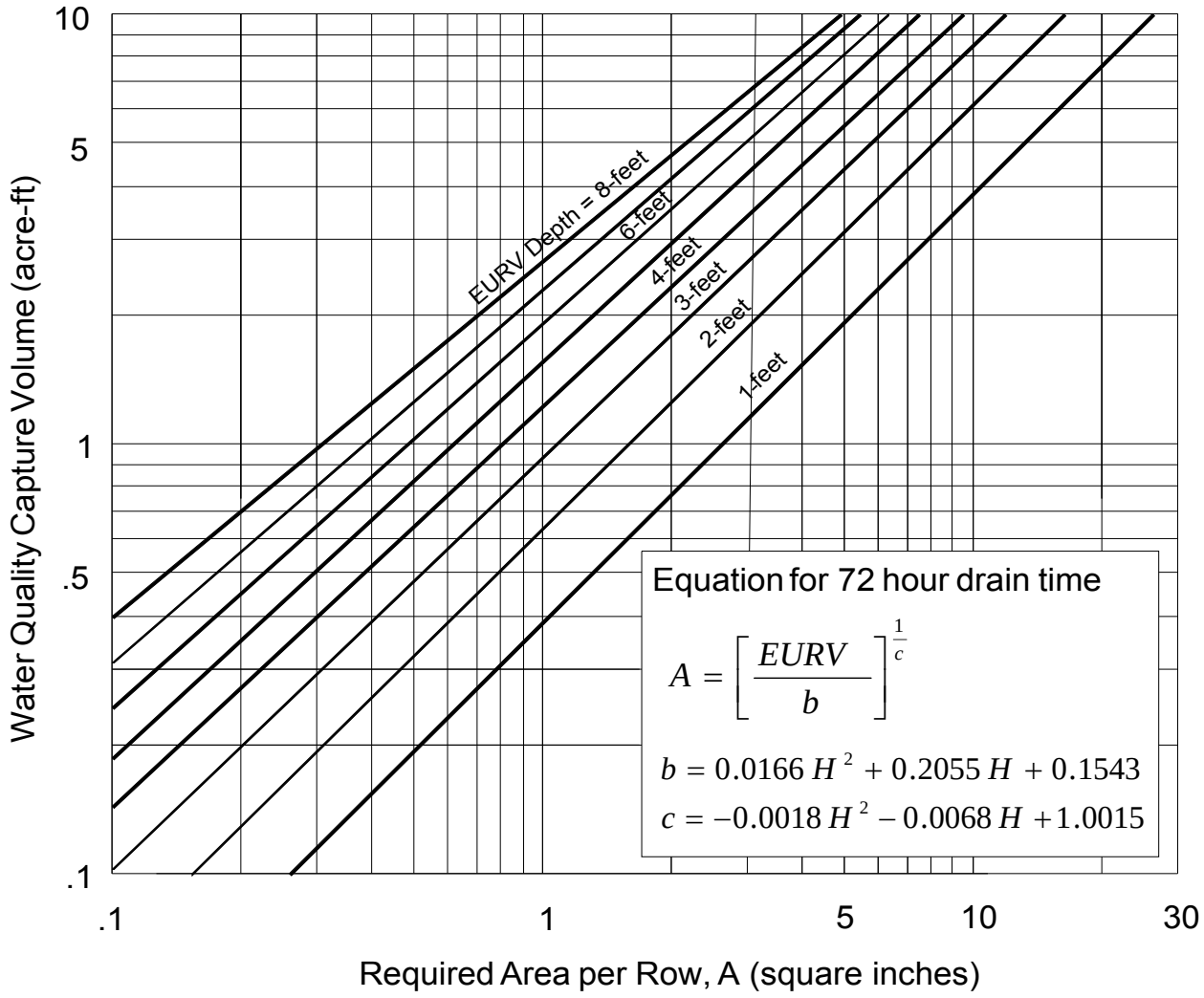

Figure SO-8—Outlet Sizing for EURV Control with 72-hour Drain Time for On-Site Detention

5.0 DISTRICT MAINTENANCE ELIGIBILITY FOR DETENTION FACILITIES

The District has a program to assist local jurisdictions in the on-going maintenance of major drainage facilities including detention facilities. These guidelines change over time as budgets, priorities and needs of the community change. Check the District's Web site (www.udfcd.org) for the most-current maintenance eligibility requirements. Maintenance Eligibility Guidelines as of June 2001 are provided on the CD version of this *Manual*.

There are some common features for which the District's policy is unlikely to change over time. One is the requirement that the facility be owned by or be under control of a public body. "Public body" is defined as a local government (city or county), special district (such as a park district), or a metropolitan district that has a service plan that includes the maintenance and operation of drainage facilities. The public body has to have a reliable funding source to fund maintenance. Legal maintenance access to the detention facility must be made available to the District by the local jurisdiction in accordance with any of the following criteria:

1. The facility is owned by a public body that has accepted primary maintenance responsibility for it.
2. The ownership of the facility is by a private entity (such as a homeowners association owning common areas), but a body has accepted primary maintenance responsibility and has a maintenance access easement(s) that allows it to perform maintenance if the owner does not. Easements crossing individual lots are not acceptable.

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6.0 DESIGN EXAMPLES

6.1 Example—Empirical Equations Sizing of a Detention Basin

Determine the required detention volume and allowable release rate for the 10-year and 100-year storm events for a 15-acre site that is in a jurisdiction that has adopted the empirical detention requirements and release rates shown in Section 3.2.1. The NRCS soil survey shows the site has hydrologic soil group B soils. The site will have a developed percentage imperviousness of 45%.

Examination of the District-approved master plan for the area indicates that the current empirical detention requirements for the area may be used. Examination of topographic mapping for the area indicates that no up-gradient off-site flows will traverse the site.

Determine the allowable release rates from Table SO-1:

10-year release rate = 0.23 · 15 acres = 3.45 cfs

100-year release rate = 0.85 · 15 acres = 12.75 cfs

Determine the 10-year required storage volume from Equations SO-1 and SO-3:

Using Equation SO-3, K_{10} = {(0.95 · 45) – 1.9}/1000 = 0.041

Using Equation SO-1, V_{10} = 0.041 · 15 acres = 0.61 acre-feet

The detention required for the 10-year storm is 0.61 acre-feet

Determine the 100-year required storage volume from Equations SO-1 and SO-2:

Using Equation SO-2, K_{100} = {(1.78 · 45) – (0.002 · 45^2) –3.56}/900 = 0.081

Using Equation SO-1, V_{100} = 0.081 · 15 acres = 1.21 acre-feet

The detention required for the 100-year storm is 1.21 acre-feet

6.2 Example—Rational Method Analysis

Use the FAA method to determine the required detention volume for the 100-year storm event for a 15-acre site that will have a developed percentage imperviousness of 45%. The NRCS soil survey shows the site has hydrologic soil group B soils. The allowable release rate from the basin has to be limited to the unit values in Table SO-1. The time of concentration has been calculated at 12 minutes. The 100-year, 1-hour point precipitation is 2.6 inches.

A runoff coefficient, C, of 0.51 is determined using Table RO-5 of the RUNOFF chapter (the 45% row and

100-year storm column of the type B soils table equals 0.51). The calculations are shown in spreadsheet form UD-Detention workbook in Table SO-2.

Table SO-2—FAA Method Calculations
(From UD-Detention Workbook)

Determination of Detention Volume Using Modified FAA Method

Rainfall durations must be entered in an increasing order.

Rainfall Duration minutes (input)	Rainfall Intensity inch/hr (output)	Inflow Volume cubic feet (output)	Adjustment Factor (output)	Average Outflow cfs (output)	Outflow Volume cubic feet (output)	Storage Volume cubic feet (output)
0.00	12.02	0				
5.00	8.72	20,021	1.00	12.75	3,825	16,196
10.00	6.95	31,902	1.00	12.75	7,650	24,252
15.00	5.83	40,119	0.90	11.48	10,328	29,791
20.00	5.05	46,316	0.80	10.20	12,240	34,076
25.00	4.47	51,257	0.74	9.44	14,153	37,105
30.00	4.02	55,351	0.70	8.93	16,065	39,286
35.00	3.66	58,838	0.67	8.56	17,978	40,861
40.00	3.37	61,873	0.65	8.29	19,890	41,983
45.00	3.13	64,559	0.63	8.08	21,803	42,757
50.00	2.92	66,967	0.62	7.91	23,715	43,252
55.00	2.74	69,150	0.61	7.77	25,628	43,522
60.00	2.58	71,147	0.60	7.65	27,540	43,607
65.00	2.45	72,987	0.59	7.55	29,453	43,535
70.00	2.32	74,694	0.59	7.47	31,365	43,329
75.00	2.22	76,287	0.58	7.40	33,278	43,010
80.00	2.12	77,780	0.58	7.33	35,190	42,590
85.00	2.03	79,186	0.57	7.28	37,103	42,083
90.00	1.95	80,514	0.57	7.23	39,015	41,499
95.00	1.88	81,774	0.56	7.18	40,928	40,846
100.00	1.81	82,972	0.56	7.14	42,840	40,132
105.00	1.75	84,114	0.56	7.10	44,753	39,362
110.00	1.69	85,206	0.55	7.07	46,665	38,541
115.00	1.63	86,252	0.55	7.04	48,578	37,675
120.00	1.58	87,256	0.55	7.01	50,490	36,766
125.00	1.54	88,222	0.55	6.99	52,403	35,820
130.00	1.49	89,152	0.55	6.96	54,315	34,837
135.00	1.45	90,050	0.54	6.94	56,228	33,823
140.00	1.41	90,917	0.54	6.92	58,140	32,777
145.00	1.38	91,757	0.54	6.90	60,053	31,704
150.00	1.34	92,569	0.54	6.89	61,965	30,604
155.00	1.31	93,358	0.54	6.87	63,878	29,480
160.00	1.28	94,123	0.54	6.85	65,790	28,333
165.00	1.25	94,867	0.54	6.84	67,703	27,164
170.00	1.23	95,590	0.54	6.83	69,615	25,975
175.00	1.20	96,295	0.53	6.81	71,528	24,767
180.00	1.17	96,981	0.53	6.80	73,440	23,541

Stormwater Detention Volume (Cubic Feet) = 43,607

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The required storage volume is 43,607 cubic feet (approx. 1.0 acre-foot). This compares to 1.21 acre-feet calculated for the same catchment in Design Example 6.1 using the empirical equations.

6.3 Example—Hydrograph Procedure Preliminary Sizing

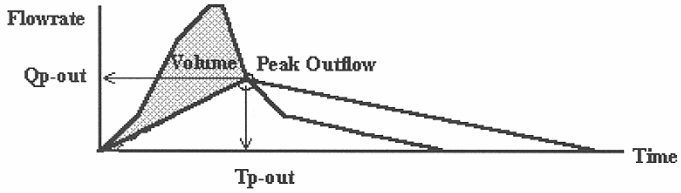
Use the hydrograph method to determine the preliminary size of a detention basin that will detain the 100-year peak flow to historic conditions for a catchment that has the following characteristics: area = 90 acres, length of catchment = 0.53 miles, length to centroid = 0.30 miles, impervious area = 67%, catchment slope = 0.0178 ft/ft, pervious retention = 0.35 inches, impervious retention = 0.05 inches, type B soils. 100-yr, 1-hour rainfall depth = 2.6 inches. The peak outflow is to be limited to the allowable unit release rates shown in Table SO-1.

The calculations are set up in tabular form similar to one illustrated in Table SO-3 that was taken from the UD-Detention workbook. The inflow hydrograph is calculated using the CUHP model and entered into the second column of the calculations. The preliminary sizing for the detention basin indicates a storage volume of 11.2 acre-feet.

Table SO-3—Detention Volume Estimate Using a Hydrograph
(From UD-Detention Workbook)

DETENTION VOLUME ESTIMATE USING A HYDROGRAPH

(For Catchments > 90 and < 160 acres)



a. Enter the inflow storm hydrograph with a time interval as:
time interval on hydrograph dt = 5.0 minutes

Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Incremental Volume acre-ft (output)	**Storage** Volume acre-ft (output)
0.0	0.00	0.00	0.00	0.00
5.0	0.00	4.78	0.00	0.00
10.0	3.00	9.56	0.00	0.00
15.0	16.00	14.34	0.01	0.01
20.0	41.00	19.13	0.15	0.16
25.0	84.00	23.91	0.41	0.58
30.0	179.00	28.69	1.04	1.61
35.0	312.00	33.47	1.92	3.53
40.0	333.00	38.25	2.03	5.56
45.0	289.00	43.03	1.69	7.25
50.0	240.00	47.81	1.32	8.58
55.0	196.00	52.59	0.99	9.56
60.0	160.00	57.38	0.71	10.27
65.0	135.00	62.16	0.50	10.77
70.0	115.00	66.94	0.33	11.10
75.0	88.00	71.72	0.11	11.22
80.0	64.00	76.50	0.00	11.22
85.0	47.00	----	----	----
90.0	36.00	----	----	----
95.0	29.00	----	----	----
100.0	25.00	----	----	----
105.0	23.00	----	----	----
110.0	21.00	----	----	----
115.0	20.00	----	----	----
120.0	20.00	----	----	----

b. You must provide the design information as:
Max. Allowable Peak Outflow Qp-out = 76.50 cfs
Time to Peak Outflow Tp-out= 80.00 minutes
(Qp-out,Tp-out) is a point on the recession of the inflow hydrograph.

C. Detention Storage Volume = 11.22 acre-ft

NOTE: THIS IS A FIRST APPROXIMATION ONLY

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7.0 CHECKLIST

Criterion/Requirement	□
If facility falls under State Engineer's jurisdiction, it must it meet all of State Engineer's requirements?	
Side slopes must be 4:1 or flatter.	
Embankment (dam fill) slopes must be 3:1 or flatter (4:1 or flatter preferred).	
Trickle channels are not required for retention ponds ("wet" ponds) and wetland basins, but the District will provide only limited maintenance assistance of these areas.	
The longitudinal slope for trickle channels shall be at least 0.4% for concrete bottoms and at least 1% for other bottoms.	
The pond bottom cross slope toward trickle channel or outlet shall be at least 1%.	
Maintenance access ramps to the pond bottom have at least 8 feet wide stabilized surface and have a 10%, or longitudinal flatter slope and turning radii that permit large maintenance equipment access.	
Provide an emergency spillway or embankment protection for flows that exceed primary outlet capacity.	
Provide a minimum 1-foot freeboard before embankment overtops.	
Outlet structures meter out the discharges as required by local municipality's criteria.	
Trash racks provided that do not interfere with the hydraulic capacity of the outlet.	
Tributary inflow points to the ponds have adequate energy dissipation and/or protection to prevent erosion.	
Designs consider the safety of the public.	
Pre-sedimentation forebay provided.	
WQCV is increased by 20% to account for sediment accumulation.	
Geotechnical considerations (embankment stability, geologic hazard, seepage) are taken into account and documented.	
Vegetation takes into account frequency and duration of inundation.	

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FLOOD PROOFING

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1.0 FLOOD PROOFING

1.1 Definition of Flood Proofing

Flood proofing is any combination of structural or nonstructural changes or adjustments incorporated in the design, construction, or alteration of individual buildings or properties that will reduce flood damages.

1.2 Overview of Flood-Proofing Methods

Some examples of flood proofing include the placement of walls or levees around individual buildings; elevation of buildings on fill, posts, piers, walls, or pilings; anchorage of buildings to resist floatation and lateral movement; watertight closures for doors and windows; reinforcement of walls to resist water pressure and floating debris; use of paints, membranes, and other sealants to reduce seepage of water; installation of check valves to prevent entrance of floodwaters at utility and sewer wall penetrations; and location of electrical equipment and circuits above expected flood levels.

1.2.1 Classification of Flood Proofing

Flood-proofing techniques can be classified on the basis of the type of protection that is provided as follows: (1) *permanent measures*—always in place, requiring no action if flooding occurs; (2) *contingent measures*—requiring installation prior to the occurrence of flood; and (3) *emergency measures*—improvised at the site when flooding occurs.

In the Denver metropolitan area, flood-proofing efforts should focus on permanent measures due to the rapid response of most of the Front Range stream systems. Contingent measures are more effective when combined with an early flood warning system or in areas not immediately adjacent to a stream channel.

1.2.2 FEMA Recommended Methods

The Federal Emergency Management Agency (FEMA) has published numerous references on the subject of flood proofing (FEMA 1984, 1986a, 1986b, 1991, 1993a, 1993b, 1993c, 1993d, 1993e, 1994, 1995, 1996). In several of these documents, FEMA outlines six methods of flood proofing as follows:

1. Elevation—Raising the structure so that the lowest floor is above the flood level.
2. Wet Flood Proofing—Making uninhabited portions of the structure resistant to flood damage and allowing water to enter during flooding.
3. Relocation—Moving the structure out of the floodplain to higher ground where it will not be exposed to flooding.
4. Dry Flood Proofing—Sealing the structure to prevent floodwaters from entering.
5. Levees and Floodwalls—Building a physical barrier around the structure to hold back floodwater.
6. Demolition—Tearing down the damaged structure and either rebuilding properly on the same

property or buying or building outside the floodplain.

1.3 Approach of *Manual* Relative to Flood-Proofing Guidance

Floodplain management includes all measurements for planning and actions that are needed to determine, implement, revise, and update comprehensive plans for the wise use of the floodplain and related water resources. This includes both corrective actions, as represented by most of the chapters of this *Manual*, and preventive actions as described in the POLICY and PLANNING chapters. Preventive measures cover a wide array of accepted and proven techniques ranging from floodplain regulation to flood forecasting to flood proofing. Due to the fact that flood proofing is often mentioned but little understood, this chapter is presented to assist drainage and flood control engineers in dealing effectively with existing development that is already flood prone.

1.4 Regulatory Considerations

Most regulations for flood proofing are based on the minimum standards of the National Flood Insurance Program (NFIP). The NFIP sets minimum regulatory standards for constructing, modifying, or repairing buildings located in the floodplain to keep flood losses to a minimum. The NFIP limits some flood proofing; for example, it prohibits obstructions, such as berms and floodwalls, in floodways.

The NFIP also requires flood proofing for a building that is substantially improved or substantially damaged. "Substantially damaged" is defined as "damage of any origin sustained by a structure whereby the cost of restoring the structure to its before damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred." Buildings that have been substantially damaged or are being substantially improved (renovated) must be elevated to or above the 100-year flood level. Nonresidential buildings must be elevated or dry flood proofed.

Other federal agencies, such as the U. S. Army Corps of Engineers (USACE), U. S. Geological Survey, and Natural Resources Conservation Service, also publish flood-proofing information, as do some state and local agencies. The USACE provides engineering and construction standards in the publication *Flood Proofing Regulations* (1995b). Additional USACE publications (1984, 1988, 1990, 1993, 1994, 1995a, 1996, 1998) provide information on case studies and detailed engineering applications of flood-proofing methods.

1.5 Flood Proofing In the Context of Overall Floodplain Management

Flood proofing is but one tool of an overall floodplain management strategy. With new development, the first option should always be to construct outside of the floodplain. If building outside of the floodplain is not practical for a site, then the structure should be constructed in compliance with local floodplain regulations. The remaining flood-proofing methods discussed in this chapter should be considered primarily for retrofitting existing structures.

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2.0 WHEN TO FLOOD PROOF

2.1 How Flooding Can Damage Structures

To understand how flooding can damage a structure, there are six important flood characteristics: depth/elevation, flow velocity, frequency, rate of rise and rate of fall, duration, and debris load. The flood conditions at a particular site are determined largely by the combination of these characteristics.

2.1.1 Depth/Elevation of Flooding

The depth and elevation of flooding are so closely related that they can be viewed as a single characteristic for the purposes of this discussion. Flood depth is the height of the floodwater above the surface of the ground or other feature at a specific point. Flood elevation is the height of the floodwater above an established reference datum. The standard datums used by most federal agencies and many state and local agencies are the National Geodetic Vertical Datum (NGVD) and the North American Vertical Datum (NAVD); however, other datums are in use. The use of other datums is important because elevations of the ground, floodwaters, and other features cannot be meaningfully compared with one another unless they are based on the same datum.

When the elevation of the ground (or another surface such as the lowest floor of the building) and the elevation of the floodwater are both based on the same datum, the flood depth at any point is equal to the flood elevation at that point minus the elevation of the ground (or other surface) at that point. Figure FP-1 illustrates this relationship. An additional point to consider: ground elevations are established by surveys; flood elevations may be calculated, or they may be known from watermarks left by past floods.

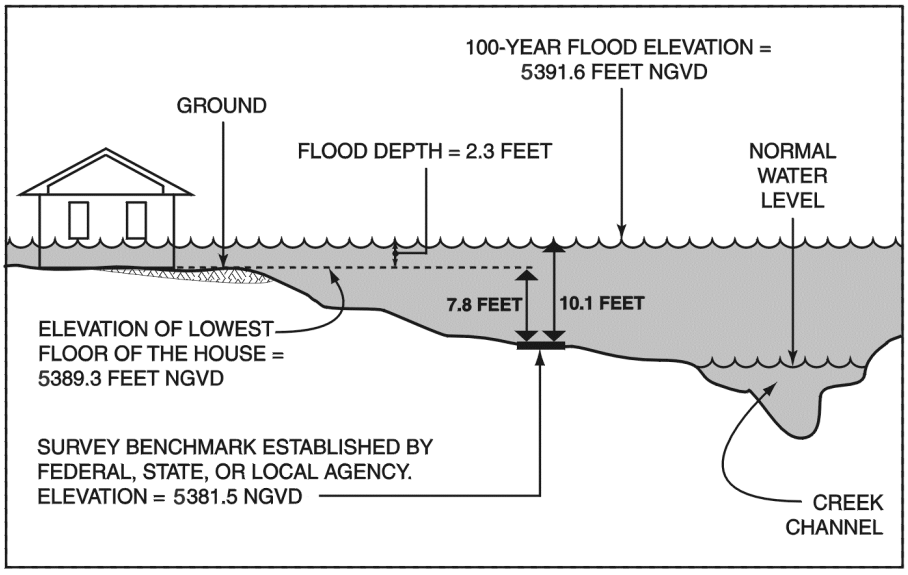

Figure FP-1—Schematic Representation of Flood Depth and Flood Elevation

The depth of flooding is important primarily because floodwaters, even when they are not moving, exert pressure on structural components such as walls and concrete floor slabs. The pressure exerted by still water is called hydrostatic pressure. It is caused by the weight of the water, so it increases as the depth of the water increases. As shown in Figure FP-2a, floodwater, including water that has saturated the soil under the building, pushes in on walls and up on floors. The upward force on floors is called buoyancy.

As shown in Figure FP-2b, water that has saturated the soil poses a special hazard for basement walls. Because hydrostatic pressure increases with the depth of the water, the pressure on basement walls is greater than the pressure on the walls of the upper floor, as indicated by the arrows in the figure. This pressure is made even greater by the weight of the saturated soil that surrounds the basement. The walls of buildings built according to standard construction practice are not designed to resist this pressure. Once the pressure exceeds the strength of the walls (including basement walls), it can push them in, cause extensive structural damage, and possibly cause the building to collapse.

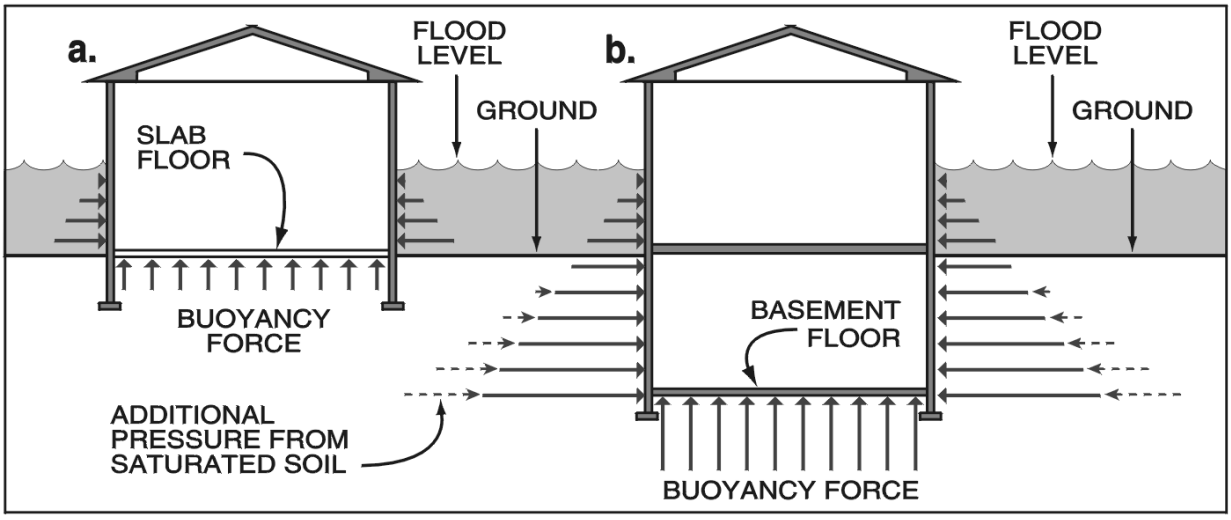

Figure FP-2 (a and b)—Hydrostatic Pressure Diagram With Dry Flood Proofing

Note that in the preceding illustration of hydrostatic pressure, no water is shown inside the building. If water is allowed to enter, the hydrostatic pressures on both sides of the walls and floor become the same, or equalized, and the walls are much less likely to fail (Figure FP-3).

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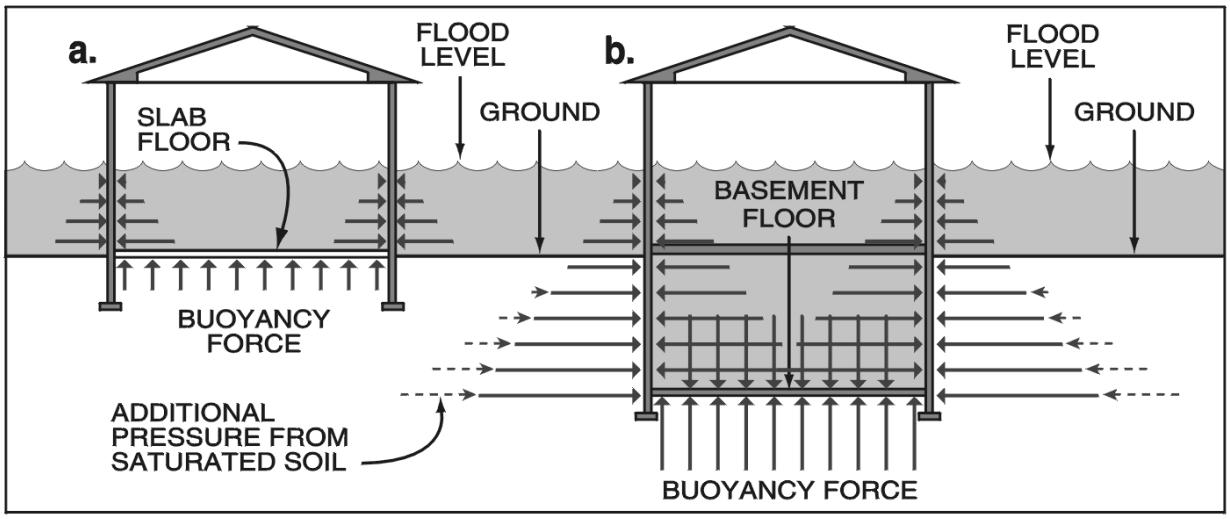

Figure FP-3—Hydrostatic Pressure Diagram With Wet Flood Proofing

2.1.2 Flow Velocity

Flow velocity is the speed at which floodwaters move. It is usually measured in feet per second (ft/sec). Flow velocities during riverine floods can easily reach 5 to 10 ft/sec, and in some situations may be even greater. Expressing velocities in ft/sec is common in floodplain studies and engineering analyses. Here, it may be helpful to relate ft/sec to a more familiar unit of measure. For example, 10 ft/sec is roughly equal to 7 miles per hour.

The velocity of riverine floodwaters depends on a number of factors; one of the most important is the slope of the stream channel and floodplain. As one might expect, floodwaters will generally move much faster along streams in steep mountainous areas than streams in flatter areas. Even within the same floodplain, however, flow velocity can still vary. As water flows over the ground, its velocity depends largely on the roughness of the ground surface. For example, water will flow more swiftly over parking lots, roads, and other paved surfaces and will flow more slowly over ground covered with large rocks, trees, dense vegetation, or other obstacles. Also, flow velocities in the floodplain will usually be higher nearer the stream channel than at the outermost fringes of the floodplain, where water may flow very slowly or not at all.

If a building is in an area where floodwaters are flowing, especially if they are moving more than about 5 ft/sec, the flow velocity is important for several reasons. Flowing water pushes harder on the walls of a building than still water. So instead of just the hydrostatic pressure caused by the weight of the floodwater resting against the walls, there is the additional pressure of moving water, referred to as hydrodynamic pressure. As water flows around the building, it pushes against the side that faces the flow (the upstream side). As it flows past the sides, it creates friction that can tear at wall coverings, such as siding. On the side of the building that faces away from the flow (the downstream side) the water may

tend to create a suction that pulls on walls. In some situations, the combination of these forces can destroy one or more walls, cause the building to shift on its foundation, or even sweep the building away.

Flowing water can also cause erosion and scour. Erosion is the removal of soil that lowers the ground surface across an area. Scour is the removal of soil around objects that obstruct flow, such as foundation walls. Both erosion and scour can weaken the structure by removing supporting soil and undermining the foundation. In general, the greater the flow velocity and the larger the building, the greater the extent and depth of erosion and scour. Also, any objects being carried by floodwaters will be moving at roughly the same speed as the water. The dangers associated with these objects are discussed in Section 2.1.6.

2.1.3 Flood Frequency

Flood frequencies are usually determined through statistical and engineering analyses performed by floodplain management agencies and other organizations who need information on which to base engineering designs and flood insurance rates. The results of those analyses define the probability, expressed as a percentage, that a flood of a specific size on a specific stream will be equaled or exceeded in any year.

The 100-year flood is particularly important for homeowners because it is the basis of National Flood Insurance Program (NFIP) flood insurance rates and regulatory floodplain management requirements. In the NFIP, the 100-year flood is referred to as the base flood, the 100-year flood elevation as the base flood elevation (BFE), and the floodplain associated with the base flood as the special flood hazard area (SFHA). Other federal agencies, such as the USACE, use the 100-year flood for planning and engineering design, as do many state and local agencies.

2.1.4 Rate of Rise and Rate of Fall

Floodwaters with high flow velocities, such as those in areas of steep terrain, and water released by the failure of a dam or levee usually rise and fall more rapidly than slower-moving floodwaters, such as those in more gently sloping floodplains. In the floodplains of streams with high rates of rise, homeowners may have only a few hours' notice of a coming flood or perhaps none at all. If the flood protection method chosen depends partly on action the homeowner must take each time flooding threatens (i.e., contingent measures), warning time is especially important.

Rate of rise and rate of fall are important also because of their effect on hydrostatic pressure. As explained in the discussion of flood depth/elevation, hydrostatic pressure is most dangerous for a building when the internal and external pressures are not equalized. This situation occurs when the level of water inside is significantly higher or lower than the level outside. When floodwaters rise rapidly, water may not be able to flow into a building quickly enough for the level in the building to rise as rapidly as the level outside. Conversely, when floodwaters fall rapidly, water that has filled a building may not be able to flow out quickly enough, and the level inside will be higher than the level outside. In either situation, the

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unequalized hydrostatic pressures can cause serious structural damage, possibly to the extent that the building collapses.

2.1.5 Duration

Duration is related to rate of rise and rate of fall. Generally, water that rises and falls rapidly will recede more rapidly, and water that rises and falls slowly will recede more slowly.

Duration is important because it determines how long the structural members (such as the foundation, floor joists, and wall studs), interior finishes (such as drywall and paneling), service equipment (such as furnaces and hot water heaters), and building contents will be affected by floodwaters. Long periods of inundation are more likely to cause damage than short periods. In addition, long duration flooding can saturate soils (Figure FP-2), increasing the pressure on the foundation. Duration can also determine how long a building remains uninhabitable.

2.1.6 Debris Impact

Floodwaters can pick up and carry objects of all types (from small to large, from light to heavy) including trees, portions of flood-damaged buildings, automobiles, boats, storage tanks, mobile homes, and even entire buildings. Dirt and other substances such as oil, gasoline, sewage, and various chemicals can also be carried by floodwaters. All of these types of debris add to the dangers of flooding. Even when flow velocity is relatively low, large objects carried by floodwaters can easily damage windows, doors, walls, and more importantly critical structural components of a building. As velocity increases, so does the danger of greater damage from debris. If floodwaters carrying large amounts of dirt or hazardous substances enter the building, cleanup costs are likely to be higher and cleanup time greater.

2.2 When Flood Proofing is Not Appropriate

Many factors influence the decision-making process for determining the feasibility of flood-proofing options. However, there are certain situations in which flood proofing should not be considered, with the exception of relocation and/or demolition. For example, structures located within a regulatory floodway cannot be retrofitted with substantial improvements that would result in any increase in flood levels during the base flood discharge. Under these conditions, the structure should be relocated out of the floodway and, preferably, out of the floodplain.

2.3 Typical Causes of Flooding Problems

Flooding in the Denver metropolitan area typically results from heavy rains during the spring and summer months. Intense rainfall can lead to flooding in several ways and is exacerbated by the increasing percentage of impervious cover associated with urban development. The time of concentration is reduced as water is conveyed via a network of gutters and storm sewers yielding increased peak flows in the drainageways. Flooding can occur at any point in the drainage system and is aggravated if debris inhibits the flow.

2.3.1 Inadequate Street Conveyance

As discussed in the STREETS/INLETS/STORM SEWERS chapter, the minor drainage system should be designed to convey between the 2- and 10-year design storms. Over time, the street conveyance capacity can diminish due to pavement overlays reducing the gutter depth and altering the design slopes. As a result, even during minor storms, flows can pond or exceed the gutter capacity resulting in localized flooding.

2.3.2 Inadequate Storm Sewer Conveyance

Older sections of the metropolitan area predate drainage criteria. In many cases, the storm sewer capacity is limited to the 2-year or less frequency design.

2.3.3 Inadequate Drainage Channel Conveyance

Prior to current floodplain and drainage criteria, development often encroached on natural drainageways resulting in the reduced capacity of open channel conveyance. Over-bank flooding is the most dangerous type due to the combination of velocity and depth of the floodwaters.

2.3.4 Sewage Backup

Flooding can often inundate and overload sanitary sewer systems and combined sanitary/storm sewer systems. As a result, water can flow backward through sewer lines and out through toilets or floor drains. The best solution to this problem is usually to install a backflow valve.

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3.0 FLOOD PROOFING METHODS

3.1 Overview of Six Methods Identified by FEMA

The following sections describe the retrofitting methods, explain how they work and where they are appropriate, and list their advantages and disadvantages.

3.1.1 Elevation

Elevating a building to prevent floodwaters from reaching living areas is an effective retrofitting method. The goal of the elevation process is to raise the lowest floor to or above the flood protection elevation (FPE) as shown in Figure FP-4. This can be done by elevating the entire building, including the floor, or by leaving the building in its existing position and constructing a new, elevated floor within the building. The method used depends largely on construction type, foundation type, and flooding conditions.

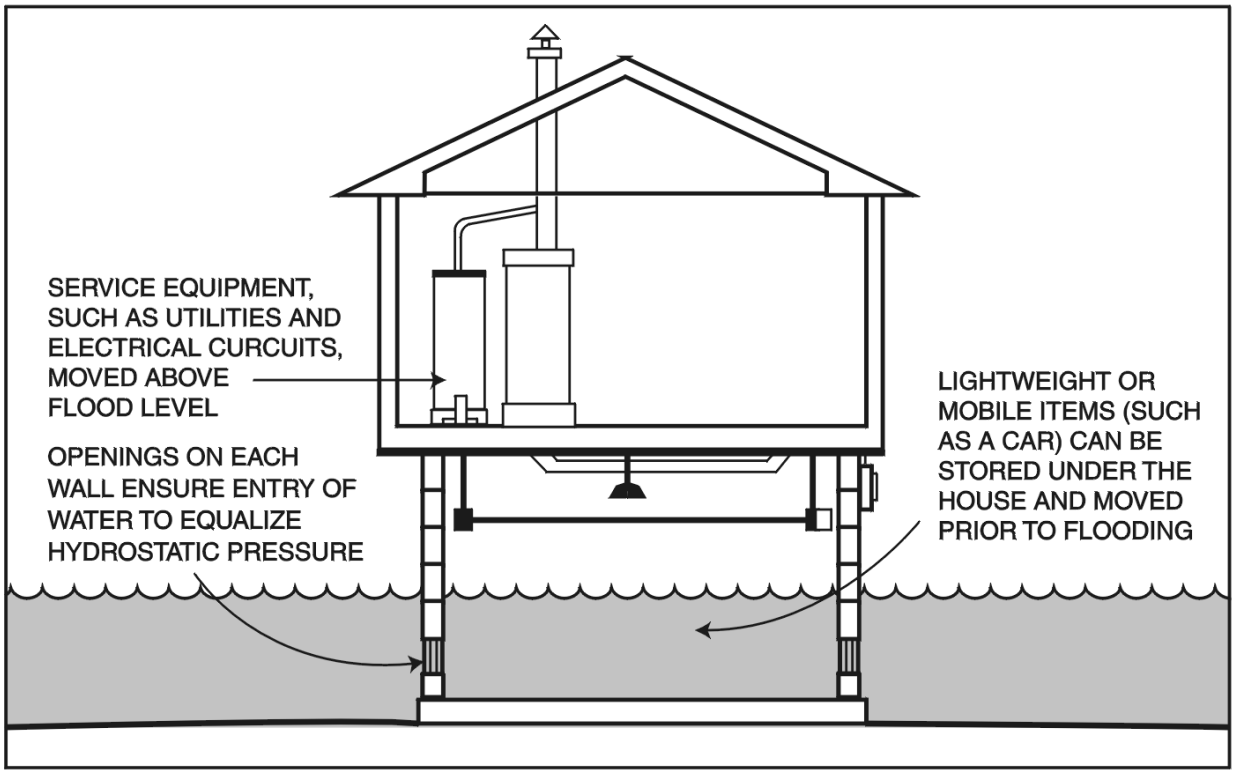

Figure FP-4—Example of a Structure Elevated on Continuous Foundation Walls

During the elevation process, most buildings are separated from their foundations, raised on hydraulic jacks, and held by temporary supports while a new or extended foundation is constructed below. This method works well for buildings originally built on basement, crawl space, and open foundations. As explained later in this section, the new or extended foundation can consist of continuous walls or separate piers, posts, columns, or pilings.

A variation of this method is used for buildings on slab-on-grade foundations. In these buildings, the slab forms both the foundation and the floor of the building. Elevating these buildings is easier if the building is left attached to the slab foundation and both are lifted together. After the building and slab are lifted, a new foundation is constructed below the slab.

Alternative techniques are available for masonry buildings on slab-on-grade foundations. These techniques do not require the lifting of the building. Instead, they involve raising the floor within the building or moving the living space to an upper story.

Although elevating a building can help protect it from floodwaters, other hazards need to be considered before choosing this method (Table FP-1). The walls and roof of an elevated building may be more susceptible to wind forces because they are higher and more exposed. In addition, both continuous wall foundations and open foundations can fail as a result of damage caused by erosion and the impact of debris carried by floodwaters. If portions of the original foundation, such as the footings, are used to support new walls or other foundation members or a new second story, they must be capable of safely carrying the additional loads imposed by the new construction and the expected flood and wind forces.

Table FP-1—Advantages and Disadvantages of Elevation

Advantages	Disadvantages
• Elevation to or above the FPE allows a substantially damaged or substantially improved building to be brought into compliance with the community's floodplain management ordinance or law. • Elevation reduces the flood risk to the building and its contents. • Except where a lower floor is used for storage, elevation eliminates the need to move vulnerable contents to areas above the water level during flooding. • Elevation often reduces flood insurance premiums. • Elevation techniques are well known, and qualified contractors are often readily available. • Elevation does not require the additional land that may be needed for construction of floodwalls or levees. • Elevation reduces the physical, financial, and emotional strain that accompanies floods.	• Cost may be prohibitive. • The appearance of the building may be adversely affected. • Access to the building may be adversely affected. • The building must not be occupied during a flood. • Unless special measures are taken, elevation is not appropriate in areas with high-velocity flows, waves, fast-moving ice or debris flow, or erosion. • Additional costs are likely if the building must be brought into compliance with current code requirements for plumbing, electrical, and energy systems. • Potential wind and earthquake loads must be considered.

3.1.2 Wet Flood Proofing

Wet flood proofing a building is done by modifying the uninhabited portions (such as a crawl space or an unfinished basement) so that floodwaters will enter but not cause significant damage to either the building

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or its contents. The purpose of allowing water into portions of the building is to ensure that the interior and exterior hydrostatic pressures will be equal (Figure FP-5). Allowing these pressures to equalize greatly reduces the likelihood of wall failures and structural damage. Wet flood proofing is often used when all other retrofitting methods are either too costly or are not feasible, but it is practical in only a limited number of situations. The advantages and disadvantages of wet flood proofing are summarized in Table FP-2.

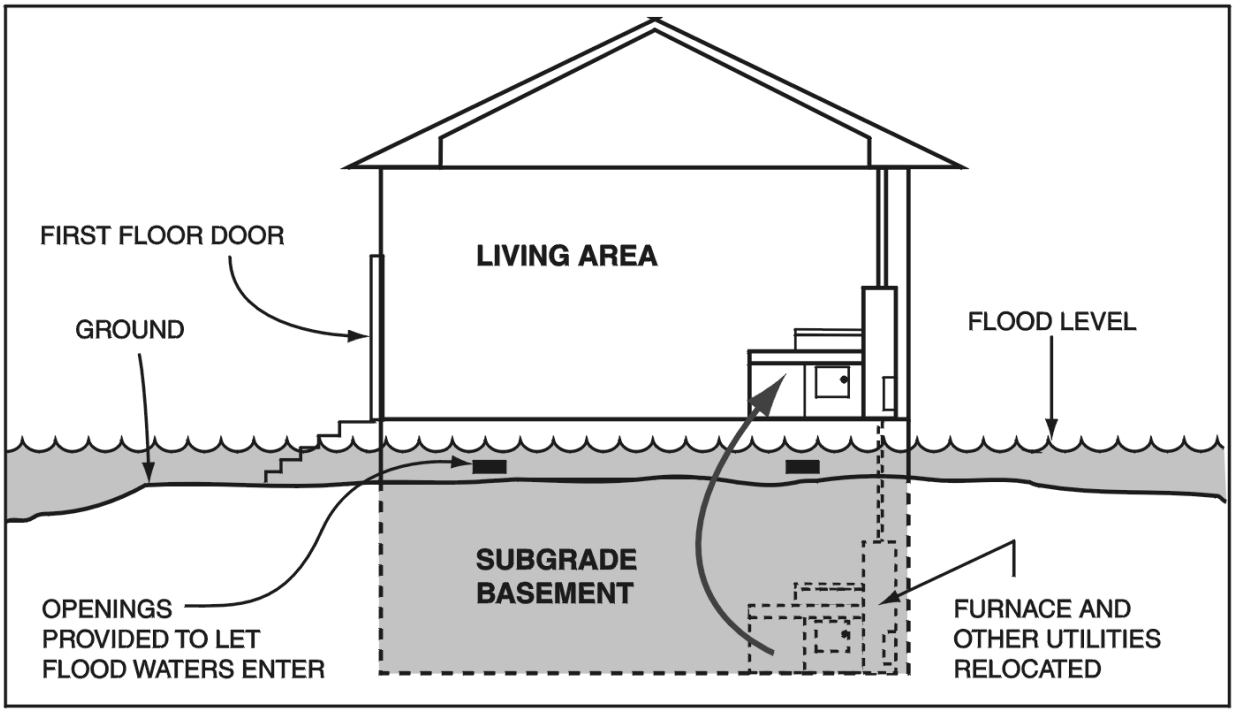

Figure FP-5—Example of a Building With a Wet Flood-Proofed Subgrade Basement

Because wet flood proofing allows floodwaters to enter the building, all construction and finishing materials below the FPE must be resistant to flood damage. For this reason, wet flood proofing is practical only for portions of a building that are not used for living space, such as a basement as defined by the NFIP regulations, a walkout-on-grade basement, crawl space, or attached garage. It would not be practical for most slab-on-grade buildings, in which the living space is at or very near the ground level. Whether or not wet flood proofing is appropriate for a building will depend on the flood conditions, the FPE selected, the design and construction of a building, and whether the building has been substantially damaged or is being substantially improved.

Table FP-2—Advantages and Disadvantages of Wet Flood Proofing

Advantages	Disadvantages
• No matter how small the effort, wet flood proofing can, in many instances, reduce flood damage to a building and its contents. • Because wet flood proofing allows internal and external hydrostatic pressures to equalize, the loads on walls and floors will be less than in a dry flood-proofed building (discussed later in this section). • Costs for moving or storing contents (except basement contents) after a flood warning is issued are covered by flood insurance in some circumstances. • Wet flood-proofing measures are often less costly than other types of retrofitting. • Wet flood proofing does not require the additional land that may be needed for floodwalls and levees (discussed later in this section). • The appearance of the building is usually not adversely affected. • Wet flood proofing reduces the physical, financial, and emotional strains that accompany floods.	• Wet flood proofing may be used to bring a substantially damaged or substantially improved building into compliance with a community's floodplain management ordinance or law only if the areas of the building below the FPE are used solely for parking, storage, or building access. • Preparing the building and its contents for an impending flood requires human intervention and adequate warning time. • The building will get wet inside and possibly be contaminated by sewage, chemicals, and other materials borne by floodwaters. Extensive cleanup may be necessary. • The building must not be occupied during a flood, and it may be uninhabitable for some time afterward. • It will be necessary to limit the uses of the floodable area of the building. • Periodic maintenance may be required. • Pumping floodwaters out of a wet flood-proofed basement too soon after a flood may lead to structural damage.* • Wet flood proofing does nothing to minimize the potential damage from high-velocity flood flow and wave action.

* **WARNING.** After floodwaters recede from the area around a building with a wet flood-proofed basement, the owner will usually want to pump out the water that filled the basement during the flood. If the soil surrounding the basement walls and below the basement floor is still saturated with water, however, removing the water in the basement too quickly can be dangerous. As the water level in the basement drops, the outside pressure on the basement walls and flood becomes greater than the inside pressure. As a result, the walls can collapse and the floor can be pushed up or cracked.

3.1.3 Dry Flood Proofing

In some situations, a building can be made watertight below the FPE, so that floodwaters cannot enter. This method is called dry flood proofing. Making the building watertight requires sealing the walls with waterproof coatings, impermeable membranes, or supplemental layers of masonry or concrete. Also, doors, windows, and other openings below the FPE must be equipped with permanent or removable shields, and backflow valves must be installed in sewer lines and drains (Figure FP-6). The flood characteristics that affect the success of dry flood proofing are flood depth, flood duration, flow velocity, and the potential for wave action and flood-borne debris.

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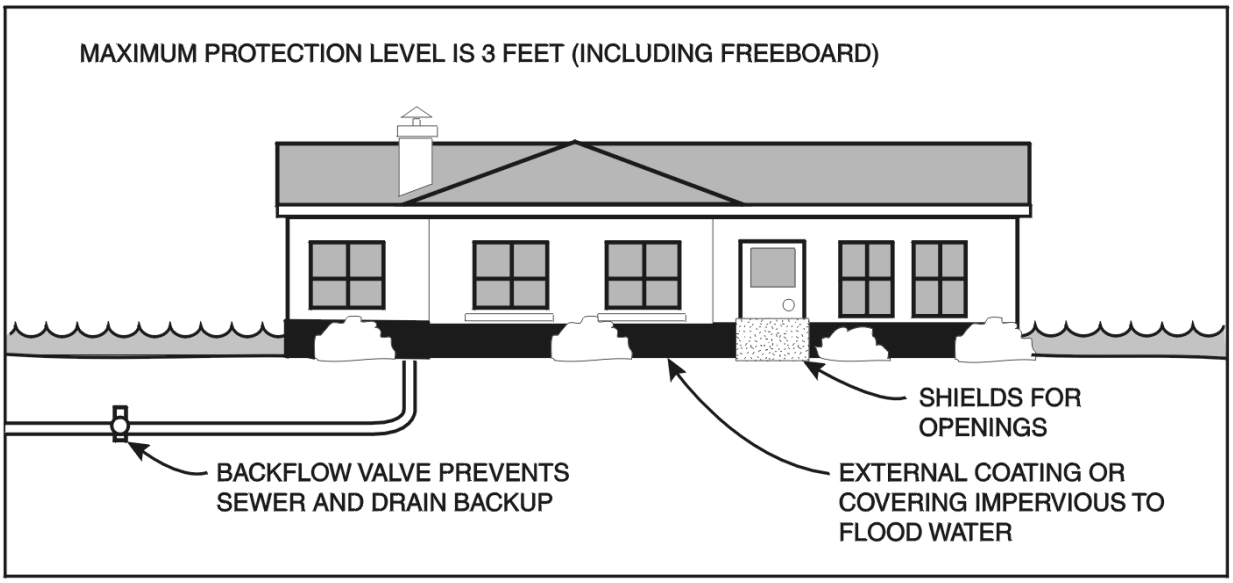

Figure FP-6—Example of a Dry Flood-Proofed House

Flood depth is important because of the hydrostatic pressure that floodwaters exert on walls and floors. Because water is prevented from entering a dry flood-proofed building, the exterior pressure on walls and floors is not counteracted as it is in a wet flood-proofed building. The ability of building walls to withstand the pressure exerted by floodwaters depends partly on how the walls are constructed. Typical masonry and masonry veneer walls, without reinforcement, can usually withstand the pressure exerted by water up to about 3 feet deep. When flood depths exceed 3 feet, unreinforced masonry and masonry veneer walls are much more likely to crack or collapse. An advantage of masonry and masonry veneer walls is that their exterior surfaces are resistant to damage by moisture and can be made watertight relatively easily with sealants. In contrast, typical frame walls are likely to fail at lower flood depths, are more difficult to make watertight, and are more vulnerable to damage from moisture. As a result, wet flood proofing is not recommended for buildings with frame walls that will be damaged by moisture.

Dry flood proofing may not be used to bring a substantially damaged or substantially improved building into compliance with a community's floodplain management ordinance or law. The advantages and disadvantages of dry flood proofing are summarized in Table FP-3.

Table FP-3—Advantages and Disadvantages of Dry Flood Proofing

Advantages	Disadvantages
• Dry flood proofing reduces the flood risk to the building and its contents. • Dry flood proofing may be less costly than other retrofitting methods. • Dry flood proofing does not require the additional land that may be needed for levees and floodwalls (discussed later in this chapter). • Dry flood proofing reduces the physical, financial, and emotional strains that accompany floods.	• Dry flood proofing may not be used to bring a substantially damaged or substantially improved building into compliance with a community's floodplain management ordinance or law. • Ongoing maintenance is required. • Flood insurance premiums are not reduced for residential structures. • Installing temporary protective measures, such as flood shields, requires human intervention and adequate warning time.* • If the protective measures fail or the FPE is exceeded, the effect on the building will be the same as if there were no protection at all. • If design loads are exceeded, walls may collapse, floors may buckle, and the building may even float, potentially resulting in more damage than if the building was allowed to flood. • The building must not be occupied during a flood. • Flood shields may not be aesthetically pleasing. • Damage to the exterior of the building and other property may not be reduced. • Shields and sealants may leak, which could result in damage to the building and its contents. • Dry flood proofing does nothing to minimize the potential damage from high-velocity flood flow and wave action.

* **WARNING.** Because dry flood proofing requires human intervention, one must be willing and able to install all flood shields and carry out all other activities required for the successful operation of the dry flood-proofing system. As a result, not only must one be physically capable of carrying out these activities, one must be in the building or able to go there in time to do so before floodwaters arrive.

3.1.4 Relocation

Moving a building to high ground, outside the flood hazard area, is the most effective of the retrofitting methods described in this *Manual*. Retrofitting literature commonly refers to this method as relocation. When space permits, it may even be possible to move a building to another location on the same piece of property.

Relocating a building usually involves jacking it up and placing it on a wheeled vehicle, which delivers it to the new site. The original foundation cannot be moved, so it is demolished and a new foundation is built

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at the new site. The building is installed on the new foundation and all utility lines are connected.

Relocation is particularly appropriate in areas where the flood hazard is severe. Relocation is also appropriate for those who want to be free of worries about damage from future floods that may exceed a selected FPE.

Although similar to elevation, relocation requires additional steps that usually make it more expensive. These include moving the building, buying and preparing a new site (including building the new foundation and providing the necessary utilities), and restoring the old site (including demolishing the old foundation and properly capping and abandoning old utility lines). The advantages and disadvantages of relocation are summarized in Table FP-4.

Table FP-4—Advantages and Disadvantages of Relocation

Advantages	Disadvantages
• Relocation allows a substantially damaged or substantially improved building to be brought into compliance with a community's floodplain management ordinance or law. • Relocation significantly reduces flood risk to the building and its contents. • Relocation can either eliminate the need to purchase flood insurance or reduce the amount of the premium. • Relocation techniques are well known, and qualified contractors are often readily available. • Relocation reduces the physical, financial, and emotional strains that accompany flood events.	• Cost may be prohibitive. • A new site (preferably outside the flood hazard area) must be located and purchased. • The flood-prone lot on which the building was located must be sold or otherwise disposed of. • Additional costs are likely if the building must be brought into compliance with current code requirements for plumbing, electrical, and energy systems.

3.1.5 Levees and Floodwalls

Levees and floodwalls are types of flood protection barriers. A levee is typically a compacted earthen structure; a floodwall is an engineered structure usually built of concrete, masonry, or a combination of both (Figure FP-7). When these barriers are built to protect a building, they are usually referred to as residential, individual, or on-site levees and floodwalls. The practical heights of these levees and floodwalls are usually limited to 6 feet and 4 feet, respectively. These limits are the result of the following considerations:

- As the height of a levee or floodwall increases, so does the depth of water that can build up behind it. Greater depths result in greater water pressures, so taller levees and floodwalls must be designed and constructed to withstand the increased pressures. Meeting this need for additional strength greatly increases the cost of the levee or floodwall, usually beyond what an individual homeowner can afford.

- Because taller levees and floodwalls must be stronger, they must also be more massive, so they usually require more space than is likely to be available on an individual lot. This is especially true of levees.

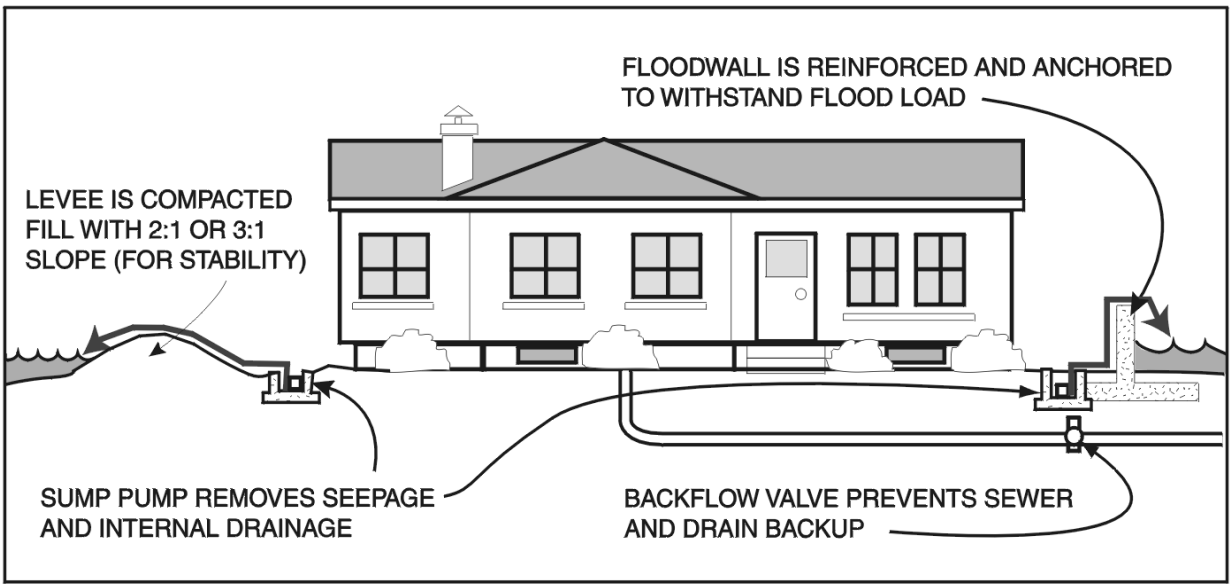

Figure FP-7—Example of Levee and Floodwall Protection

Both levees and floodwalls should provide at least 3 feet of freeboard. For example, if building a levee to protect a building from the base flood, the top of the levee should be 1 foot above the FPE.

For a levee to be effective over time, it must be constructed of soils that cannot be easily penetrated by floodwaters; it must have proper side slopes for stability, and it must be periodically inspected and maintained. In areas where high flow velocities could erode the surface of a levee, the side of the levee exposed to floodwater is usually protected with riprap or with other erosion-resistant material. Levees can surround a building, or they may be built only across low areas and tied into existing high ground.

A floodwall can surround a building, or, depending on flood depths, site topography, and design preferences, it can protect isolated openings such as doors, windows, and basement entrances, including entry doors and garage doors in walkout-on-grade basements. When built with decorative bricks or blocks or as part of garden areas, floodwalls can become attractive architectural or landscaping features. But they can also be built solely for utility, usually at a much lower cost.

Because a floodwall is made of concrete or masonry rather than compacted earth, it is more resistant to erosion than a levee and generally requires less space than a levee that provides the same level of protection; however, floodwalls are usually more expensive. As a result, floodwalls are normally considered only for sites where there is not enough room for a levee or where high flow velocities may erode a levee. Also, some homeowners prefer floodwalls because they can be more aesthetically

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pleasing and allow for the preservation of existing site features, such as trees.

An interior drainage system, including a sump pump, must be installed in the area protected by a levee or floodwall. The purpose of the system is to remove rainwater trapped inside the protected area and, during flooding, to remove water that enters through seepage or infiltration.

Special design considerations are necessary when levees or floodwalls are built to protect a building with a basement. Even though the surface water is kept from coming into contact with the building, the soil below the levee or floodwall and around the building can become saturated, especially during floods of long duration. The resulting pressure on basement walls and floors can cause them to crack, buckle, or even collapse.

3.1.6 Demolition

Demolition, as a retrofitting method, is tearing down a damaged building and either rebuilding properly somewhere on the same property or moving to a building on other property outside the regulatory floodplain. This retrofitting method may be the most practical of all those described in this *Manual* when a building has sustained extensive damage, especially severe structural damage.

Whether rebuilding or moving, the damaged building must be torn down and the site restored. Site restoration usually involves filling in a basement, grading, and landscaping. As a result, the services of a demolition contractor will probably be needed.

All demolition, construction, and site restoration work must be done according to the regulatory requirements of the community. Permits may be required for all or part of this work. If the new structure is built on the site of the old building, it must be rebuilt properly, which means ensuring that the lowest floor of the new building is at or above the FPE and that the new building is located outside the floodway. This can be accomplished by elevating the new building on an extended foundation as described in Section 3.1.1 or on compacted fill dirt. If the property includes an alternative building site outside the regulatory floodplain, a better approach is to build on that site, where standard construction practices, including the construction of a basement, can be used. If the building is reconstructed on the existing site within the regulatory floodplain, the community's floodplain management ordinance or law will not allow the new building to have a basement (as defined by the NFIP regulations).

The advantages and disadvantages of demolition depend on the decision of where to rebuild the structure (Table FP-5). If one of the flood-proofing methods is used, such as relocation or elevation, then the advantages and disadvantages of those methods will apply.

Table FP-5—Advantages and Disadvantages of Levees and Floodwalls

Advantages	Disadvantages
• The building and the area around it will be protected from inundation, and no significant changes to the building will be required. • Floodwaters cannot reach the building or other structures in the protected area and, therefore, will not cause damage through inundation, hydrodynamic pressure, erosion, scour, or debris impact. • The building can be occupied during construction of levees and floodwalls. • Levees and floodwalls reduce the flood risk to the building and its contents. • Levees and floodwalls reduce the physical, financial, and emotional strains that accompany flood events.	• Levees and floodwalls may not be used to bring a substantially damaged or substantially improved building into compliance with a community's floodplain management ordinance or law. • Cost may be prohibitive. • Periodic maintenance is required. • Human intervention and adequate warning time are required to close any openings in a levee or floodwall. • If a levee or floodwall fails or is overtopped by floodwaters, the effect on the building will be the same as if there were no protection at all. • An interior drainage system must be provided. • Local drainage can be affected, possibly creating or worsening flood problems for others. • The building must not be occupied during a flood. • Access to the building may be restricted. • Levees and floodwalls do not reduce flood insurance rates. • Floodplain management requirements may make levees and floodwalls violations of codes and/or regulations. • A large area may be required for construction, especially for levees. • Hydrostatic pressure on below-ground portions of a building may still be a problem, so levees and floodwalls are not good retrofitting methods for buildings with basements.

3.2 Engineering Aspects

Engineering aspects of flood proofing include evaluating the site and building characteristics, determining the flooding characteristics, and analyzing the potential loads on the structure during a flood event.

3.2.1 Analysis of Flood Hazards

Determining the potential depth of flooding is the first and most logical step in assessing flood hazards, since it is often the primary factor in evaluating the potential for flood damage. The depth of flooding is also critical in determining the extent of retrofitting that will be needed, and which method(s) will be the most appropriate for a given site. Detailed flood information is given in Flood Insurance Studies (FISs)

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and Flood Insurance Rate Maps (FIRMs) where such studies are available, and can be obtained from the District or local community in the form of Flood Hazard Area Delineations (FHADs).

The next step is to calculate the forces acting upon a structure during a flood. These forces include hydrostatic, hydrodynamic, and impact loads. Hydrostatic forces include lateral water pressure, saturated soil pressures, combined water and soil pressures, equivalent hydrostatic pressures due to low velocity flows (< 10 ft/sec), and buoyancy pressures. Hydrodynamic forces consist of frontal impact by the mass of moving water against the projected width and height of the obstruction represented by the structure, drag effect along the sides of the structure, and eddies or negative pressures on the downstream side of the structure. Impact loads are imposed on the structure by objects carried by moving water.

3.2.2 Site Characteristics

Important site characteristics to evaluate include the location of the structure relative to sources of potential flooding and geotechnical considerations. The site location should be evaluated with respect to mapped floodplains and floodways and the potential for local flooding from stormwater conveyance elements.

Soil properties during conditions of flooding are important factors in the design of any surface intended to resist flood loads. These properties include saturated soil pressures, allowable bearing capacity, potential for scour, frost zone location, permeability, and shrink-swell potential.

3.2.3 Building Characteristics

The building should be evaluated with respect to the type of construction and the condition of the structure. The type of foundation, foundation materials, wall materials, and the method of connection all play a role in deciding which retrofitting method will be most applicable. Operations involving a building in poor condition may easily wind up further damaging the building and costing more than its original value.

3.3 Selection of Flood-Proofing Techniques

In addition to the engineering aspects, the selection of the flood-proofing technique is a function of several factors that are dependent on the owner of the structure.

3.3.1 Regulatory Considerations

Federal, state, and local regulations may restrict the choice of retrofitting measures. Such regulations may include state and local building codes, floodplain management ordinances or laws, zoning ordinances, federal regulations concerning the alteration of buildings classified as historic structures, deed restrictions, and the covenants of homeowners associations.

State and local regulations may require that a retrofitted building be upgraded to meet current code requirements that were not in effect when the building was built. Portions of the electrical, plumbing, and heating/ventilation/air conditioning systems could be affected. For example, the electrical panel might

have to be upgraded from fuses to circuit breakers. These changes are required for the safety of the homeowner. Other code-required upgrades include those necessary for increased energy efficiency. Any required upgrade can add to the scope and cost of the retrofitting project.

3.3.2 Appearance

The final appearance of a building and property after retrofitting will depend largely on the retrofitting method used and the FPE. For example, elevating a building several feet will change its appearance much more than elevating it only 1 or 2 feet, and a building elevated on an open foundation will not look the same as one elevated on extended foundation walls. However, a change in appearance will not necessarily be a change for the worse.

3.3.3 Accessibility

Accessibility refers to how easy or difficult it is to routinely reach and enter the building after the retrofitting project is completed. The retrofitting methods described in this *Manual* affect accessibility in different ways. For example, elevating a building will usually require the addition of stairs, which may be unacceptable to some. Wet flood proofing will have little, if any, effect on accessibility. The effect of relocation on accessibility will depend on the location and configuration of the new site.

3.3.4 Human Intervention Required

For retrofitting methods that require human intervention, owners must be willing, able, and prepared to take the necessary action, such as operating a closure mechanism in a floodwall or placing flood barriers across the doors of a dry flood-proofed building. Also, the owner must always have adequate warning of a coming flood and must be present or near enough to reach the building and take the necessary action before floodwaters arrive. If these conditions cannot be met, retrofitting methods that require human intervention should be eliminated from consideration.

3.3.5 Benefit/Cost Analysis

The cost of retrofitting will depend largely on the retrofitting method used and the FPE. For some methods, the construction type (frame, masonry, etc.) and foundation type (crawl space, slab, etc.) will also affect the cost. In general, costs will increase as the FPE increases, but there may be tradeoffs between alternative methods. For example, elevating may be less expensive than relocating when a building is raised only 1 or 2 feet but may become more expensive at greater heights. The benefits considered in a flood-proofing measure are the future damages and losses that are expected to be avoided as a result of the measure.

3.3.6 Other

Building owners may need to consider other factors, such as the availability of federal, state, and local financial assistance; the current value of the building versus the inconvenience and cost of retrofitting; the amount of time required to complete the retrofitting project; and the need to move out of the building during construction (including the availability and cost of alternative housing).

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4.0 PROVIDING ASSISTANCE TO PROPERTY OWNERS

4.1 Decision Making Process for Property Owners

The decision of which flood-proofing method to use will be based primarily on legal requirements, the technical limitations of the methods, and cost. Other considerations might include such things as the appearance of the building after retrofitting and any inconvenience resulting from retrofitting.

4.1.1 Determine Flood Hazards

Information about flooding in the area is available from the District and local officials. Local officials, design professionals, and contractors can use this information, along with the flood hazard information developed by FEMA and other agencies and organizations, to provide advice about retrofitting options.

4.1.2 Inspect Structure

The structure should be inspected to determine the construction method and the type of foundation. Four characteristics of a building that are particularly important in retrofitting are construction type, foundation type, lowest floor elevation, and condition. Key to the inspection is performing a "Low Point of Entry" determination as illustrated in Figure FP-8.

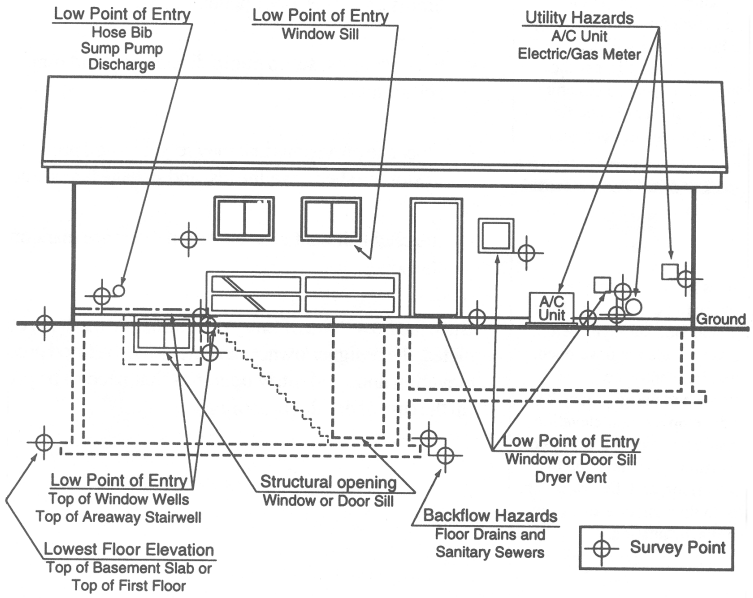

Figure FP-8—Example of a Low Point of Entry Survey

4.1.3 Contact Local Officials

The District and local officials have copies of the FIS and FIRM published for the community by FEMA. District or community officials can determine whether a building is in the regulatory floodplain and, if so, the FPE at the location of the building.

Local officials will provide federal, state, and local regulations, codes, and other requirements that can determine what retrofitting methods will be allowed. They can also provide information about federal, state, and local programs that provide financial assistance for homeowner retrofitting projects. If the property is 50 or more years old and receiving federal financial assistance for a retrofitting project, then the State Historic Preservation Office should also be contacted.

4.1.4 Consult With Professionals

The owner of a structure that needs flood proofing will need to consult with a design professional and a contractor in order to choose the appropriate flood-proofing method and ensure that the method is properly constructed. Table FP-6 shows the types of contractors and design professionals that may be required for each of the retrofitting methods.

4.2 Potential Sources of Financial Assistance at Federal, State, and Local Levels

FEMA and other federal agencies have a wide array of financial assistance programs that help states, communities, and individual property owners mitigate the negative effects of flood hazards. Property owners may be eligible to receive financial assistance through one or more of these programs that will help pay for the retrofitting project. If a presidential declaration of a major disaster has been issued for the area, property owners should seek information from FEMA and the state and local government representatives supporting the post-disaster recovery of the community.

The community's floodplain management ordinance or law includes requirements concerning construction in the community's regulatory floodplain. These requirements apply not only to new buildings but also to existing buildings that have been substantially damaged or that are being substantially improved. If the structure falls into one of the latter two categories, one of the following will be required:

- Elevate the building so that its lowest floor is at or above the FPE (Elevation).
- Move the building out of the regulatory floodplain (Relocation).
- Wet flood proof the part of the building that is below the FPE (Wet Flood Proofing). (This alternative is allowed only if the part of the building that is below the FPE is used solely for parking, storage, and building access and is not a basement as defined by the NFIP.)

Table FP-6—Requirements for Contractor and Design Professional Services

Method	Need for Contractor and/or Design Professional	Primary Services
Elevation	Design Professional	Evaluating the condition, stability, and strength of the existing foundation to determine whether it can support the increased load of the elevated building, including any wind and seismic loads
	Contractor: Building Elevation Contractor	Disconnecting utilities, jacking up the building, increasing the height of the foundation, and connecting utilities
Wet Flood Proofing	Design Professional	Designing any necessary replacements of vulnerable structural materials and relocated utility systems
	Contractor: General Construction Contractor	Replacing vulnerable structural and finishing materials below the FPE with flood-resistant materials, raising utilities and appliances to a location above the FPE, and installing openings required to allow the entry of floodwaters
Relocation	Design Professional	Designing any new building, foundation, and site improvements that may be required, such as new utility systems
	Contractor: Building Moving Contractor	Jacking up the building, moving it to the new site, and installing it on the new foundation
	Contractor: General Construction Contractor	Preparing the new site (including grading, foundation construction, and utilities) and cleaning up the old site (including demolition)
Dry Flood Proofing	Design Professional	For masonry walls to be dry flood proofed higher than 3 feet and for masonry veneer or frame walls to be dry flood proofed higher than 2 feet, evaluating the condition, stability, and strength of the existing walls to determine whether they can withstand the pressure from floodwaters at the FPE; designing or selecting flood shields for openings
	Contractor: General Construction Contractor	Applying waterproof sealants and membranes, installing flood shields over openings below the FPE, installing backflow valves in sewer and water lines, and, if necessary, bracing or modifying walls so that they can withstand the pressure from floodwaters at the FPE
Levees and Floodwalls	Design Professional	Assessing the adequacy of soils at the site and preparing the engineering design to ensure that the levee or floodwall, including any closures required, will be structurally stable under the expected flood loads and will be able to resist erosion, scour, and seepage
	Contractor: General Construction Contractor	Constructing the levee or floodwall
Demolition	Design Professional	Designing any new building, foundation, and site improvements that may be required, such as new utility systems
	Contractor: Demolition Contractor	Disconnecting and capping utility lines, tearing down the damaged building, hauling away debris, and cleaning up the old site
	Contractor: General Construction Contractor	Building the new building on the new site (May also be able to do all demolition work)

Communities with more restrictive floodplain management ordinances or laws may require a greater level of protection.

Although the substantial damage/substantial improvement requirement helps protect lives and property, it has at times placed an additional burden on property owners who were trying to repair their damaged buildings. Under the original terms and conditions of the NFIP Standard Flood Insurance Policy (SFIP), the owner of a substantially damaged building was reimbursed for the costs of repairing the damage but not for the costs of complying with state and local requirements concerning substantially damaged structures. For example, the homeowner would not have been reimbursed for the cost of elevating the building, even though state or local ordinances or laws required elevating.

In 1997, to provide relief for the owners of houses substantially damaged by flooding, Congress authorized the inclusion of Increased Cost of Compliance (ICC) coverage in the SFIP. With this change in effect, the SFIP reimburses homeowners not only for the cost of repairing flood damage but also for the additional cost, up to a maximum amount stated in the SFIP, of meeting certain state and local floodplain management requirements concerning substantial damage and repetitive losses. Other sources of assistance include:

- Small Business Administration (SBA)—In areas declared a major disaster area by the President, the SBA provides low-interest disaster assistance loans to individuals for both businesses and private residences. These loans cover the cost of rebuilding a damaged building, including the cost of bringing the building into compliance with applicable ordinances and laws. The loans can pay for retrofitting of substantially damaged buildings required by ordinances or laws (including elevating flood-prone buildings and rebuilding badly damaged flood-prone buildings at an alternative location), as well as some mitigation projects that are not required by ordinances or laws. At the applicant's request, the amount of the loan may be increased by up to 20 percent for hazard mitigation measures not required by the community's ordinances or laws.

- Department of Housing and Urban Development (HUD)—In an area declared a major disaster area by the President, HUD may provide additional, or allow for the reprogramming of existing, community development block grants. If a community wishes, these grants may be used for retrofitting substantially damaged or substandard buildings (including elevating flood-prone buildings and acquiring badly damaged flood-prone buildings).

- U.S. Army Corps of Engineers (USACE)—The USACE has the statutory authority to participate in flood protection projects that may include residential retrofitting (including elevating flood-prone buildings and acquiring badly damaged flood-prone buildings).

- Natural Resources Conservation Service (NRCS)—The NRCS has the statutory authority to participate in small watershed flood protection projects that may include residential retrofitting.

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REVEGETATION

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1.0 INTRODUCTION

This chapter provides information on methods and plant materials needed for revegetation of drainage facilities within the Urban Drainage and Flood Control District (District). Establishment of a robust cover of vegetation is critical to the proper functioning of drainage structures such as grass-lined channels, detention basins, retention ponds, and wetlands. Vegetation serves multiple purposes, including stabilization of structures to prevent excessive erosion and removal of pollutants in stormwater. The semi-arid nature of the climate, prevalence of introduced weeds, and variety of soil types encountered in the District virtually mandate prompt implementation of a revegetation plan to achieve revegetation success.

2.0 SCOPE OF THIS CHAPTER AND RELATION TO OTHER RELEVANT DOCUMENTS

This chapter provides guidelines and recommendations for plant materials and methods for revegetation of components of the drainage system that are to be vegetated. Such components include:

- Natural channels
- Grass-lined channels
- Detention ponds
- Retention ponds
- Constructed wetlands/wetland channels
- Streambank stabilization and grade control structures

This chapter addresses the different revegetation requirements of the various parts of these facilities. For example, the bottom, side slopes and areas immediately adjacent to a facility have different moisture regimes and, therefore, should be planted with different plant species. Different plant forms (e.g., grasses, shrubs, trees) may also be limited to specific areas to enable proper functioning of the facility. For example, planting trees and shrubs along the bottom of a channel can reduce the hydraulic capacity of the channel, increase maintenance requirements, and cause the plugging of downstream bridges and culverts when uprooted by higher flows.

Additional information on revegetation methods in the District can be found in *Guidelines for Development and Maintenance of Natural Vegetation* (Don Godi and Associates 1984) and in *Design Workbook for Establishment of Natural Vegetation* (Don Godi and Associates 1993). Establishment of temporary and permanent vegetation for construction BMPs is addressed in the CONSTRUCTION BMPs chapter in Volume 3 of this *Manual*.

Although the information in this chapter is generally consistent with the information in these other documents, certain areas and topics have been updated (e.g., recommended seed mixes). Refer to the other documents listed for additional information, especially on factors to consider in preparing a revegetation plan.

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3.0 GENERAL GUIDELINES FOR REVEGETATION

The guidelines below should be followed when developing a revegetation plan to the extent feasible.

3.1 Plant Materials

- The form(s) of vegetation and species used should be adapted to the soil and moisture conditions and use (e.g., conveyance of flow, side slopes, etc.) of the area.
- Native, perennial species should be used to the extent possible.
- Use of bluegrass and other species requiring irrigation and high maintenance should be avoided except along formal park settings.
- Sod-forming grasses are preferred over bunch grasses.
- Containerized nursery stock should be used for wetlands, trees, and shrubs to the extent feasible.
- Wetland plantings should not include cattails.
- Maintenance requirements should be considered in plant selection (e.g., tall grasses should not be used in urban areas unless regular mowing will occur).
- Live stakes, willow bundles, and cottonwood poles should be obtained from local, on-site sources, whenever possible (see Section 4.7.1).

3.2 Site Preparation

- All areas to be planted should have at least 6 inches of “topsoil” suitable to support plant growth (Don Godi and Associates 1984). Native topsoil should be stripped and saved for this purpose whenever a site is graded.
- The upper 3 inches of the soils in areas to be seeded should not be heavily compacted and should be in a friable condition. An 85% standard proctor density is acceptable.
- When necessary, soil amendments should be added to correct topsoil deficiencies (e.g., soil texture, pH or percent organic matter). (If topsoil and native seed mixes are used, fertilizer is often not needed.)
- Fertilizer should be used if specified by a soil analysis. Slow-release type fertilizers should be used to reduce weed growth and protect water quality. Fertilizer should be worked into soil during seedbed preparation.

3.3 Seeding and Planting

- Seed mixtures should be sown at the proper time of year specified for the mixture.
- Recommended seeding rates specified as “pounds pure live seed per acre” (lbs PLS/acre) should be used.
- Seed should be drill seeded, whenever possible.
- Broadcast seeding or hydro-seeding may be substituted on slopes steeper than 3(H):1(V) or on other areas not practical to drill seed.
- Seeding rates should be doubled for broadcast seeding or increased by 50% if using a Brillion drill or hydro-seeding.
- Broadcast seed should be lightly hand raked into the soil.
- Seed depth should be ⅓ to ½ inch for most mixtures.
- All seeded areas should be mulched, and the mulch should be adequately secured.
- If hydro-seeding is conducted, mulching should be conducted as a separate, second operation.
- All containerized nursery stock should be kept in a live and healthy condition prior to installation.
- Containerized trees and shrubs should be installed according to the planting details provided in Section 4.4.
- Live stakes, poles and willow bundles should be installed when dormant (late winter and early spring) according to the planting details in Section 4.7.
- Beaver protection should be provided for trees and shrubs for species known to be attractive to beavers if beavers are known to be in the area (see Figure RV-6).

3.4 Maintenance

- Sites should be routinely inspected following planting to implement follow-up measures to increase success. Immediate attention to a problem (e.g., weed infestation, failure of seed to germinate) can prevent total failure later.
- Access to and grazing on recently revegetated areas should be limited with temporary fencing and signage while plants are becoming established (normally the first year).
- Weed infestations should be managed using appropriate physical, chemical, or biological methods as soon as possible. (See the other documents referenced for details on weed

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management options.)

- Stakes and guy wires for trees should be maintained, and dead or damaged growth should be pruned.
- Beaver protection cages should be used around tree plantings.
- Mulch should be maintained by adding additional mulch and redistributing mulch, as necessary.
- Areas of excessive erosion should be repaired and stabilized.
- Planted trees and shrubs should be watered monthly or as needed from April through September until established.

4.0 PREPARATION OF A PLANTING PLAN

4.1 General

A plan (drawings and specifications) needs to be prepared for revegetation work. The plan should address the following:

- Soil bed preparation
- Species, types, and sizes of materials to be planted
- Planting methods
- Mulching/fertilization
- Planting schedule

Figure RV-1 is a matrix that shows the steps involved in the revegetation process. Additional information on planning and design of a revegetation plan is included in *Design Workbook for Establishment of Natural Vegetation* (Don Godi and Associates 1993). This includes a "design analysis revegetation matrix" and several "checklists." This and other relevant documents should be consulted for details on preparation of a planting plan. In addition, refer to the DESIGN EXAMPLES chapter of this *Manual* for more information on planting plans.

4.2 Soil Amendments

Native topsoil should be stripped and saved for revegetation. If this is not appropriate due to poor soil quality or for some other reason, then subsoil can be made conducive for plant growth through the use of amendments. Since soil pH is typically suitable within the District, amendments are usually needed for increasing organic matter content or providing nutrients in the form of fertilizers. Consideration should be given to importing topsoil, instead of amending poor quality subsoil, as this may be less expensive.

Peat moss, composted manure, composted organic materials, grass clippings, and plowed-in green crops can be used to increase the organic matter content of a soil. Several of these also provide a source of nutrients. Inorganic and organic fertilizers are commonly used to increase the nutrient content of soils. Deficiencies with trace elements also occur on occasion. Soil samples should be sent to a laboratory for testing (e.g., Colorado State University Soils Test Laboratory), and fertilizer recommendations followed.

Detailed information on the types and amounts of soil amendments and fertilizers needed is beyond the scope of this document and can be found in the documents previously referenced. However, information is provided on the use of humate soil conditioner and biosol fertilizer. Both of these materials are relatively new and show promise as soil conditioners and sources of slow-release fertilizers for revegetation work in the District.

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4.2.1 Humate Conditioner

1. Utilize natural humic acid-based concentrated solution or granular material with the following characteristics:
   - Maximum of 10% retained on a #50 mesh screen
   - 4% N, 20% P as P_2O_5, 20% K as K_20
   - 1% Ca, 0.4% Fe, 0.4% S, humic acid 45%
2. Apply granular humate at a rate of 750 pounds/acre in a uniform manner prior to tilling soils for seeding.
3. Apply soluble concentrate at 1.0 pound/acre.
4. Thoroughly mix into soil to increase organic matter and nutrient content.

4.2.2 Biosol

1. Utilize organic fertilizer with the following characteristics:
   - 6% N, 1% P as P_2O_5, 3% K as K_2O
   - 90% fungal biomass
2. Apply at a rate of 1,200 pounds/acre in a uniform manner prior to tilling soils for seeding.
3. Thoroughly mix into soil to increase nutrients.

4.3 Recommended Seed Mixes

Unlined drainage facilities and all areas disturbed during construction should be actively revegetated. Seed mixes should be selected to match the conditions where they will be used. Seed mixes can be developed for the revegetation plan consistent with the guidelines in Section 3.0, or the mixes presented in this section can be used.

Recommended seed mixes for the bottom (wet soils) and side slopes of drainage facilities within the District are included in Tables RV-1 and RV-2. Mixes for different soil conditions in upland areas are provided in Tables RV-3 to RV-6. The seeding rates in these mixes are recommended minimum rates that should be used for drill seeding. These rates should be doubled for broadcast seeding and increased by 50% if a Brillion drill or hydro-seeding is used.

The recommended seed mixes are suitable for the Colorado Front Range for sites from 4,500 to 7,000 feet in elevation and latitude 38° to 42° North. Applications outside these ranges should be made after consultation with a qualified revegetation specialist.

Table RV-1—Recommended Seed Mix for High Water Table Conditions[1]

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/Acre
Redtop*	*Agrostis alba*	Warm	Sod	5,000,000	0.1
Switchgrass (Pathfinder)	*Panicum virgatum*	Warm	Sod/bunch	389,000	2.2
Western wheatgrass (Arriba)	*Pascopyrum smithii*	Cool	Sod	110,000	7.9
Inland saltgrass	*Distichlis spicata*	Warm	Sod	520,000	1.0
Wooly sedge	*Carex lanuginose*	Cool	Sod	400,000	0.1
Baltic rush	*Juncus balticus*	Cool	Sod	109,300,000	0.1
Prairie cordgrass	*Spartina pectinata*	Coll	Sod	110,000	1.0
					12.4
Wildflowers					
Nuttall's sunflower	*Helianthus nuttallii*	---	---	250,000	0.10
Wild bergamot	*Monarda fistulosa*	---	---	1,450,000	0.12
Yarrow	*Achillea millefolium*	---	---	2,770,000	0.06
Blue vervain	*Verbena hastata*	---	---		0.12
					0.40

[1] For areas of facilities located near or on the bottom or where wet soil conditions occur. Planting of potted nursery stock wetland plants 2-foot on-center is recommended for sites with wetland hydrology.

* Nonnative.

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Table RV-2—Recommended Seed Mix for Transition Areas[1]

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/Acre
Sheep fescue (Durar)	*Festuca ovina*	Cool	Bunch	680,000	1.3
Western wheatgrass (Arriba)	*Pascopyrum smithii*	Cool	Sod	110,000	7.9
Alkali sacaton	*Spolobolus airoides*	Warm	Bunch	1,758,000	0.5
Slender wheatgrass	*Elymus trachycaulus*	Cool	Bunch	159,000	5.5
Canadian bluegrass (Ruebens)*[2]	*Poa compressa*	Cool	Sod	2,500,000	0.3
Switch grass (Pathfinder)	*Panicum virgatum*	Warm	Sod/bunch	389,000	1.3
					16.8
Wildflowers					
Blanket flower	*Gaillardia aristata*	---	---	132,000	0.25
Prairie coneflower	*Ratibida columnaris*	---	---	1,230,000	0.20
Purple prairie clover	*Petalostemum purpurea*	---	---	210,000	0.20
Gayfeather	*Liatris punctata*	---	---	138,000	0.06
Flax	*Linum lewisii*	---	---	293,000	0.20
Penstemon	*Penstemon strictus*	---	---	592,000	0.20
Yarrow	*Achillea millefolium*	---	---	2,770,000	0.03
					1.14

[1] For side slopes or between wet and dry areas.

[2] Substitute 1.7 lbs PLS/acre of inland salt grass (*Distichlis spicata*) in salty soils.

* Nonnative.

Table RV-3—Recommended Seed Mix for Alkali Soils

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/Acre
Alkali sacaton	*Sporobolus airoides*	Cool	Bunch	1,750,000	0.5
Streambank wheatgrass (Sodar)	*Agropyron riparium*	Cool	Sod	156,000	5.6
Inland salt grass	*Distichlis stricta*	Warm	Sod	520,000	1.7
Western wheatgrass (Arriba)	*Pascopyrum smithii*	Cool	Sod	110,000	7.9
Blue grama (Hachita)	*Chondrosum gracile*	Warm	Sod	825,000	4.0
Buffalograss	*Buchloe dactyloides*	Warm	Sod	56,000	2.0
					21.7
Wildflowers					
Blanket flower	*Gaillardia aristata*	---	---	132,000	0.25
Prairie coneflower	*Ratibida columnaris*	---	---	1,230,000	0.20
Purple prairie clover	*Petalostemum purpurea*	---	---	210,000	0.20
Gayfeather	*Liatris punctata*	---	---	138,000	0.06
Blue Flax	*Linum lewisii*	---	---	293,000	0.20
Rocky Mountain penstemon	*Penstemon strictus*	---	---	592,000	0.20
Yarrow	*Achillea millefolium*	---	---	2,770,000	0.03
					1.14

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Table RV-4—Recommended Seed Mix for Loamy Soils

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/Acre
Sheep fescue (Durar)	*Festuca ovina*	Cool	Bunch	680,000	0.6
Canby bluegrass	*Poa canbyi*	Cool	Bunch	926,000	0.5
Thickspike wheatgrass (Critana)	*Elymus lanceolatus*	Cool	Sod	154,000	5.7
Western wheatgrass (Arriba)	*Pascopyrum smithii*	Cool	Sod	110,000	7.9
Blue grama (Hahita)	*Chondrosum gracile*	Warm	Sod/bunch	825,000	1.1
Switchgrass (Pathfinder)	*Panicum virgatum*	Warm	Sod/bunch	389,000	1.0
Sideoats grama (Butte)	*Boutelou curtipendula*	Warm	Sod	191,000	2.0
					18.8
Wildflowers					
Blanket flower	*Gaillardia aristata*	---	---	132,000	0.25
Prairie coneflower	*Ratibida columnaris*	---	---	1,230,000	0.20
Purple prairie clover	*Petalostemum purpurea*	---	---	210,000	0.20
Gayfeather	*Liatris punctata*	---	---	138,000	0.06
Flax	*Linum lewisii*	---	---	293,000	0.20
Penstemon	*Penstemon strictus*	---	---	592,000	0.20
Yarrow	*Achillea millefolium*	---	---	2,770,000	0.03
					1.14

Table RV-5—Recommended Seed Mix for Sandy Soils

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/Acre
Blue grama (Hachita)	*Chondrosum gracile*	Warm	Sod/bunch	825,000	2.1
Little bluestem (Camper)	*Schizachyrium scoparium*	Warm	Bunch	260,000	3.0
Prairie sandreed	*Calamovilfa longifolia*	Warm	Sod	274,000	3.0
Sand dropseed	*Sporobolus cryptandrus*	Warm	Bunch	5,298,000	0.3
Sideoats grama (Vaughn)	*Bouteloua curtipendula*	Warm	Sod/bunch	191,000	5.6
Western wheatgrass (Arriba)	*Pascopyrum smithii*	Cool	Sod	110,000	8.0
					22.0
Wildflowers					
Blanket flower	*Gaillardia aristata*	---	---	132,000	0.25
Prairie coneflower	*Ratibida columnifera*	---	---	1,230,000	0.20
Purple prairie clover	*Petalostemum purpurea*	---	---	210,000	0.20
Gayfeather	*Liatris punctata*	---	---	138,000	0.06
Flax	*Linum lewisii*	---	---	293,000	0.20
Penstemon	*Penstemon strictus*	---	---	592,000	0.20
Yarrow	*Achillea millefolium*	---	---	2,770,000	0.03
					1.14

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Table RV-6—Recommended Seed Mix for Clay Soils

Common Name (Variety)	Scientific Name	Growth Season	Growth Form	Seeds/Lb	Lbs PLS/Acre
Buffalograss	*Buchloe dactyloides*	Warm	Sod	56,000	14.0
Sideoats grama (Vaughn)	*Bouteloua curtipendula*	Warm	Sod	191,000	3.0
Blue grama (Hachita)	*Chondrosum gracile*	Warm	Sod/bunch	825,000	1.1
Western wheatgrass (Arriba)	*Pascopyrum smithii*	Cool	Sod	110,000	7.9
Alkali sacaton	*Sporobolus airoides*	Warm	Bunch	1,758,000	1.0
Inland saltgrass	*Distichlis stricta*	Warm	Sod	520,000	2.0
					29.0
Wildflowers					
Gayfeather	*Liatris punctata*	---	---	138,000	0.1
Purple prairie clover	*Petalostemum purpureum*	---	---	210,000	0.1
Scarlet globemallow	*Sphaeralcea coccinea*	---	---	500,000	0.1
Rocky Mountain beeplant	*Cleome serrulata*	---	---	65,900	0.1
					0.4

The seed mixes in Tables RV-1 through RV-6t06 also include recommended wildflowers that can be included in a mix when wildflowers are desired. The wildflower seeds can be sown at the same time or after the grass seed mix. Table RV-7 includes a general wildflower seed mix that can be used in sunny locations. This mix stresses more drought tolerant, native perennials, and can be sown at the same time as a grass seed mix, or after. The mix in Table RV-7 is recommended instead of the species shown in Tables RV-1 through RV-6, when more wildflowers are desired.

Table RV-7—Wildflower Mix (to be seeded with grass seed mix)[1]

Common Name (Variety)	Scientific Name	Flower Color	Seeds/Lb	Lbs PLS/Acre
Scarlet globemallow	*Sphaeralcea coccinea*	Red/orange	500,000	0.6
Blue flax	*Linum lewisii*	Blue	293,000	0.6
Purple prairie clover	*Petalostemum purpureum*	Red-purple	210,000	0.7
White prairie clover	*Petalostemum candidum*	White	354,000	0.6
California poppy	*Eschscholtzia californica*	Orange	293,000	0.3
Blanket flower	*Gaillardia aristata*	Yellow/red	132,000	1.0
Prairie aster	*Aster tanacetifolius*	Violet	496,000	0.3
Blackeyed Susan	*Rudbeckia hirta*	Yellow	1,710,000	0.3
Purple coneflower	*Echinacea purpurea*	Purple	117,000	0.9
Yarrow	*Achillea millefolium*	White	2,770,000	0.1
Gayfeather	*Liatris punctata*	Rose/purple	138,000	0.6
Total				6.0

[1] This is a general mix for the District that stresses native perennials that do well in a range of soil types in sunny locations.

4.4 Trees, Shrubs and Wetland Plantings

Trees and shrubs add diversity to a planting plan and value for wildlife and birds. Trees and shrubs that impede flow and reduce the capacity of the structure should not be planted in the bottom of a drainage channel. It is recommended that containerized stock of the species listed in Table RV-8 be planted, as shown on Figures RV-2 and RV-3. Alternatively, cottonwood pole plantings and coyote (or sandbar) willow cuttings may be used to establish cottonwood trees and willows especially in soils with a shallow groundwater table.

The species of trees and shrubs to be planted should be chosen carefully to meet specific site conditions. For example, a shrub species that requires moderate to high soil moisture (e.g., sandbar willow) should not be planted on a dry hillside or upper streambank unless there is evidence of a high groundwater table or another continuous water source.

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Table RV-8—Recommended Shrubs and Trees[1]

Common Name	Scientific Name	Height (ft)	Sun/Shade	Planting Zone	Notes
Shrubs					
Saskatoon serviceberry	*Amelanchier alnifolia*	3 – 15	Sun	Upland	Good for wildlife
Lead plant	*Amorpha fruticosa*	3 – 8	Sun	Upland	Drought tolerant
Rubber rabbitbrush	*Chrysothamnus nauseosus*	2 – 3	Sun	Upland	Drought tolerant
Wild plum	*Prunus Americana*	5 – 20	Sun/shade	Transition	Forms thickets
Chokecherrry	*Prunus virginiana*	5 – 20	Sun/shade	Transition	Forms thickets
Smooth sumac	*Rhus glabra*	4 – 7	Sun/shade	Upland	Good for wildlife
Oakbrush sumac	*Rhus trilobata*	2 – 6	Sun/shade	Upland	Drought tolerant
Wax currant	*Ribes cereum*	3 – 5	Sun/shade	Transition	Good for wildlife
Redosier dogwood	*Cornus stolonifera*	3 – 9	Shade	Wetland	Drought tolerant
Sandbar willow	*Salix exigua*	6 – 10	Sun	Transition or wetland	Requires more water
Snowberry	*Symphoricarpos oreophilus*	2 – 5	Sun/shade	Transition	Prefers moist area
Spanish bayonet	*Yucca glauca*	1 – 2	Sun	Upland	Drought tolerant
Woods rose	*Rosa woodsii*	2 – 3	Sun	Upland	Establishes quickly
Silver buffaloberry	*Shepherdia argentea*	6 – 13	Sun	Upland	Drought tolerant
Trees					
Narrow leaf cottonwood	*Populus angustifolia*	10 – 30	Sun	Transition or wetland	Requires more water
Plains cottonwood	*Populus deltoides*	50	Sun	Transition	Requires more water
Rocky Mountain juniper	*Juniperus scopulorum*	5 – 15	Sun	Upland	Drought tolerant
Colorado blue spruce	*Picea pungens*	60 – 100	Sun	Transition	Requires more water
Ponderosa pine	*Pinus ponderosa*	75 – 100	Sun	Upland	Drought tolerant
Peach leaf willow	*Salix amygdaloides*	15 – 30	Sun	Wetland	Requires more water

[1] Trees and shrubs should not be planted in the bottoms of drainage channels or where they could impede flow and decrease channel capacity. It is recommended that containerized stock (e.g., 2-gallon, 5-gallon) be used for trees and shrubs.

Wetland vegetation should be established in constructed wetlands, wetland bottom channels and, at times, along the shoreline of retention ponds. Such vegetation serves multiple functions, including assistance with pollutant removal, shoreline stabilization, aesthetics, and wildlife and bird habitat. Wetland plants should be planted in “zones” based on water depth. A common problem with establishing

wetlands within the District is invasion by cattails. Actively planting a constructed wetland and keeping open areas with a water depth greater than 2 feet will discourage cattail invasion. Recommended plants for wetlands are shown in Table RV-9 by water depth. It is recommended that containerized stock be used for wetland plantings. Additional information on design of constructed wetlands and retention ponds can be found in Volume 3 of this *Manual*.

Table RV-9—Recommended Plants for Constructed Wetlands and Retention Pond Shelf[1]

Depth of Water (ft)	Common Name	Scientific Name	Notes
0 - 1.5	Soft stem bulrush Hard stem bulrush Arrowhead Alkali bulrush Smart weed	*Scirpus validus* *Scirpus acutus* *Sagittaria latifolia* *Scirpus maritimus* *Polygonum persicaria*	• Planted plants should extend above water • Plants will invade deeper water with time
0.25 - 0.5	Three-square Spike rush	*Scirpus americanus* *Eleocharis palustris*	• Planted plants should extend above water
0 - 0.25	Rice cut grass Nebraska sedge Soft rush Baltic rush Torrey's rush Foxtail barley	*Leersia oryzoides* *Carex nebrascensis* *Juncus effuses* *Juncus balticus* *Juncus torreyi* *Hordeum jubatum*	• Species will adjust to moisture conditions with time
Height above water 0 – 1 0 – 3	 Milkweed Switchgrass Prairie cordgrass Beebalm	 *Asclepias incarnata* *Panicum virgatum* *Spartina pectinata* *Monarda fistulosa*	 • Best to plant near water where soil is wet • Colorful wildflower

[1] It is recommended that containerized stock be used for wetland plantings. It is not recommended that cattails be planted since they will invade naturally.

4.5 Mulching

All planted areas should be mulched preferably immediately following planting, but in no case later than 14 days from planting. Mulch conserves water and reduces erosion. The most common type of mulch used is hay or grass that is crimped into the soil to hold it. However, crimping may not be practical on slopes steeper than 3:1.

The following guidelines should be followed with mulching:

- Only weed-free and seed-free straw mulch should be used (grass hay often contains weedy exotic species). Mulch should be applied at 2 tons/acre and adequately secured by crimping,

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tackifier, netting, or blankets.

- Crimping is appropriate on slopes of 3:1 or flatter and must be done so as to tuck mulch fibers into the soil 3 to 4 inches deep.
- Tackifier or netting and blankets anchored with staples should be used on slopes steeper than 3:1.
- Hydraulic mulching may also be used on steep slopes or where access is limited. Wood cellulose fibers mixed with water at 2,000 to 2,500 pounds/acre and organic tackifier at 100 pounds per acre should be applied with a hydraulic mulcher.
- Wood chip mulch should be applied to planted trees and shrubs, as shown in Figures RV-2 and RV-3.

Additional details on mulching can be found in Volume 3 of this *Manual*.

4.6 Bioengineering

Willow bundles, live stakes, and cottonwood poles are plant materials that can be used to revegetate drainage facilities. Willow bundles can be placed to provide bank protection along lower slopes of channels. Live stakes and poles can be planted near the toe of a slope where there is a source of high groundwater. They are especially applicable for vegetating large riprap and boulders filled with soil. Information is provided below on methods for collecting and planting willow bundles, live stakes and cottonwood poles. In addition, see Section 4.5, Bioengineered Channels, in the MAJOR DRAINAGE chapter of this *Manual* for additional information and figures.

4.7 Collection of Live Stakes, Willow Cuttings, and Poles

Live stakes, willow cuttings, and poles are straight branches or saplings that have been cut and pruned from dormant living plant material (plants that have lost their leaves).

Single live stakes: The live branches which shall be trimmed and cut to length for this installation shall be a minimum of 2½ feet long and a minimum of ½ inch in diameter for bare ground installation, and a minimum of 3½ feet long for riprap joint planting. These units shall be free from all side branches. The terminal bud must remain undamaged. The "root" end of each cutting shall be cut at a 45-degree angle. This serves as an indicator of which end of the stake to tamp into the ground or riprap and also facilitates the tamping process.

Willow bundling: The live branches, which shall be trimmed and cut to length for this installation, shall be a minimum of 4 feet long and a minimum of ⅜ inch in diameter. These units shall be free from all side branches. The "root" end of each cutting shall be cut at a 45-degree angle. This serves as an indicator of

which end of the stake to insert into the ground or riprap.

Cottonwood poling: The live saplings or straight branches, which shall be trimmed and cut to length for this installation, shall be a minimum of 10 feet long and a minimum of 1 inch in diameter. These units shall be free from all side branches. The "root" end of each pole shall be cut at a 45-degree angle. This serves as an indicator of which end of the pole to insert into the ground or riprap.

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4.7.1 Harvest Procedure

1. Timing of harvest and Installation: All live willow staking, bundling, and poling shall be performed between February 1 and April 1, prior to leafing out.

2. Source and species of live cut materials: Live cuttings shall be taken from approved, existing, natural, native-growing sites. All cuttings shall be taken from a dormant plant. Willow species shall be *Salix exigua* (Sandbar willow) or approved equivalent. Cottonwood species shall be *Populus deltoides* (Plains cottonwood) or equivalent. Willow cuttings shall be at least ¼ inch in diameter, and cottonwood poles no less than ¾ inch in diameter.

3. Cutting: The use of weed whips with metal blades, loppers, brush cutters, and pruners is recommended, provided that they are used in such a manner that they leave clean cuts. The use of chain saws is not recommended. Live plant materials shall be cut and handled with care to avoid bark stripping and trunk wood splitting. Cuts shall be made 8 to 10 inches from the ground when cutting from the approved sites. Cuts shall be made flat or at a blunt angle.

   All cuttings should be placed in water deep enough to cover at least the lower 6 inches of the cutting immediately after harvest.

4. Harvesting site: No more than 30% of available branches should be harvested at a site. The harvesting site must be left clean and tidy. Excess woody debris should be removed from the site and disposed of properly, or could be cut up into 16-inch lengths and evenly distributed around the site.

5. Binding and storage: Live branch cuttings shall be bound together securely with twine at the collection site, in groups, for easy handling and for protection during transport. Live branch cuttings shall be grouped in such a manner that they stay together when handled. Outside storage locations shall be continually shaded and protected from the wind. Cuttings shall be held in moist soils or kept in water until ready for planting. Cuttings shall be protected from freezing and drying at all times.

6. Transportation: During transportation, the live cuttings shall be placed on the transport vehicles in an orderly fashion to prevent damage and to facilitate handling. The live cuttings shall be kept wet and covered with a tarp or burlap material during transportation.

7. Arrival time: All cuttings shall arrive on the job site within 8 hours of cutting. Upon arrival at the installation site, cuttings shall be inspected for acceptability. Cuttings not installed on the day of arrival at the job site shall be stored and protected (kept in water and in cold storage) until installation. All cuttings shall be installed within 24 hours of harvesting.

8. Inspection and approval: Upon arrival at the construction site, live branch cuttings shall be

inspected for acceptability. Live cuttings shall be collected from sources that shall be approved prior to the commencement of cutting operations.

4.7.2 Installation

Single live stakes: Live stakes shall be planted in three rows starting 0.5 feet above the ordinary high water line, at 1 foot spacing. Stakes shall be installed in a 2-feet by 2-feet grid pattern. Live stakes shall be tamped directly into the soil or between rock riprap and shall protrude 4 to 8 inches from the soil surface. Live stakes shall be installed at least 12 inches into the soil and at least 6 inches into saturated soil. In no case will the live stakes protrude more than 8 inches above the soil surface. In the case of joint planting in riprap, the protruding measurement shall be taken from the soil level between the rocks and not from the top of rock. Only dead blow hammers or rubber mallets shall be used to tamp the live stakes into the soil. Care shall be taken to prevent splitting the stakes due to impact from the hammers. Sledgehammers shall not be used to tamp the live stakes into the soil. In cases where the soil is too hard to tamp the live stake in directly, a metal rod of ½- to ¾-inch-diameter may be driven in first to prepare a pilot hole. Backfill around the installed live stake with the original soil to eliminate air voids, then tamp the ground lightly around the stake with a hammer to hold it securely in place. A slight "saucer" shall be formed around each cutting to capture and hold precipitation. This saucer should be filled with water after planting. After the stakes are fully tamped into the soil, the top 1 to 2 inches of each live stake shall be pruned to a clean, non-damaged cut. Figure RV-4 shows a typical installation of live willow staking.

Willow bundling: Bundles shall consist of five to seven cuttings bound together into a 2- to 3-inch-diameter. Bundles shall be planted in rows starting 0.5 feet above the ordinary high water line at 4-foot spacing. Bundles shall be inserted directly into the soil or between rock riprap and shall protrude 4 to 8 inches from the soil surface. Bundles shall be installed at least 12 inches into the soil and reach at least 6 inches into saturated soil. In no case should the cuttings protrude more than 8 inches above the soil surface. In the case of joint planting in riprap, the protruding measurement shall be taken from the soil level between the rocks and not from the top of rock. If tamping is necessary, care shall be taken to prevent splitting the cuttings. Backfill around the installed bundle with the original soil to eliminate air voids, then tamp the ground lightly around the bundle with a hammer to hold it securely in place. A slight saucer shall be formed around each bundle to capture and hold precipitation. This saucer should be filled with water after planting. After the bundles are fully inserted into the soil, the top 1 to 2 inches of each cutting shall be pruned if necessary to a clean, non-damaged cut. Figure RV-5 shows a typical installation of willow bundling.

Cottonwood poling: All branches must be trimmed from the pole except those at the tip. Prepare the pilot hole by using an auger, stinger, or probe to bore to a minimum depth of 5 feet or as needed to penetrate groundwater. Poles should pass through 18 inches of aerated soil before penetrating the water table.

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The pilot hole shall be of sufficient diameter to facilitate easy insertion of a cottonwood pole. Backfill around the installed pole with loose sand to eliminate air voids, then tamp the ground lightly around the pole with a hammer to hold it securely in place. A slight saucer shall be formed around each pole to capture and hold precipitation. This saucer should be filled with water after planting. Cottonwood poles should be protected against beaver damage by the installation of a 30-inch-diameter beaver protection sleeve made from an 8½-foot length of 48-inch-wide 2-inch by 2-inch welded wire fabric fastened with wire or hogring fasteners. Figure RV-6 shows a typical installation of cottonwood poles.

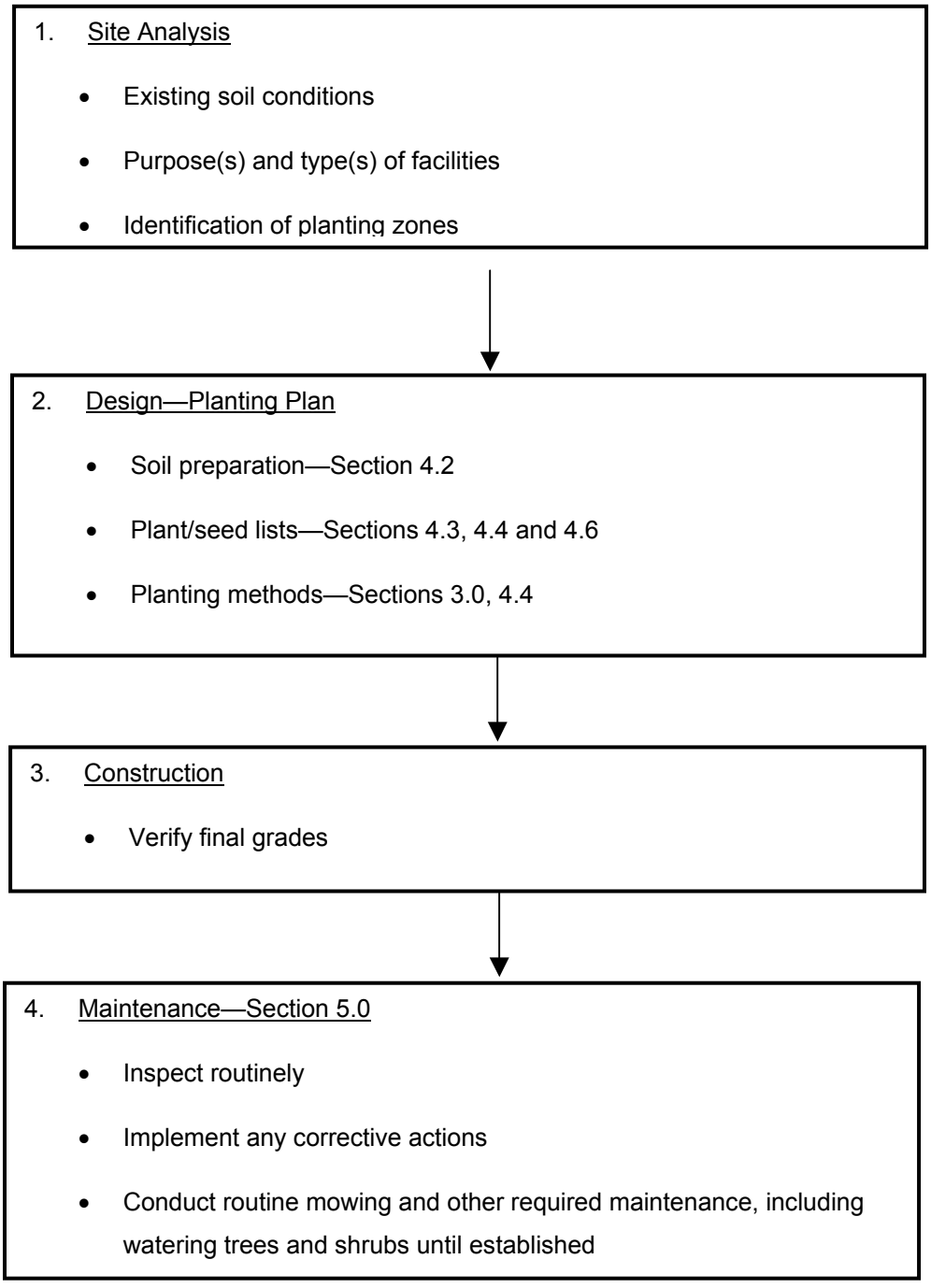

Figure RV-1—Revegetation Process Chart

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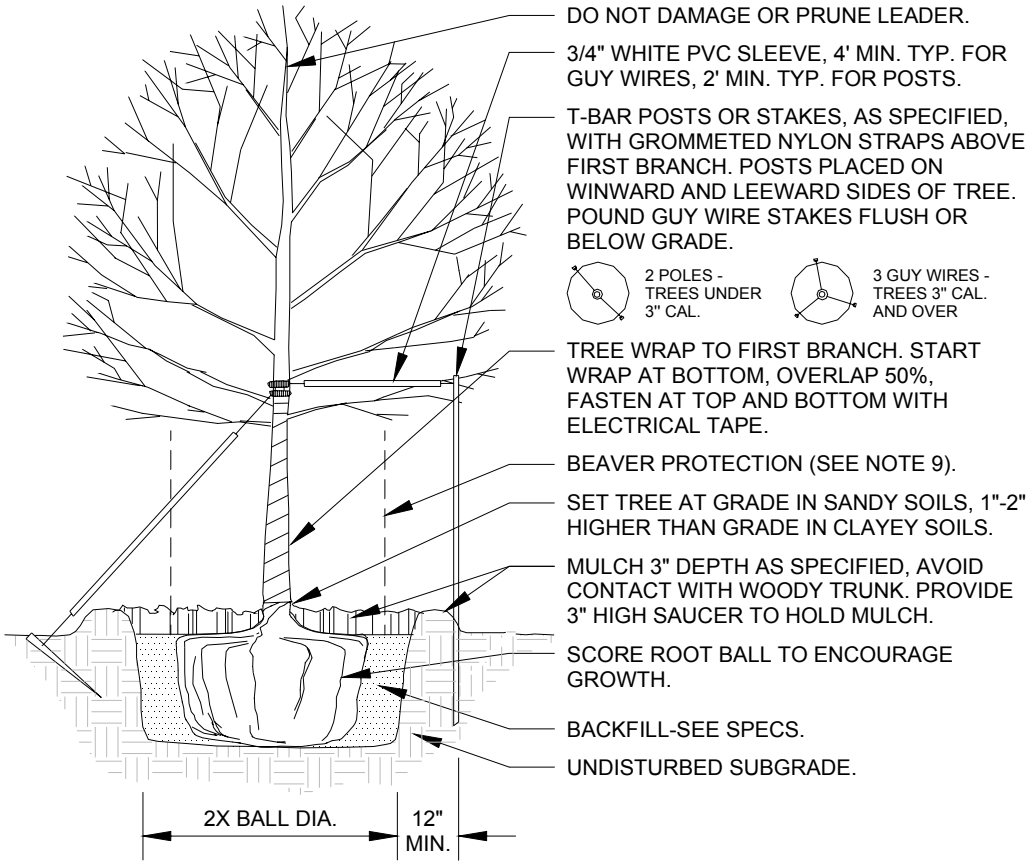
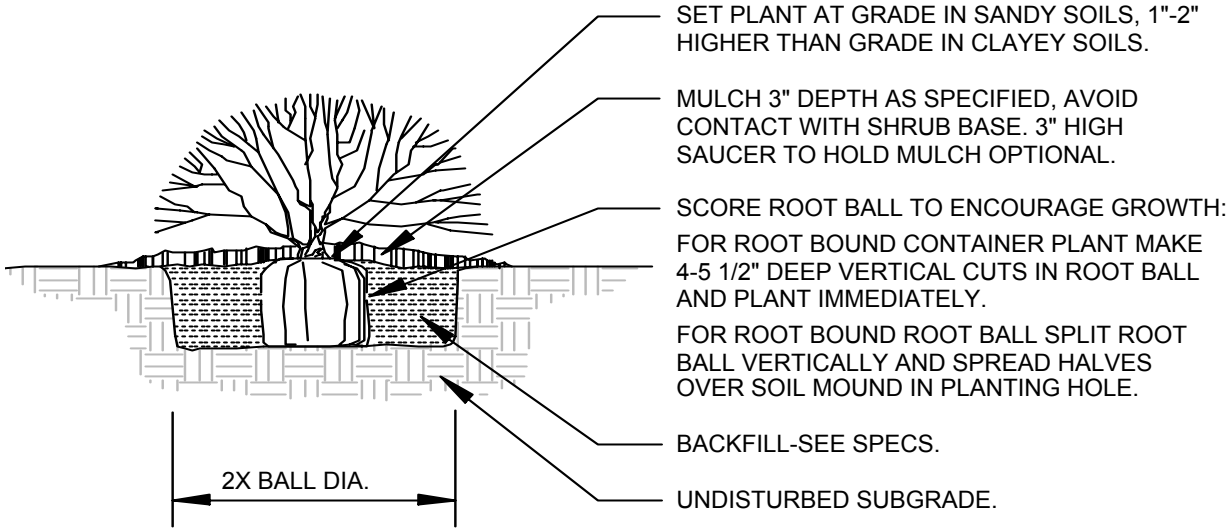


NOTES:

1. SEE SPECS FOR ADDITIONAL PLANTING REQUIREMENTS.
2. KEEP PLANTS MOIST AND SHADED UNTIL PLANTED. PRUNE ALL DAMAGED AND DEAD BRANCHES AND WEAK OR NARROW CROTCHES. DO NOT REMOVE LOWER LIMBS AND SPROUTS FOR AT LEAST TWO GROWING SEASONS.
3. PLUMB AND ORIENT PLANTS FOR BEST APPEARANCE.
4. REMOVE ALL TWINE AND WIRE FROM ROOT BALL AND FOLD BURLAP BACK 2/3. REMOVE ALL RESTRAINING MATERIAL AFTER TREE IS SET IN PLANTING HOLE.
5. ROOT BALL SHALL REST ON FIRM, UNDISTURBED SOIL. IN SANDY SOIL PLANTING HOLE SHALL BE NO DEEPER THAN ROOT BALL. IN CLAYEY SOIL PLANTING HOLE SHALL BE 1"-2" SHALLOWER THAN ROOTBALL.
6. SCARIFY VERTICAL SLOPES INSIDE HOLE WITH SPADE.
7. ON SLOPES GREATER THAN 5:1 SET ROOT BALL 2" ABOVE LINE OF SLOPE AT GRADE. PROVIDE SAUCER RIM ON DOWNHILL SIDE OF ROOT BALL, 2:1 MAX. SLOPE, COVER EXPOSED ROOT BALL MIN. 6".
8. WATER ALL PLANTS WELL AT PLANTING.
9. PROVIDE A BARRIER PROTECTION SLEEVE (SEE FIGURE RV-6) WHENEVER BEAVER ARE SUSPECTED TO LIVE OR ARE EXPECTED TO MOVE INTO THE PROJECT AREA LATER.

Figure RV-2—Tree Planting Details



NOTES:

1. SEE SPECS FOR ADDITIONAL PLANTING REQUIREMENTS.
2. KEEP PLANTS MOIST AND SHADED UNTIL PLANTED. PRUNE ALL DAMAGED AND DEAD WOOD.
3. PLUMB AND ORIENT PLANTS FOR BEST APPEARANCE.
4. REMOVE ALL TWINE FROM ROOT BALL AND FOLD BURLAP BACK 2/3. REMOVE PLASTIC BURLAP, CONTAINERS AND WIRE BASKETS ENTIRELY.
5. ROOT BALL SHALL REST ON FIRM, UNDISTURBED SOIL. IN SANDY SOIL PLANTING HOLE SHALL BE NO DEEPER THAN ROOT BALL. IN CLAYEY SOIL PLANTING HOLE SHALL BE 1"-2" SHALLOWER THAN ROOTBALL.
6. SCARIFY VERTICAL SLOPES INSIDE HOLE WITH SPADE.
7. ON SLOPES GREATER THAN 5:1 SET ROOT BALL EVEN WITH LINE OF SLOPE AT GRADE. PROVIDE SAUCER RIM ON DOWNHILL SIDE OF ROOT BALL, 2:1 MAX. SLOPE, COVER EXPOSED ROOT BALL MIN. 6".
8. WATER ALL PLANTS WELL AT PLANTING.

Figure RV-3—Shrub Planting Details

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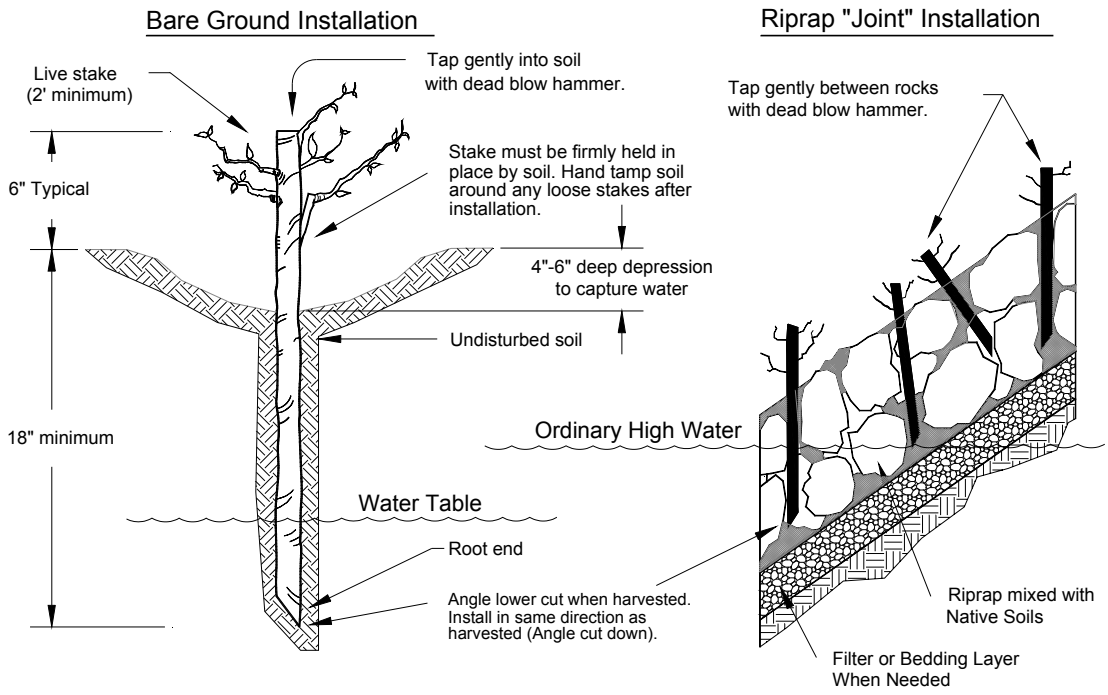

Figure RV-4—Single Willow Stake Detail for Use in Granular Soils With Available Groundwater

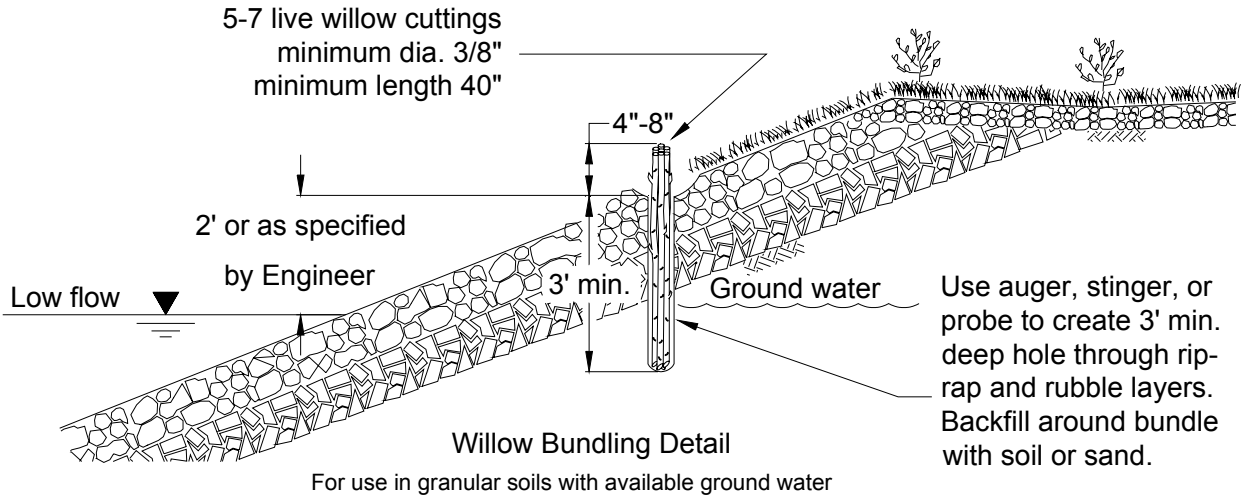

Figure RV-5—Willow Bundling Detail

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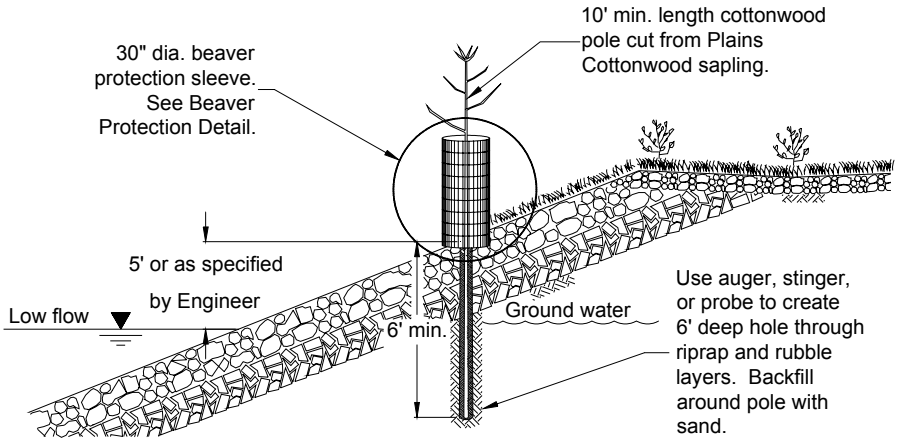
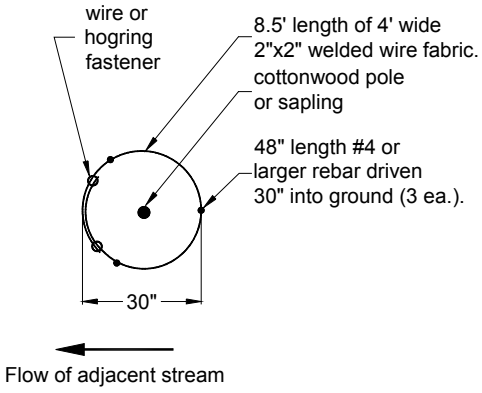
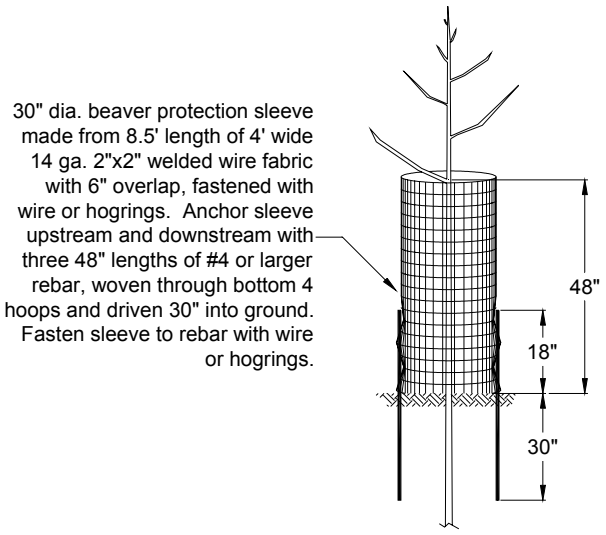


Cottonwood Poling Detail

For use in granular soils with available ground water





Beaver Protection Detail

Figure RV-6—Cottonwood Poling Details

5.0 POST-CONSTRUCTION MONITORING

Monitoring is necessary to check the status of revegetation work and to implement any follow-up measures needed, such as mowing, weed control, watering, overseeding, etc. This is especially important for establishing native species since it may take several years for vegetation to become adequately established. Sites should be observed several times during their first two growing seasons and at least once a year thereafter. The guidelines in Section 3.4 should be followed.

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6.0 REFERENCES

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———. 1993. *Design Workbook for Establishment of Natural Vegetation*. Denver, CO: Urban Drainage and Flood Control District.

DESIGN EXAMPLES

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Table DE-1—List of Design Examples 1

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1.0 INTRODUCTION

The purpose of this chapter is to provide design examples, featuring actual projects in the Denver metropolitan area. These examples were prepared by the consulting engineers and landscape architects/planners listed in Table DE-1.

Table DE-1—List of Design Examples

Section	Case Study Name and Location	Prepared By
2.0	**Stapleton Redevelopment**[1] in the City and County of Denver	Matrix Design Group BRW
3.0	**Willow Creek** in Arapahoe County	Muller Consulting Engineers Wenk Associates
4.0	**Rock Creek** in Superior	McLaughlin Water Engineers, Ltd. The Norris/Dullea Company
5.0	**Sand Creek** in Adams County	Aquatic and Wetland Consultants Camp Dresser and McKee (CDM)
6.0	**Goldsmith Gulch** at Bible Park in the City and County of Denver	Sellards & Grigg Consulting Engineers Wenk Associates
7.0	**Greenwood Gulch** in the City of Greenwood Village	Water & Waste Consulting Engineers Sellards & Grigg Consulting Engineers Design Concepts, Inc.
8.0	**Lena Gulch** in Wheatridge	Taggart Engineering Associates EDAW

[1] Comprehensive design example with calculations.

DISCLAIMER

Several design examples are presented in this chapter to illustrate specific problem-solving approaches for projects having particular circumstances and drainage characteristics. The design examples have been selected to represent typical District situations and to show application of drainage principles and design criteria as described in Chapters 1 through 12. The design examples represent standard District technology and application and, for the most part, have been approved by the District and responsible governmental agencies leading to construction. Nonetheless, the designs shown shall be used at the sole risk of the user, and the District and the contributing consultants do not warrant these designs for any particular application. None of the examples represent proprietary design criteria or information and may be freely used as guidelines and examples, as with an engineering textbook. The designs and/or calculations shown represent methods and techniques recommended by the District and are in the public domain.

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2.0 CASE STUDY—STAPLETON REDEVELOPMENT

2.1 Project Setting

The following example illustrates application of this *Manual* for the design of conveyance and detention facilities, including use of computational spreadsheets described in pertinent sections of the *Manual*. Redevelopment of the former Stapleton International Airport in Denver poses significant opportunities and challenges for stormwater management. Like many airports, the site was graded to create gentle grades for runway operations. A formal storm sewer system was installed to control minor storm events, while major 100-year storms were conveyed via sheet flow or by overflow open channels. Consequently, significant drainage infrastructure improvements were needed. The challenge was to strike a balance between conveyance and detention to optimize the reuse of the existing system and minimize grading and demolition.

Figure 1 shows the project location and hydrologic setting for the *Stapleton East-West Linear Park Flood Control Project*. As indicated on Figure 2, the project incorporates a watershed of 104.0 acres that has been delineated into Sub-Basins “031” and “032”. The mixture of residential, park, and school uses represents an average surface imperviousness of 44%. This assignment involved providing preliminary-level engineering for a sub-regional detention pond and associated outfall sewer and overflow channel. It is expected to be constructed by 2002 to support redevelopment of the Stapleton site near Yosemite Boulevard and 26th Avenue. The pond had to be designed to meet both detention volume requirements and enable reuse of an existing 54-inch storm sewer that outfalls to Westerly Creek. As a result, the detention volume had to be computed by V=KA, the modified Federal Aviation Administration (FAA) Method and a synthetic unit hydrograph to determine the controlling criteria.

2.2 Project Objectives

A multi-disciplinary team of engineers, landscape architects, planners, and scientists was formed to plan and design facilities to achieve the following objectives:

Provide a detention facility that offers multiple benefits, including park and recreation uses, flood control, water quality enhancement, and educational benefits.

Minimize demolition in and grading of the sub-basin by designing detention facilities to enable a retrofit and reuse of an existing 54-inch storm sewer.

Perform hydraulic engineering to determine the capacity of the existing outfall system and preliminarily size new collection and conveyance systems required to support land development at Stapleton.

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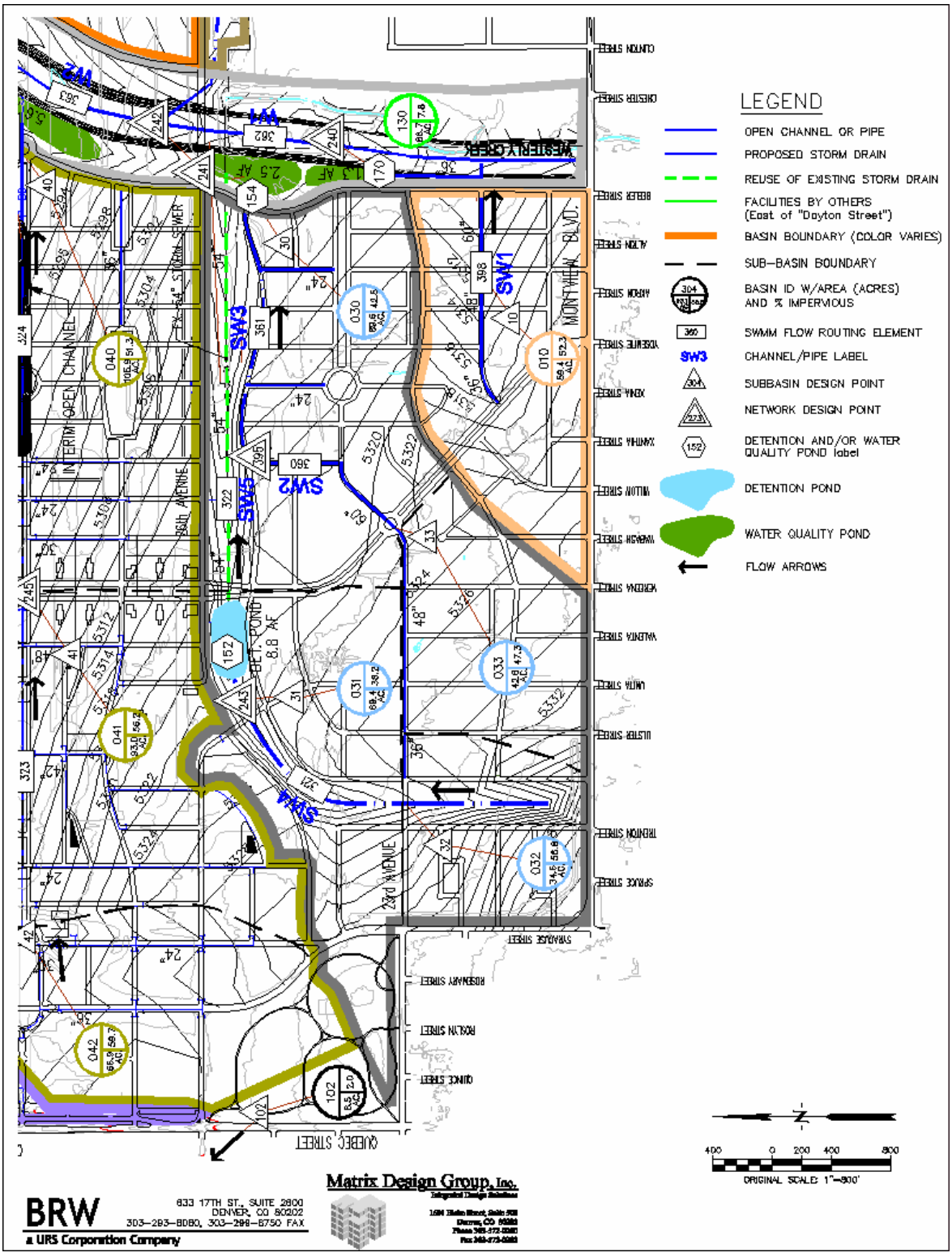

Figure 1—Stapleton Redevelopment Drainage Map

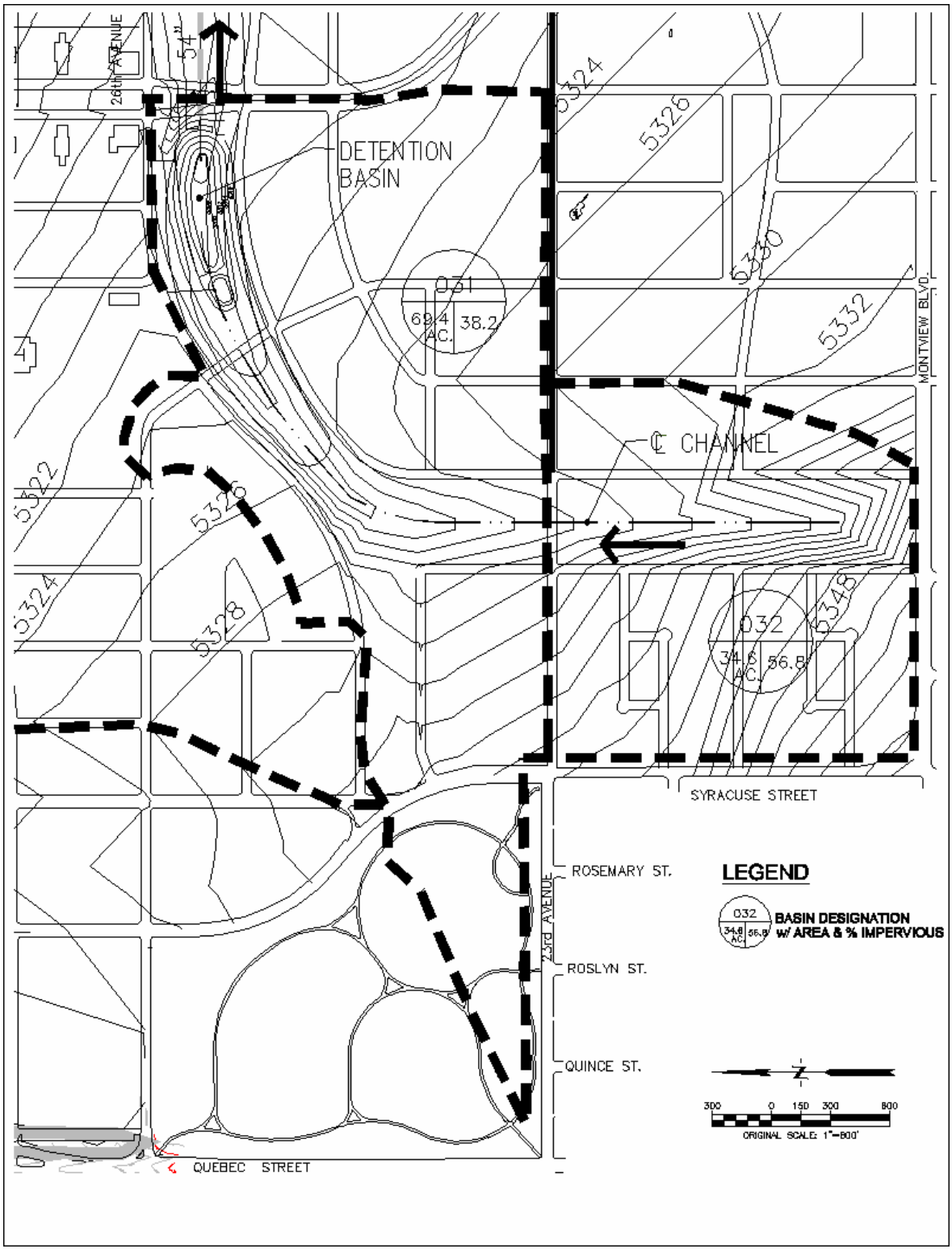

Figure 2—Stapleton Redevelopment Drainage Catchment Map

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2.3 Hydrologic Evaluation For Detention Pond Sizing

Three hydrologic methods were used to establish the required detention pond size:

1. The Colorado Urban Hydrograph Procedure (CUHP) and UDSWM
2. The modified FAA Method
3. The V=KA approach

Because of the basin area (greater than 90 acres) and the need to match discharges with the established capacity of an outfall system, the utilization of a more detailed assessment with a synthetic hydrograph generated by CUHP and UDSWM was required. All three methods were used to verify reasonableness of the results and to ensure that appropriate local detention sizing criteria were satisfied.

2.3.1 CUHP and UDSWM

Input data for CUHP and UDSWM are shown in Table 1. Two discharge rates were considered for the pond routing: the allowable release rate and the flow capacity of the 54-inch storm sewer. The allowable release for the 104-acre basin was 88.4 cfs, relating to 0.85 cfs per acre for Type B Soils. The capacity of the 54-inch RCP (n=0.013, slope=0.38%) was 121 cfs and, consequently, the allowable release rate governed the design of the detention volume. Storage characteristics were developed with a preliminary grading plan to enable stage-storage-discharge data to be used in UDSWM routing.

Table 2 presents the modeling results with the required storage volumes for attenuation of flows to the allowable release rate. Figure 3 graphs the inflow and pond discharge hydrographs for the 100-year storm and shows the required minimum detention volume of 8.8 acre-feet.

Table 1—CUHP and UDSWM Input

CUHP Basin Data

Basin	Area (acres)	Imperviousness	Slope	Length (ft)	Time of Concentration (min)	Centroid Length (ft)
031	69.4	38.2%	0.8%	3820	31.2	1600
032	34.6	56.8%	2.0%	1240	16.9	590

Note: Hydrologic Soil Group B Soils are used in this example.

UDSWM Pond Routing Data

Elevation (Feet)	Depth (Feet)	Storage (Acre-feet)	Discharge (cfs)
5308.7	0.0	0.00	0.0
5310.0	1.3	1.99	0.1
5310.0	1.3	2.00	20.0
5312.2	3.5	4.50	23.9
5312.3	3.6	4.60	88.4
5314.0	5.3	8.78	88.4
5314.1	5.4	8.80	90.0
5316.0	7.3	20.00	5000.0

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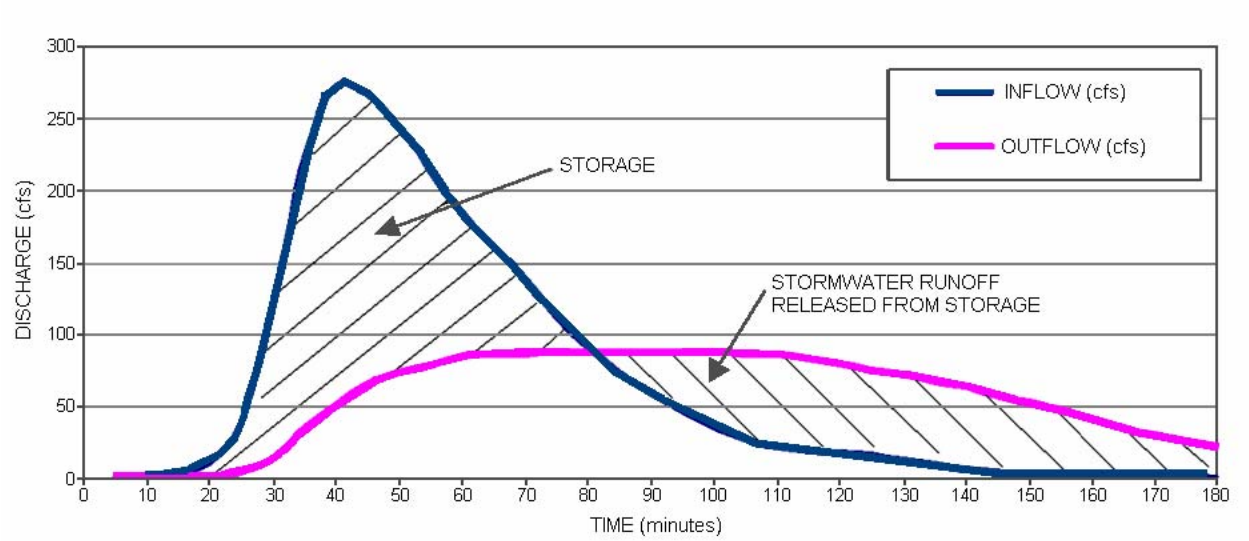


Figure 3—Detention Pond Inflow/Outflow Hydrographs

Table 2—CUHP and UDSWM Modeling Results

Return Period	Q_{in} (cfs)	Q_{out} (cfs)	Detention Storage Volume (acre-feet)
2	44	20	2.1
5	83	22	3.3
10	106	24	4.3
50	222	88	7.0
100	273	88	8.8

2.3.2 Rational Method Hydrology

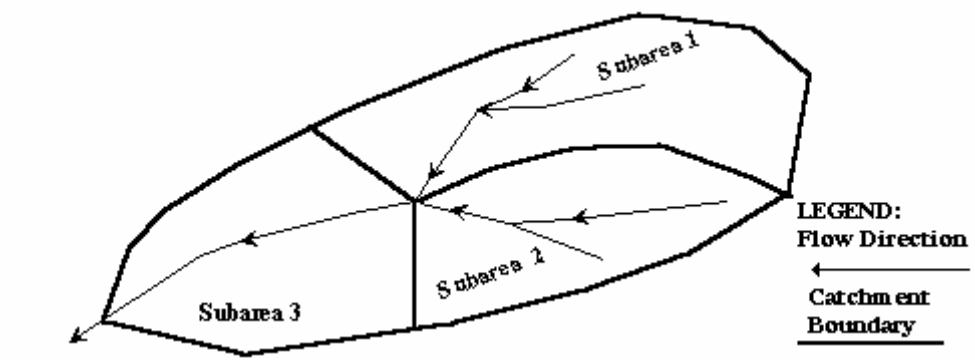
For purposes of this design example, the basin was also analyzed using the Rational Method. Figures 4 and 5 are spreadsheets used to determine the composite runoff coefficients for the basin; they show the 10-year composite runoff coefficient to be 0.55 and the 100-year composite runoff coefficient to be 0.65. By evaluating the basin runoff coefficients, overland flow path, and concentrated flow path, the resulting time of concentration is 35 minutes.

The time of concentration is related to rainfall intensity for use in the Rational Method. By inputting the basin area, runoff coefficients, and rainfall intensity into the Rational Method equation, Q=CIA. Figures 6 and 7 show the 10-year and 100-year peak discharges into the detention pond from the 104-acre drainage basin to be 131 cfs and 250 cfs, respectively.

Area-Weighting for Runoff Coefficient Calculation

Project Title = Stapleton Redevelopment Area
Catchment ID = 31.1, 31 and 32
Return Period = 10yr (initial event), 100yr (major event)

Illustration



Instructions: For each catchment Sub area, enter values for A and C.

(10-yr Event)

Subarea ID	Area acres A	Runoff Coeff C	Product CA
input	input	input	output
31.1A	5.23	0.50	2.62
31.1B	1.10	0.60	0.66
31.1C	1.19	0.50	0.60
31.1D	0.26	0.50	0.13
31.1E	0.42	0.50	0.21
31	61.20	0.50	30.60
32	34.60	0.65	22.49
Sum:	**104.00**	**Sum:**	**57.30**
		Weighted Runoff Coeffecient (sum CA / sum A) =	**0.55**

(100-yr Event)

Subarea ID	Area acres A	Runoff Coeff C	Product CA
input	input	input	output
31.1A	5.23	0.60	3.14
31.1B	1.10	0.70	0.77
31.1C	1.19	0.60	0.71
31.1D	0.26	0.60	0.16
31.1E	0.42	0.60	0.25
31	61.20	0.60	36.72
32	34.60	0.75	25.95
Sum:	**104.00**	**Sum:**	**67.70**
			0.65

Figures 4 & 5—Area-Weighting for Runoff Coefficient Calculation

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CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

I. Catchment Hydrologic Data

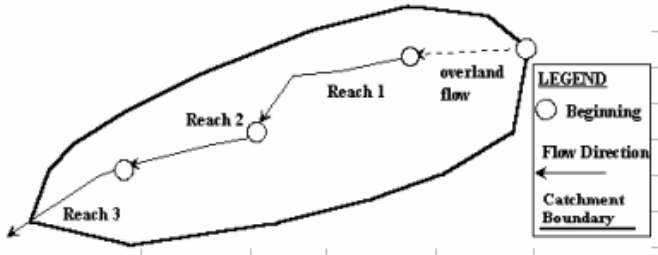
	(10-yr Event)			(100-yr Event)	
Catchment ID =	31, 32		(input)	Catchment ID	31, 32
Area (A) =	104.00		(input)	Area (A) =	104.00
Runoff Coeff (C)=	0.55		(input)	Runoff Coeff (C	0.65

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^ C3

Tr =	10	years	(input)	Tr =	100	years
C1 =	28.50		(input)	C1 =	28.50	
C2=	10.00		(input)	C2=	10.00	
C3=	0.786		(input)	C3=	0.786	
P1=	1.61	inches	(input)	P1=	2.60	inches

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Illustration



SCS Type	Heavy Meadow	Tillage Field	Forest Woods	Short Pasture	Bare Soil	Grass Swale	Paved Flow
Conveyance	2.50	5.00	5.00	7.00	10.00	15.00	20.00

Calculations:

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 input	SCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0050	60.00	0.45		0.09	11.43
1	0.0060	550.00		20.00	1.55	5.92
2	0.0200	1000.00		20.00	2.83	5.89
3	0.0084	3000.00		20.00	1.83	27.28
4						
5						
Sum		4610.00				50.51
					Regional Tc =	35.61
					Min value of Regional Tc and Flow Time is Recommended Tc =	35.61

IV. Peak Runoff Prediction

(10-yr Event)			(100-yr Event)		
I =	2.28	inch/hr	I =	3.68	inch/hr
Qp =	130.56	cfs	Qp =	249.10	cfs

Figures 6 and 7—Calculation of a Peak Runoff Using Rational Method

2.3.3 FAA Method

The modified FAA Method utilizes the Rational Method to estimate detention volumes using a mass diagram. It is appropriate for basins smaller than 160 acres without multiple detention ponds or unusual watershed storage characteristics. Table 3 highlights key input data for use of the FAA Method.

Table 3—FAA Method Input Data

	Area (acres)	Runoff Coefficient C	SCS Soil Type	T_c (min)	Release Rate (cfs/acre)	1-Hour Precip. (in)
10-Year	104	0.55	B	35	0.23	1.60
100-Year	104	0.65	B	35	0.85	2.60

Figure 8 shows the computation of the 10-year storage volume using the FAA method. The plot of mass inflow versus mass outflow is depicted on Figure 9. Figures 10 and 11 show the corresponding information for the 100-year storage volume. The vertical difference between the plots of the 100-year inflow and modified outflow relates to a minimum detention volume of 382,399 cubic feet (8.8 acre-feet).

2.3.4 Denver Regression Equation

For checking purposes, the use of the formula V=KA is required in the Denver Metropolitan area. The formulae for the coefficient, K, for initial and major storm events are stated below.

$K_{10} = (0.95I - 1.90)/1000$

$K_{100} = (1.78I - 0.002[I]^2 - 3.56)/1000$

where I = Basin Imperviousness (%)

For a 104-acre basin with an imperviousness of 44%, the corresponding detention volumes are as shown below in Table 4.

Table 4—Detention Volume

	BASIN 031		BASIN 032		TOTAL	
Area =	69.40	acres	34.60	acres	**104.00**	**acres**
Imp. =	38%		57%		**44.4%**	
K_{10} =	0.034		0.052		**0.040**	
K_{100} =	0.062		0.091		**0.072**	
VOL_{10} =	2.387	acre-feet	1.801	acre-feet	**4.188**	**acre-feet**
VOL_{100} =	4.269	acre-feet	3.152	acre-feet	**7.421**	**acre-feet**

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For catchments less than 160 acres only. For larger catchments, use hydrograph routing methods.
(Note: for catchments larger than 90 acres, CUHP hydrograph and routing are recommended).

10-YEAR

Design Information (Input)

Catchment Drainage Area	A =	104.00	acres
Runoff Coefficient	C =	0.55	
Predevelopment NRCS Soil Group	Type =	B	B
Return Period for Detention Control	T =	10	10
Time of concentration of Watershed	Tc =	35	minutes
Allowable Unit Release Rate (See Table A)	q =	0.23	Default
One-hour Precipitation	P1 =	1.60	inches

Design Rainfall IDF Formula I = C1* P1/(C2+Td)^ C3

Coefficient one	C1 =	28.50	Click Here to Accept Denver Area Default Values
Coefficient two	C2 =	10.00	
Coefficient three	C3 =	0.79	

Determination of Average Outflow from the Basin (Calculated)

Inflow Peak Runoff	Qp-in =	128.92	cfs
Allowable Peak Outflow Rate	Qp-out =	23.92	cfs
Ratio of Qp-out/Qp-in	Ratio =	0.19	

100-YEAR

Design Information (Input)

Catchment Drainage Area	A =	104.00	acres
Runoff Coefficient	C =	0.65	
Predevelopment NRCS Soil Group	Type =	B	B
Return Period for Detention Control	T =	100	10
Time of concentration of Watershed	Tc =	35	minutes
Allowable Unit Release Rate (See T	q =	0.85	Default
One-hour Precipitation	P1 =	2.60	inches

Design Rainfall IDF Formula I = C1* P1/(C2+Td)^ C3

Coefficient one	C1 =	28.50	Click Here to Accept Denver Area Default Values
Coefficient two	C2 =	10.00	
Coefficient three	C3 =	0.79	

Determination of Average Outflow from the Basin (Calculated)

Inflow Peak Runoff	Qp-in =	247.59	cfs
Allowable Peak Outflow Rate	Qp-out =	88.40	cfs
Ratio of Qp-out/Qp-in	Ratio =	0.36	

Recommended Unit Flow Release Rate in cfs/acre of tributary catchment within UDFCD boundaries.

Design Frequency	NRCS (SCS) Hydrologic Soil Group		
	A	B	C & D
2-year	0.02	0.03	0.04
5-year	0.07	0.13	0.17
10-year	0.13	0.23	0.30
25-year	0.24	0.41	0.52
50-year	0.33	0.56	0.68
100-year	0.50	0.85	1.00

Recommended Unit Flow Release Rate in cfs/acre of tributary catchmen within UDFCD boundaries.

Design Frequency	NRCS (SCS) Hydrologic Soil Group		
	A	B	C & D
2-year	0.02	0.03	0.04
5-year	0.07	0.13	0.17
10-year	0.13	0.23	0.30
25-year	0.24	0.41	0.52
50-year	0.33	0.56	0.68
100-year	0.50	0.85	1.00

Determination of Detention Volume Using Modified FAA Method

Rainfall duration must be entered in an increasing order.

10-YEAR

Rainfall Duration minutes (input)	Rainfall Intensity inch/hr (output)	Inflow Volume cubic feet (output)	Adjustment Factor (output)	Average Outflow cfs (output)	Outflow Volume cubic feet (output)	Storage Volume cubic feet (output)
5.00	5.37	92,123	1.00	23.92	7,176	84,947
10.00	4.28	146,791	1.00	23.92	14,352	132,439
15.00	3.59	184,600	1.00	23.92	21,528	163,072
20.00	3.10	213,116	1.00	23.92	28,704	184,412
25.00	2.75	235,851	1.00	23.92	35,880	199,971
30.00	2.47	254,687	1.00	23.92	43,056	211,631
35.00	2.25	270,734	1.00	23.92	50,232	220,502
40.00	2.07	284,699	0.94	22.43	53,820	230,879
45.00	1.92	297,056	0.89	21.26	57,408	239,648
50.00	1.80	308,136	0.85	20.33	60,996	247,140
55.00	1.69	318,180	0.82	19.57	64,584	253,596
60.00	1.59	327,368	0.79	18.94	68,172	259,196
65.00	1.51	335,836	0.77	18.40	71,760	264,076
70.00	1.43	343,692	0.75	17.94	75,348	268,344
75.00	1.36	351,020	0.73	17.54	78,936	272,084
80.00	1.30	357,891	0.72	17.19	82,524	275,367
85.00	1.25	364,359	0.71	16.88	86,112	278,247
90.00	1.20	370,471	0.69	16.61	89,700	280,771
95.00	1.15	376,267	0.68	16.37	93,288	282,979
100.00	1.11	381,779	0.68	16.15	96,876	284,903
105.00	1.07	387,035	0.67	15.95	100,464	286,571
110.00	1.04	392,059	0.66	15.77	104,052	288,007
115.00	1.01	396,873	0.65	15.60	107,640	289,233
120.00	0.97	401,493	0.65	15.45	111,228	290,265
125.00	0.95	405,937	0.64	15.31	114,816	291,121
130.00	0.92	410,218	0.63	15.18	118,404	291,814
135.00	0.89	414,348	0.63	15.06	121,992	292,356
140.00	0.87	418,339	0.63	14.95	125,580	292,759
145.00	0.85	422,200	0.62	14.85	129,168	293,032
150.00	0.83	425,940	0.62	14.75	132,756	293,184
155.00	0.81	429,568	0.61	14.66	136,344	293,224
160.00	0.79	433,089	0.61	14.58	139,932	293,157
165.00	0.77	436,512	0.61	14.50	143,520	292,992
170.00	0.75	439,841	0.60	14.42	147,108	292,733
175.00	0.74	443,082	0.60	14.35	150,696	292,386
180.00	0.72	446,241	0.60	14.29	154,284	291,957
185.00	0.71	449,321	0.59	14.22	157,872	291,449

Stormwater Detention Volume (Cubic Feet) = 293,224
Stormwater Detention Volume (Acre Feet) = 6.731

100-YEAR

Rainfall Duration minutes (input)	Rainfall Intensity inch/hr (output)	Inflow Volume cubic feet (output)	Adjustment Factor (output)	Average Outflow cfs (output)	Outflow Volume cubic feet (output)	Storage Volume cubic feet (output)
5.00	8.72	176,919	1.00	88.40	26,520	150,399
10.00	6.95	281,905	1.00	88.40	53,040	228,865
15.00	5.83	354,515	1.00	88.40	79,560	274,955
20.00	5.05	409,280	1.00	88.40	106,080	303,200
25.00	4.47	452,942	1.00	88.40	132,600	320,342
30.00	4.02	489,114	1.00	88.40	159,120	329,994
35.00	3.66	519,932	1.00	88.40	185,640	334,292
40.00	3.37	546,751	0.94	82.88	198,900	347,851
45.00	3.13	570,482	0.89	78.58	212,160	358,322
50.00	2.92	591,761	0.85	75.14	225,420	366,341
55.00	2.74	611,051	0.82	72.33	238,680	372,371
60.00	2.58	628,695	0.79	69.98	251,940	376,755
65.00	2.45	644,958	0.77	68.00	265,200	379,758
70.00	2.32	660,044	0.75	66.30	278,460	381,584
75.00	2.22	674,119	0.73	64.83	291,720	382,399
80.00	2.12	687,313	0.72	63.54	304,980	382,333
85.00	2.03	699,735	0.71	62.40	318,240	381,495
90.00	1.95	711,473	0.69	61.39	331,500	379,973
95.00	1.88	722,604	0.68	60.48	344,760	377,844
100.00	1.81	733,189	0.68	59.67	358,020	375,169
105.00	1.75	743,283	0.67	58.93	371,280	372,003
110.00	1.69	752,932	0.66	58.26	384,540	368,392
115.00	1.63	762,176	0.65	57.65	397,800	364,376
120.00	1.58	771,049	0.65	57.09	411,060	359,989
125.00	1.54	779,583	0.64	56.58	424,320	355,263
130.00	1.49	787,804	0.63	56.10	437,580	350,224
135.00	1.45	795,736	0.63	55.66	450,840	344,896
140.00	1.41	803,400	0.63	55.25	464,100	339,300
145.00	1.38	810,816	0.62	54.87	477,360	333,456
150.00	1.34	817,999	0.62	54.51	490,620	327,379
155.00	1.31	824,965	0.61	54.18	503,880	321,085
160.00	1.28	831,728	0.61	53.87	517,140	314,588
165.00	1.25	838,301	0.61	53.58	530,400	307,901
170.00	1.23	844,695	0.60	53.30	543,660	301,035
175.00	1.20	850,920	0.60	53.04	556,920	294,000
180.00	1.17	856,985	0.60	52.79	570,180	286,805
185.00	1.15	862,900	0.59	52.56	583,440	279,460

Stormwater Detention Volume (Cubic Feet) = 382,399
Stormwater Detention Volume (Acre Feet) = 8.779

Figures 8 and 9—Detention Volume by Modified FAA Method

(See Chapter 5-Runoff of this *Manual* for description of method)

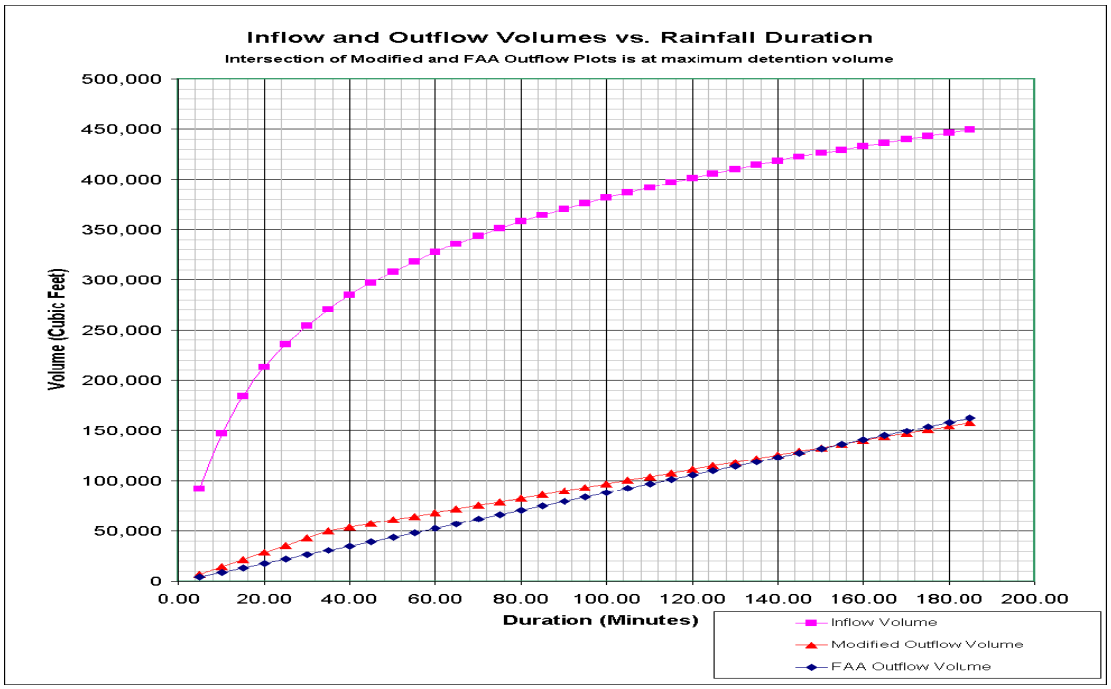

Figure 10—10-Year Modified FAA Method

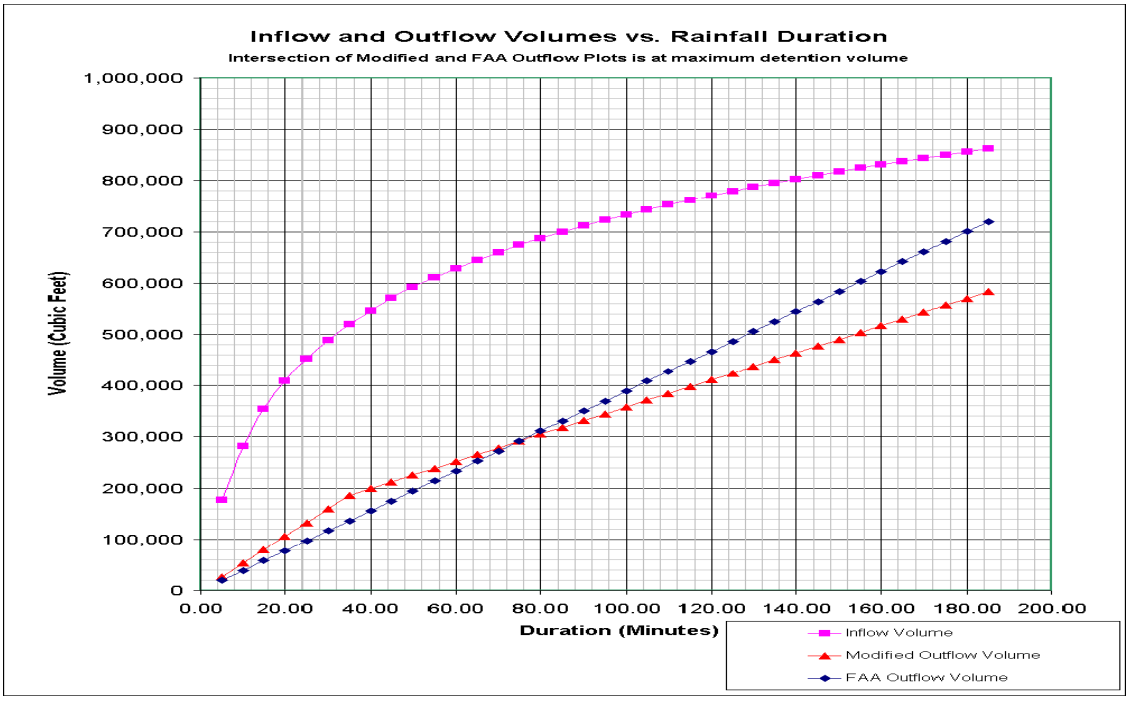

Figure 11—100-Year Modified FAA

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2.3.5 Comparison of the Sizing Methodologies

Table 5 offers a comparison of the modeling results for detention sizing.

Table 5—Summary Comparison of Sizing Methodologies

	V=KA (Acre-Feet)	FAA Method (Acre-Feet)	CUHP/SWM (Acre-Feet)
10-Year	4.2	6.7	4.3
100-Year	7.4	8.8	8.8

For the purposes of this design, the results of the CUHP/UDSWM analysis were used with a required storage volume of 8.8 acre-feet.

2.4 Detention Pond Outlet Configuration

A more detailed grading plan and storm sewer layouts for the detention pond area and adjacent roadways are illustrated on Figure 12. In order to prepare a design for the detention pond, it was necessary to confirm the adequacy of pond volume and establish related water surface depths. The outlet had to be designed to restrict discharges to the design criteria for each storm event and corresponding depth (and hydraulic head) condition. Additionally, the water quality capture volume (WQCV) had to be computed and included in the design volume.

Other objectives of the pond design included:

- For aesthetic purposes, the landscape architect determined that a more elongated and contoured shape was desirable.
- In order to provide for safety and to address the potential risk associated with the adjacent elementary school site, a dry detention pond scheme was selected. A maximum depth of 6 ft was provided and a more flatly graded perimeter area was chosen as a safety shelf.
- A multi-stage outlet was designed to control discharges of the WQCV, 10-year, and 100-year events.
- An overflow spillway and overland channel to Westerly Creek had to be provided for events greater than the 100-year storm and emergency operations.
- Due to the embankment height of less than 10 feet, the Colorado State Engineer did not regulate the pond and a Probable Maximum Flood (PMF) analysis was not required. However, in final design the emergency spillway must be designed for the un-attenuated inflow peak 100-year flow rate of 273 cfs or more and the embankment stability checked for a total flow of 273 cfs.

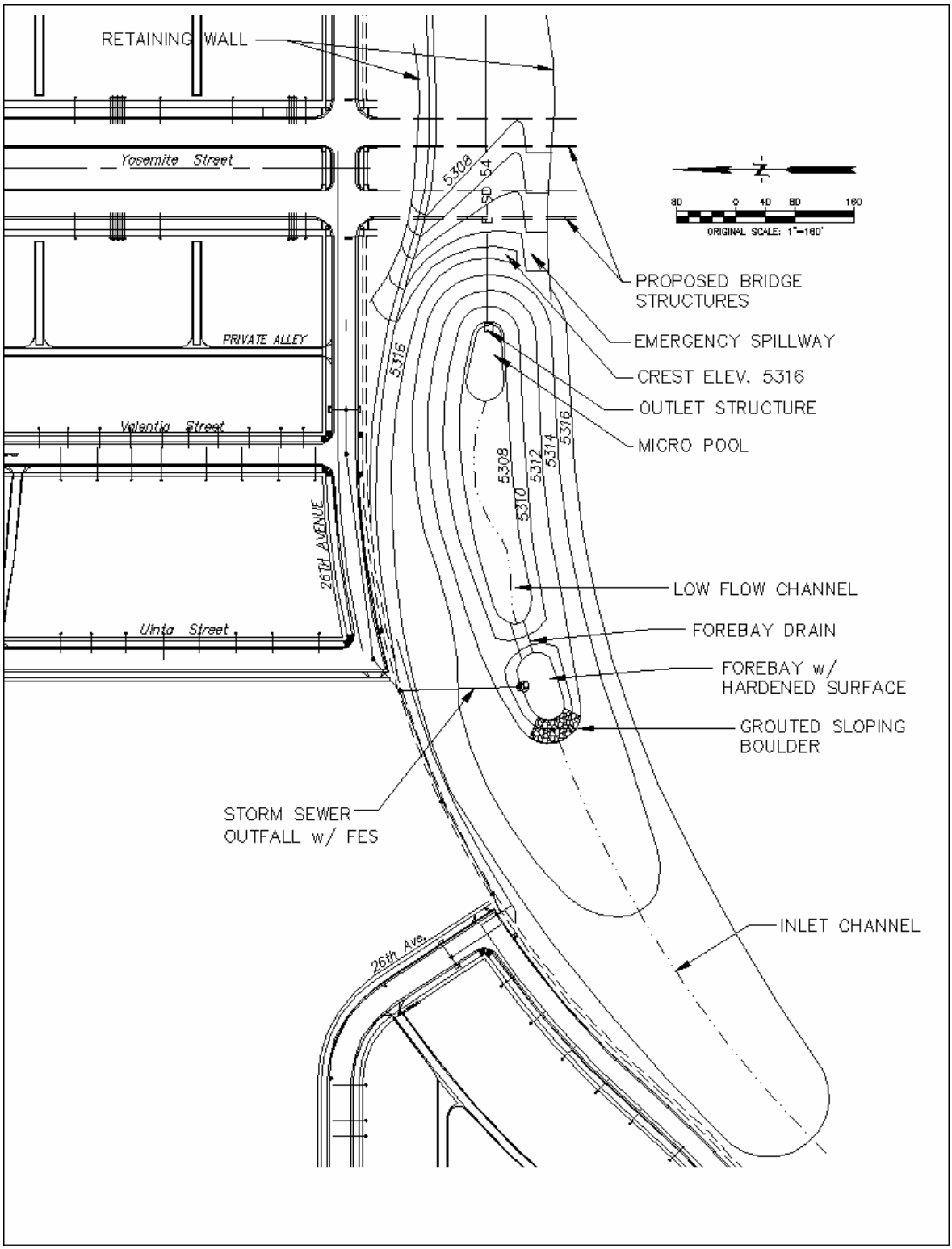

Figure 12—Stapleton Redevelopment Detention Pond Detail

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2.4.1 Stage-Storage Relationships

To properly size the outlet works, it is important to develop depth versus cumulative storage volume relationships for the final detention pond configuration, as shown on Table 6. Figure 13 graphically shows the rating curve for the pond.

Table 6—Stapleton East-West Detention Pond Cumulative Volume Analysis

Contour (feet)	Area (sq. ft.)	Avg Area (sq. ft.)	Volume (cu. ft.)	Cum. Vol. (cu. ft.)	Cum. Vol. (ac-ft)
5306	2,788				
		10,992	21,984	21,984	0.50
5308	22,303				
		28,992	57,983	79,967	1.84
5310	36,242				
		52,065	104,131	184,098	4.23
5312	69,696				
		102,551	205,102	389,200	8.93
5314	139,392				
		188,602	377,203	766,403	17.59
5316	242,542				

2.4.2 Water Quality Volume Requirements

The WQCV must also be determined and incorporated into the pond design. Figure 14 (3 pages) shows the computation of the WQCV from the **Extended Dry Detention Spreadsheet** of Volume 3 of this *Manual.* This computation includes the analysis of the perforated plate, trash rack, forebay, micro-pool and outlet structure components for proper operation. As indicated on line 1(D), a volume of 1.99 acre-feet will be required. Figure 15 is the same analysis of the perforated plate for WQCV using the newly developed spreadsheet from Volumes 1 and 2 of this *Manual*. This computation shows a total of 20 holes (1.50-inch diameter with 5 columns and 4 rows) that will release runoff at the appropriate rate for water quality treatment. Figure 16 is the analysis of the 10-year pond outlet orifice to accomplish the desired release rate of 0.23 cfs/acre (Type B soils), or 24 cfs for a 104-acre drainage basin. Figure 17 is the computation form for the 100-year release rate of 0.80 cfs/acre (Type B soils), or 88 cfs for the drainage catchment area.

2.4.3 Final Pond Outlet Configuration

The final recommended outlet configuration is shown in plan and section view in Figure 18. As shown the WQCV of 2.0 acre-feet will require a ponded depth of 1.3 feet. The 100-year detention volume of 8.8 acre-feet will pond to a depth of 5.3 feet (excluding the micro-pond). These include the WQCV released over a 40-hour period. A horizontal grate at elevation 5313 controls the 100-year event.

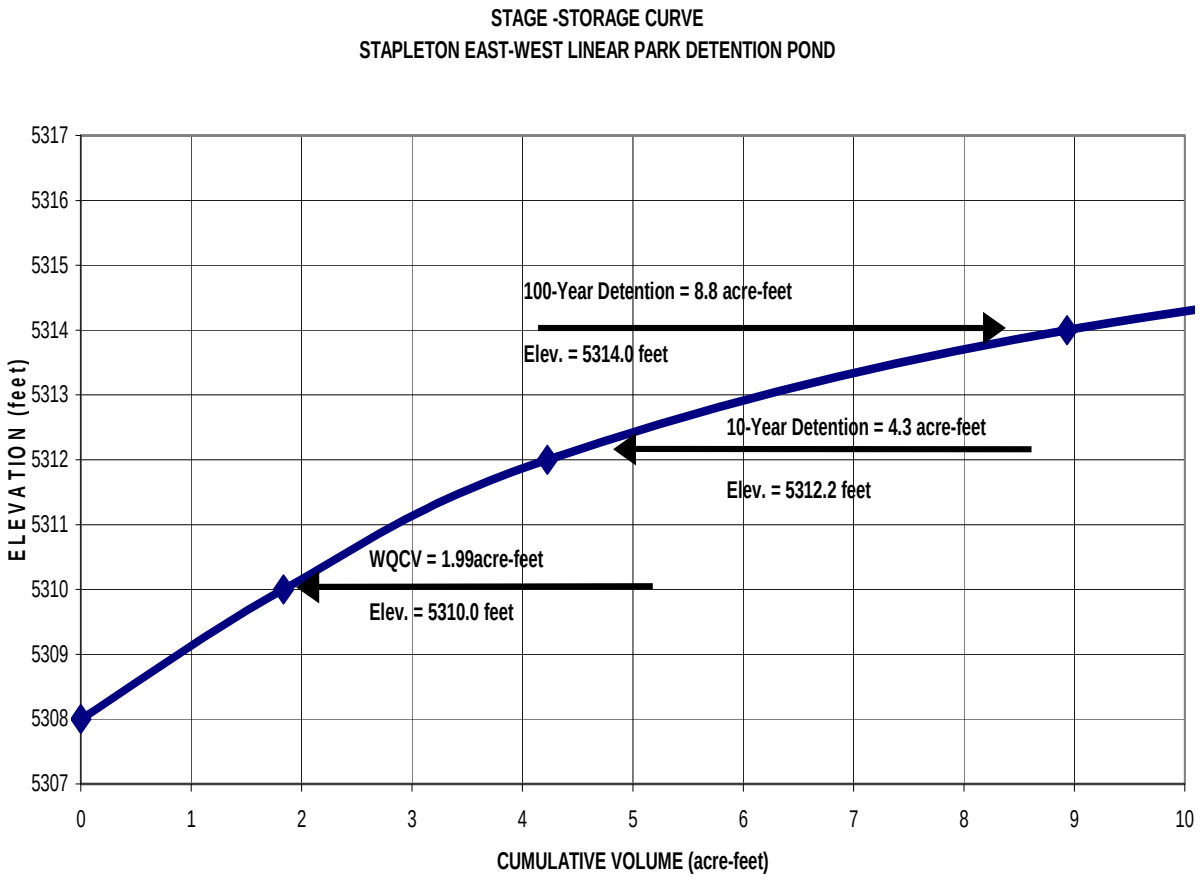

Figure 13—Stage-Storage Curve Stapleton East-West Linear Park Detention Pond

SARB_009327

Sheet 1 of 3

Designer:
Company:
Date: **February 9, 2001**
Project: **UDFCD Example**
Location: **Stapleton Redevelopment**

Figure 14

1.	Basin Storage Volume			
		I_a =	44.40	%
	A) Tributary Area's Imperviousness Ratio (i = I_a / 100)	i =	0.44	
	B) Contributing Watershed Area (Area)	Area =	104.00	acres
	C) Water Quality Capture Volume (WQCV)	WQCV =	0.19	watershed inches
	(WQCV =1.0 * (0.91 * i^3 - 1.19 * i^2 + 0.78 * i))			
	D) Design Volume: Vol = (WQCV / 12) * Area * 1.2	Vol =	1.990	acre-feet
2.	Outlet Works			
	A) Outlet Type (Check One)	X	Orifice Plate	
			Perforated Riser Pipe	
			Other:	
	B) Depth at Outlet Above Lowest Perforation (H)	H =	1.30	feet
	C) Required Maximum Outlet Area per Row, (A_o)	A_o =	9.57	square inches
	D) Perforation Dimensions **(enter one only)**:			
	i) Circular Perforation Diameter **OR**	D =	1.5000	inches, **OR**
	ii) 2" Height Rectangular Perforation Width	W =		inches
	E) Number of Columns (nc, See Table 6a-1 For Maximum)	nc =	5	number
	F) Actual Design Outlet Area per Row (A_o)	A_o =	8.84	square inches
	G) Number of Rows (nr)	nr =	4	number
	H) Total Outlet Area (A_{ot})	A_{ot} =	34.46	square inches
3.	Trash Rack			
	A) Needed Open Area: A_t = 0.5 * (Figure 7 Value) * A_{ot}	A_t =	1,102	square inches
	B) Type of Outlet Opening (Check One)	X	≤ 2" Diameter **Round**	
			2" High **Rectangular**	
			Other:	
	C) For 2", or Smaller, **Round Opening** (Ref.: Figure 6a):			
	i) Width of Trash Rack and Concrete Opening (W_{conc}) from Table 6a-1	W_{conc} =	60	inches
	ii) Height of Trash Rack Screen (H_{TR})	H_{TR} =	40	inches

Figure 14—Design Procedure For Extended Detention Basin Sedimentation Facility

Design Procedure Form: Extended Detention Basin (EDB) - Sedimentation Facility

Sheet 2 of 3

Designer:
Company:
Date: February 9, 2001
Project: UDFCD Example
Location: Stapleton Redevelopment

Figure 14

iii) Type of Screen (Based on Depth H), Describe if "Other"	X	S.S. #93 VEE Wire (US Filter)	
		Other:	
iv) Screen Opening Slot Dimension, Describe if "Other"	X	0.139" (US Filter)	
		Other:	
v) Spacing of Support Rod (O.C.)	1.00	inches	
Type and Size of Support Rod (Ref.: Table 6a-2)	**TE 0.074 in. x 1.00 in.**		
vi) Type and Size of Holding Frame (Ref.: Table 6a-2)	**1.25 in. x 1.50 in. angle**		
D) For 2" High **Rectangular Opening** (Refer to Figure 6b):			
I) Width of Rectangular Opening (W)	W =		inches
ii) Width of Perforated Plate Opening (W_{conc} = W + 12")	W_{conc} =		inches
iii) Width of Trashrack Opening ($W_{opening}$) from Table 6b-1	$W_{opening}$ =		inches
iv) Height of Trash Rack Screen (H_{TR})	H_{TR} =		inches
v) Type of Screen (based on depth H) (Describe if "Other")		Klemp™ KPP Series Aluminum	
		Other:	
vi) Cross-bar Spacing (Based on Table 6b-1, Klemp™ KPP Grating). Describe if "Other"		inches	
		Other:	
vii) Minimum Bearing Bar Size (Klemp™ Series, Table 6b-2) (Based on depth of WQCV surcharge)			
4. Detention Basin length to width ratio		4.00	(L/W)
5 Pre-sedimentation Forebay Basin - Enter design values			
A) Volume (5 to 10% of the Design Volume in 1D)		0.199	acre-feet
B) Surface Area		0.199	acres
C) Connector Pipe Diameter (Size to drain this volume in 5-minutes under inlet control)		24	inches
D) Paved/Hard Bottom and Sides		Y	yes/no

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Design Procedure Form: Extended Detention Basin (EDB) - Sedimentation Facility

Sheet 3 of 3

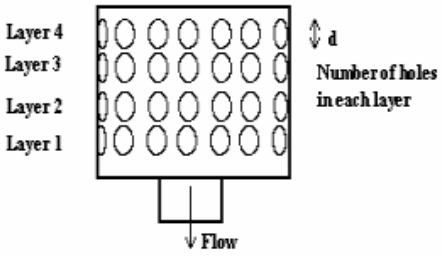
Designer:
Company:
Date: February 9, 2001
Project: UDFCD Example
Location: Stapleton Redevelopment

Figure 14

6.	Two-Stage Design			
	A) Top Stage (D_{WQ} = 2' Minimum)	D_{WQ} =	2.00	feet
		Storage=	1.493	acre-feet
	B) Bottom Stage (D_{BS} = D_{WQ} + 1.5' Minimum, D_{WQ} + 3.0' Maximum, Storage = 5% to 15% of Total WQCV)	D_{BS} =	3.50	feet
		Storage=	0.299	acre-feet
		Surf. Area=	0.085	acres
	C) Micro Pool (Minimum Depth = the Larger of 0.5 * Top Stage Depth or 2.5 Feet)	Depth=	2.50	feet
		Storage=	0.214	acre-feet
		Surf. Area=	0.086	acres
	D) Total Volume: Vol_{tot} = Storage from 5A + 6A + 6B Must be ≥ Design Volume in 1D	Vol_{tot} =	1.990	acre-feet
7.	Basin Side Slopes (Z, horizontal distance per unit vertical) Minimum Z = 4, Flatter Preferred	Z =	4.00	(horizontal/vertical)
8.	Dam Embankment Side Slopes (Z, horizontal distance per unit vertical) Minimum Z = 4, Flatter Preferred	Z =	4.00	(horizontal/vertical)
9.	Vegetation (Check the method or describe "Other")	X	Native Grass	
			Irrigated Turf Grass	
			Other:	

Notes:

Flow Capacity of a Riser (Inlet Control)



1 Description of Riser

Diameter of holes	d =	1.500	in
Number of holes per layer	n =	5	
Vertical Distance Between Holes	h =	4	in
Orifice Discharge Coefficient	C_o =	0.60	
Total opening area at each layer	A_o =	8.8358	sq in
		0.0614	sq ft

2 Calculation of Collection Capacity

The starting elevation of water surface must be >= central elevation of the first layer.

Starting with Layer 1, enter the central elevation of each layer of holes (up to 10 layers) to calculate flow rates.

Elevations of water surface must be entered in an increasing order.

	Water Surface Elevation ft (input)	Central Elevations of Layers of Holes **in feet**										
		Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 9	Layer 10	Flow Rate cfs
		5308.76	5309.09	5309.43	5309.76							
		Collection Capacity for Each Layer of Holes in cfs										
start	5308.80	0.06	0.00	0.00	0.00							**0.06**
	5308.90	0.11	0.00	0.00	0.00							**0.11**
	5309.00	0.14	0.00	0.00	0.00							**0.14**
	5309.10	0.17	0.02	0.00	0.00							**0.20**
	5309.20	0.20	0.10	0.00	0.00							**0.29**
	5309.30	0.22	0.13	0.00	0.00							**0.35**
	5309.40	0.24	0.16	0.00	0.00							**0.40**
	5309.50	0.25	0.19	0.08	0.00							**0.52**
	5309.60	0.27	0.21	0.12	0.00							**0.60**
	5309.70	0.29	0.23	0.15	0.00							**0.67**
	5309.80	0.30	0.25	0.18	0.06							**0.79**
	5309.90	0.32	0.27	0.20	0.11							**0.89**
	5310.00	0.33	0.28	0.22	0.14							**0.98**
	5311.00	0.44	0.41	0.37	0.33							**1.55**
	5312.00	0.53	0.50	0.47	0.44							**1.95**
	5313.00	0.61	0.58	0.56	0.53							**2.28**
	5314.00	0.68	0.65	0.63	0.61							**2.57**
	5315.00	0.74	0.72	0.70	0.68							**2.83**
	5316.00	0.79	0.78	0.76	0.74							**3.07**

Figure 15—Flow Capacity of a Riser (Inlet Control)

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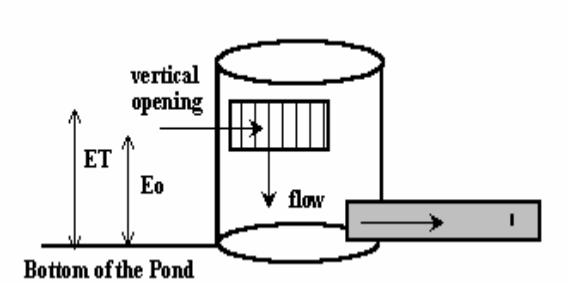


1 Description of Vertical Orifice

Net Opening Area	A_o =	4.2	sq ft
Orifice Coefficient	C_o =	0.65	
Top Elevation of Orifice Opening Area	E_t =	5312.00	ft
Center Elevation of Orifice Opening	E_o =	5311.00	ft

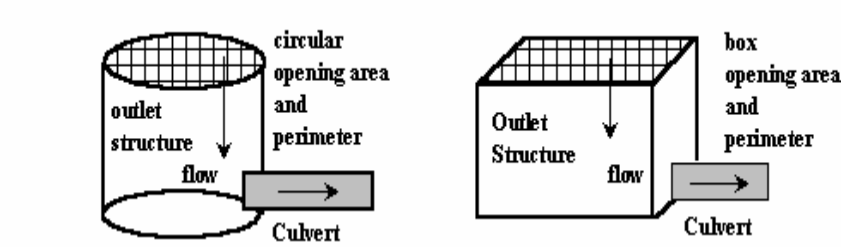
2 Calculation of Collection Capacity

The starting elevation of water surface >= top of the orifice opening.

Elevations of water surface must be entered in an increasing order.

	Water Surface Elevation ft (input)	Collection Capacity cfs (output)
start	5312.00	21.91
	5312.10	22.98
	5312.20	24.00
	5312.30	24.98
	5312.40	25.92
	5312.50	26.83
	5312.60	27.71
	5312.70	28.56
	5312.80	29.39
	5312.90	30.20
	5313.00	30.98

Figure 16—Collection Capacity of Vertical Orifice (Inlet Control)



1 Description of Horizontal Orifice

Net Opening Area (after Trash Rack Reduction)	A_o =	50.0	sq ft
Net Perimeter as Weir Length	L_w =	30.0	ft
Orifice Coefficient	C_o =	0.560	
Weir Coefficient	C_w =	3.000	
Center Elevation of Orifice Opening	E_o =	5313.00	ft

2 Calculation of Collection Capacity

The starting elevation of water surface must be >= Eo
Elevations of water surface must be entered in an increasing order.

	Water Surface Elevation ft (input)	Weir Flow cfs (output)	Orifice Flow cfs (output)	Collection Capacity cfs (output)
start	5313.00	0.00	0.00	0.00
	5313.10	2.85	71.06	2.85
	5313.20	8.05	100.49	8.05
	5313.30	14.79	123.07	14.79
	5313.40	22.77	142.11	22.77
	5313.50	31.82	158.89	31.82
	5313.60	41.83	174.05	41.83
	5313.70	52.71	188.00	52.71
	5313.80	64.40	200.98	64.40
	5313.90	76.84	213.17	76.84
	5314.00	90.00	224.70	90.00

Figure 17—Collection Capacity of Horizontal Orifice (Inlet Control)

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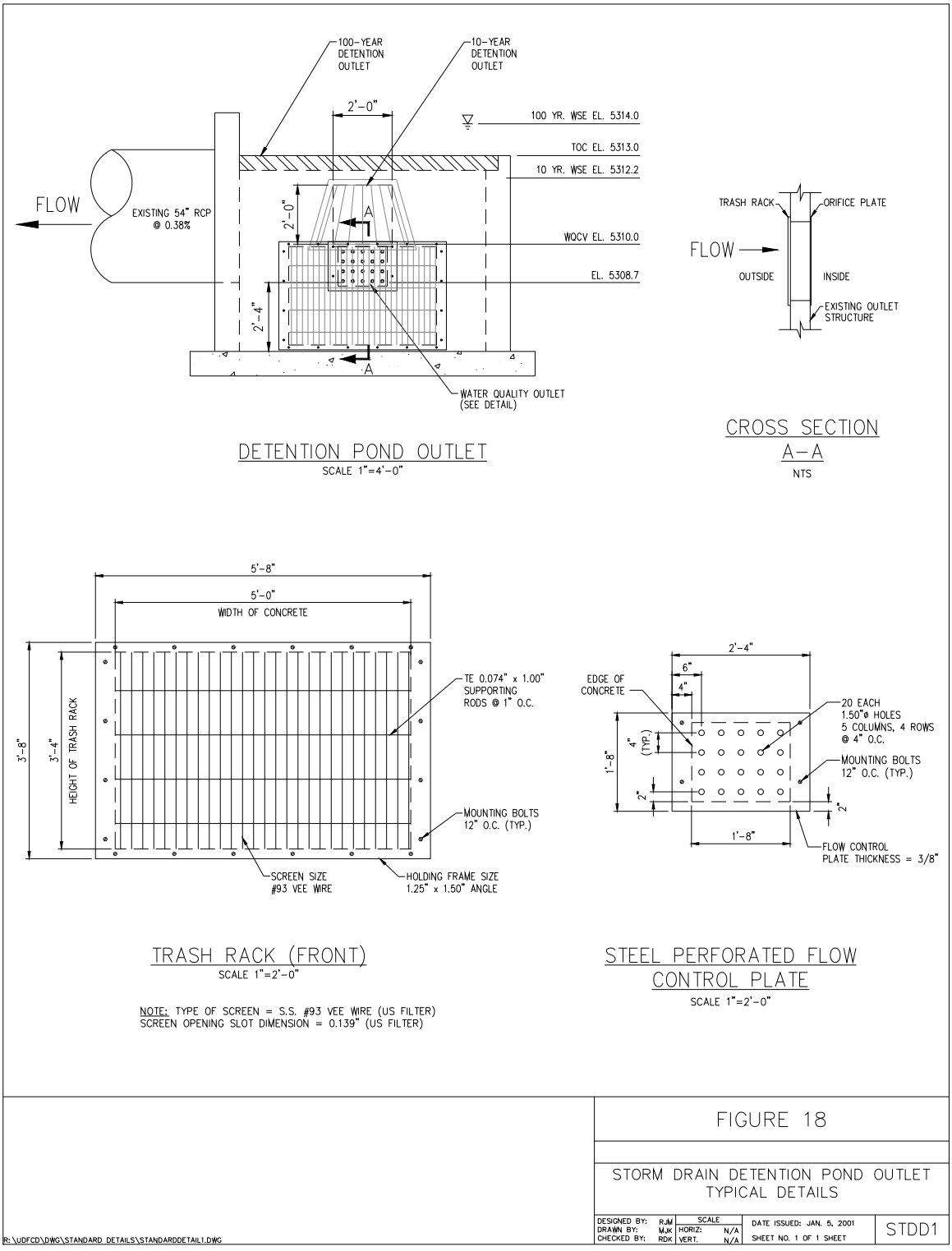

Figure 18—Detention Pond Outlet

2.5 Hydraulic Analysis And Capacity Verification Of The Existing Outfall

The capacity of the existing 54-inch storm sewer is a critical consideration in the design of the East-West Linear Park drainage system. Because the system outfalls to a major drainageway (Westerly Creek) that may create a tailwater control during peak flood flow conditions, a more detailed standard-step backwater analysis was performed. Figure 19 presents the profile of the existing pipeline.

The standard-step backwater is based on Manning's Equation to compute friction losses. Minor (form) losses should also be accounted for using the equations and factors described in the STREETS/INLETS/ STORM SEWERS chapter of this *Manual*. Figure 20 tabulates the computational process for the 100-year storm and a discharge rate of 88.4 cfs. The 100-year Westerly Creek floodplain elevation at the outfall of 5,304 ft is used as the beginning water surface elevation. Figure 21 provides a plot of the computed hydraulic grade line (HGL) and energy grade line (EGL) for the system. As indicated by an HGL above the crown of the pipe, a pressure flow condition exists for the 100-year storm. Because the 100-year HGL at the inlet is below the crown of pipe (outlet controlled), the allowable release rate of 88.4 cfs was used in the design of a multi-stage outlet (versus a restricting pipe capacity).

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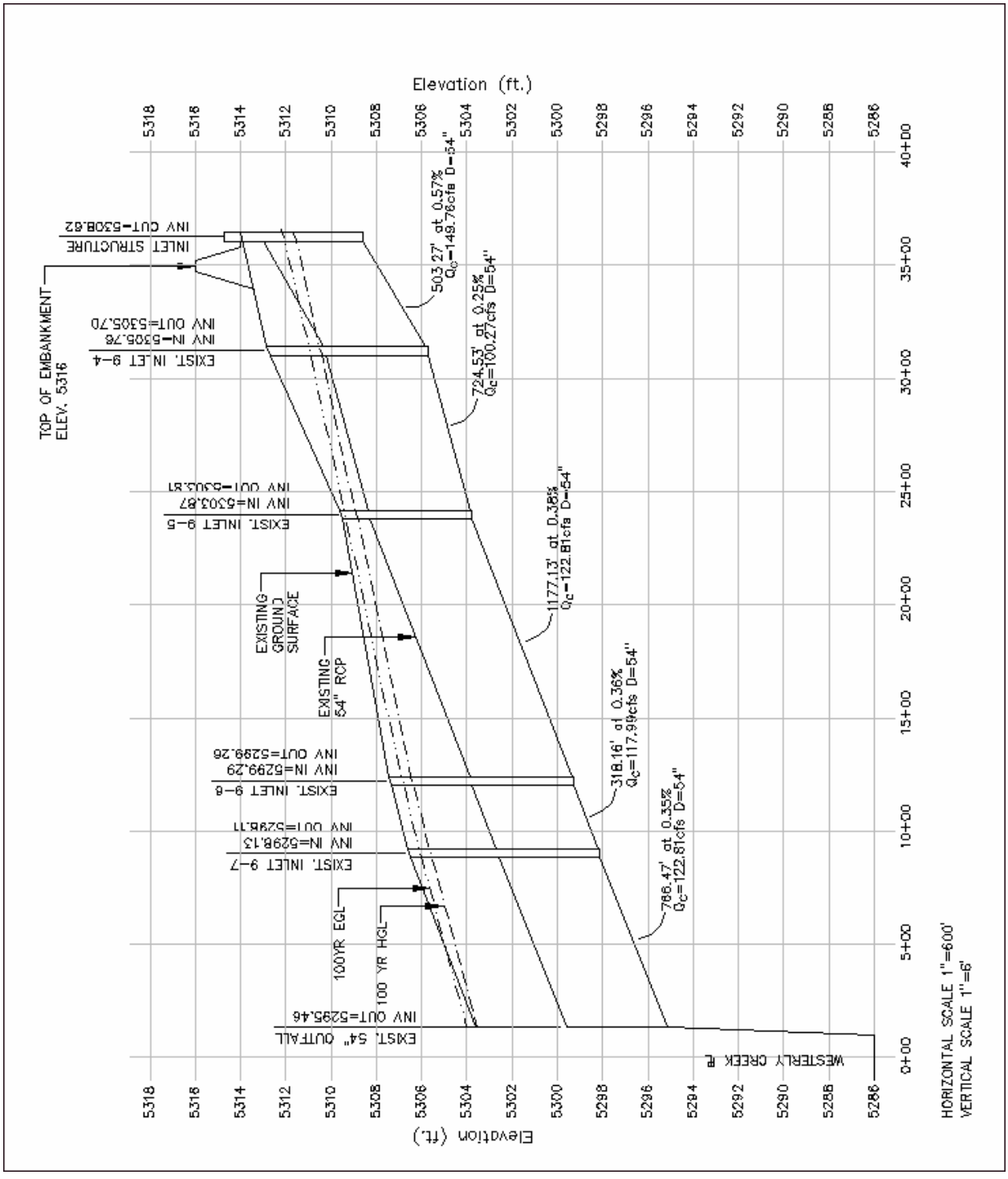


Figure 19—54" Pipe Outfall Profile

HYDRAULIC DESIGN OF STORM SEWER SYSTEMS

STANDARD STEP BACKWATER ANALYSIS FOR FULL PIPE GEOMETRY

PROJECT: Stapleton East-West Linear Park Outfall

Manning's N-Value = 0.013 Full Flow Factor = 0.9

NOTES:
1 Computed values shown in Italics. All other values are required input
2 Freeboard criteria: HGL at or below rim or grnd.
3 Starting EGL set at Westerly Creek 100-Year floodplain elevation, assuming velocity head in Westerly Creek is negligible at culvert entrance

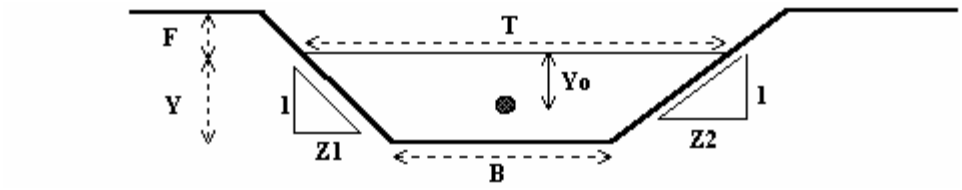
Design Point	Rim or Grnd. Elev.	Inv.	Sewer Grade	E.G.L.	U/S pipe dia.	Area	Q	Vel.	Vel. Hd.	H.G.L	Friction Slope	Pipe Length	Frict. Loss	Junction Loss		Exit/Form Loss		Total Losses		Freel
									Hv		Sf	L	Hf	Km	Hm	Ke	He	frict.	other	HGL
	(ft)	(ft)	%	(ft)	(in)	(sq.ft)	(cfs)	(fps)	(ft)	(ft)	(ft/ft)	(ft)	(ft)		(ft)		(ft)	(ft)	(ft)	(ft)
Westerly Creek	5305.0	5295.45		5304.00	54	*15.90*	*88.4*	*5.6*	*0.48*	5303.52										1.5
			0.35								0.00201	766.5	*1.54*	0	*0.00*	1	*0.48*	*1.54*	*0.48*	
Inlet #9-7, d/s	5306.6	5298.11		5306.02	54	*15.90*	*88.4*	*5.6*	*0.48*	5305.54										1.0
			n/a								0.00201	0.1	*0.00*	0.75	*0.12*	0.05	*0.02*	*0.00*	*0.14*	
Inlet #9-7, u/s	5306.6	5298.13		5306.17	54	*15.90*	*88.4*	*5.6*	*0.48*	5305.69										0.9
			0.36								0.00201	318.2	*0.64*	1	*0.00*		*0.00*	*0.64*	*0.00*	
Inlet #9-6, d/s	5307.4	5299.26		5306.80	54	*15.90*	*88.4*	*5.6*	*0.48*	5306.33										1.1
			n/a								0.00201	0.1	*0.00*	0.75	*0.12*	0.05	*0.02*	*0.00*	*0.14*	
Inlet #9-6, u/s	5307.4	5299.29		5306.95	54	*15.90*	*88.4*	*5.6*	*0.48*	5306.47										0.9
			0.38								0.00201	1177.1	*2.37*	1	*0.00*		*0.00*	*2.37*	*0.00*	
Inlet #9-5, d/s	5309.5	5303.81		5309.32	54	*15.90*	*88.4*	*5.6*	*0.48*	5308.84										0.7
			n/a								0.00201	0.1	*0.00*	0.75	*0.12*	0.05	*0.02*	*0.00*	*0.14*	
Inlet #9-5, u/s	5309.5	5303.87		5309.46	54	*15.90*	*88.4*	*5.6*	*0.48*	5308.98										0.5
			0.25								0.00201	724.5	*1.46*	1	*0.00*		*0.00*	*1.46*	*0.00*	
Inlet #9-4, d/s	5312.8	5305.70		5310.92	54	*15.90*	*88.4*	*5.6*	*0.48*	5310.44										2.4
			n/a								0.00201	0.1	*0.00*	0.75	*0.12*	0.05	*0.02*	*0.00*	*0.14*	
Inlet #9-4, u/s	5312.8	5305.76		5311.06	54	*15.90*	*88.4*	*5.6*	*0.48*	5310.58										2.2
			0.57								0.00201	503.3	*1.01*	1	*0.00*		*0.00*	*1.01*	*0.00*	
Inlet #9-3, d/s	5314.0	5308.62		5312.07	54	*15.90*	*88.4*	*5.6*	*0.48*	5311.59										2.4
			n/a								0.00201	0.1	*0.00*	0.75	*0.12*	0.05	*0.02*	*0.00*	*0.14*	
Inlet #9-3, u/s	5314.0	5308.77		5312.22	54	*15.90*	*88.4*	*5.6*	*0.48*	5311.74										2.2

Figure 20—Hydraulic Design of Storm Sewer Systems

SARB_009337

Project = STAPLETON REDEVELOPMENT

Channel ID = DETENTION POND EMERGENCY OVERFLOW CHANNEL



Design overflow channel for 100-year peak inflow without attenuation (273 cfs).

Design Information (Input)			
Channel Invert Slope	So =	0.0030	ft/ft
Channel Manning's N	N =	0.038	
Bottom Width	B =	30.0	ft
Left Side Slope	Z1 =	4.0	ft/ft
Right Side Slope	Z2 =	4.0	ft/ft
Freeboard Height	F =	1.0	ft
Design Water Depth	Y =	**2.25**	ft

Normal Flow Condition (Calculated)			
Discharge	**Q =**	**279.6**	cfs
Froude Number	**Fr =**	**0.42**	
Flow Velocity	**V =**	**3.2**	ft
Flow Area	A =	87.8	ft
Top Width	T =	48.0	sq ft
Wetted Perimeter	P =	48.6	ft
Hydraulic Radius	R =	1.8	fps
Hydraulic Depth	D =	1.8	ft
Specific Energy	Es =	2.4	ft
Centroid of Flow Area	Yo =	1.0	ft
Specific Force	Fs =	7.4	klb's

Figure 21—Normal Flow Analysis - Trapezoidal Channel

2.6 Local Storm Sewer Design

The detention facility will adequately provide subregional storage for sub-basins 031 and 032 to protect downstream structures and control discharges to Westerly Creek. It will be essential to provide a conveyance system within the local sub-basins to collect and safely transport stormwater to the detention pond. Similar to most drainage systems, the Stapleton East-West Linear Park Flood Control Project utilizes a combination of roadway, open channel, and formal storm sewers for these purposes.

Figure 22 illustrates local basin 031 with further delineation of tributary areas (031.1A through 031.1E) to allow computation of hydrologic and hydraulic conditions at major intersections and inlet locations. An enlarged view of the storm sewer layout is shown on Figure 23, including an initial set of inlets at the intersection of 24th and 26th Avenues and installation of 24-inch RCP for conveyance to the detention pond.

2.6.1 Determination of Allowable Street Capacity

Inlets are provided to drain intersections without excessive encroachment and at street locations where needed to maintain allowable inundation depths for the initial and major storm events. Figure 24 shows computation of street capacity for the initial storm (2-year) with a normal depth, Y, to the top of curb. The corresponding capacity, Q_{max}, is 7.06 cfs. A similar calculation is performed in Figure 25 for the major storm for the specific roadway cross-section being constructed using Manning's Equation and the allowable depths indicated in this *Manual*. The corresponding capacity, Q_{max}, is 87.5 cfs.

2.6.2 Determination of Inlet Hydrology

The Rational Method is used to determine peak discharges for the local tributary area to each inlet. Figure 26 shows computation of the 2-year discharge for sub-basin 0.31.1B and the corresponding flow rate of 1.06 cfs. A check of the flow conditions in the street is provided on Figure 27 for 1.1 cfs and computation of the V_sD (velocity times depth product) to be 0.61 ft^2/sec.

2.6.3 Inlet Capacity Calculations

Figure 28 demonstrates use of the **UDINLET** spreadsheet for a **Curb Opening Inlet in a Sump** for inlet 26-5A. For the 2-year discharge of 1.1 cfs, a 6-foot curb opening in a sump condition will provide full capture (with a maximum capacity of 6.8 cfs).

2.6.4 Street and Storm Sewer Conveyance Computations

To determine the appropriate combination of inlet, storm sewer, and street conveyance capacity, a detailed hydrologic and hydraulic analysis must be performed for each tributary area under initial (2-year) and major (100-year) conditions. The computational spreadsheets shown on Figures 29 and 30 present these analyses for the local street and storm sewer system.

SARB_009359

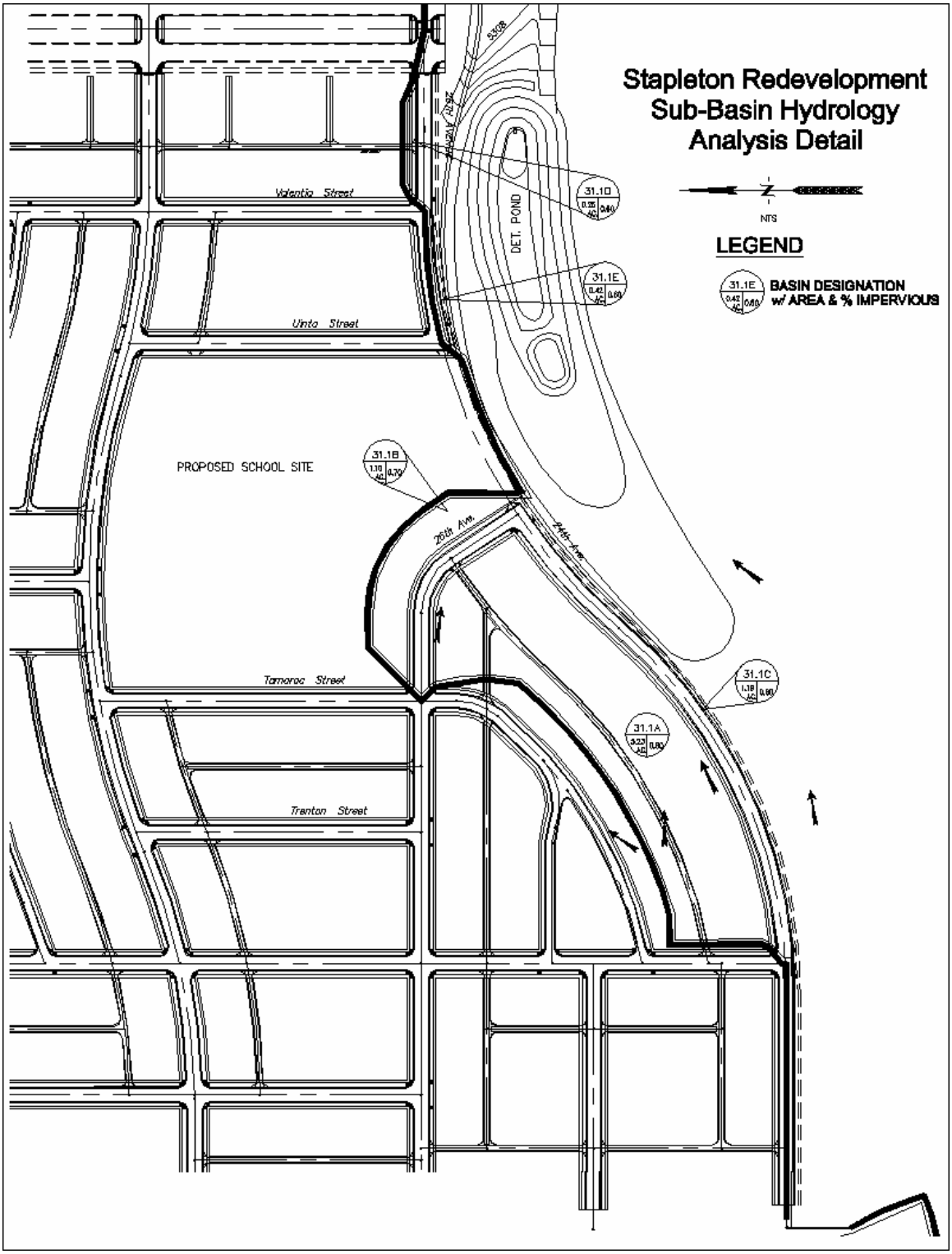


Figure 22—Sub-Basin Hydrology Analysis Detail

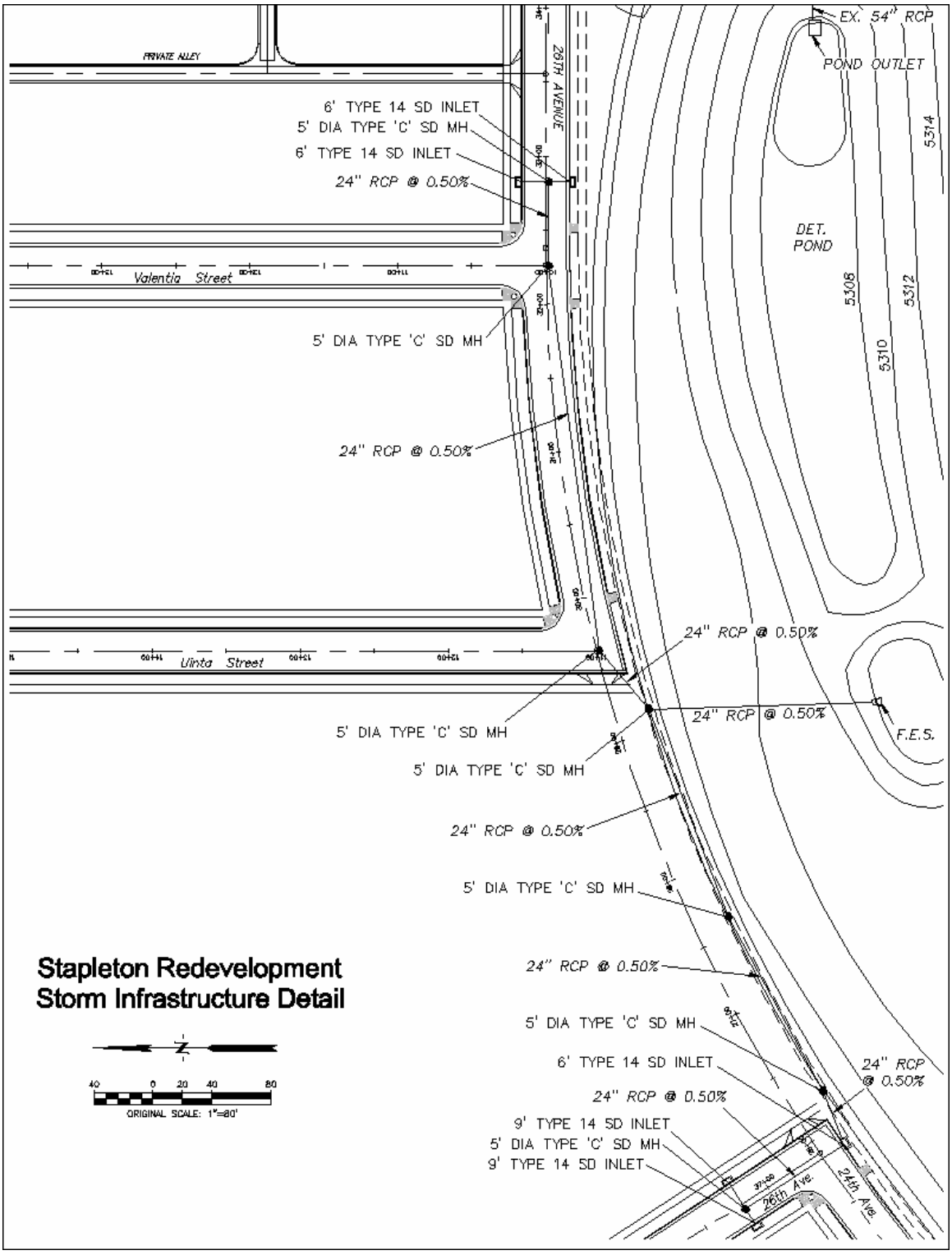
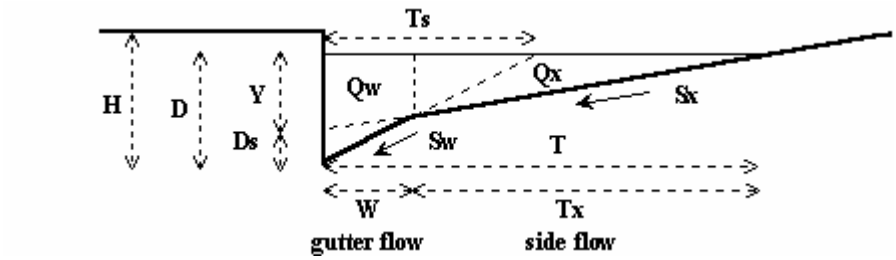


Figure 23—Storm Infrastructure Detail

SARB_009341

Project = Stapleton Redevelopment

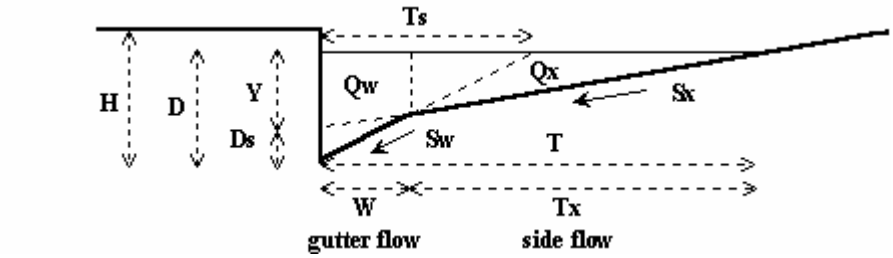
Street ID = 26th Avenue (32' Fl - Fl Local Street)



Gutter Geometry			
Curb Height	H =	6.00	inches
Gutter Width	W =	2.00	ft
Gutter Depression	Ds =	2.00	inches
Street Transverse Slope	Sx =	0.0200	ft/ft
Street Longitudinal Slope	So =	0.0050	ft/ft
Gutter Cross Slope:	Sw =	0.0833	ft/ft
Manning's Roughness	N =	0.016	
Maximum Allowable Water Spread for Major Event	T =	16.00	ft
Gutter Conveyance Capacity Based On Maximum Water Spread			
Water Depth without Gutter Depression	Y =	0.32	ft
Water Depth with a Gutter Depression	D =	0.49	ft
Spread for Side Flow on the Street	Tx =	14.00	ft
Spread for Gutter Flow along Gutter Slope	Ts =	5.84	ft
Flowrate Carried by Width Ts	Qws =	4.3	cfs
Flowrate Carried by Width (Ts - W)	Qww =	1.4	cfs
Gutter Flow	Qw =	2.9	cfs
Side Flow	Qx =	4.1	cfs
Maximum Spread Capacity	**Q-Tm =**	**7.1**	**cfs**
Gutter Full Conveyance Capacity Based on Curb Height			
Spread for Side Flow on the Street	Tx =	16.67	ft
Spread for Gutter Flow along Gutter Slope	Ts =	6.00	ft
Flowrate Carried by Width Ts	Qws =	4.7	cfs
Flowrate Carried by Width (Ts - W)	Qww =	1.6	cfs
Gutter Flow	Qw =	3.1	cfs
Side Flow	Qx =	6.6	cfs
Gutter Full Capacity	**Q-full =**	**9.7**	**cfs**
Gutter Design Conveyance Capacity Based on Min(Q-Tm, R*Q-full)			
Reduction Factor for Minor Event	R-min =	1.00	
Gutter Design Conveyance Capacity for Minor Event	**Q-min =**	**7.1**	**cfs**

Figure 24—Gutter Stormwater Conveyance Capacity for Initial Event

Project = Stapleton Redevelopment
Street ID = 26th Avenue (32' Fl - Fl Local Street)



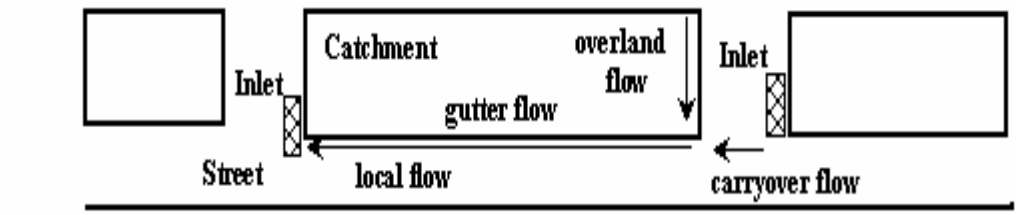
Gutter Geometry			
Curb Height	H =	12.00	inches
Gutter Width	W =	2.00	ft
Gutter Depression	Ds =	2.00	inches
Street Transverse Slope	Sx =	0.0200	ft/ft
Street Longitudinal Slope	So =	0.0050	ft/ft
Gutter Cross Slope	Sw =	0.0833	ft/ft
Manning's Roughness	N =	0.016	
Maximum Water Spread for Major Event	T =	16.00	ft
Gutter Conveyance Capacity Based On Maximum Water Spread			
Water Depth without Gutter Depression	Y =	0.32	ft
Water Depth with a Gutter Depression	D =	0.49	ft
Spread for Side Flow on the Street	Tx =	14.00	ft
Spread for Gutter Flow along Gutter Slope	Ts =	5.84	ft
Flowrate Carried by Width Ts	Qws =	4.3	cfs
Flowrate Carried by Width (Ts - W)	Qww =	1.4	cfs
Gutter Flow	Qw =	2.9	cfs
Side Flow	Qx =	4.1	cfs
Maximum Spread Capacity	**Q-Tm =**	**7.1**	**cfs**
Gutter Full Conveyance Capacity Based on Curb Height			
Spread for Side Flow on the Street	Tx =	41.67	ft
Spread for Gutter Flow along Gutter Slope	Ts =	12.00	ft
Flowrate Carried by Width Ts	Qws =	29.7	cfs
Flowrate Carried by Width (Ts - W)	Qww =	18.3	cfs
Gutter Flow	Qw =	11.4	cfs
Side Flow	Qx =	76.1	cfs
Gutter Full Capacity	**Q-full =**	**87.5**	**cfs**
Gutter Design Conveyance Capacity Based on Min(Q-Tm, R*Q-full)			
Reduction Factor for Major Event	R-maj =	1.00	
Gutter Design Conveyance Capacity for Major Event	**Q-maj =**	**7.1**	**cfs**

Figure 25—Gutter Stormwater Conveyance Capacity for Major Event

SARB_009345

Design Flow = Local Flow + Carryover Flow

Project =	Stapleton Redevelopment
Street ID =	26th Avenue (32' Fl-Fl Local Street)
Return Period	2 year (Basin 31.1B)



A.LOCAL FLOW ANALYSIS

Area (A) =	1.10	acres	(input)
Runoff Coeff (C) =	0.45		(input)

Rainfall Information I (inch/hr) = 28.5 * P1 /(10 + Td)^0.786

P1 =	0.95	inches	(input one-hr precipitation)

Calculations of Time of Concentration

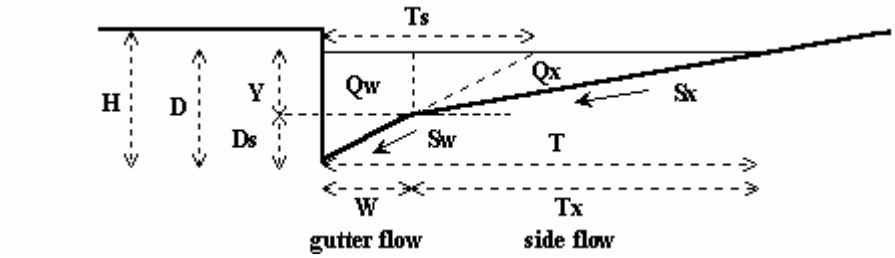
Reach ID	**Slope ft/ft** input	**Length ft** input	**5-yr Runoff Coeff** input	**Flow Velocity fps** output	**Flow Time minutes** output
Overland Flow	0.0150	50.00	0.50	0.12	6.70
Gutter Flow	0.0050	900.00		1.41	10.61
Sum		950.00			17.31
	Regional Tc =	15.28	minutes		
	Recommended Tc =	15.28	minutes		
	Enter Design Tc =	15.28	minutes		

B.LOCAL PEAK FLOW

Design Rainfall	I =	2.14	inch/hr	(output)
Local Peak Flow	Qp =	1.06	cfs	(output)
C.CARRYOVER FLOW	Qco =	0.00	cfs	(input)
D.DESIGN PEAK FLOW	Qs =	**1.06**	cfs	(output)

Figure 26—Determination Of Design Peak Flow On The Street

Project = Stapleton Redevelopment
Street ID = 26th Avenue (32' Fl-Fl Local Street)

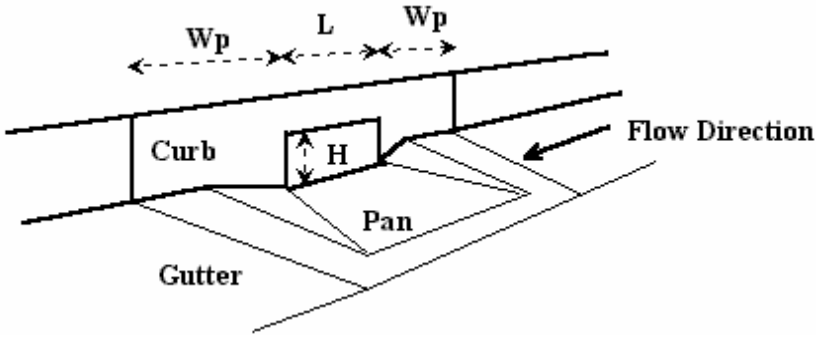


Street Geometry (Input)			
Design Discharge in the Gutter	**Qo =**	**1.1**	**cfs**
Curb Height	H =	6.00	inches
Gutter Width	W =	2.00	ft
Gutter Depression	Ds =	2.00	inches
Street Transverse Slope	Sx =	0.0200	ft/ft
Street Longitudinal Slope	So =	0.0100	ft/ft
Gutter Cross Slope	Sw =	0.0833	ft/ft
Manning's Roughness	N =	0.016	
Gutter Conveyance Capacity			
Water Spread Width	T =	4.32	ft
Water Depth without Gutter Depression	Y =	0.09	ft
Water Depth with a Gutter Depression	D =	0.25	ft
Spread for Side Flow on the Street	Tx =	2.32	ft
Spread for Gutter Flow along Gutter Slope	Ts =	3.04	ft
Flowrate Carried by Width Ts	Qws =	1.07	cfs
Flowrate Carried by Width (Ts - W)	Qww =	0.06	cfs
Gutter Flow	Qw =	1.01	cfs
Side Flow	Qx =	0.05	cfs
Total Flow (Check against Qo)	**Qs =**	**1.1**	**cfs**
Gutter Flow to Design Flow Ratio	Eo =	0.95	
Equivalent Slope for the Street	Se =	0.10	
Flow Area	As =	0.35	sq ft
Flow Velocity	Vs =	3.00	fps
VsD product	**VsD =**	**0.76**	**ft^2/s**

Figure 27—Gutter Conveyance Capacity

SARB_009345

Project = Stapleton Redevelopment
Inlet ID = 6' Type 14 (Basin 31.1B)



Design Information (Input)			
Design discharge on the street (from Street Hy)	**Qo =**	**1.1**	**cfs**
Length of a unit inlet	Lu =	6.00	ft
Side Width for Depression Pan	Wp =	2.00	ft
Clogging Factor for a Single Unit	Co =	0.20	
Height of Curb Opening	H =	0.50	ft
Orifice Coefficient	Cd =	0.65	
Weir Coefficient	Cw =	2.30	
Water Depth for the Design Condition	Yd =	0.55	ft
Angle of Throat	Theta =	1.05	rad
Number of Curb Opening Inlets	N =	1	
Curb Opening Inlet Capacity in a Sump			
As a Weir			
Total Length of Curb Opening Inlet	L =	6.00	ft
Capacity as a Weir without Clogging	Qwi =	9.0	cfs
Clogging Coefficient for Multiple Units	Clog-Coeff =	1.00	
Clogging Factor for Multiple Units	Clog =	0.20	
Capacity as a Weir with Clogging	Qwa =	7.9	cfs
As an Orifice			
Capacity as an Orifice without Clogging	Qoi =	9.0	cfs
Capacity as an Orifice with Clogging	Qoa =	7.2	cfs
Capacity for Design with Clogging	**Qa =**	**7.2**	**cfs**
Capture %age for this inlet = Qa/Qs =	**C% =**	**682.80**	**%**

Figure 28—Curb Opening Inlet In A Sump

STORM DRAINAGE SYSTEM COMPUTATION FORM — **Design Storm: 2 yr**

Location: Stapleton Filing No 2 — Computed by: — Checked by:

									Overland Time (ti)			Travel Time (tt)					tc Check		Runoff		
Basin ID	Inlet No.	Area	Cumulative Area	Coefficient "C2"	Coefficient "C5"	Coefficient "C100"	CA	Cumulative CA	Length (300' max)	Slope	ti	Length	Slope	Velocity (Fig. 3-2)	tt	tc=ti+tt	Total length	tc = (l/180+10)	Final tc	Intensity "I"	Total Peak Discharge "Q"
		acres	acres						ft	%	min.	ft	%	fps	min	min	ft	min	min	in/hr	cfs
31.1A	26-5A	5.23		0.40	0.45	0.60	2.09		60	0.5%	11.4	325	0.5%	1.5	3.6	15.0	385	12.1	12.1	2.37	5.0
31.1B	26-5B	1.10		0.45	0.50	0.70	0.50		70	0.5%	11.4	1017	0.5%	1.5	11.3	22.7	1087	16.0	16.0	2.09	1.0
PIPE			6.33	0.41				2.59											16.0	2.09	5.4
31.1C	26-5C	1.19		0.87	0.89	0.91	1.04		50	1.5%	2.3	1017	0.5%	1.5	11.3	13.6	1067	15.9	13.6	2.25	2.3
PIPE			7.52	0.48				3.62											16.0	2.09	7.6
PIPE			7.52	0.48				3.62											16.0	2.09	7.6
PIPE			7.52	0.48				3.62											16.0	2.09	7.6
31.1D	26-10B	0.26		0.40	0.45	0.60	0.10		50	0.5%	10.4	220	0.5%	1.5	2.4	12.9	270	11.5	11.5	2.43	0.3
31.1E	26-10A	0.42		0.87	0.89	0.91	0.37		50	0.5%	3.3	810	0.5%	1.5	9.0	12.3	860	14.8	12.3	2.36	0.9
PIPE			0.68	0.69				0.47											12.3	2.36	1.1
PIPE			0.68	0.69				0.47											12.3	2.36	1.1
PIPE			8.20	0.50				4.09											16.0	2.09	8.5
			8.20	**0.50**				**4.09**											**16.0**	**2.09**	**8.5**

Sub-Basin Data		Street				Inlet		System		Pipe											
Basin ID	Slope	Allowable Capacity (half of street)	Bypassed Flow	New Flow	Total Street Flow	Length	Allowable Capacity	Intercepted Flow	Street Flow	Pipe Identification (Upstream - Downstream)	Length	Slope	Size	Allowable Capacity (0.80 Capacity)	Pipe Flow	q/Q(0.8 Full)	v/V(Full) (from Fig 8-1)	Velocity	Pipe Flow Time	Enough Capacity?	Remarks
	%	cfs	cfs	cfs	cfs	ft	cfs	cfs	cfs		(ft)	%	in	cfs	cfs			fps	min		
31.1A	0.50%	5.8	0.0	5.0	5.0	9	8.6	5.0	0.0	26-5A 26-5	20	0.50%	18	5.9	5.0	0.84	1.00	3.4	0.1	no	
31.1B	0.63%	8.1	0.0	1.0	1.0	9	8.6	1.0	0.0	26-5B + 26-5	12	0.83%	18	7.7	1.0	0.14	0.58	2.5	0.1	no	
PIPE								5.4	0.0	26-5 + 26-5C	79	0.50%	24	12.8	5.4	0.42	0.80	3.3	0.4	no	
31.1C	0.50%	5.8	0.0	2.3	2.3	6	2.9	2.3	0.0	26-5C + 26-6	35	0.50%	24	12.8	2.3	0.18	0.63	2.6	0.2	no	
PIPE								7.6	0.0	26-6 + 26-7	117	0.50%	24	12.8	7.6	0.59	0.89	3.6	0.5	no	
PIPE								7.6	0.0	26-7 + 26-8	150	0.50%	24	12.8	7.6	0.59	0.89	3.6	0.7	no	
PIPE								7.6	0.0	26-8 + 26-9	54	0.50%	24	12.8	7.6	0.59	0.89	3.6	0.2	no	
31.1D	0.53%	6.5	0.0	0.3	0.3	6	5.8	0.3	0.0	26-11B + 26-11	18	0.60%	18	6.5	0.3	0.04	0.45	1.7	0.2	no	
31.1E	0.53%	6.5	0.0	0.9	0.9	6	5.8	0.9	0.0	26-11A + 26-11	14	0.79%	18	7.5	0.9	0.12	0.56	2.4	0.1	no	
PIPE								1.1	0.0	26-11 + 26-10	262	0.50%	24	12.8	1.1	0.09	0.52	2.1	2.1	no	
PIPE								1.1	0.0	26-10 + 26-9	57	0.50%	24	12.8	1.1	0.09	0.52	2.1	0.4	no	
PIPE								8.5	0.0	26-9 + OUTLET	180	0.61%	30	25.6	8.5	0.33	0.75	3.9	0.8	no	
	-	-						**8.5**	**0.0**			**0.61%**	**30**	**25.6**	**8.5**					yes	OUTLET TO DETENTION BASIN

Figure 29—Storm Drainage System Computation Form—2 Year

SARB_009347

STORM DRAINAGE SYSTEM COMPUTATION FORM — **Design Storm: 100 yr**

Location: Stapleton Filing No 2 — Computed by: — Checked by:

Sub-Basin Data									Overland Time (ti)			Travel Time (tt)					tc Check		Runoff		
Basin ID	Inlet No.	Area	Cumulative Area	Coefficient "C2"	Coefficient "C5"	Coefficient "C100"	CA	Cumulative CA	Length (300' max)	Slope	ti	Length	Slope	Velocity (Fig. 3-2)	tt	tc=ti+tt	Total length	tc = (l/180+10)	Final tc	Intensity "I"	Total Peak Discharge "Q"
		acres	acres						ft	%	min.	ft	%	fps	min	min	ft	min	min	in/hr	cfs
31.1A	26-5A	5.23		0.40	0.45	0.60	3.14		60	0.5%	11.4	325	0.5%	1.5	3.6	15.0	385	12.1	12.1	6.49	20.4
31.1B	26-5B	1.10		0.45	0.50	0.70	0.77		70	0.5%	11.4	1017	0.5%	1.5	11.3	22.7	1087	16.0	16.0	5.72	4.4
PIPE			6.33			0.62		3.91											16.0	5.72	22.3
31.1C	26-5C	1.19		0.87	0.89	0.91	1.08		50	1.5%	2.3	1017	0.5%	1.5	11.3	13.6	1067	15.9	13.6	6.17	6.7
PIPE			7.52			0.66		4.99											16.0	5.72	28.5
PIPE			7.52			0.66		4.99											16.0	5.72	28.5
PIPE			7.52			0.66		4.99											16.0	5.72	28.5
31.1D	26-10B	0.26		0.40	0.45	0.60	0.16		50	0.5%	10.4	220	0.5%	1.5	2.4	12.9	270	11.5	11.5	6.65	1.0
31.1E	26-10A	0.42		0.87	0.89	0.91	0.38		50	0.5%	3.3	810	0.5%	1.5	9.0	12.3	860	14.8	12.3	6.45	2.5
PIPE			0.68			0.79		0.54											12.3	6.45	3.5
PIPE			0.68			0.79		0.54											12.3	6.45	3.5
PIPE			8.2			0.67		5.53											16.0	5.72	31.6
			8.20			**0.67**		**5.53**											**16.04**	**5.72**	**31.6**

Sub-Basin Data		Street				Inlet						Pipe										
Basin ID	Slope	Allowable Capacity*	Bypassed Flow (Negative flows indicates bypass flow to another DP system (See Remarks))	New Flow	Total Street Flow	Length	Allowable Capacity	Intercepted Flow (if inlet is in series, less intercepted flow is possible -- see remarks)	Bypassed Street Flow	Pipe Identification (Upstream-Downstream)	Length	Slope	Size	Allowable Capacity	Pipe Flow	q/Q(Full)	v/V(Full)	Velocity	Pipe Flow Time	Enough Capacity (Street + Storm Sewer)?	Remarks
	%	cfs	cfs	cfs	cfs	ft	cfs	cfs	cfs		(ft)	%	in	cfs	cfs			fps	(min)		
31.1A	0.50%	23.3	0.0	20.4	20.4	9	12.2	7.4	13.0	26-5A 26-5	20	0.5%	18	7.4	7.4	1.0	1.01	4.3	0.1	yes	
31.1B	0.63%	32.1	13.0	4.4	17.4	9	12.2	9.6	7.8	26-5B + 26-5	12	0.8%	18	9.6	9.6	1.0	1.01	5.5	0.0	yes	
PIPE				22.3				16.0	6.3	26-5 + 26-5C	79	0.5%	24	16.0	16.0	1.0	1.01	5.2	0.3	yes	
31.1C	0.50%	23.3	6.3	6.7	13.0	6	12.2	12.2	0.8	26-5C + 26-6	35	0.5%	24	16.0	12.2	0.8	0.98	3.8	0.2	yes	
PIPE				28.5				16.0	12.5	26-6 + 26-7	117	0.5%	24	16.0	16.0	1.0	1.01	5.2	0.4	yes	
PIPE				28.5				16.0	12.5	26-7 + 26-8	150	0.5%	24	16.0	16.0	1.0	1.01	5.2	0.5	yes	
PIPE				28.5				16.0	12.5	26-8 + 26-9	54	0.5%	24	16.0	16.0	1.0	1.01	5.2	0.2	yes	
31.1D	0.53%	25.8	0.0	1.0	1.0	6	8.2	1.0	0.0	26-11B + 26-1	18	0.6%	18	8.1	1.0	0.1	0.57	0.3	0.9	yes	
31.1E	0.53%	25.8	0.0	2.5	2.5	6	8.2	2.5	0.0	26-11A + 26-1	14	0.8%	18	9.3	2.5	0.3	0.70	1.0	0.2	yes	
PIPE				3.5				3.5	0.0	26-11 + 26-10	262	0.5%	24	16.0	3.5	0.2	0.66	0.7	5.9	yes	
PIPE				3.5				3.5	0.0	26-10 + 26-9	57	0.5%	24	16.0	3.5	0.2	0.66	0.7	1.3	yes	BYPASS FLOW TO LOW POINT @ INLET
PIPE				31.6				19.5	0.0	26-9 + OUTLE	180	0.6%	30	32.0	19.5	0.6	0.90	3.6	0.8	yes	
				31.6				**19.5**	**0.0**			**0.6%**	**30**	**32.0**	**19.5**						OUTLET TO DETENTION BASIN

Figure 30—Storm Drainage System Computation Form—100 Year

DESIGN EXAMPLES—SECTION 3

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Figure 8—Brush Layering Detail, Wrapped Soil Lift Detail, and Fill Slope Cross Section 49

3.0 CASE STUDY—WILLOW CREEK

Willow Creek meanders through a natural open space park in Southern Arapahoe County (Figure 1). The low-flow channel carries about 200 cfs, and almost the entire open space is within the 100-year floodplain. The basin tributary to Willow Creek is 8.10 square miles; the lower portion is fully developed and the upper portion is actively being developed. Because of the changes in the basin runoff characteristics, Willow Creek is experiencing higher low-flow volumes. Frequent storms and increased base flows have created a 30-foot-high vertical cliff where the open space borders a residential development. If nothing was done, the house at the top of the cliff was in imminent danger (Photo 1).



Photo 1. Cliff Created by Erosion from Creek

Summary of Flows

Base Flow	> 5 cfs
2-year Storm	1,650 cfs
5-year Storm	3,000 cfs
10-year Storm	4,100 cfs
50-year Storm	5,500 cfs
100-year Storm	6,100 cfs

Because of these safety issues and potential loss of private property, Arapahoe County and South Suburban Parks and Recreational District requested assistance from the Urban Drainage and Flood Control District (District). The sponsors selected Muller Engineering Company, who teamed with Wenk Associates, to design the Willow Creek Channel Improvements. It was agreed at the outset that bioengineering techniques should be explored for this channel improvement project. The client team and the design team both saw this as a great opportunity to try new approaches to channel and bank stabilization.

3.1 Design

Designing a retaining wall to stabilize the cliff was one alternative considered by the client team, but it was rejected because of the cost, safety issues, and “hard” unnatural characteristics. The final design was chosen because it best satisfied the project goals for safety, aesthetics, habitat improvement, and affordability. The design included moving the creek from the south side to the north side of the existing stand of cottonwood trees. The trees’ root systems would provide some stabilization for what would then be the outer bend of the meander. The trees would still receive sufficient water from the relocated stream. With the creek now 60 feet from the toe of the cliff, a safer 2:1 slope could be built to replace it (Figure 2).



Photo 2. Existing "Texas" Low-flow Crossing



Photo 3. New Grouted Boulder Structure & Pedestrian Bridge

Although moving the creek made it feasible to fill in the vertical cliff, it also reduced the amount of area to mitigate to about 0.5 acres of

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Photo 4. Biolog & Erosion Mat Installation

wetlands. Wenk designed a wetland backwater area inside the meander to accommodate the additional area needed. The water pools up during a storm event and then slowly drains, creating a good wetland water regime. A temporary wetland drain pipe from the creek was installed to feed the area until the plants were established (Figure 2).



Photo 5. Reconstructed Slope with Wrapped Soil Lifts at Toe

The realignment of the creek shortened the total length of channel and increased its slope. Two grouted boulder grade control structures, with 1-foot drops, were incorporated as permanent "hard" improvements to establish a stable channel slope of 0.5% (for bioengineered channels a milder slope of 0.3 to 0.4% is normally recommended by the District). Adjacent to the grade control structures, box culvert/pedestrian bridges were built to replace the existing slippery "Texas" low-flow crossings, which had been high maintenance for South Suburban as well as being a safety hazard (Photos 2 & 3).



Photo 6. Construction of Brush Layering

Incorporating "hard" grade control structures with the new bridges allowed the rest of the project area to have improvements with a "soft" appearance (Figure 3). Wenk designed a "biolog" or coir-roll stream edge for the outer bank of the low-flow channel. Two biologs, stacked almost on top of each other, laid next to and above a buried rock blanket, line the edge of the new low-flow channel between the bridges. The biologs were partially buried, staked, tied, and overlapped so that they could not be dislodged during a storm event. Willow stakes were also planted through them. Permanent erosion control mat was placed on the bank above the biologs (Photo 4). The inner bank of the meander was covered with a plastic permanent "enkamat" geotextile, designed to trap sediment that is washed around the bend and encourage wetland and riparian plant growth (Figures 4, 6, & 7).



Photo 7. Completed Slope with Brush Layering, Erosion Mat, and Wrapped Soil Lifts

Bioengineering techniques were also used to stabilize and help establish vegetation on the 2:1 fill slope of the 30-foot vertical cliff. Extra stabilization was needed at the toe of the new slope to protect up to the 100-year water surface elevation. Six layers of wrapped soil lifts made of a double layer of coir fabric encasing a 6-inch lift of soil protects the soil from erosion at the toe of the slope while still allowing vegetation to grow (Photo 5 & 9). The upper portion of the



Photo 8. Complete Channel with Plantings

slope is a test area for both brush layering and traditional erosion control matting. For the brush layering, Wenk specified that willow and cottonwood branches be placed horizontally in the slope with about 3 inches of the tips sticking out. These little “fingers” of the mostly dead branches collect leaves and natural debris while breaking up the water that trickles down the slope, preventing rill erosion (Photo 6). The brush layering was used on half of the new fill slope, and the other half received a temporary erosion control blanket. These two methods will be compared over the years to see if one is more successful than the other (Photo 7 and Figure 5).

The channel edges and the wrapped soil lifts were then planted with willow stakes. Cottonwood whips were also planted within the meander and around the check structures (Photo 8). All the willow stakes, the cottonwood whips, and even the brush for the brush layering were harvested from the immediate area.

As an added precaution, the District asked Muller to design modified riprap bank protection, which was buried behind the biologs as a secondary line of defense. Also, to save several existing cottonwood trees, huge boulders were placed as retaining walls to hold back the fill slope from the bases of these trees.

3.2 Criteria

District criteria were followed for the design of this project to the maximum extent possible. As within many District projects that address existing problems, right-of-way limitations often dictate a need to deviate from some of the criteria, knowing full well that had the criteria been followed, the problems that had to be addressed would not have materialized. The new channel slope is 0.5%, and the radius of the new curve is 150 feet. Buried riprap was placed on the downstream side of the box culvert/pedestrian bridge in accordance with the District. The riprap bank protection behind the biologs was slimmed down from the District criteria since it was installed as a precautionary measure. Reference materials obtained from an International Erosion Control Association seminar and from King County, Washington entitled “Guidelines for Bank Stabilization Projects” were used to assist in the design of the bioengineering. However, at the time of the design, there were no established design criteria available for the bioengineering aspects of the project.



Photo 9. Construction of Wrapped Soil Lifts

3.3 Construction

L&M Enterprises was awarded the contract for the construction of this channel project. It was necessary

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to use small equipment to build the wrapped soil lifts and the brush layering, which made the job go slower than expected. It was also difficult to compact the slope with the brush layering inside of it. The biggest challenge during construction was dealing with higher than anticipated creek flows due to a wet winter and spring. Construction began in October 1998, and in early 1999 there were spring storms that tested the channel before the vegetation took root. Overall, the channel held up well.

In retrospect, it was determined that wider rolls of geotextiles would function better and would be easier to install. The permanent “enkamat” geotextile came in 3-foot-wide rolls, and after the pieces were overlapped, there was little left to cover the ground. Also, there would have been fewer areas of failure if the trees were planted prior to installing the geotextile.

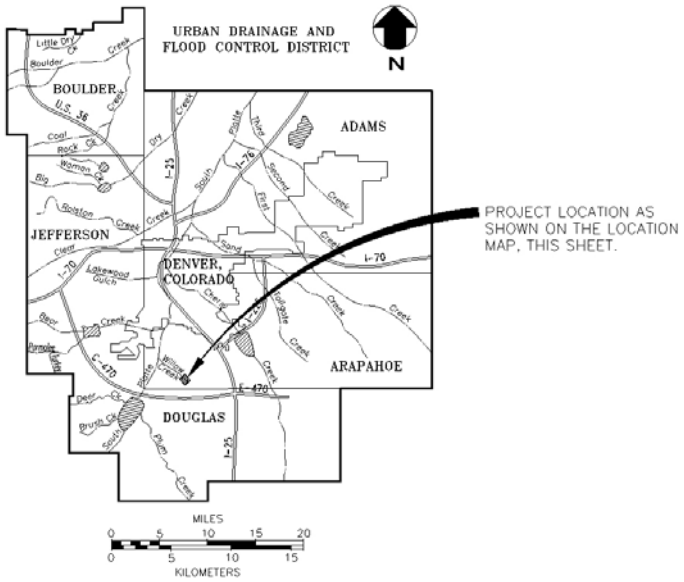
3.4 Success

The Willow Creek Channel Improvement Project continues to be a success story. The new channel has seen numerous storm events, and sediment has deposited on the inside of the bend without eroding the outside. Almost every willow stake has sprouted. Many of the cottonwood whips are growing. The biologs are secure with their double-tied stakes and will soon be permanently anchored by the willows and grasses growing in them. The secondary riprap protection acts as a backup measure for protection during very large flood events. The most surprising success was the cottonwood branches that were placed in the brush layering even without irrigation. The very next season, sprouts were already 3 feet tall. Also, the wetland backwater idea has been incorporated into other projects because of its success.

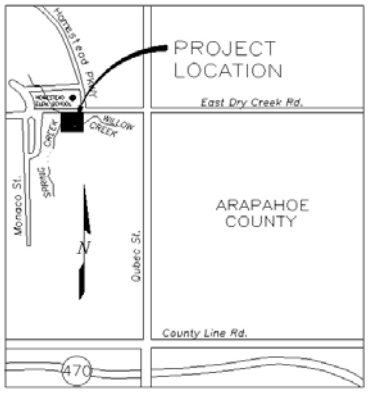


Photo 10. Relocated Channel & New Pedestrian Bridge

Willow Creek is once again a meandering creek in this reach with two check structures that mimic splashing waterfalls which are enjoyed by the trail users and the residential neighbors. The looming 30-foot cliff and the slippery channel crossings are gone, and a safe and beautiful Colorado open space was created.



VICINITY MAP



LOCATION MAP

MULLER

WILLOW CREEK CHANNEL IMPROVEMENTS,
ARAPAHOE COUNTY, COLORADO

Figure 1—Location Map

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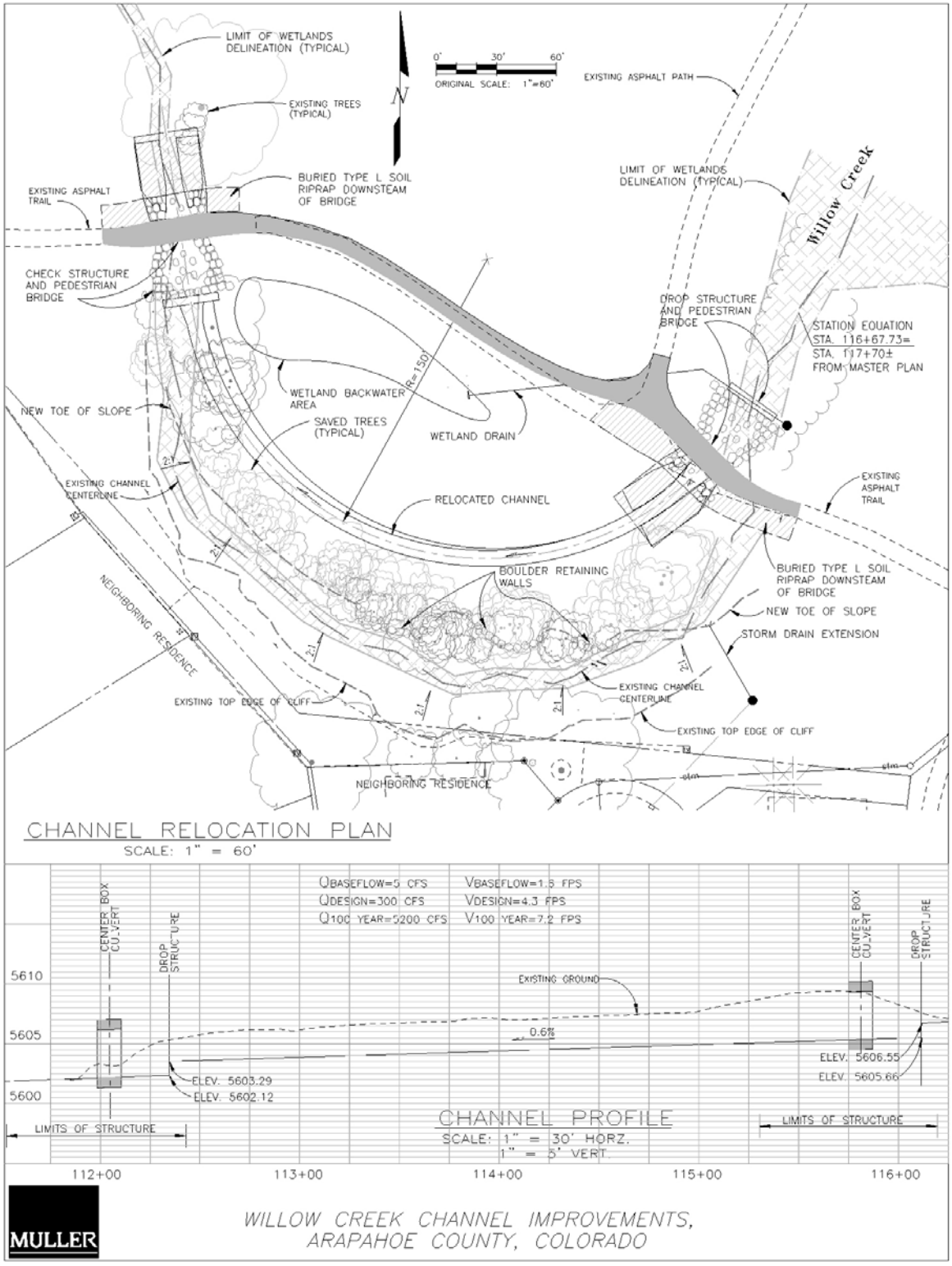

Figure 2—Channel Relocation Plan

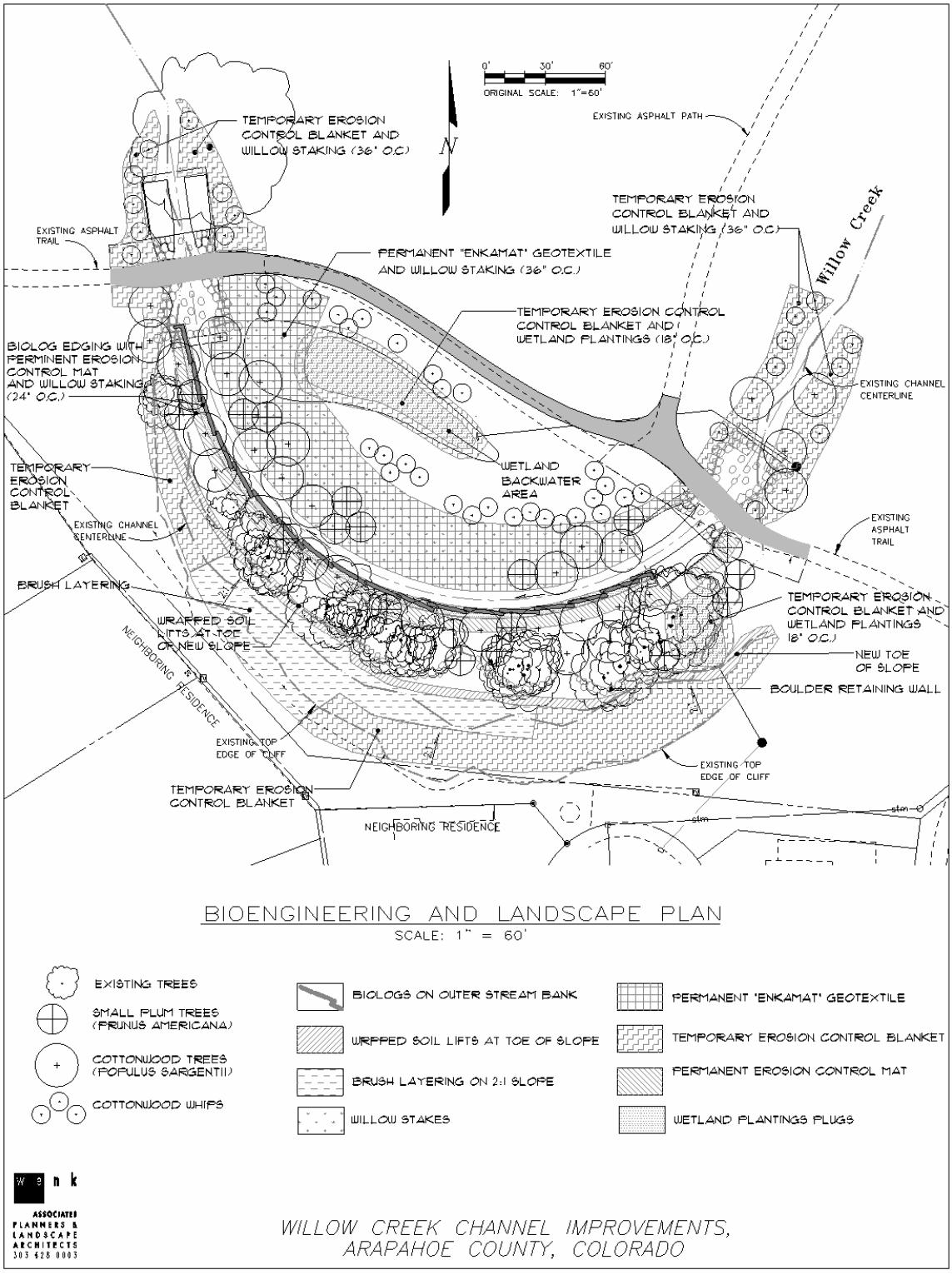

Figure 3—Bioengineering and Landscape Plan

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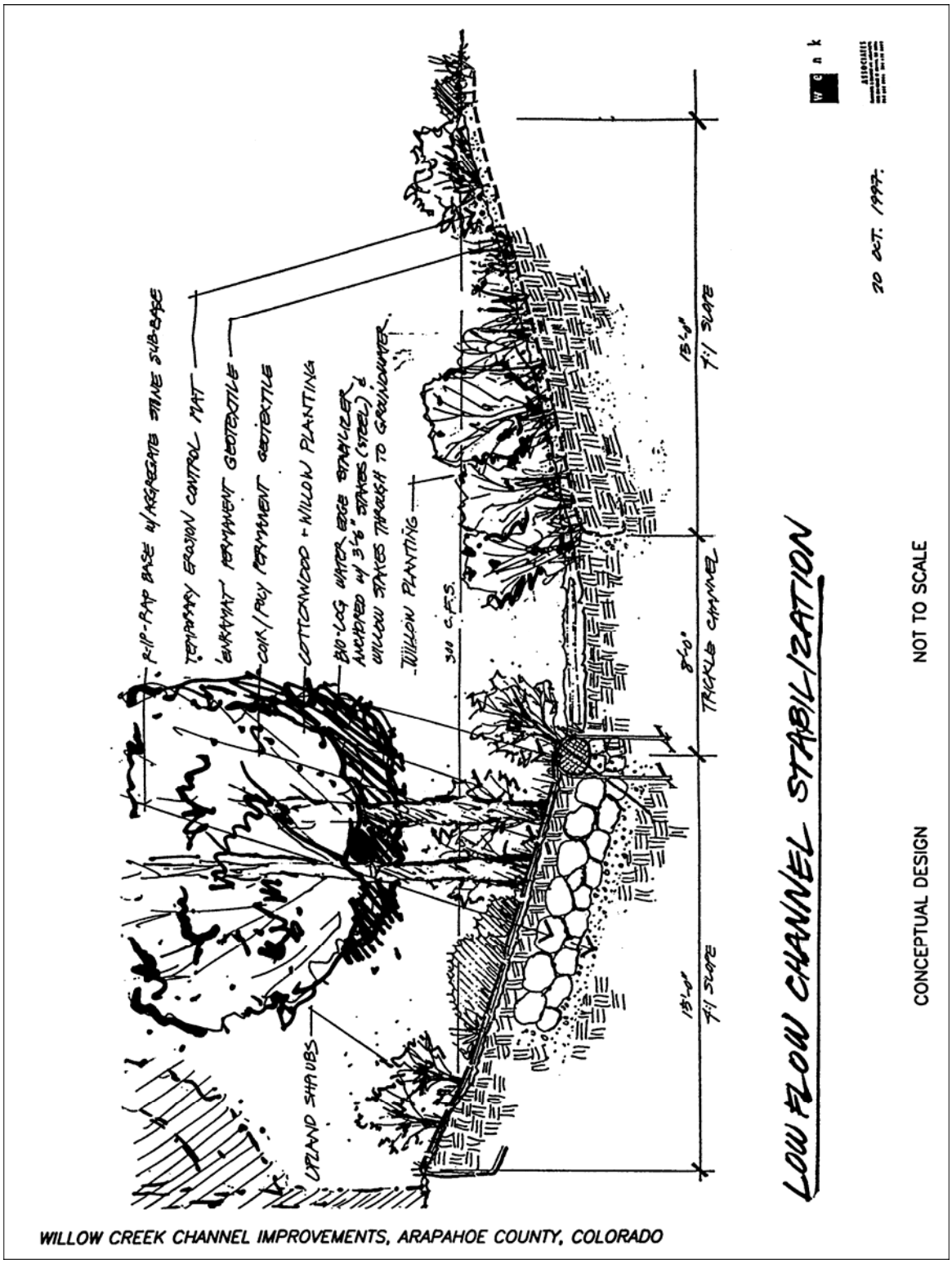

Figure 4—Low-Flow Channel Stabilization

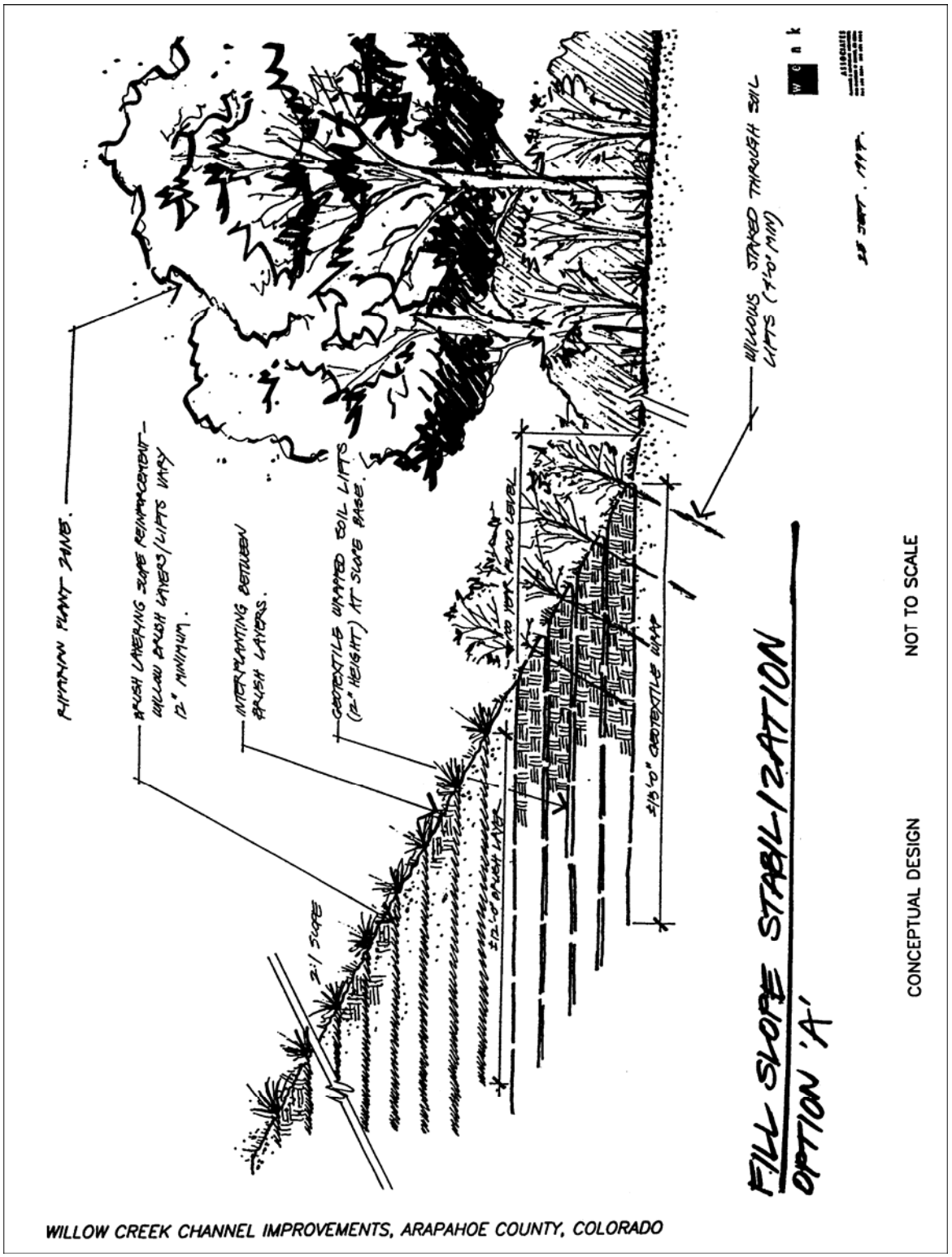

Figure 5—Fill Slope Stabilization Option A

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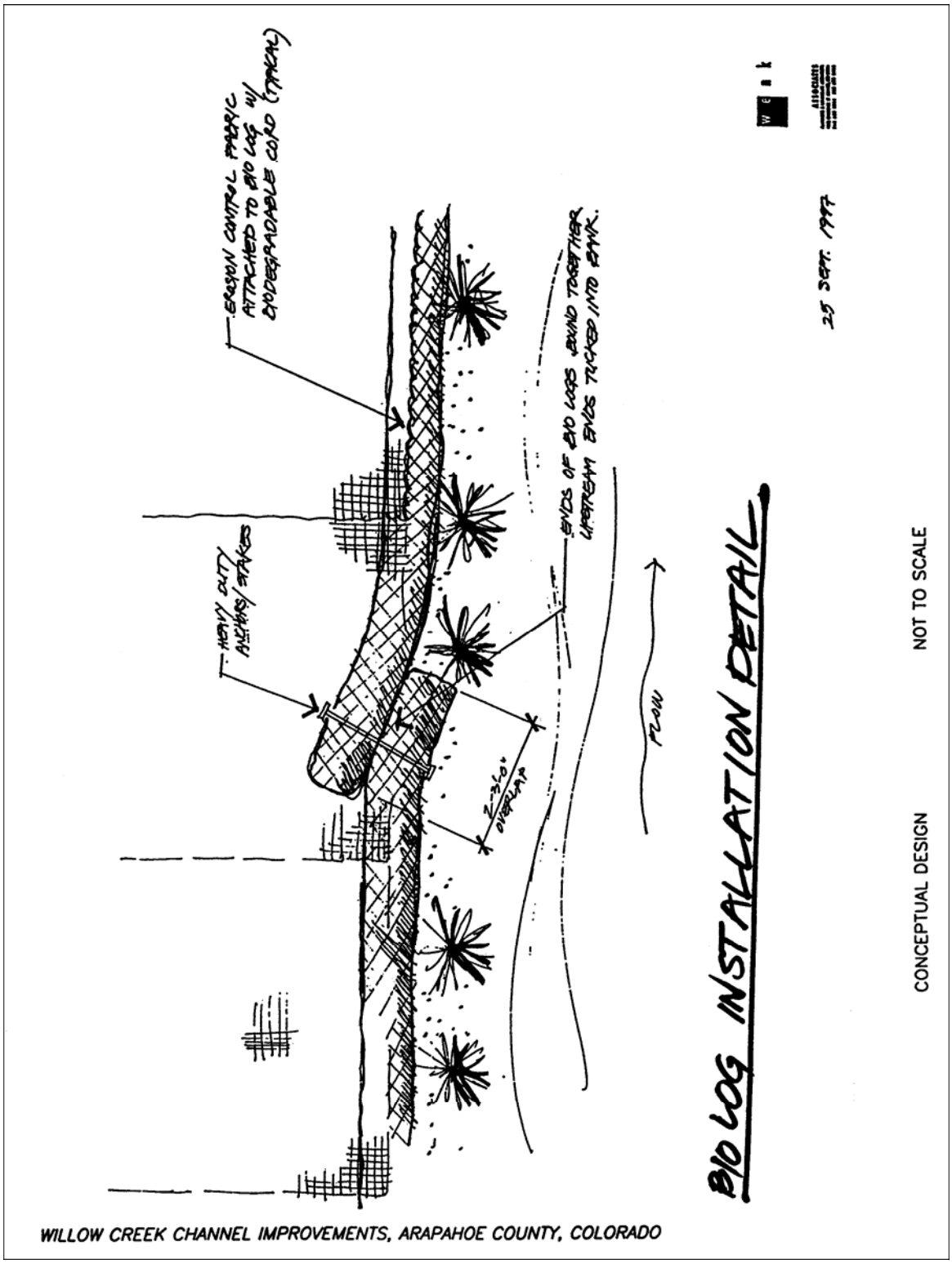

Figure 6—Biolog Installation Detail

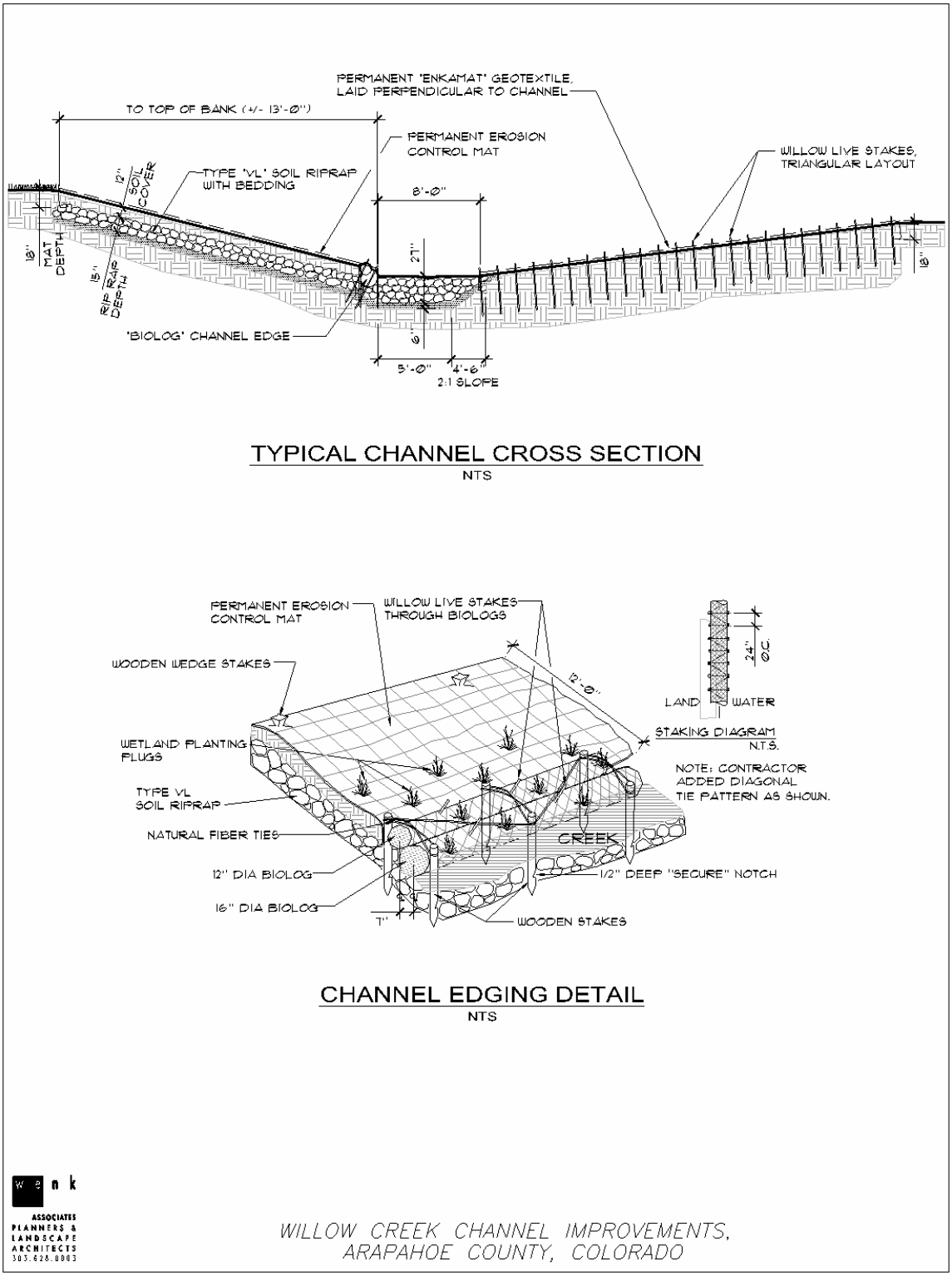

Figure 7—Typical Channel Cross Section and Channel Edging Detail

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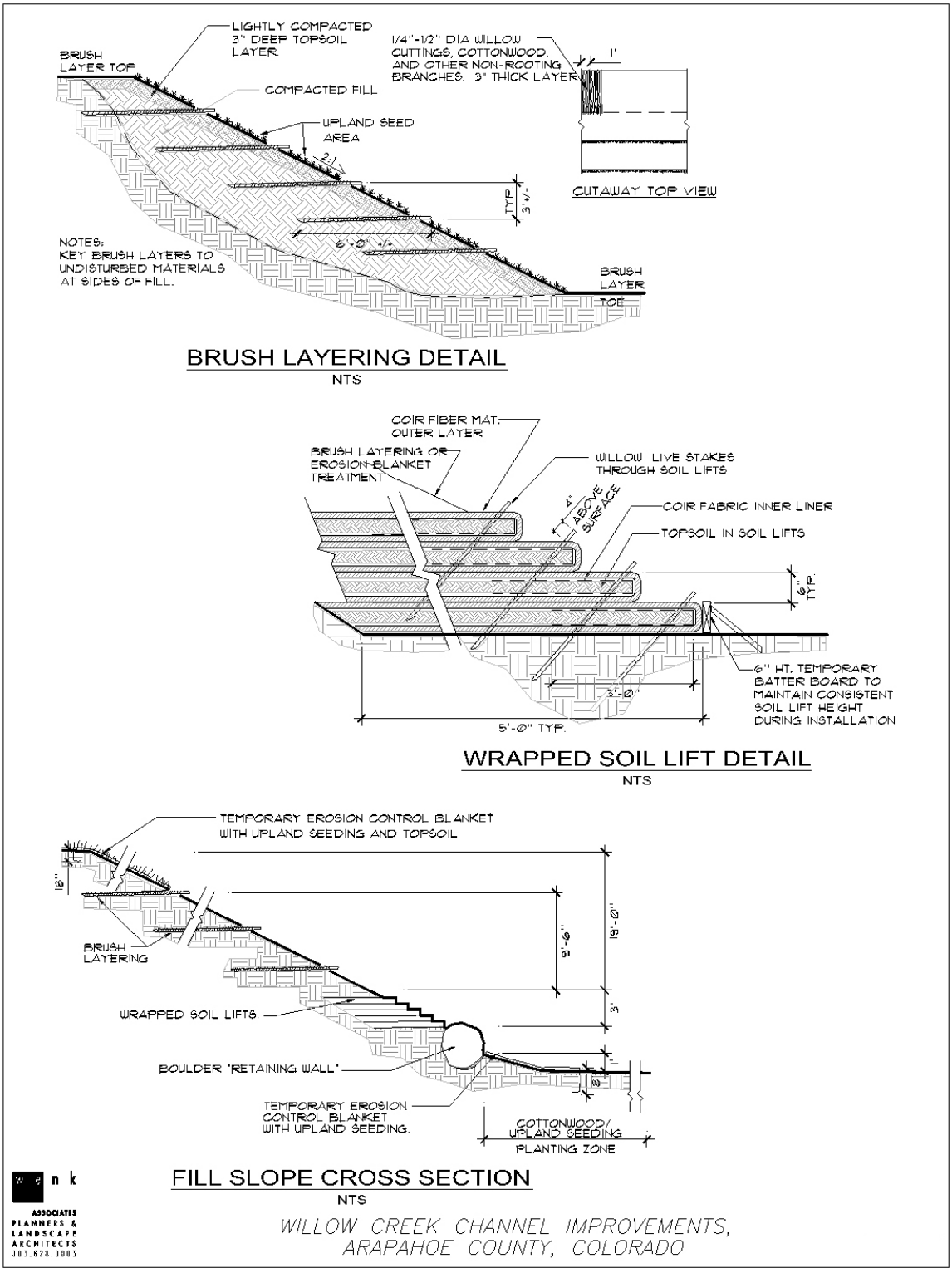

Figure 8—Brush Layering Detail, Wrapped Soil Lift Detail, and Fill Slope Cross Section

DESIGN EXAMPLES—SECTION 4

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4.0 CASE STUDY—ROCK CREEK

The purpose of this case study is to demonstrate the following features:

- Detention facility
- Grouted boulder drop structure
- Grouted boulder check structures and wetland bottom channels
- Stream bank stabilization including grouted boulder check structure with low-water crossing, slope flattening and revegetation

McLaughlin Water Engineers, Ltd. (MWE) and the Norris/Dullea Company (both based in Denver) prepared the attached drawings. Photographs are provided for each of the facilities featured in this case study.

The formal names of these projects are:

1. Tributary LB-3 Channel and Flor Storage Facility
2. Rock Creek Stabilization, Tributary RB-3 Outfall Pipe, and Community Pond East

The client for MWE and Norris/Dullea Company was Superior Metropolitan District No. 1 and the relevant drawings were prepared in 1994 and 1997.

Public reaction to the facilities shown on the attached pages and to the overall drainage plan has been extremely positive due to the aesthetic nature of the facilities, the fact that they nicely integrate into the community, their environmentally-sensitive nature and multi-purpose benefits. There is no question that the drainage system in Rock Creek substantially enhances community character and the value of residential properties.





Detention Facility—Flor Storage Facility





Detention Facility—Flor Storage Facility
and Interpretive Sign

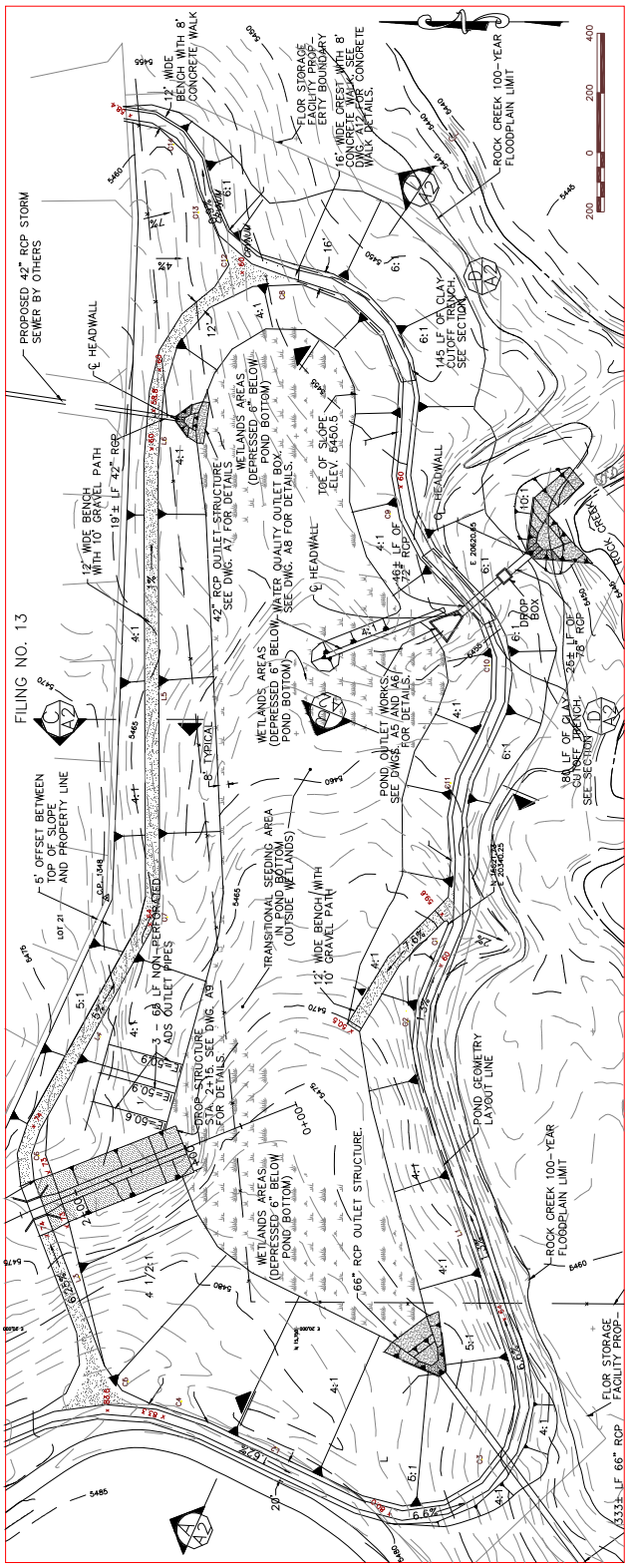


Figure 1—Flor Storage Facility Plan View

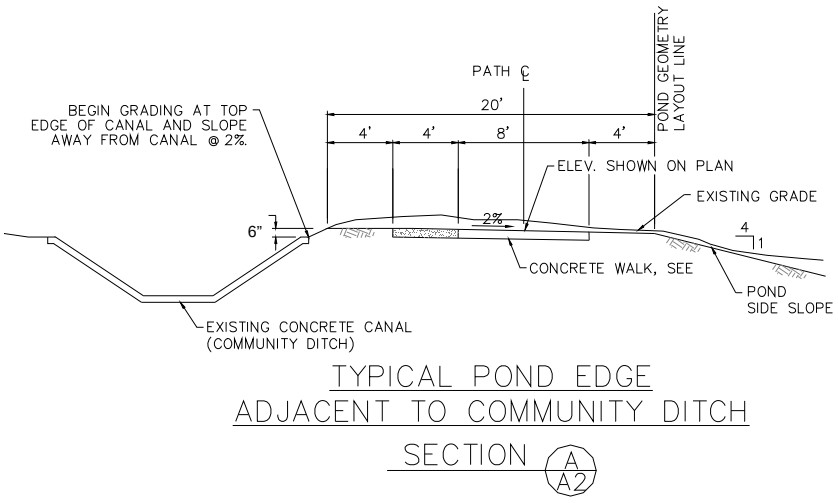


Figure 2—Typical Pond Edge Adjacent to Community Ditch

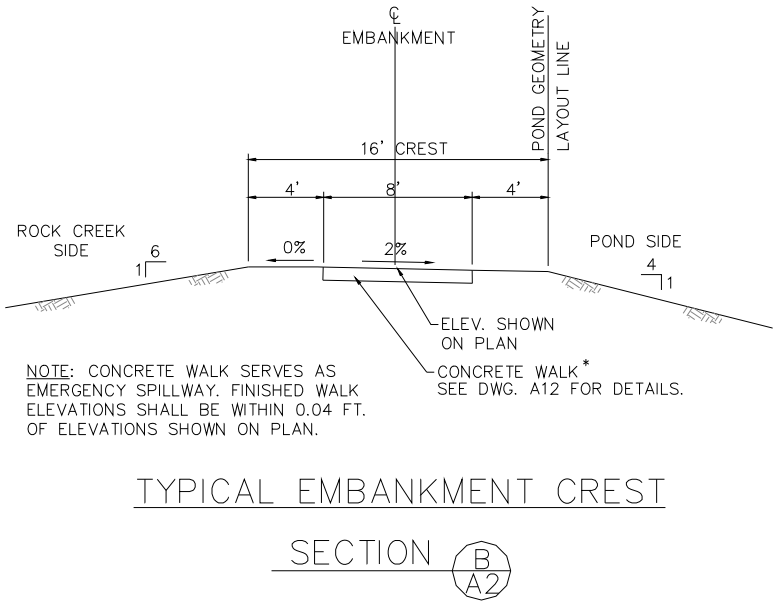


Figure 3—Typical Embankment Crest

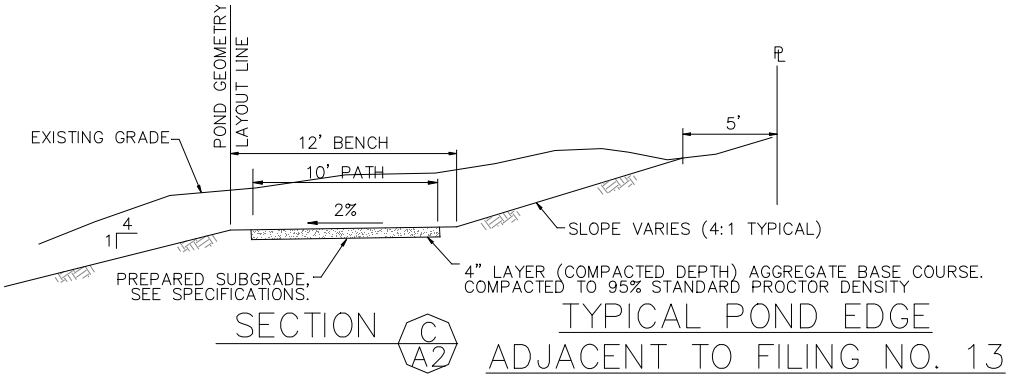


Figure 4—Typical Pond Edge Adjacent to Filing No. 13

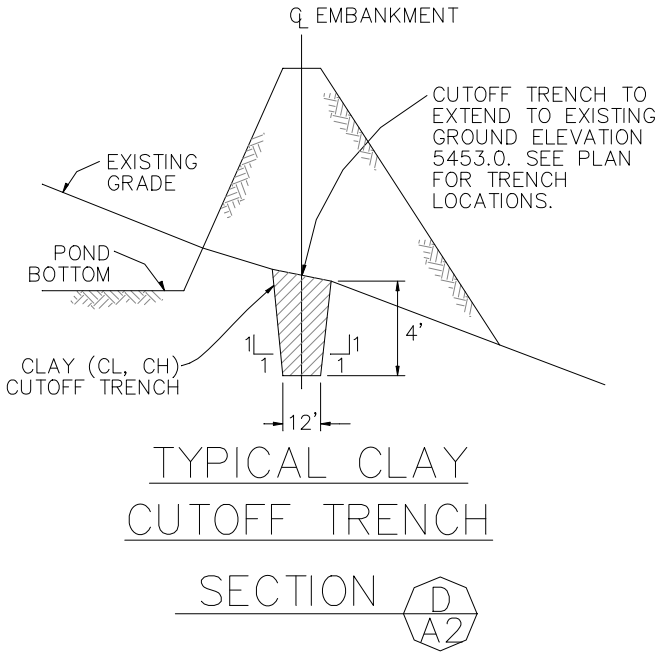


Figure 5—Typical Clay Cutoff Trench

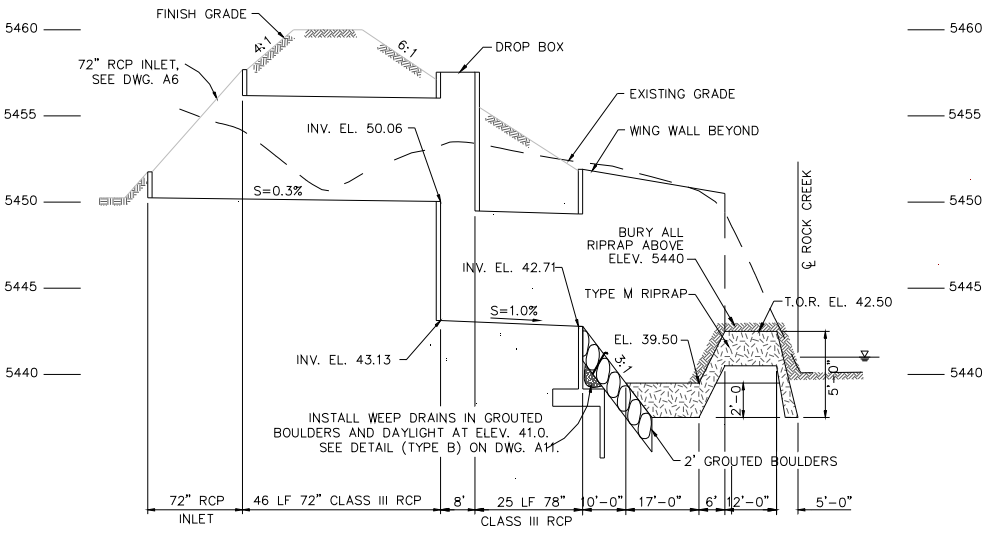


Figure 6—Profile Pond Outlet Works

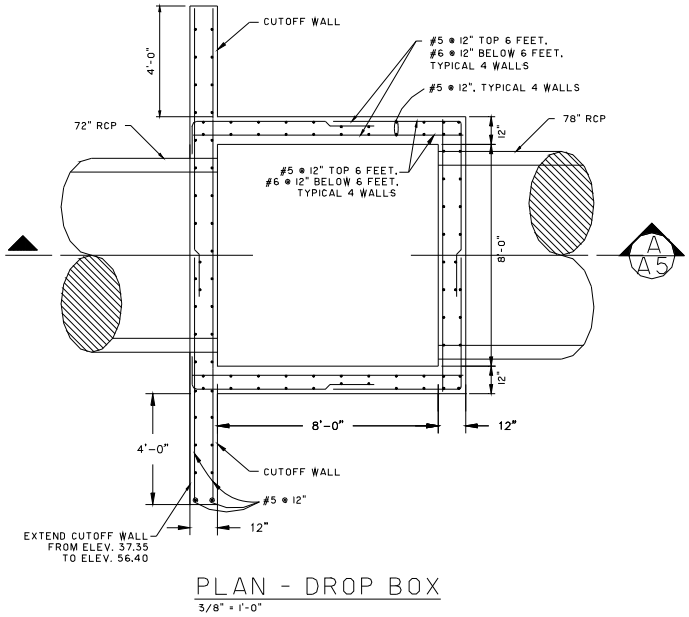


Figure 7—Plan Drop Box

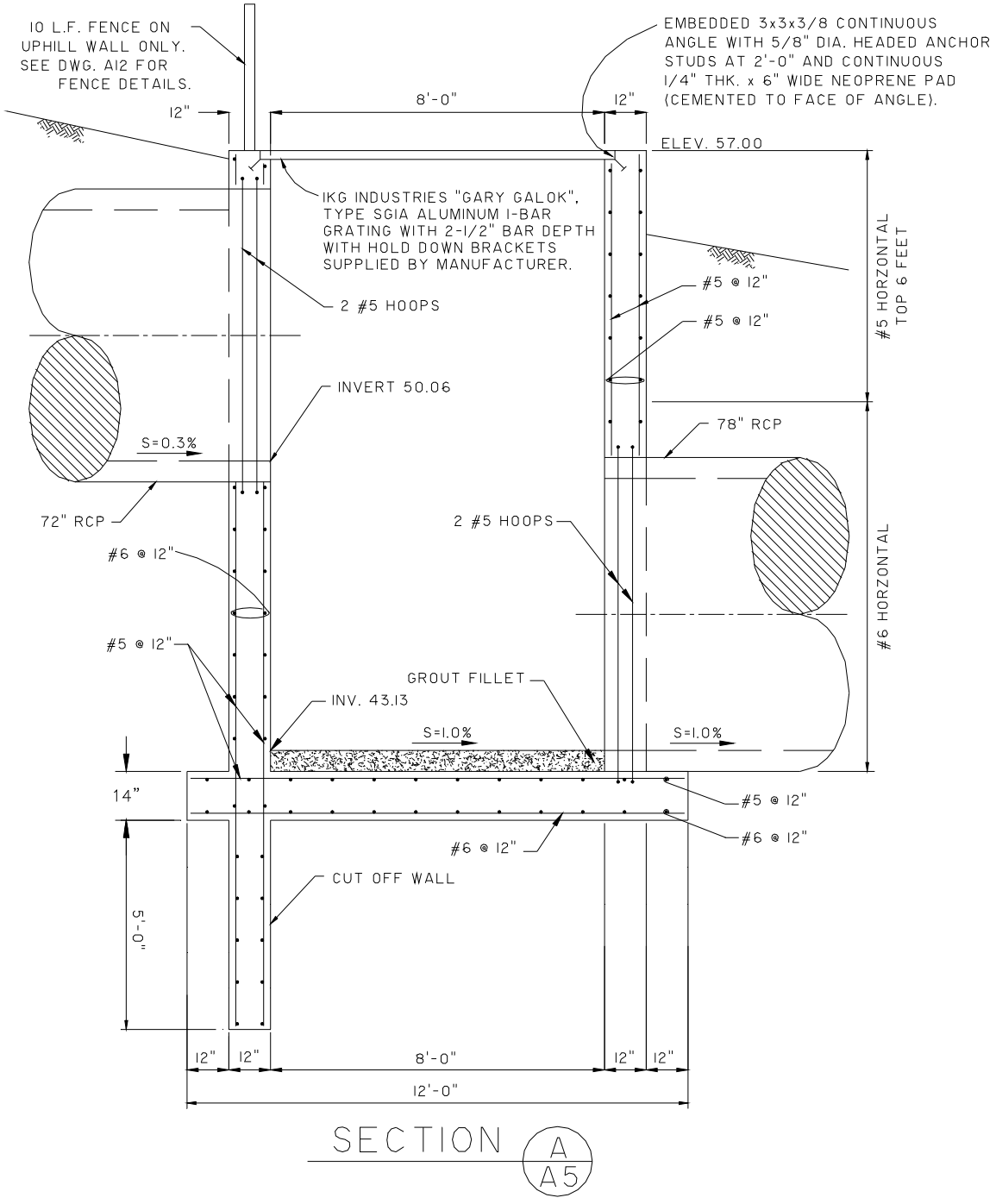


Figure 8—Section Drop Box

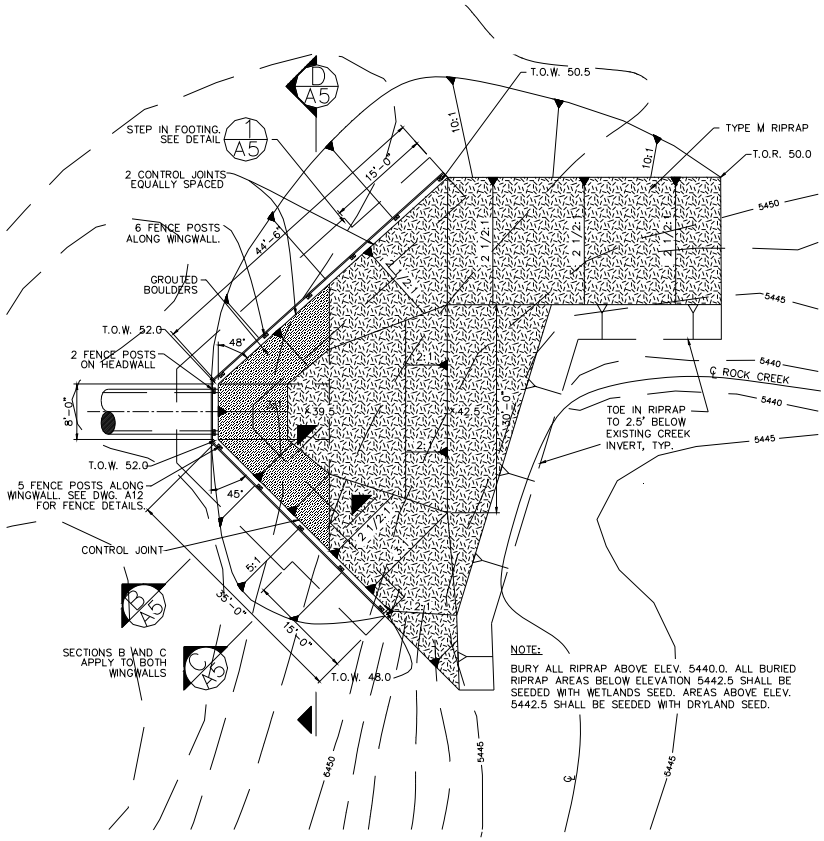


Figure 9—Plan 78" RCP Outlet

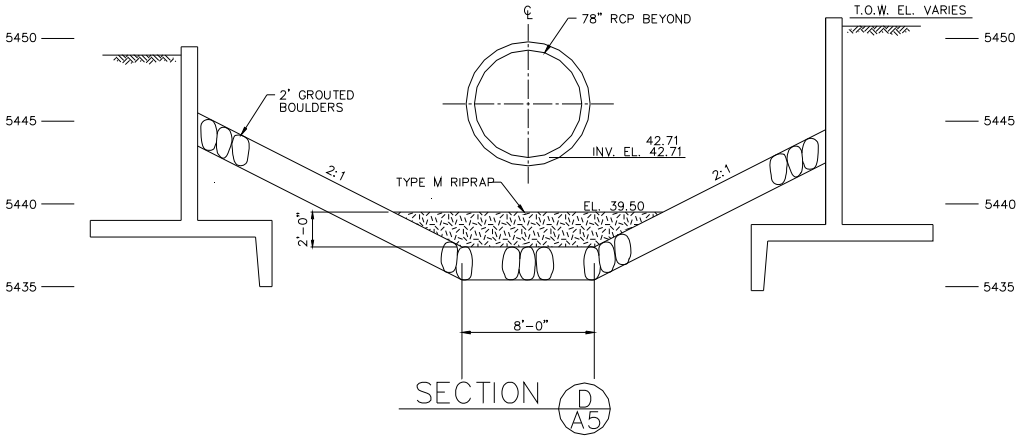


Figure 10—Section 78" RCP Outlet

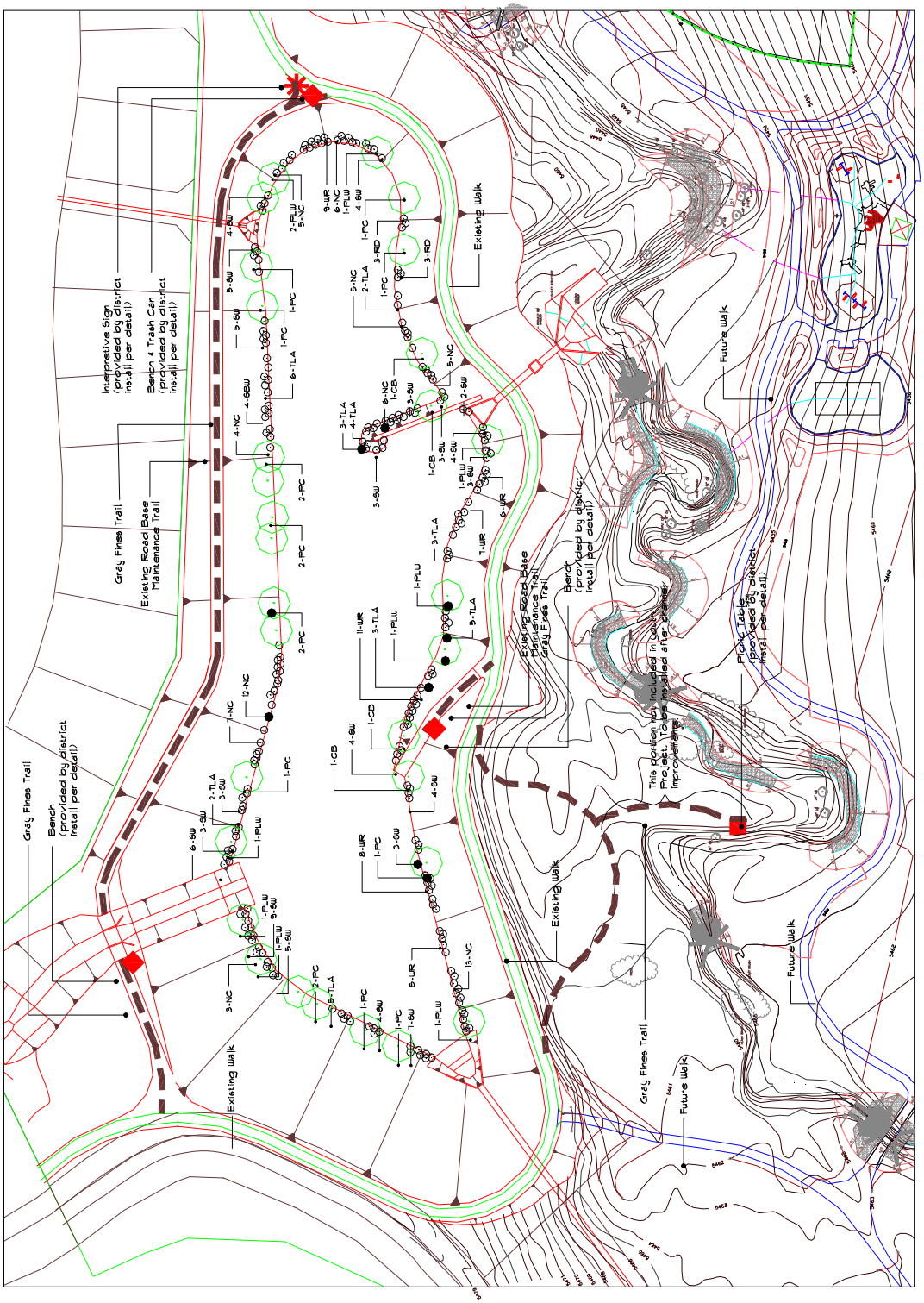


Figure 11—Rock Creek Flor Storage and Landscape Plan

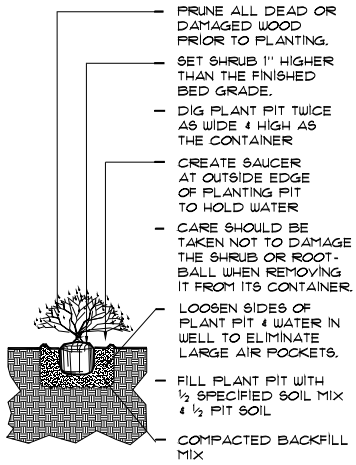
Construction Notes

1. All plant material, trial surface material, and site furniture will be provided and delivered to project area by the district. Installation of these items shall be by the Boulder County Youth group.
2. Trail cutting by district contractor. Trail surface installation by Boulder Co. Youth. Minimize disturbance to grades and vegetation by removing cut material from the site. Do not pile soil on existing vegetation adjacent to the trial. Seed disturbed areas with native seed.
3. Notify The Norris Dullea Company for Trial, Plant, and Site Furniture locations prior to installation.
4. Trees and shrubs to be planted per detail. Install plant material in general locations shown on plan. Adjust location relative to moisture conditions for each species. Refer to Plant Legend for optimal moisture conditions for each species.
5. Water all planted material every 2 days for the first 30 days after planting. Reduce watering to every 4 days from 31 days to 90 days after planting. fully saturate soil within planting saucer with pond water. Minimize disturbance to the pond bank while obtaining water. Suspend watering schedule if pond floods. Resume watering after water levels reaches normal pool level.
6. Compact crusher fines in 2" lifts with sod roller. Maintain crusher fine material within the 6' cut area. Mound crusher fines 1" above edges in center of trail.

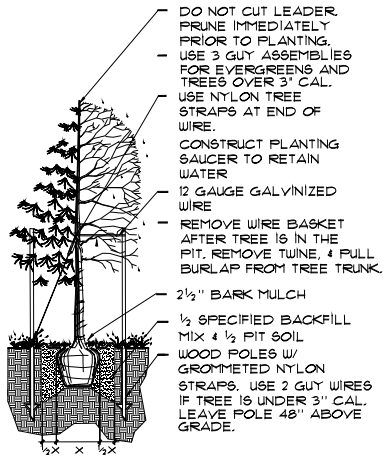
Plant Legend

Sym.	Plant Name	Size/Condition	Planting Instructions
PC	Plains Cottonwood	1 1/2" Cal. B&B	1'-2' above water table no water in planting pit not in water quality zone
PLW	Peach Leaf Willow	1 1/2" Cal. B&B	1'-2' above water table no water in planting pit not in water quality zone
CB	Common Boxelder	1 1/2" Cal. B&B	.5'-1.5' above water table no water in planting pit
TLA	Thin-Leaf Alder	5 Gal.	.5'-1.5' above water table no water in planting pit
NC	Native Chokecherry	5 Gal.	2'-3' above water table no water in planting pit not in water quality zone
SW	Sandbar Willow	5 Gal.	.5'-1' above water table no water in planting pit
RD	Redosier Dogwood	5 Gal.	.5'-1' above water table no water in planting pit
WR	Woods Rose	5 Gal.	2'-4' above water table no water in planting pit not in water quality zone

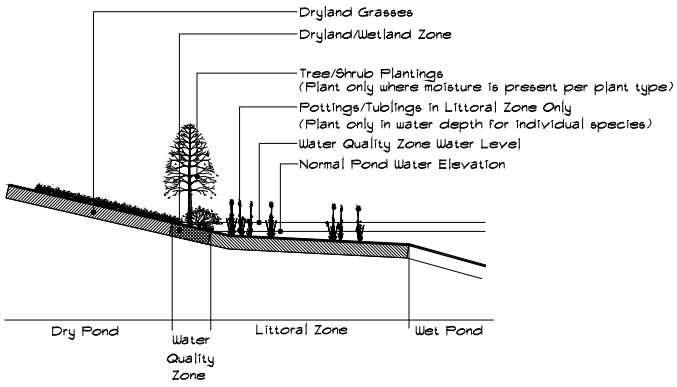
Figure 12—Landscape Plan Construction Notes and Plant Legend



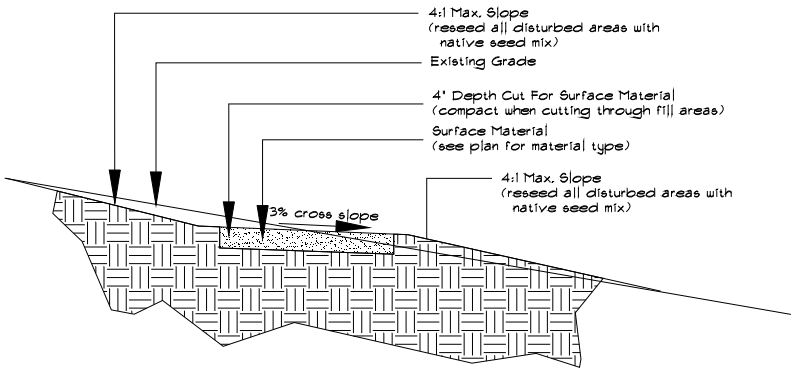
Shrub Planting Detail



Tree Planting Detail



Wetland Planting Section



Trail Construction Section

Figure 13—Planting and Trail Details





Grouted Boulder Drop Structures on Tributary LB-3 Channel



Grouted Boulder Drop Structures on Tributary LB-3 Channel

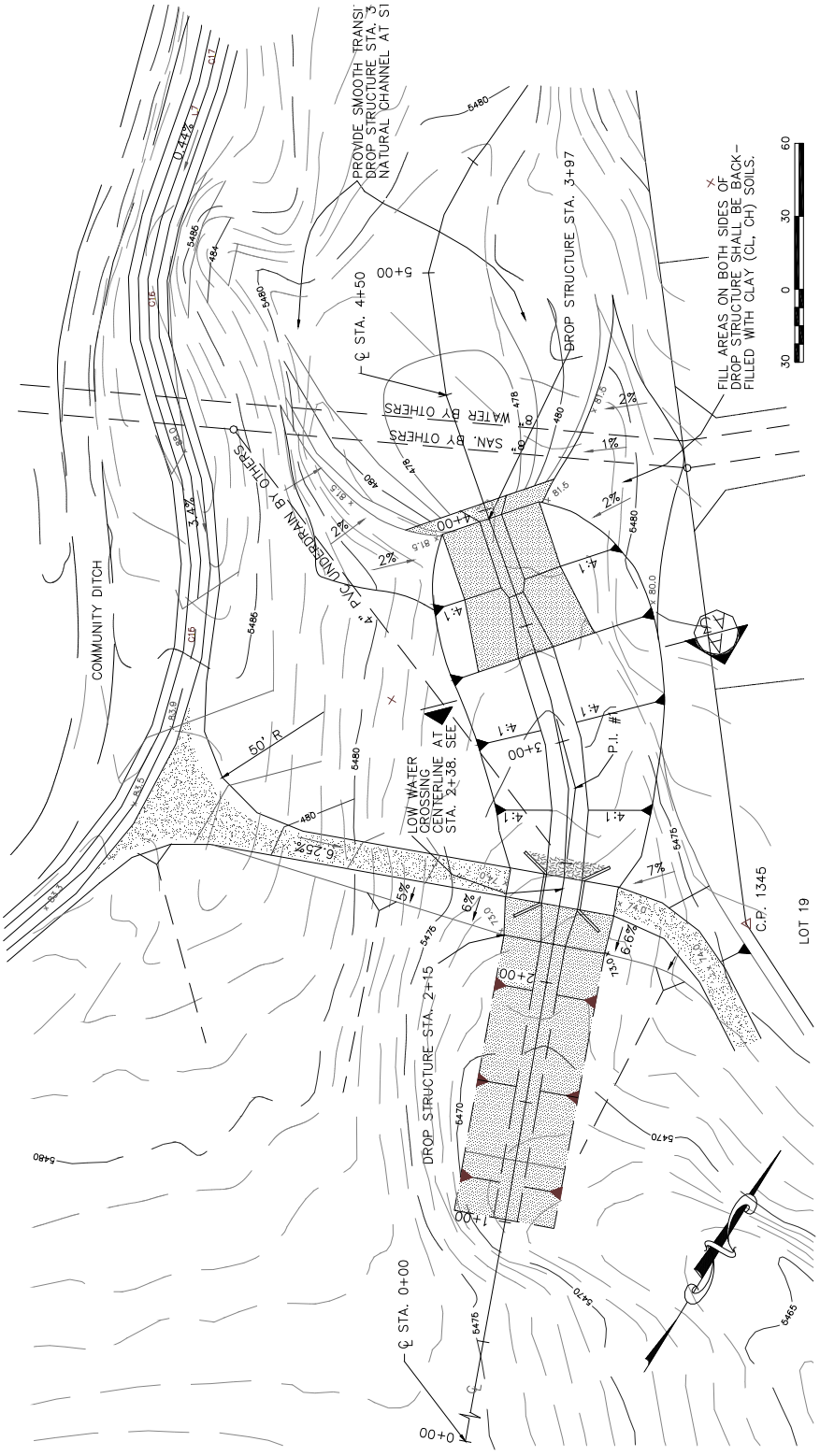


Figure 14—Grouted Boulder Drop Structures

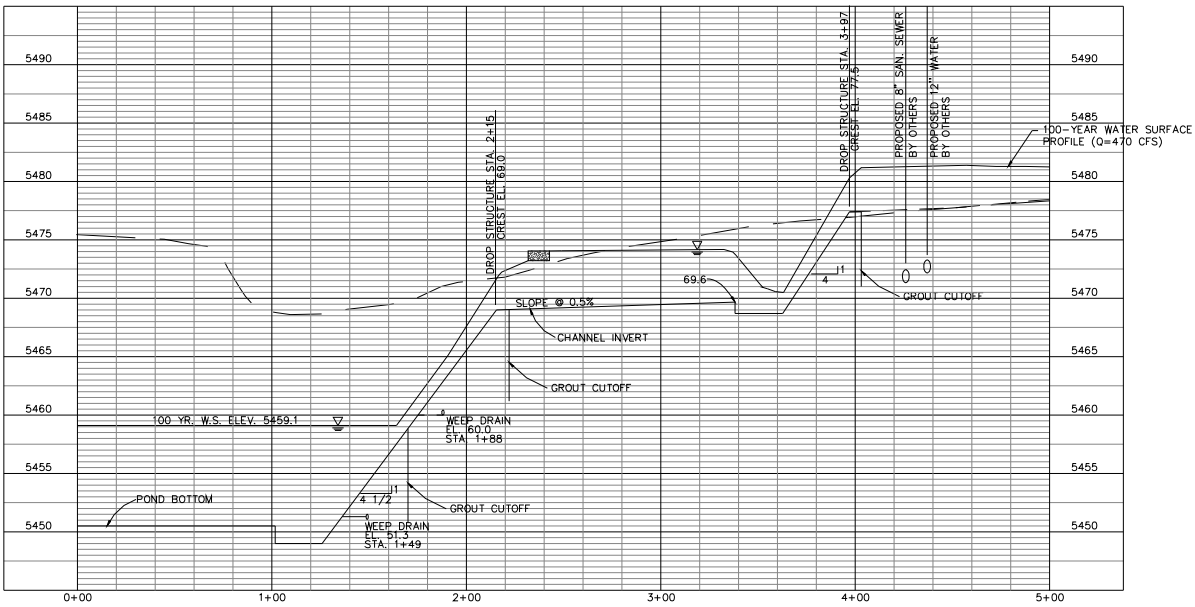


Figure 15— LB3 Channel Profile

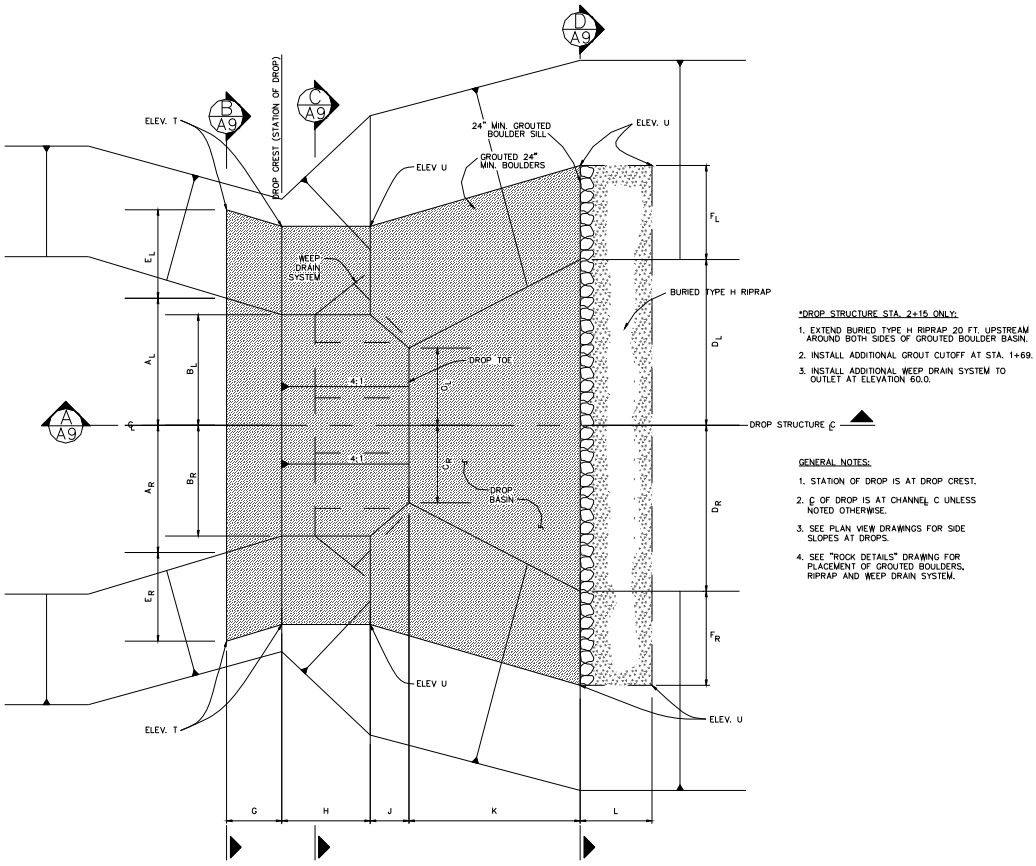


Figure 16—Typical Drop Structure

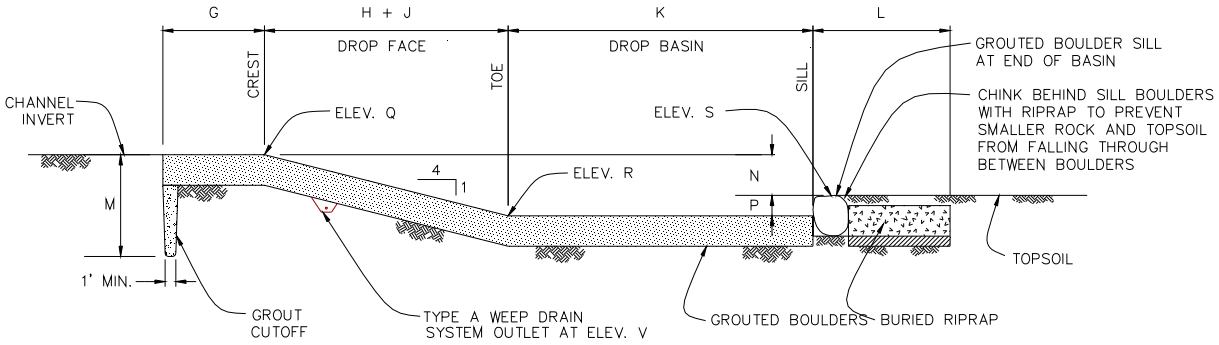


Figure 17—Grout Cutoff Section

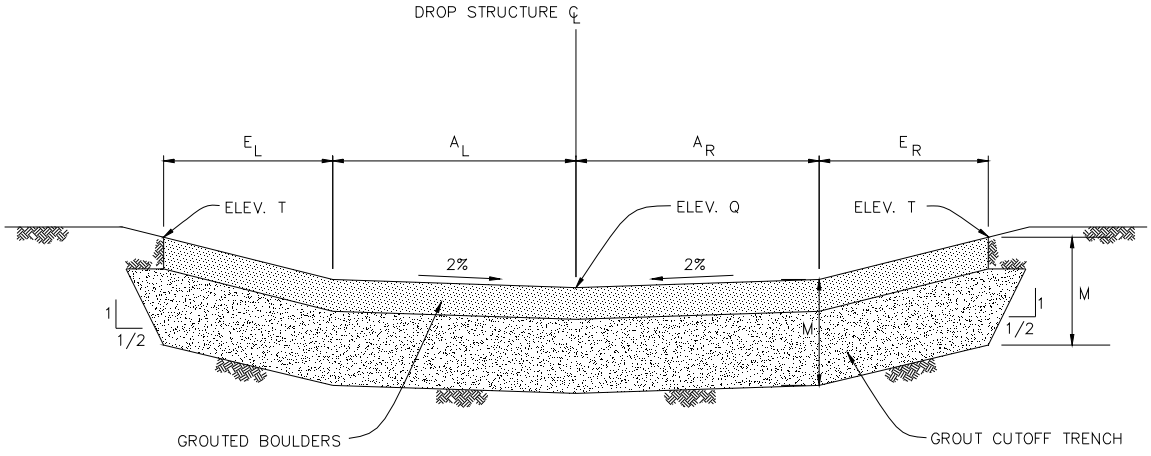


Figure 18—Drop Structure Profile

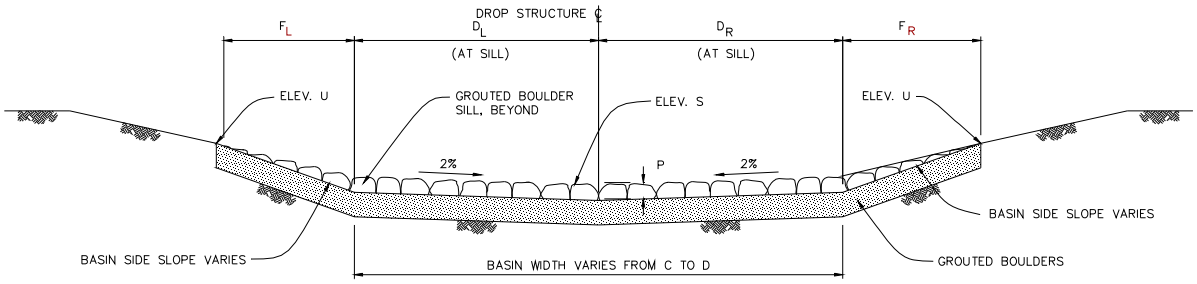


Figure 19—Typical Drop Basin Section and Sill

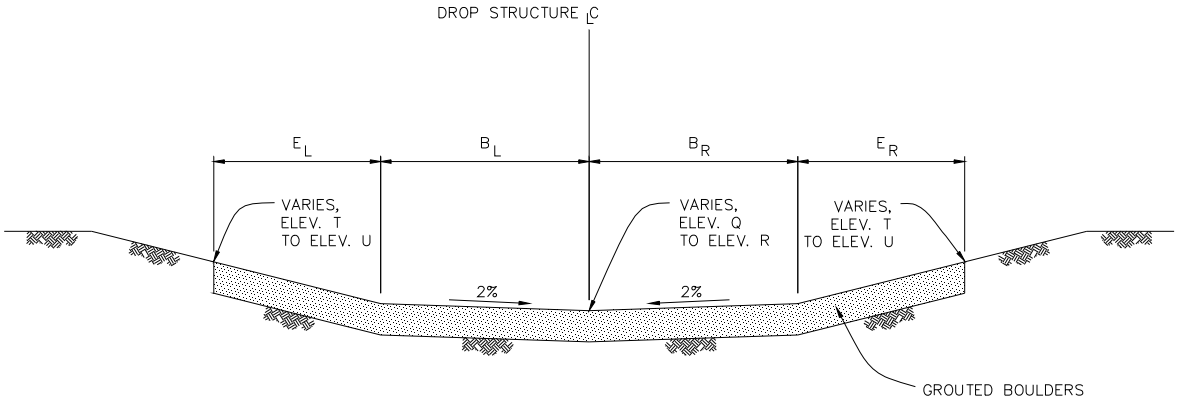


Figure 20—Typical Drop Face Section

DROP STRUCTURE MEASUREMENT TABLE

(ALL DIMENSIONS ARE IN FEET)

STATION OF DROP	A_L	A_R	B_L	B_R	C_L	C_R	D_L	D_R	E_L	E_R	F_L	F_R	G	H	J	K	L	M	N	P	ELEV. Q	ELEV. R	ELEV. S	ELEV. T	ELEV. U	ELEV. V	REMARKS
2+15	6.7	6.7	5	5	5	5	5	5	16	16	16	16	7	83.25	6.75	25	10	8	18.5	1.5	69.0	49.0	50.5	73.0	54.5	51.3 & 60.0	FACE SLOPE IS 4-1/2:1 ELEV. T = 73.7 AT UPSTREAM END OF DROP; ELEV. U = 60.5 AT SILL AND DOWNSTREAM
3+97	11	11	5	5	3	3	7.5	7.5	16	16	16	16	6	31.2	4	25	10	6.5	7.9	1.0	77.6	68.7	69.6	81.5	73.7	70.4	

Figure 21—Drop Structure Measurement Table





Grouted Boulder Check Structures And Wetland Bottom Channels





Grouted Boulder Check Structures And Wetland Bottom Channels



Wetland Bottom Channel

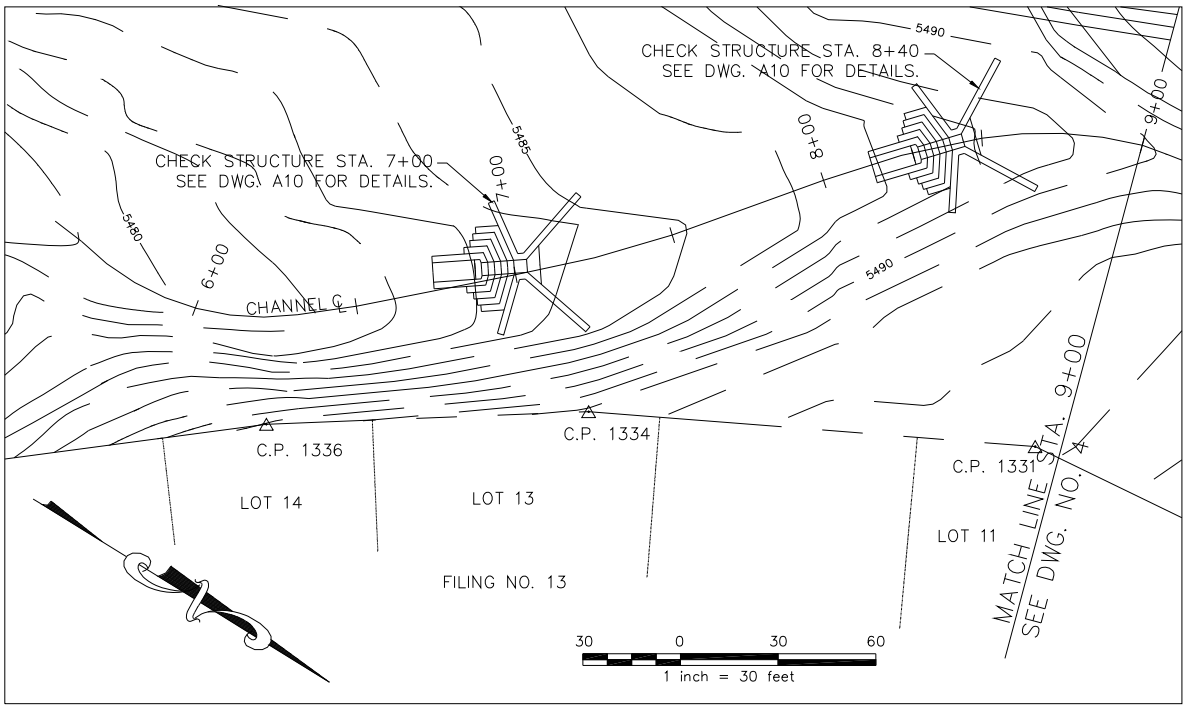


Figure 22—LB3 Channel Plan

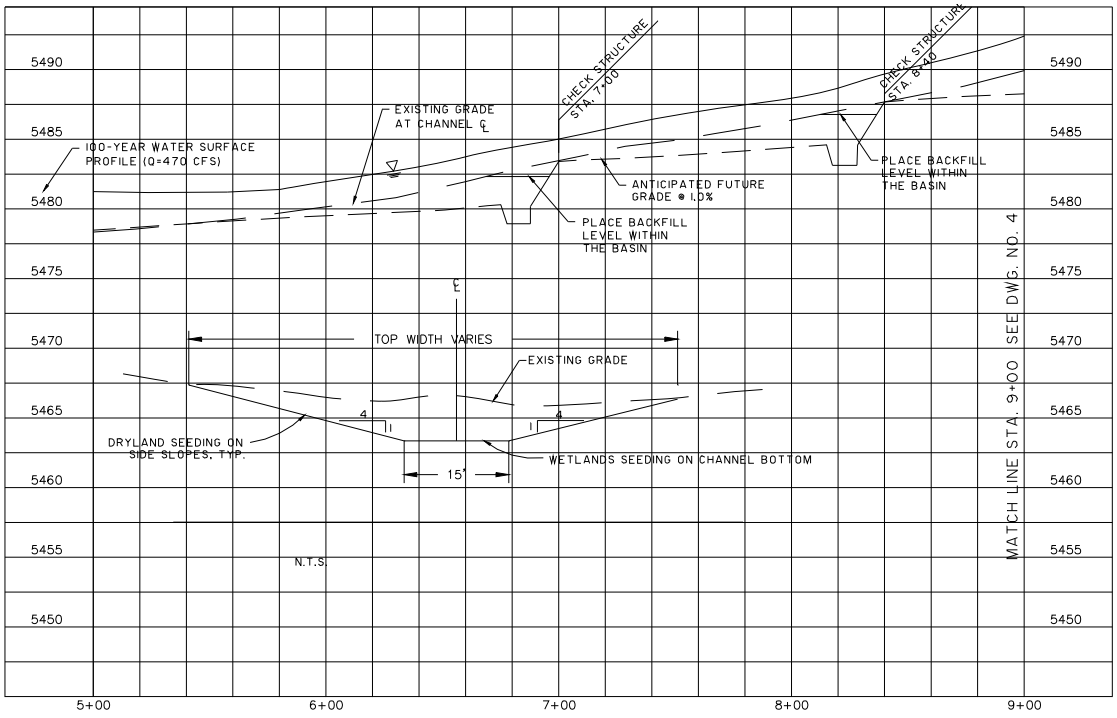


Figure 23—Typical Wetland Channel Section and LB3 Channel Profile

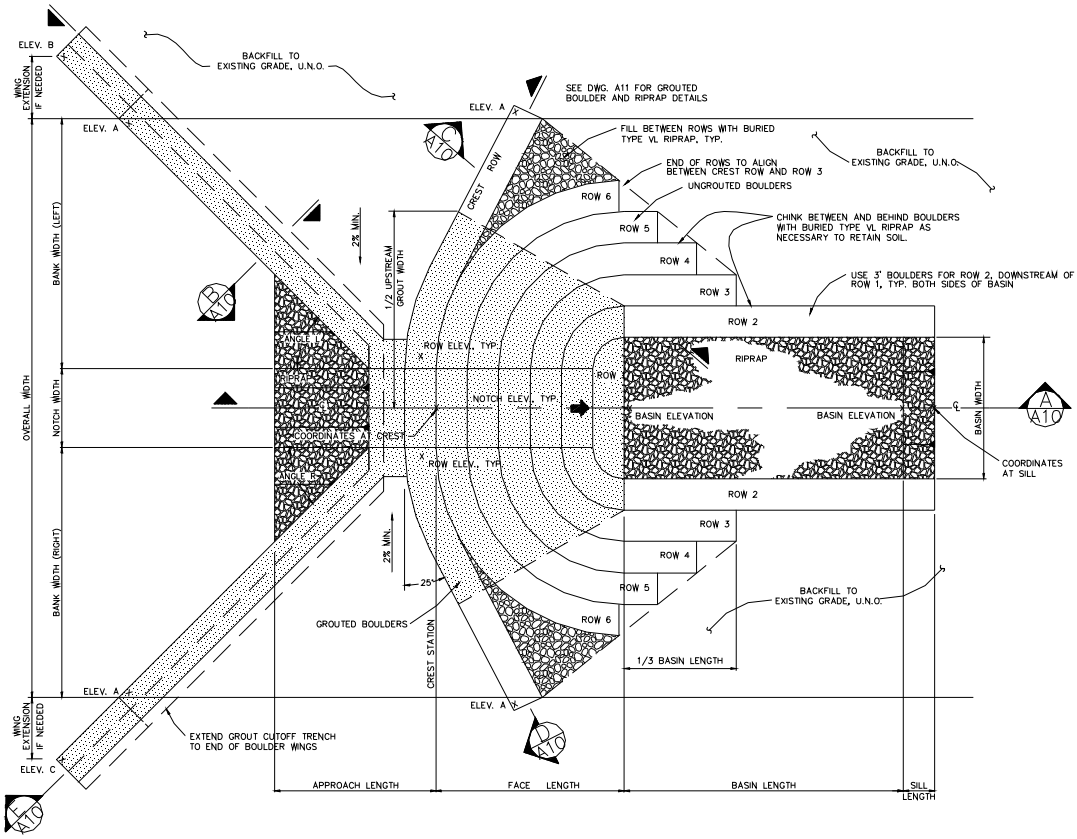


Figure 24—Check Structure Plan

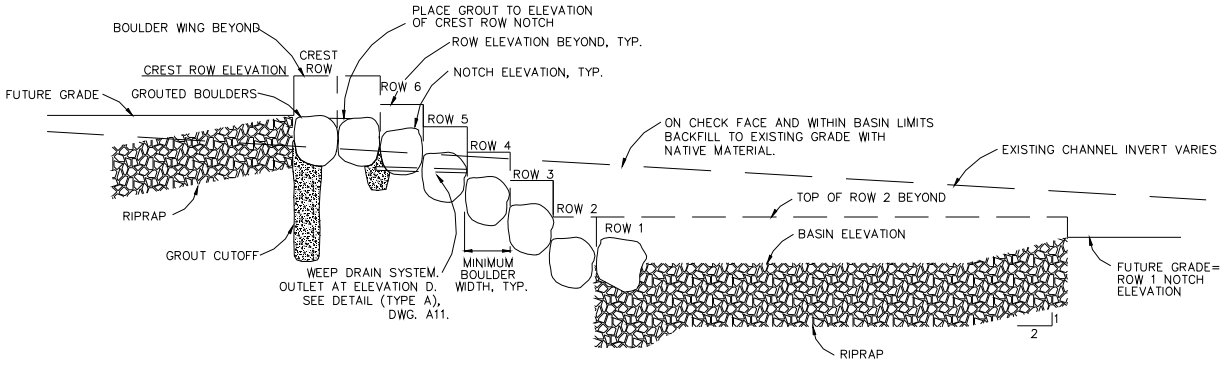


Figure 25—Check Structure Profile

CHECK STRUCTURE LAYOUT TABLE (all dimensions in feet, U.N.O.)

CHECK STRUCTURE DESIGNATION	STA. 7+00	STA. 8+40	STA. 10+50
SILL LENGTH	3'	3'	3'
BASIN LENGTH	10'	10'	10'
FACE LENGTH	12'	12'	12'
APPROACH LENGTH	8'	8'	8'
NOTCH WIDTH	4'	4'	4'
BANK WIDTH	18' L/18' R	18' L/18' R	18' L/18' R
WING EXTENSION	0' L/0' R	0' L/0' R	0' L/0' R
OVERALL WIDTH	40'	40'	40'
BASIN WIDTH	6'	6'	6'
1/2 UPSTREAM GROUT WIDTH	13' L/13' R	13' L/13' R	13' L/13' R
MINIMUM BOULDER SIZE	2'	2'	2'
RIPRAP TYPE FOR BASIN AND APPROACH	H	H	H
COORDINATES AT CREST			
NORTHING	16,333	16,427.5	16,628
EASTING	19,849	19,747	19,729
COORDINATES AT SILL			
NORTHING	16,313	16,411	16,603.5
EASTING	19,864	19,766	19,723
BASIN ELEVATION	79.2	83.5	88.5
NOTCH ELEVATIONS/ROW ELEVATIONS			
ROW 1	80.4/80.4	84.7/84.7	89.7/89.7
ROW 2	80.4/80.9	84.7/85.2	89.7/90.2
ROW 3	81.0/81.6	85.3/85.9	90.3/90.9
ROW 4	81.7/82.3	86.0/86.6	91.0/91.6
ROW 5	82.4/83.0	86.7/87.3	91.7/92.3
ROW 6	83.1/83.7	87.4/88.0	92.4/93.0
CREST ROW	83.4/84.4	87.7/88.7	92.7/93.7
BOULDER WING ELEVATIONS			
ELEVATION A	84.7	89.0	94.0
ELEVATION B	NA	NA	NA
ELEVATION C	NA	NA	NA
CUTOFF DEPTH	5'	5'	5'
ANGLE L (in degrees)	45°	45°	45°
ANGLE R (in degrees)	45°	45°	45°
WEEP DRAIN OUTLET–ELEVATION D	80.9	85.2	90.2

* IF NA APPEARS IN TABLE, THEN THAT PARTICULAR ROW OR ELEVATION IS NOT REQUIRED IN THE CHECK STRUCTURE.

Figure 26—Check Structure Layout Table

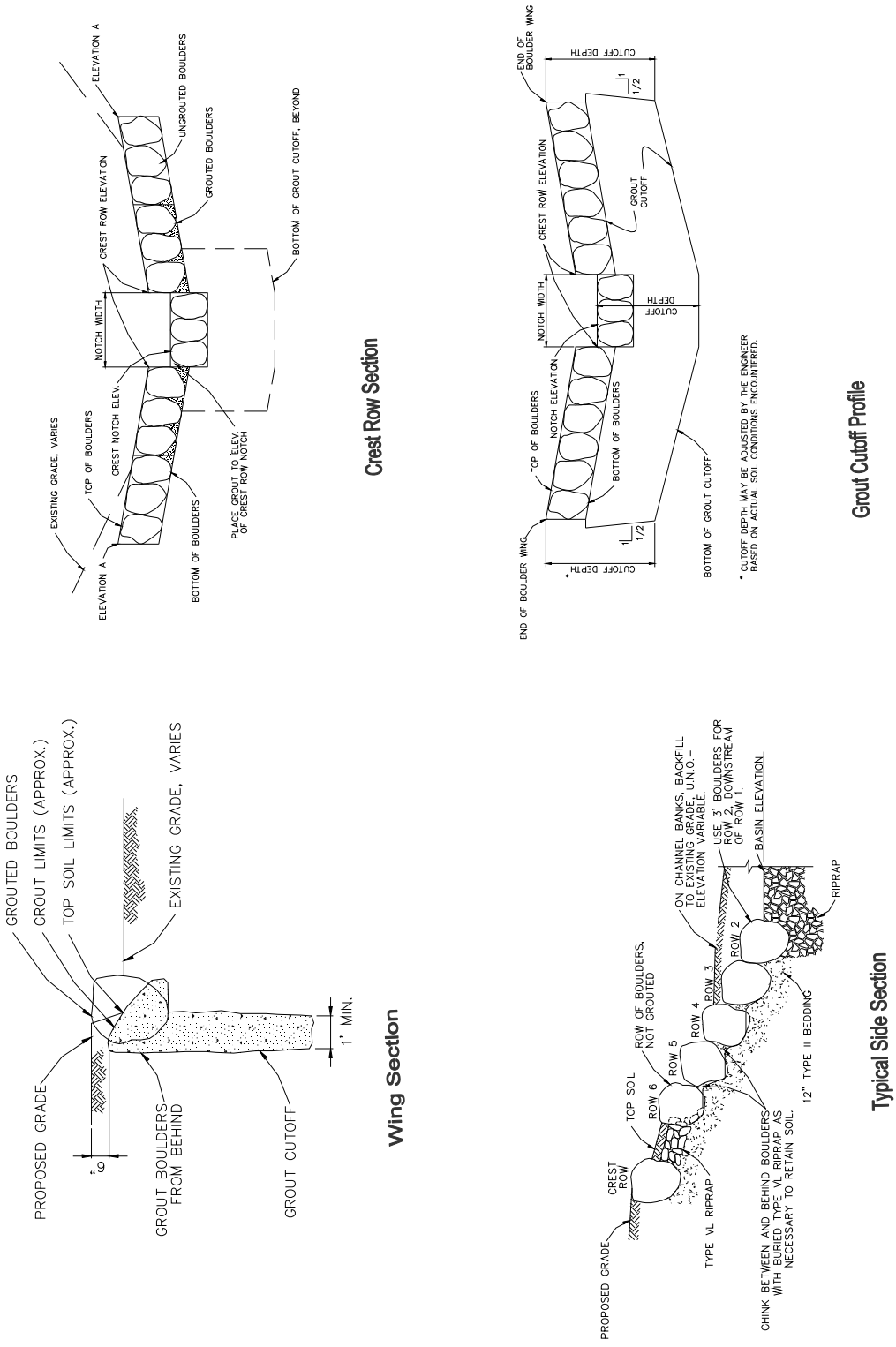


Figure 27—Check Structure Details





Stream Bank Stabilization Including Grouted Boulder Check Structure With Low-Water Crossing, Slope Flattening, And Revegetation





Stream Bank Stabilization Including Grouted Boulder Check Structure With Low-Water Crossing, Slope Flattening, And Revegetation





Stream Bank Stabilization Including Grouted Boulder Check Structure With Low-Water Crossing, Slope Flattening, And Revegetation

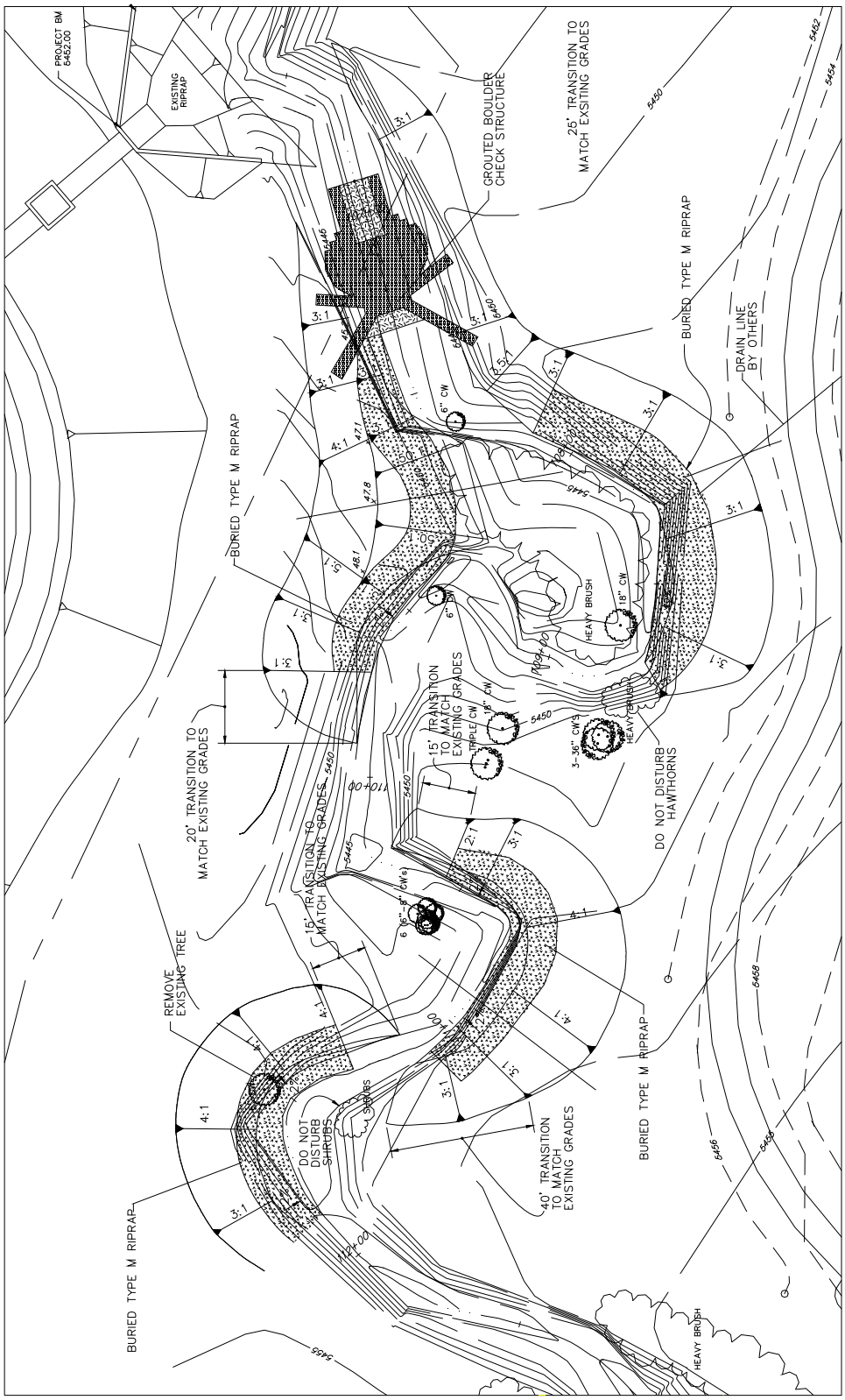


Figure 28—Stream Stabilization Plan

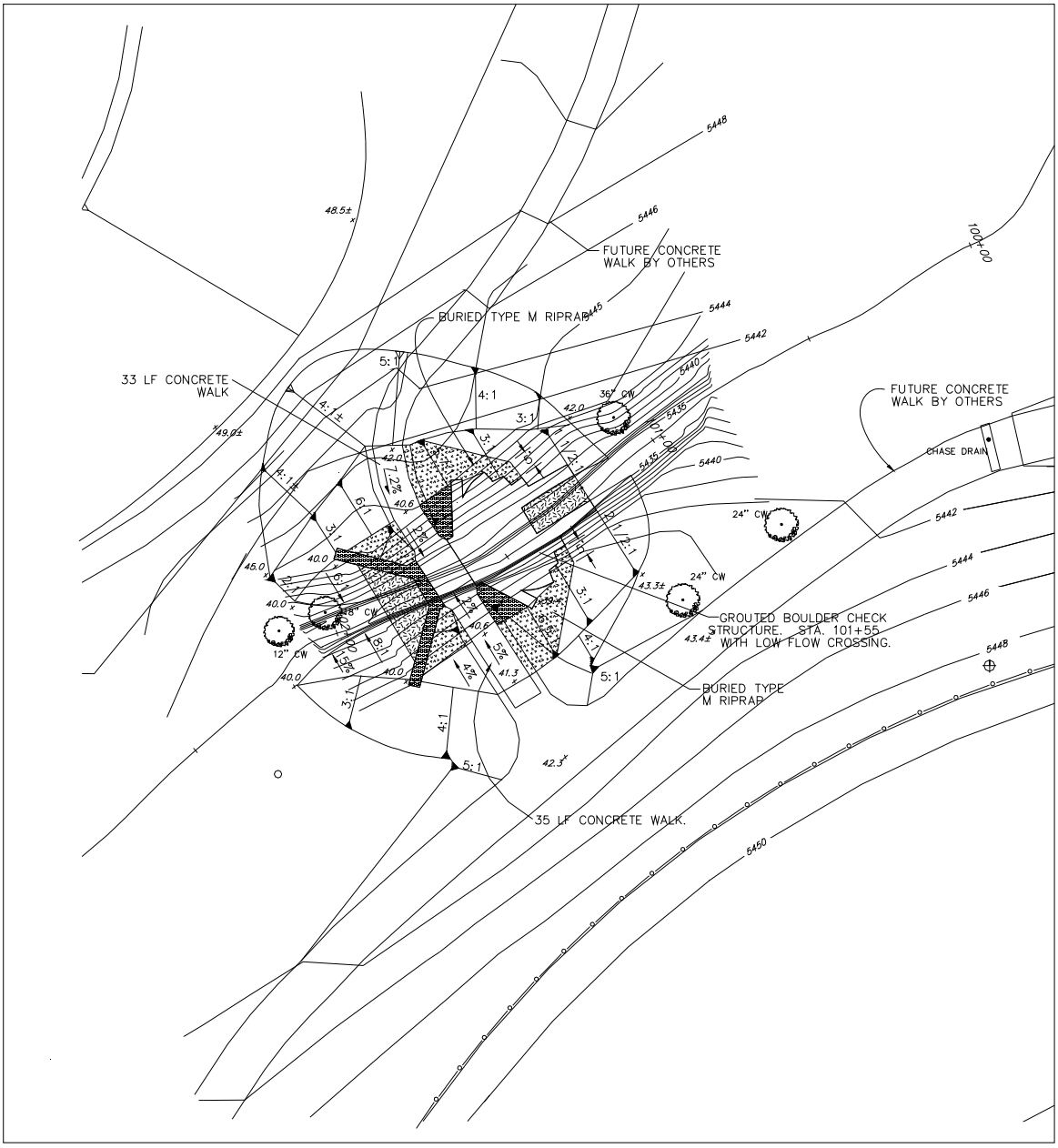


Figure 29—Grouted Boulder Check Structure with Low-Water Crossing Site Plan

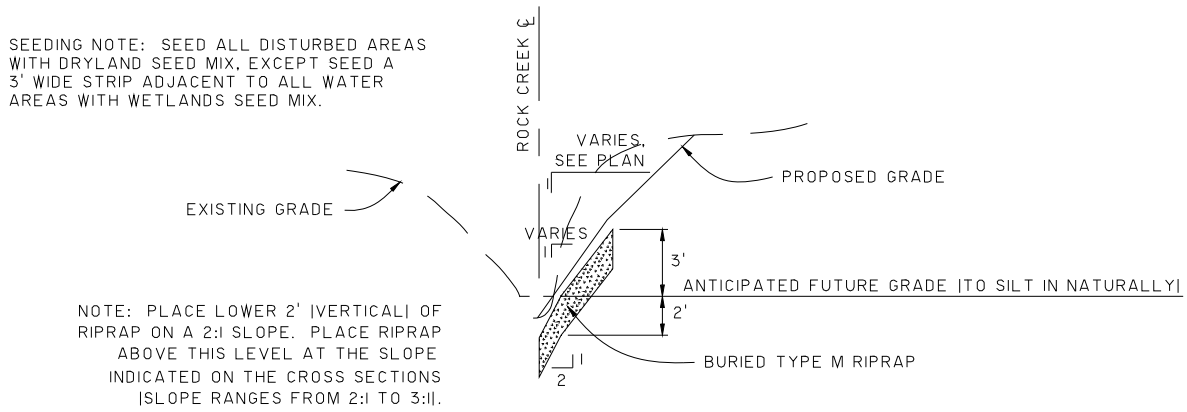


Figure 30—Typical Stream Stabilization Detail

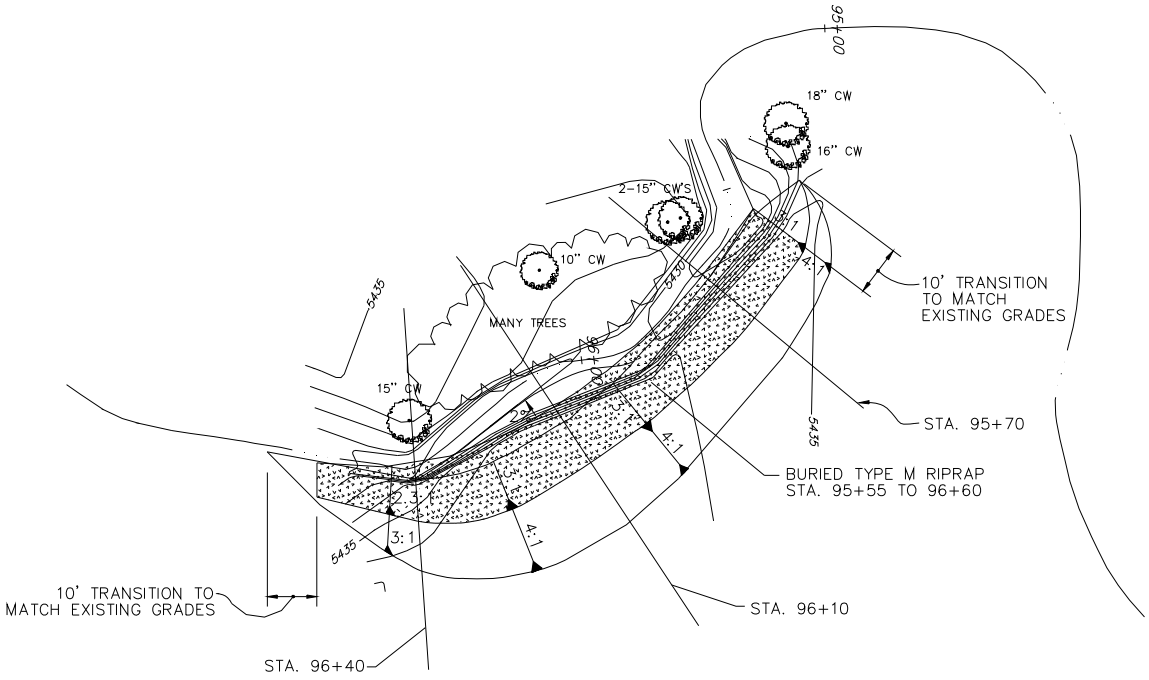


Figure 31—Stream Stabilization Site Plan

DESIGN EXAMPLES—SECTION 5

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5.0 CASE STUDY—SAND CREEK



Bluff Lake Park is a 123-acre park that was created by the City and County of Denver to serve as an educational facility for Denver public school children and also as a gateway to the Sand Creek corridor. The site is located within the former Stapleton Airport operations area and includes the 9-acre Bluff Lake impoundment, 30 acres of wetland areas, abundant shortgrass prairie habitat, a remnant cottonwood gallery, and 3600 feet of Sand Creek, a major South Platte River tributary. The park is both a recreational area (pedestrians, joggers, etc.) and an educational facility where students learn about water quality, wetland, and riverine habitats. Improvements to this reach of Sand Creek include channel stabilization and enhancement of biological function along the corridor.

Historically Sand Creek contained very little or no base flow, with intermittent surface flows occurring in response to precipitation events. Most of the Sand Creek drainage flowed underground as part of the alluvial aquifer. Urbanization of the upstream watershed had impacted the creek, resulting in a flashy hydrograph, increased recurrence of flood flows, and development of a base flow. Erosion and deposition was occurring along the channel bed and banks as the channel tried to conform to the altered hydrology. The bank erosion threatened several structures adjacent to the creek, so bank-hardening treatments had been installed in localized areas as protection. The hardened banks were impeding the channel's natural tendency to meander and exacerbating the erosion problems. The altered flow conditions, the constrictions, and the channel's inclination to restore its wide, shallow, meandering flow pattern (all applied to the channel's highly erodible sandy substrate) were combining to create channel stability problems. These effects had been offset somewhat in the past by an undersized culvert bridge at Havana Road (downstream end of the project reach), which was creating a large backwater area and effectively slowing upstream velocities. The replacement of the culverts with a clear span bridge caused a substantial increase in velocities through the reach. The result was vertical streambanks that were over 12 feet high and channel downcutting up to 4 feet in some areas. Additionally, a large on-site meander was cut off as headcutting occurred through the reach. The unstable bed and banks were



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threatening a treated wastewater reuse pipeline crossing and several structures situated along the streambank. The continual erosion had left virtually no streamside vegetation. Additionally, the degrading channel bed was causing an associated drop in the local water table, resulting in adverse impacts to streamside vegetation and related riparian and wetland habitats. Native plants along the corridor, especially the mature cottonwoods, which are an important park feature both for their age and because they provide nesting habitat for species such as Swainson's hawk and the great-horned owl, were showing signs of stress and losing ground to invasive species, including salt cedar tamarisk and Russian olive. Understory grasses and forbs also showed signs of takeover by invaders such as knapweed and leafy spurge.

Aquatic and Wetland Company (AWC) and Camp Dresser and McKee, Inc. (CDM) provided design and construction services for the City and County of Denver for the improvements to the Sand Creek corridor. The option of restoring the historically wide floodplain was not possible due to the adjacent development. Additionally, restoration of a wide floodplain through such high cutbanks would not have been economically feasible due to the large amounts of excavation that would be required. Therefore, the project sought to stabilize the channel bed and banks. All work needed to be compatible with and contribute to the use of the area as a recreational and educational facility. To that end, bioengineering treatments were integrated with more traditional bank stabilization methods, and the additional goals of riparian, wetland, and upland habitat restoration were included. Traditional bank stabilization measures, such as riprap and boulders, were limited to eroded slopes that were too steep for bioengineering treatments and to the critical junction of the channel bank and channel bed. Boulders placed at this junction provide protection to allow sufficient time for vegetation to be established and, eventually, cover the rock. The boulders and vegetation jointly provide protective cover for both vertebrate and macroinvertebrate fauna.



5.1 Design

In addition to the integration of bioengineering techniques and traditional methods to provide the necessary stabilization, an important design concept was to create a meandering low-flow channel within the armored outer banks, or flood channel. A 25- to 40-foot-wide low-flow channel designed to convey a base flow of 20 to 50 cfs was left completely unconstrained to meander at will within the 40- to 140-foot-wide channel (conveying the more frequently



occurring smaller flood flows), in an imitation of the creek's natural condition.

The primary treatment for stabilization of the main channel banks was a double boulder terrace with brush layering. The treatment consisted of two rows of large boulders set on a deep, concrete rubble foundation. The foundation was constructed using recycled runway concrete blocks from the demolition of Stapleton Airport. The minimum cutoff achieved by the boulders and the rubble foundation was 3 feet below the low-flow channel invert. A continuous line of coyote willow (*Salix exigua*) cuttings (brush layering) was then installed behind the lower boulder toe. The provision of vegetation along the immediate channel edge was especially important to restoring biological function because the plants provide leaf litter to the stream system (i.e., base of the food chain), as well as providing overhead cover for fish, and performing shading/cooling functions for the system. A planting terrace with a maximum slope of 3H:1V was created between the rows of boulders. The terraces were planted and seeded with native riparian trees, shrubs, grasses, and forbs. Two unique plant communities were established along the terraces – cottonwood gallery and riparian scrub-shrub. The bank side slopes created by the combination of boulders and terracing were designed with a maximum effective slope of 2.5H:1V, which provided a substantial reduction from existing slopes. In most areas, the effective side slopes that were achieved were flatter than the design maximum. The slope protection in this treatment comes primarily from the two rows of boulders and secondarily from the root structure, which will be created as the vegetation matures.



In some areas, such as low-risk inside bends, hard protection was not needed. A willow log designed specifically for the project was used for toe material, in place of boulders, in these areas. The logs were manually constructed on-site using coir erosion control fabric, native fill material generated by the project, supplemental imported mulch, and willow cuttings. In addition to creating a stabilizing toe for less critical banks, the logs were used to create a check structure to control the minor inflow, consisting of treated wastewater effluent, routed from the neighboring Aurora Wastewater Reuse Plant. The intent of the specialized willow logs was to let the willows in the outer layer of the log produce stabilizing roots and overhead foliage, which will continually increase bank protection as well as riparian habitat. The problem of securing the logs into loose, sandy soil was solved through the use of Duckbill anchors. The Duckbills have anchors that rotate when pulled, locking themselves into place deep in the banks. They perform exceptionally well in sands where typical staking may be ineffective.



Stabilization of the channel bed was accomplished through the installation of two grouted boulder drop

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structures with sheetpile cutoffs. The drop heights (4-foot and 8-foot) were set to achieve an average 0.2 % slope for the reach. The drop structures were designed with a step-pool configuration, with a maximum drop of 1.5 feet between each step and a minimum pool depth of 3 feet. These specifications allow for fish passage and provide resting habitat for migrating fauna. The boulder crests were installed in curving alignments and pools were given uneven shapes and sizes to avoid an overly structured look. The larger drop included a planting terrace along its length to restore streamside vegetation and soften the look of the structure. The structure included the wastewater effluent pipeline crossing in its crest. The cascading step-pool design of the grade control structures makes a nice park amenity with its soothing sound and natural aesthetic quality. Additionally, propane testing has indicated that the structure is an excellent passive re-aerator, with the 8-foot drop exhibiting an overall efficiency of 60% and individual step efficiency of close to 19%.

5.2 Criteria

The use of drop structures to reduce the channel slope to 0.2 % follows the recommendations of the District's 1984 Sand Creek Major Drainageway Plan. The channel improvements were designed for general channel stability up to the 10-year flow of 9,000 cfs. The low-flow channel carries the channel's base flow of approximately 20 to 50 cfs. Bioengineering techniques were utilized to the maximum extent possible. Wherever conditions exceeded the expected stabilization potential of available bioengineering methods, vegetative treatments were added to the riprap, boulder, and concrete techniques.

5.3 Construction

AWC and CDM Engineers and Constructors constructed the Sand Creek channel improvements. The 3,600 feet of channel improvements included almost 50,000 cubic yards of cut/fill (largely due to realignment of the lower reach of the creek to avoid the new Colorado Department of Correction Women's Detention Facility), sheetpile installation, structural concrete and grout work, boulder placement, and comprehensive planting and seeding. Timing was the biggest construction challenge. Contract delays caused a late construction start, which pushed construction into the summer thunderstorm season. As a result, construction was interrupted several times by rapidly rising water levels.



5.4 Success

Many of Bluff Lake's patrons have praised the Sand Creek Channel Improvements Project for the natural look that was achieved and for the improved habitat along the creek corridor. The project has, to date, met its goals of stabilizing the channel bed and banks

and enhancing biological function, while maintaining compatibility with the District's master plan recommendations and contributing to the use of the park as an education facility. Healthy growth has been observed in the willow brush layering (installed behind the boulder toes, on top of buried rubble as part of all double boulder terrace bank treatments). Combined with pre-existing willow stands located along the creek, the new treatments have created over 5,000 linear feet of solid willow coverage along the water's edge. Individual plant growth was noted at over 3 feet in one growing season in some sections. The planted willows are healthy and robust and appear to be continuing the strong growth pattern as they mature. Great blue herons, hawks, and families of ducks have been observed along the creek and among the willows since the project's completion. This project illustrates that in this reach of Sand Creek, a reach that has been impacted by upstream urbanization, the combination of structural elements with bioengineering techniques can produce an environmentally productive and stable urban stream.

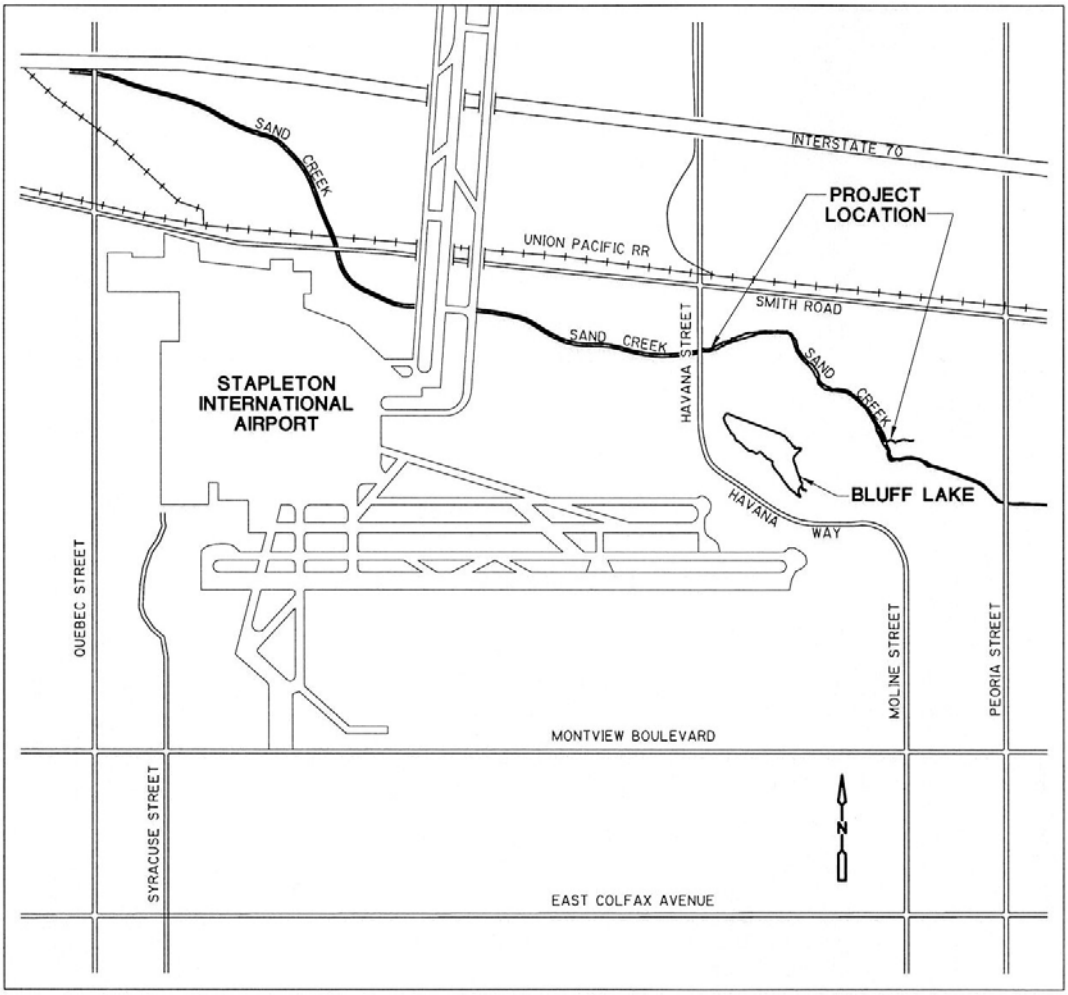

Figure 1—Location Map

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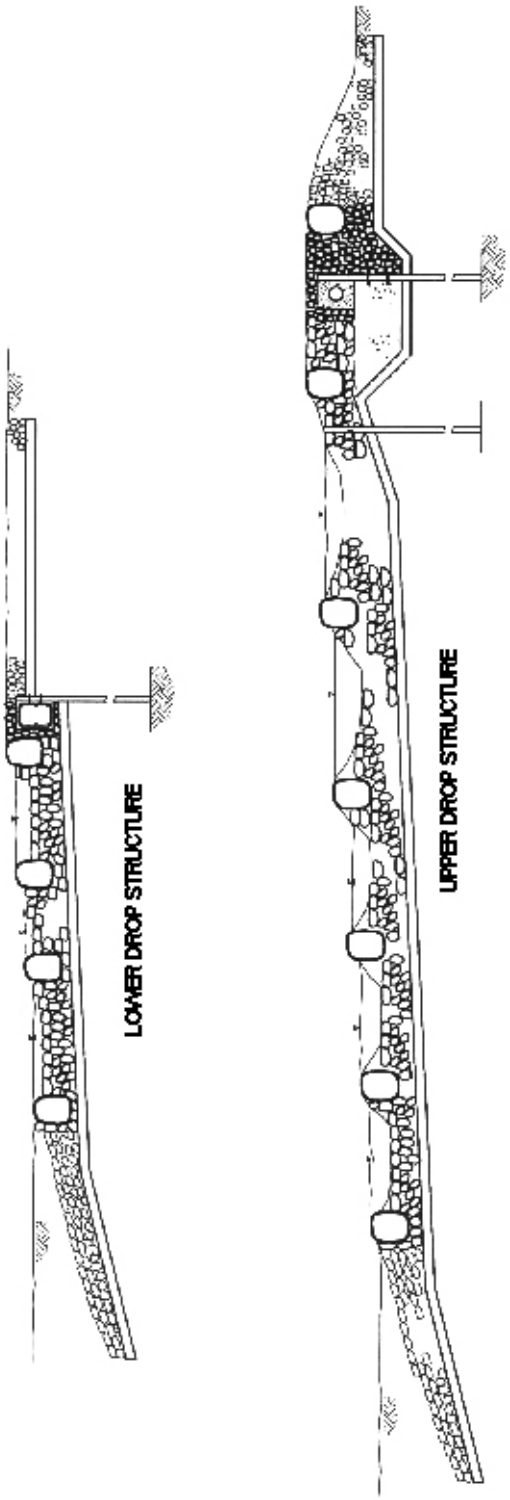

Figure 2—Drop Structures

Sand Creek Channel Improvements at Bluff Lake Park
Denver, Colorado

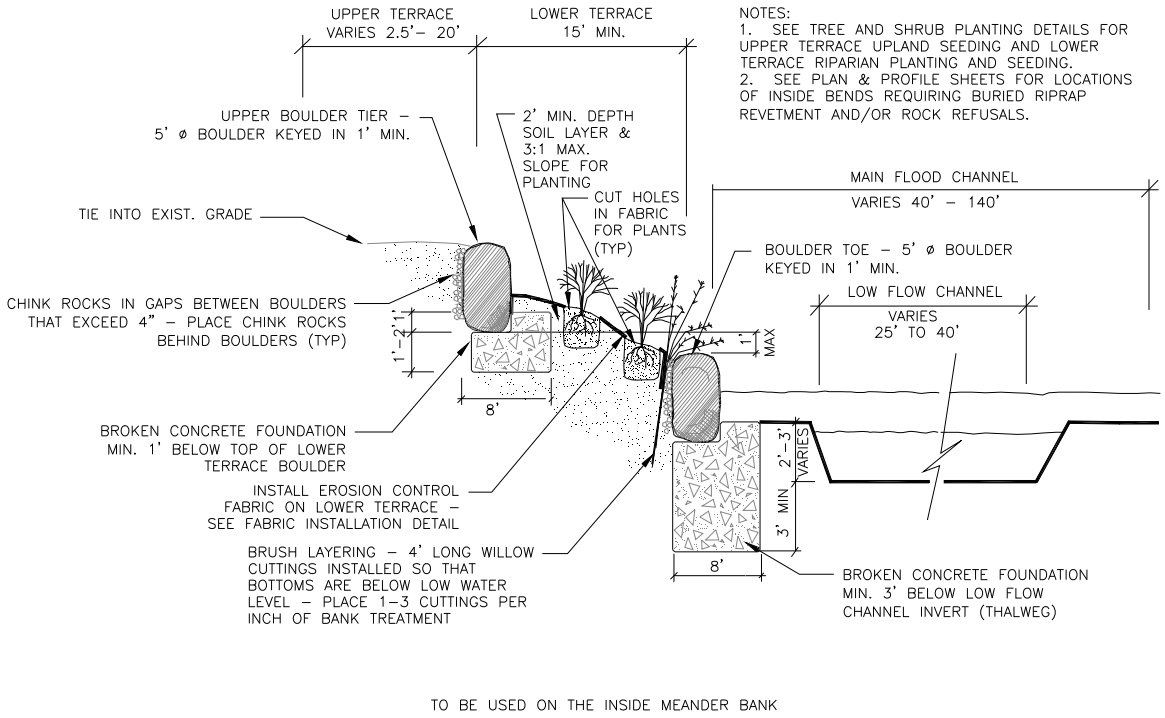

Figure 3—Double Boulder Terrace

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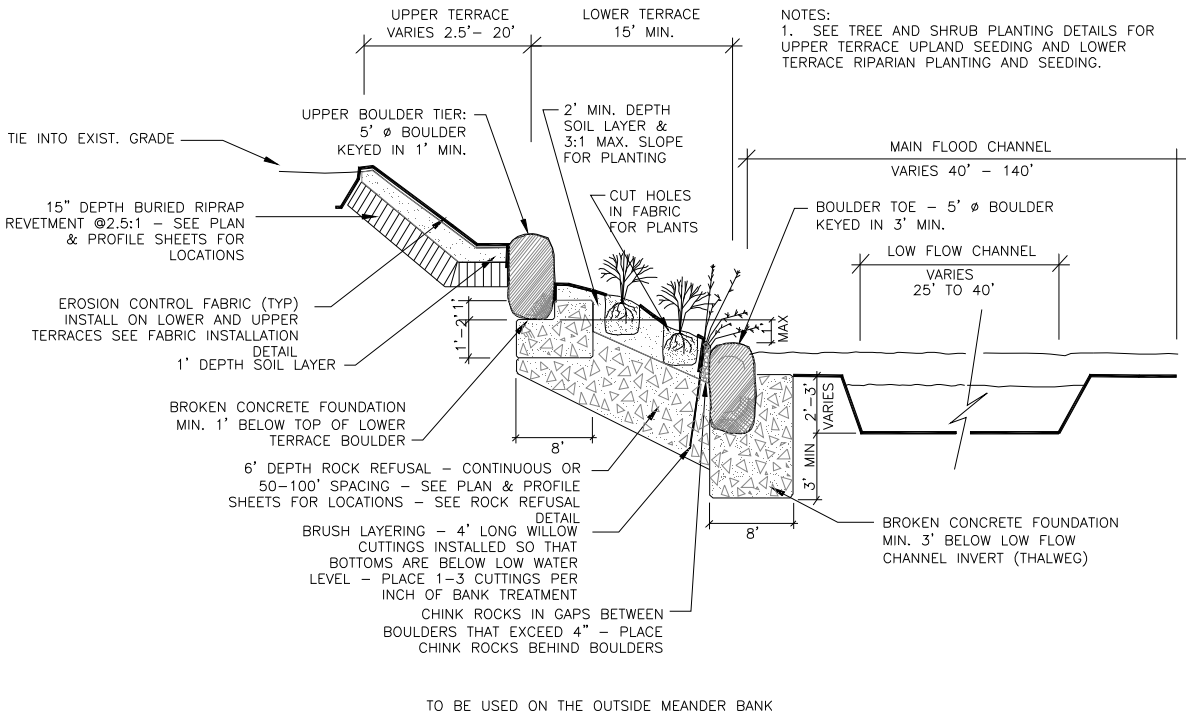

Figure 4—Double Boulder Terrace with Buried Riprap Revetment

Sand Creek Channel Improvements at Bluff Lake Park
Denver, Colorado

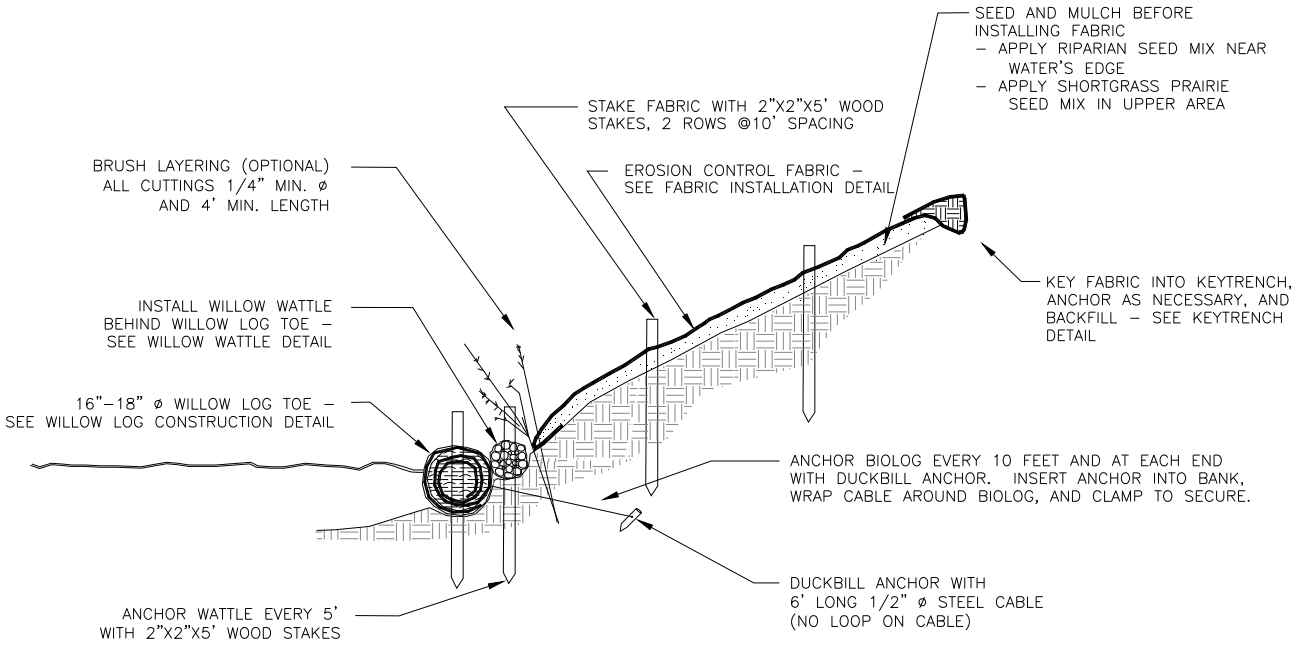

Figure 5—Willow Log Toe with Willow Wattle

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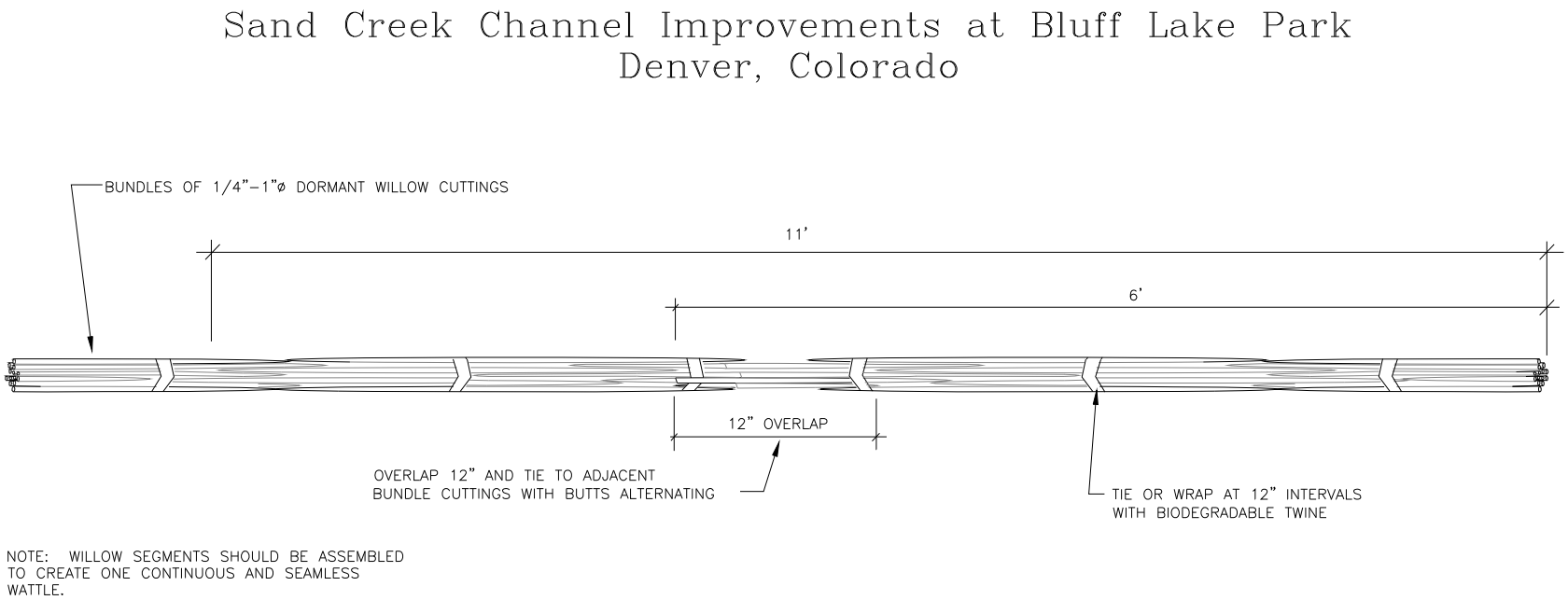

Figure 6—Willow Wattle

Sand Creek Channel Improvements at Bluff Lake Park
Denver, Colorado

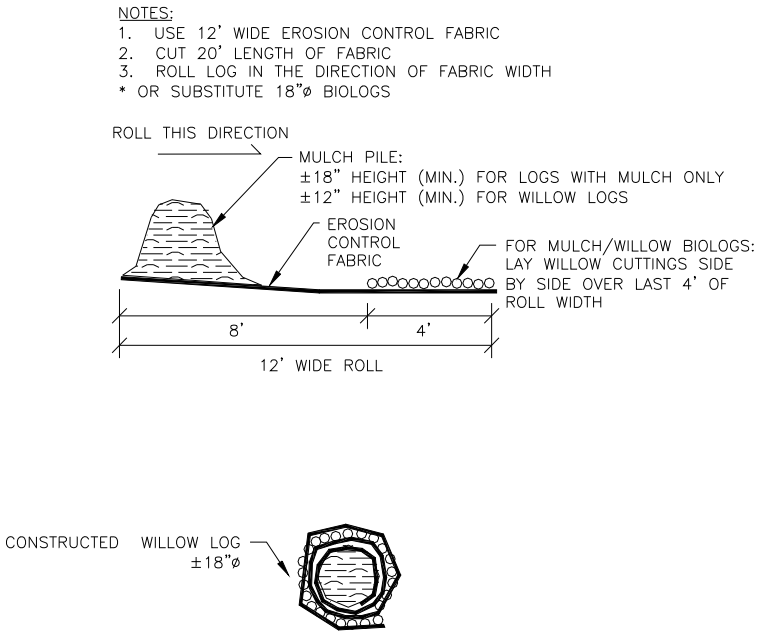

Figure 7—Willow Log Construction

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6.0 CASE STUDY— GOLDSMITH GULCH

Goldsmith Gulch flows through Bible Park in southeast Denver. Bible Park is located between Monaco Parkway and Quebec Street and south of Yale Avenue. The Highline Canal flows around the perimeter of the park. Bible Park has active recreational areas that include ball fields, tennis courts and playgrounds. The park has a significant trail system that connects the active recreational components of the park and allows for enjoyment of the passive areas. The channel in Bible Park had become deeply incised and very linear. The average slope of the existing channel in Bible Park prior to the drainageway maintenance project was approximately 0.5 percent. The channel bottom elevation at the upstream and downstream ends of the park was controlled but the channel in the park had become very incised with sloughing banks. The incised channel and unstable banks greatly reduced the potential for enjoyment of the channel by park users and presented a definite safety issue. The Urban Drainage and Flood Control District, the Denver Wastewater Management Division and the Denver Parks Department undertook a rehabilitative maintenance project for the Goldsmith Gulch channel in Bible Park in 1996. Sellards & Grigg, Inc. and Wenk Associates performed the design. Dames & Moore provided environmental consultation. The rehabilitative maintenance of the Goldsmith Gulch channel was undertaken with the primary goals of stabilizing the channel in a manner that was environmentally sensitive and that enhanced the wildlife habitat in the park. A secondary goal was to enhance the passive and active enjoyment of the park. Bioengineering techniques were combined with traditional methods of channel stabilization to accomplish the project goals.



6.1 Design

Inherent in all of the alternatives that were considered for channel stabilization was the concept of reducing the channel slope by the construction of drop structures. As a result of the extensive public involvement process that was undertaken during the design phase of the project, it was decided that there would be two drop structures that would divide Bible Park into three distinctly different channel reaches.



6.1.1 Channel Reaches

The lower reach of the channel was constructed with boulder walls to protect a large area of trees that was adjacent to the channel. An island was created around the area of trees. The development of the island resulted in a new channel adjacent to the trail that connects to the below-grade crossing under Yale Avenue. The island in the lower channel reach provides for a more interesting and aesthetic experience for the park trail user. The reduced velocity and constant inundation in the widened low-flow channel upstream and downstream of the island has resulted in flourishing wetland vegetation.

The middle channel reach was the most deeply incised and linear. The middle channel reach is located in the passive area of the park. The width of the park in the middle reach was sufficient to allow for the redevelopment of a new meandering channel. The new meandering channel was designed with sweeping oxbows that would be frequently flooded to sustain wetland vegetation. Sand blankets were installed in the low-lying overbank areas on the inside of bends in an attempt to provide a direct hydraulic connection to the wetland vegetation during low-flow conditions. The low-flow channel banks for the middle reach of the channel were protected with soil riprap that was vegetated with wetland species. Over the course of time, the vegetation in the low-flow channel bank has obscured the soil riprap. A foot path constructed with crusher fines follows close to the constructed meandering channel in the middle portion of the park. The footpath allows for passive enjoyment of the tranquil meandering channel and the enhanced wildlife habitat.



The upper channel reach was not as severely incised as the middle channel reach. There were a significant number of trees in close proximity to the channel. For the most part, the existing channel alignment was maintained in the upper portion of the park. The moderately degraded channel in the upper channel reach was stabilized by the design of the upper drop with a crest elevation somewhat above the existing channel bottom. The channel bottom in the upper third of the park was allowed to fill in by natural sedimentation processes in the pool area behind the drop. There is a very large five-cell box culvert at the upstream end of Bible Park. The channel immediately downstream of the five-cell box culvert was protected from erosion using bioengineering techniques. Soil riprap was planted with wetland species that have become very prolific in this area.

6.1.2 Drop Structures

The lower drop structure has significant drop and provides an interesting overlook for park users by combining the drop with a pedestrian crossing. There are significant structural elements to the lower drop

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structure. A concrete cutoff wall was integrated with the upstream edge of the trail crossing and the intermediate crests of the rock walls on the downstream face of the drop structure were stabilized with concrete walls that are hidden from view. The upper drop was constructed of boulders and was intended to provide a separation between the meandering channel portion of the park and the existing channel portion of the park. The drop structures have reduced the longitudinal slope of the channel to 0.21 percent.





6.2 Criteria

For the most part, the District criteria were followed for this project. The channel slope has been reduced to approximately 0.2 percent through the construction of grade control structures. The low-flow channel has been constructed for 100 cfs, which is approximately 3 percent of the 100-year flow of 3570 cfs. The lower drop structure is unique. There are three intermediate pools between the upper channel and the lower channel. The areas lateral to the low-flow throat of the lower drop structure have been armored with loose boulders. Subsequent to the completion of construction, the crevices between the loose boulders have become vegetated. The intermediate pools on the downstream side of the pedestrian crossing provide for an interesting sound effect that often captures the attention of the trail user. There is an interesting view of the island and the wetland area upstream of the island from the pedestrian crossing of the lower drop structure.

6.3 Construction

L&M Enterprises was the General Contractor for the rehabilitative maintenance in Bible Park. The project included substantial earthwork, structural concrete, placement of boulders and soil riprap, trail construction, and the establishment of vegetation. Getting the wetland species established was probably the biggest challenge of the project. The significant flood events that were experienced during construction and immediately after construction made it difficult to establish the wetland vegetation.

Replanting the wetland areas was necessary in the first growing season after the completion of the project.

6.4 Success

The rehabilitative maintenance project in Bible Park has been well received by the public and has attained the goals set by the sponsors and the design team. The experience of the design team and the project sponsors demonstrated that patience and perseverance are required when bioengineered solutions are employed for erosion protection in a drainageway that is subject to frequent flooding. It took approximately two years for the wetlands to become well established and provide for their intended erosion protection. Ultimately, the approach of combining armoring with bioengineered solutions resulted in a successful project. The project has stabilized the Goldsmith Gulch channel and has provided for enhanced enjoyment by the people who use the park.

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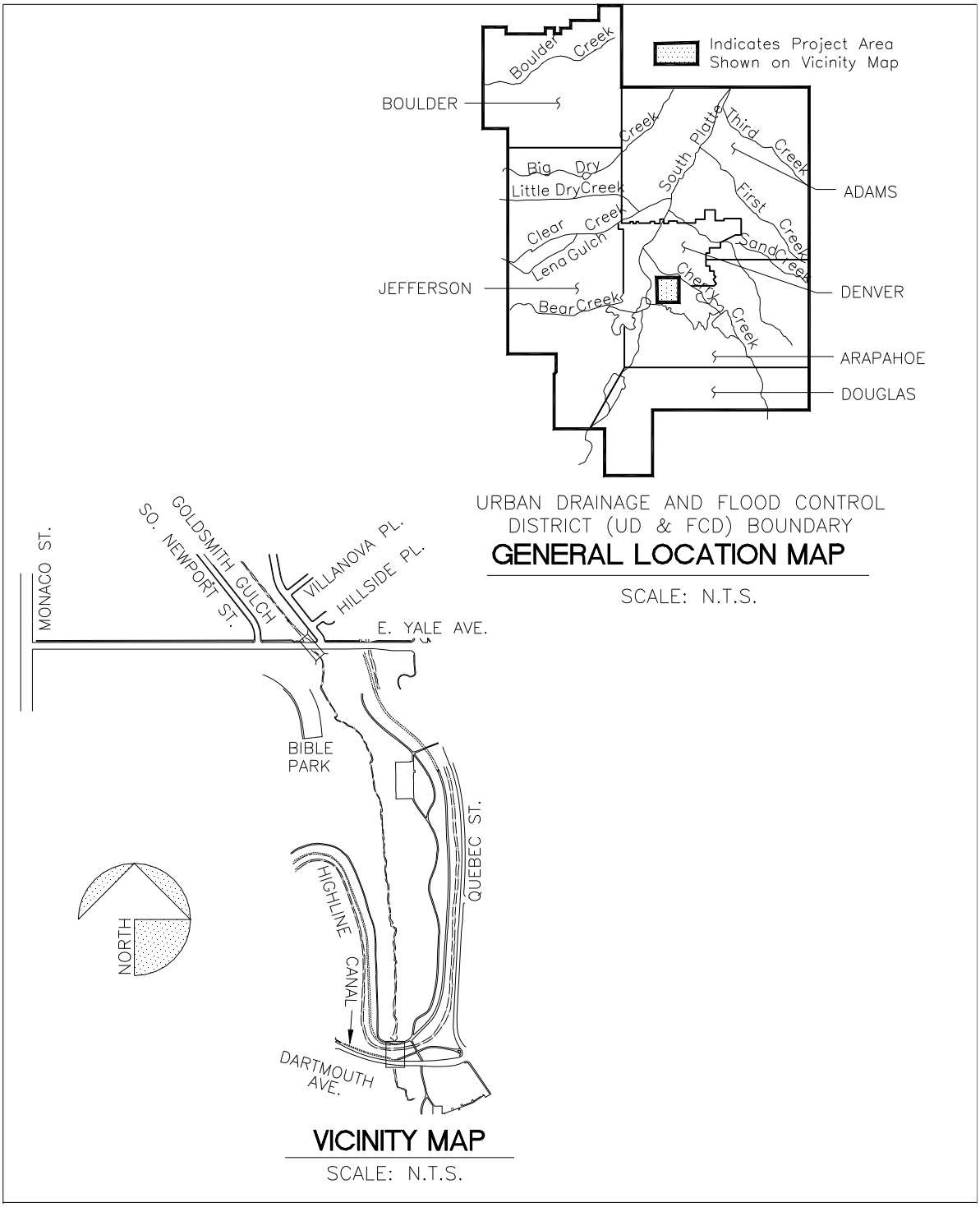

Figure 1—Location and Vicinity Map

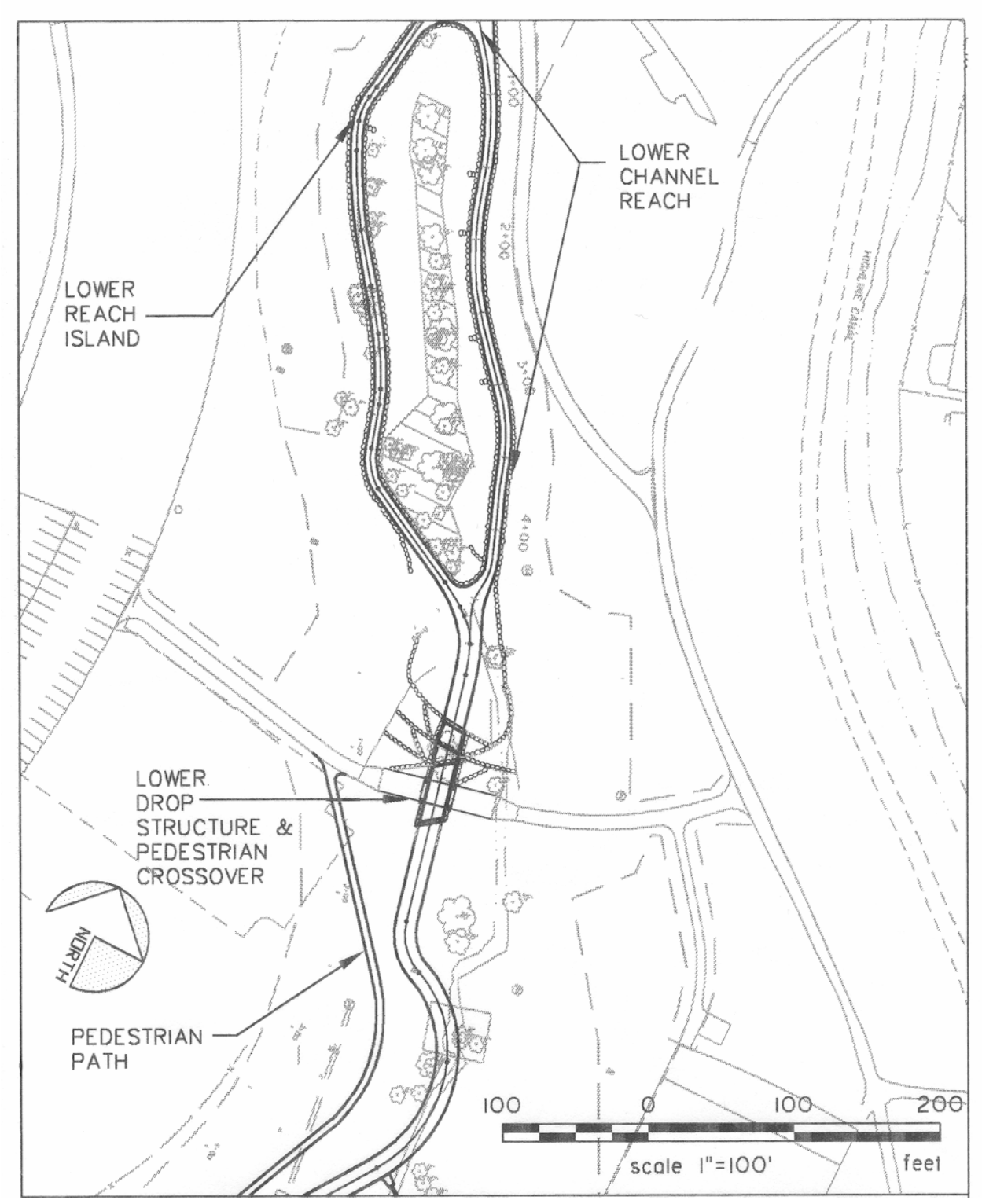

Figure 2—Lower Channel Reach

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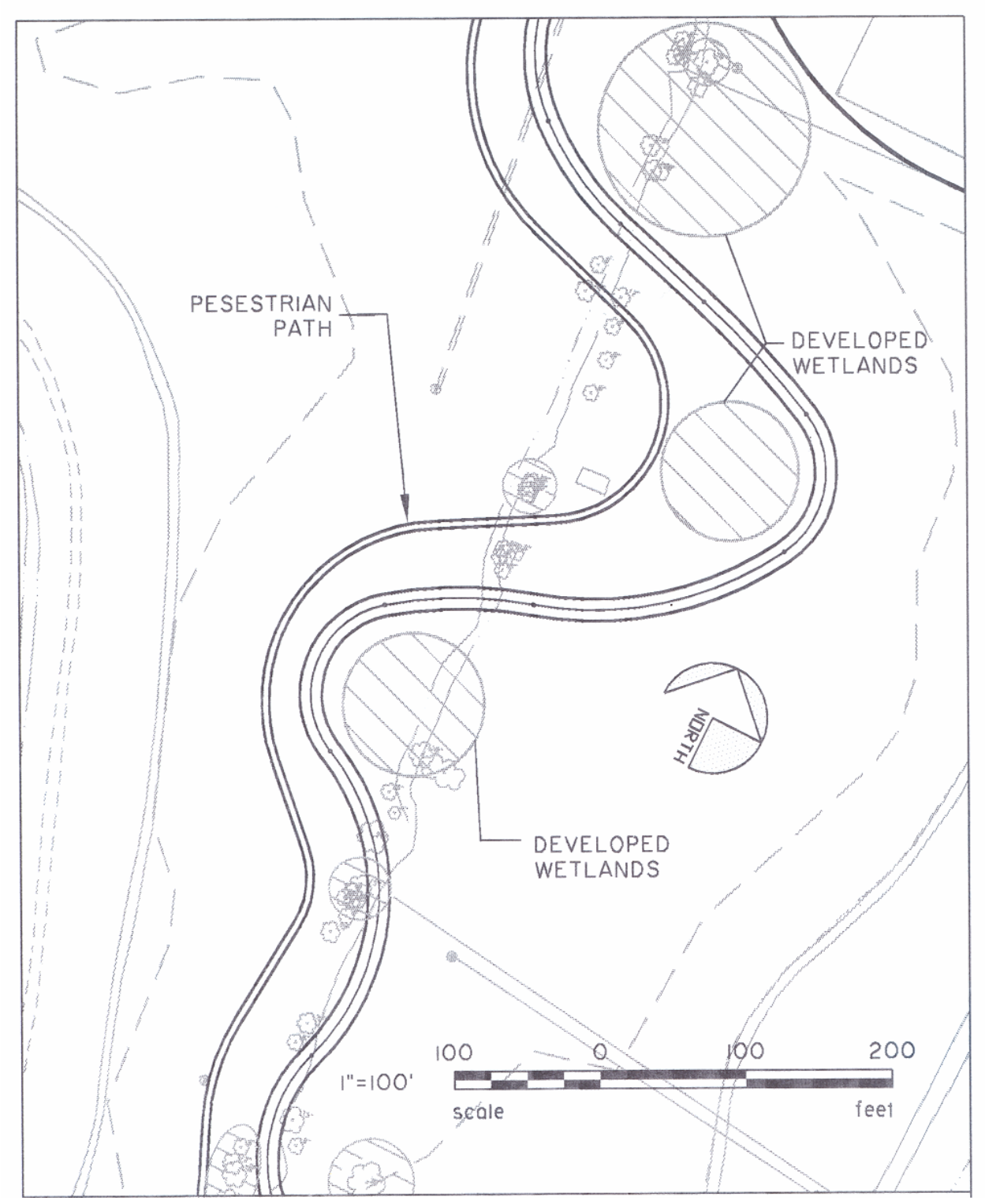

Figure 3—Middle Channel Reach

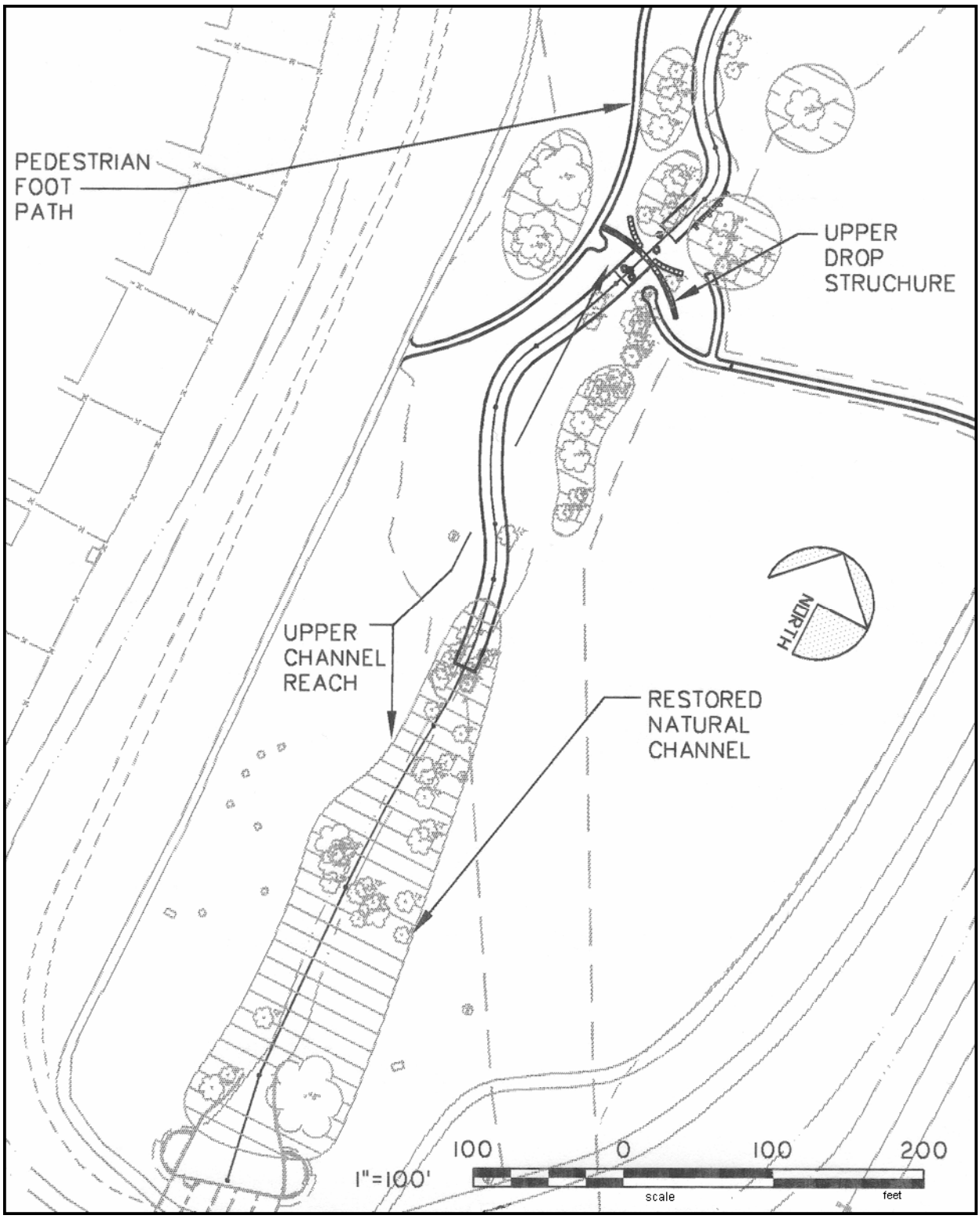

Figure 4—Upper Channel Reach

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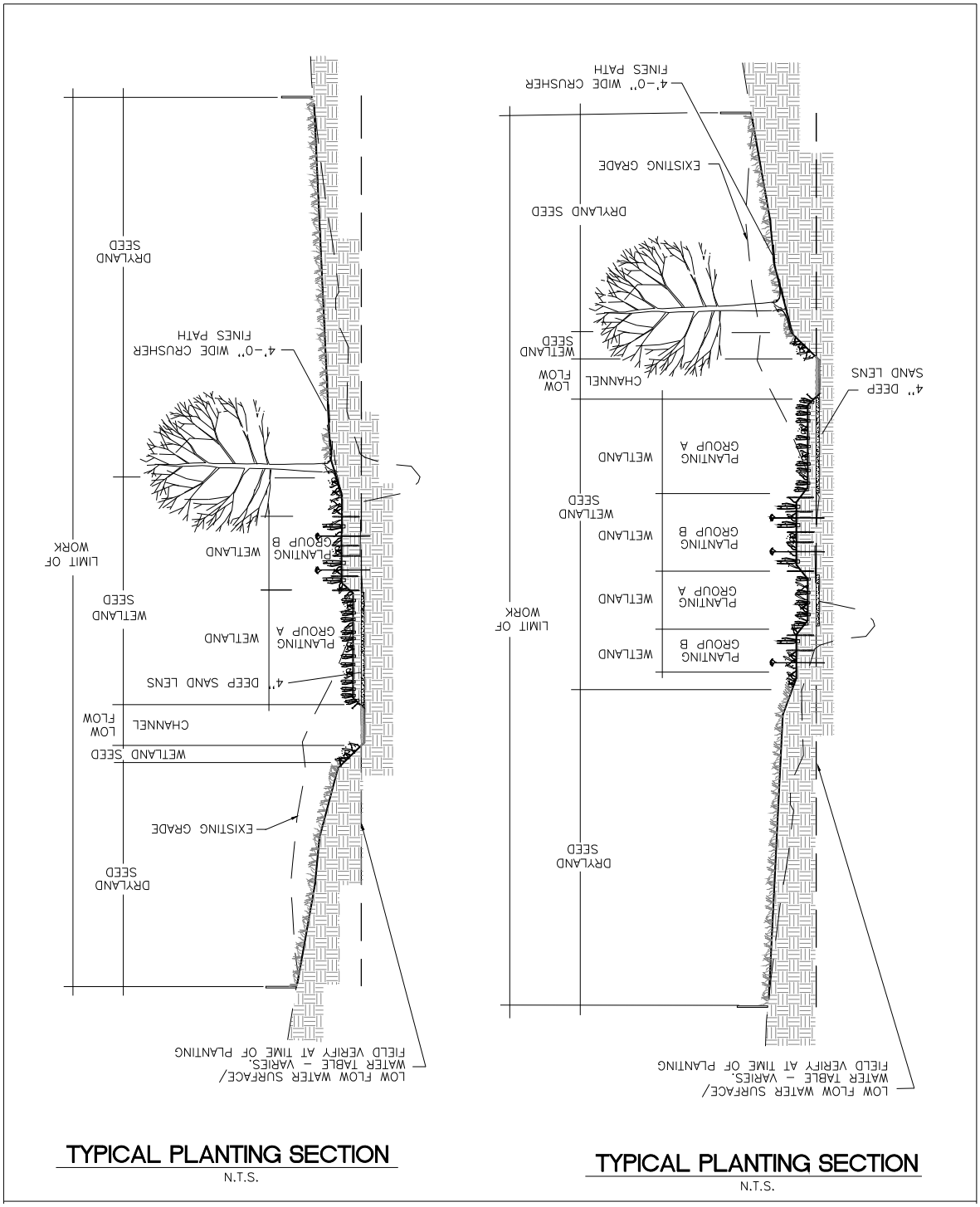

Figure 5—Typical Section for Areas of Wetland Development

DESIGN EXAMPLES—SECTION 7

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7.0 CASE STUDY—GREENWOOD GULCH

Greenwood Gulch, a tributary of Little Dry Creek, flows in a northwesterly direction through Greenwood Village (Figures 1 and 2). The headwater area of Greenwood Gulch is dominated by high density office park developments, the central area by single family residential development and the lower area by a regional park, rural residential lots and a residential golf course development. The Highline Canal transverses the basin near the center of the watershed and intercepts the entire base flow of Greenwood Gulch. The watershed is virtually built-out with little potential for additional infill development.

Table 1—Greenwood Gulch Hydrology

Condition	Flow at Holly Street
Base Flow	
winter	2 cfs
summer	5 cfs
2-year Storm	830 cfs
10-year Storm	1200 cfs
50-year Storm	1620 cfs
100-year Storm	1750 cfs

The urbanization of the watershed has changed Greenwood Gulch from an intermittent stream to a perennial stream with an average wintertime base flow of approximately 2 cfs and an average summertime base flow of approximately 5 cfs. Stormwater flows have also increased substantially over predevelopment conditions. The new flow regime has caused significant erosion of the stream channel in the central parts of the watershed.

The increased erosion, in combination with some residential encroachment of the natural floodplain, threatened some private properties between Orchard Avenue and Holly Street (Photo 1). Informal attempts at erosion control by the property owners along Greenwood Gulch proved to be ineffective. The eroded materials tended to be deposited downstream in the vicinity of the Holly Street bridge. The aggradation of the channel and over bank areas at the Holly Street bridge reduced the flood conveyance capacity of the bridge and increased the flood risks for neighboring properties.



Photo 1. Erosion of Residential Properties

The new flow regime initially caused the growth of wetlands in the Greenwood Gulch floodplain between Holly Street and the Highline Canal. A new residential development in this area in the 1990s perceived the wetlands as a valuable asset, avoided encroachment in the floodplain, included wetland symbols in its logo and adopted “The Preserve” as its name. Homes were constructed and occupied alongside the riparian corridor of the 100-year floodplain beginning in the early 1990s. The Greenwood Gulch corridor also contained a heavily used regional trail connecting to the Highline Canal Trail and Greenwood Village’s Perry Preserve Regional Park.

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The changing flow and channel erosion regimes, however, were dynamic and eventually the channel became incised in some places to a depth of approximately 10 feet (Photo 2). This further changed the hydrologic regime by lowering the water table in the floodplain, drying up the riparian wetlands and allowing for the encroachment of noxious weeds. The public voiced significant concern with the erosion damage to the trail and the loss of the wetland habitat.



Photo 2. Loss of Wetland Habitat

7.1 Design

The District, in cooperation with Greenwood Village, initially identified four options in 1996 for controlling erosion in the 1,400-foot reach of Greenwood Gulch from Orchard Avenue to approximately 700 feet upstream of the Holly Street bridge. The local community requested an expansion of the study to control erosion for the entire 2,100-foot reach between Orchard Avenue and Holly Street, restore the lost flood conveyance capacity of the Holly Street bridge, and control the ongoing erosion and loss of wetland habitat in the 2,900-foot reach between Holly Street and the Highline Canal.

Pre-design studies evaluated excavation of aggraded materials to restore the conveyance capacity of the Holly Street Bridge, relocation of the trail beneath the bridge alongside the improved stream channel, placement of six additional low-head drop structures in the floodplain downstream of the Holly Street bridge and placement of one moderate head drop structure (8 feet) in the channel immediately upstream of the Highline Canal. The low-head drop structures downstream of the Holly Street bridge would be designed to span the entire 100-year floodplain (60 to 100 feet wide) to eliminate channel erosion and spread the base flows to restore the wetland hydrology throughout the width of the floodplain. Hydraulic studies were also completed using HEC-RAS computer modeling methods to ensure that the flattened channel grades between drop structures would not increase flood elevations during the 100-year storm event.

The District, after consideration of all the alternatives, decided to participate in the costs for the final design, construction, and maintenance of the Greenwood Village proposal. The District retained the design team of Sellards and Grigg, Inc., Water & Waste Engineering, Inc., and Design Concepts, Inc. to prepare the final design and construction documents.

7.2 Criteria

The design followed the District criteria that were applicable to the aesthetic, recreation and wetland restoration goals of the community.

The final design for the reach between Orchard Avenue and the Holly Street bridge included one 4-foot large boulder drop structure immediately downstream of the Orchard Road bridge and six large boulder 1.5-foot drop structures (Photo 3 and Figures 3 and 4). The inclusion of these drop structures flattened the channel bottom slope to an average of 0.30%. The channel side slopes were regraded to slopes ranging from 2:1 to 3.7:1 and were protected with Type M riprap soil.



Photo 3 Large Boulder Drop Structure

The large boulders (5 to 6 feet diameter) presented the opportunity to minimize the depth of grout required to stabilize the boulders. This improved the design aesthetics without any apparent increase in the costs of construction. The locations and alignments for the drop structures were chosen carefully to encourage the formation of some sinuosity in the alignment of the channel. The placement of the boulders during construction was also carefully managed to bring a natural appearance to the construction. The side slopes were planted with a mixture of native grasses, shrubs and trees to control side slope erosion and riparian wildlife habitat (Figure 5).

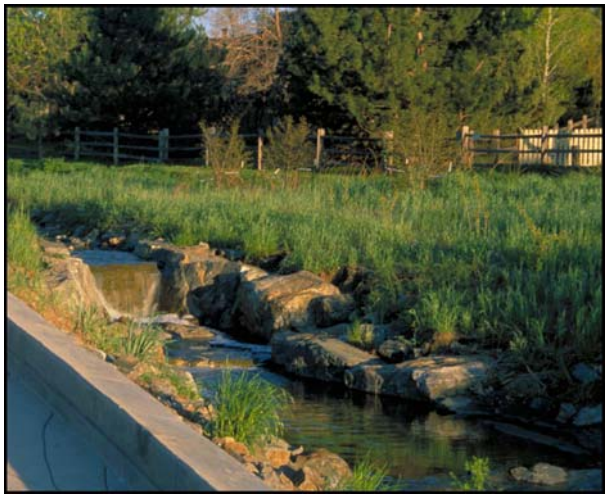

Photo 4 Two-Tier Large Boulder Drop Structure



Photo 5 Holly Street Bridge and Riparian Trail

One two-tier large boulder 4.0-foot drop structure was added upstream of the Holly Street bridge to lower the channel bottom to restore the conveyance capacity of the Holly Street bridge (Photo 4 and Figures 3 and 6).

The bridge abutments and an 18-inch gas main crossing the stream channel complicated the relocation of the trail below the Holly Street bridge (Figure 6). The bridge abutments required structural shoring with a 12-inch-thick by 5.2-foot-high concrete wall. The trail was separated from the stream channel by means of a 6-

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foot-high curved wall (Photo 5). In one location, the top of the trail was approximately 2 feet below the channel bottom. A sump pump dewaters the foundation for the trail. The trail is protected with a Type H riprap slope against the trail wall with the opposite protected by Type M riprap soil.

The design for the restoration of the wetland habitat downstream of Holly Street was based on analyses of 1948 to 1995 aerial photographs to document the changing wetland habitat, soil borings, four groundwater monitoring wells, and detailed vegetation surveys. The goal of the design was the restoration and maintenance of approximately 8 acres of wetland habitat between Holly Street and the Highline Canal.

The construction included the excavation of approximately 9,000 cubic yards of sediment deposits (Photo 6). The floodplain was then graded to maintain a "channel" slope of 0.38% to 0.40% between three drop structures constructed with 36-inch minimum dimension boulders (Figure 7). The boulders were carefully placed with strict tolerances (+/-2 inches) for top edge elevations to create a wide (80 to 170 feet) flat-bottomed channel (Figure 8). The drop structures were installed in a curvilinear configuration to minimize their potential visual impact.



Photo 6 Excavation of Accumulated Sediment

This wide and level configuration for the drop structures encouraged surface flows to spread throughout most of the width of the floodplain shortly following construction (Photos 7 and 8). The flat channel slopes control channel erosion and the wide flow path encourages infiltration of base flows and stormwater. In addition, the cutoff walls at each drop structure impede the longitudinal flow of groundwater, causing it to rise closer to the surface. These higher groundwater elevations, combined with the shallow surface



Photo 7 Upstream View toward Holly Street with Lower Drop No.1 in Foreground



Photo 8 Downstream View from Holly Street toward Lower Drops No. 2 and No. 3

flows, combine to create wetland conditions throughout much of the floodplain. The trail was moved to the edge of the floodplain into an upland area (above the 10-year flood elevation wherever possible). This made the trail more usable and reduced the risk of further erosion damage.

Transplanted root pads (minimum 6 square feet by 6 inches deep) were placed in the channel bottom to encourage rapid restoration of the wetland areas. Upland shrubs and trees were planted along the edge of the channel bottom to provide shading and a variety of wildlife habitat (Figure 9). The wetland vegetation spread very quickly, and within the first growing season, a healthy community of wetland plants was established in the designated areas (Photos 9 and 10).

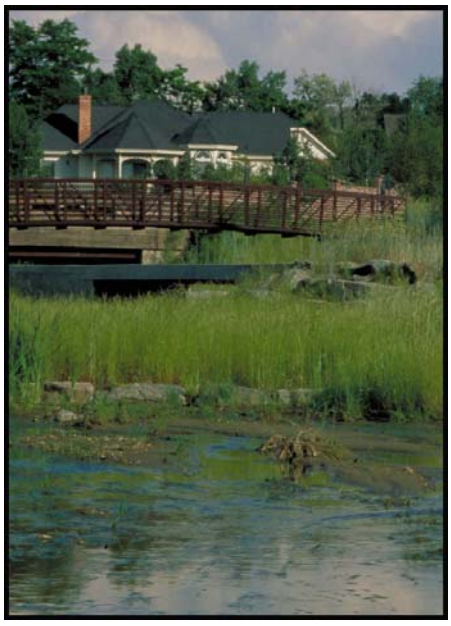

Photo 9 View toward Holly Street and Wetland Area and Lower Drop No. 2

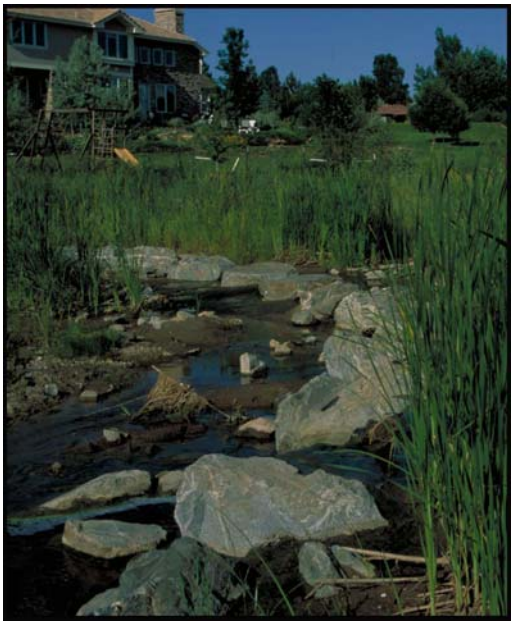

Photo 10 Base Flow over Lower Drop

The design of the lowermost drop structures, immediately upstream of the Highline Canal, presented different challenges. Greenwood Gulch had split into two distinct flow channels. The slopes of the channels were less than 0.5% and a healthy wetland habitat dominated the last 1,100 feet of the Greenwood Gulch floodplain before it discharged into the Highline Canal. Two 8-foot-deep erosion channels, however, had worked their way about 150 feet back from the Highline Canal. If left alone, these erosion channels would likely continue to work their way back upstream and ultimately threaten the nearby wetland areas.

Two large boulder drop structures were constructed approximately 150 feet upstream of the Highline Canal on the two channels (Figure 10 and Photo 11). The same large boulder design concepts used upstream of Holly Street were applied to these lowermost 4-foot-high two-tiered drop structures. Both

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included bridges for pedestrian trail crossings over the split Greenwood Gulch channels.

7.3 Construction

The District awarded the construction contract to Randall & Blake, Inc. in the spring of 1998. The District administered the contract via an intergovernmental agreement with Greenwood Village. The contract was awarded in two phases to accommodate right of way negotiations with homeowners adjacent to the upstream portion of the project. Some delays were encountered during construction due to thunderstorm activity and unforeseen conditions at the Holly Street bridge. The construction sequence was adjusted in the fall of 1998 to accommodate the critical fall planting of vegetation.

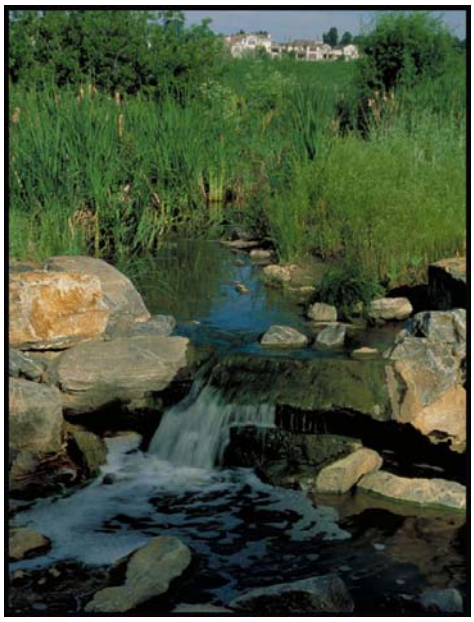

Photo 11 Upstream View of Drop Structure No. 2 from Pedestrian Crossing

7.4 Success

The Greenwood Gulch Channel Improvement Project is a success. The revegetation has been successful and the erosion has been controlled. The damage to private properties from Orchard Road to Holly Street has been stopped and approximately 8 acres of wetland habitat have been restored from Holly Street to the Highline Canal. The trail from Orchard Road to the Highline Canal is one of the most heavily used trails in the Greenwood Village trail system. The large boulder drop structures are visual amenities and the riffle/pool flow patterns in the narrow channel upstream of Holly have improved the wildlife habitat of the riparian corridor. The wetlands below Holly Street also improve the urban wildlife habitat and are an amenity for enjoyment by the users of the trail. The entire project has enhanced the property values for the area and has received ongoing support from the local community.

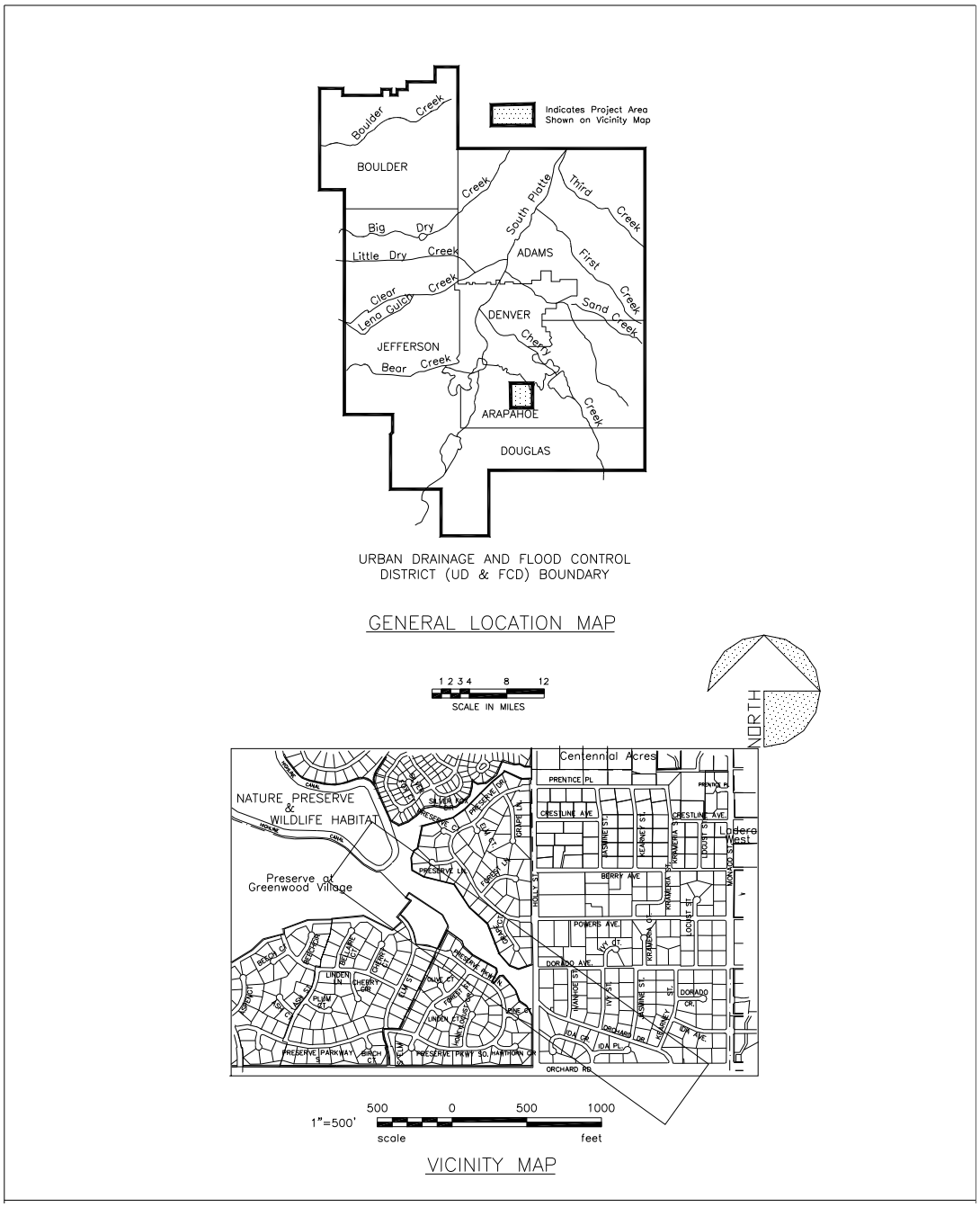

Figure 1—Location and Vicinity Maps

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Figure 2—Urbanization of Greenwood Gulch

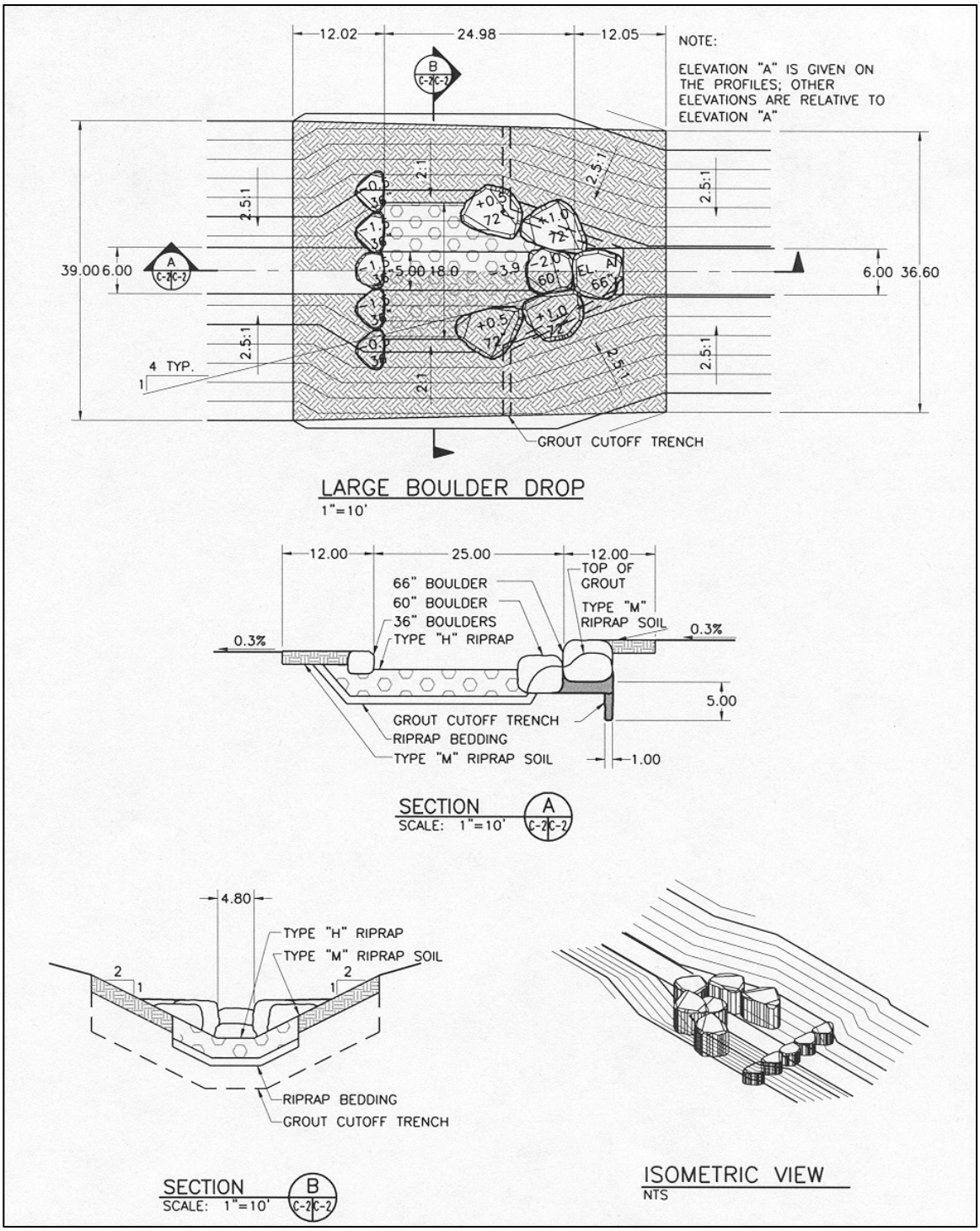

Figure 3—Large Boulder Drop Structure

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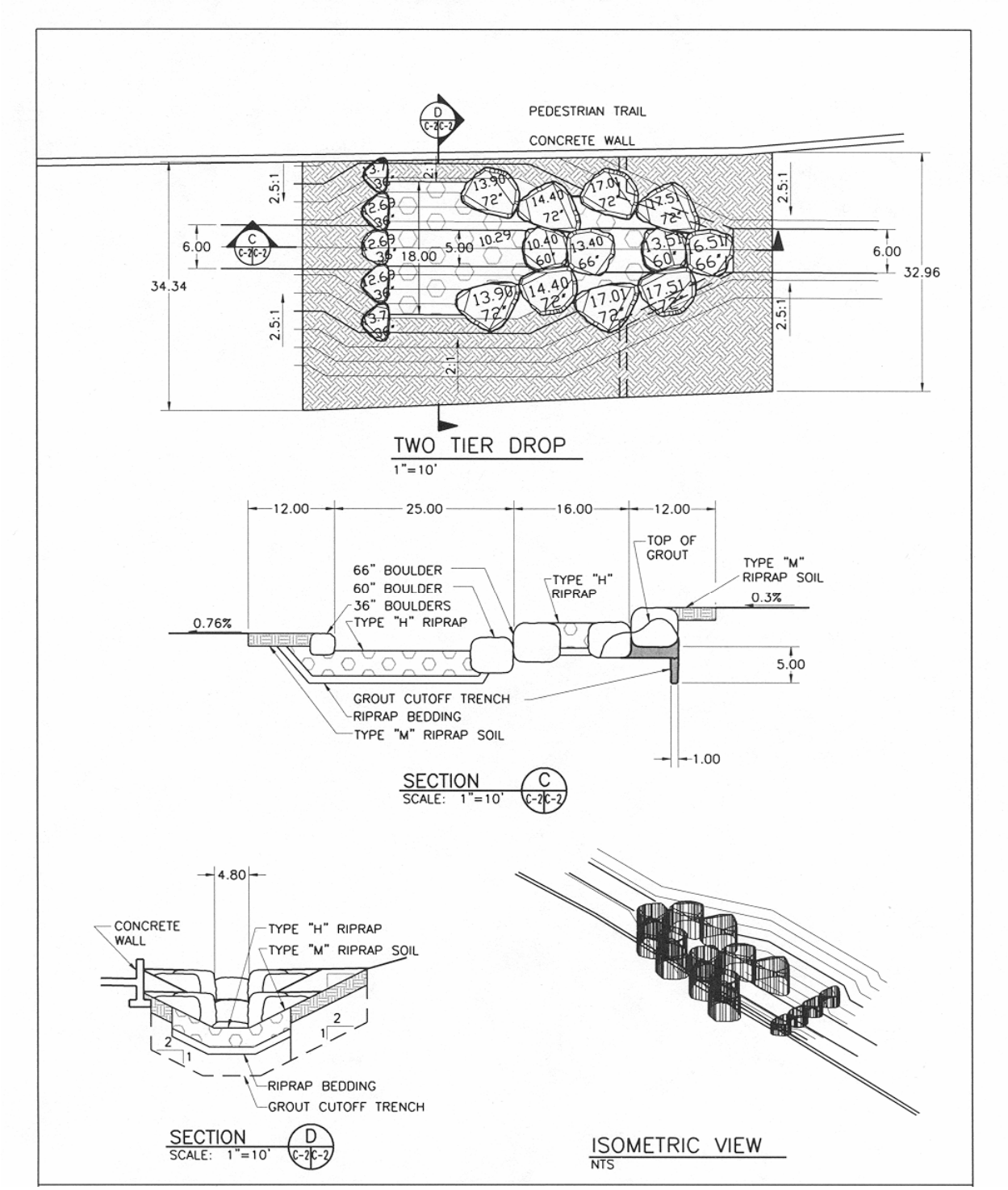

Figure 4—Large Boulder Drop Structure

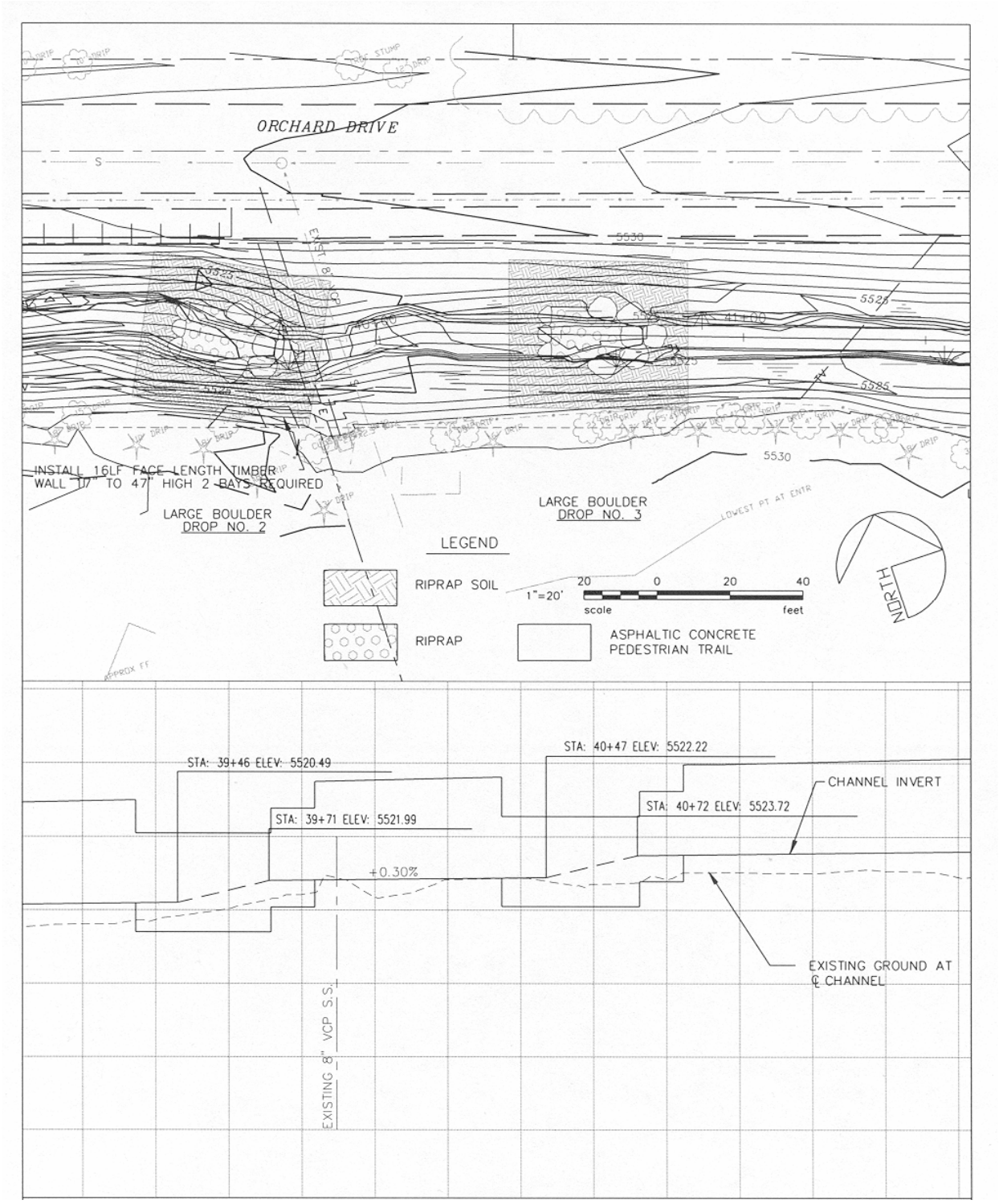

Figure 5—Plan and Profile Upstream of Holly Street

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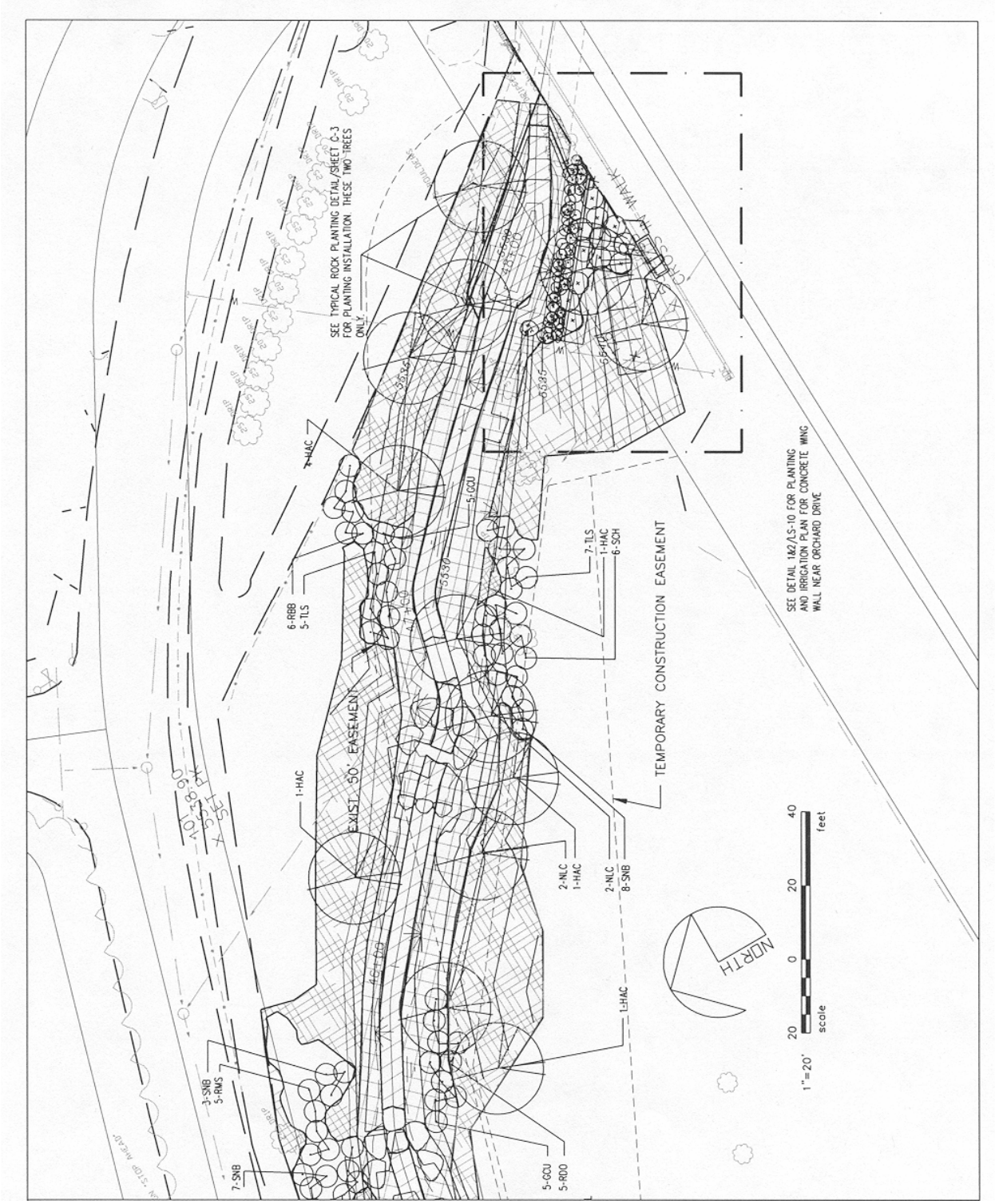

Figure 6—Landscape Plan Upstream of Holly Street

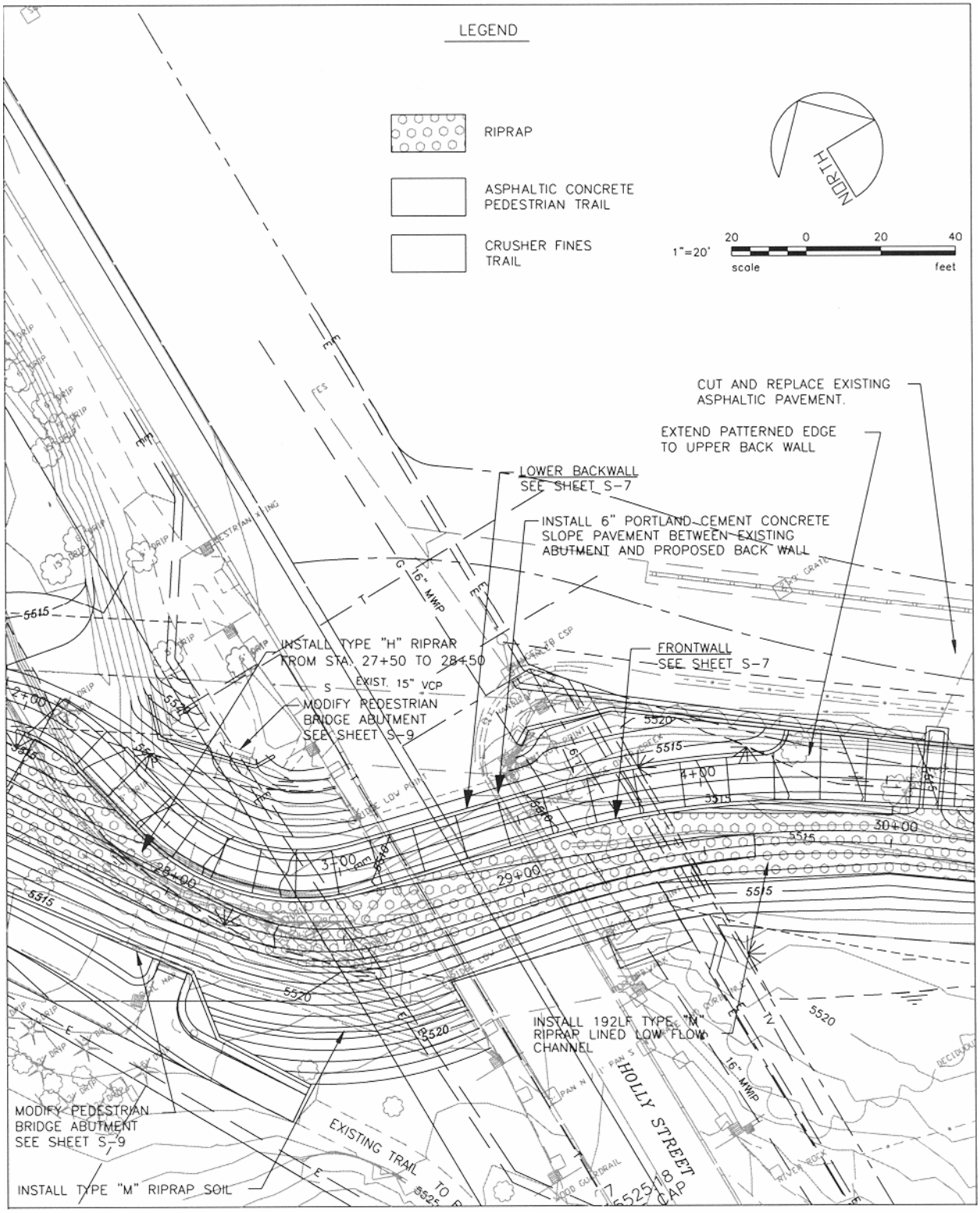

Figure 7—Holly Street Bridge

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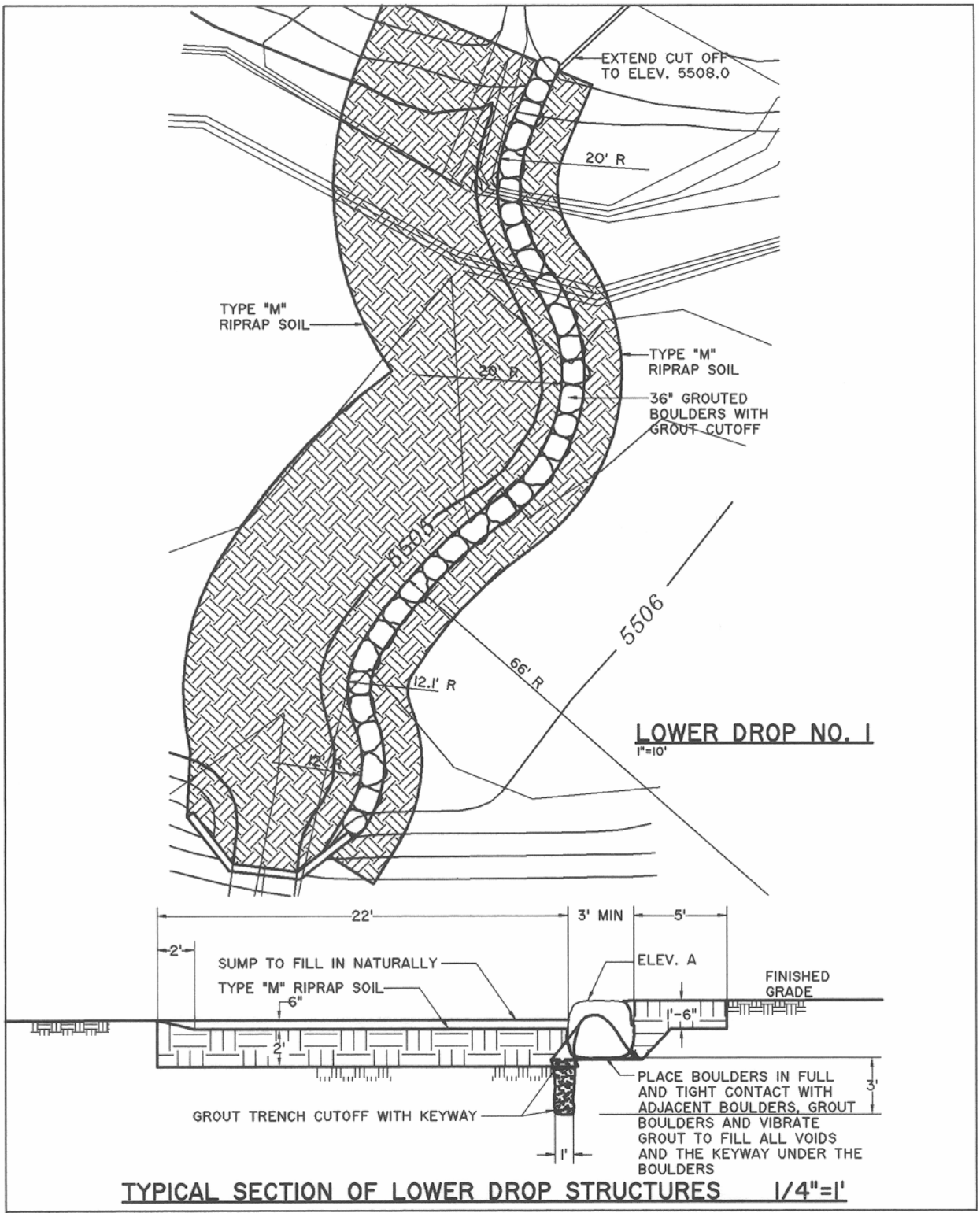

Figure 8—Lower Drop Structure Downstream of Holly Street

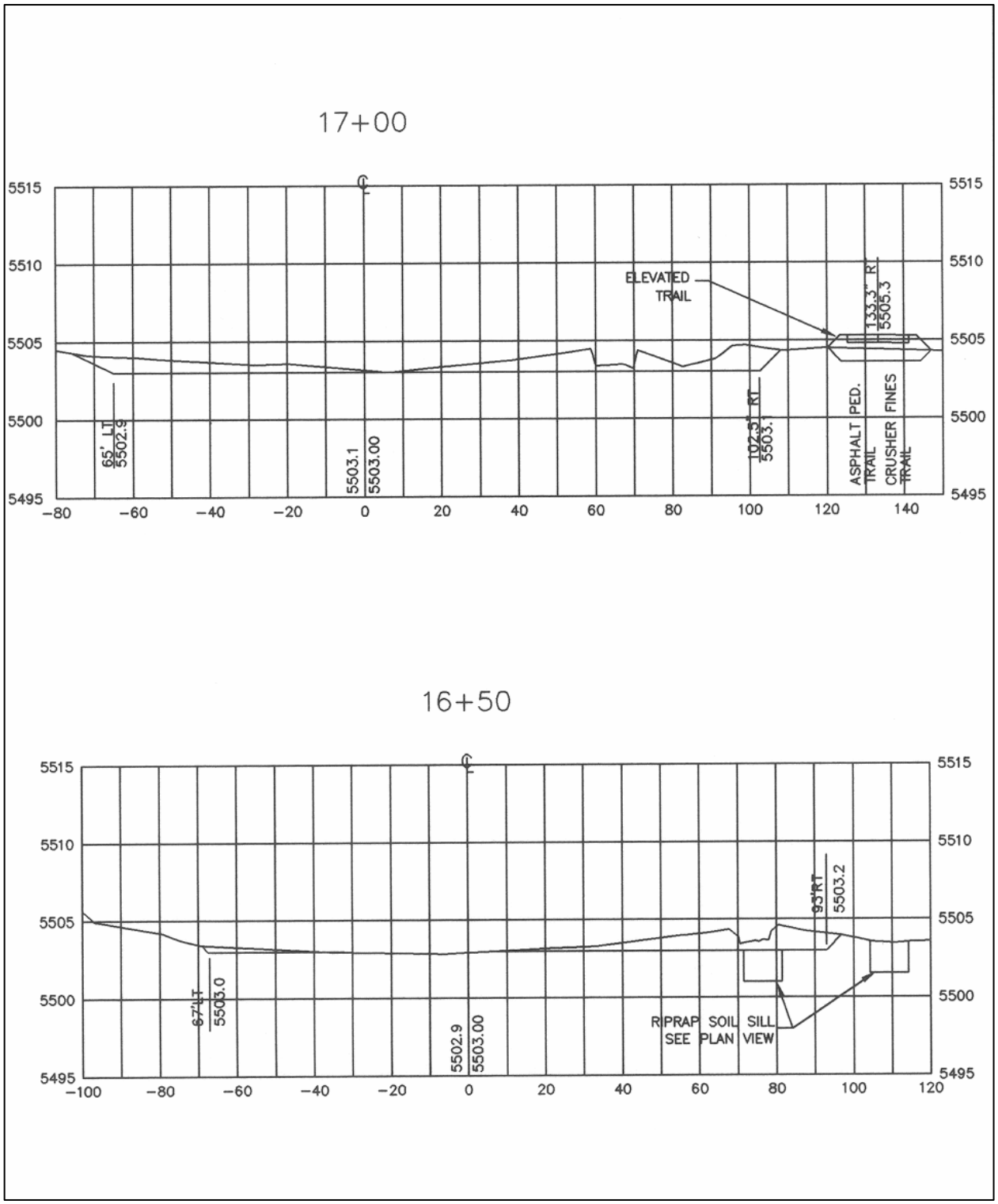

Figure 9—Downstream of Holly Street Channel Cross Sections

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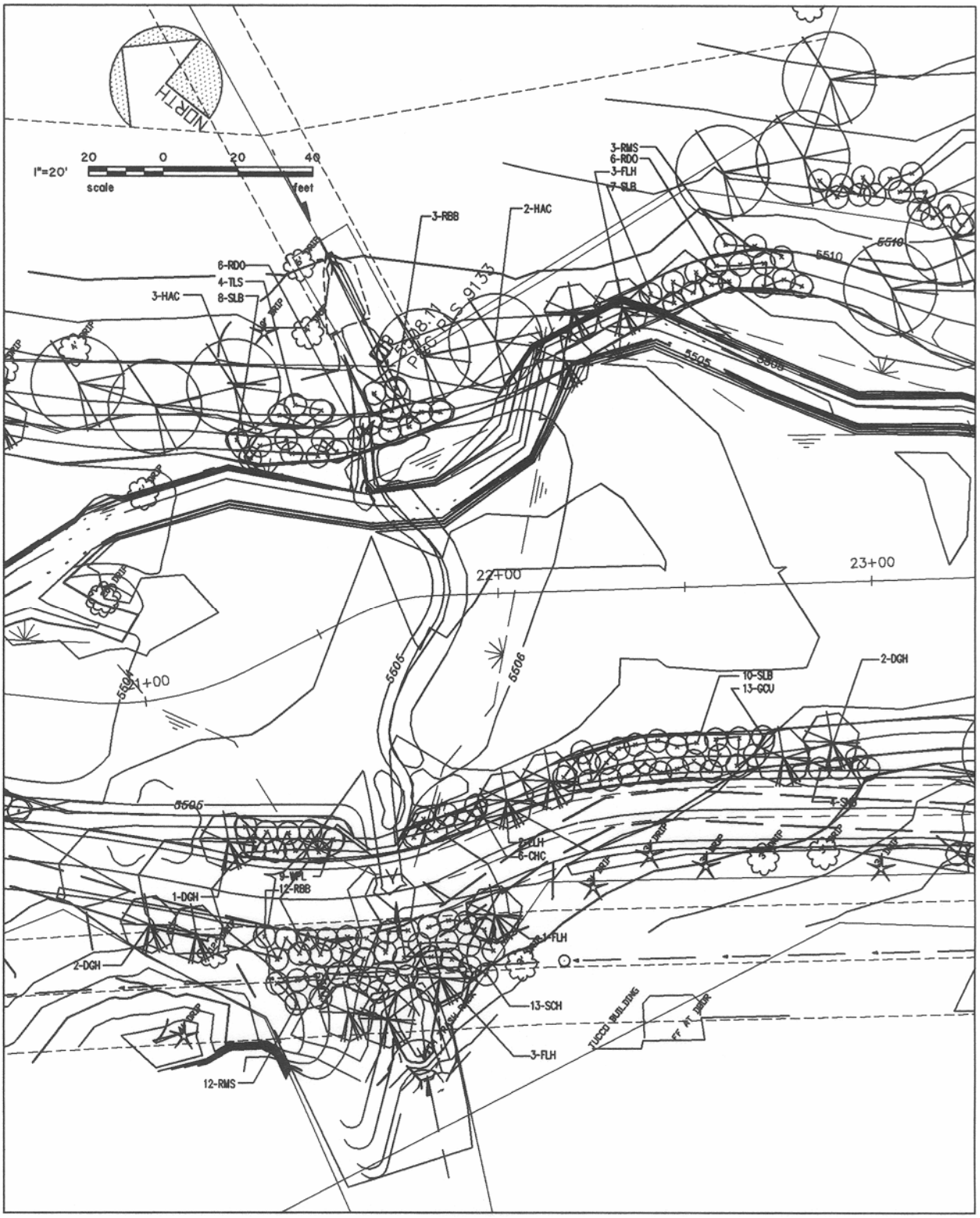

Figure 10—Landscape Plan Downstream of Holly Street

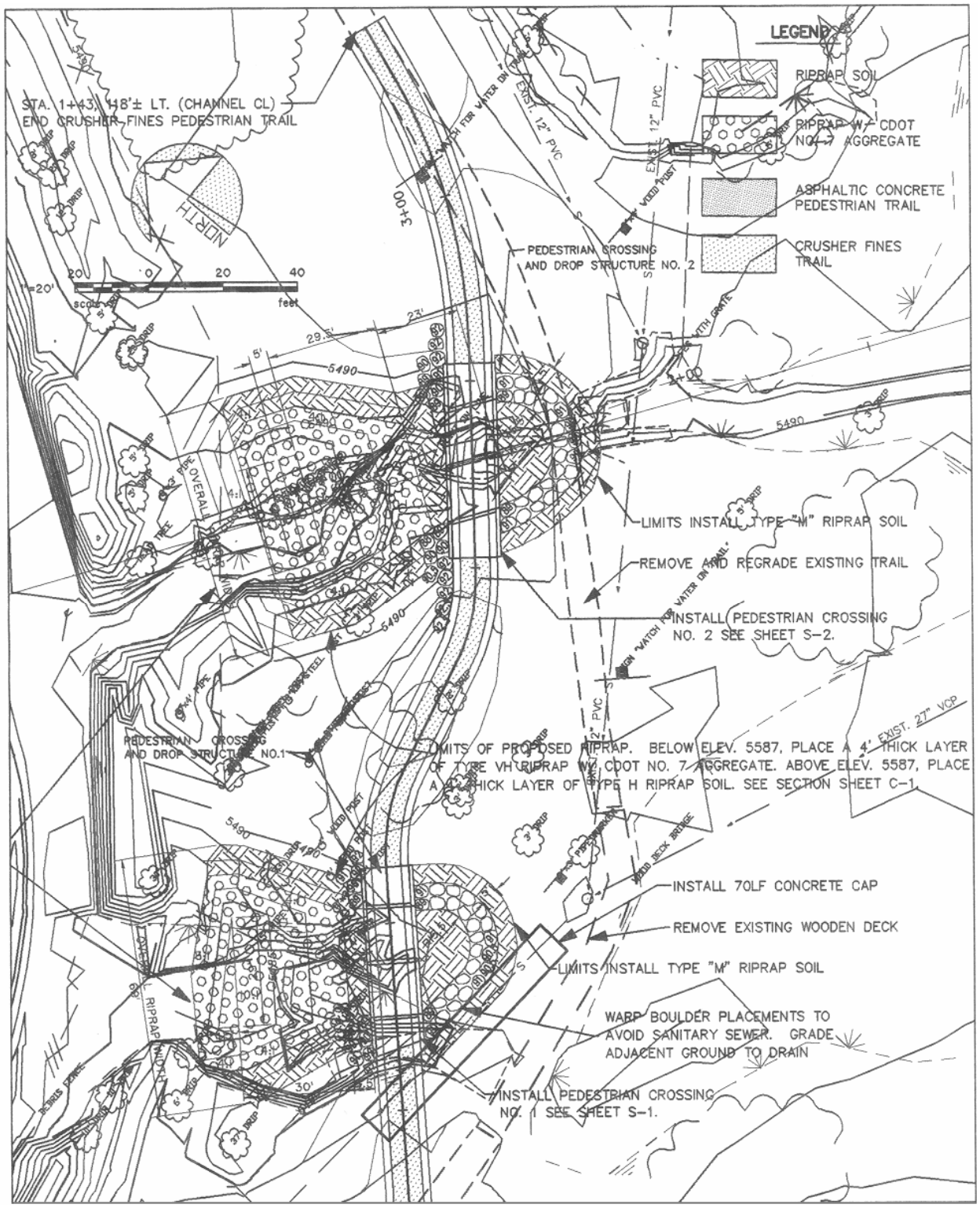

Figure 11—Large Boulder Drop Above Highline Canal

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DESIGN EXAMPLES—SECTION 8

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8.0 CASE STUDY—LENA GULCH DROP STRUCTURE

8.1 Background

Lena Gulch is a major drainageway that flows through Jefferson County in Colorado. The drainage basin area is approximately 13.9 square miles and is almost completely developed. At one point, Lena Gulch flows into and out of Maple Grove Reservoir, which serves as a water storage facility operated by the Consolidated Mutual Water Company. The water level of the reservoir is controlled by an inflatable fabridam. Downstream of the reservoir, Lena Gulch flows from a flat, wide channel into a steep, narrow dumped-concrete and sheet-pile drop structure, which was severely undercut and in danger of complete failure. Downstream of the drop structure, scour and bank erosion were endangering a home and a pedestrian bridge over Lena Gulch. Because of these safety and drainage concerns, the City of Wheat Ridge requested assistance from the District to replace this structure.



Photo 1.

The existing failing drop structure was situated on a jurisdictional boundary that required the involvement of three different local government sponsors in addition to the District, the City of Lakewood, the City of Wheat Ridge, and the Consolidated Mutual Water Company. The lower end of the drop structure and channel were situated on private property, which required the close involvement of the affected homeowner. The District needed both permanent and temporary construction easements to construct the project, so addressing their needs was critical. The project team interviewed several consultants and chose Taggart Engineering Associates to design the drop structure and channel improvements.

8.2 Design Considerations

Since there were five different participants on the project team, each with their own design considerations and concerns, the initial meetings were critical to the success of the design. Consolidated Mutual Water's concerns were the efficient transportation of water through their property and the removal of some existing ponding just upstream of the failing drop structure. The City of Lakewood, which is responsible for the trail in the area and bridge over the drop structure, was concerned about trail access during construction and placement of the bridge on a new alignment. The City of Wheat Ridge, which

represents the homeowners downstream of the drop, was primarily concerned with reducing the flood hazard to their constituents.

The District had two primary issues that needed to be addressed with the new drop structure. First was the ability of the new drop structure to funnel the 100- year flood from a wide floodplain into a deep, narrow flow. The second was the possibility of failure of the inflatable fabridam upstream at Maple Grove Reservoir. If the fabridam stayed intact during the 100-year flood, the design flow at the drop structure was approximately 1725 cfs. If the fabridam failed in the flood event, the flow downstream increased to approximately 3800 cfs. The project team believed that it was imperative that the new drop structure be designed for the 1725 cfs flow, but be able to handle the 3800 cfs in the event of fabridam failure.

In addition to the local government concerns were the concerns of the homeowners immediately downstream of the failing drop structure. They would have to grant a significant permanent easement in their backyard where the pool of the new drop structure was to be constructed. Their property had been designated as a Backyard Wildlife Habitat, and they were concerned that the disturbance caused by the project would adversely affect this habitat. In order to keep the wildlife habitat designation, the final design would have to replace food-bearing bushes and trees lost during construction, provide habitat for aquatic and terrestrial life, and improve the creek aeration. The property owner was also concerned with the aesthetic aspects of the project since the project would severely impact most of their backyard.

After reviewing several different design alternatives, a final design was chosen that addressed all of the project requirements. A four-stage drop structure was designed which alternatively funnels the water and dissipates energy with an upstream curved, grouted, stacked boulder drop, a deep grouted boulder-lined transition pool, a lower cascade drop, and a lower stilling pool (Figures 1 and 2). The resulting drop structure looked natural, but the size and location of every drop and rock in the waterway and on the banks were strategically sized and placed for flood control and habitat. Below the curved entrance, a sheet pile cutoff wall was installed, and the joints were sealed with a water sensitive expansive product.

Adjacent to the drop structure, an overflow spillway was designed to handle the additional flow in the event of failure of the fabridam. This area was shaped to direct flow back into the main channel at the stilling basin. The spillway was lined with boulders and riprap to prevent scour and vegetated with trees and shrubs.

In addition to the structural components of the drop structure, a number of innovative planting techniques were used to soften the appearance of the rock and provide the required habitat. Adjacent to the main pools of the drop, planted grouted boulders were used (Figure 3). The boulders in these areas were only grouted halfway up the rock's depth, and the remaining depth between the boulders was filled with soil and then planted with native material. Above the main pool areas along the bank, planted riprap was used to provide additional energy dissipation and help anchor the riprap. Below the stilling basin area, a

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variety of plants were selected and installed along the water's edge to provide a food source for the birds and cover for the fish. In addition, a number of trees were planted to provide additional habitat and screening for the affected property owner.

8.3 Construction

L & M Enterprises was awarded the contract for construction of this project. Because of the tight site constraints, coordination with the local governments and the affected homeowner was critical. The contractor was required to provide temporary trail access across the drainageway as much as possible during construction. This was accomplished by constructing a temporary channel crossing upstream of the project area and diverting users along the new alignment. Another challenge during construction was effectively handling the constant base flow of the gulch and the occasional storm event, which severely tested the water control. In addition, L & M worked closely with the homeowner to minimize the impacts during construction and allow as much use of the property as possible.

Construction began in the fall of 1997 and was completed in early 1998. The plant material was installed shortly after construction was completed, but before the wet spring season. The homeowners were happy with the appearance and function of the new drop structure. They took real ownership of the completed project and provided all irrigation and maintenance of the newly installed plants, shrubs, and trees. Since the project has been completed, they have installed additional landscaping and plantings to further enhance their backyard habitat.



Photo 2

8.4 Conclusion

The Lena Gulch Drop Structure Project is a real success story. The project started as a complicated design with multiple concerns to address, and finished as an award-winning project with which all project participants are very pleased. It has been several years since the project has been completed, and in that time, it has seen numerous storm events. The drop structure has functioned well, and the revegetation has been established and is thriving (Photos 1 & 2). The homeowner was able to keep the Backyard Wildlife Habitat designation and noted that several species of fish have moved into the pools below the drop structure.

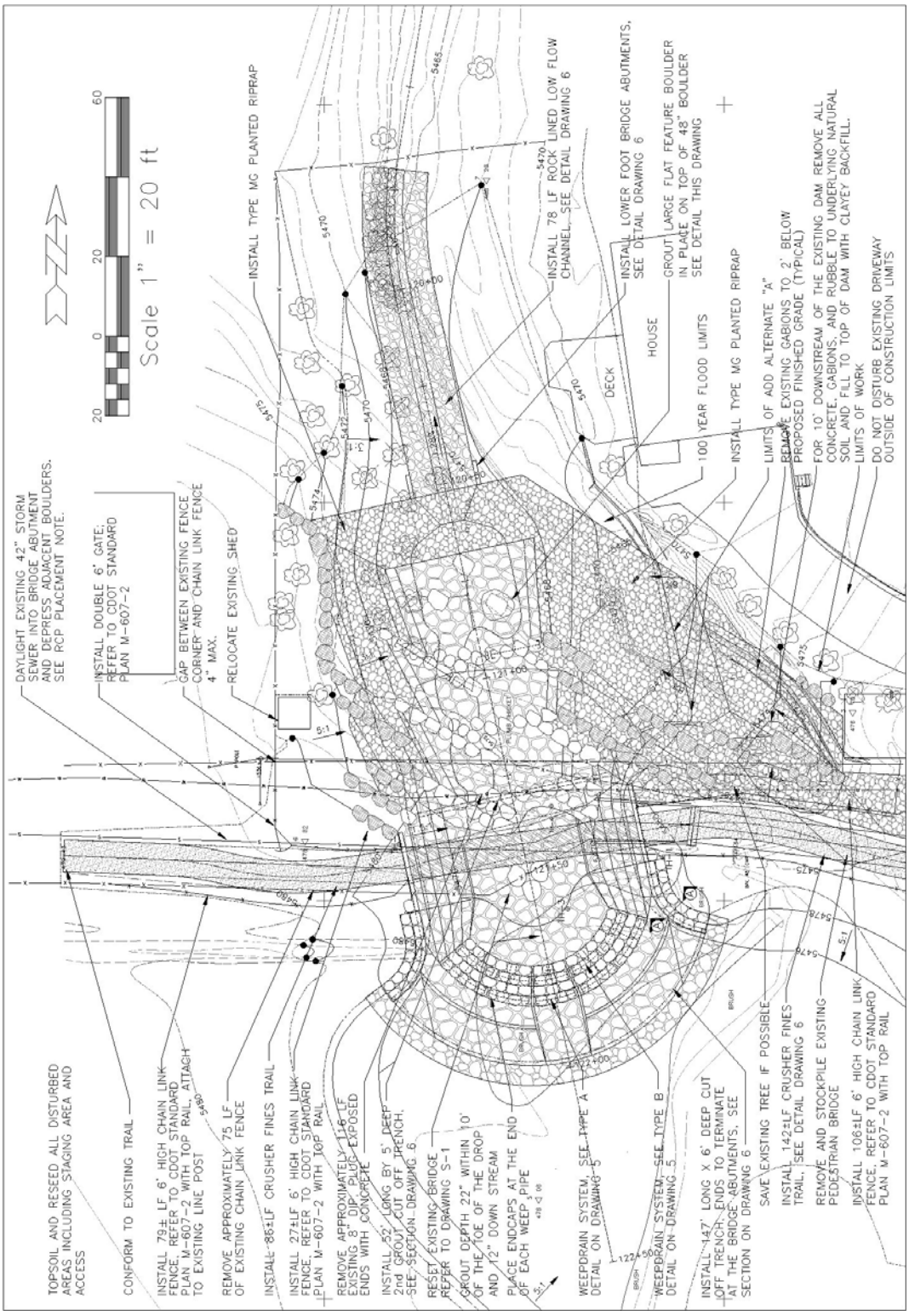

Figure 1—Plan

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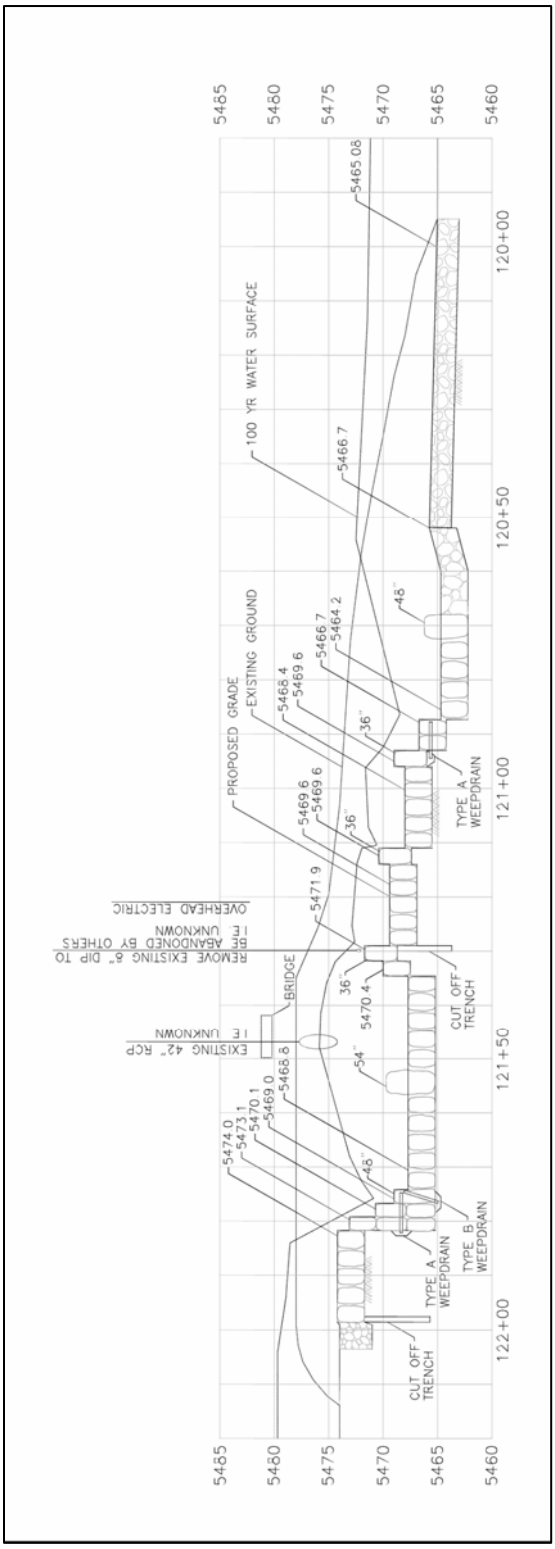

Figure 2—Profile

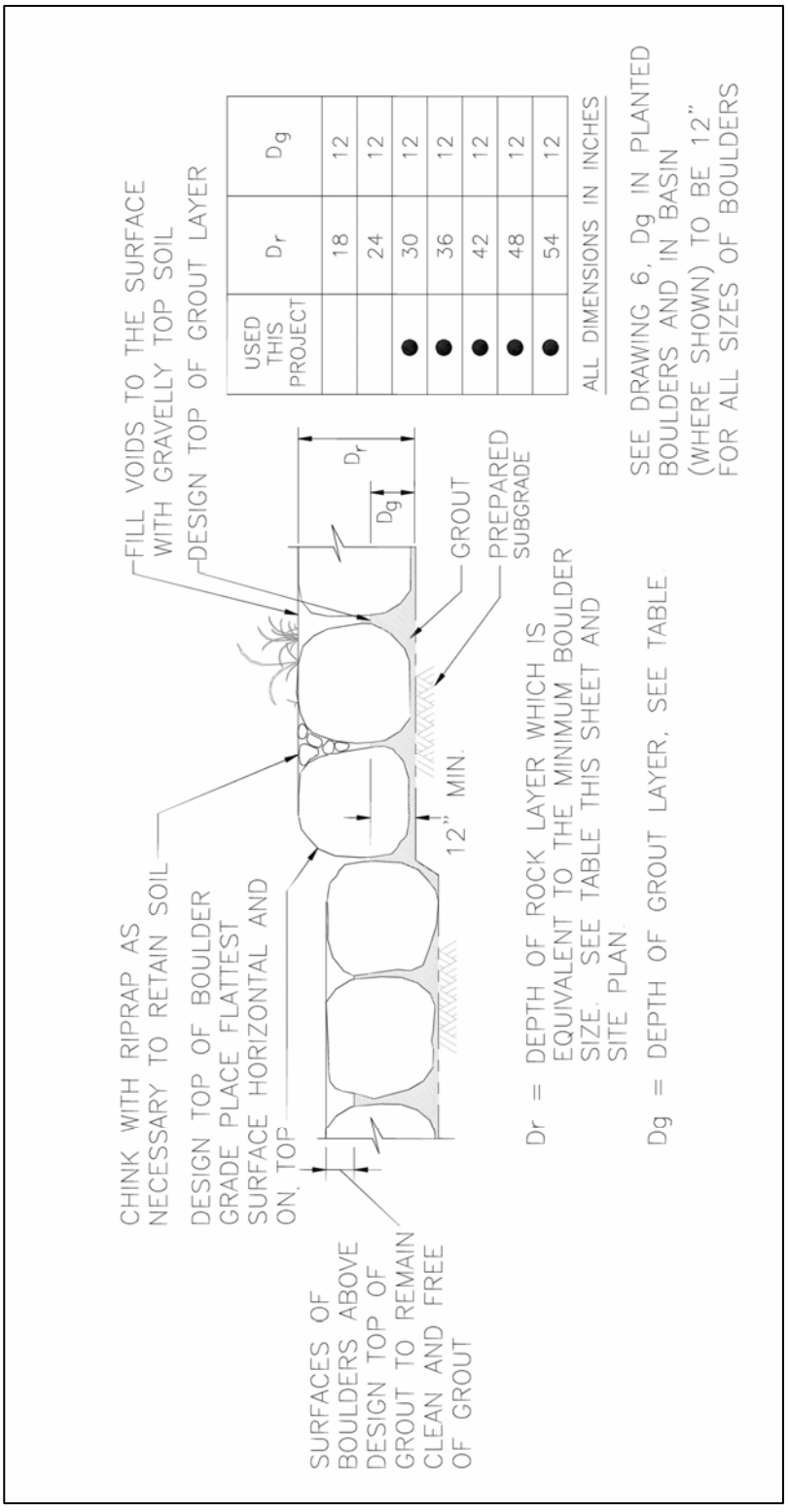

Figure 3—Planted Grouted Boulders

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Table of Contents
Technical Manuals

	Author/Agency/Organization	Title	Date	URL
1	Alameda Countywide Clean Water Program	Protecting Water Quality in Development Projects: A Guidebook of Post-Construction BMP Examples	08/05	http://www.basmaa.org/resources/files/ACCWP_Site_Design_Guidebook_final.pdf
2	Bay Area Stormwater Management Agencies Association (BASMAA)	Start at the Source	1999	http://www.basmaa.org/resources/files/Start%20at%20the%20Source%20%2D%20Design%20Guidance%20Manual%20for%20Stormwater%20Quality%20Protection%2Epdf
3	Bay Area Stormwater Management Agencies Association (BASMAA)	Using Site Design Techniques to Meet Development Standards for Storm Water Quality	05/03	http://www.basmaa.org/resources/files/Using%20Site%20Design%20Techniques%2Epdf
4	Caltrans, State of California Department of Transportation	Stormwater Quality Handbooks: Project Planning and Design Guide, Stormwater Pollution Prevention Plan (SWPPP)	9/02	www.dot.ca.gov/hq/oppd/stormwtr/PPDG-with-revisions-7-26-05.pdf
5	Integrated Land Management, Inc.	Green Technology: The Delaware Urban Runoff Management Approach	01/04	http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/DURMM_TechnicalManual_01-04.pdf
6	New York State	New York State Stormwater Management Design Manual	10/01	
7	Prince George's County, Maryland, Department of Environmental Resources Programs and Planning Division	Low-Impact Development Hydrologic Analysis	07/99	http://www.epa.gov/owow/nps/lid_hydr.pdf
8	Puget Sound Action Team / Washington State University Pierce County Extension	Low Impact Development: Technical Guidance Manual for Puget Sound	01/05	http://www.psat.wa.gov/Publications/LID_tech_manual05/LID_manual2005.pdf
9	Puget Sound Action Team and CH2M Hill	Technical Memorandum No. 1: Review of Low-Impact Development Techniques	1/16/04	http://www.psat.wa.gov/Programs/LID/LID_tech.htm
10	Puget Sound Action Team and CH2M Hill	Technical Memorandum No. 2: Analysis and Recommendations for the Use of LID Techniques in Puget Sound	1/16/04	http://www.psat.wa.gov/Programs/LID/LID_tech.htm
11	Puget Sound Action Team and CH2M Hill	Technical Memorandum No. 3: Suggested Adaptations to BMPs in the Washington Stormwater Management Manual to Include Benefits of LID Techniques	1/16/04	http://www.psat.wa.gov/Programs/LID/PSAT_TechMemo3.pdf
12	Texas Water Development Board	The Texas Manual on Rainwater Harvesting	2005	http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf
13	Urban Drainage and Flood Control District of Denver, Colorado	Urban Storm Drainage Criteria Manual		www.udfcd.org/downloads/down_critmanual.htm
14	Watershed Protection Techniques	Better Site Design	01/00	

Protecting Water Quality in Development Projects

A Guidebook of Post-Construction BMP Examples



Alameda Countywide
Clean Water Program
A Consortium of Local Agencies

August 2005

SARB_009446



Alameda Countywide
Clean Water Program
A Consortium of Local Agencies

Protecting Water Quality in Development Projects

A Guidebook of Post Construction BMP Examples

Prepared by:
EOA, Inc.

August 2005

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Alameda Countywide
Clean Water Program
A Consortium of Local Agencies

CREDITS

This document was prepared by the Alameda Countywide Clean Water Program (ACCWP) for use by ACCWP municipalities, other local agencies, and the land development community. ACCWP expresses its appreciation to all those who contributed to this document.

This document was developed under the guidance of the New Development Subcommittee. We appreciate the comments, suggestions, and guidance provided by the participating Subcommittee members.

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EOA, Inc., as the NPDES permit compliance consultant to ACCWP, compiled all the project information, provided project descriptions and photographs of BMPs where needed, and coordinated the overall preparation of this document.

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Acronyms and Abbreviations

AC Transit	Alameda-Contra Costa Transit District
ADA	Americans with Disabilities Act
ACCWP	Alameda Countywide Clean Water Program
BART	Bay Area Rapid Transit
BASMAA	Bay Area Stormwater Management Agencies Association
CO	Commercial
DCIA	Directly Connected Impervious Area
MF	Multi-Family Residences
MU	Mixed Use Residential/Commercial
NPDES	National Pollutant Discharge Elimination System
PA	Public Areas
SF	Single Family Residences
Water Board	San Francisco Bay Regional Water Quality Control Board

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Post-Construction BMP Examples

SECTION I

Introduction

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BACKGROUND

In February 2003, the San Francisco Bay Regional Water Quality Control Board (Water Board) adopted Order R2-2003-0021 reissuing the Alameda Countywide Clean Water Program's (ACCWP's) NPDES municipal stormwater Permit to include new requirements (New and Redevelopment Requirements) in Provision C.3. For more information on permit requirements, see the ACCWP *C.3. Stormwater Handbook*.

This Guidebook has been created as part of the effort to encourage the use of site design measures that benefit water quality in project designs. It is intended to serve as a reference during the conceptual design and review stage and to be used by both project applicants and municipal staff. This document provides examples of innovative site design elements in the Alameda County.

SITE PLANNING CONCEPTS

Site design measures integrate basic stormwater management and hydrologic concepts into site planning to create developments that mitigate their impact on stormwater quality. Examples include working with the natural topography of a site, clustering the development on the least sensitive portions of a site while protecting sensitive areas, and using design techniques to minimize impervious surface area and infiltrate runoff. This document presents examples of site designs that incorporate the following approaches.

Protect Sensitive Areas from Encroachment

This concept includes such techniques as ensuring adequate protective setbacks from creeks, wetlands, and riparian areas; preserving significant trees and native or significant vegetation to protect soil structure, increase soil permeability and reduce the volume and velocity of rainwater runoff; and avoiding construction on and disturbance of erosive soils and slopes, such as steep or large continuous slopes, soils high in silt or fine sand, or soils lacking vegetative cover.

Minimize Impervious Surface Area

❖ *Street and right-of-way widths*

Streets make up about 25% of a development's total land area, and street pavement makes the largest contribution to a site's impervious land coverage. Designing streets with less surface area by reducing widths, incorporating parking pullouts, or using permeable pavements for low use or parking areas can protect water quality while preserving the street's primary function. (BASMAA, 1999)

Fire department requirements for minimum street widths and cul-de-sac radii can conflict with better site design goals. In addition, street and parking areas need to be designed to withstand the impacts of heavy load vehicles (e.g., fire, garbage and delivery trucks). For

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these reasons, the fire department should be included in the development of design standards to ensure safety while allowing measures such as narrow streets, alternative turnarounds, and permeable pavement such as turf block.

❖ *Cluster or infill development*

Clustering high density development on a portion of the site while preserving high quality open space elsewhere on the site can improve overall watershed health. Although the densely developed area has a high percentage of impervious land coverage, the total impervious area is reduced and land disturbance is minimized. (BASMAA, 1999)

❖ *Parking lots*

Parking lots make up a large portion of land use and are constructed mostly of impervious pavement. Some municipal zoning codes and standards mandate that parking areas exceed the usual parking demand. (BASMAA, 1999) In order to provide adequate but not excessive parking supply, site design features such as overflow parking and landscaped reserve areas can be used. Also, curb cuts allowing drainage into swales and landscaping, trees, and permeable pavement materials can be installed in order to reduce and treat parking lot runoff.

Use Drainage as a Design Element

Landscaping combined with site engineering (grading and drainage) can improve stormwater quality. Runoff draining to landscaping can to be filtered by biota and infiltrated into the soil. Site design features that can be included are areas that drain to a detention basin; streets and parking lots draining to vegetated and rocky swales, biofilters (vegetated channels), vegetated cul-de-sacs or turnarounds; and roof downspouts that drain to landscaping ("disconnected downspouts"). Disconnecting impervious surface areas (i.e., allowing runoff to drain to pervious surfaces in between impervious surfaces) reduces the velocity and amount of water, lowers downstream peak flows and reduces flood and erosion potential.

Promote Alternatives to Automobiles

Automobiles are a major source of water pollution. Designing sites that promote a variety of transportation alternatives has the potential to reduce automobile trips. Design examples are provided that promote bicycling, walking, carpooling, and mass transit.

ADDITIONAL RESOURCES

For more detailed descriptions and guidelines on these topics, refer to the Bay Area Stormwater Management Agencies Association's (BASMAA's) *Start at the Source Manual* (1999) and its companion document *Using Site Design Techniques to Meet Development Standards for Stormwater Quality* (2003) (available at the Program's website www.basmaa.org). Of substantial benefit to project proponents, using site design techniques to help meet the requirements of Provision C.3. can also result in fewer or

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smaller-sized treatment controls required and a corresponding savings in the operation and maintenance costs over the life of the project. Additional information regarding stormwater quality-friendly site designs is available on the ACCWP's website (www.cleanwater.org) and in the ACCWP's *C.3. Stormwater Handbook*.

CONTENTS OF MANUAL

This document provides examples of local site design measures that control storm water quality impacts. The examples are organized into Sections II through VII, based on type of development. For each site, the design examples provide the location, features with pictures, cost information and lessons learned (where available), and contact information. Contacts were asked for additional information including construction and maintenance costs and considerations, project size and completion date. This information is provided where available.

Section I contains the background and introduction to the Alameda Countywide Clean Water Program's Guidebook of Post-Construction BMP Examples.

Section II focuses on single-family residences, where many site design techniques can be integrated for maximum effectiveness.

Section III focuses on multi-family residences. For the purposes of this document, the distinguishing factor between single- and multi- family houses is that, in the latter, the residences share adjoining walls.

Section IV focuses on mixed-use developments, generally high density residential units combined with commercial businesses.

Section V focuses on commercial and industrial developments. This section is divided into campus/industrial parks and other areas. Generally campus/industrial parks are on large sites dedicated for one or more businesses and include common areas that provide opportunities for features that can improve water quality.

Section VI focuses on projects that are on publicly owned and managed land. These include greenbelts, bike paths to parks, and public buildings.

Section VII includes two indices to assist the user in locating: 1) particular site design techniques illustrated in this document; and 2) all the examples within a specific municipality.

REFERENCES

Bay Area Stormwater Management Agencies Association, *Start at the Source*, 1999.

Alameda Countywide Clean Water Program, *C.3. Stormwater Handbook*, 2004.

SECTION II

Single Family Residences

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Bailey Ranch
SF-1

Site Location:

Hayward Boulevard
Hayward, CA
Constructed July 2002

Stormwater Benefits:

- Natural treatment of runoff
- Reduced velocity of flows

Features:

- Detention basin



Stormwater runoff is directed into the detention pond, allowing for settling of sediments and removal of pollutants. This detention basin was built for 56 single family homes and is maintained as part of the Bailey Ranch Home Owners Association.

Lessons Learned:

- The basin should have been designed to not allow standing water beyond 72 hours to prevent mosquito breeding and algae growth.

Municipal Contact:
Jim Lear
City of Hayward
(510) 583-4785

Site Contact:
Walsh Property Management
(510) 888-8965

Ivywood
SF-2

Site Location:

33801-33909 Alvarado-Niles Road
Union City, CA
Constructed 2003

Features:

- Vegetated buffer strip
- Disconnected downspouts (not shown)



This house has a large vegetated buffer strip in front.



The front walkway drains to this vegetated area where the runoff can be treated naturally through the turf grass.

Stormwater Benefits:

- Natural treatment of runoff
- Reduced velocity and volume of runoff
- Reduced directly connected impervious area (DCIA)



The house is surrounded by vegetated areas to allow infiltration and naturally treat the water.

Municipal Contact:
Clean Water Program Coordinator
City of Union City
(510) 675-5360

Dublin Ranch
SF-3

Site Location:

Fallon Road
Dublin, CA

Feature:

- Large vegetated swale with underdrain

Stormwater Benefits:

- Reduced impervious surface area
- Reduced volume and velocity of runoff



This vegetated swale drains runoff from the Dublin Ranch subdivision and roads.



The developers maintained the connectivity of the swale by building bridges over the swale to reach some homes.



This vegetated swale is as large, if not larger, than many detention basins, however it is equipped with an underdrain and therefore should not detain the water during storms.



This swale has an underdrain to allow the swale to drain when there is more flow than can be treated in the swale.

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The houses are built directly adjacent to the swale, allowing runoff to drain from the houses into the swale.



This swale also preserves open space for residents providing an aesthetically pleasing vegetated area.

Municipal Contact:
Saied Aminian
City of Dublin
(925) 833-6632

Bay Cove
SF-4

Site Location:

Bay Farm Island
Alameda, CA

Features:

- Disconnected downspouts
- Permeable pavers



The guest parking area in Bay Cove is made up of ungrouted pavers providing an area for infiltration to occur.



The roof leaders also drain to grassy areas like this, which can naturally treat the runoff.

Stormwater Benefits:

- Reduced impervious surface area
- Reduced directly connected impervious surface area (DCIA)
- Natural treatment of runoff



The permeable parking areas are not as frequently used because they are for guests and therefore do not sustain the load of typical parking areas.



The disconnected roof leaders allow the water to infiltrate into the landscaping.

Municipal Contact:
James Barse
City of Alameda
(510) 749-5840

Lindenwood
SF-5

Site Location:

Taite Lane and Robinson Circle
Livermore, CA
Completed 2004

Features:

- Vegetated swales
- Narrow streets
- Disconnected downspouts (not shown)

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced directly connected impervious area (DCIA)



This swale is composed of rocks and vegetation to naturally treat the runoff.



The homeowners association is responsible for maintenance of this swale.

Lessons Learned:

- Install swales with underdrains to avoid ponding from landscape irrigation runoff during the summer months.
- Promote water "wise irrigation" by discouraging the use of area and "bubble-up" drains.

Municipal Contact:
Steve Aguiar
City of Livermore
(925) 960-8100
smaguiar@ci.livermore.ca.us

Site Contact:
Contact Steve Aguiar for site contact information.

Cedar Boulevard
SF-6

Site Location:

Cedar Boulevard
between Forbes Dr. and Central Ave.
Newark, CA
Constructed January 2002

Features:

- Pop-up drainage emitter
- Vegetated swales



The pop-up drainage emitter discharges roof and rear yard runoff.

Stormwater Benefits:

- Natural treatment of runoff
- Reduced velocity of runoff
- Reduced volume of runoff
- Reduced directly-connected impervious surface area (DCIA)



The runoff flows from the pop-up emitter though the vegetated swale into the storm drain inlet located here.

Lessons Learned:

- Bubble-ups should be located 10 feet from the storm drain to ensure treatment of runoff prior to discharge into the storm drain system.

Municipal Contact:
Michael Carmen
City of Newark
(510) 794-2320
michael.carmen@newark.org

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Civic Terrace Residence
SF-7

Site Location:

5538 Civic Terrace
Newark, CA
Constructed January 2005

Features:

- Disconnected downspouts



The landscaping is beneficial in the area where the runoff flows, but the other areas are not vegetated.

Lessons Learned:

- It may be more aesthetically pleasing to use ½" to 1" diameter rocks for energy dissipation instead of splash blocks, and also to provide a wider distribution of roof runoff within the landscaping.

Stormwater Benefits:

- Reduced directly connected impervious areas (DCIA)
- Natural treatment of runoff
- Reduced velocity of flows



Rooftop runoff drains through downspouts to landscaping for treatment and infiltration.



The downspouts are directed into splash blocks and flow to an area of landscaping.

Municipal Contact:
Michael Carmen
City of Newark
(510) 794-2320
michael.carmen@newark.org

Centex/Five Canyons
SF-8

Site Location:

Gold Creek Avenue
Fairview (Unincorporated Alameda County), CA
Constructed 1995

Features:

- Disconnected downspouts

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff



Rooftop runoff is drained to vegetated areas like this, where it can infiltrate into the subsurface and reduce the velocity and volume of runoff.



Runoff from the rooftop is piped to this bubble-up, which "bubbles" the stormwater up into landscaped areas.



This roof leader bubble-up was placed too close to the sidewalk edge, preventing water from filtering through plants or soil.



Lawn mowers can cause damage to drainage systems.

Lessons Learned:

- Bubble-ups can hold standing water if there is no under drain.
- Bubble-ups can be tricky during maintenance; in this case, some were broken by lawn mowers.
- Some residents decided to replumb the roof leaders to the street through the curb (there were no CC&Rs prohibiting this).
- Some roof leader outfalls were placed too close to the sidewalk edge of the yard and water ends up not filtering through plants or soil.

Municipal Contact:
Diamera Bach
Alameda County
Unincorporated Area
(510) 670-5763
diamera@acpwa.org

Mission Sienna
SF-9

Site Location:

Mission Siena and
Mission Tierra Place
Fremont, CA

Features:

- Disconnected downspouts

Stormwater Benefits:

- Reduced directly connected impervious area (DCIA)



The disconnected downspouts are connected to bubblers that irrigate the landscaping. The bubbler systems are maintained by the homeowners association.



Water flows from the rooftops, down the rain gutters and through a pipe to the bubble-ups, or bubblers, where it is discharged through cobbles before reaching the vegetated areas.

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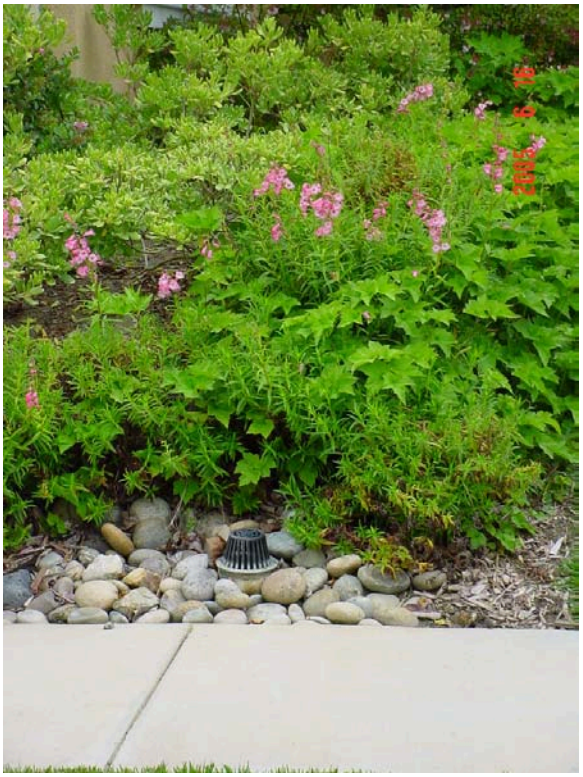

This is a close up of the bubbler, where rooftop runoff is discharged through cobbles which slow the runoff before infiltrating through the vegetation.



Runoff is discharged through a bubbler system that drains through an area of cobbles. The cobbles around the bubbler help prevent erosion and scour around the bubbler.

Municipal Contact:
Shannan Szychowski
City of Fremont
(510) 494-4584
sszychowski@ci.fremont.ca.us

Site Contact:
Mike Meyer
O'Brian Group
2001 Winward Way
San Mateo, CA 94404

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Post-Construction BMP Examples

SECTION III

Multi-Family Residences

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Wisteria Place
MF-1

Site Location:

33801-33909 Alvarado-Niles Road
Union City, CA
Under construction

Features:

- High density (multi-story) senior housing with reduced building footprints
- Disconnected downspouts
- Trash enclosures
- Permeable pavers



The disconnected downspouts discharge rooftop runoff to this vegetated area.

Stormwater Benefits:

- Trash-related pollutant reduction
- Reduced impervious surface area
- Reduced volume of runoff
- Reduced directly connected impervious area (DCIA)



This walkway drains to the vegetation and permeable pavers. The pavers create temporary access to the building and utilities while minimizing impervious surface.



This is an up-close look at the permeable pavers that allow water to seep through the gaps, reducing the amount of impervious surface area.

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This affordable senior housing complex was created as high density, reducing the building footprint.



The room behind the doors is designated as an indoor trash enclosure, which prevents pollutants from the dumpster from entering the storm drain. The dumpster is wheeled out for pick up.



This walkway at the rear of the building drains to landscaped areas, reducing the volume of runoff.

Municipal Contact:
Clean Water Program Coordinator
City of Union City
(510) 675-5360

Site Contact:
Eden Housing
http://www.edenhousing.org

SECTION IV

Mixed Use Residential/Commercial

Gaia Building
MU-1

Site Location:

2180 Allston Way
Berkeley, CA
Completed August 2002

Features:

- High-density (multi-story) housing with reduced building footprints integrated with commercial areas and art space
- Located near mass transit including BART and AC Transit
- Parking lift system
- Garden area on roof



Photograph taken from http://www.panoramicinterests.com/

This multi-story development is located near the Downtown Berkeley BART station and AC Transit routes, promoting alternative transportation

Stormwater Benefits:

- Transportation-related pollutant reduction
- Reduced impervious surface area
- Reduced volume of runoff



This roof area provides a garden setting for residents instead of adding additional impervious area (walkways, etc.) around the building perimeter.



Parking lift systems reduce the impervious surface area by having parking pits with lifts that stack cars while parked, reducing the impervious surface area needed per car.

Note: This photo was taken at MU-6, where the same parking lift system is used.

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Photograph taken from http://www.panoramicinterests.com/

This is photograph of the redevelopment area before the building was completed (June 2000).



Photograph taken from http://www.panoramicinterests.com/

This is a photograph was after the structure was constructed (August 2001).



Rooftop vegetation collects some of the runoff reducing the volume during rain events.

Lessons Learned:

- There are some parking lift systems that do not have approved listings for fire safety. The fire department needs to be involved early on the design phase to carefully determine fire sprinkler requirements for parking pit areas to provide the greatest fire protection.

Municipal Contact:
Nate French
City of Berkeley
(510) 981-7451
nfrench@ci.berkeley.ca.us

Site Contact:
Patrick Kennedy
Panoramic Interests
(510) 883-1000
www.paroramicinterests.com

The Benton
MU-2

Site Location:

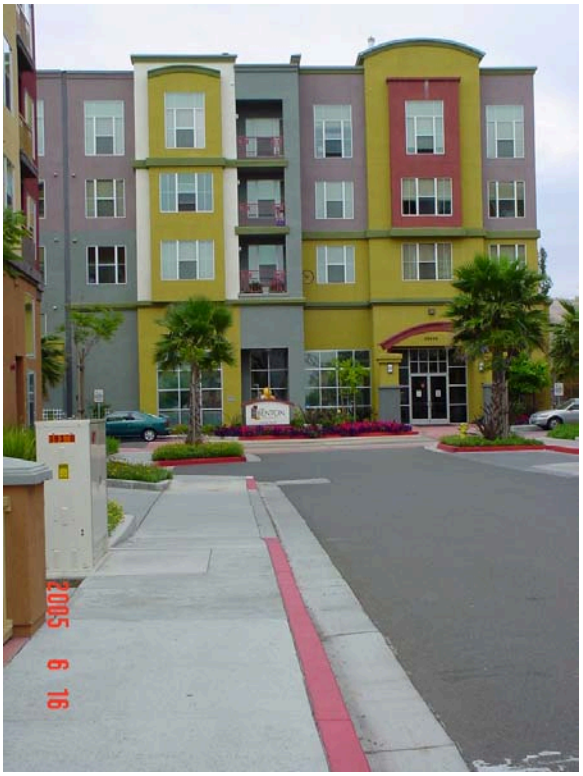
Civic Center Drive
Fremont, CA

Features:

- High density (multi-story) housing with reduced building footprints integrated with commercial areas
- Located near mass transit including BART
- Underground parking

Stormwater Benefits:

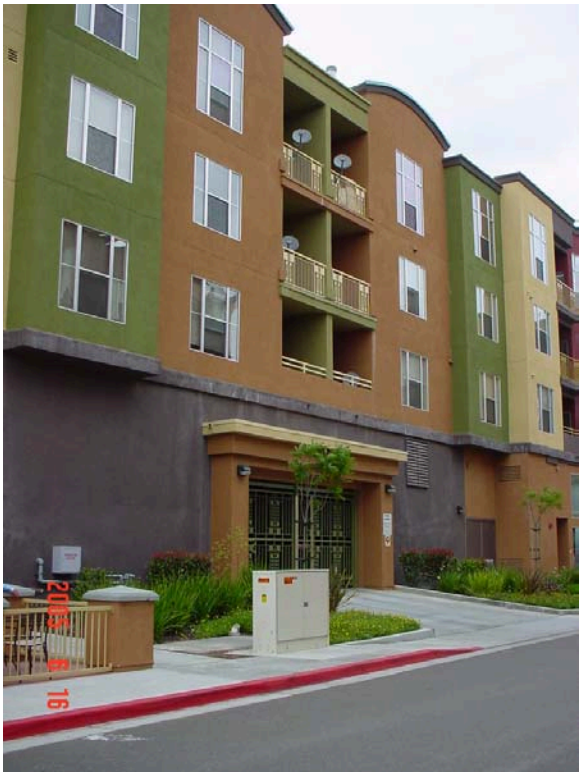
- Transportation-related pollutant reduction
- Reduced impervious surface area



The Benton has a walking path to the Fremont BART Station (across street) and is near Lake Elizabeth-Central Park, the Shinn Historic Park, Centerville Farmers Market, and Irvington Farmers Market.



This is the entrance to the underground parking garage, which reduces the amount of impervious surface area required for the complex.



Multi-story housing reduces the building footprint and, thus, impervious surface area.



Mixed use commercial businesses located within the Benton encourage residents to walk to shops thereby reducing the reliance on motor vehicles.

Municipal Contact:
Shannan Szychowski
City of Fremont
(510) 494-4584
sszychowski@ci.fremont.ca.us

Site Contact:
The Benton in Fremont
(510) 792-1299
TheBentonInFremont.com

Dwight Way Mixed-Use Development
MU-3

Site Location:

2480 Martin Luther King Jr. Way
Berkeley, CA
Completed December 2003

Features:

- Live/work spaces
- Located near mass transit including AC Transit
- Disconnected downspouts
- Pervious driveway and parking area
- Tuck under parking

Stormwater Benefits:

- Transportation-related pollutant reduction
- Reduced directly connected impervious area (DCIA)
- Reduced impervious surface area
- Reduced volume of runoff

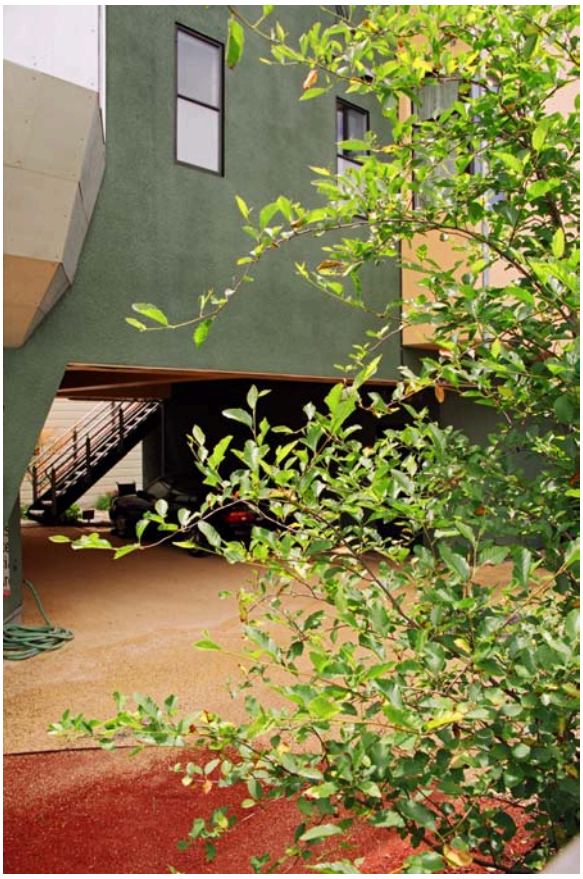


This mixed use development is located on multiple AC Transit routes and also nearby the Berkeley bike boulevard system, promoting alternative transportation.



The rooftop rain gutter drains into landscaping and dry wells reducing the amount of directly-connected impervious area (DCIA).

SARB_009478



This section of the building allows for a covered parking area in the breezeway, reducing the amount of impervious area.



The driveway and parking area is made of compacted road base with a decomposed granite surface layer. This pervious paving has been relatively easy to maintain and the decomposed granite has not washed out.



These live work spaces used many "green building" concepts including using recycled materials in a unique way to create a environmentally friendly environment.

Lessons Learned:

- Downspouts were directed to dry wells, but the wells were undersized and the clay soil prohibited proper infiltration. The solution was to separate downspouts and add more dry wells.

Municipal Contact:
Nate French
City of Berkeley
(510) 981-7451
nfrench@ci.berkeley.ca.us

Site Contact:
Karl Wanaselja
Leger Wanaselja Architecture
(510) 848-8901
www.greendwellings.com

Hesperian Boulevard
MU-4

Site Location:

Hesperian Boulevard
Hayward, CA
Constructed March 2004

Stormwater Benefits:

- Natural treatment of runoff
- Reduced velocity of flows

Features:

- Detention basin



Stormwater runoff is directed into the detention pond, where pollutants are removed primarily through settling. If the pond becomes filled, water is allowed to flow through the outlet to the storm drain.



This detention basin was built in conjunction with an industrial area, sports park, and single family homes and is maintained as by the Alameda County Flood Control and Water Conservation District.

Lessons Learned:

- Although this detention basin was designed prior to the stormwater permit requirements, the basin should have been designed to not allow standing water beyond 48 hours to prevent mosquito breeding from occurring.

Municipal Contact:
Jim Lear
City of Hayward
(510) 583-4785

Allston Lofts
MU-5

Site Location:

2161 Allston Way
Berkeley, CA
Completed March 2003

Features:

- High density (multi-story) housing with reduced building footprints integrated with commercial areas
- Located near mass transit including BART and AC Transit
- Modular pavers
- Located building to protect existing heritage tree

Stormwater Benefits:

- Transportation-related pollutant reduction
- Reduced impervious surface area
- Reduced volume of runoff



The courtyard is made up of ungrouted modular pavers to allow runoff to seep between the pavers.



During construction, the preparation of base material and careful observation of paver placement is required to ensure that ADA standards are met. These modular pavers provide easy access to underground utilities because no concrete needs to be removed and the pavers can be re-used.

SARB_009481



Located in downtown Berkeley, public transportation is easily accessible and there are many businesses nearby including some on the bottom floor of the Allston Lofts complex to promote pedestrian activities and alternative transportation.



The courtyard was built around this existing heritage tree, preserved during the redevelopment project.

Municipal Contact:
Nate French
City of Berkeley
(510) 981-7451
nfrench@ci.berkeley.ca.us

Site Contact:
Brani-Gerson, Bakar & Associates
(510) 845-5501

Hillside Village
MU-6

Site Location:

1797 Shattuck
Berkeley, CA

Features:

- High-density (multi-story) housing with reduced building footprints integrated with commercial areas
- Located near mass transit including BART and AC Transit
- Parking lift system



This building is build above a parking area that utilizes the parking lift system.



Parking lift systems reduce the impervious surface area by having parking pits with lifts that stack cars while parked, reducing the impervious surface area needed per car.

Stormwater Benefits:

- Transportation-related pollutant reduction
- Reduced impervious surface area



This dense, stacked infill residential development over commercial space is located on multiple AC Transit routes and also nearby the Berkeley bike boulevard system, promoting alternative transportation.

Lessons Learned:

- There are some parking lift systems that do not have approved listings for fire safety. The fire department needs to be involved early on the design phase to carefully determine fire sprinkler requirements for parking pit areas to provide the greatest fire protection.

Municipal Contact:
Nate French
City of Berkeley
(510) 981-7451
nfrench@ci.berkeley.ca.us

Site Contact:
Rony Rolinski
Architect
(415) 370-3141
ronyrolarchitect@aol.com

Alameda Countywide
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Post-Construction BMP Examples

SECTION V

Commercial

Bayside Business Center
CO-1

Site Location:

2501 Davis Street
San Leandro, CA
Constructed 2003

Features:

- Vegetated swales
- Detention pond



The parking lot is sloped to drain toward the vegetated swale which reduces the volume and velocity of runoff from the parking lot.



Parking lot runoff drains through the curb cuts into the swale where the water can be naturally treated through biofiltration.

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff



This pond was established for a nine (9) parcel, commercial development project. Stormwater is directed into the detention pond where pollutants and sediments are filtered out before slowly being released into the storm drain.



This is a photograph of the detention pond with the outlet structure in the center, which allows the water to slowly drain from the pond after a storm event.

Lessons Learned:

- The vegetation used in the swales should be easily established to ensure proper treatment of runoff.

Municipal Contact:
Jagtar Dhaliwal
City of San Leandro
(510) 577-3417
jdhaliwal@ci.san-leandro.ca.us

Site Contact:
Robert McClendon
McMahon Development Group
500 Stevens Avenue, Suite 200
Solana Beach, CA 92075

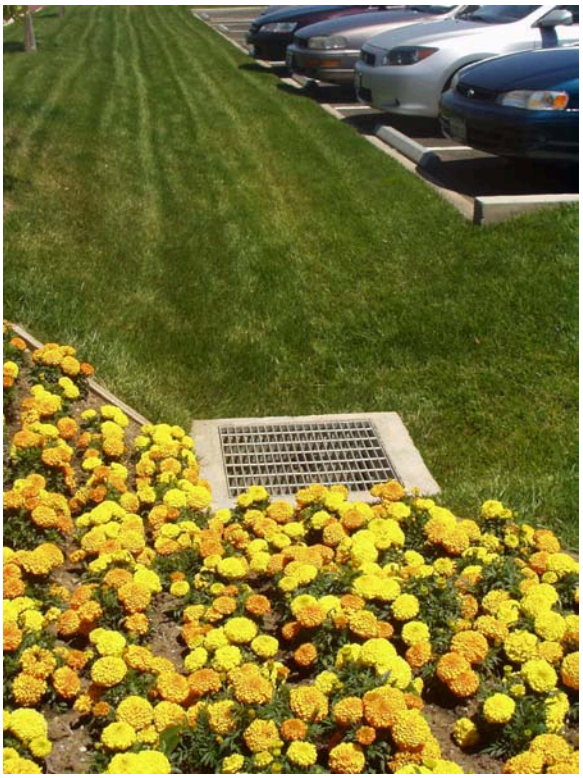
Central Avenue Commercial Building Complex
CO-2

Site Location:

33280 Central Avenue
Union City, CA
Completed 2004

Features:

- Vegetated swale
- Disconnected downspouts
- Bike racks promote bicycle commuting



At the end of this swale, there are flowers that are an aesthetically pleasing aspect of the swale.

Stormwater Benefits:

- Natural treatment of runoff
- Reduced velocity and velocity of runoff
- Reduced directly connected impervious areas (DCIA
- Transportation-related pollutant reduction



The parking lot is flush with the top of the swale to allow the parking lot to drain directly into the swale



This is an up-close look at the curb cut that allows drainage from the driveway to enter the swale.



This building has disconnected downspouts that drain through rocky areas and in this case into the nearby vegetated areas.



These disconnected downspouts drain through the rocks out into the parking lot. Fortunately the parking lot drains to the swales and does not increase the amount of runoff into the storm drains.



Bike racks provide an area for employees or visitors to store their bikes, which promotes alternative transportation.

Municipal Contact:
Clean Water Program Coordinator
City of Union City
(510) 675-5360

Site Contact:
Harvest Properties Incorporated
(510) 594-2050

ARTech Building
CO-3

Site Location:

2002 Milvia
Berkeley, CA
Completed August 2003

Features:

- High-density (multi-story) infill office and commercial development with reduced building footprints
- Located near mass transit including BART and AC Transit
- Garden area on roof
- Parking lift system

Stormwater Benefits:

- Transportation-related pollutant reduction
- Reduced impervious surface area
- Reduced volume of runoff



This dense, stacked, infill development with offices over commercial space is located near BART and AC Transit routes, and also nearby the Berkeley bike boulevard system, promoting alternative transportation.



This roof area provides a garden setting for employees instead of adding additional impervious area (walkways, etc) around the building perimeter.



Parking lift systems reduce the impervious surface area by having parking pits with lifts that stack cars while parked, reducing the impervious surface area needed per car.

Lessons Learned:

- There are some parking lift systems that do not have approved listings for fire safety. The fire department needs to be involved early on the design phase to carefully determine fire sprinkler requirements for parking pit areas to provide the greatest fire protection.

Municipal Contact:
Nate French
City of Berkeley
(510) 981-7451
nfrench@ci.berkeley.ca.us

Site Contact:
Patrick Kennedy
Panoramic Interests
(510) 883-1000
www.paroramicinterests.com

Kaiser Center
CO-4

Location:

Webster and 21st Street
Oakland, CA
Constructed in 1961

Features:

- Roof garden
- Multi-story parking structure



Photograph courtesy of Camp Dresser & McKee, Inc. (CDM)

This aerial view of the building's roof garden shows the vegetative areas planted on top of the building, which create a park-like setting on top of a parking garage and also serve to conceal cars from the neighboring office buildings. The nine story parking structure reduces the building footprint required for parking.

Stormwater Benefits:

- Reduced impervious surface area
- Natural treatment of runoff
- Reduced volume and velocity of runoff

Other Issues:

- The large trees and water features in the roof garden require substantial structural reinforcement.



Photo taken from http://www.jwdliftech.com/llocation.html

The entrance to the Kaiser Center visitor parking garage is between the Kaiser tower and a mall, providing public access through this pleasant walkway.

Municipal Contact:
Don Smith
City of Oakland
(510) 238-4778
dsmith@oaklandnet.com

Site Contact:
International Parking Design
Architecture, Engineering, Consulting
7700 Edgewater Drive Suite 635
Oakland, CA 94621
(510) 553 2120
www.ipd-global.com

Park Avenue
CO-5

Site Location:

1375 Park Avenue
Emeryville, CA
Constructed June 2004

Features:

- Pervious concrete parking lot



This parking lot was paved with pervious concrete, which allows runoff to drain through the concrete.



The inconsistent appearance of the parking lot is due to the phased construction, with differing compaction and colorants.

Stormwater Benefits:

- Reduced impervious surface area
- Reduced volume of runoff



This up close shot shows the differentiation between the appearance of the regular concrete driveway and the pervious concrete.

Lessons Learned:

- Previous concrete must be studied carefully in relation to the soil hydrology of the site. It may be more appropriate in areas farther from the bay where the groundwater is not so high and clayey soils are not so pervasive. The use of an underdrain in areas with clayey soils may result in only minimal infiltration of stormwater. A better solution would be to excavate clayey soils and replace with Type A or B soil. Cost and aesthetics are also challenges.

Municipal Contact:
Peter Schultze-Allen
City of Emeryville
(510) 596-3728

Venture Commerce Center
CO-6

Site Location:

35453-35483 Dumbarton Court
Newark, CA
Constructed June 2004

Features:

- Vegetated swale
- Roofed trash enclosure with sanitary sewer connection

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume and velocity of flows
- Water treatment



The vegetated swale was constructed to treat runoff naturally through the vegetation.



This covered trash enclosure has drains that connect to the sanitary sewer system. This prevents any pollutants from the trash containers or water that comes in contact with the refuse from entering storm drains.



This vegetation in this swale did not grow because overwatering washed away the seeds.

Lessons Learned:

- The vegetated swale should not be overwatered at the beginning stages (after planting the seeds) and inspections should confirm the adequacy of the sprinkler system and the swale design.

Municipal Contact:
Michael Carmen
City of Newark
(510) 794-2320
michael.carmen@newark.org

Site Contact:
Venture Corporation
Mill Valley office: (415) 381-1600
Silicon Valley office: (408) 778-6600
www.venture-corp.com

Costco
CO-7

Site Location:

40580 Albrae Street
Fremont, CA

Features:

- Vegetated swale

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff



Rocks are used to reduce erosion at the entrance of the vegetated swale, in which water can infiltrate, reducing the amount of water entering the storm drain system.



Water flows from the parking lot, through curb cuts and rock-lined area before being treated naturally in the vegetated swale.

Municipal Contact:
Shannan Szychowski
City of Fremont
(510) 494-4584
sszychowski@ci.fremont.ca.us

Longard Business Park
CO-8

Site Location:

Longard Road
Livermore, CA
Constructed 2003

Features:

- Vegetated swales
- Covered trash enclosures (not shown)

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced trash related pollutants



The parking lot runoff has drained to the swale, illustrating the good performance of the swale immediately after the rain.



This swale is a good example of how a swale can be designed with the trees off to the side of the swale so that they do not impede the flow.



The owner of the commercial site is responsible for maintenance of this swale, which is primarily mowing the grass.

Municipal Contact:
Steve Aguiar
City of Livermore
(925) 960-8100
smaguiar@ci.livermore.ca.us

Site Contact:
Contact Steve Aguiar for site contact information.

Zhone Technologies
CO-9

Site Location:

7295 Oakport Street
Oakland, CA

Features:

- Vegetated swale

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff



The parking lot is flush with the vegetated swale so that runoff can drain to the swale where it is naturally filtered before entering the storm drain.

Municipal Contact:
Don Smith
City of Oakland
(510) 238-4778
dsmith@oaklandnet.com

Site Contact:
Joe Ernst
(510) 864-5985

Shea Business Center
CO-10

Site Location:

2000 Constitution Drive
Livermore, CA
Constructed 2002

Features:

- Vegetated swales
- Disconnected roof leaders (not shown)
- Covered trash enclosures (not shown)



The parking lot is flush with the swale so that the runoff can drain directly into the vegetation.



The vegetation in the swale can treat the parking lot runoff through natural processes.

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced directly connected impervious area (DCIA)
- Reduced trash related pollutants



This landscaping swale is a good example of how a swale can be designed to meet stormwater treatment requirements.

Municipal Contact:
Steve Aguiar
City of Livermore
(925) 960-8100
smaguiar@ci.livermore.ca.us

Site Contact:
Contact Steve Aguiar for site contact information.

Zwissig Commercial Building
CO-11

Site Location:

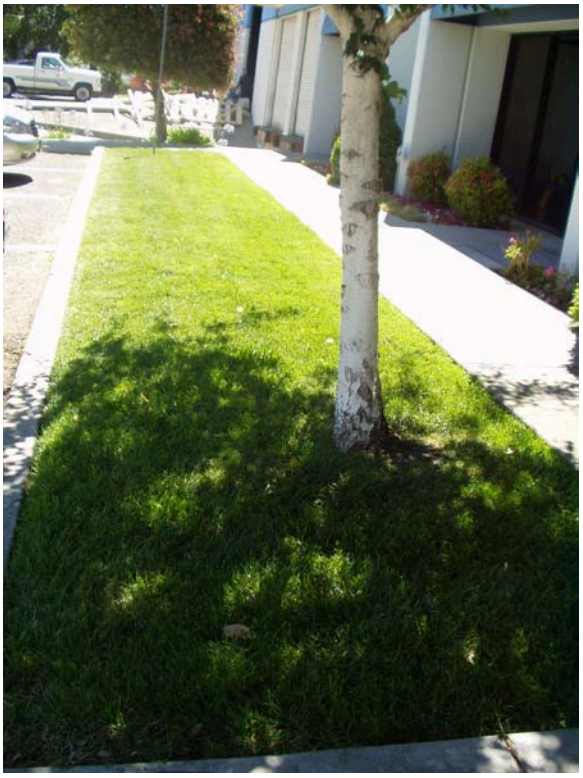
Zwissig
Union City, CA
Constructed 2003

Stormwater Benefits:

- Natural treatment of runoff
- Reduced velocity of runoff
- Reduced volume of runoff

Features:

- Vegetated swale



The runoff from this walkway in from of the building drains to the vegetated swale, reducing the flow from the impervious surface.



The vegetated areas collect some of the runoff from the sidewalk, where it can naturally filter out pollutants from the water.

Municipal Contact:
Clean Water Program Coordinator
City of Union City
(510) 675-5360

Form Factor Campus
CO-12

Site Location:

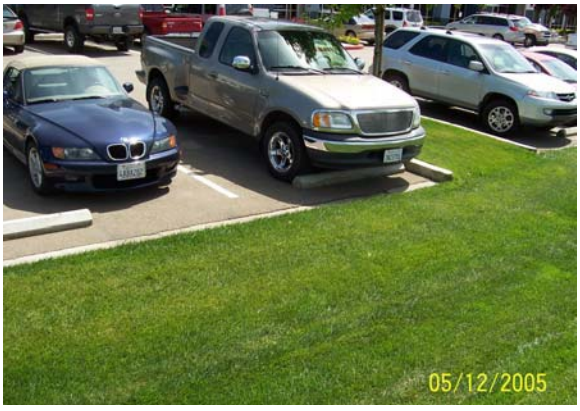
501 Lawrence Road
Livermore, CA
Constructed 2003

Features:

- Vegetated swales
- Disconnected roof leaders (not shown)
- Covered trash enclosures (not shown)



The raised inlet directs overflow to the storm drain system to prevent excessive ponding.



The parking lot is flush with the swale so that the runoff can drain directly into the vegetation.

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced directly connected impervious area (DCIA)
- Reduced trash related pollutants



This swale is a good example of how a swale can be designed with the trees off to the side of the swale so that they do not impede the flow.

Municipal Contact:
Steve Aguiar
City of Livermore
(925) 960-8100
smaguiar@ci.livermore.ca.us

Site Contact:
Contact Steve Aguiar for site contact information.

Target Store – Albany
CO-13

Site Location:

1057 Eastshore Highway
Albany, CA
Constructed October 2004

Features:

- Vegetated swales
- Underground CDS unit

Stormwater Benefits:

- Natural treatment of runoff
- Reduced velocity and volume of runoff
- Mechanical treatment of runoff



The parking lot is equipped proprietary underground CDS units (Vortechnics), which mechanically treat the runoff before entering the storm drain system.



The parking lot runoff drains to the vegetated swale, reducing the volume and velocity of runoff during storms.



The runoff drains through the curb cuts into the landscaping.

Lessons Learned:

- It is important to have the landscape architect inspect after installation to ensure proper completion, especially if the owner is responsible for maintenance as in this case.

Municipal Contact:
Billy Gross
City of Albany
(510) 528-5765
bgross@albanyca.org

Site Contacts:
Gates + Associates,
Landscape Architects
(925) 736-8176

AMS Associates, Engineering
(925) 943-2777

Michael's
CO-14

Site Location:

39170 Argonaut Way
Fremont, CA

Feature:

- Disconnected downspouts

Stormwater Benefits:

- Reduced directly connected impervious areas (DCIA)
- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff



The rooftop runoff drains to the landscaping surrounding the building.



Disconnected roof downspouts reduce the amount of directly connected impervious area (DCIA).

Municipal Contact:
Shannan Szychowski
City of Fremont
(510) 494-4584
sszychowski@ci.fremont.ca.us

Thera Sense
CO-15

Site Location:

1360 South Loop Road
Alameda, CA

Feature:

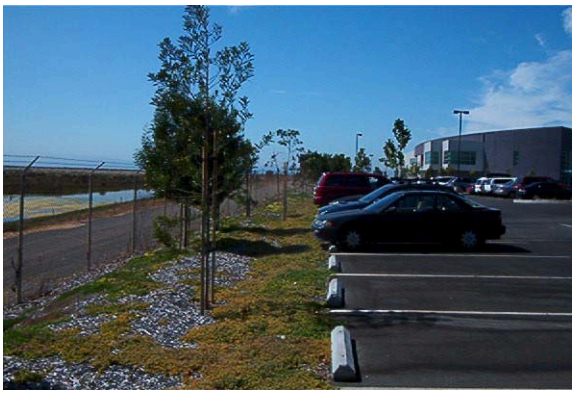
- Vegetated swales

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff



The parking lot runoff has ample room to drain through the parking wheel stops into the swale.



This swale provides a buffer between the parking lot and the street, which prevents runoff from reaching offsite onto the street.



This vegetated swale is filled with plants to naturally treat the runoff.

Municipal Contact:
James Barse
City of Alameda
(510) 749-5840

Target Store – Hayward
CO-16

Site Location:

2499 Whipple Road
Hayward, CA
Constructed October 2002

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff

Features:

- Vegetated swales
- Underground CDS unit (not shown)



Parking lot drains through curb cuts into the swale. Oil spills may contaminate the runoff, however, the swale is capable of removing some pollutants from the water.



Trees are placed in the center of the swale, although this is aesthetically pleasing, the trees can impede flow.

Lessons Learned:

- Do not place trees at bottom of swale; it impedes flow especially when the roots grow up.

Municipal Contact:
Jim Lear
City of Hayward
(510) 583-4785

Livermore Auto Mall
CO-17

Site Location:

3000 Las Positas Road
Livermore, CA
Constructed 2005

Features:

- Vegetated swales
- Disconnected roof leaders (not shown)
- Covered trash enclosures (not shown)

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced directly connected impervious surface area (DCIA)



Parking lot runoff can drain directly into the swale because the parking lot is flush with the top end of the swale. This is possible because new cars are parked by the auto mall employees only.



The owner of the commercial site is responsible for maintenance of this swale, which is primarily mowing the turf grass.

Lessons Learned:

- Provide underdrain in swales when slope is minimal, provide greater offset of trees and light standards when located in swale area.

Municipal Contact:
Steve Aguiar
City of Livermore
(925) 960-8100
smaguiar@ci.livermore.ca.us

Site Contact:
Contact Steve Aguiar for site contact information.

Re Max
CO-18

Site Location:

41111 Mission Boulevard
Fremont, CA

Features:

- Vegetated swales
- Curb cuts

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff



This vegetated swale is used to reduce the velocity and volume of parking lot runoff.



Curb cuts allow runoff water to drain into the vegetated areas from the parking lot.



This walkway was constructed as a bridge so that the runoff could still flow continuously through the swale.



Cobbles prevent erosion at this storm drain inlet, to which runoff flows after filtering through the swale.

Lessons Learned:

- The walkway bridges should line up with the white lines separating the parking stalls to allow pedestrian navigation around cars.
- Ivy should not be planted in swales, because it is difficult to maintain and keep the storm drain inlets clear of vegetation.

Municipal Contact:
Shannan Szychowski
City of Fremont
(510) 494-4584
sszychowski@ci.fremont.ca.us

Site Contact:
JP Mobasher
(510) 580-8262

Alameda Countywide
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Post-Construction BMP Examples

SECTION VI

Public Areas

Vineyard Avenue Realignment
PA-1

Site Location:

Vineyard Avenue
(East of Clara Lane)
Pleasanton, CA
Constructed April 2005

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced impervious surface area

Features:

- Vegetated swales
- Decomposed granite
- Detention pond



Detention pond not only provides an area for stormwater treatment, but also provides habitat for wildlife (egret pictured).

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This grassy swale was constructed during the realignment of Vineyard Road. The roadway runoff drains to the swale, which is flush with the road.



The swale drains to the storm drain after naturally treating runoff.



Decomposed granite walkway was constructed next to the swale to provide an area for pedestrian activity.

Municipal Contact:
Kaushik Bhatt
City of Pleasanton
(925) 931-5664
KBhatt@ci.pleasanton.ca.us

Site Contact:
Jim Gotcher
(925) 931-5684

Zone 7 Water Agency
PA-2

Site Location:
100 North Canyons Parkway
Livermore, CA

Features:
- Vegetated swale
- Disconnected downspouts

Stormwater Benefits:
- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced directly connected impervious area (DCIA)



The roof leader from the Zone 7 office building drains into a cobble, which allows sedimentation to occur before entering into a grassy swale, and eventually ending up in the storm drain.

Municipal Contact:
Mary Lim
Zone 7
(925) 454-5036
mlim@zone7water.com

Pleasanton Sports Park
PA-3

Site Location:
Hopyard Road
north of Valley Avenue
Pleasanton, CA
Constructed August 2004

Features:
- Turf block fire access
- Vegetated swales (not shown)

Stormwater Benefits:
- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff



This grassy area at the Pleasanton Sports Park is composed of turf block and used for fire access to maintenance building nearby. Fire trucks can drive through the fence gate and directly to the building over the turf block marked by the concrete curb.

Municipal Contact:
James Kelcourse
City of Pleasanton
(925) 931-5676
jkelcourse@ci.pleasanton.ca.us

City of Pleasanton Park and Ride Lot
PA-4

Site Location:

7295 Johnson Drive
Pleasanton, CA
Constructed September 2005

Features:

- Vegetated swales
- Promotes alternative transportation

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced transportation-related pollutants



This parking lot serves as an area for commuters to park their cars and take public transportation.



The parking lot drains through curb cuts into the vegetated swales onsite where the runoff is naturally treated.

Municipal Contact:
James Kelcourse
City of Pleasanton
(925) 931-5676
jkelcourse@ci.pleasanton.ca.us

Sycamore Road
PA-5

Site Location:

Sycamore Road
(East of Amber Lane)
Pleasanton, CA
Constructed 2004

Stormwater Benefits:

- Natural treatment of runoff
- Reduced volume of runoff
- Reduced velocity of runoff
- Reduced impervious surface area

Features:

- Drainage swale



The road drains to this vegetated swale where pollutants are removed naturally and the velocity and volume of runoff is reduced.

Municipal Contact:
Kaushik Bhatt
City of Pleasanton
(925) 931-5664
KBhatt@ci.pleasanton.ca.us

Site Contact:
Tim Armbruster
(925) 931-5609

Dublin Boulevard
PA-6

Site Location:

Dublin Boulevard
(Over Alamo Canal)
Dublin, CA
Completed 2004

Features:

- Stormceptor (mechanical treatment)

Stormwater Benefits:

- Oil and sediment pollutant removal



During the widening of Dublin Boulevard, a Stormceptor system was installed to remove oil and sediments from road runoff.



The Stormceptor system, owned and maintained by the City of Dublin is being lowered into the vault.

Lessons Learned:

- The manhole for the Stormceptor system should not be placed in the traffic lane line. Since Stormceptors need to be maintained frequently (at least once a year and after major storm events), there should be easy access, preferably not requiring closing a traffic lane.

Municipal Contact:
Ferd Del Rosario
City of Dublin
(925) 833-6630

Site Contact:
Dan Elshire
Granite
715 Comstock Street
Santa Clara, CA 95054
(408) 224-4124

Berkeley Traffic Circles
PA-7

Site Location:

Grant and Addison
Berkeley, CA
Completed Summer 2005

Features:

- Converting impermeable area to permeable area



This landscaped island, provides an area for infiltration to occur.



This is another traffic circle created to maintain speeds, but also reduces the overall impervious area.

Stormwater Benefits:

- Reduced impervious surface area



This traffic island creates a bulb out for parking along this street.

Lessons Learned:

- The selection of traffic calming devices required review by the public.
- The street widths needed to maintain clearances to allow passage of fire equipment.
- The traffic circles and islands should have been created to allow roadway infiltration through curb cuts. This would allow more runoff to be treated in the landscaped areas.

Municipal Contact:
Danny Akagi
City of Berkeley
(510) 981-6394
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SECTION VII

Indexes

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Post-Construction BMP Examples by Best Management Practice

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SAS Pg. #*	31	31	31		93, 142, 143	67	98	19-22, 10-119	47, 100		70			28	30, 84-85	91, 104	70, 139		Other Description
	CO-2	CO-3	CO-3	CO-6	CO-1	SF-7	CO-4	SF-5	CO-5	SF-2	CO-3	CO-3	MU-2	MU-5	MU-3	PA-3	CO-1	CO-13	Underground CDS Unit
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		MU-2	MU-2		PA-1	CO-14	MU-1		MU-5		MU-1	MU-6					CO-6	PA-7	Converting impervious area to pervious area
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* This indicates the page number in Start at the Source that may provide additional information on the Post-Construction BMP listed.

Post-Construction BMP Examples by Municipality

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- **SF-4:** Bay Cove

Alameda County – Unincorporated
- **SF-8:** Centex/Five Canyons

City of Albany
- **CO-13:** Target Store Albany

City of Berkeley
- **CO-3:** ARTech Building
- **MU-1:** Gaia Building
- **MU-3:** Dwight Way Mixed-Use Development
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City of Dublin
- **SF-3:** Dublin Ranch
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City of Emeryville
- **CO-5:** Park Avenue

City of Fremont
- **CO-7:** Costco
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- **CO-18:** ReMax
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City of Hayward
- **CO-16:** Target Store Hayward
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- **SF-1:** Bailey Ranch

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- **CO-10:** Shea Business Center
- **CO-12:** Form Factor Campus
- **CO-17:** Livermore Auto Mall
- **SF-5:** Lindenwood

City of Newark
- **CO-6:** Venture Commerce Cener
- **SF-6:** Cedar Boulevard
- **SF-7:** Civic Terrace Residence

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City of Oakland
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- **CO-9:** Zhone Technologies

City of Pleasanton
- **PA-1:** Vineyard Road Realignment
- **PA-3:** Pleasanton Sport Park
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- **PA-5:** Sycamore Road

City of San Leandro
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- **CO-11:** Zwissig Commercial
- **MF-1:** Wisteria Place
- **SF-2:** Ivywood

Zone 7 Water Agency
- **PA-2:** Zone 7 Water Agency

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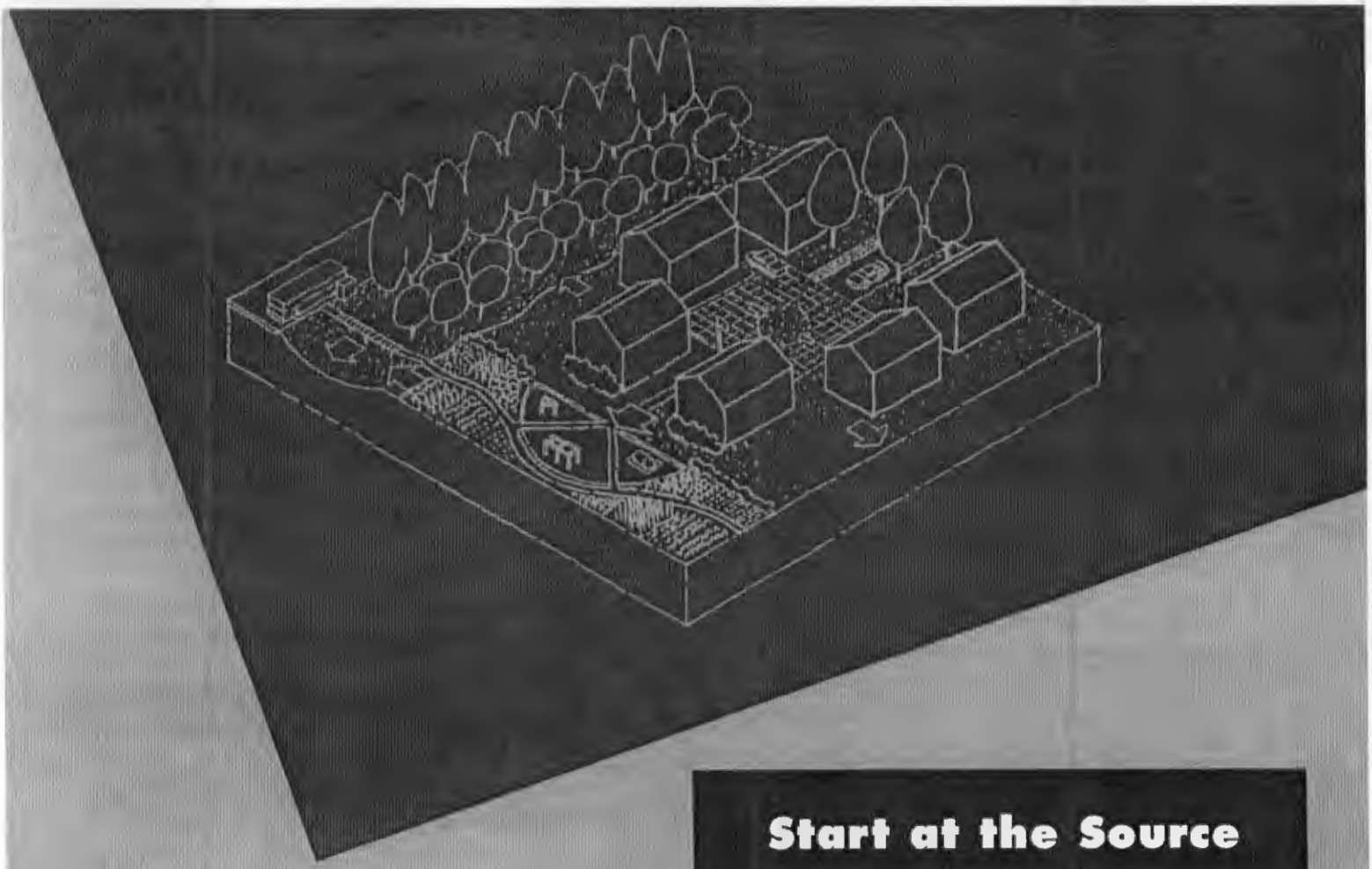
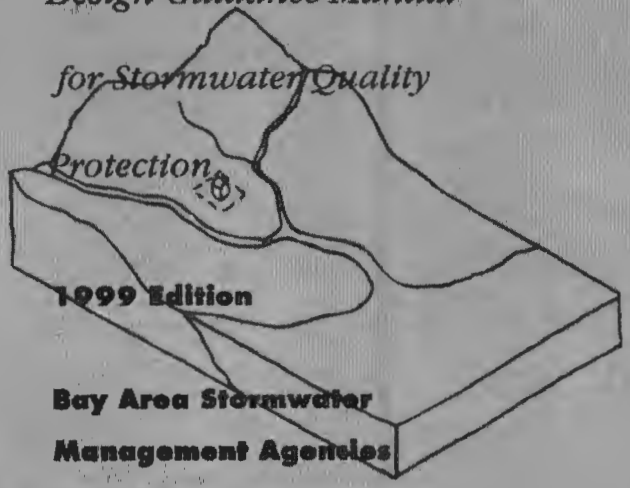


Start at the Source

Design Guidance Manual for Stormwater Quality Protection



1999 Edition

Bay Area Stormwater Management Agencies Association

Bay Area Stormwater Management Agencies Association

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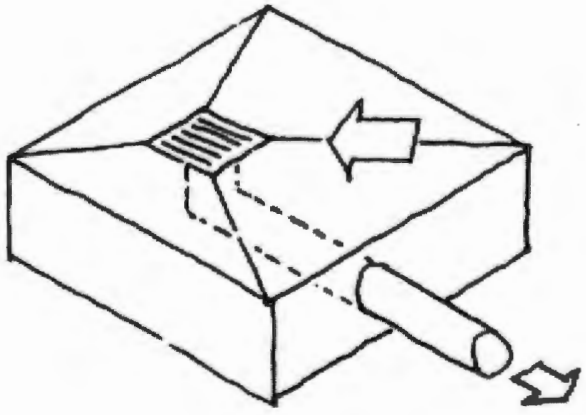
Two approaches to stormwater management

The conveyance approach to stormwater management seeks to "get rid of the water." A conveyance stormwater system collects and concentrates runoff through a network of impervious gutters, drainage structures and underground pipes. As the conveyance system flows downstream, additional tributary conveyance systems feed into it, requiring it to be continually enlarged as it approaches its outfall. Because the system collects water from impermeable surfaces and carries it through impervious pipes, suspended pollutants are concentrated in the rapidly flowing runoff. When the system reaches its outfall, large volumes of polluted water can be emptied, untreated, into a natural water body.

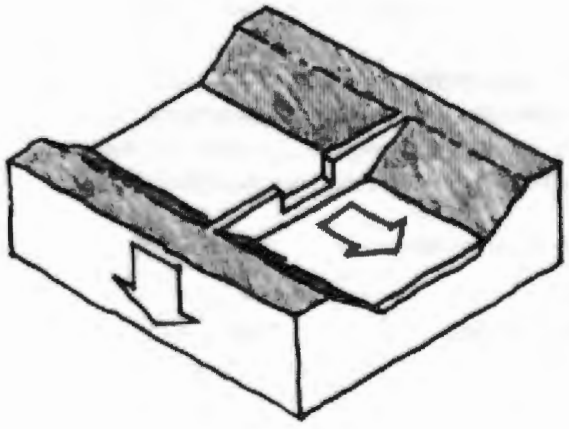
Several factors contribute to stormwater degradation in a conventional development. Large paved roadway surfaces create and collect runoff. Building sites may be graded severely, removing natural vegetation that absorbs runoff. The curbs, gutters and catch basins collect runoff and carry it rapidly, providing little opportunity for infiltration. In this way, large quantities of runoff are created and carried in a short time to the outfall of a conveyance stormwater system, carrying sediments and other pollutants as a fast flowing untreated discharge into the bay.

The infiltration approach to stormwater management seeks to "preserve and restore the hydrologic cycle." An infiltration stormwater system seeks to infiltrate runoff into the soil by allowing it to flow slowly over permeable surfaces. These permeable surfaces can double as recreational and landscape areas during dry weather. Because the infiltration network allows much of the runoff to return to the soil, overall runoff volume is reduced, and more water is available to replenish groundwater and maintain stream base flows. The slow flow of runoff allows pollutants to settle into the soil where they are naturally mitigated. The reduced volume of runoff that remains takes a long time to reach the outfall, and when it empties into a natural water body, its pollutant load is greatly reduced.

A development designed for stormwater quality generates less runoff because overall impervious land coverage is reduced through clustering and other means. Building sites are fit into the contours, and preserve vegetation as far as feasible. The drainage system attempts to slow runoff, and provides opportunities for it to filter into the soil. In dry weather these infiltration areas can be used for recreation or wildlife habitat. Smaller runoff volumes are created overall, and these volumes take a longer time to the outfall. When runoff from an infiltration-based system arrives, it's cleaner, and moving more slowly as it empties into the bay.



Conveyance Approach



Infiltration Approach

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2 Concepts

A *few basic concepts form the foundation for drainage systems that preserve and restore the hydrologic cycle. Once these basic concepts are understood, the ingenuity of designers, planners and builders can be applied to invent specific techniques for the special requirements of any site.*

The concepts spring from an integrated, comprehensive approach to stormwater management, considering each site's unique position within a larger watershed, and each smaller watershed within a site.

The application of these concepts consistently within a site will create a stormwater management approach that minimizes impervious area, reduces direct connections between impervious areas and the stormdrain system, and mimics natural systems while being economical, aesthetically pleasing, and technically sound.

Concepts

2.1 Every site is in a watershed. Rain falls on every site. What happens to the rain depends on the site's place in the larger watershed, and on the smaller watersheds within the site. From where does water enter the site? To where does it go? Understanding that a site has a position in the larger context is essential to stormwater management.

2.2 Start at the source. What happens immediately after a drop of rain hits the ground? Rather than convey stormwater away for treatment at the end of a pipe, water quality is most easily and economically achieved if stormwater management starts at the point that water contacts the earth.

2.3 Think small. For decades planners, engineers and builders have been trained to think big– to design systems that will handle peak flows from the biggest storms. Yet a significant amount of pollutants and flow-induced impacts to streams are in the early rains and small storms. Designing systems to accommodate the big storm is still essential for protection of life and property, but small-scale techniques, applied consistently over an entire watershed, can have a big impact — both improving stormwater quality and reducing overall runoff volume.

2.4 Keep it simple. A wide variety of simple and effective strategies can be employed to achieve stormwater quality goals. Designed for the small storms, these simple strategies often use natural methods and materials, and sometimes require a different kind of engineering or maintenance than conventional modern drainage systems. By employing an array of a few simple techniques throughout a site, improved stormwater management can be achieved economically with modest maintenance requirements, and can often be cost-effectively integrated into larger, flood control-type facilities.

2.5 Integrate the solutions. Providing stormwater management facilities is not a problem – it's an opportunity. By integrating solutions into the overall site plan, stormwater facilities can provide recreational, aesthetic, habitat, *and* water quality benefits.

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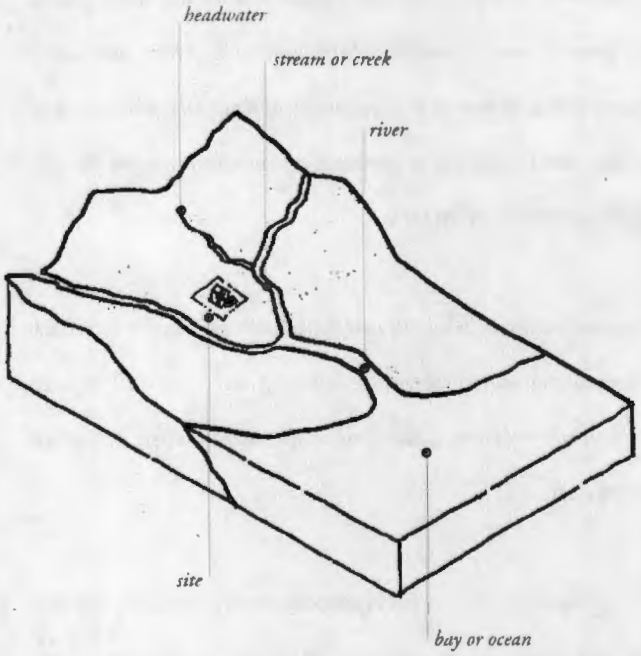
Concepts

2.1 *Every site is in a watershed*

Once a single drop of rain reaches the earth, its journey is determined by the watershed in which it lands. A watershed is defined by the U.S. Environmental Protection Agency as "the geographic region within which water drains into a particular river, stream, or body of water."[8]



A small puddle in an uneven field reflects a tiny, localized watershed. At a neighborhood scale, gradual changes in elevation, or man-made artifacts like roadways or railroad embankments may define watersheds. Regionally, a range of mountain ridges may create a watershed that is drained by a network of small streams and creeks, each of which forms a tributary to larger water bodies, forming larger watersheds, all of which ultimately empty into a lake, bay or ocean.

No matter where you are in a watershed, or at what scale of watershed you are working, what you do on any particular site always has effects on the overall hyrologic system. By understanding that every site has a relationship to its adjoining watersheds, by investigating the soil and hydrologic conditions of the site, and by appreciating the micro-watersheds within each site, designers can best achieve the overall objective: restoration and preservation of the natural hydrologic system.

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Concepts

2.2 *Start at the source*

***W**hen a single drop of rain lands, it is carried by gravity and soil physics downward into the soil.*

If the soil is covered with an impervious material, such as rooftops, concrete, or asphalt, the single drop of rain flows along whatever surface it encounters, moving downhill, joining with other drops of rain to create runoff.

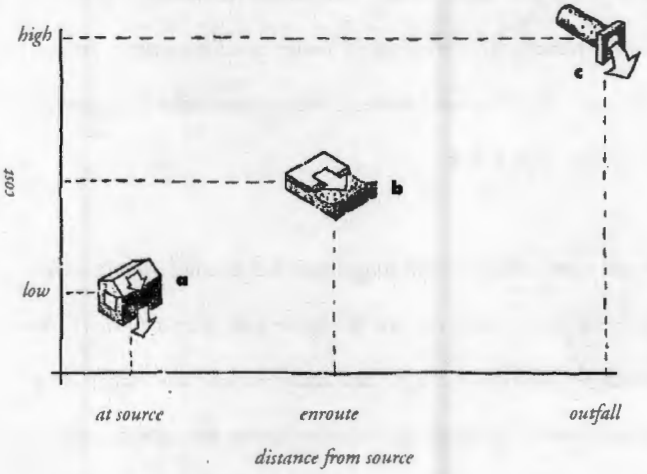
If this runoff is collected in pipes and conveyed long distances before treatment many opportunities for improved water quality are lost. "End of pipe" strategies, such as large retention ponds, can be important components of an overall stormwater management system, but are more complex and costly than strategies that start at the source.

Small collection strategies, located at the point where runoff initially meets the ground, repeated consistently over an entire project, will usually yield the greatest water quality improvements for the least cost.

Source control is cheapest

If runoff is infiltrated or detained at its source (a) the least costs are incurred and maintenance is minimal. If runoff is carried some distance and treated enroute (b), costs and maintenance demands rise. If runoff is carried directly to the outfall (c), cost for treatment controls are highest and most maintenance intensive.

The most economical, simplest stormwater management opportunities for water quality are at the source of the runoff.



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Concepts

2.3 *Think small*

Small storms add up. *Because of their frequency, small storms, meaning storm sizes that recur once every two years or more frequently, produce the vast majority of total runoff over time. In the Bay Area, small storms account for eighty percent of total annual rainfall.*

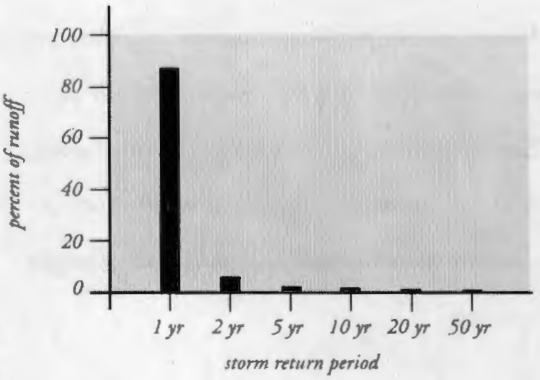
By targeting these small storms, rainfall can be managed for water quality through relatively small water quality systems. In this way, managing frequent small storms can address a large part of the pollution problem.

In the past, stormwater management has focused almost exclusively on flood protection. In the same way that a freeway designed for rush hour traffic can easily handle the traffic on a quiet weekend morning, stormwater systems that can accommodate flood flows are more than adequate to convey more frequent small storms. So, in designing only for flood protection, designers have been able to neglect the small storm and its impacts.

With an awareness of the importance of small storms for water quality protection designers now consider small storms, because of their frequency and cumulative impacts, as well as the infrequent large rainfall event.

Small storms add up

Rainfall is distributed between relatively infrequent large storms and more frequent small storms. For example, in the Bay Area, approximately eighty percent of the total annual rainfall is produced by the accumulated contribution of the many small storms, the size that recurs every two-years or less (two-year recurrence interval). These small storms typically produce between 0.5 to 1.25 inches of rain, depending on microclimate. By comparison, all of the larger storms combined (five, ten, twenty and fifty year intervals) typically produce less than twenty percent of the total annual rainfall.



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Concepts

2.4 *Keep it simple*

The techniques illustrated in this document were purposefully kept simple. Being simple, they are easy to understand. They are also relatively easy and inexpensive to design, build and maintain.

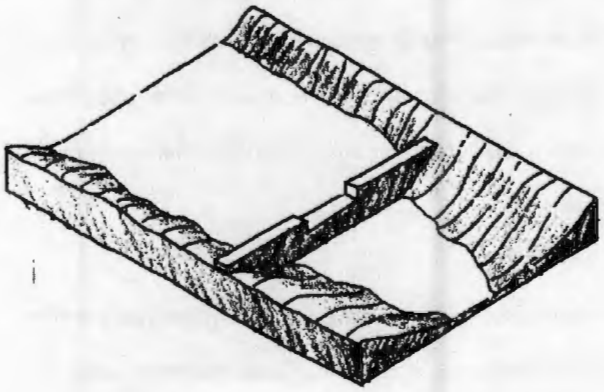
To address the many diverse sites found in the Bay Area, this document illustrates a wide variety of techniques, applicable to different soils, sites, and conditions. It is not intended that all *the techniques illustrated here will be appropriate for each project, but instead, that planners, landscape architects, and engineers select and adapt those few that are most suited to a particular site.*

A simple gravel strip, a concave instead of convex planting area, an infiltration basin at the end of a downspout — all of these are simple, but effective strategies for integrating stormwater management into a site plan.

The best stormwater management system will rely on a few simple techniques, applied consistently over an entire project or site.

Simple but effective

Because most stormwater management has generally been focused on complex, large systems, small, simple solutions may appear at first glance less effective. Yet simple solutions can be just as effective, and must undergo the same rigorous engineering analysis as more complex approaches. The difference is that the simple systems generally use lower technology materials and rely on natural materials integrated with the landscape, rather than mechanical or man-made processes, to manage stormwater.



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Concepts
2.5

Integrate the solutions

The stormwater management system can become an organizing element for site planning and design. Infiltration devices, drainage swales, and retention areas can be integrated into a site plan to improve aesthetics and provide recreational resources.

For example, a landscaped area, if slightly concave or depressed, can also serve as a temporary detention basin. Drainage swales can be landscaped with attractive riparian species. Pathways can follow these swales, creating attractive greenbelts that reflect natural landforms. A sandy area can serve as a children's playground in the dry season, but become a shallow infiltration basin in the winter rains.

Home buyers and business tenants consistently indicate a preference for water features. A network of small ephemeral pools and swales, treated carefully with attractive planting and maintenance, can satisfy this desire for a relationship to water and give developments a competitive advantage.

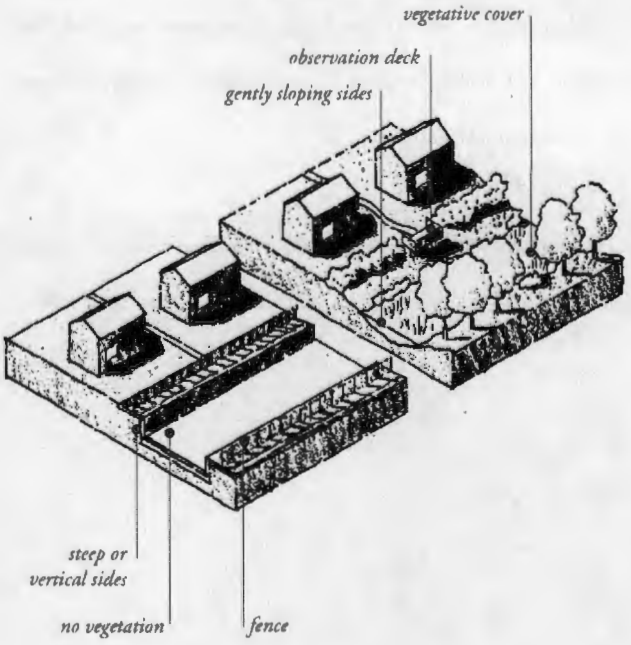
An integrated site plan will generally yield a series of smaller stormwater management facilities rather than one large basin at the end of a traditional conveyance system. This integrated approach not only reduces cost while achieving environmental goals, but it also maximizes land values, improves marketability, adds aesthetic interest, and provides increased recreational opportunities.

Design out the hazard, design in the people

Often environmentally sound stormwater management facilities, such as retention basins, are fenced or hidden from view. This approach to stormwater management not only adds significant "opportunity costs" through lost building sites or recreational potential, but also sends a symbolic message that stormwater is hazardous.

There are legitimate concerns for safety and liability, but they can usually be mitigated through simple design strategies such as shallow basin depths and gently sloping sides. By designing out the hazards and designing in the people, most drainage features can be integrated into the site plan to mimic the natural hydrologic cycle, add aesthetics, and increase recreational value.

Water as an amenity



Water as a hazard

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3 Planning & Zoning

Planning and zoning practices profoundly influence the impact of development on watersheds.

Planning determines the pattern of development, what type is permitted, and its relationship to streams and other natural features. Zoning determines where particular land uses are located, requirements for parking, sizes of roadways, permitted impervious land coverage, and types of approved drainage systems.

By understanding how these powerful tools work, they can be focused to protect water quality.

Planning & Zoning

3.1 Watersheds and planning - historical context. Political decisions made a century ago affect our ability to plan for watershed quality. Understanding the historical context of watershed planning helps us to focus current efforts more effectively.

3.2 Watershed-based planning & zoning. Conventional zoning practices don't typically address the impact of development on water quality. Specific zoning approaches can be adopted to make zoning a more effective water quality tool.

3.3 Cluster/infill development. Clustering development at higher densities on a portion of a site can have a beneficial impact on overall watershed health. The denser area may have a very high percentage of impervious land coverage, but total impervious area and land disturbance will be less.

3.4 Street design standards. Streets comprise a very large proportion of land use – up to 25% of total land area. The street pavement itself is often the largest component of total impervious land coverage. A carefully designed street system can protect water quality while also serving its primary transportation function.

3.5 Parking requirements. Parking is often the greatest single land use, and usually it is made of impervious pavement. The amount of parking mandated by zoning codes and standards often far exceeds the usual parking demand. A variety of zoning and planning tools are available to provide adequate, but not excessive, parking supply.

3.6 Community education and outreach. Education and outreach are critical elements of designing for water quality protection. Generating public awareness increases general interest and acceptance and improves long-term maintenance prospects.

3.7 SWMPs, SWPPPs, and BMPs. An alphabet soup of acronyms define government regulations relating to stormwater quality protection. Understanding these regulations is a key to successfully navigating the approval process.

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Planning & Zoning
3.1

Watersheds and planning – historical context



SF Bay drains a vast watershed

In 1878, Major John Wesley Powell, the first Director of the United States Geological Survey, submitted his *Report on the Lands in the Arid Region of the United States* to the U.S. Congress on the future of the American west. In this document, Powell recognized that water would be the limiting resource in the future development of the arid west. He understood that the rectilinear surveys used to divide properties and political entities in the rainy east would not work in the drier west. Instead of boundaries drawn along arbitrary lines, Powell proposed that drainage divides, or watersheds, be the organizing land use principal.

Congress ignored Powell's recommendation, continuing its practice of dividing properties and political entities along arbitrary lines. Where waterways such as rivers or creeks were used for creating political divisions, they often were used to form the border between entities. Yet, ecologically speaking, waterways do not divide land, but unite it by collecting drainage from throughout the watershed. Thus, in the adopted planning system, the political function of a waterway is often precisely opposite to its environmental function. [9]

These kinds of political and jurisdictional barriers to watershed planning also effect the San Francisco Bay, which drains a vast regional watershed extending from the coast ranges in the east to Mount Shasta in the north to Kern County in the south to Lake Tahoe in the east. County and city jurisdictions occasionally follow watershed boundaries (like the Mayacmas ridge separating Sonoma from Napa County), but more often lie in the center of watersheds (like San Francisquito Creek which divides San Mateo from Santa Clara County).

As planners and scientists recognize the threats to water quality, they create new mechanisms to better facilitate watershed-based planning and zoning. These include specific efforts to protect specific streams, such as the San Francisquito Creek Watershed Coordinated Resource Management Process, a collaboration between two counties and multiple cities along San Francisquito Creek, as well as larger regional efforts, such as the Santa Clara Basin Watershed Management Initiative, the Alhambra Creek Watershed Program, the Alameda Creek Watershed Management Program, many regional water quality programs, BASMAA, and the Association of Bay Area Governments (ABAG).

In Powell's scheme, the San Francisco Bay Area would have been treated as a single political entity, and the counties within it would have been divided on the basis of sub-watersheds, protecting the precious water resource and making environmental planning much easier.



Major John Wesley Powell (on horseback) proposed that watersheds be the organizing land use principal in the arid west.

(photo by Smithsonian Institution)

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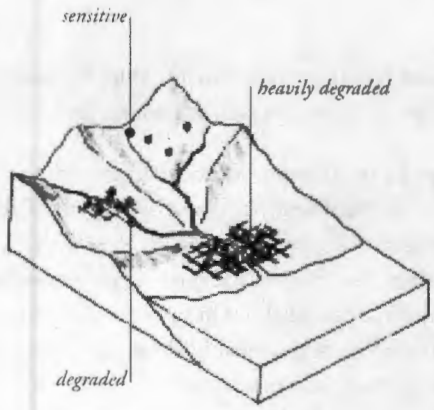
Planning & Zoning
3.2

Watershed-based planning & zoning



Land use patterns and the types of development permitted are determined by the planning process, which considers social, political, institutional, natural and other factors. In all planning and zoning, protection of natural resources must be balanced with other community priorities such as roads, schools, housing and economic development.

Limits of conventional planning and zoning. Conventional planning and zoning can be limited in their ability to protect the environmental quality of creeks, rivers and other waterbodies. This is a result of two principal factors. First, conventional zoning arises from political, transportation, and social factors that often do not mirror the natural watershed boundaries of a community. Second, conventional zoning can limit development by density (units per acre or allowable square footage). These regulations often address the maximum density of rooftop impervious cover, but have limited impact on the transportation network's contribution to impervious land coverage (roads, parking, pathways, driveways, etc.). Because this transportation component is usually greater than the rooftop component of impervious land coverage, density is an indirect and imprecise measure of forecasting the effect of development on water quality.

State planning law offers guidelines for resource protection but does not require specific protection measures. Local governments consider various priorities to develop General Plans that guide growth over a relatively long time horizon, such as twenty or thirty years. In some instances, local governments may consider the relationship of development to natural features such as creeks and hillsides, and may guide land use changes to minimize impact to these features. These local considerations may differ from city to city and can be difficult to coordinate regionally. In some local jurisdictions, natural factors may only be addressed to the extent of identifying hazards and land that is not suitable for development, while other jurisdictions may set a higher value on natural resource protection. Regardless of the approach of any particular local planning jurisdiction, the priorities of complex natural systems can be difficult to address at the local level, making a balanced pattern of development and resource protection at the regional level difficult to achieve.

Watershed based planning. An alternative to conventional planning and zoning is natural resource and watershed-based planning. Because such planning is natural resource-based, it begins by considering the natural resources of a given area. By being watershed-based, it orients such considerations to watershed areas, rather than only within town, city, or county lines. Such planning enables multiple jurisdictions to work together to plan for both development and conservation that can be environmentally as well as economically sustainable.

The regional approach is inherently difficult because it involves balancing the interests of many independent local governments. When practiced effectively, however, regional resource-based planning enables local and regional areas to realize economic, social and other benefits associated with growth, while conserving the resources needed to sustain such growth, including water quality.

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This kind of comprehensive planning involves four basic steps:

- identify the watersheds shared by the participating jurisdictions,
- identify, assess, and prioritize the natural, social and other resources in the watersheds,
- prioritize areas for growth, protection and conservation, based on prioritized resources, and,
- develop plans and regulations to guide growth and protect resources.

Watershed-wide plans can become very detailed, with in-depth data gathering and assessment, extensive public involvement, identification of problems and needs, development of management strategies, and long-term implementation of policies and actions. Local governments, however, can start with simpler yet important steps toward effective watershed planning, such as adopting a watershed-based planning approach, articulating this basic strategy in their General Plans, and beginning to pursue the basic strategy in collaboration with neighboring local governments who share the watersheds.

Watershed-based zoning. Some watershed protection strategies have been adopted under conventional zoning, but they typically have limited value. These strategies include large lot residential zoning, which can reduce the overall impervious area on individual lots, but expands the impervious coverage of the roadway network as well as contributing to urban sprawl.

Another approach is the widespread use of stormwater treatment devices (often called BMPs) to mitigate the impact of impervious land coverage. These devices, even in the best of circumstances, have limited value as a watershed protection strategy, and their performance is often compromised by poor design, construction, or lack of maintenance.

Some resource-based zoning policies that can be developed and incorporated into conventional zoning include:

- overlay districts,
- performance zoning,
- incentive zoning,
- imperviousness overlay zoning,
- planned unit development zoning.

The intent of each of these tools is to introduce flexibility into the zoning structure to encourage natural resource protection.

Restoration. In many cases, municipalities undertake efforts towards preservation or restoration of existing natural resources, such as streams or other water bodies. In areas with the highest levels of existing urbanization, streams may have been impacted so that they don't support habitat in their present degraded condition. It is usually not practical in these circumstances to restore degraded streams to a pristine pre-development condition, with full habitat and ecological function. In these cases, an "urbstine" condition, or one of enhanced environmental vitality consistent with the urban context, may be sought. Planners can work with the community, water quality engineers and wildlife fisheries biologists to define the criteria for an "urbstine" condition, and work to achieve those goals.

Efforts to restore biological diversity may include:

- preventing the introduction of urban pollutants to protect downstream waters,
- mitigating effects of development using biofilters, detention/infiltration basins, pervious pavements, and other strategies,
- retaining the natural riparian corridor and carefully applying measures to prevent or treat runoff,
- protecting and restoring creekbank vegetation,
- restoring the riffle/pool structure and meander length,
- preventing unauthorized diversions of water.

Ideally, General Plans need to look at development projects in the context of the entire watershed, considering site impacts in terms of an overall watershed plan.

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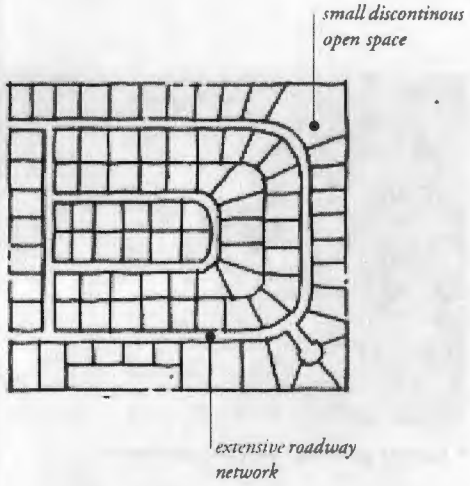
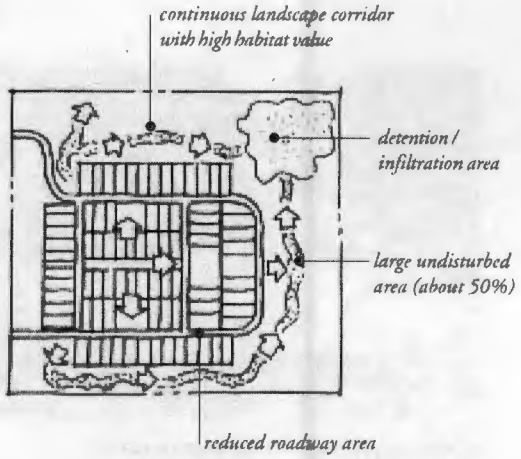
Planning & Zoning
3.3

Cluster / infill development





Conventional development standards use setbacks, frontages, roadway geometry, and other methods to arrange individual buildings on individual lots. Development based on the individual lot usually creates a homogeneous community, an extensive roadway network and other infrastructure systems.

Cluster development, a site planning technique in use for several decades, considers not only individual lots, but larger site boundaries. It concentrates development on one portion of a site, and conversely maintains more of the site in open space. One of the principal results of cluster development is reducing the length of the roadway network. Because the other infrastructure elements, such as sewer, power, telephone, and water follow the roads, their costs are also reduced. This means that cluster development can be significantly less expensive to build than conventional single lot development. On-going costs for city services, such as police and fire protection, are also reduced, because the community is more concentrated and therefore more efficiently served. Finally, cluster development provides increased area for passive recreation, because the open space is concentrated in a public or semi-public place, rather than divided in many large, private yards. However, cluster developments can face resistance in the marketplace, because home buyers sometimes prefer the larger lot sizes and wider streets of conventional development patterns.

From a water quality viewpoint, cluster development has multiple benefits compared to conventional zoning. These include:

- reduced impervious surface area by 10 to 50%,
- reduced stormwater runoff,
- reduced encroachment on stream buffers,
- reduced soil erosion since 25 to 60% of site is never cleared and steep hillsides are avoided,
- reduced need for expensive flood control measures,
- larger urban wildlife habitat islands, and,
- reduced reliance on automobiles, because shorter distances make pedestrian, bicycle and mass transit more attractive.

Most cluster development zoning policies have not been explicitly created to support water quality protection. To enhance these benefits, proponents of cluster development for stormwater quality protection have suggested the following cluster development criteria:[10]

- significant impervious surface reduction from reduced roadway network compared to conventional zoning,
- minimum site size (approximately 5 acres),
- minimum open space requirement of approximately 50% of total site,
- consolidation of open space, such that at least 75% is in a contiguous unit for habitat value,
- maintenance of approximately half of the open space in undisturbed vegetated areas (i.e. wetlands, forests, meadows), with the other half as a community green space (i.e. turfgrass, playgrounds, constructed stormwater basins),
- formation of private legal entity to maintain open space in perpetuity (e.g. homeowner's association), and,
- dedication of open space to a public open space district.

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Planning & Zoning
3.4

Street design standards



A typical pre-war residential street
28 foot wide with tree-lined parkway between the curb and sidewalk. This traditional design can be found in older neighborhoods throughout the Bay Area.



A typical post-war residential street
36 foot wide with no parkway between sidewalk and curb. This modern design can be found in newer neighborhoods throughout the Bay Area.

Streets are at the nexus of a wide variety of land use and environmental issues. An understanding of their scope, history, and function helps to explain their central importance in the design of development for stormwater quality.

Considered a number of ways, the street is a large design element. In a typical neighborhood, the public right-of-way – the street – comprises approximately 20 to 25% of total land area, making it the single most important determinant of neighborhood character. Streets also can comprise up to 70% of a community's total impervious land coverage, with the remainder of impervious land coverage from rooftops and other structures. This can make street design the single greatest factor in a development's impact on stormwater quality. Because the street exists in the public right-of-way, it comprises a large proportion of total public open space in a typical development. It is also subject to municipal ordinances, standards, and management, giving local jurisdictions a great deal of control over street design. For these reasons, the street is the one of the most important design elements in site planning, and an element that can be most directly affected by local ordinances and policies.

Residential streets. Residential streets present a significant opportunity to apply design for water quality. Unlike streets in commercial and industrial settings, which must be sized to accommodate large trucks, high speeds, and heavy volumes, residential streets typically are intended for low volume, low speed automobile traffic.

Prior to World War II, traditional residential streets were designed as multiple use spaces, shared by pedestrians, children at play, animals, and low volumes of vehicular traffic traveling at low speed. The prototypical residential subdivision, laid out by Frederick Law Olmsted at Riverside, Illinois, in 1869, has 24 foot wide streets with concrete curb and gutter, lined with broad 12 foot wide parkway strips planted with trees. Outside of the parkway strip is a 5 foot wide sidewalk on both sides.[11] This model was copied all over the United States, and many pre-war neighborhoods can be found today with similar traditional street geometries.

After World War II, new street standards were developed to facilitate the automobile, which was growing both in dominance and number. Standards set by professional associations such as the Institute of Transportation Engineers (ITE) and the American Association of State Highway and Transportation Officials (AASHTO) as well as rules promulgated by the Federal Housing Administration increased paved area by up to 50% compared to pre-war designs, setting typical residential street width at 36 feet, plus curb, gutter and 5 feet of sidewalk on both sides.[12]

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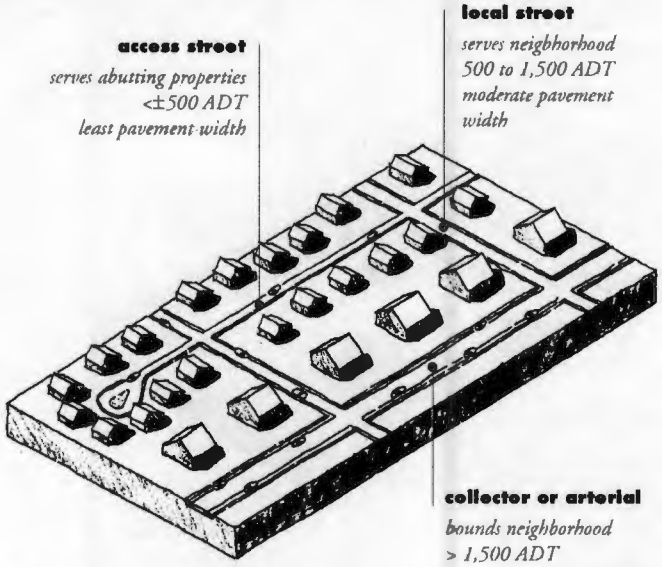
Planning & Zoning
3.4

Street design standards, continued



3.4a Street hierarchy

These standards were applied in communities throughout the Bay Area and the United States. For ease of maintenance, many communities abandoned the parkway strip between the curb and sidewalk, bringing the sidewalk flush with the back of the curb and eliminating the street trees. In a typical 50 foot wide right-of-way, this 46 foot wide pavement section (36 feet of street plus 10 feet of sidewalk) creates 92% impervious land coverage in the right-of-way. Compared to the inviting, park-like space of the original Olmsted model, with its 57% impervious land coverage (34 feet of pavement inside a 60 foot right of way), the modern residential street with its 90% impervious coverage can be a hot, treeless place that generates signifcant runoff.

Today professionals from many fields, including transportation engineers, landscape architects, urban designers, and environmental scientists, are reevaluating residential streets with the intent of creating new standards that are more hospitable and more environmentally responsible. New street standards based on the pre-war models (known as "neo-traditional design") are now being studied and adopted in municipalities across the country. At the national professional level, ITE has published neo-traditional street standards that permit local streets between 22 and 30 feet wide, allowing parking on both sides, with or without curbs.

3.4a Street hierarchy. Municipal standards generally classify street widths by the planned function of the street: local, collector or arterial. *Local streets*, the smallest class, are intended to provide access to abutting properties, and have a typical average daily traffic (ADT) of less than 1,500 vehicles. By definition, through traffic and truck traffic are generally discouraged on local streets. *Collector streets* are an intermediate class, intended to collect traffic from local streets and deliver it to larger arterial streets. They also can serve as the primary traffic route within a residential or commercial area, and have a typical ADT between 1,500 and 3,000. Finally, the largest class (except highways and freeways), *arterial streets,* have an ADT between 3,000 and 10,000, and are intended to provide long distance travel, with controlled intersections and higher speeds. For residential design, local streets are most relevant.

A survey of Bay Area municipalities reveals that the **typical current standard** for a two-way local street with parking on both sides requires two moving lanes, plus two parking lanes, plus curb, gutter and sidewalks each side, making a total of 40 to 50 feet of pavement within a typical 50 foot right-of-way (see table).

Yet, the number of vehicle trips on a local street can vary considerably, depending on the number of abutting dwelling units.

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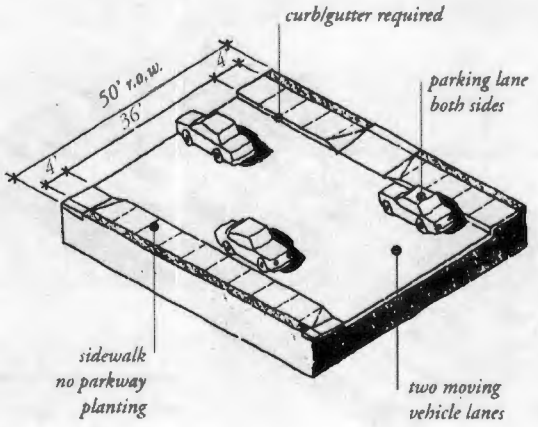

Typical current standard for a local street:

90± % impervious land coverage

Given the generally accepted rule-of-thumb for residential street design of 10 vehicle trips per day per dwelling unit, a street with ten single family homes can be expected to generate an ADT of 100, or an average of one vehicle trip approximately every 15 minutes (every 6 minutes in the peak hour). In comparison, a local street serving one hundred homes (1,000 ADT) will generate an average of one vehicle trip every 90 seconds (every 30 seconds in the peak hour). When built to typical municipal standards, the two mandated moving lanes of a local street use a great deal of land area for very little traffic. If the street is considered in terms of space, rather than lanes, a central space wide enough for one vehicle can be retained for movement, with parking and waiting space along both sides. In the infrequent instance when two vehicles approach in opposite directions, one vehicle can pull into the parking lane to allow the other vehicle to pass in the central moving space. The many driveway openings on either side of the street ensure than at any given segment of the street some space will be available for waiting, even if parking spaces are full on both sides. On lightly traveled streets, the minor inconvenience of waiting for oncoming traffic does not occur very often, making a shared central moving space feasible for streets serving up to 50 dwelling units (500 ADT, one vehicle every 3 minutes average, every 1.5 minutes peak).[13]

Impervious land coverage and street design standards.

Most Bay Area municipal street standards mandate over 80% impervious land coverage in the public right-of-way. Alternative standards can significantly reduce impervious land coverage while meeting access needs of local, residential streets.

Representative local street standards for Bay Area municipalities.

Jurisdiction	Street width	curb/gutter required	sidewalk required	parkway planting	r.o.w. imper.
Alameda Co.	40 ft.	yes	5'/side	no	100%
Concord	36	yes	4'/side	varies	90%
Contra Costa Co.	32	yes	4'/side	no	78%
Palo Alto	40	yes	4'/side	yes	85%
San Jose (std.)	35	yes	5'/side	no	100%
San Mateo Co.	36	yes	4'/side	no	94%
Alternative street standards for local and access streets.					
Neotraditional	28±	no	4'±	yes	74%
Rural	20±	no	no	yes	36%
San Jose (alt.)†	30	yes	4'/side	yes	81%

(All standards reflect minor or local street standards for flat areas to accommodate two way traffic, with parking both sides, typical right-of-way between 45 and 60 feet wide.)

† San Jose Narrow Residential street standard, parking one side only.

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Street design standards, continued

Unlike most municipal standards, which set street width by number of vehicle lanes and roadway classification (local, collector, arterial), street design by anticipated traffic volumes (ADT) allows for varying pavement width to match usage. Using the analogy of stream flow, this "headwaters streets" system allows the most "upstream" streets, those serving approximately 50 adjacent dwelling units, to have widths as low as 16 feet while allowing two-way traffic. As traffic volumes increase on neighborhood streets, pavement widths also increase, just as streams widen downstream to accommodate increased water volumes.[14] In practice this generates a new class of street for very low traffic volumes, referred to as "access" streets, which are below "local" street in the standard street hierarchy.

For example, an access street serving 50 single family homes (25 each side) with 50 foot width lots would require 1,250 linear feet of street [(50 sfh/2) x 50 ft = 1250]. A 36 foot wide street would cover 45,000 square feet, usually in impervious asphalt or concrete pavement. A 26 foot wide street would cover 32,500 square feet, a reduction of 12,500 of impervious land coverage. Assuming street construction costs of $3 per square foot, this reduction in pavement generates a $37,500 reduction in development costs, or $750 per lot. This does not account for added cost reductions in reduced need for drainage systems because of smaller impervious land coverage. Even greater reductions in pavement can be achieved if on-street parking is not required on both sides the entire length of the street, or if sidewalks are not required on both sides.

General considerations for residential street design. Alternative standards are feasible for local residential streets that employ "neo-traditional" or "headwaters street" design. These alternative standards can reduce impervious land coverage and provide drainage systems with less impact on stormwater quality compared to current typical municipal street standards, while accommodating local traffic and emergency access.

Street designs are often controversial, and development of new street standards must meet a variety of engineering, public safety and functional criteria. Municipal agencies with a strong interest in street design, such as Public Works, Planning, and emergency service providers, often differ on priorities and approaches. Alternative standards must be developed cooperatively so that each agency's legitimate interests are accommodated. In municipalities which have not adopted alternative standards, developers can propose these designs as part of a planned unit development zoning, subject to government approval.

Several communities in the United States have recently adopted new street standards for local access streets, including Bucks County, PA., Boulder, CO., Portland, OR, and San Jose, CA.[15] These new municipal street standards vary, but they all include reduced street widths (generally between 16 and 30 feet), shared moving lanes, reduced design speeds, and an ability to omit curbs, gutters and/or sidewalks on one or both sides. New ITE neo-traditional street design standards currently in review may help formalize acceptable alternative residential street designs.[16]

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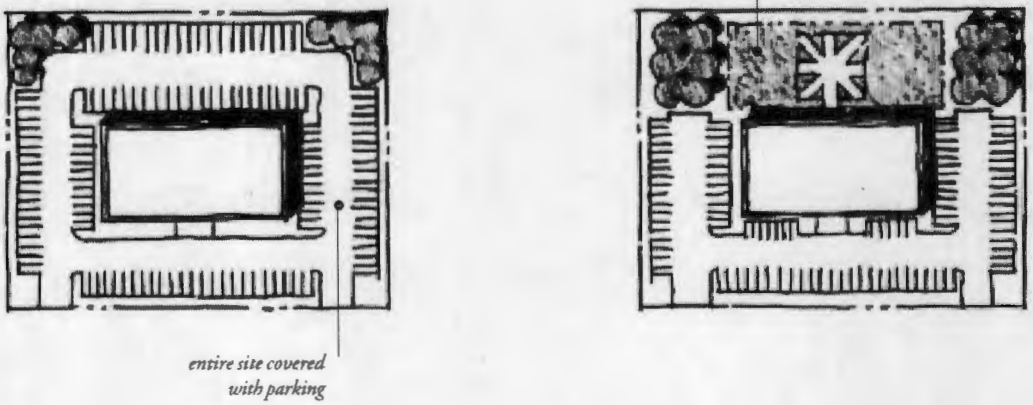
Planning & Zoning
3.5

Parking requirements



Parking is the greatest single land use in most industrial, office, and commercial development. Municipal codes usually mandate a minimum amount of parking and the type of approved pavement. Adjusting these requirements can significantly mitigate the negative environmental impact of parking, while still providing adequate storage space for cars.

Amount of parking. Parking minimums have been established by planners and professional associations, such as Urban Land Institute, the Institute of Transportation Engineers, the National Parking Association, and the American Planning Association. These minimums are based on empirical methods, usually by counting cars parked at existing land uses, identifying the peak use, and then requiring developers to supply enough parking to meet the peak demand (or near peak demand). These standards typically result in a large, underutilized parking capacity.

For example, a 1995 study of office buildings in ten California cities found that peak parking demand averaged only 56% of capacity. In shopping centers, parking lot design standards supply enough parking for the demand at the "20th busiest hour" of the year. This means that for all but 19 of the 3,000 hours that a typical center is open annually there will be a parking surplus, leaving at least half of the center's spaces vacant at least 40 percent of the time.

Because of these high minimum standards, parking and its associated transportation system usually account for the majority of land use in commercial and industrial sites. A recent survey completed by the City of Olympia, Washington, for example, found that over half of the city's commercial sites were devoted to parking and driveways.

Not only do these standards and their related zoning ordinances mandate high parking minimums– developers are free to build more. They usually do, if they can, because retailers and office tenants demand "plenty of parking" – they naturally want to make it easy for shoppers and tenants to reach their sites. Also, conventional asphalt parking lots are less expensive to build and maintain than turf or landscaped areas, further contributing to the tendency to build even more than the minimum standards.

Land Use Solutions. Several solutions can promote a more balanced approach to parking and land use.

a. institute paid parking. Studies show that motorists park free for 99 percent of all automobile trips. By pricing parking at its true cost, natural economics would tend to reduce demand, free more land for other uses, and encourage alternative transportation. Employer-paid parking programs, with cash incentives for employees who opt not to park, or employee-paid parking, have both proven effective at reducing parking demand in commercial and office uses.

b. reduce parking minimums. Reducing the mandated parking minimums in zoning ordinances can significantly reduce the amount of parking provided. For example, reducing the office use minimum from four to three spaces per thousand square

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Parking requirements, continued

feet (1:250, 1:333) would reduce the number of required parking spaces for a 100,000 square foot office building from 400 to 300, a reduction of 25%, or approximately an acre of land that could be converted from parking to landscape that can be designed to filter and infiltrate the runoff from impervious surfaces (see 6.6). Depending on the number of building occupants and availability of alternative transportation, reduced parking minimums may be adequate for a variety of uses.

c. establish parking maximums. Some municipalities, in seeking to reduce the negative impacts of these large parking demands, have established *maximum* parking ratios instead of the more conventional parking minimums. For example, Lacey, Washington, has developed a phased program to implement maximum parking standards for its downtown. These standards will be reduced in three year intervals, giving businesses and travelers time to adjust driving patterns. Parking maximums prevent developers from building more than the maximum allowed parking, and the scarcity of parking, usually coupled with pricing strategies, naturally reduces parking demand and encourages alternative transportation. [17]

d. allow reduced minimum requirements as incentives. Some municipalities allow reduced minimum parking requirements as incentives for transportation demand management programs or for developments that encourage alternative transportation such as live-work, transit oriented residences, office buildings with bicycle commuter facilities, or neighborhood retail shopping areas. In these areas parking requirements can be reduced by as much as 20 to 30%, reflecting the fact that a significant proportion of people do not park at the site.

e. establish landscape reserves. Another strategy to reduce the amount of parking that allows for parking expansion if needed is to identify "landscape reserve" on site plans. These landscape reserves are areas adjacent to parking lots that are of appropriate size and geometry to accommodate additional parking. They are initially installed as landscape areas, but identified as "landscape reserve" on approved plans. If the need for parking increases beyond the amount originally provided, the landscape reserve can be converted to parking.

f. allow shared parking facilities. Shared parking facilities are another strategy to reduce overall parking supply, while still meeting demand. For example, a movie theater's parking demand is usually evenings and weekends, while office building demand usually peaks on weekdays-- these uses can share a single parking lot, owned either by the city, or by one or both of the property owners. In commercial districts, parking supply for shoppers can be maintained by allowing employees to park on nearby residential streets, since resident parking peaks in the evening while employee parking peaks during the day. There are considerable obstacles to these shared parking approaches, such as zoning regulations that do not allow combining parking for separate uses, resistance of neighborhood residents towards employee parking on their streets, and liability and insurance issues surrounding sharing of a single, privately owned parking facility by multiple property owners.

g. promote parking garages. Underground or above ground parking garages reduce land coverage by allowing parking to be stacked or combined with building area. The expense of these solutions can be mitigated by providing building credits, in-lieu parking fees, subsidies, or fee waivers.

Parking lot paving. Aside from the amount of occupied land area, the type of parking lot pavement has a direct impact on stormwater quality. Parking lots are usually built of impervious pavement, such as conventional asphalt, and their large land area makes them a significant contributor to environmental degradation. Permeable materials such as porous asphalt, crushed aggregate, open-celled unit pavers, or turf block can be suitable parking lot pavements, especially for parking stalls (as opposed to aisles– see 6.3a Hybrid parking lot), for outlying spaces that are only typically used during peak demand (see 6.3c Overflow parking), or for occasional uses such as churches or sports stadiums.

Many municipalities mandate an impermeable pavement such as conventional asphalt or concrete for parking lots and prohibit the use of other materials. Where these impermeable pavements are mandated, rewriting municipal codes to allow permeable pavement alternatives is a prerequisite for their use.[18]

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Planning & Zoning
3.6

Community education and outreach

All those involved in the development industry need to understand the impacts of development on water quality, as well as the appropriate application of various strategies. This includes not only those who design and build, but the residents, occupants, and maintenance staff.

Community education and outreach are the key to building this understanding. Furthermore, community education and outreach on stormwater impacts is a minimum requirement of the NPDES regulations.

The NPDES regulations mandate public education and outreach and public involvement/participation as *minimum* control measures.

The activities enumerated in the regulations include:

- distributing of educational materials to the community
- conducting outreach activities on the impacts of stormwater
- providing public education on how to reduce stormwater pollution
- informing individuals and households on proper maintenance of stormwater systems
- teaching how to limit the use and runoff of garden chemicals
- promoting local stream restoration through conservation corps and other citizen groups
- participating in storm drain stenciling
- targeting specific industries or groups with specific stormwater impacts (e.g. restaurants and grease impacts on storm drains)
- engaging the public in a participatory process to develop, implement and review the local stormwater management program
- impaneling a group of citizens to participate in the decision-making process, hold meetings, or work with volunteers
- reaching out to all members of a community.

This outreach effort can be directed towards members of the public and individuals, as well as to targeted groups of commercial, industrial, and institutional entities likely to have significant stormwater impacts. For example, restaurants can be targeted with specific information on the impact of grease on storm drains, and architects can be targeted with specific information on selection of building materials and design for stormwater quality management.

Finally, it is important to involve the public in the development of outreach programs, and to tailor the message to address the viewpoints and concerns of all communities, including minority groups, disadvantaged communities, and children.

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Planning & Zoning
3.7

SWMPs, SWPPPs, and BMPs

The current construction environment presents designers and developers with an array of mandates, regulations, and conditions for approval that relate to stormwater quality. By understanding the alphabet soup of acronyms, review agencies, and conditions it becomes easier to navigate the approval process and anticipate the design strategies that will be successful.

The National Pollution Discharge Elimination System (**NPDES**), a provision of the federal Clean Water Act, mandates that each large population center obtain a permit to discharge stormwater. BASMAA's seven participating stormwater programs, for example, serve as umbrella organizations for their co-permittee municipalities.

These NPDES permits are issued by the Regional Water Quality Control Board (**RWQCB**), a division of the State of California Environmental Protection Agency. There are nine regions throughout the state, and each Regional Board monitors each permittee for compliance.

To meet the goals of the NPDES permit, each local stormwater program, and each co-permittee within a program, establishes a Stormwater Management Plan (**SWMP**). These SWMPs give specific local requirements targeted to meet the environmental needs of each watershed, as well as reflecting the political consensus of each community. Because of the differences in each watershed's environmental context, as well as each permittee's attitude towards balancing environmental protection with economic growth, regional SWMPs may have different goals, methods, or targets.

In order to comply with the NPDES permit and requirements for a construction permit, each new development project resulting in a land disturbance of five acres or larger must prepare a Storm Water Pollution Prevention Plan (**SWPPP**). In a typical project, a SWPPP is a document consisting of narrative and a separate sheet within the construction document set, usually in the Civil Engineering or Landscape series, that outlines both a plan to control stormwater pollution during construction (temporary controls) and after construction is completed (the permanent constructed stormwater pollution prevention elements). The permanent controls are usually found on the sheet within the construction documents.

A SWPPP is a series or collection of Best Management Practices (**BMP**). The term Best Management Practice is a widely used, but somewhat inaccurate nomenclature, because the elements described as BMPs are not necessarily always best, nor are they always management practices. They can range from public education, like stenciling catch basins (which may not be as good as replacing the catch basin with an infiltration area), to site planning and design features, like a vegetated swale (which requires management but is not a management practice), to street sweeping (which actually is a management practice). In any case, the term BMP has wide currency and has been formalized in many local ordinances and codes. This document doesn't explicitly use the term BMP to describe the design alternatives presented, though each could be identified as a BMP in any particular SWPPP, depending on the requirements of the local SWMP.

The true management practices widely adopted in the past twenty years like stenciling catch basins and street sweeping, can be considered *"first wave BMPs."* These housekeeping practices have value, and deserve to be continued. But they perpetuate a conventional approach to stormwater management based on collection and conveyance.

Given development pressures and the environmental goals established by the Clean Water Act, more fundamental changes are required. Because the most economical and effective strategies arise in site planning and design, this document emphasizes ways to minimize the creation of new runoff, and to infiltrate or detain runoff in the landscape.

These *"second wave BMPs"* go beyond incremental changes to a conveyance storm drain system. They require a new way of thinking about impervious land coverage and stormwater management. They are a collection of proven methods and techniques that integrates stormwater management into planning and design, that reduces overall runoff, and manages stormwater as a resource, by starting at the source.

These *"second wave BMPs"* require a new way of thinking about impervious land coverage and stormwater management.

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4 Site Design

The fundamental hydrological concepts and stormwater management concepts can be applied to site planning to generate forms that are more integrated with natural topography, that reinforce the hydrologic cycle, that are more aesthetically pleasing and that are often less expensive to build.

A few site planning principles help to locate development on the least sensitive portions of a site, and to create urban and suburban forms that accommodate land use while mitigating its impact on stormwater quality.

The application of these principles in developing a site plan will create opportunities for employment of a wide variety of simple design techniques to infiltrate significant amounts of runoff, improve aesthetics, and reduce development costs.

Site Design

4.1 Define development envelope & protected areas. Each site possesses unique topographic and hydrological features, some of which are more suitable for development than others. By identifying the development envelope and protected areas, a site plan can be generated that minimizes both environmental impacts and construction costs.

4.2 Minimize directly connected impervious areas. For decades planners, engineers and builders have been trained to get rid of stormwater. This is accomplished by connecting impervious areas to storm drains. Yet these "directly connected impervious areas (DCIAs)" are a principal contributor to nonpoint source pollution and flow impacts.

4.3 Maximize permeability. A parallel strategy to minimizing DCIAs is to maximize the permeability of the site. This is accomplished both by preserving open space and by using permeable pavement surfaces where feasible.

4.4 Maximize choices for mobility. By planning for alternative modes of transportation – bicycles, pedestrians, transit – reliance on automobiles can be reduced.

4.5 Use drainage as a design element. Unlike conveyance storm drain systems that hide water beneath the surface and work independently of surface topography, a drainage system for stormwater quality protection can work with natural land forms and land uses to become a major design element of a site plan.

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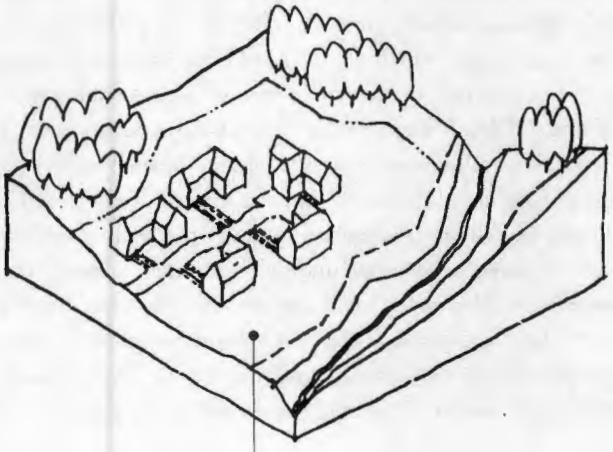
Site Design

4.1

Define development envelope and protected areas

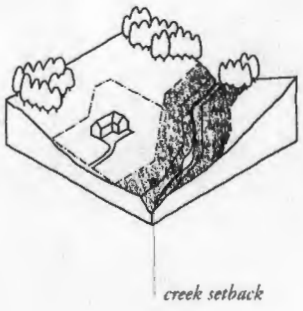


development envelope

The first step in site planning is to define the development envelope. This is done by identifying protected areas, setbacks, easements and other site features, and by consulting applicable local standards and requirements. Site features to be protected may include important existing trees, steep slopes, erosive soils, riparian areas, or wetlands.

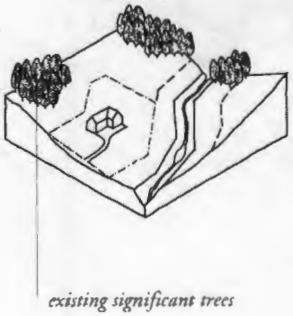
By keeping the development envelope compact, environmental impacts can be minimized, construction costs can be reduced, and many of the site's most attractive landscape features can be retained. In some cases economics or other factors may not allow avoidance of all sensitive areas. In these cases, care can be taken to mitigate the impacts of development through site work and other landscape treatments.

Set back development from creeks, wetlands, and riparian habitats.



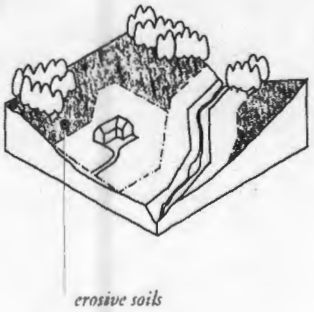
creek setback

Preserve significant trees. Trees protect soil structure, aid in soil permeability, and provide aesthetics.



existing significant trees

Avoid erosive soils and slopes. These include steep or long continuous slopes, soils high in silt or fine sand, or soils lacking vegetative cover.



erosive soils

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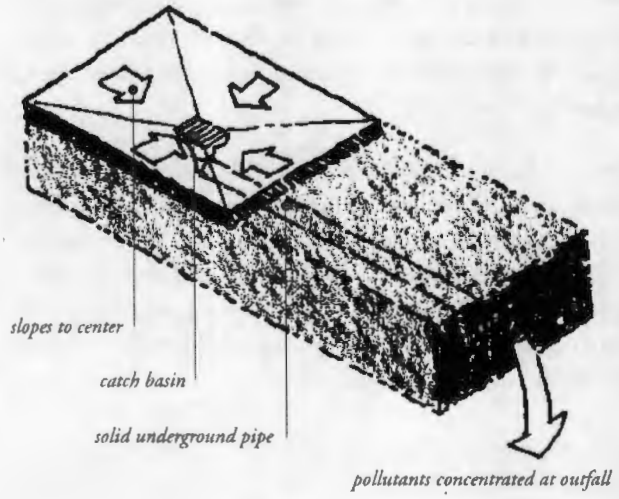
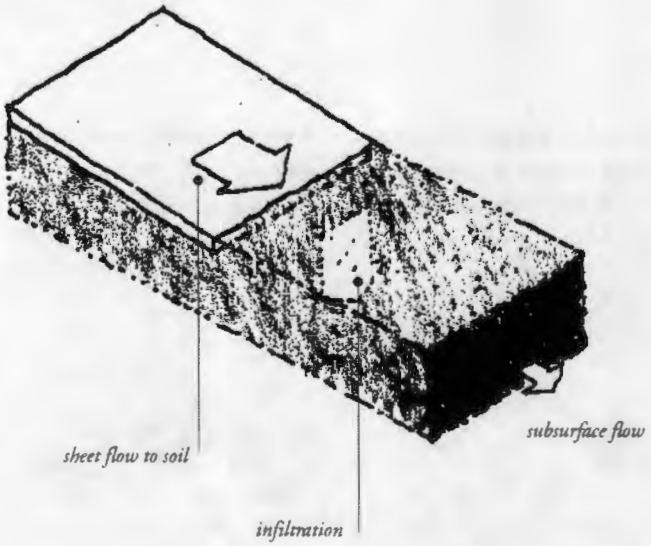
Site Design

4.2 *Minimize "directly connected impervious areas"*

Directly connected impervious area (DCIA)



Not-directly connected impervious area



Impervious areas directly connected to the storm drain system are the greatest contributor to nonpoint source pollution. Any impervious surface which drains into a catch basin, area drain, or other conveyance structure is a "directly connected impervious area (DCIA)." As stormwater runoff flows across parking lots, roadways, and paved areas, the oils, sediments, metals, and other pollutants are collected and concentrated. If this runoff is collected by a drainage structure and carried directly along impervious gutters or in sealed underground pipes, it has no opportunity for filtering by plant material or infiltration into the soil. It also increases in speed and volume, which may cause higher peak flows downstream, and may require larger capacity storm drain systems, increasing flood and erosion potential.

A basic site planning principle for stormwater management is to minimize these directly connected impervious areas. This can be done by limiting overall impervious land coverage or directing runoff from these impervious areas to pervious areas and/or small depressions, especially the first 1/3 to 1/2 inch of rain. This means that if the site is 50% impervious, then the pervious areas must have capacity to infiltrate two times the treatment depth. In this example, that is 2/3" to 1" of rain, because both surfaces are subject to rain. Larger storms may require an underground storm drain system, but even these systems can mitigate stormwater quality impacts if runoff from impervious surfaces passes through pervious areas and depressions before being collected in conveyance devices.

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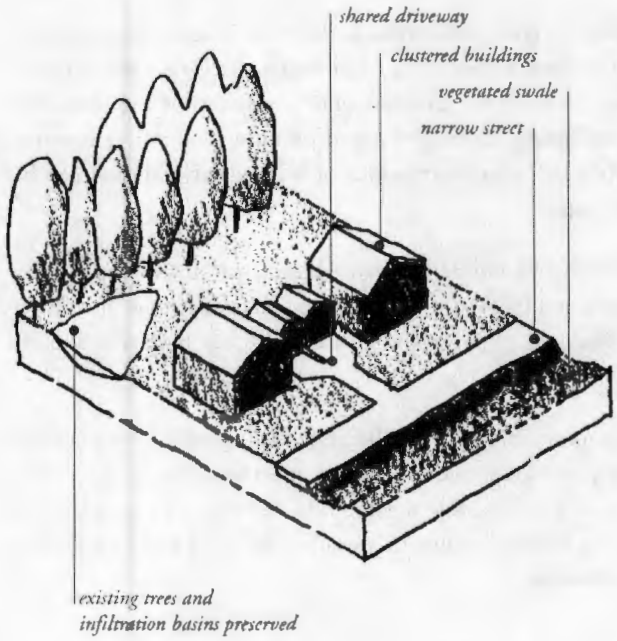
Site Design

4.3 *Maximize permeability*



Within the development envelope, many opportunities are available to maximize the permeability of new construction. These include minimizing impervious areas, paving with permeable pavement materials, clustering buildings, and reducing the land coverage of buildings by building taller and narrower footprints. All of these strategies make more land available for infiltration and open space.

Clustered driveways, small visitor parking bays, and other strategies can also minimize the impact of transportation-related surfaces while still providing adequate access.

Once site coverage is minimized through clustering and careful planning, pavement surfaces can be selected for permeability. A patio of brick-on-sand, for example, is more permeable than a large concrete slab. Gravel, mulch, and lawns are permeable ground covers suitable for a wide variety of uses. Pervious concrete and porous asphalt, used in the eastern United States, are alternative materials that can preserve permeability where a larger, more intensely used paved area is needed.

Maximizing permeability at every possible opportunity requires the integration of many small strategies. These strategies will be reflected at all levels of a project, from site planning to materials selection. In addition to the environmental and aesthetic benefits, a high-permeability site plan may allow the reduction or elimination of expensive underground conveyance storm drain systems, yielding significant savings in development costs.

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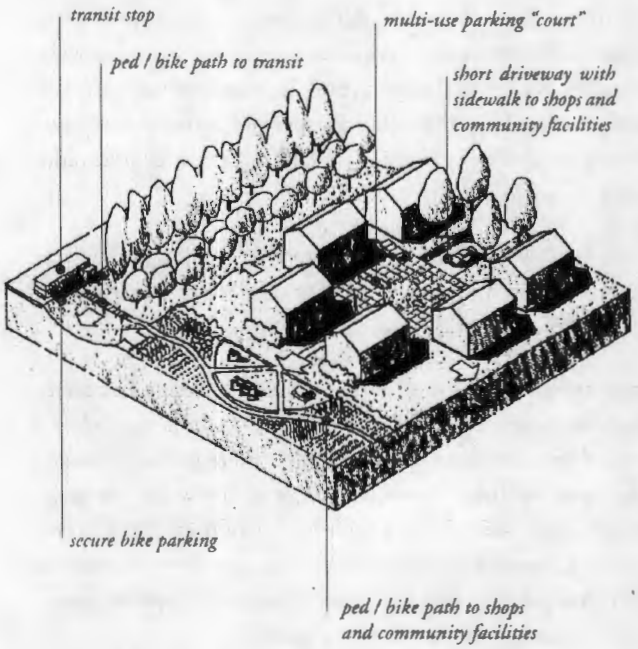
Site Design

4.4

Maximize choices for mobility



Given the costs of automobile use, both in land area consumed and pollutants generated, maximizing choices for mobility is a basic principle for environmentally responsible site planning. By designing developments to promote alternatives to automobile use, a primary source of stormwater pollution can be mitigated.

Bicycle lanes and paths, secure bicycle parking at community centers and shops, direct, safe pedestrian connections, and transit facilities are all site planning elements that maximize choices for mobility.

The automobile is a valuable, essential element of our current transportation system, and its use must be accommodated. But by giving comparable accommodation to other transportation modes, less environmentally costly choices for mobility become more viable.

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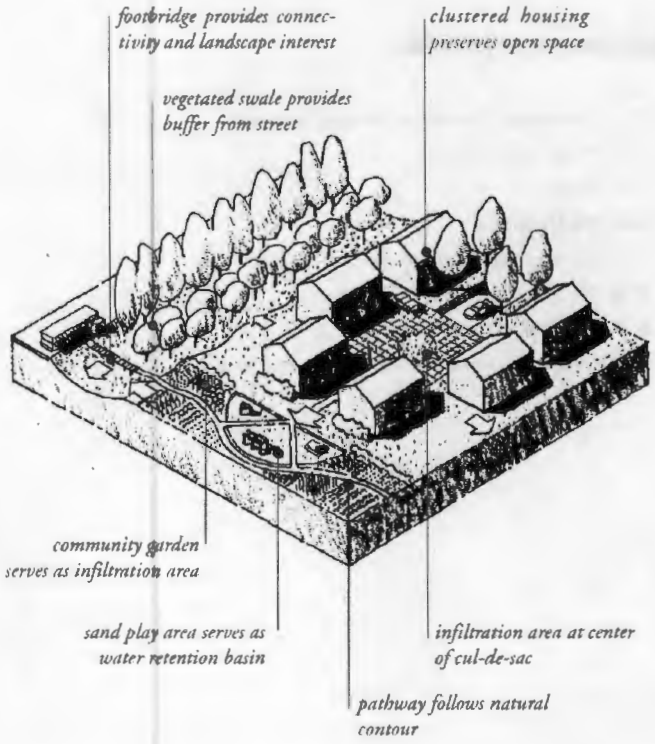
Site Design

4.5

Use drainage as a design element



Unlike conveyance storm drain systems that hide water beneath the surface and work independently of surface topography, a drainage system for stormwater infiltration can work with natural land forms and land uses to become a major design element of a site plan.

By applying stormwater management techniques early in the site plan development, the drainage system can suggest pathway alignment, optimum locations for parks and play areas, and potential building sites. In this way, the drainage system helps to generate urban form, giving the development an integral, more aesthetically pleasing relationship to the natural features of the site. Not only does the integrated site plan complement the land, it can also save on development costs by minimizing earthwork and expensive drainage structures.





Attractive? Yes. Nuisance? Not necessarily. Because of concerns about safety and liability, many developers and municipal agencies are reluctant to combine stormwater facilities with recreational uses. Yet, a well-designed stormwater facility can be safe and attractive.

This sand play area at Village Homes in Davis, California, doubles as a stormwater detention basin. Designed to hold about six inches of rainwater, this playground has been in use for over twenty years without any reported water-related accidents, lawsuits, or injuries.[19] It shows that multi-use stormwater management facilities can be both attractive and safe.

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5 Drainage Systems

Conventional drainage systems are designed to achieve a single objective — flood control during large, infrequent storms. This objective is met by conveying and/or detaining peak runoff from large, infrequent storms. Drainage systems designed to meet a single flood control objective fail to address the environmental effects of increases in runoff volume and velocity caused by development, as well as flow peaks. Increased runoff from small, frequent storms erodes urban streams and washes eroded sediment and other constituents from the urban landscape into downstream receiving waters, often damaging adjoining property and impairing their use by people and wildlife.

Today's drainage systems must cost-effectively manage flooding, control streambank erosion, and protect water quality. To do this, designers must integrate conventional flood control strategies for large, infrequent storms with three basic stormwater quality control strategies for small, frequent storms:

- *infiltrate runoff into the soil,*
- *retain/detain runoff for later release,*
- *convey runoff slowly through vegetation.*

Integrated flood control/stormwater quality control designs must meet a variety of engineering, horticultural, aesthetic, functional, economic, and safety standards. This chapter briefly outlines methods and criteria for drainage system design.

Drainage Systems

5.1 Drainage system design process
5.2 Site conditions
5.3 Soils
5.4 Pollutants
5.5 Drainage system elements
5.6 System design techniques
5.7 Water quality volume
5.8 Manufactured treatment devices

Today's drainage systems must cost-effectively manage flooding, control streambank erosion, and protect water quality.

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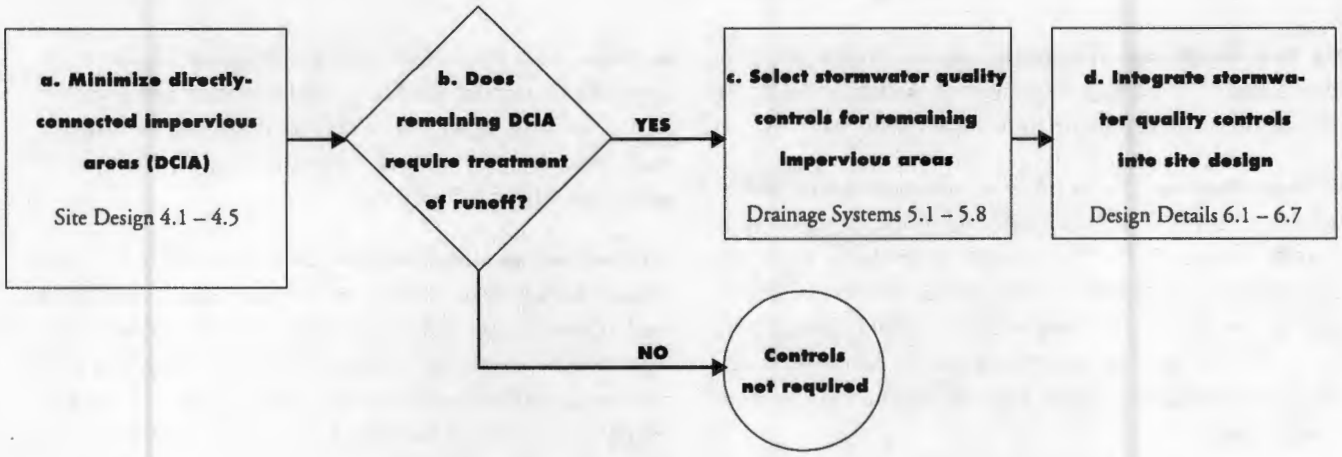
Drainage Systems

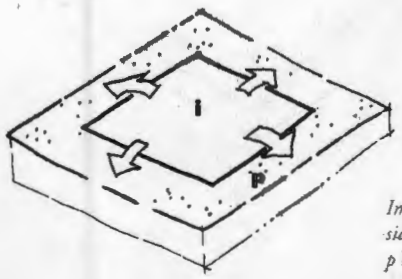
5.1 *Drainage system design process*



5.1 Drainage system design process. The simple design process described below establishes the foundation of a drainage system for stormwater quality.

a. Minimize directly connected impervious area (DCIA). Using the concepts and site planning strategies outlined previously, design a project to minimize directly connected impervious area.

The DCIA is measured by adding together the square footage of all impervious surfaces that flow directly into a conveyance stormwater system. These impervious surfaces are principally comprised of rooftops and conventional pavements. Impervious surfaces that are not directly connected to a conveyance system are not included in the calculation of DCIA. However, to be considered "disconnected," intervening pervious areas receiving runoff (p) must be at least one half the size of impervious surface areas generating runoff (i). The pervious area must also be of appropriate width, location and slope, and design to effectively manage runoff. [20]



Impervious areas are considered "disconnected" if: $p \geq 1/2\, i$

b. Identify DCIA requiring treatment. In some areas, a site's DCIA coverage may not require stormwater controls if the required treatment is based on other factors (e.g. if site is located upstream from existing or regional treatment facilities, or if it is an infill development in an existing urbanized watershed). If site DCIA coverage is not treated in another manner, some form of stormwater quality control on-site is probably needed.

c. Select stormwater quality controls for remaining impervious areas. There are three stormwater quality controls appropriate for the Bay Area: infiltration, detention/retention, and biofilters. Using these approaches, alone or in combination depending on site conditions and soils, drainage systems can be designed to reduce flows and manage pollutants.

d. Integrate stormwater quality controls into site design. The Design Details section (Chapter 6) describes the many opportunities available to site designers for reducing DCIA and incorporating stormwater quality controls into site design. Local municipalities and developers can evaluate their particular opportunities and constraints to determine practical solutions within the framework presented here. Chapter 8 has more detailed information on each of these design details.

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Drainage Systems

5.2 *Site conditions*

5.2 Site conditions. Site designers and municipal site plan reviewers must understand site conditions and use these as the basis for selecting appropriate stormwater quality controls.

a. Local climate. The Bay Area is distinctive for its widely varied local climates. Local climate will influence selection of controls for a specific site. For example, controls that rely upon vegetation to stabilize soils and filter pollutants may be appropriate in coastal areas with more moisture and/or moderate temperatures, while pervious pavements may be better in hotter, drier portions of the Bay region where vegetation must be more heavily irrigated.

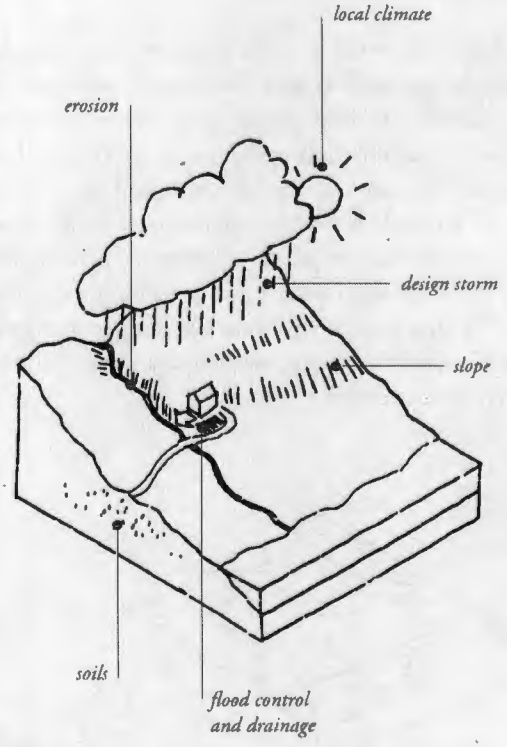
b. "Design storm" size. Design storms used to size stormwater quality controls are significantly different than those used for conventional drainage and flood control facilities. Stormwater quality design storms generally are based on the capture of a certain fraction of the average annual runoff from the site or development. The rainfall analysis presented in the California Storm Water Best Management Practices Handbook indicates that the most "cost-effective" level of stormwater quality protection occurs when about 75 to 85 percent of the annual rainfall is captured and held long enough to allow about 80 percent of the suspended solids to settle (between 12 and 40 hours). This design storm volume ranges between 1 and 1.6 times the average storm volume of about 0.05 feet (0.6 inches) in the Bay Area.[21] The actual design storm volume within this range depends on the drawdown time of the selected stormwater quality control.

c. Soils. Site designers must know the soils at the site when considering infiltration measures including pervious pavements. Soil conditions will determine whether a site is suitable for infiltration, or if a detention/retention system is required. See 5.3 Soils.

d. Erosion. Erosive soils impair the effectiveness of most stormwater quality controls, and must be stabilized before installing these controls. Excessive sediment clogs infiltration devices, rapidly fills detention basins, and covers vegetative measures.

e. Slope. Most stormwater quality controls are sensitive to the slope of local terrain. Biofilters and infiltration basins cannot be used in steep terrain, while detention basins usually can be made to work on any reasonably sized land parcel, as long as the area is not subject to landslides.

f. Flood control and drainage. Stormwater quality controls are sized to capture runoff from storms much smaller than those used to size drainage and flood control systems. Site developers should first consider an integrated system that achieves both stormwater quality and flood control objectives. In these integrated systems, runoff from small storms and the first portion of larger storms enters the stormwater quality control system. Flows exceeding the runoff volume of the stormwater quality control system are either bypassed into a separate drainage/flood control system or accommodated within the stormwater quality control system (as long as these larger flows do not "flush out" the pollutants captured from smaller storms).



5.2 Site conditions

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Drainage Systems

5.3 *Soils*

5.3 Soils. The USDA Natural Resources Conservation Service (NRCS) [formerly the Soil Conservation Service (SCS)], classifies a soil's hydrologic effects into four Hydrologic Soil Groups (HSG), labeled A through D. Group A and B soils possess the greatest infiltration rates (unless soils are compacted during construction) and are generally best suited to stormwater infiltration. However, the Bay Area has a relatively high concentration of Group C and D soils, which possess lower infiltration rates that generally limit use of infiltration-based stormwater management systems.

Some soils have compound classifications, such as A/D. This indicates that the natural soil is in group D because of a high water table which impedes infiltration and transmission, but following artificial drainage using such methods as perforated pipe underdrains, the soil's classification is changed to A, making it more appropriate for infiltration with proper site design.

For a specific site, the HSG designation can be obtained by referring to a local soil survey, by consulting the complete national listing given in NRCS Technical Release 55, or by performing an on-site investigation. The accompanying table presents soil infiltration rates for each soil group determined by laboratory studies and measurements. Site designers should compare the design runoff volume with the available soil storage volume to determine if infiltration is feasible, and then use the infiltration rates to determine if the design runoff volume can infiltrate within a reasonable time (generally 24 to 48 hours). For sites with Group C and D soils, retention- and detention-based strategies are often more feasible than infiltration designs.

Hydrologic soil groups (HSG)[22]

Group A: Low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well-drained sands or gravels. These soils have a high rate of water transmission.

Group B: Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained sandy loam soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C: Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of silty-loam soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

Group D: High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Typical soil infiltration rates.[23]

Soil Type	*Min. Infiltration Rate (inches per hour)*
A	0.30 to 0.45
B	0.15 to 0.30
C	0.05 to 0.15
D	0 to 0.05

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Drainage Systems

5.4 *Pollutants*

5.4 Pollutants. In a natural state, water is not chemically pure. It contains sediment, minerals, and other impurities depending on the surrounding geology and climate. These impurities do not often arrive at lakes, streams, and bays (known as "receiving waters") in concentrated form, because rainfall can infiltrate slowly into the soil, where it is cleansed by natural biologic processes. When rain falls faster than it can infiltrate, runoff flows over the surface. In most natural conditions, this runoff travels slowly through vegetation, and suspended particles settle or are filtered, sending cleaner runoff to receiving waters.

The impervious surfaces associated with urbanization prevent water from infiltrating and increase the rate of runoff. One can see rain fall on urbanized impervious surfaces – streets, rooftops, parking lots, trash and fuel handling areas, and pervious surfaces such as lawns, playfields, and exposed construction sites. Less visible are the foreign constituents that runoff carries as it flows quickly across urbanized surfaces and empties into its final receiving water. Understanding what pollutants are and where they come from can aid in designing effective stormwater treatment controls.

Constituents[24]

Sediment. Roads, parking lots, and roofs are common sources of sediment due to wear. Unstabilized landscaped areas, stream banks, unprotected slopes and denuded dirt areas also contribute. Sediment is a main component of total suspended solids (TSS), and is detrimental to aquatic life. Sediment also transports pollutants such as trace metals, nutrients, and hydrocarbons that attach to each particle.

Organic Compounds. These compounds are derived from automotive fluids, pesticides, and fertilizers. Organic compounds often attach to soil particles. Removal of soil particles from runoff via sedimentation or filtration will likely reduce the surface water pollution potential of organic compounds as well.

Nutrients. Nutrients include nitrogen, phosphorus, and other organic compounds which can be found in organic litter, fertilizers, food waste, sewage and sediment. Excess nutrients impact creek health and impair use of water in lakes and other water supply sources by promoting excessive growth of algae or vegetation (i.e. eutrophication).

Metals. Sources of trace metals (copper, lead, cadmium, chromium, nickel, and zinc) can include motor vehicles, roofing and construction materials, and chemicals. Trace metals can be toxic to aquatic organisms and, in accumulated quantities, can contaminate drinking water supplies. Removal of sediment from runoff via sedimentation combined with surface infiltration will reduce the amount of metals that reach receiving waters.

Bacteria and viruses. Sources include animal excrement (found in areas where pets are often walked), sanitary sewer overflow, and trash handling areas (dumpsters). Bacteria and viruses may pose public health and safety concerns if they are present in drinking water reservoirs or recreational water bodies.

Oil and Grease. Sources of oil and grease include motor vehicles, food service establishments, and fueling stations. Oil and grease act as carriers for heavy metals and contain hydrocarbon compounds, which even at low concentrations may be toxic to aquatic organisms.

With proper maintenance of stormwater management systems, pollutants infiltrating into the soil do not usually pose a risk of contaminated soil or groundwater. Risk is greater when there is a concentrated source of pollutants, such as in a heavy industrial site or in the case of illegal disposal.

A case study by the USGS of a groundwater recharge basin in Fresno showed that a wide variety of urban runoff pollutants were removed by sorption within the top 1.5 inches of sediment in the basin, but no pollutants were found in the sediment at depth greater than six inches. This shows that the pollutants have not traveled more than six inches deep – well above the level of groundwater wells.[25]

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Pollutants, continued

Residential developments present the least potential of contamination of groundwater or soil from infiltration systems, according to a recent study completed by the EPA.[26] This is because residential developments generally have low concentrations of pollutants, and the pollutants that are present have low solubility and mobility. High concentrations, when they occur, such as nitrates and pesticides or an oil spill in a driveway, are localized and small. Based on recent EPA analysis of groundwater protection and infiltration, the Santa Clara Valley Water District, for example, is currently considering revising their policy to permit infiltration basins 10 feet or less in depth.[27]

Risk of groundwater contamination from residential infiltration systems is further minimized by findings that metals tend to remain within the upper one foot of soil depth. Organics such as petroleum hydrocarbons migrate slowly downward– allowing natural degradation to occur. Furthermore, drinking water is typically drawn from significantly greater depths. In the Santa Clara Valley, for example, wells pumped for drinking water supply are deeper than 50 feet by ordinance. In some portions of the valley, water companies pump from in the range of 400 feet, much deeper than the potential migration of most common pollutants. [28]

Some pollutants, such as nitrates and solvents, can migrate to depths that can ultimately threaten water supply wells. Illegal dumping of waste oil, pesticides, herbicides, paint, paint thinner and other chemical products into any type of infiltration device presents additional risk to groundwater. Local water districts and other agencies generally have policies and strategies to protect groundwater supplies from these threats. These policies are an attempt to balance the environmental benefits of infiltration with the compelling need to protect soil and groundwater supplies.

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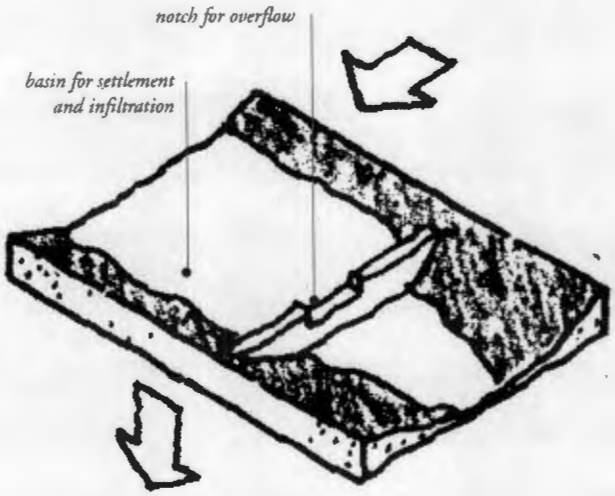
Drainage Systems

5.5 *Drainage system elements*



5.5a Infiltration basin

5.5 Drainage system elements. Drainage systems can achieve stormwater management goals by using one of three basic elements, either alone or in combination, depending on site and other conditions: infiltration, retention/detention, and biofilters.

5.5a Infiltration. Infiltration is the process where water enters the ground and moves downward through the unsaturated soil zone. Infiltration is ideal for management and conservation of runoff because it filters pollutants through the soil and restores natural flows to groundwater and downstream water bodies. Infiltration systems are designed to infiltrate the majority of runoff from small storms into the soil rather than discharging it into a surface water body. Infiltration basins can range from a single shallow depression in a lawn, to an integrated swale, pond, and underground storage basin network.

Site soil conditions generally determine if infiltration is feasible. In Soil Groups A and B (see 5.3) infiltration is usually acceptable, but it is severely limited in Soil Groups C and D. It is also limited where high groundwater, steep slopes, or shallow bedrock is present.

Infiltration basins can be either open or closed. Open infiltration basins, which include ponds, swales, and other landscape features, are usually vegetated – the vegetation maintains the porous soil structure and reduces erosion. Closed infiltration basins can be constructed under the land surface with open graded crushed stone, leaving the surface to be used for parking or other uses. Subsurface, closed basins are generally more difficult to maintain and more expensive than surface systems, and are used primarily where high land costs demand that the land surface be reclaimed for economic use.

Other design considerations include clogging that may occur in very fine or poorly drained soils and impacts on slope stability of hillside sites. Infiltration basins are best installed at the end of construction, after the site is fully stabilized. If installed early, bypass flows until the site is stabilized, as construction-related runoff may contain a high proportion of silts which can clog the basin floor.

Infiltration systems have been used by Caltrans and local jurisdictions in California for about three decades[29], though heavy Bay Area soils sometimes limit their local application. The basic

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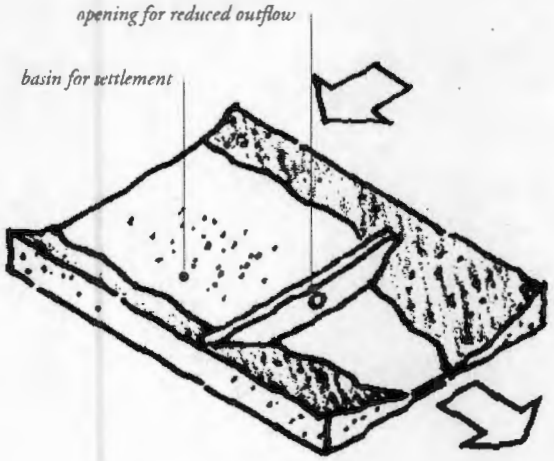
Drainage system elements, continued



5.5b Retention/detention basin

design goal of infiltration systems is to provide opportunities for rainwater to enter the soil. This is generally accomplished by retarding the flow of runoff, and by bringing it in contact with the soil, either by holding it in ponds or moving it slowly along the ground surface. Infiltration basins are most economical if placed near the source of runoff, but they should be avoided on steep, unstable slopes or near building foundations.

5.5b Retention and detention. Retention and detention systems differ from infiltration systems primarily in intent. While infiltration systems are intended to percolate water into the soil, retention/detention systems are designed primarily to store runoff for later release. Detention systems store runoff for one to two days after a storm and are dry until the next storm. Retention systems usually have a permanent pool that retains the runoff volume until it is replaced during the following storm. Properly designed retention/detention systems release runoff slowly enough to reduce downstream peak flows to their pre-development levels, allow fine sediments to settle, and uptake dissolved nutrients in the runoff where wetland vegetation is included. Retention/detention systems are most appropriate for areas where soils percolate poorly, that is, C/D soils.

The permanent pool of a retention system and the storage volume in a detention basin are both sized equal to the runoff volume from the stormwater quality design storm, plus an additional 20 percent of this volume for sediment storage. Detention system outlets are generally sized to release 50 percent of this volume within 12 to 16 hours, and the remainder in another 24 to 32 hours.

Outlets of detention systems may clog easily if not properly designed and maintained. Retention system outlets must both maintain the permanent pool and slowly release runoff during each storm. Retention times in the permanent pool commonly are set at one to three days for removal of fine sediments, and up to two weeks for removal of dissolved nutrients through biological uptake by wetland vegetation. Common outlet designs are orifices, perforated risers, and V-notch weirs, with an emergency spillway provided to safely convey storms larger than the stormwater quality design storm.

5.5c Biofilters. Biofilters, also known as vegetated swales, are vegetated slopes and channels designed and maintained to transport shallow depths of runoff slowly over vegetation. Biofilters

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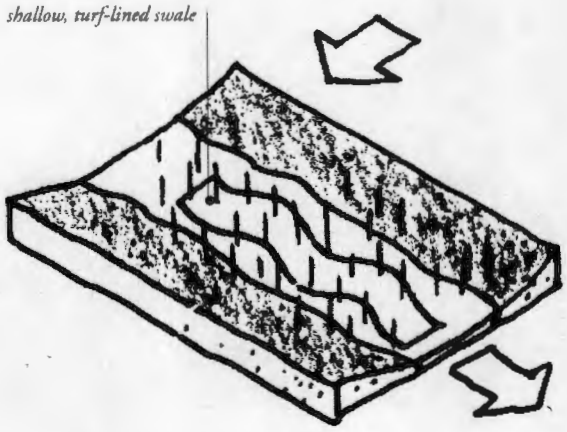

5.5c Biofilter

are effective if flows are slow and depths are shallow. This is generally achieved by grading the site and sloping pavement in a way that promotes sheet flow of runoff. For biofilter systems, features that concentrate flow, such as curb and gutter, paved inverts, and long drainage pathways across pavement, must be minimized. The slow movement of runoff through the vegetation provides an opportunity for sediments and particulates to be filtered and degraded through biological activity. In most soils, the biofilter also provides an opportunity for stormwater infiltration, which further removes pollutants and reduces runoff volumes.

Slow, shallow sheet flow is maintained in the biofilter by constructing it with gently sloping sides (3:1 slope max.), minimal longitudinal slope (1 to 2% recommended, with check dams for steeper slopes), and a flowpath length of at least 10 feet. The key concept is to move water slowly through the vegetation. The most common ground cover material is turfgrass, which must be irrigated through the dry season. For a turfgrass lined biofilter to work effectively, the turf must be mowed regularly and the cuttings removed.[29] Where slopes are less than 1% or where groundwater is high, wetland vegetation can be used in biofilters. Clay soils, or soils where vegetation are inhibited, are generally not appropriate for biofilters.

Biofilters are especially applicable to parking lots, as the long aisles can be sloped into linear grass swales to collect and treat runoff from pavement surfaces. Adjacent pavement elevations should be set slightly higher than the adjacent biofilter. If water enters at concentrated points, as opposed to sheet flow, erosion control should be included at inlets and outlets.[30]

Biofilters should be designed using the stormwater quality design storm. The peak depth of the hydrograph should be less than 3 inches and peak velocity less than 1 ft/second. Large storms should bypass the biofilter, or the biofilter should be sized to accommodate larger storms while meeting water quality criteria. The bottom width of the swale is generally 2 to 8 feet, with grass height of 4 to 6 inches and maximum water depth of less than 2 inches.

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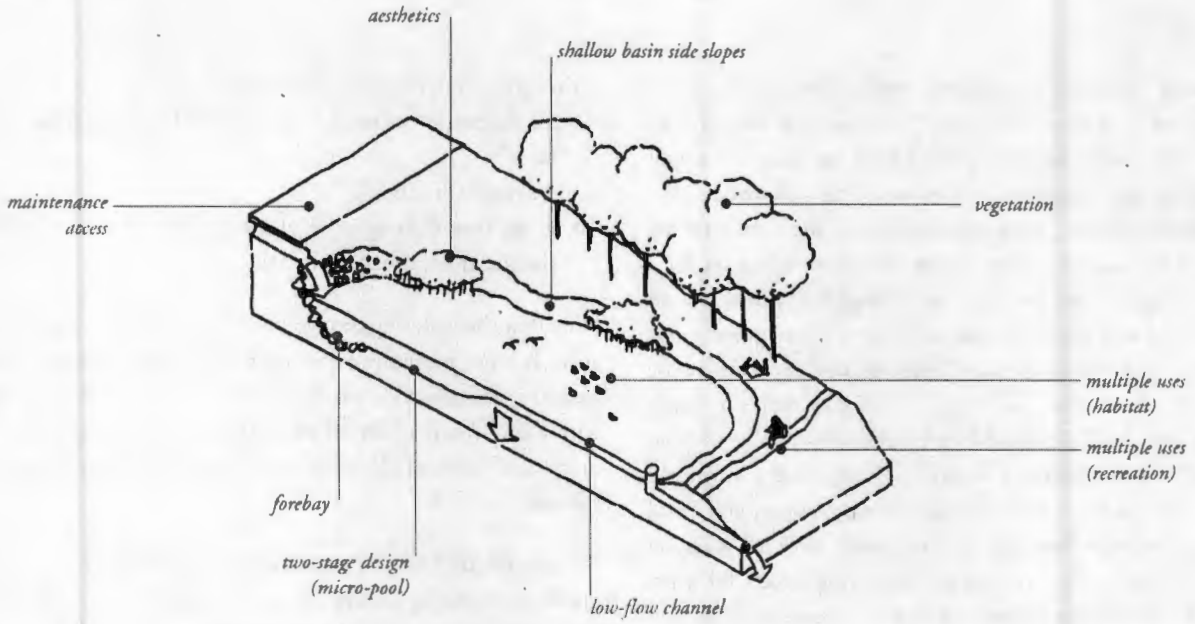
5.6 *System design techniques*



5.6 System design techniques. A variety of techniques are available to design stormwater management systems for water quality protection so that safety and aesthetics are maximized while minimizing maintenance. A key element of system design is to provide a means for managing the runoff from large storms – either a spillway or an embankment designed to withstand overtopping. The stormwater management system is usually comprised of a series of individual elements – basins, swales and pipes – in an interconnected, continuous system. Some of the techniques available to integrate these elements into the site plan and improve their functionality include:

a. Two-stage design. Place 15 to 25% of the volume at a lower stage to create a micro-pool that fills often, keeping the rest of the basin dry and sediment-free most of the time.

b. Basin side slopes. Set side slopes at 4:1 or flatter to prevent bank erosion and minimize risk of drowning.

c. Forebay. Design basins so that larger particles settle in depressions at basin inlets, and so inflows do not erode or resuspend materials in forebay. Plan for maintenance to remove trash, debris and sediment that collects in the forebay, as this is essential to protecting the aesthetic value of the basin and in reducing long-term maintenance costs.

d. Low flow channel. A low-flow channel conveys dry-weather flows and the last of captured volume to the basin outlet.

e. Vegetation. Plant vegetation to control erosion and enhance sediment entrapment.

f. Maintenance access. Access for maintenance must be included in the design of all elements. While most smaller basins and swales can be serviced by typical garden maintenance methods, larger basins may require stable vehicular access ways to forebays and outlets for periodic cleaning or dredging.

g. Multiple uses. Incorporate flood control, recreational facilities, landscaping, and/or wildlife habitat into system design.

h. Aesthetics. Integrate the basins and swales into the site to take advantage of the aesthetic qualities of water and plant materials.

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Drainage Systems

5.7 *Water quality volume*

Stormwater systems are engineered to handle specific runoff volumes and flow rates. For flood protection, systems are designed with capacity for the expected peak runoff volumes and flow rates of a given design storm size. This is known as the "peak runoff volume." Peak runoff volumes and flow rates are calculated for various design storm sizes, depending on local conditions, codes, and the potential damage that can be caused by flooding. Large drainage systems flood very infrequently, but they are expensive to construct. Therefore, drainage systems are typically sized to balance flooding risk and cost. Street drainage systems are typically designed for a 10-year storm, meaning that there is a 10 percent chance in any given year that a storm will be large enough to overwhelm the drainage system and flood the street. Since the flooding of a street once every ten years, on average, is a minor inconvenience, designing streets for a ten year storm represents a generally accepted balance of protection and cost. Homes and buildings suffer more severe damage from flooding, and are typically designed to remain protected in the 100 year storm, meaning that the probability of flooding is one percent in any given year.

The same need to balance costs and benefits applies to drainage system design for stormwater quality protection. Many pollutants may be carried by small, frequent storms. Because of this phenomenon, the water quality protection component of a drainage system can be designed to manage a much smaller volume and flow rate of water than the flood protection component. Also, because most rainfall occurs in small, frequent storms, water quality systems with relatively small capacities can have a large impact in minimizing overall runoff and preserving base stream flows.

This amount of water that can be managed to protect water quality is called the "water quality volume (wqv)." The water quality volume can be managed through pollution prevention, infiltration, retention/detention, and biofiltration.

The wqv is the amount of runoff from impervious areas that must be managed before being released into the conveyance storm drain network or receiving water. As with flood control volumes, there are a variety of approaches and standards for defining the water quality volume:

- as a proportion of total annual runoff from impervious surfaces
- as a depth of rainfall
- as the runoff from impervious surfaces of a storm with a particular recurrence interval.

Note that the water quality volume applies only to impervious areas. It is not generally necessary to treat runoff from pervious areas. For this purpose, pervious areas are defined as those areas with a coefficient of runoff of 0.30 or less, meaning that 70% or more of the rainfall landing on a given surface infiltrates into the soil.

Because BASMAA is an association of several stormwater programs representing dozens of municipalities, each with different circumstances, this document does not establish specific hydrologic criteria or a specific water quality volume.

As with flood control, there are a variety of standards and approaches for quantifying how to manage stormwater for water quality protection. The California Storm Water Quality Task Force, in its *Storm Water Best Management Practice Handbooks* (1993), and the Water Environment Federation/American Society of Civil Engineers in their jointly published *Urban Runoff Quality Management* (1998) each adopted an 80% annual capture rate as a standard of practice for the water quality volume. In the San Francisco Bay Area, this translates into approximately the first 0.50-1.25 inches of rain, or a two-year recurrence interval storm.

The Center for Watershed Protection in Silver Spring, Maryland, a leading independent research center, recommends a 90% annual capture rate. Some jurisdictions, such as the City of Olympia (WA) and the Washington State Department of Ecology, have focused on reducing impervious land coverage, adopting impervious surface reduction targets rather than emphasizing a specific water quality volume.

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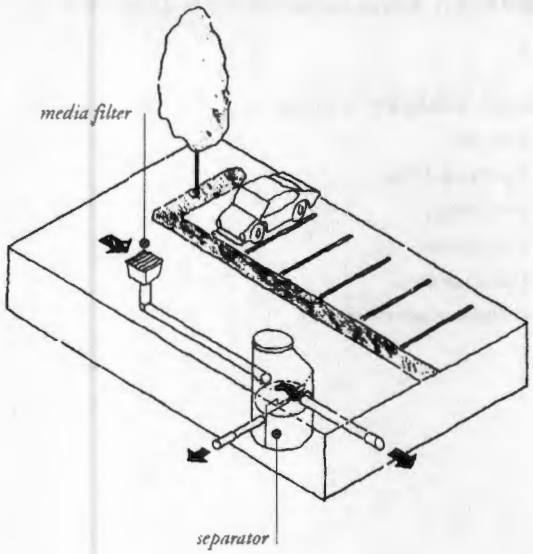
Drainage Systems

5.8

Manufactured treatment systems



Some areas are so densely developed that streets, buildings and walkways provide almost complete impervious land coverage. Here, land values prohibit the use of landscape solutions such as biofilters, infiltration basins, or wet ponds. In addition, the soil conditions in these highly urbanized locations often do not support infiltration, further reducing the practicality of landscape stormwater quality systems.

In these areas, if treatment is required, manufactured treatment systems can be inserted into a conventional conveyance storm drain system. In some cases, these devices can supplement more integrative site planning and landscape strategies.

These devices are available from many manufacturers, and generally function to separate urban pollutants from runoff. They have minimal impact on reducing overall runoff volumes or mitigating peak flows. Other considerations include both initial expense and the cost of intensive, regular maintenance recommended by device manufacturers, which can include trash removal, replacement of filters, flushing cartridges, and vacuuming of sediment.

Though promoted by their manufacturers, these devices are considered experimental by the scientific community, and their efficacy is still under study. Though many proprietary designs are available, general product categories are presented here.

Catch basin or inlet inserts. Also referred to as inlet filters, catch basin inserts are trays or baskets containing filter and/or oil-absorbent materials installed on the inside of storm drain inlets to filter and capture pollutants. They work through filtration, settling, and absorption.

Separators. These devices (also called oil/grit or oil/water separators, water quality inlets, interceptors) are structures designed to remove pollutants from a wastewater stream based on physical differences between the pollutant and water. Lighter materials such as oil and buoyant trash will float to the surface and heavier materials such as sediments will sink.

Media filters. These devices use media to filter pollutants from urban runoff. Media includes sand, gravel, peat, compost, activated carbon, fabric, and resin.

In a watershed plan that employs clustered, dense development to preserve open space, on-site treatment in the more densely developed portion of the watershed may not be necessary. Dense or clustered development allows for significant areas to be preserved and remain undeveloped, reducing the need to mitigate throughout the entire watershed.

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6 Site Design and Landscape Details

Once a site plan is generated, a multitude of small design decisions must be made, each of which will affect the hydrology of a development. These design decisions include selection of paving materials, collection of roof runoff, grading of landscaped areas, and many other details.

Any particular detail may make little difference in the overall impact of a development, but taken together, these details exert a profound influence on the ability of a development to meet stormwater quality goals. Consistent with the concept of starting at the source, these details look for opportunities to manage small quantities of runoff at many diverse locations throughout a site.

A variety of design techniques and details are presented in this chapter. Each illustrates an approach to design and construction for maximizing infiltration, providing retention, slowing runoff, and minimizing impervious land coverage. The techniques presented here are not all-inclusive, and may not be appropriate for every site or condition, but it is hoped that, once the intent of these details is understood, designers and builders will use their ingenuity to develop additional strategies consistent with water quality goals.

Site Design and Landscape Details

6.1 Permeable pavements
6.2 Streets
6.3 Parking lots
6.4 Driveways
6.5 Buildings
6.6 Landscape
6.7 Outdoor work areas

Look for opportunities throughout the site.

• For more information about these design details, see Chapter 8.

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Design Details Matrix

This matrix summarizes the details described on the following pages by their initial construction cost, maintenance cost, relative effectiveness at meeting stormwater quality goals, and their suitability for use in expansive, clay soils. Conventional approaches are also evaluated for comparison.

Legend ○ Least ◗ ● Most

	Cost (initial)	Cost (maint.)	Effectiveness	OK in clay†
6.1 Permeable pavements				
Conventional asphalt/concrete	◗	○	○	●
6.1a Pervious concrete	●	●	●	○
6.1b Porous asphalt	●	●	●	○
6.1c Turf block	◗	●	●	◗
6.1d Brick	●	◗	◗	◗
6.1e Natural stone	●	◗	◗	◗
6.1f Concrete unit pavers	●	◗	◗	◗
6.1g Crushed aggregate	○	◗	●	●
6.1h Cobbles	○	◗	◗	●
6.2 Streets				
Conventional street standards	●	○	○	●
6.2a Access street: urban neo-traditional standard	○	○	●	●
6.2b Access street: rural standard	○	◗	●	●
6.2c Urban curb/swale system	◗	◗	●	◗
6.2d Rural swale system	○	◗	●	◗
6.2e Dual drainage system	●	●	●	●
6.2f Concave median	○	○	●	◗
6.2g Cul-de-sac	○	○	●	◗
6.3 Parking lots				
6.3a Hybrid parking lot	○	◗	●	●
6.3b Parking grove	◗	○	●	●
6.3c Overflow parking	○	◗	●	●
6.3d Porous pavement recharge bed	●	●	●	●
6.4 Driveways				
Conventional driveway	○	◗	○	●
6.4a Not directly-connected impervious driveway	○	○	●	◗
6.4b Crushed aggregate	○	◗	●	●
6.4c Unit pavers on sand	●	◗	◗	◗
6.4d Paving only under wheels	○	◗	●	●
6.4e Flared driveways	○	○	●	●
6.4f Temporary parking	○	◗	●	●
6.5 Buildings				
Conventional pipe system	●	◗	○	●
6.5a Dry-well	○	◗	●	◗
6.5b Cistern	●	◗	◗	●
6.5c Foundation planting	○	○	●	◗
6.5d Pop-up emitters	○	◗	●	○
6.5e Building materials	◗	◗	●	●
6.6 Landscape				
Conventional pipe system	●	◗	○	●
6.6a Grass/vegetated swales	○	◗	●	●
6.6b Extended detention (dry) ponds	○	◗	●	●
6.6c Wet ponds	○	●	●	●
6.6d Plant species selection for infiltration areas	○	◗	●	●
6.6e Landscape maintenance for stormwater systems	◗	◗	●	●

† Details are indicated suitable for clay if they either reduce DCIA or can be designed as retention/detention systems.

• For more information about these design details, see Chapter 8.

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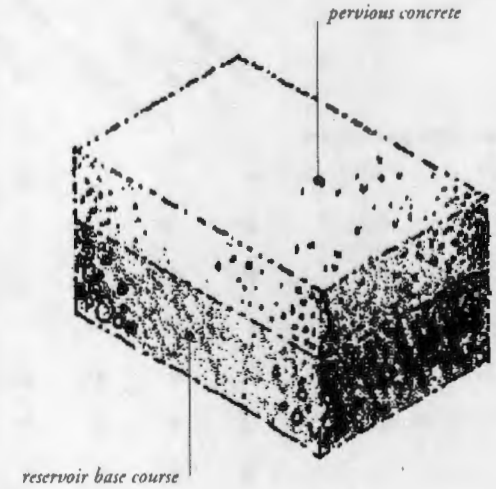
Details

6.1 *Permeable pavements*



6.1a Pervious concrete

6.1 Permeable pavements. Permeable pavements are a method of infiltrating stormwater while simultaneously providing a stable load-bearing surface. While forming a surface suitable for walking and driving, permeable pavements also contain sufficient void space to infiltrate runoff into the underlying reservoir base course and soil. In this way they can dramatically reduce impervious surface coverage without sacrificing intensity of use.

There are three main categories of permeable pavements: poured-in-place pervious concrete and porous asphalt, unit pavers-on-sand, and granular materials.

All of these permeable pavements (except turf block) have in common a reservoir base course. This base course provides a stable load-bearing surface as well as an underground reservoir for water storage. The base course must meet two critical requirements:

- it must be *open graded*, meaning that the particles are of a limited size range, so that small particles do not choke the voids between large particles. Open-graded crushed stone of all sizes has a 38 to 40% void space, allowing for substantial subsurface water storage.[31]
- it must be *crushed stone*, not rounded river gravel. Rounded river gravel will rotate under pressure, causing the surface structure to deform. The angular sides of a crushed stone base will form an interlocking matrix, allowing the surface to remain stable.

Depending on the use of the surface, a permeable, engineered base section may need to be added to support the intended load. This applies to areas subject to heavy vehicle loads, but is also important for large areas where settling could result in unwanted puddles in areas such as pedestrian walkways.

Pervious concrete and porous asphalt are two emerging paving materials with similar properties. Like their impervious, conventional counterparts, both make a continuous, smooth paving surface. They differ from their conventional counterparts in that they allow water to pass through the surface course to the rock base course that serves as a reservoir and infiltration basin for stormwater. Both pervious concrete and porous asphalt share similar design considerations.

6.1a Pervious concrete. Pervious concrete, also known as Portland cement pervious pavement, is most commonly used in Florida, where it was developed in the 1970s. Pervious concrete is a discontinuous mixture of coarse aggregate, hydraulic cement and other cementitious materials, admixtures, and water, which forms a permeable pavement.

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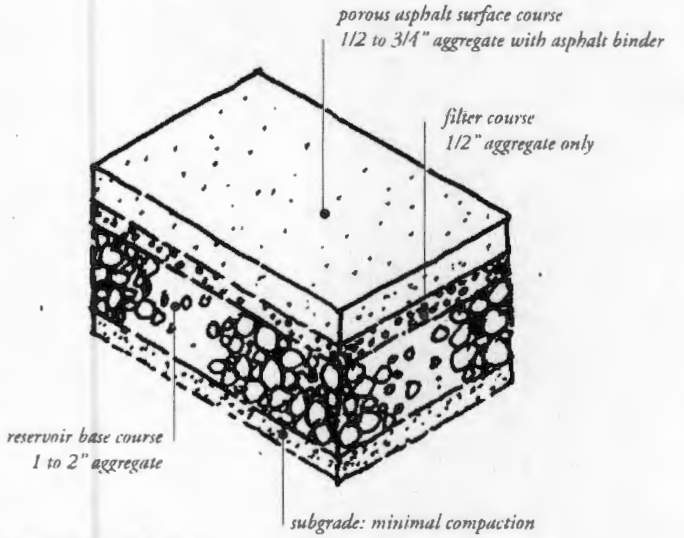
Details

6.1

Permeable pavements, continued



6.1b Porous asphalt

(adapted from City of Rockville, MD. specifications)

Pervious concrete, like other concretes, acts as a rigid slab. It has an appearance very similar to exposed aggregate concrete, and provides a similar walking or riding surface. An aggregate base course can be added to increase total pavement thickness or hydraulic storage. Pervious concrete is an extremely permeable material: in tests by the Florida Concrete and Products Association, permeability of new surfaces has been measured as high as 56 inches per hour. With improper installation or mix, permeability can be reduced to 12 inches per hour. Even after attempts to clog the surface with soil by pressure washing, the material retained some permeability.[32] Because of its porosity, pervious concrete pavements usually do not require curbs and gutters for primary drainage control.

6.1b Porous asphalt. Porous asphalt consists of an open-graded asphalt concrete over an open-graded aggregate base, over a draining soil. Unlike traditional asphalt concretes, porous asphalt contains very little fine aggregate (dust or sand), and is comprised almost entirely of stone aggregate and asphalt binder, giving it the common name "popcorn mix." Without fines filling the voids between larger particles, porous asphalt has a void content of 12-20%, making it very permeable.

Porous asphalt is used by Caltrans as a wearing course on freeways because its porosity creates a superior driving surface in rainy weather. These installations are always over an impermeable asphalt layer and are not permeable pavements.[33]

In installations where porous asphalt has been used over a permeable base, the pavement becomes an infiltration system, allowing water to pass through the surface and collect in the open-graded aggregate base, achieving stormwater management without curb or gutter systems. In these sites, mostly parking lots and light duty roads in the eastern United States, permeability has been maintained over long periods without special maintenance. The oldest porous asphalt pavement in the United States, at the University of Delaware Visitors' Center, was built in 1973, and is still permeable and structurally sound after 23 years.[34]

On light duty streets built of porous asphalt, some loss of porosity occurs in localized areas due to sedimentation or scuffing at intersections due to repeated wheel turning, but the overall performance of the pavement is not significantly compromised.[35]

Pervious concrete and porous asphalt design considerations: Sealing and clogging of the pavement surface is possible, even with maintenance and high power vacuuming. Most successful installations are in Florida and other coastal areas where slopes are

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flat, soils sandy, and winter sanding/salting minimal. Avoid installation in high traffic areas, and stabilize surrounding land to minimize sediment deposition on the pavement.

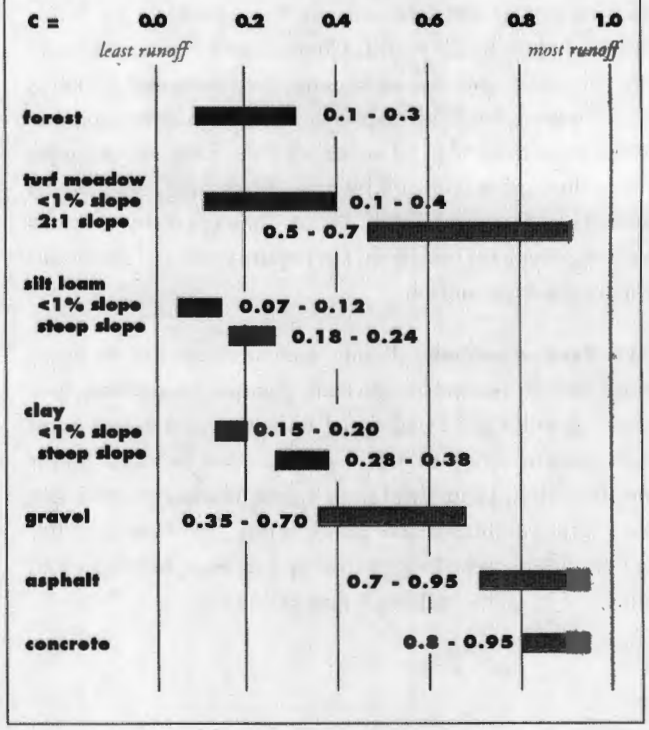
Installation must meet special requirements. Subgrade uniformity is essential, and slopes over a few percent are not recommended because of potential subgrade erosion. A permeable base and an infiltration rate of at least 0.5 inches/hour in the native soil is required (i.e. a HSG A or B soil).

Installation of pervious concrete and porous asphalt requires special tools and has narrower tolerances than traditional concretes or asphalts. Finally, lack of independent testing (especially in the case of pervious concrete) limits the ability to make judgements about long-term performance.

Unit costs of these permeable pavements are greater than traditional concrete and asphalt, though this cost can be offset by not building a curb and gutter drainage system. Potentially a valuable means of reducing impervious land coverage in areas requiring a large, smooth pavement, their relative unfamiliarity, special requirements and lack of conclusive testing have made pervious concrete and porous asphalt little used in the San Francisco Bay Area to date. If these materials begin to gain wider local acceptance, their relative costs will likely go down.

Coefficients of Runoff

The chart below illustrates typical ranges for the coeficient of runoff (C) for various materials.[36]



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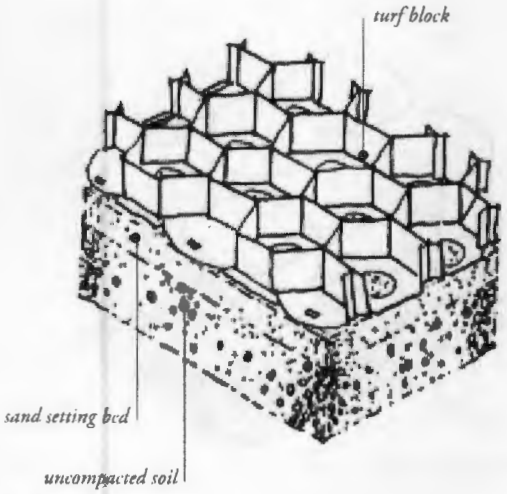
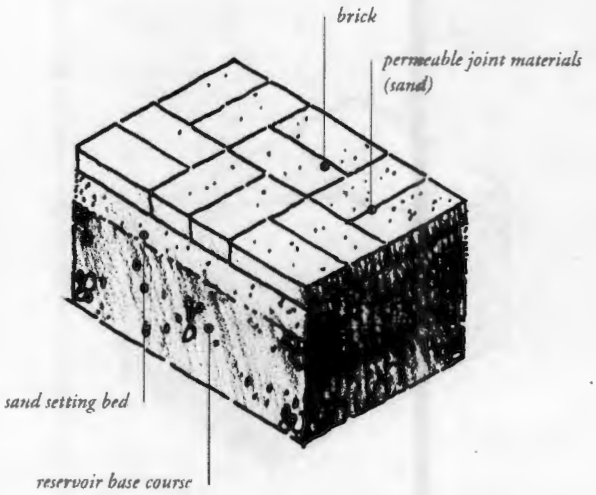
Details

6.1 *Permeable pavements, continued*



6.1c Turf block



6.1d Brick

Unit pavers-on-sand. A wide variety of unit pavers are available for use in outdoor applications. Unlike poured-in-place concretes or asphalts, which create one continuous surface, unit pavers are discrete units that are set in a pattern on a prepared base. This gives unit pavers great flexibility in design, construction, and maintenance. *Open-celled unit pavers* are designed to create a permeable pavement surface, allowing water to pass through precast voids. *Solid unit pavers,* made of impermeable materials, can produce permeable pavement surfaces if they are spaced to expose a permeable joint and set on a permeable base. Unit pavers are available in many colors, shapes, and textures. Sometimes colored concrete is stamped to appear like unit pavers, but this pavement surface performs both hydrologically and structurally like a poured concrete slab, and does not provide the stormwater infiltration opportunities of unit pavers-on-sand.

6.1c Turf block. Turf block is one example of an open celled unit paver. These open celled unit pavers are available in both precast concrete or plastic, and are filled with soil and planted with turf. They were developed in Germany in the 1960s to reduce the "heat island" effect of large parking areas and are now used throughout the world. The products vary in size, weight, surface characteristics, strength, durability, interlocking capabilities, proportion of open area per grid, runoff characteristics, and cost. Laboratory tests have shown that open celled units have runoff coefficients of from 0.05 to 0.35, depending on slope, and surface configuration.[37]

When planted with turf, they are generally most successful in overflow parking areas, driveways, or emergency access roads. If installed in heavily used parking areas the turf often does not get adequate sunlight, and on heavily traveled roadways it can be worn away from tire abrasion. Occasionally open celled unit pavers are filled with alternatives to turf, either an inert gravel or a lower maintenance groundcover such as chamomile, that can absorb some traffic. Because of their irregular surface, open celled unit pavers generally do not provide comfortable walking surfaces, though the degree of comfort varies depending on design.

6.1d Brick. Clay fired brick is an ancient, solid paving material of great durability and flexibility. When laid on a permeable base with sand joints, brick paving provides an opportunity for a limited amount of stormwater infiltration, especially at low rainfall intensities. One experiment found coefficient of runoff volume to rainfall volume between 0.13 and 0.51 at half hour rainfall intensities up to 0.03 inches, increasing to between 0.66 and 0.76 at intensities between 0.06 and 0.12 inches per half hour.[38] The larger the joints, the greater the permeability.

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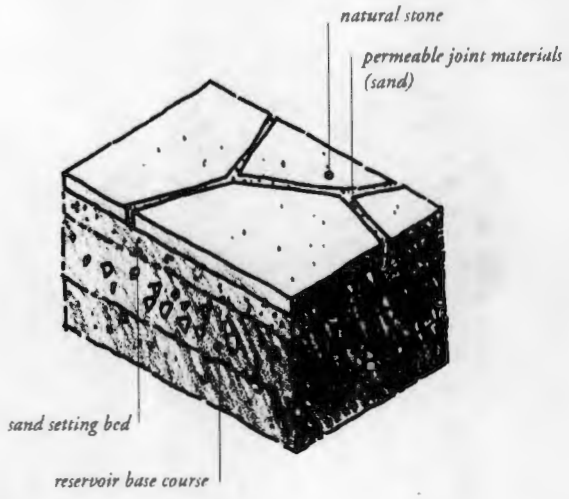
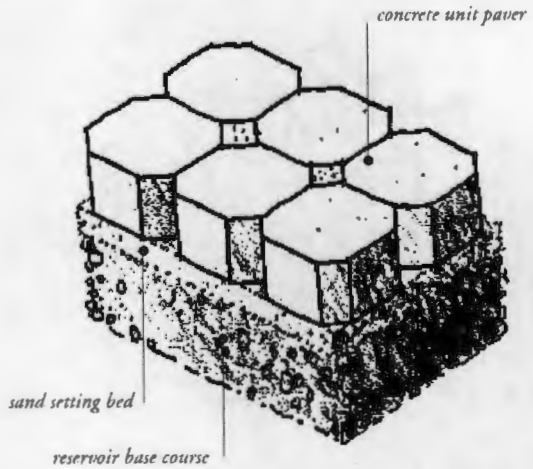


6.1e Natural stone



6.1f Concrete unit pavers

Brick is available in a wide range of colors and finishes, and can be set in a variety of patterns. When laid on sand, it creates a very suitable walking or riding surface. Though it was widely used for roads in the early part of this century, it is today generally used for driveways, pathways, plazas, and patios.

Because brick is a relatively soft material, brick pavements can develop a rich character over time as the surface becomes slightly worn with use and the natural colors and textures are exposed. Brick is generally comparable in cost with other solid unit pavers, though shipping costs and special finishes or colors can affect price significantly.

6.1e Natural stone. Natural stone paving materials are available in a wide variety of shapes and colors. Because of their high cost and relative brittleness, they are usually laid in thin pieces on a mortar bed over concrete, making an impervious pavement. Some natural stone materials, such as flagstone and granite, are available in thicker slabs suitable for laying on sand. When laid in a random pattern with wide sand, gravel, or soil joints (from 1/2 to 4 inches) random cut stone can create a highly permeable pavement. The joints can be planted with small groundcovers or left bare. Smaller, square cut stones can also be made into permeable pavements. The cobblestone walks of older European cities are a familiar example of natural stone pavement. Stones set in these tighter sand joints can be expected to have a permeability similar to brick-on-sand.

Because of their high cost natural stone pavements are generally limited to patio areas or walkways, where they can be attractive accents. Some stone materials, such as flagstone and slate, are relatively brittle and suitable for pedestrian areas only. Paving made of harder stone, such as granite, can bear vehicular loads.

6.1f Concrete unit pavers. Solid precast concrete unit pavers are available in a wide variety of colors, shapes, sizes, and textures. They are designed to be set on sand, and form an interlocking pavement surface that can bear heavy traffic loads. Their permeability and performance is similar to brick-on-sand. Some manufacturers are now producing concrete unit pavers with small voids to increase permeability (e.g. "Ecostone"). The cost of concrete unit pavers is generally the lowest of all unit pavers, though it can vary depending on shipping, special colors or finishes.

Unit pavers-on-sand considerations. Installation costs for unit pavers on sand are higher than traditional asphalt or concrete paving. Unit pavers-on-sand, however, are generally less expensive to install than mortar-set unit pavers on a rigid concrete base, especially considering the added cost of drainage struc-

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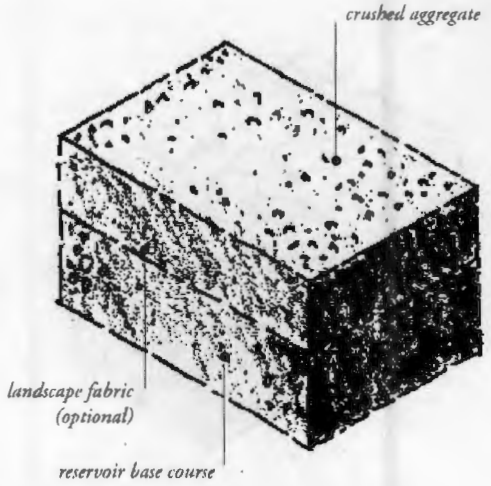
Permeable pavements, continued



6.1g Crushed aggregate

tures required for the mortared design. Solid unit pavers require no special maintenance, though the joints between units may require occasional weed supression, depending on the size of the joints, the subgrade, and other conditions. Grassed open-celled unit pavers require the same maintenance as lawns. Open-celled pavers filled with gravel require periodic "topping off" of the voids to replace gravel picked up by tire tread and pedestrians.

Unit pavers are especially valuable for walkable surfaces around trees, as they allow infiltration of water and air. If root growth causes the pavement surface to become uneven, the unit pavers can be removed and reset smoothly. Differential settlement can occur in a pavement made of unit pavers on sand, creating tripping hazard. This most often occurs if the base is improperly prepared, but can be remedied by recompacting the base and relaying the pavers. Penetration of mineral and organic particles into narrow sand joints of solid unit pavers-on-sand can severely limit permeability over time.

Granular materials. A wide variety of loose aggregates can be made to form permeable pavements suitable for walking, jogging, biking, or light vehicular traffic. The size of these granular materials ranges from fine aggregates to large stones, and can be divided into two general categories: gravels and cobbles. Depending on the aggregate size, these granular pavements have a runoff coefficient of 0.20 to 0.40.[39]

6.1g Crushed aggregate (gravel). A variety of crushed aggregates, generally known as gravel, can be used to form a permeable pavement. Aggregates are available in many sizes, ranging from approximately 2" to sand sized grains known as "fines." Relatively inexpensive to purchase and easy to install, gravel can be laid in any shape or configuration. To keep aggregates confined to its desired area, it is laid in a field that is bounded by some rigid frame such as wood header, metal edging or concrete band. Many colors, grades, and types of parent material are available, including crushed decomposed granite, base rock, and pea gravel. In selecting gravel pavements for pedestrian or vehicular traffic, crushed stones provide the most suitable surface, as the angled facets of the aggregate form an interlocking, semi-rigid matrix. Naturally worn small stones, such as pea gravel, have smooth round surfaces which rotate under pressure, making for a less firm footing. For surfaces subject to vehicular use, crushed gravel sizes between 3/8" and 3/4" make a stable surface that is also easy to walk on.

Found in a variety of settings ranging from Parisian cafes to Japanese ceremonial gardens to rural roadways, crushed aggre-

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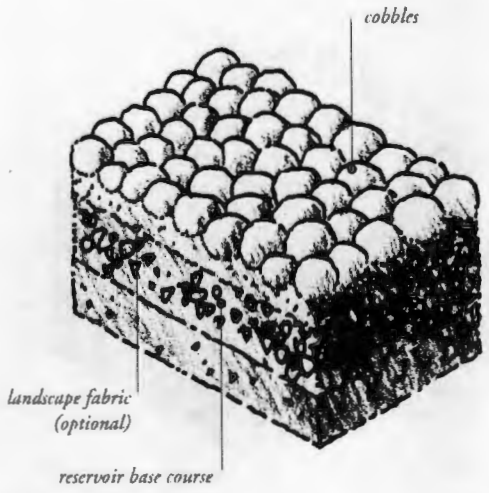
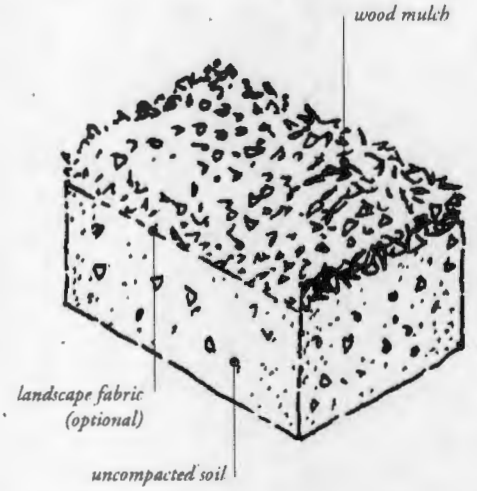


6.1h Cobbles



6.1i Wood mulch

gate is a versatile, economical permeable pavement material with a long history of use.

6.1h Cobbles. Larger granular materials are known as cobbles. Cobble sizes generally range from approximately 6" to 24" diameter and are available in a variety of stones and colors. Cobbles do not make a suitable surface for walking or vehicular traffic, but are useful as a permeable pavement in areas where little traffic is desired, such as under large trees, or in hard to maintain areas such as median islands. Cobbles have similar construction characteristics as gravel, except they are somewhat more labor intensive to install because each cobble must generally be set individually.

6.1i Wood mulch. Wood mulches and wood chips are among organic granular materials that can be used as permeable surfaces suitable for light pedestrian use. Some of these mulches meet federal requirements for playground fall surfaces, and can be inexpensive, permeable pavements for outdoor play areas.

Granular materials considerations. If laid on a slope, and subjected to moderate traffic or concentrated runoff, loose gravel can be displaced and require periodic regrading. Organic materials such as bark or wood chips decompose over time and must be replenished. Weed abatement may be required periodically, though this can be minimized by laying permeable landscape fabric between the gravel and subgrade. Installation costs for gravel and other granular materials are generally the least of all permeable pavements, but require a degree of periodic maintenance to preserve the integrity of the pavement surface.

Concrete and asphalt. Conventional concrete and asphalt (technically known as **portland cement concrete** and **asphaltic concrete**, respectively) are impervious pavements widely used in site development. Because of their ease of installation, flexibility, durability, economy, and load bearing capabilities, concrete and asphalt are the most commonly used pavement materials. With a runoff coefficient of near 1.0, conventional concrete and asphalt pavements are principal contributors to impervious land coverage in most development.

In site design for stormwater quality, these materials are best used sparingly. If more permeable pavement materials cannot be used, minimizing the area of concrete and asphalt surfaces through clustering and other techniques will reduce the resulting impervious land coverage. For remaining area, designing asphalt and concrete pavement surfaces to slope towards infiltration basins instead of into directly-connected collection structures will minimize their negative impact on water resources.

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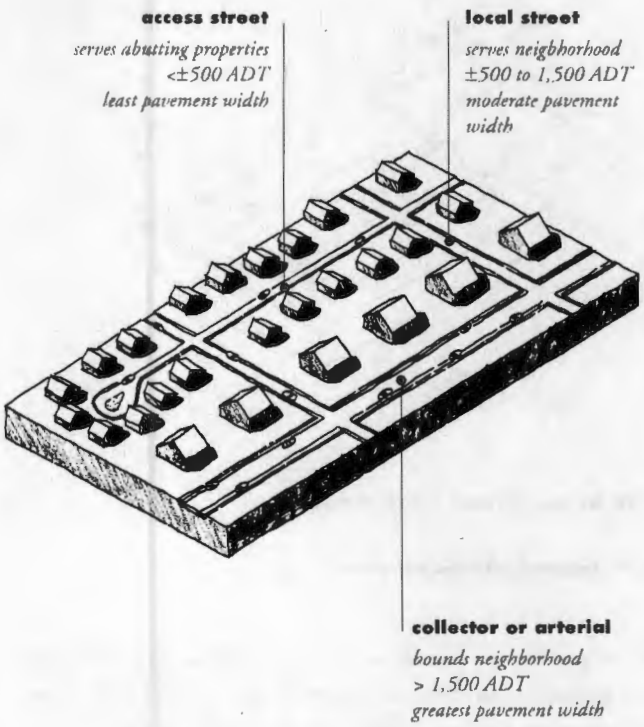
Details

6.2 *Streets*



More than any other single element, street design has a powerful impact on stormwater quality. Streets and other transport-related structures typically can comprise between 60 and 70% of the total impervious area, and, unlike rooftops, streets are almost always directly connected to an underground stormwater system.[40]

The combination of large, directly connected impervious areas, together with the pollutants generated by automobiles, makes the street network a principal contributor to nonpoint source pollution. Locally, the Santa Clara Valley Urban Runoff Program estimated that automobiles were the source of half or more of the copper, cadmium and zinc in its waterways.[41]

Street design is usually mandated by local municipal standards. These standards have been developed since World War II to facilitate efficient automobile traffic and maximize parking. Most require large impervious land coverage, with a typical Bay Area local street standard mandating that 85% or more of the public right-of-way be covered with impervious pavement.

In recent years new street standards have been gaining acceptance that meet the access requirements of local residential streets while reducing impervious land coverage. These standards generally create a new class of street that is smaller than the current local street standard, called an "access" street. An access street is at the lowest end of the street hierarchy and is intended only to provide access to a limited number of residences.

Two approaches in particular have been implemented with success in various American communities: "neo-traditional design" and "headwaters streets."[42] Neo-traditional design seeks to emulate the tree-lined, compact streets found in pre-war, traditional residential neighborhoods. The headwaters streets concept suggests that streets be scaled to traffic volume just as stream size increases with water volume. Both strategies allot street space according to anticipated traffic levels rather than mandating a predetermined number of vehicle lanes.

Recognizing that street design is the greatest factor in a development's impact on stormwater quality, it is important that designers, municipalities and developers employ street standards that reduce impervious land coverage.

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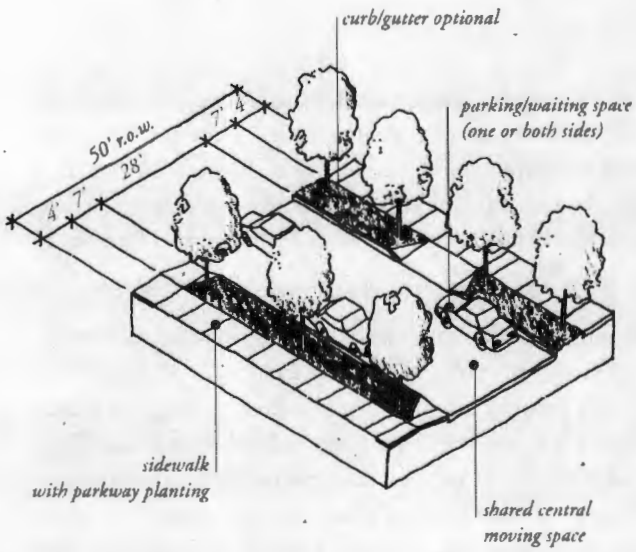
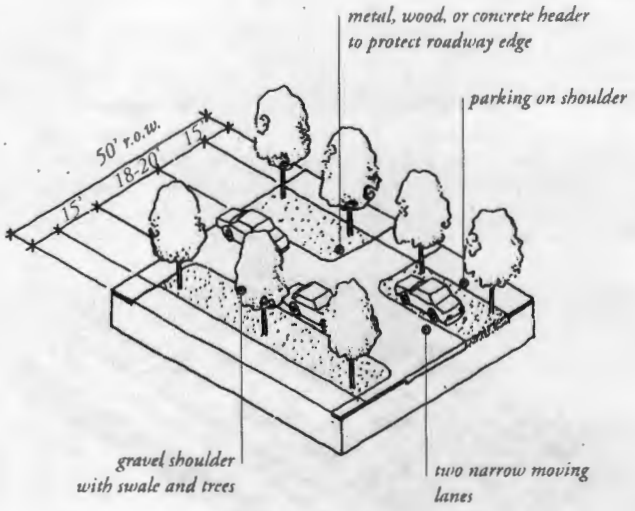


6.2a Access street: urban neo-traditional standard

74± % impervious land coverage



6.2b Access street: rural standard

36± % impervious land coverage

Two types of access streets can be built using neo-traditional standards: urban or rural.

6.2a Urban neo-traditional standard. An urban standard will utilize curbs and gutters, though the gutter may be tied to a biofilter or swale rather than an underground storm drain. According to an informational report published by the Institute of Transportation Engineers (ITE), pavement widths for neo-traditional urban streets are typically from 26 to 30' wide with a shared central moving lane, and parking permitted on one or both sides. Sidewalks are provided on at least one side of the street, though usually preferable on both sides.[43]

6.2b Rural Standard. A rural standard can be used where aesthetics and other factors permit, with curbs and gutters replaced by gravel shoulders, further reducing construction costs and improving opportunities for stormwater infiltration. The gravel shoulders are graded to form a drainage way, with opportunities for infiltration basins, ponding and landscaping. A narrow two-lane paved roadway is provided, approximately 18 to 22 feet wide. Most of the time single vehicles use the center of the paved roadway. When two cars are present moving in opposite directions, drivers reduce speeds and move towards the right hand shoulder. Protection of the roadway edge and organization of parking are two issues in rural street design. Roadway edge protection can be achieved by flush concrete bands, steel edge, or wood headers. Parking can be organized by bollards, trees, or allowed to be informal. On very low volume, low speed, access streets, sidewalks may not be required, as pedestrians walk in the street or on the shoulder.

The current typical municipal street standards that mandate 80 to 100% impervious land coverage in the public right-of-way are a principal contributor to the environmental degradation caused by development. A street standard that allows a hierarchy of streets sized according to average daily traffic volumes yields a wide variety of benefits: improved safety from lower speeds and volumes, improved aesthetics from street trees and green parkways, reduced impervious land coverage, less heat island effect, and lower development costs. If the reduction in street width is accompanied by a drainage system that allows for infiltration of runoff, the impact of streets on stormwater quality can be greatly mitigated.

Street width considerations. The experience of both the pre-war traditional streets and newer subdivisions of neo-traditional design has shown that low volume streets with shared moving lanes can be safe, often safer than wider streets, because drivers are

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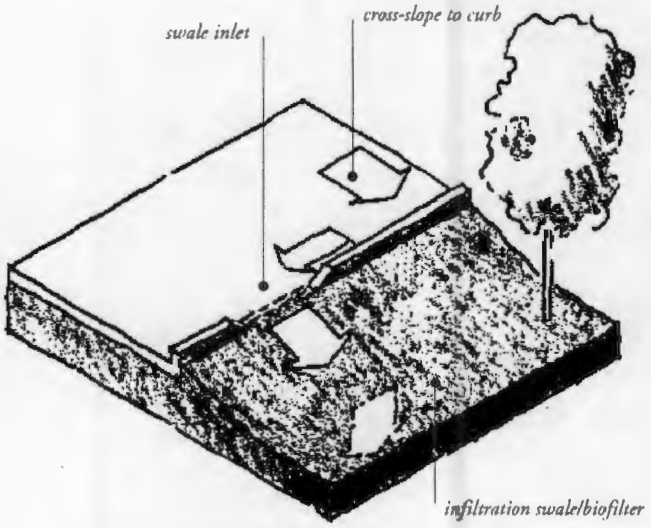
Details

6.2 *Streets, continued*



6.2c Urban curb/swale system

more cautious. These neo-traditional streets are designed for traffic speeds between 15 to 25 mph, compared to a design speed of 30 mph for most current municipal standards.[44] This reduced design speed increases safety, particularly for pedestrians. Nevertheless, shared moving space may promote unsafe conditions or high incidences of driver inconvenience if traffic volumes are much above 500-750 ADT. On access streets where bicycle traffic is especially high, such as designated bike routes or in university towns, wider streets may be advisable to provide adequate space.

Emergency service providers often raise objections to reduced street widths. Typical Fire Department standards require greater moving space for emergency access than accommodated by neo-traditional designs. A principal concern is that emergency access may be blocked if a vehicle becomes stalled in the single moving lane. Grid street systems provide multiple alternate emergency access routes to address this concern, though there may be a marginal increase in response times. Documenting the number of instances where delay has occurred in existing pre-war neighborhoods with street widths below current Fire Department standards may be a suitable way to asses the risk of this situation arising in new neighborhoods with neo-traditional street design, and to balance it with the demonstrated increased risk from higher traffic speeds on wider streets.



Inlet detail for urban curb/swale system

Just as a drop inlet collects runoff into an underground pipe system, a swale inlet collects runoff into a surface infiltration system. This swale inlet includes boulders set in soil to dissipate flow velocities and minimize erosion.

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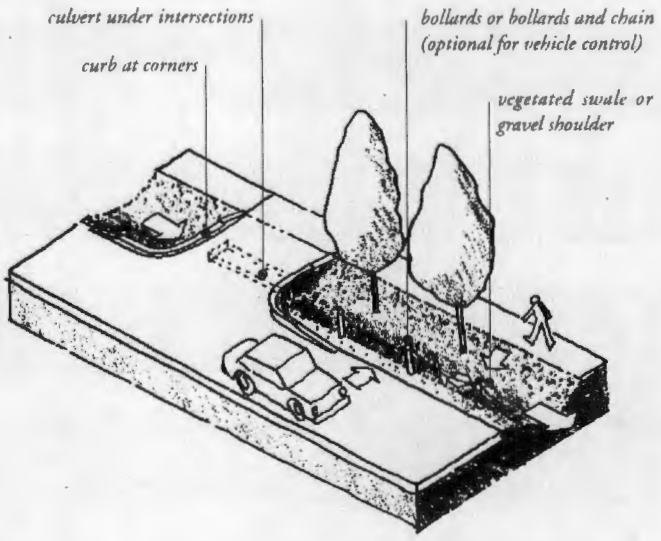

6.2d Rural swale system

Emergency service access is one factor of many that form a general assessment of neighborhood safety. One way to balance emergency service access with the benefits of access streets is to allow parking on one side only to preserve a wider moving space.

Hillside sites have special access concerns and fire risks. Because of the potential of shared moving lanes to be blocked by a single vehicle, with no comparable alternate route, reduced street widths may not be advisable on long cul-de-sac streets or narrow hillside sites.

Street drainage. Current Bay Area municipal standards generally require concrete curb and gutter along both sides of a residential street, regardless of number of houses served. The curb and gutter serves several purposes: it collects stormwater and directs it to underground conveyance drainage systems, it protects the pavement edge, it prevents vehicle trespass onto the pedestrian space, it provides an edge against which street sweepers can operate, and it helps to organize on-street parking.

Curb and gutter systems provide a directly connected conduit to natural water bodies and may act to collect and concentrate pollutants. There are two alternatives to typical curb and gutter systems that meet functional requirements while lessening the street's impact on stormwater quality.

6.2c Urban curb/swale system. On streets where a more urban character is desired, or where a rigid pavement edge is required, curb and gutter systems can be designed to empty into drainage swales. These swales can run parallel to the street, in the parkway between the curb and the sidewalk, or can intersect the street at cross angles, and run between residences, depending on topography. Runoff travels along the gutter, but instead of being emptied into a catch basin and underground pipe, multiple openings in the curb direct runoff into surface swales or infiltration/detention basins. If planted with turfgrass and gently sloped, these swales function as biofilters (see Drainage systems 5.5c). Because concentration of flow will be highest at the curb opening, erosion control must be provided, which may include a settlement basin for ease of debris removal.

6.2d Rural swale systems. On streets where a more rural character is desired, concrete curb and gutter need not be required. Since there is no hard edge to the street, the pavement margins can be protected by a rigid header of steel, wood or a concrete band poured flush with the street surface. Parking can be permitted on a gravel shoulder. If the street is crowned in the middle, this gravel shoulder also can serve as a linear swale, permitting infiltration of stormwater along its entire length. Because runoff from the street is not concentrated, but dispersed

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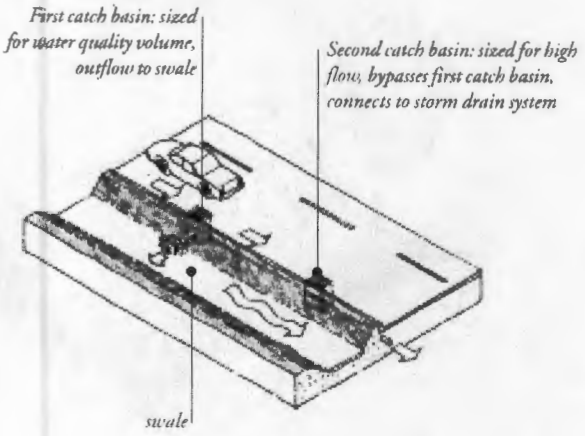
Details

6.2 *Streets, continued*



6.2e Dual drainage system

along its entire length, the buildup of pollutants in the soil is minimized. If parking is not desired on the shoulder, or if it needs to be organized, bollards, trees or groundcovers can be installed along the shoulder to prevent vehicle trespass.

In these ways edge treatments other than continuous concrete curb and gutters with underground drainage systems can be integrated into street design to create a headwaters street system that minimizes impact on stormwater quality and that captures the most attractive elements of traditional neighborhood design.

6.2e Dual drainage system. A dual drainage system is one that captures the first flush of rainfall from the 2-year storm event in a catch basin that outflows to a grass swale with small check dams. Consituents are filtered as water passes through the swale, to the outlet that directs flow back into the main storm drainage system. Runoff in excess of the 2-year storm event is captured by a second catch basin that is directly connected to the storm drain. This system can work effectively at treating the small storms while making provisions for the large storms.

Street drainage considerations. The perception that surface swale systems require a great deal of maintenance is a barrier to their acceptance. In practice, maintenance is required for all drainage systems, and surface systems can require comparable or less maintenance than underground systems. Design factors for low maintenance include:

- erosion control at curb openings
- shallow side slopes and flat bottoms (as opposed to ditches which erode)
- planting with easily maintained groundcover such as turf
- minimizing weeds through proper plant selection or installation of permeable landscape fabric.

Maintenance practices for surface systems are different than most urban Public Works Departments currently practice, and some employee retraining may be required to facilitate maintenance of street systems using surface swales instead of concrete curbs and underground pipes. One advantage of surface drainage systems is that problems, when they occur, are easy to fix because they are visible and on the surface.

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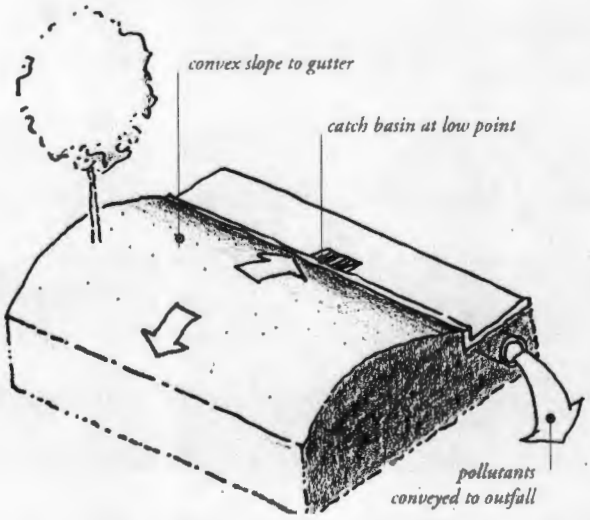
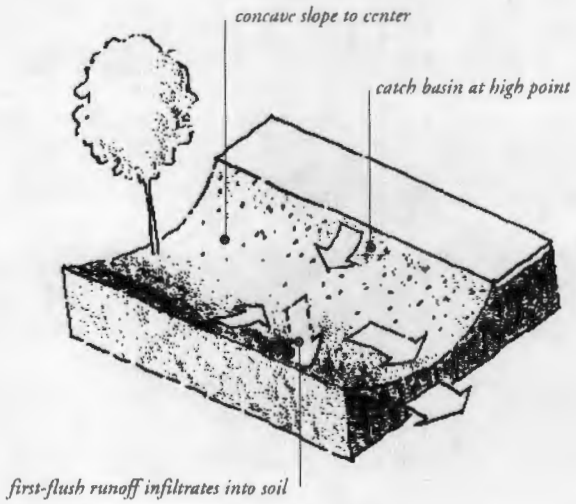


Conventional median design: convex surface



6.2f Concave median

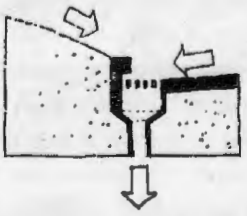
Medians. Sometimes streets are designed with central medians to divide traffic for safety or aesthetics.

Conventional median design includes a convex surface rising above the pavement section, with drainage directed towards a curb and gutter system. Runoff is conveyed rapidly off the median and the street directly into a catch basin/underground pipe system, concentrating pollutants and carrying them to water bodies.

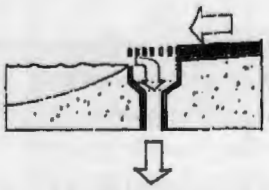
6.2f Concave median. If the soil level in the median is designed as a concave surface slightly depressed below the pavement section, water is directed from the street into the median.

Concave medians are especially valuable at treating the first-flush runoff, which carries a high concentration of oils and other pollutants off the street, especially if the median is designed as a landscaped swale or turf lined biofilter. Because of the relatively small area provided by the median for stormwater infiltration and retention, a catch basin and underground storm drain system may be required. By setting catch basin rim elevations just below the pavement elevation, but above the flow line of the infiltration swale, a few inches of water will collect in the swale before overflowing into the underground system.

Catch-basin design for medians.



A catch basin located at the low point of a ***conventional convex median*** and gutter collects all runoff – including the first flush.



Like an overflow drain in a bathtub, a catch basin located just below the pavement surface, and a few inches above the flow line of a ***concave median***, provides an opportunity to pond runoff while also providing drainage for larger storms.

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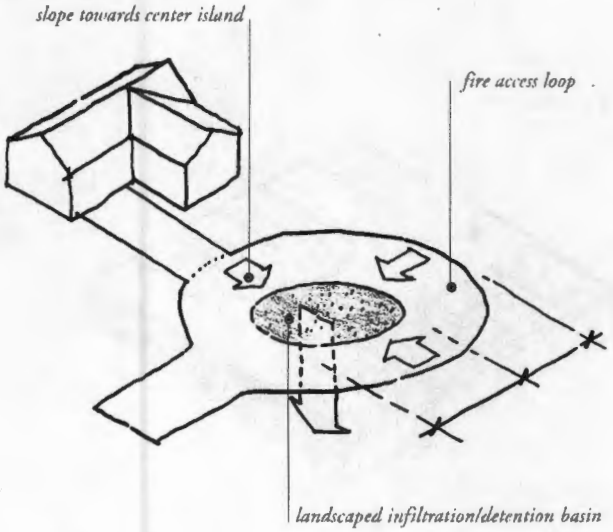
Details

6.2 *Streets, continued*



6.2g Cul-de-sac

6.2g Cul-de-sac. Cul-de-sac streets present special opportunities and challenges. Because cul-de-sac streets terminate, they require a turn-around area large enough to accommodate large trucks, such as occasional moving vans and emergency access vehicles. Fire departments, in particular, often require 60 feet or greater diameter turnarounds. If an entire 60 foot diameter turnaround is paved, it creates an 11,000 square foot impervious circle, or $^1/_4$ acre of impervious land coverage. Aside from the implications for stormwater quality, this is especially unfortunate as a design element, because it creates an unattractive heat island at the front of several homes.

A turnaround with a central concave landscaped area can create an opportunity for stormwater infiltration or detention. A landscaped area in the center of a cul-de-sac can reduce impervious land coverage 30 to 40%, depending on configuration. Design of a landscaped cul-de-sac must be coordinated with fire department personnel to accommodate turning radii and other operational needs.

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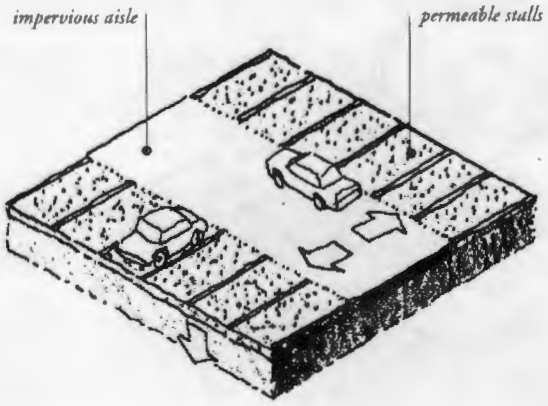
Details

6.3 *Parking lots*



6.3a Hybrid parking lot

6.3 Parking lots. In any development, storage space for stationary automobiles can consume many acres of land area, often greater than the area covered by streets or rooftops. In a neighborhood of single family homes, this parking area is generally located on private driveways or along the street. In higher density residential developments, parking is often consolidated in parking lots.

The space for storage of the automobile, the standard parking stall, occupies only 160 square feet, but when combined with aisles, driveways, curbs, overhang space, and median islands, a parking lot can require up to 400 square feet per vehicle, or nearly one acre per 100 cars. Since parking is usually accommodated on an asphalt or concrete surface with conventional underground storm drain systems, parking lots typically generate a great deal of directly-connected impervious area.

There are many ways to both reduce the impervious land coverage of parking areas and to filter runoff before it reaches the storm drain system.

6.3a Hybrid parking lot. Hybrid lots work on the principle that pavement use differs between aisles and stalls. Aisles must be designed for speeds between 10 and 20 mph, and durable enough to support the concentrated traffic of all vehicles using the lot. The stalls, on the other hand, need only be designed for the 2 or 3 mph speed of vehicles maneuvering into place. Most of the time the stalls are in use, vehicles are stationary. Hybrid



Hybrid parking lot.
This hybrid lot in a mixed-use development in Medford Village, N.J. uses crushed aggregate parking stalls and a conventional asphalt aisle.
(photo: Bruce Ferguson)

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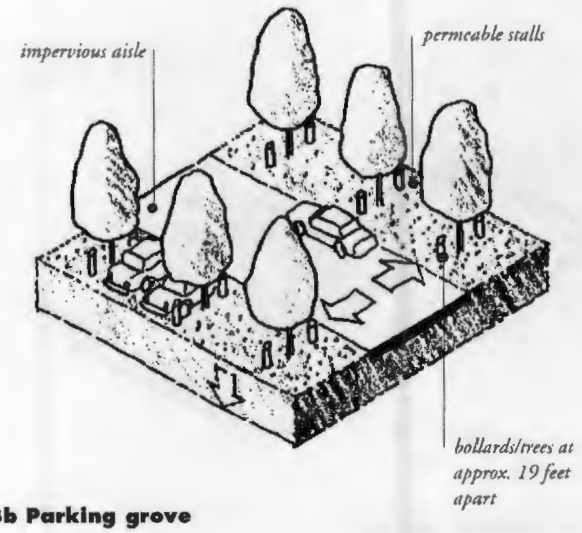
Details

6.3 *Parking lots, continued*



6.3b Parking grove

lots reduce impervious surface coverage in parking areas by differentiating the paving between aisles and stalls, combining impervious aisles with permeable stalls.

If the aisles are constructed of a more conventional, impermeable material suitable for heavier vehicle use, such as asphalt, the stalls can be constructed of a permeable pavement. This can reduce the overall impervious surface coverage of a typical double-loaded parking lot by 60%, and avoid the need for an underground drainage system.

Permeable stalls can be constructed of a number of materials, including crushed aggregate, open-celled unit pavers, porous asphalt, or pervious concrete (see Permeable Pavements, 6.1). A hybrid lot of crushed aggregate stalls and conventional asphalt aisles is a low-cost, practical design that is easily constructed from standard materials (see photo, previous page). In most cases, stall markings are not required, as the geometry of the edges promotes orderly parking. If desired, stalls can be indicated with wood headers, change in unit paver color, or pavement markers ("botts dots").

6.3b Parking Grove. A variation on the permeable stall design, a grid of trees and bollards can be used to delineate parking stalls and create a "parking grove." If the bollard and tree grid is spaced approximately 19 feet apart, two vehicles can park between each row of the grid. This 9.5 foot stall spacing is slightly more generous than the standard 8.5 to 9 foot stall, and allows for the added width of the tree trunks and bollards. A benefit of this design is that the parking grove not only shades parked



Parking Grove.
This parking grove at a Seaside, FL. hotel uses bollards and trees at approximately 10 ft. on center to create a shady courtyard that accommodates parking. The crushed oyster shell pavement is permeable and stable for walking and driving.

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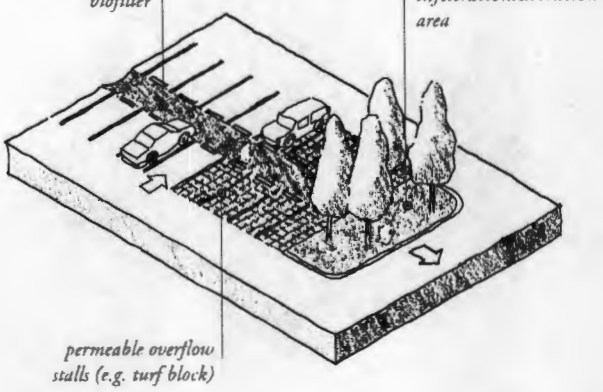
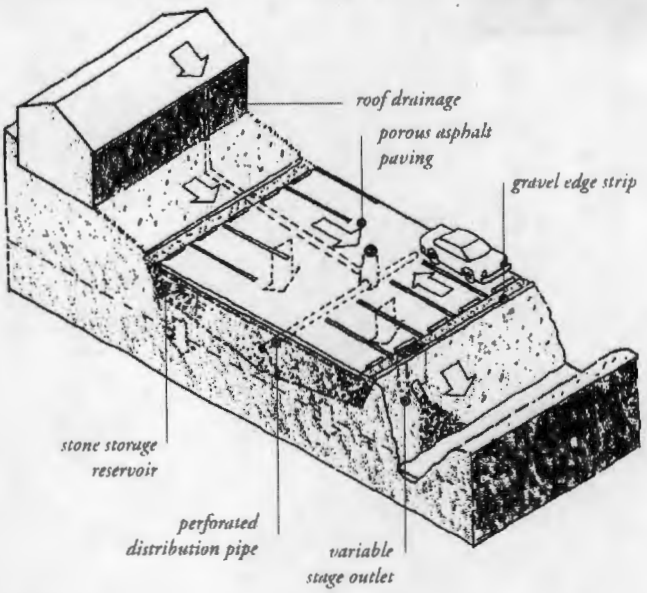


6.3c Overflow parking



6.3d Porous pavement recharge bed
(adapted from Prince Georges Co., MD)

cars, but presents an attractive open space when cars are absent.

6.3c Overflow parking. In some locations daily parking needs fluctuate, often with peak use occurring only for special events or seasons. Typically, parking lots must be constructed to accommodate the peak demand, generating a high proportion of impervious land coverage of very limited usefulness.

An alternative is to differentiate between regular and peak parking demands, and to construct the peak parking stalls of a different, more permeable, material. This "overflow parking" area can be made of a turf block, which appears as a green lawn when not occupied by vehicles, or crushed stone. The same concept can be applied to areas with temporary parking needs, such as emergency access routes or, in residential applications, RV or trailer parking (see 6.4f Temporary parking).

6.3d Porous pavement recharge bed. In some cases parking lots can be designed to perform more complex stormwater management functions. Subsurface stormwater storage and infiltration can be achieved by constructing a stone-filled reservoir below the pavement surface and directing runoff underground by means of perforated distribution pipes. Subsurface infiltration basins eliminate the possibilities of mud, mosquitoes and safety hazards sometimes perceived to be associated with ephemeral surface drainage. They also can provide for storage of large volumes of runoff, and can be incorporated with roof runoff collection systems. These underground infiltration and storage systems are relatively expensive, and required extensive engineering, but have been used in a variety of locations in the eastern United States where land values are high and the need to control runoff is great.[45] Similar high land values are found throughout the Bay Area, and as emphasis on stormwater management increases, the economic viability of these solutions will increase.

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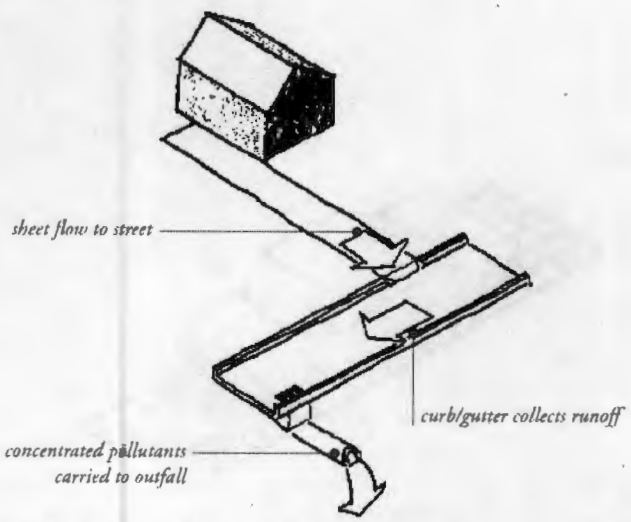
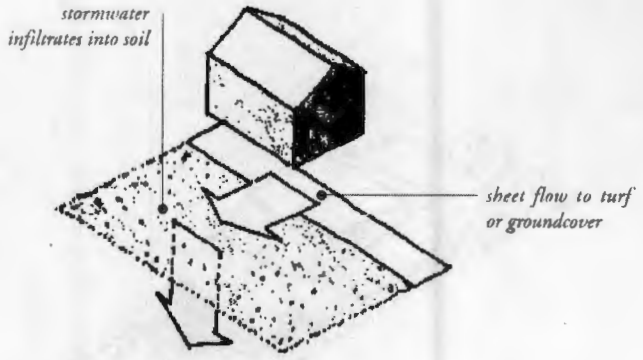
Details

6.4 *Driveways*



Directly-connected impervious driveway



6.4a Not directly-connected impervious driveway

6.4 Driveways. Driveways can comprise up to 40% of the total transportation network in a conventional development, with streets, turn-arounds and sidewalks comprising the remaining 60%.

Driveway length is generally determined by garage setback requirements, and width is usually mandated by municipal codes and ordinances. If garages are set back from the street, long driveways are required, unless a rear alley system is included to provide garage access. If parking for two vehicles side-by-side is required, a 20 foot minimum width is required. Thus, if a 20 foot setback and a two-car wide driveway are required, a minimum of 400 square feet of driveway will result, or 4% of a typical 10,000 square foot residential lot. If the house itself is compact, and the driveway is long, wide, and paved with an impervious material such as asphalt or concrete, it can become the largest component of impervious land coverage on the lot.

Municipalities can reduce the area dedicated to driveways by allowing for tandem parking (one car in front of the other). Also, if shared driveways are permitted, then two or more garages can be accessed by a single driveway, further reducing required land area. Rear alley access to the garage can reduce driveway length, but overall impervious surface coverage may not be reduced if the alleys are paved with impervious materials and the access streets remain designed to conventional municipal standards.

6.4a Not directly-connected impervious driveway. A conventional driveway that is a "directly connected impervious area" drains directly to the storm drain system – collecting and concentrating pollutants. The easiest way to reduce the impact of a conventional impervious driveway on water quality is to slope it to drain onto an adjacent turf or groundcover area. By passing driveway runoff through a permeable landscaped area, pollutants can be dispersed and cleansed in the soil. A conventional impervious driveway directly connected to the storm drain network collects and concentrates pollutants.

6.4b Crushed aggregate driveway. Gravel and other granular materials can make a suitable permeable pavement for driveways especially those that serve single family homes. Because it is lightly used by very slow moving vehicles, a well-constructed driveway of granular material can serve as a relatively smooth

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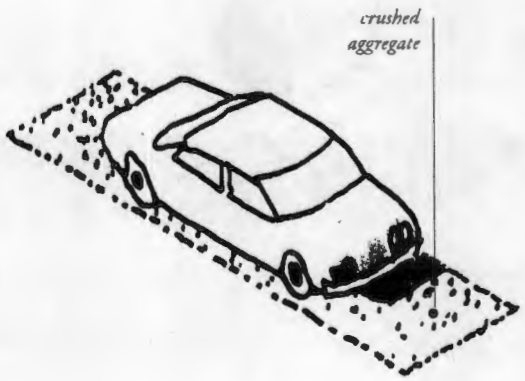
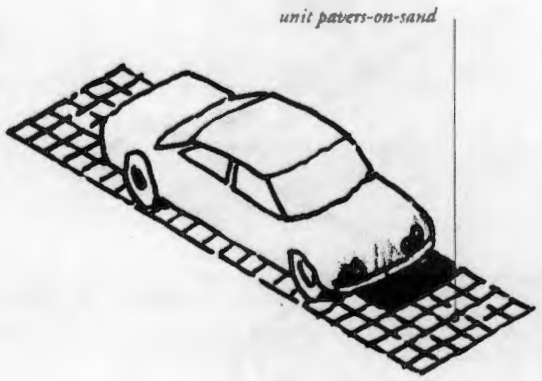


6.4b Crushed aggregate driveway

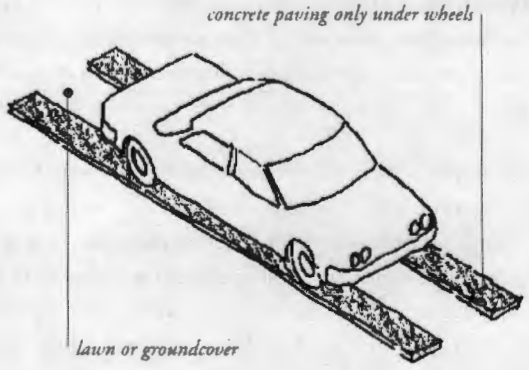


6.4c Unit pavers on sand

pavement with minimal maintenance. In choosing a granular material for a gravel driveway, use crushed stone aggregate. For proper infiltration and stormwater storage, the aggregate must be open-graded (see 6.1 Permeable pavements).

6.4c Unit pavers on sand. Unit pavers on sand can make a permeable, attractive driveway. A pavement of brick-on-sand or turf-block can make the driveway more integrated with the garden rather than an extension of the street penetrating deep into the garden space. For parking, a permeable, engineered base structural section may be required in addition to the sand setting bed.

6.4d Paving only under wheels. Concrete paving only under the wheel tracks is a viable, inexpensive design if the driveway is straight between the garage and the street. By leaving the center strip open to be planted with grass, groundcover or filled with a permeable material such as gravel, a driveway of two concrete wheel tracks can reduce impervious surface coverage by 60 to 70% compared with a single lane concrete driveway.



6.4d Paving only under wheels

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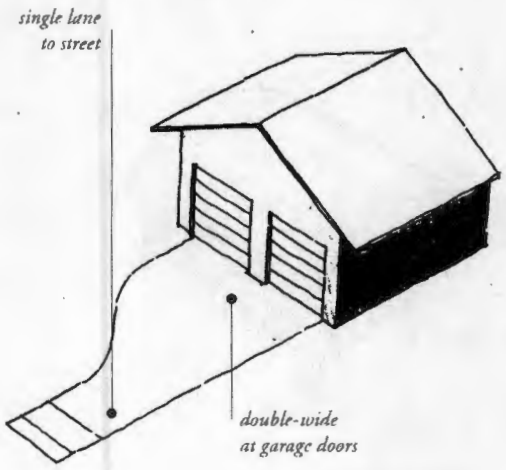
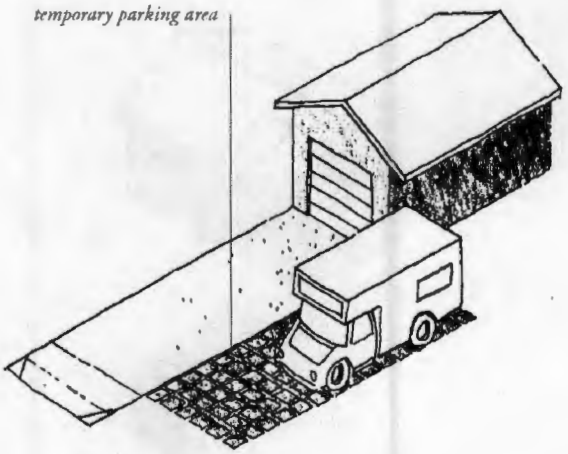
Details

6.4 *Driveways (continued)*



6.4e Flared driveways



6.4f Temporary parking

6.4e Flared driveways. Long driveways or driveways that serve multi-car garages do not require the full multi-lane width along their entire length. The approach to the garage can be a single lane, adequate to accommodate the relatively infrequent vehicle trips, while the front of the garage can be flared to provide access to all garage doors. This strategy can reduce overall pavement cost and land coverage while maintaining adequate access for all parking spaces.

6.4f Temporary parking. In some areas, parking or access is required infrequently. These areas can be paved with a permeable turf-block or similar paver, and maintained as a landscaped surface. For the majority of the time when it is not used for parking, it appears and functions as a green space. When needed for parking or access, the surface supports vehicle loads. This is an especially valuable strategy for emergency access routes or overflow parking.

Driveway considerations. Driveways offer a relatively simple opportunity to improve both the aesthetics and permeability of residential developments.

By allowing tandem parking, shared driveways, or rear alley access, municipalities can minimize mandated driveway requirements.

For designers and developers, the driveway's intimate relationship with the residence, and its relative freedom from government regulation, make it an element that can be designed to increase permeability and market appeal.

Some treatments, such as turf-block or gravel, require greater maintenance than poured-in-place asphalt or concrete designs. Other materials, such as brick or unit pavers, require a greater initial expense. Both the maintenance and cost implications of these designs can be balanced by the improved aesthetic and market appeal of driveways made from more attractive, more permeable pavements.

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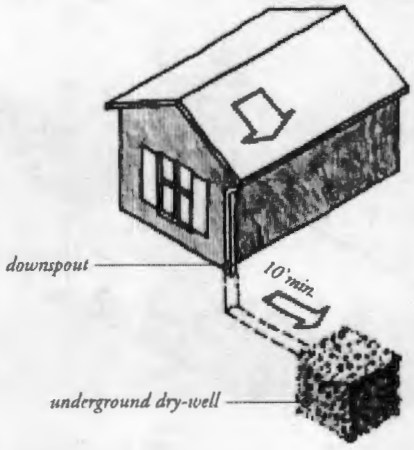
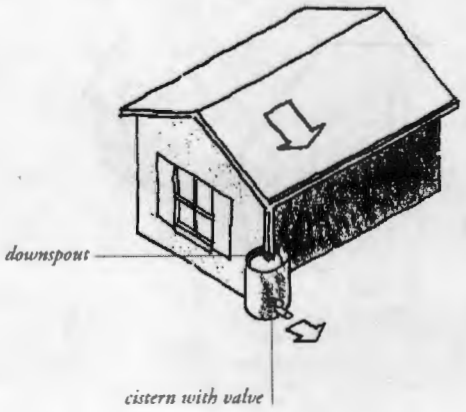
Details 6.5 *Buildings*



6.5a Dry-well



6.5b Cistern

6.5 Buildings. By definition, buildings create impervious land coverage. An important planning consideration is the site coverage and floor area ratio (F.A.R.). Buildings of equal floor area ratio can have widely different impervious coverage. For example, a two story building with 1,000 square feet of floor area will create 500 square feet of impervious area, while a one story building of the same floor area will create twice as much impervious land coverage. Therefore, tall skinny buildings have less impact on stormwater quality than low, spreading ones.

Once the building size and coverage is determined, there are a limited number of techniques for managing runoff from individual buildings to collect rooftop runoff and allow it to infiltrate into the soil.

6.5a Dry-well. If a gutter and downspout system is used to collect rainwater that falls on a roof, runoff becomes highly concentrated. If the downspout is connected to a dry-well, this runoff can be stored and slowly infiltrated into the soil.

A dry-well is constructed by digging a hole in the ground and filling it with an open graded aggregate. An underground connection from the downspout conveys water into the dry well, allowing it to be stored in the voids. To minimize sedimentation from lateral soil movement, the sides and top of the stone storage matrix can be wrapped in a permeable filter fabric, though the bottom may remain open. A perforated observation pipe can be inserted vertically into the dry-well to allow for inspection and maintenance.

In practice, dry-wells receiving runoff from single roof downspouts have been successful over long periods because they contain very little sediment. They must be sized according to the amount of rooftop runoff received, but are typically 4 to 5 feet square, and 2 to 3 feet deep, with a minimum of 1 foot soil cover over the top (maximum depth of 10 feet).

To protect the foundation, dry-wells must be set away from the building at least 10 feet. They must be installed in soils that accommodate infiltration. In poorly drained soils, dry-wells have very limited feasibility.

6.5b Cistern. Another way to store and slowly release roof runoff into the soil is to empty the downspout into a cistern. A cistern is an above ground storage vessel with either a manually operated valve or a permanently open outlet.

If the cistern has an operable valve, the valve can be closed to store stormwater for irrigation or infiltration between storms. This system requires continual monitoring by the resident or

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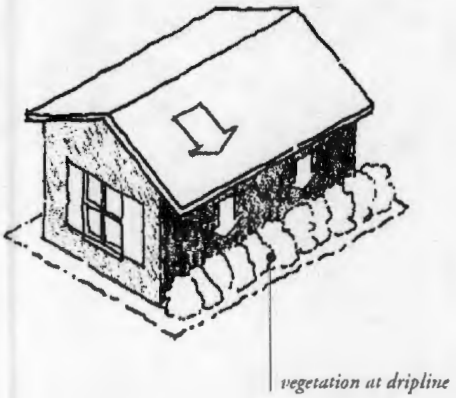
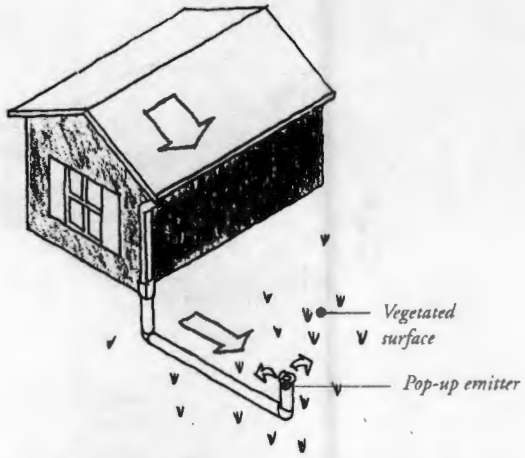


6.5c Foundation planting



6.5d Pop-up drainage emitter

grounds crews, but provides greater flexibility in water storage and metering. If a cistern is provided with an operable valve and water is stored inside for long periods, the cistern must be covered to prevent mosquitoes from breeding.

A cistern system with a permanently open outlet can also provide for metering stormwater runoff. If the cistern outlet is significantly smaller than the size of the downspout inlet (say 1/4 to 1/2 inch diameter), runoff will build up inside the cistern during storms, and will empty out slowly after peak intensities subside. This is a feasible way to mitigate the peak flow increases caused by rooftop impervious land coverage, especially for the frequent, small storms.

Cisterns can be incorporated into the aesthetics of the building and garden. Japanese, Mediterranean and American Southwest architecture provide many examples of attractive cisterns made of a variety of materials.

If a cistern holds more than 6" depth of water, it must be covered securely or have a top opening of 4" or less to prevent small children from gaining access to the standing water. The cistern must be designed and maintained to minimize clogging by leaves and other debris.

6.5c Foundation planting. For buildings that do not use a gutter system, landscape planting around the base of the eaves can provide increased opportunities for stormwater infiltration and protect the soil from erosion caused by concentrated sheet flow coming off the roof.

Foundation plantings can reduce the physical impact of water on the soil and provide a subsurface matrix of roots that encourage infiltration. These plantings must be sturdy enough to tolerate the heavy runoff sheet flows, and periodic soil saturation.

6.5d Pop-up drainage emitter. Discharging the downspout to landscaped areas allows for polishing and infiltration of the runoff. The downspout can be directly connected to a pipe which daylights some distance from the building foundation, releasing the roof runoff through a pop-up emitter. Similar to a pop-up irrigation head, the emitter only opens when there is flow from the roof. The emitter remains flush to the ground during dry periods, for ease of lawn or landscape maintenance.

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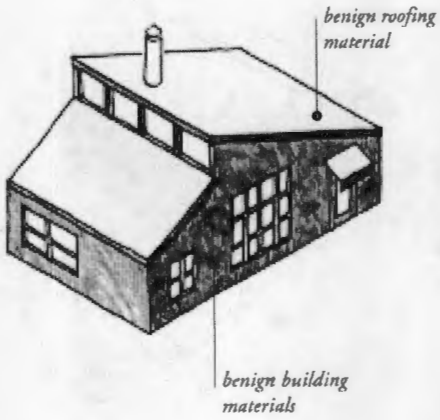

6.5e Building materials

6.5e Building materials. Selection of building materials and construction practices has an affect on stormwater quality. Some building materials contribute to stormwater degradation as they age or combine with rainwater and air. Some construction practices use materials that pollute runoff. Other materials and practices are more benign. Examples of considerations in materials selection and building practices include:

Concrete. Check the contents and source of the concrete mixture for impurities. Avoid form separators such as diesel fuel or petroleum based oil. Vegetable oil can be used as a non-toxic alternate (though plaster and stucco may not adhere effectively to an oiled concrete substrate).

Wood. For landscape materials such as steps and walls, avoid using railroad ties and woods that have been pressure treated with creosote or penta wood preservatives. Many recycled plastic products are becoming more commonly available and are often suitable wood substitutes for decking, headers and other landscape uses. Steel studs and frames are also becoming a cost-effective substitute for wood framing.

Roofing. Materials that can generate polluted runoff under some conditions include copper sheeting (trace metal), asphalt shingles (by-product of oil refining process), zinc (trace metal; lead used in zincing process). Some alternative roofing materials include: slate, steel, stone, and terra cotta tiles. These materials are durable and fireproof. They may also require design attention to accommodate the added weight load.

Paints and coatings. Lead-based paints have been commonly used in building. White lead was used on wood siding, door and window frames, and casings. Red lead was used as a primer for steel window frames on commercial and industrial buildings When renovating old buildings, test for lead in the existing paint before proceeding with removal practices such as sanding or water blasting to avoid paint chips landing on and leaching into the soil.

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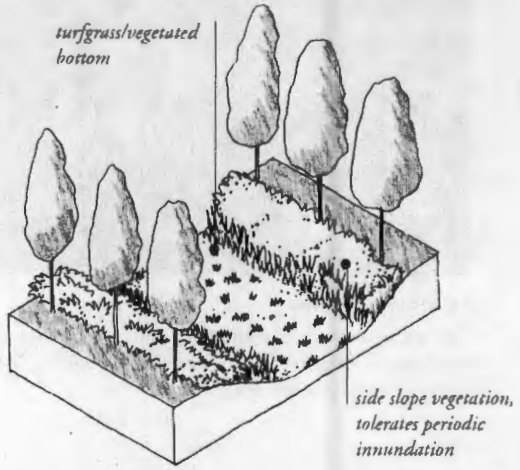
Details

6.6 *Landscape*



6.6a Grass/vegetated swales

6.6 Landscape. In the natural landscape, most soils infiltrate a high percentage of rainwater through a complex web of organic and biological activities that build soil porosity and permeability. Roots reach into the soil and separate particles of clay, insects excavate voids in the soil mass, roots decay leaving networks of macropores, leaves fall and form a mulch over the soil surface, and earthworms burrow and ingest organic detritus to create richer, more porous soil. These are just a few examples of the natural processes that occur within the soil.[46]

In development, a certain amount of soil must be covered with impervious surface, but the remaining landscape can be designed and maintained to maximize its natural permeability and infiltration capacity.

One simple strategy to improve infiltration is to use the grading of landscape surfaces. Landscape surfaces are conventionally graded to have a slight convex slope. This causes water to run off a central high point into a surrounding drainage system, creating increased runoff. If a landscape surface is graded to have a slightly concave slope, it will hold water. The infiltration value of concave vegetated surfaces is greater in permeable soils. Soils of heavy clay or underlain with hardpan provide less infiltration value. In these cases concave vegetated surfaces must be designed as retention/detention basins, with proper outlets or underdrains to an interconnected system.

Multiple small basins. Biofilters, infiltration, retention/detention basins are the basic elements of a landscape designed for stormwater management (see Drainage system elements 5.5). The challenge for designers is to integrate these elements creatively and attractively in the landscape – either within a conventional landscape aesthetic, or by presenting a different landscape image that emphasizes the role of water and drainage.

Multiple small basins can provide a great deal of water storage and infiltration capacity. These small basins can fit into the parkway planting strip or shoulders of street rights-of-way. If connected by culverts under walks and driveways, they can create a continuous linear infiltration system. Infiltration and retention/detention basins can be placed under wood decks, in parking lot planter islands, and at roof downspouts. Outdoor patios or seating areas can be sunken a few steps, paved with a permeable pavement such as flagstone or gravel, and designed to hold a few inches of water collected from surrounding rooftops or paved areas for a few hours after a rain.

All of these are examples of small basins that can store water for

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An ordinary lawn.
This lawn presents a conventional landscape appearance – its role as an effective biofilter capable of holding a few inches of water is barely noticable.



A different landscape image.
This infiltration basin uses simple landscape materials to create a landscape of great diversity that accentuates its role in a surface drainage network.

Basins for every landscape type.

a brief period, allowing it to infiltrate into the soil, slowing its release into the drainage network, and filtering pollutants.

6.6a Grass/vegetated swales. Parking lot drainage can be integrated with landscaping to provide infiltration and retention/detention basins. Grass swales can be a particularly effective design strategy in large conventionally paved parking lots, by providing low maintenance, linear biofilters along the perimeter of the lot or along internal islands. Stormwater is directed to these linear landscaped spaces and travels slowly over turfgrass or other vegetated surfaces, allowing pollutants to settle and slowing runoff velocities (See chapter 8 for details).

6.6b Extended detention (dry) ponds. Extended detention (dry) ponds can be used for both pollutant removal and flood control. These ponds store water during storms anywhere from a few hours up to a few days, discharge it to adjacent surface waters, and are dry between storms. Clay or impervious soils should not affect pollutant removal effectiveness, as the main removal mechanism is settling.

Extended detention ponds are generally appropriate for developments of ten acres or larger, and have the potential for multiple uses including flood control basins, parks, playing fields, tennis courts, open space, and overflow parking lots.

It is important to consider design elements to improve pond safety. The most important being shallow side slopes of no steeper than 3:1. This prevents people from accidentally falling into deep water. Barriers such as fencing and/or vegetation are also used, but they prevent access for recreational use, and also can present a hazardous situation if the side slopes are steep, because people drawn to the water can breach or climb the barrier and fall into deep water.

6.6c Wet ponds. Wet ponds are permanent pools of water that detain and treat stormwater runoff. These ponds, if designed with a fringe wetland at the pond edge, can increase property values by providing a significant landscape amenity with opportunities for passive recreation (e.g., birdwatching, fishing), and can be combined with pedestrian and bicycle circulation to provide active recreation. The fringe wetland is also an important factor in increasing pollutant removal.

6.6d Plant species selection for infiltration areas. The proper selection of plant materials can improve the infiltration potential of landscape areas. Deep rooted plants help to build soil porosity. Plant leaf-surface area helps to collect rainwater before it lands on the soil, especially in light rains, increasing the overall water-holding potential of the landscape. A single street tree can have a total leaf surface area of several hundred to

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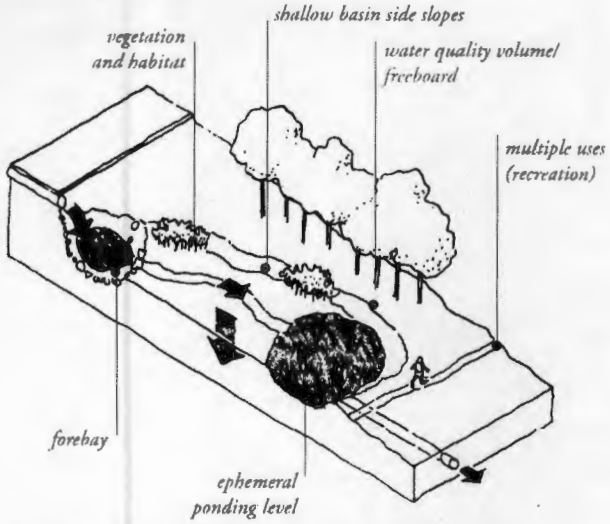
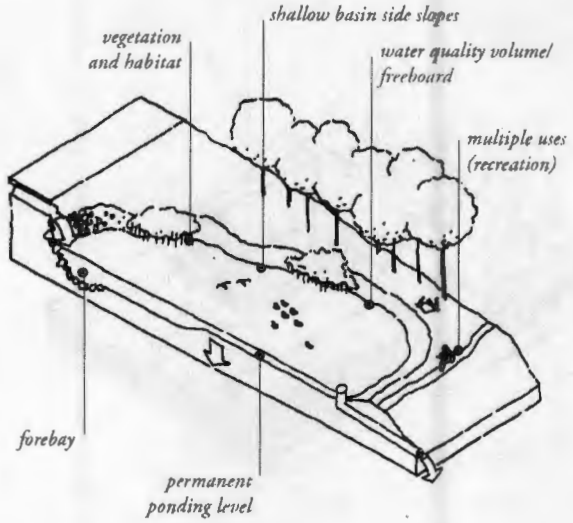
Landscape, continued



6.6b Extended detention (dry) ponds



6.6c Wet ponds

several thousand square feet, depending on species and size. This above ground surface area created by trees and other plants greatly contributes to the water-holding capacity of the land.

A large number of plant species will survive moist soils or periodic inundation. These plants provide a wide range of choices for planted infiltration/detention basins and drainage swales. Most inundated plants have a higher survival potential on well-drained alluvial soils than on fine-textured shallow soils or clays. Though oaks generally do not tolerate summer moisture, mature valley and blue oaks (*Quercus lobata* and *Q. douglasii*) in alluvial soils can survive winter inundation for up to 100 days annually.[47]

Landscape considerations. Landscape can perform a wide variety of stormwater management functions. In designing landscapes for stormwater management, appropriate groundcover must be selected. Turf grass lawns, woody perennials, and cobbles can all be used, depending on the desired aesthetic effect.

6.6e Landscape maintenance for stormwater systems. All landscape treatments require maintenance. Landscapes designed to perform stormwater management functions are not necessarily more maintenance intensive than highly manicured conventional landscapes. A concave lawn requires the same mowing, fertilizing and weeding as a convex one, and often less irrigation because more rain is filtered into the underlying soil. Sometimes infiltration basins may require a different kind of maintenance than conventionally practiced.

Typical maintenance activities include periodic inspection of surface drainage systems to ensure clear flowlines, repair of eroded surfaces, adjustment or repair of drainage structures, soil cultivation or aeration, care of plant materials, replacement of dead plants, replenishment of mulch cover, irrigation, fertilizing, pruning and mowing. Also, dead or stressed vegetation may indicate chemical dumping. Careful observation should be made of these areas to determine if such a problem exists.

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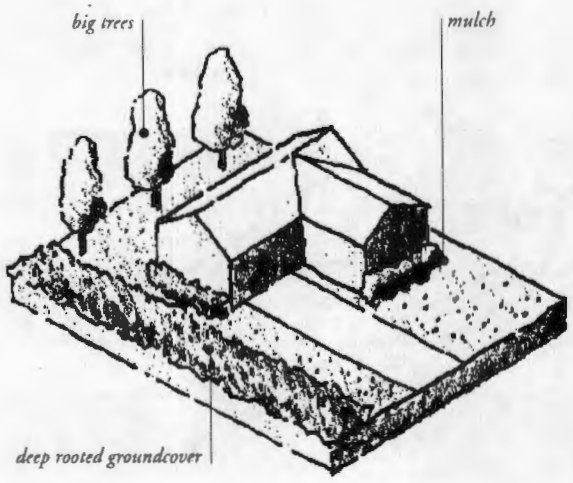

6.6d/e Plant selection and landscape maintenance

Landscape maintenance can have a significant impact on soil permeability and its ability to support plant growth. Most plants concentrate the majority of their small absorbing roots in the upper 6 inches of the soil surface if the surface is protected by a mulch or forest litter. If the soil is exposed or bare, it can become so hot that surface roots will not grow in the upper 8 to 10 inches. The common practice of removing all leaf litter and detritus with leaf blowers creates a hard crusted soil surface of low permeability and high heat conduction. Proper mulching of the soil surface improves water retention and infiltration, while protecting the surface root zone from temperature extremes.[47]

In addition to impacting permeability, landscape maintenance practices can have adverse effects on water quality. Because commonly used fertilizers and herbicides are a source of organic compounds, it is important to keep these practices to a minimum, and prevent overwatering.

When well-maintained and designed, landscaped concave surfaces, infiltration basins, swales and bio-retention areas can add aesthetic value while providing the framework for environmentally sound, comprehensive stormwater management systems.

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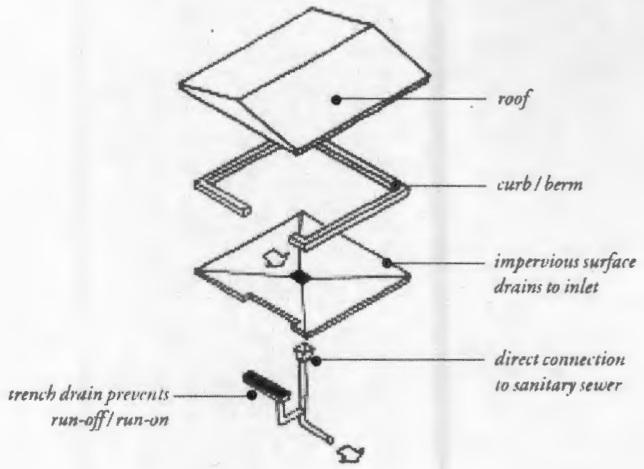
Details

6.7 *Outdoor work areas*



6.7 Typical outdoor work area

6.7 Outdoor work areas. The site design and landscape details listed in previous chapters are appropriate for uses where low concentrations of pollutants can be mitigated through infiltration, retention and detention. Often in commercial and industrial sites, there are outdoor work areas in which a higher concentration of pollutants exists, and thus a higher potential of pollutants infiltrating the soil. These work areas often involve automobiles, equipment, machinery, or other commercial and industrial uses, and require special consideration.

Outdoor work areas are usually isolated elements in a larger development. Infiltration and detention strategies are still appropriate for and can be applied to other areas of the site, such as parking lots, landscape areas, employee use areas, and bicycle paths. It is only the outdoor work area within the development – such as the loading dock, fueling area, or equipment wash – that requires a different drainage approach. This drainage approach is often *precisely the opposite* from the infiltration/detention strategy– in other words, collect and convey.

In these outdoor work areas, infiltration is discouraged and runoff is often routed directly to the sanitary sewer, not the storm drain. Because this runoff is being added to the loads normally received by the water treatment plants (known as "publicly owned treatment works" or POTW), it raises several concerns that must be addressed in the planning and design stage. These include:

- higher flows (if area is exposed to rainfall) that could exceed the sewer system capacity,
- catastrophic spills that may cause harm to POTW operations, and,
- a general increase in pollutants.

These concerns can be addressed at policy, management, and site planning levels.

Policy. Piping runoff and process water from outdoor work areas directly to the sanitary sewer for treatment by a downstream POTW displaces the problem of reducing stormwater pollution. Municipal stormwater programs and/or private developers can work with the local POTW to develop solutions that minimize effects on the treatment facility.

Management. Commercial and industrial sites that host special activities need to implement a pollution prevention program, minimizing hazardous material use and waste. For example, if restaurant grease traps are directly connected to the sanitary sewer, proper management programs can mitigate the amount of grease that escapes from the trap. This grease, if released in large volumes, can clog sewer systems and cause overflows, or

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Outdoor work areas

Outdoor work areas that may require structural treatment include:

Auto recycle facilities

Auto wrecking yards

Commercial nurseries

Corporation yards

Fueling stations

Fleet storage areas

Rooftop equipment

Marinas

Outdoor container storage

Outdoor loading/unloading facilities

Public works storage areas

Vehicle service and maintenance areas

Vehicle and equipment washing/steam cleaning facilities

All sites requiring a hazardous materials management plan (HMMP)

Source: Technical Note No. 87. *Watershed Protection Techniques.* Vol. 2, No. 2. February 1997.

damage the downstream treatment system.

Site Planning. Outdoor work areas can be designed in particular ways to reduce their impacts on both stormwater quality and sewage treatment plants (if drainage system is connected):

- create an impermeable surface. This can be a conventional pavement, such as concrete or asphalt, or a prefabricated metal drip pan, depending on the use.
- cover the area with a roof. This prevents rain from falling on the work area and becoming polluted runoff.
- berm or mounding around the perimeter of the area to prevent water from adjacent areas to flow on to the surface of the work area. In this way, the amount of polluted runoff is minimized.
- directly connect runoff. Unlike other areas, runoff from these work areas is directly connected to the sanitary sewer or other specialized containment systems. This allows the more highly concentrated pollutants from these areas to receive special treatment that removes particular constituents. Approval for this connection must be obtained from the appropriate sanitary sewer agency.
- locate the work area away from storm drains or catch basins. If the work area is adjacent to or directly upstream from a storm drain or landscape drainage feature (e.g.

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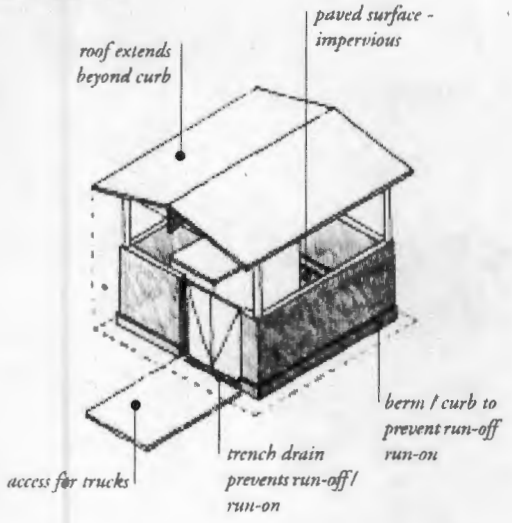
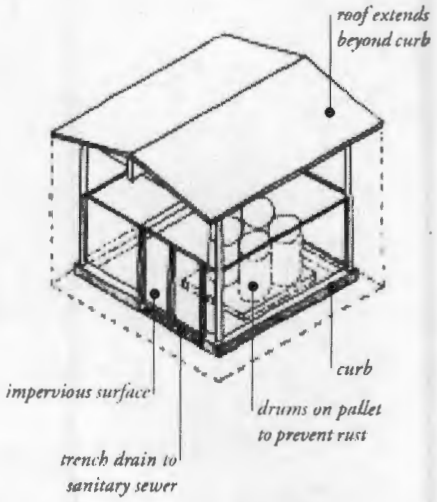
Details

6.7 *Outdoor work areas, continued*



6.7a Garbage and recycling area



6.7b Maintenance and storage area

bioswale), debris or liquids from the work area can migrate into the stormwater system.

These design elements are general considerations for work areas. In designing any outdoor work area, evaluate local ordinances affecting the use, as many local jurisdictions have specific requirements.

Some activities are common to many commercial and industrial sites. These include garbage and recycling, maintenance and storage, and loading. These activities can have a significant negative impact on stormwater quality, and require special attention to the siting and design of the activity area.

6.7a Garbage and recycling. Garbage and recycling areas must be designed to consider a wide range of factors. These include sizes of receptacles for both trash and a variety of recycled materials. They must be sited so that receptacles are accessible for collection by standard collection trucks, yet out of the way so as not to disturb the aesthetics of the site. Garbage and recycling areas should also be located away from drainage paths and waterways to prevent debris and spills from entering the drainage system.[49] Regular maintenance plans should be implemented for sweeping, litter control, and spill cleanup.

Protection from rainfall and "run-on" surface drainage can be achieved by designing a roof or covering for the enclosure, and a curb or berm around the perimeter to contain any leakage from trash containers and dumpsters. The dumpsters or trash containers need to sit on a paved area, not lawn or unpaved soil, to prevent infiltration of leakage. Plastic liners may also be used to contain liquid waste. In cases where water cannot be diverted from the areas (such as areas located within a low spot), a self-contained drainage system must be designed.

6.7b Maintenance and storage. To reduce the possibility of contact with stormwater runoff, maintenance and storage areas can be sited away from drainage paths and waterways.[50] Implementing a regular maintenance plan for sweeping, litter control, and spill cleanup, also helps prevent stormwater pollution.

Specifying impermeable surfaces for vehicle and equipment maintenance areas will reduce the chance of pollutant infiltration. A concrete surface will usually last much longer than an asphalt one, as vehicle fluids can either dissolve asphalt or can be absorbed by the asphalt and released later.[51]

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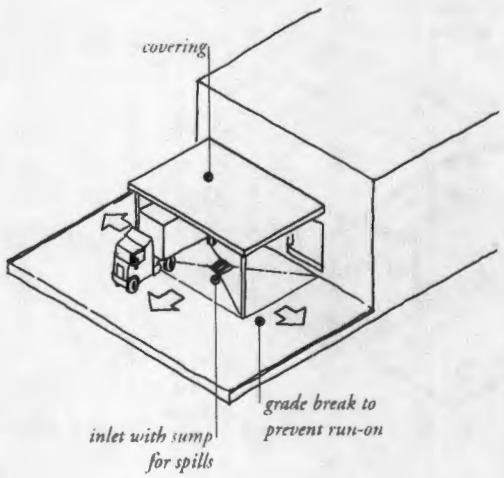

6.7c Loading area

Vehicle and equipment washing. It is generally advisable to cover areas used for regular washing of vehicles, trucks, or equipment, surround them with a perimeter berm, and clearly mark them as a designated washing area. Sumps or drainlines can be installed to collect wash water, which may be treated for reuse or recycling, or for discharge to the sanitary sewer. The POTW may require some form of pretreatment, such as a trap, for these areas.

Fueling and maintenance activities must be isolated from the vehicle washing facilities. These activities have specific requirements (see below).

Storage of bulk materials, fuels, oils, solvents, other chemicals, and process equipment should be accommodated on an impervious surface covered with a roof. To reduce the chances of corrosion, materials should not be stored directly on the ground, but supported by a wire mesh or other flooring above the impervious pavement. In uncovered areas, drums or other containers can be stored at a slight angle to prevent ponding of rainwater from rusting the lids. Liquid containers should be stored in a designated impervious area that is roofed, fenced within a berm, to prevent spills from flowing into the storm drain.

If hazardous materials are being used or stored, additional specific local, state or federal requirements may apply.

6.7c Loading. Loading areas and docks can be designed with a roof or overhang, and a surrounding curb or berm. The area should be graded to direct flow toward an inlet with a shutoff valve or dead-end sump. The sump must be designed with enough capacity to hold a spill while the valve is closed. If the sump has a valve, it must be kept in the closed position and require an action to open it. All sumps must have a sealed bottom so they cannot infiltrate water. Contaminated accumulated waste and liquid must not be discharged to a stormdrain and may be discharged to the sanitary sewer only with the POTW's permission. If it does not receive approval for discharge to the sanitary sewer, it must be conveyed to a hazardous waste (or other offsite disposal) facility, and may require pretreatment.[52]

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Details

6.7 *Outdoor work areas, continued*

Some specific uses have unique requirements.

Restaurants. Though special regulations and zoning ordinances address restaurant pollutants, there are still areas in which poor maintenance practices contribute to stormwater pollution. It is preferable that all cooking and cleaning activities occur inside the restaurant. If these activities are performed outside, there are some simple site design elements that can help reduce the potential for stormwater pollution (See case study 7.2f).

Containment curbs or berms can be designed around areas in which floor mat, container washing, exhaust filter and sink cleaning may take place. A covered, secondary containment area can be designed so that kitchen grease is contained, collected, and removed regularly by a recycling/disposal service, or disposed of through a grease trap with a sanitary sewer connection.[53]

Fueling areas. In all vehicle and equipment fueling areas, plans must be developed for cleaning near fuel dispensers, emergency spill cleanup, and routine inspections to prevent leaks and ensure properly functioning equipment.[54]

If the fueling activities are minor, fueling can be performed in a designated, covered and bermed area that will not allow run-on of stormwater or runoff of spills.[55]

Retail gasoline outlets and vehicle fueling areas have specific design guidelines (See case study 7.2g). These are described in a Best Management Practice Guide for retail gasoline outlets developed by the California Stormwater Quality Task Force, in cooperation with major gasoline corporations. The practice guide addresses standards for existing, new, or substantially remodeled facilities.

Fuel dispensing areas are defined as extending 6.5 feet from the corner of each fuel dispenser or the length at which the hose and nozzle assemble may be operated plus 1 foot, whichever is less. These areas must be paved with smooth impervious surface, such as Portland cement concrete, with a 2%-4% slope to prevent ponding, and must be covered. The cover must not drain onto the work area. The fuel dispensing area must be separated by the rest of the site by a grade break that prevents run-on of stormwater.

Within the gas station, the outdoor trash receptacle area (garbage and recycling), and the air/water supply area must be paved and graded to prevent stormwater run-on.

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7 Case Studies

The site planning principles and design concepts described in the previous pages are integrated on the following pages in a series of case studies reflecting the diverse topography and market conditions of the Bay Area.

The case studies are illustrative. They show an approach to site planning and design that integrates stormwater management as an organizing element. Each of the details in Chapter 6 is illustrated at least once to show how the details work in combination with each other. Real sites, and real projects, will require unique combinations to suit unique conditions.

Site planning and design is a complex and demanding process. To be successful, a new development must meet marketing, economic, regulatory, engineering, environmental, construction, and design criteria. The following case studies attempt to show that by treating stormwater as a resource, and using it as a means to generate design, communities can be built that reward investment, enhance the natural environment, and make better places for people to live and work.

Case Studies

Economic benefits of stormwater management

7.1 Residential development

7.1a Small single lot

7.1b Large single lot

7.1c High density multi-family site

7.1d Small hillside site

7.1e Large hillside site

7.1f Large flat site

7.2 Commercial/Industrial/Institutional development

7.2a Shopping center

7.2b Industrial park

7.2c Strip mall

7.2d Schools and parks

7.2e Office building

7.2f Restaurant

7.2g Gas stations

7.2h Hotel/motel

SARB_009596

Economic benefits of stormwater management

People have a strong emotional attachment to water, arising from its aesthetic qualities– tranquility, coolness and beauty. As a result, most waterbodies within developments can be used as marketing tools to set the tone for entire projects. A recent study conducted by the National Association of Home Builders indicates that "whether a beach, pond, or stream, the proximity to water raises the value of a home by up to 28 percent."[56]

In California's semi-arid climate, most of the techniques described in this document will not be year-round water features, but instead will hold water only during the rainy months. These ephemeral ponds and streams have a unique character, changing with the seasons and reflecting (literally) daily changes in weather.

Water features command a premium in the marketplace. Homebuyers and renters nation-wide demonstrate a willingness to pay a premium for properties adjacent to urban runoff controls that are designed with aesthetics in mind. According to the US E.P.A., land values for lots fronting runoff controls commanded 5 to 15% premiums over comparable lots at residential projects in Virginia, Colorado, Illinois and Kansas. In Davis, California, properties at Village Homes, a residential subdivision built in the late 1970s with seasonal swales and other environmental features, command significantly higher values than comparable homes in nearby conventionally designed subdivisions.

Stormwater management for water quality presents developers with an opportunity to design more attractive projects that will have an advantage over conventionally designed competitors. Not only do subdivisions sell faster and at a premium, but development costs are generally lower for surface drainage systems compared to conventional underground systems.[57]

Factors that lead to increases in property values. Urban runoff systems that appear to be natural systems are most effective at commanding increases in property values. If recreation is included (e.g. a walking path along a swale or playfield/infiltration basin), an additional premium is realized. These recreational areas and wetlands can become a feature attraction when advertising the property. Amenities such as trails and gazebos may add costs, but these can be compensated for by faster sales and additional profits. Developers can charge premiums for properties with water views, stream frontage, access to greenbelts, or other amenities.

Maintenance. Proper maintenace of the drainage system is essential for homebuyer acceptance and marketing. Runoff controls that are poorly maintained can be a hazard or a nuisance. Maintenance costs need not be significantly higher than conventionally designed projects. For example, a concave lawn requires the same maintenance as a convex one, though the concave lawn can form part of a stormwater management system. In some designs, such as vegetated swales or seasonal ponds, periodic maintenance will be required, but it is less than other amenities routinely included in new development, such as fountains or tennis courts.

Green marketing. Many consumers today demonstrate a preference for products and services that are "environment friendly." Organically grown cotton clothing, natural foods, and recycled papers are a few of the products that sell at a premium to conventional competitors but command increasing market share. Homebuyers, too, respond to products that consciously promote more environmentally responsible designs, as long as these designs are safe, attractive and functional. By promoting a natural drainage system, developers can meet federal mandates for environmental quality while simultaneously differentiating their product through increased habitat, a more diverse landscape, and additional recreational opportunities.



This drainage swale, integrated with a pathway system and landscaping, makes an attractive recreational area that enhances property values.

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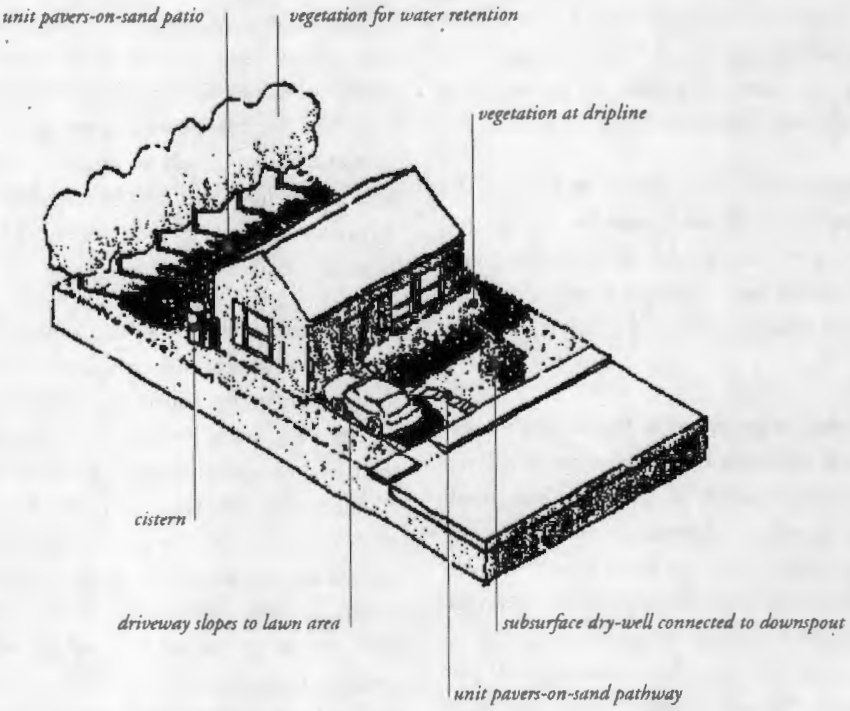
Case Study

7.1a *Small single lot*



7.1a Small single lot. Even a small, single-family home lot can provide opportunities for stormwater management. Because they occur at the intimate, garden level, these opportunities can add aesthetic richness that will directly benefit residents. Stormwater management techniques can also provide habitat for wildlife, create shade, improve character, provide supplemental irrigation water, and promote growth of landscape planting.

Homeowner education is an important element of stormwater management techniques at all levels, but especially at the single lot scale. Residents need to be educated on the intent of various design elements, and their proper care. They especially need to understand the maintenance needs of more active elements, such as cisterns, which need periodic cleaning or emptying. If drywells are included, residents must also understand that they are for rainwater only – never as a place to dump oil, pesticides, paint thinner, solvents, cleaners such as 409, degreasers, or other unwanted wastes.

The techniques illustrated in this example are:

- unit pavers-on-sand patio
- not directly connected impervious driveway
- unit pavers-on-sand pathway
- dry-well connected to roof downspout
- cistern
- vegetation for water retention (deep rooted trees)
- vegetation at dripline of roof.

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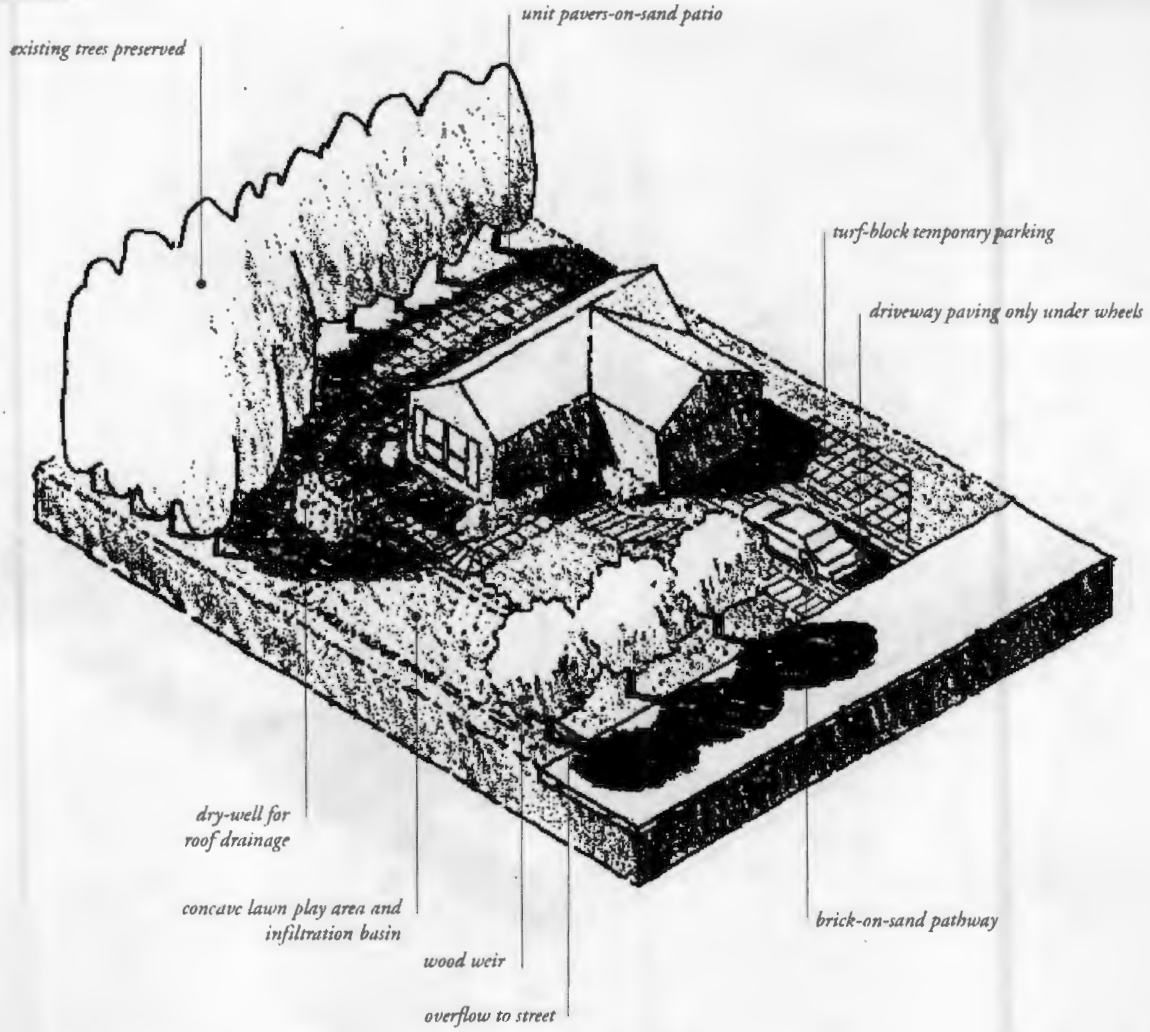
Case Study

7.1b *Large single lot*



7.1b Large single lot. A large single-family home lot usually provides many opportunities for stormwater management. Because the ratio of impervious cover relative to land area is usually low, adequate landscape area is available to accommodate a variety of subtle infiltration strategies.

As will the small single lot, homeowner education is important so that residents understand the intent of various design elements, and their proper care. They especially need to understand the maintenance needs of more active elements, such as cisterns, which need periodic cleaning or emptying. If dry-wells are included, residents must also understand that they are for rainwater only – never as a place to dump oil, pesticides, paint thinner, solvents, cleaners, degreasers, or other unwanted wastes.

The techniques illustrated in this example are:

- unit pavers-on-sand patio
- concave lawn play area and infiltration basin
- not directly connected impervious driveway
- brick-on-sand pathway
- dry-well connected to roof downspout
- cistern
- vegetation for water retention (deep rooted trees)
- vegetation at dripline of roof.

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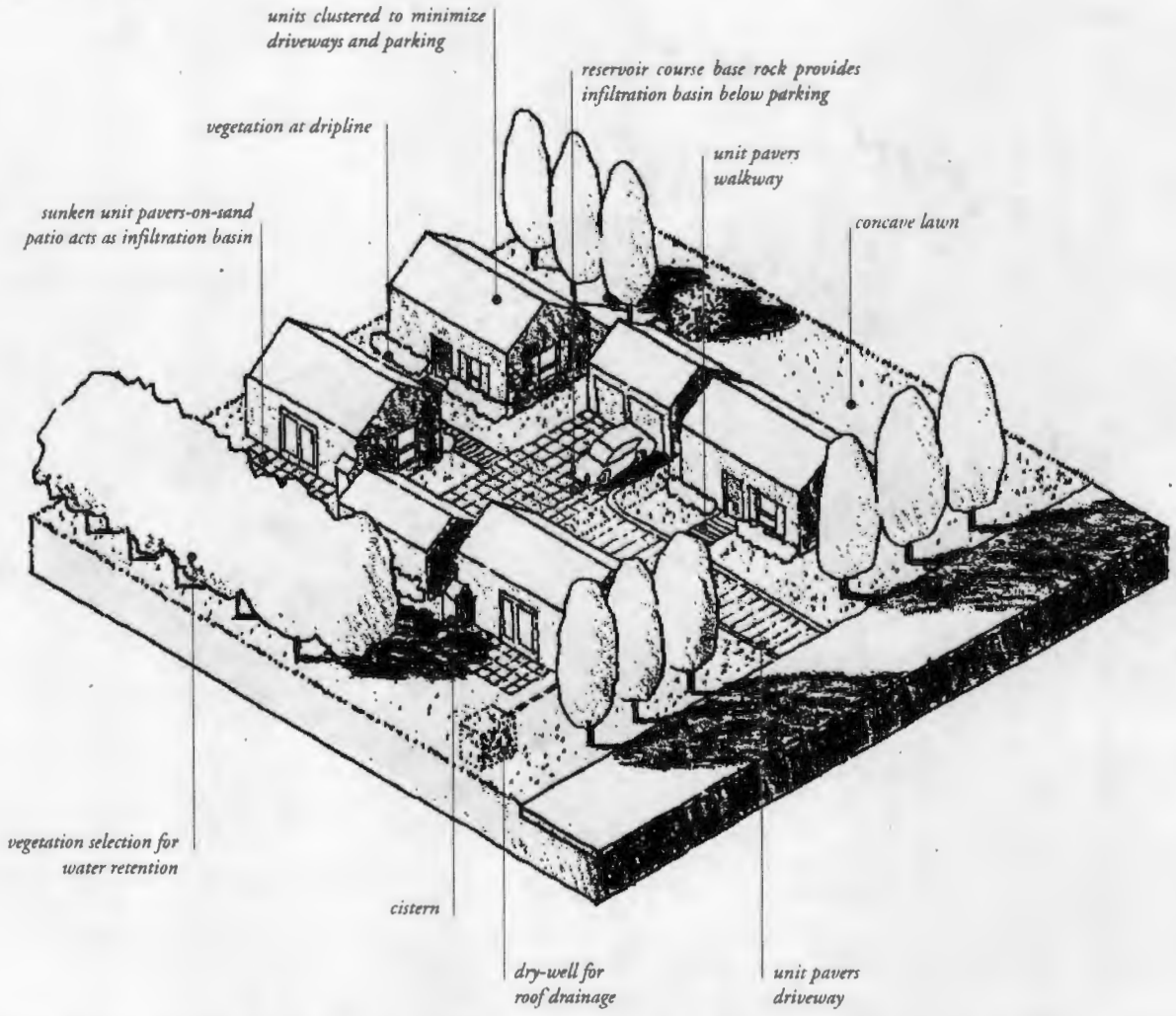
Case Study

7.1c

High density multi-family site



7.1c High density multi-family site. In the Bay Area, many of the sites for new construction are infill or redevelopment sites. These sites usually have higher densities (typically from 12 to 40 units per acre) which demands a greater proportion of pavement and roof coverage.

Opportunities for on-site stormwater management usually still exist, even in the most densely developed infill site, though they may require greater creativity or multiple use of space.

Continuous homeowner education is needed to prevent dumping. Hazardous waste disposal must be provided for used oil/solvents, cleaners, etc.

The techniques illustrated in this example are:

- unit pavers-on-sand patio
- concave lawn play area and infiltration basin
- not directly connected impervious driveway
- brick-on-sand pathway
- dry-well connected to roof downspout
- cistern
- vegetation for water retention (deep rooted trees)
- vegetation at dripline of roof.

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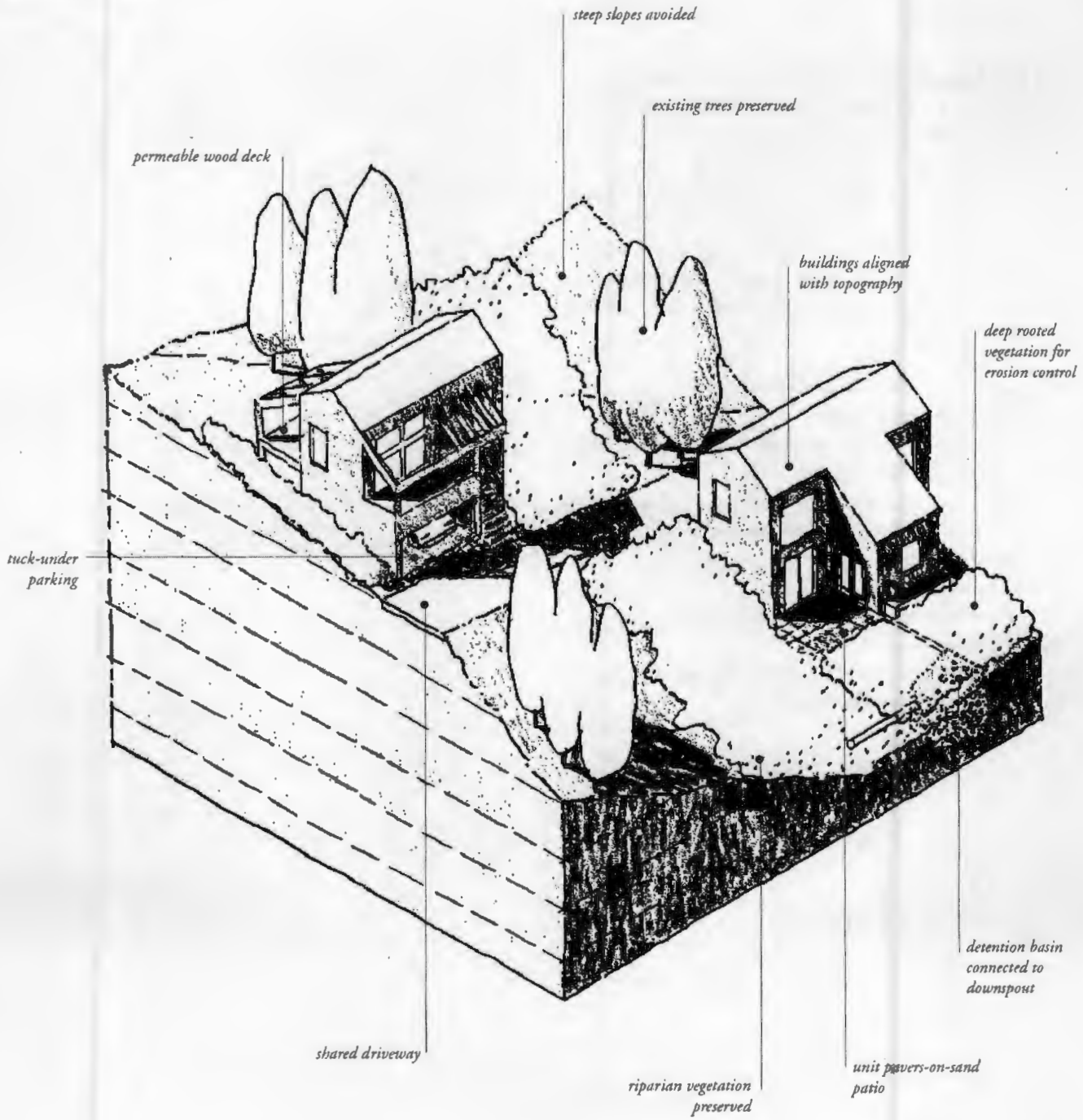
Case Study

7.1d *Small hillside site*



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7.1d Small hillside site. Hillside sites present particular challenges for stormwater management. Because slopes are often pronounced, some infiltration strategies that are best suited to more level sites, such as dry wells or infiltration basins, are impractical and can cause landslides or severe damage. Erosion must be prevented through siting with contours to minimize grading and careful stabilization of disturbed slopes. Finally, drainage systems and detention devices must be located so that water does not compromise the integrity of building foundations and other structures.

The techniques illustrated in this example are:

- avoidance of steep slopes
- buildings aligned with topography to minimize grading
- preservation of existing trees
- preservation of riparian vegetation
- deep rooted vegetation for erosion control
- shared driveway
- tuck-under parking
- permeable wood deck for outdoor use area
- unit pavers-on-sand patio
- detention basin connected to roof downspout (downslope from building)

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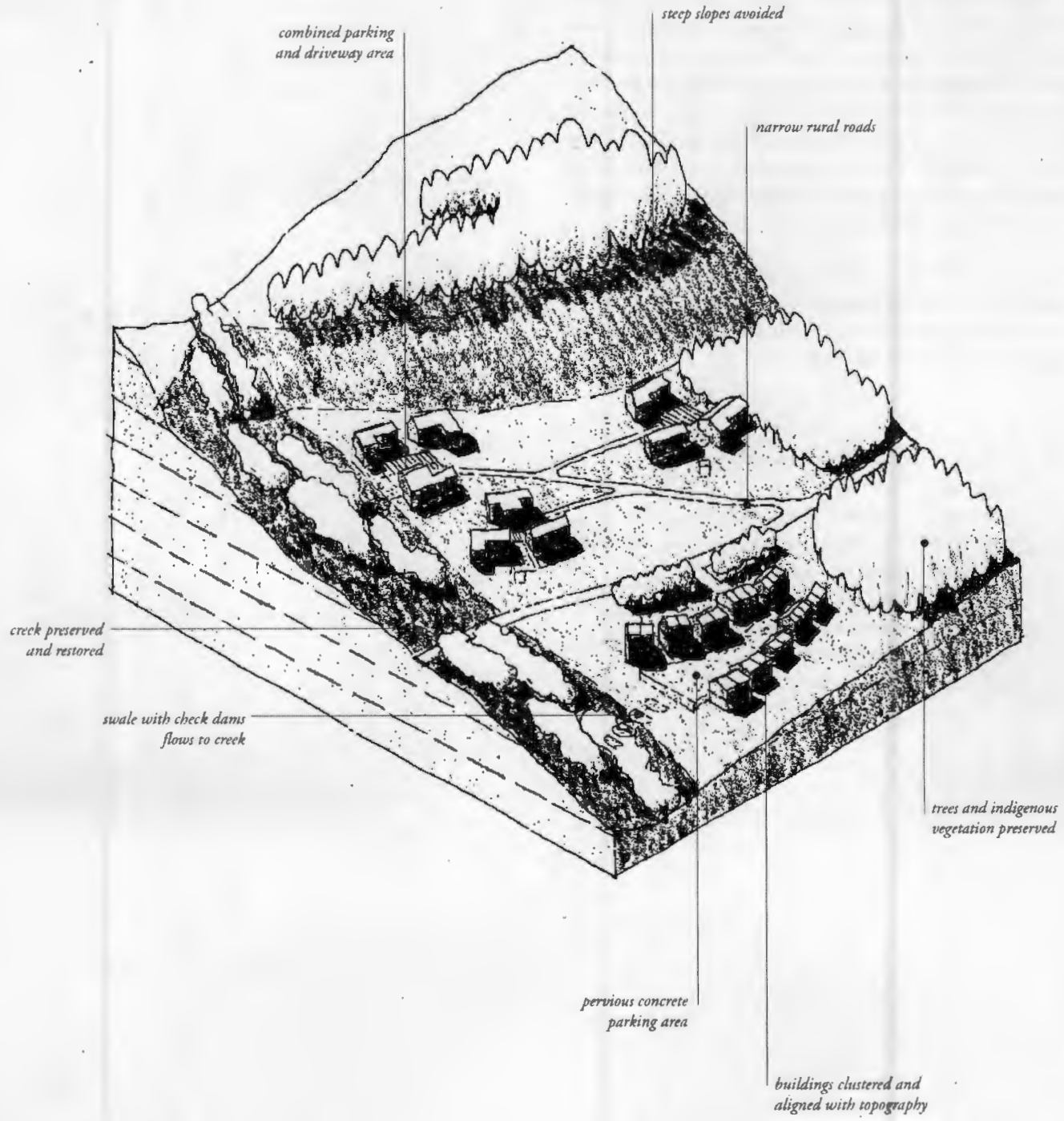
Case Study

7.1e

Large hillside site



SARB_009603

7.1e Large hillside site. Larger hillside sites present similar challenges as smaller sites, but sometimes offer more opportunities for stormwater management. Because slopes are often pronounced, some infiltration strategies that are best suited to more level sites are impractical and may cause landslides. Erosion must be prevented through siting with contours to minimize grading and careful stabilization of disturbed slopes. Finally, drainage systems, infiltration basins and detention devices must be located so that water does not compromise the integrity of building foundations and other structures.

This example shows a large scale application of the site planning and design principles discussed earlier. Each cluster of buildings could also contain the finer grain elements like those illustrated for the small hillside site (7.1d).

The techniques illustrated in this example are:

- avoidance of steep slopes
- buildings clustered and aligned with topography
- preservation of existing trees and indigenous vegetation
- creek preserved and restored
- narrow rural roads
- combination parking and driveway area
- pervious concrete parking area
- swale with check dams flows to creek

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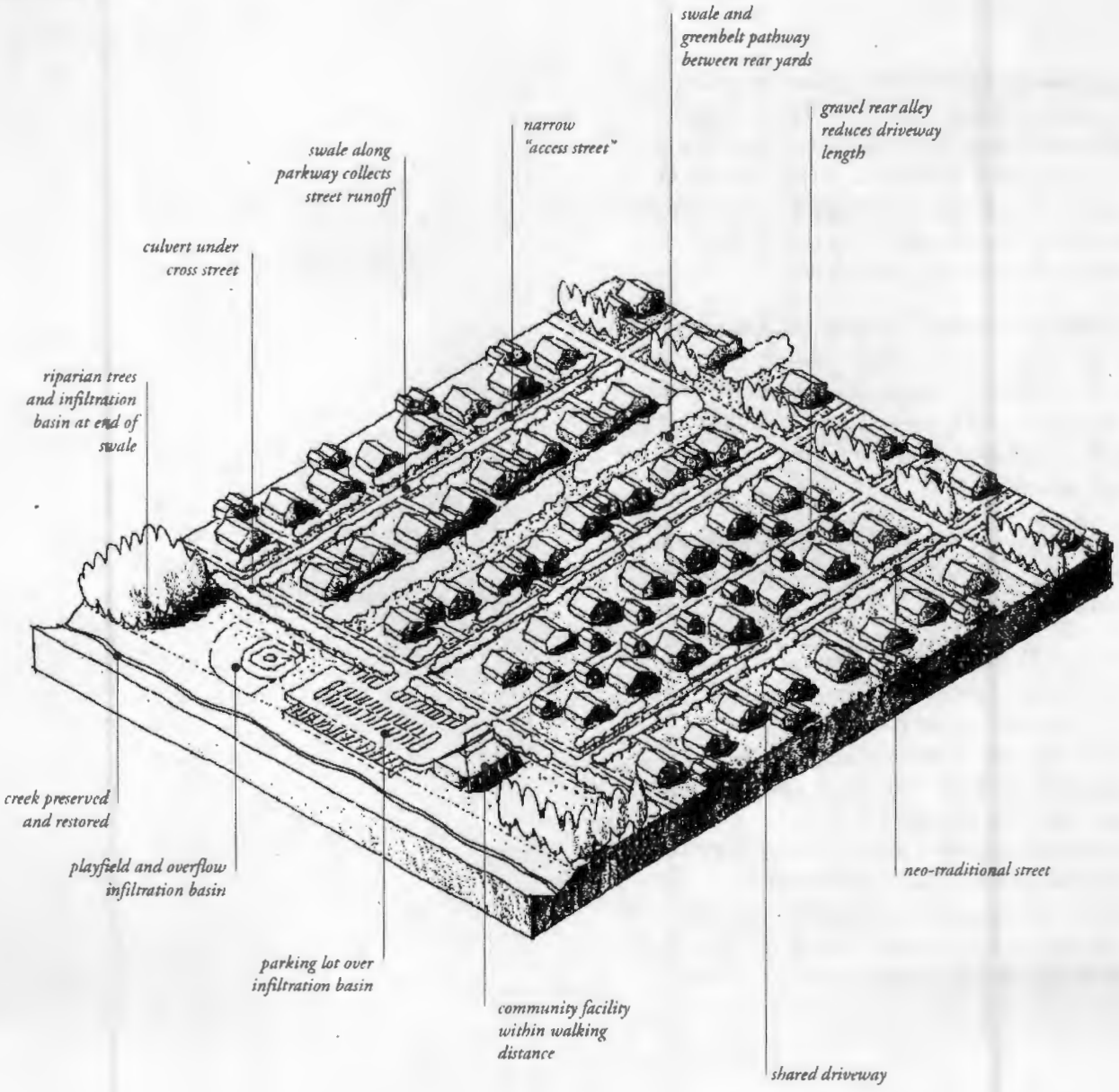
Case Study

7.1f

Large flat site



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7.1f Large flat site. Larger flat sites present some of the greatest opportunities for stormwater management. If soils have adequate percolation rates, infiltration swales and basins are easily incorporated. In more poorly drained soils, flat sites allow for detention and retention systems to slow the speed of runoff and hold it for later release. This allows sediments to settle and minimzes stream bank erosion from high velocity flows.

This example applies the site planning and design principles discussed earlier at the neighborhood scale. For the purposes of illustration, two different street access systems are shown: driveways from the street or rear alley access. Each has different planning implications, but both can be integrated with appropriate stormwater management.

Each cluster of buildings could also contain the finer grain elements like those illustrated for the small single lot, large single lot and infill site.

The techniques illustrated in this example are:

- neo-traditional street design
- gravel rear alley reduces driveway length
- shared driveways to minimze pavement
- community facility within walking distance
- parking lot over infiltration basin
- depressed playfield with multiple use as infiltration basin
- swale along parkway collects street runoff
- culvert to carry parkway swale under cross street
- riparian trees and infiltration basin at end of swale
- swale and greenbelt pathway between rear yards

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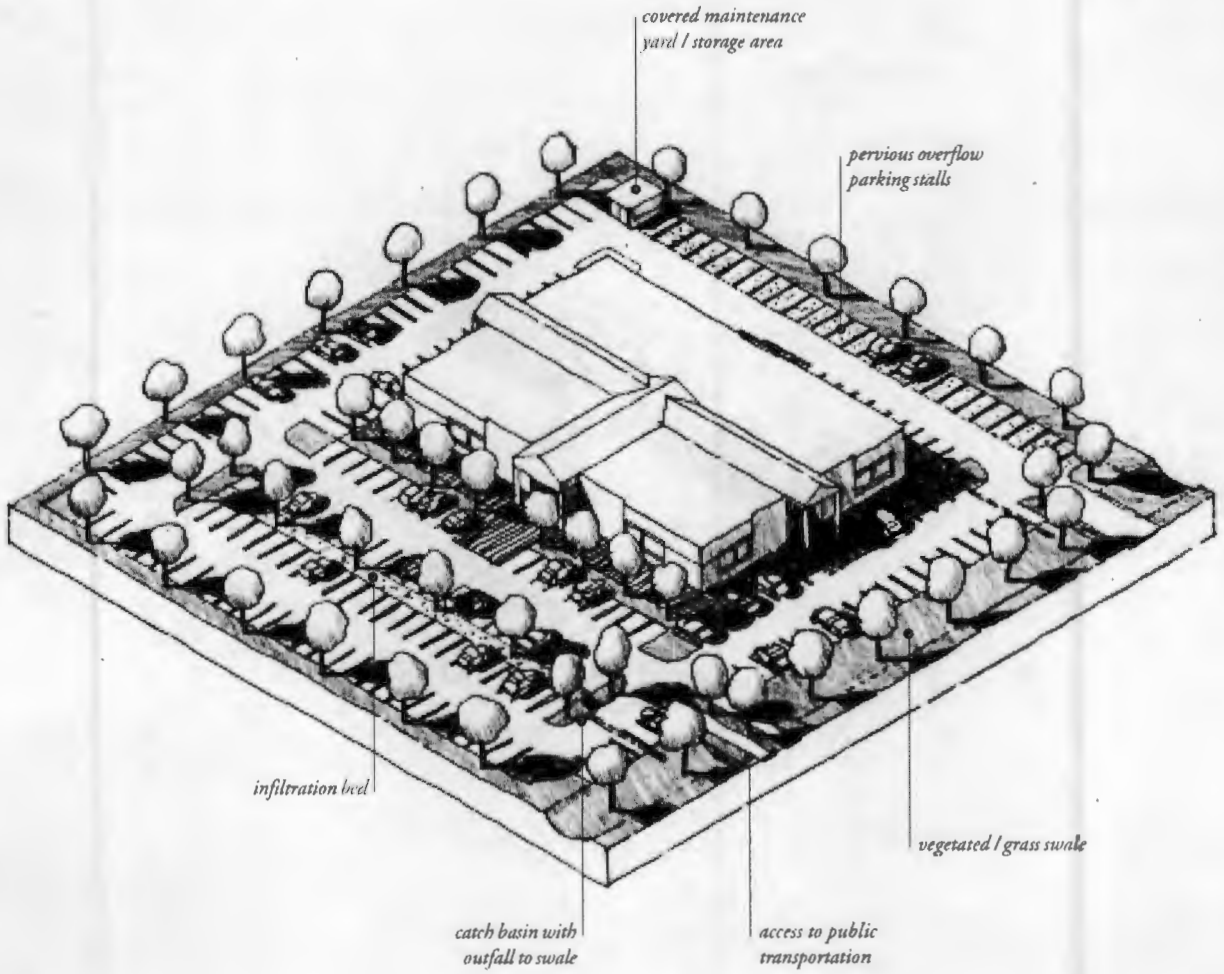
Case Study

7.2a *Shopping center*



7.2a Shopping center. Shopping centers present many opportunities for stormwater management, especially in the parking areas. Infiltration swales and extended detention (dry) basins can be incorporated into space between parking aisles. Recognizing that much of the parking is only necessary during peak times, such as the holiday season, a proportion of outlying stalls may be paved with a more permeable pavement such as crushed aggregate or turfblock .

The utility functions inherent in any shopping center also need attention, such as restaurant wash-down areas, trash collection areas, and service yards. These outdoor work areas require specific techniques to prevent polluted runoff from entering the storm drain system or local water bodies. Similarly, potential hazardous materials use within the shopping center, i.e. dry cleaning establishments, requires special attention and treatment.

If well designed, correctly installed, and properly maintained, stormwater management techniques can enhance the aesthetic character of a shopping center and improve its marketability.

The techniques illustrated in this example are:

- vegetated/grass swale along perimeter
- infiltration bed to divide parking aisles
- pervious overflow parking stalls
- public transportation service
- covered maintenance yard/service areas

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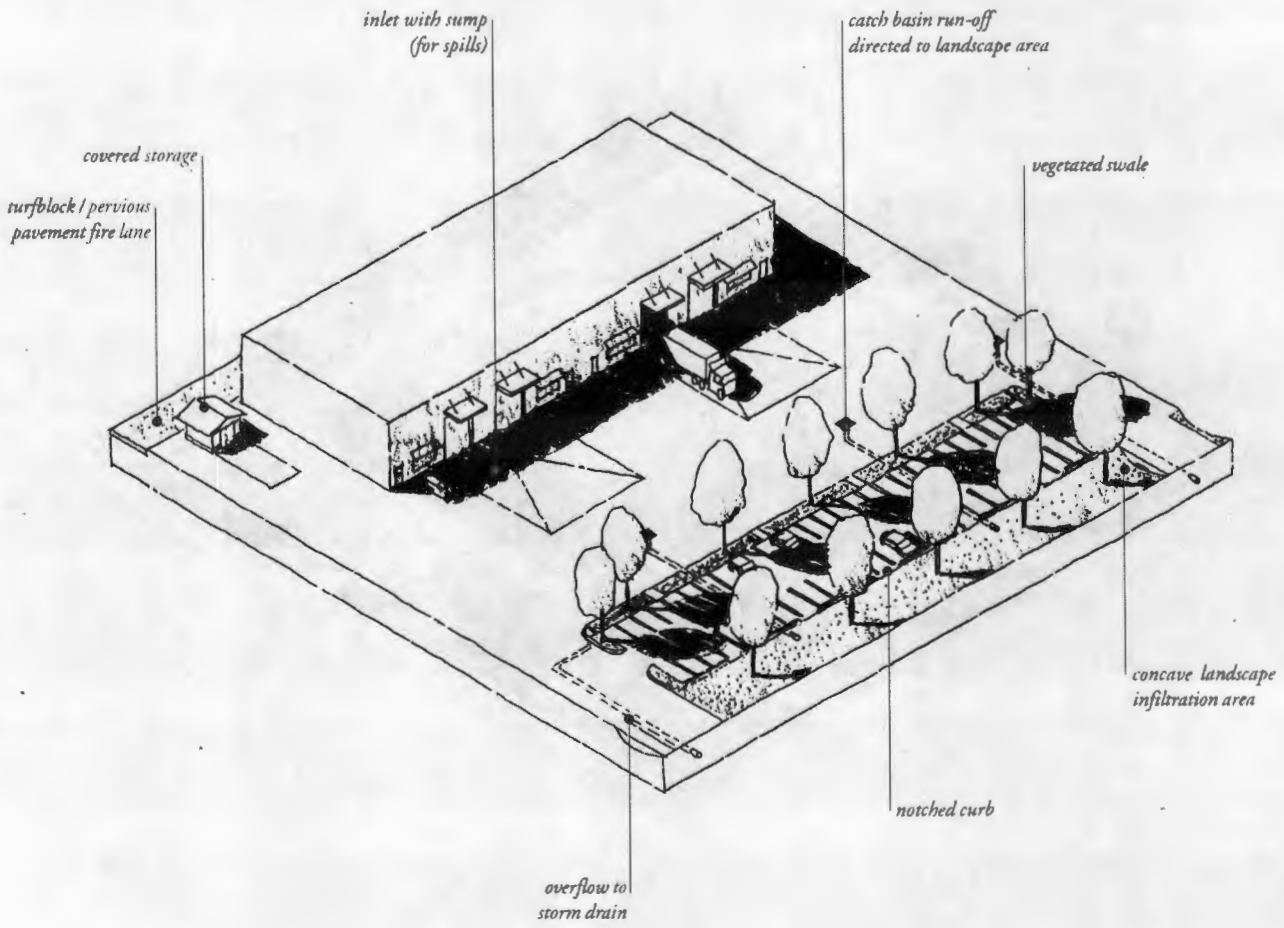
Case Study

7.2b *Industrial park*



7.2b Industrial park. Industrial parks present special challenges when designing for stormwater management. They usually require large paved areas for truck access and employee parking, and space is usually limited. They also often have chemical storage and other special activity areas that require that infiltration techniques are avoided.

Still, there are opportunities to incorporate design details to protect stormwater quality. These include minimizing impervious surface area through the use of permeable pavements, infiltration areas to collect runoff, and proper treatment of special activity areas.

The techniques illustrated in this example are:

- vegetated/grass swale along perimeter
- catch basin runoff directed to infiltration area
- permeable pavement fire lane
- notched curb to direct runoff from parking area into swale
- proper loading dock design
- covered maintenance yard/service areas

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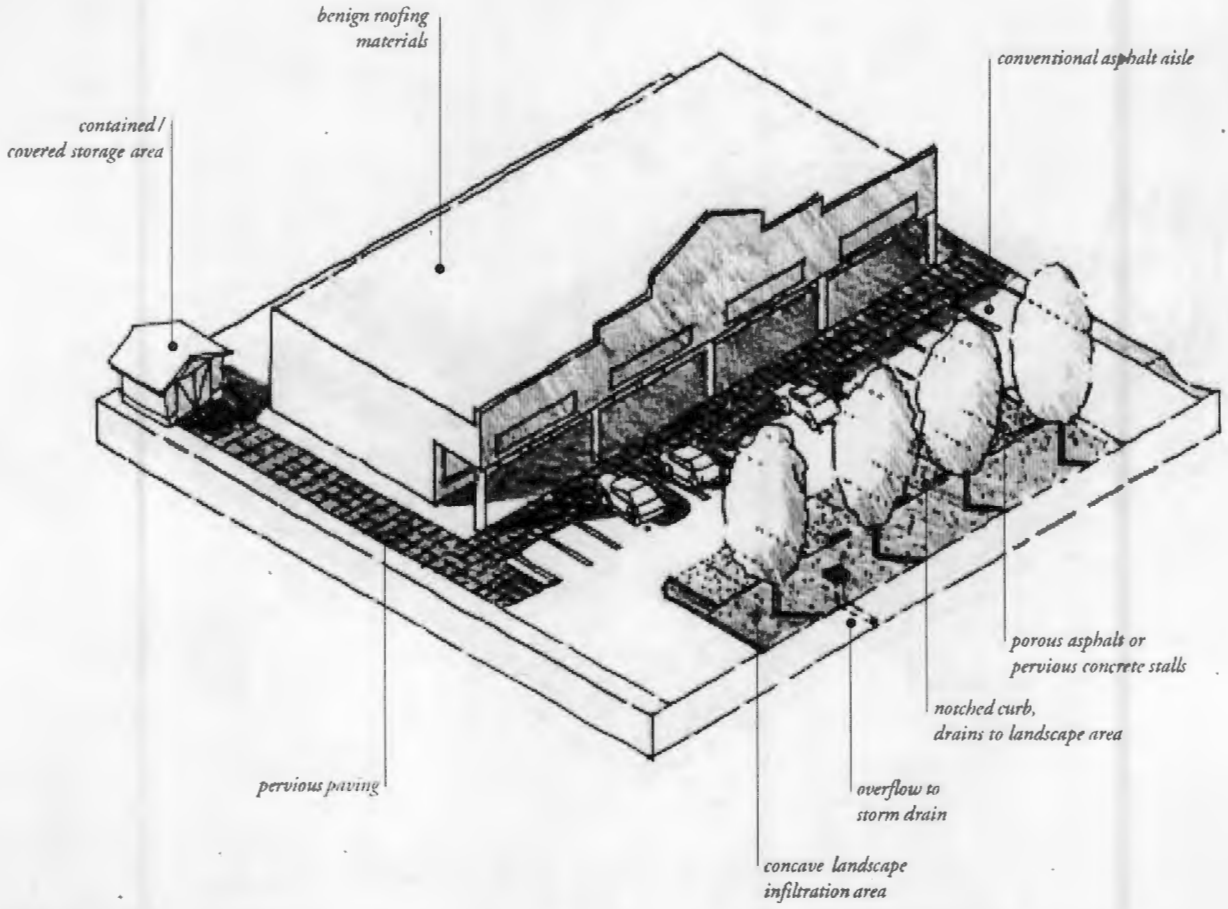
Case Study

7.2c *Strip Mall*



7.2c Strip Mall. Though strip malls are usually very densely developed, they present opportunites for stormwater management techniques. These can be implemented without changing the normal aesthetics or function.

Parking areas can be paved in porous asphalt or other permeable pavements. Buildings can be constructed from benign materials, and the landscape buffers, usually required by local jurisdictions, can be designed as infiltration areas with appropriate overflow into the storm drain system.

Finally, trash and other storage areas can be properly designed and constructed to prevent pollutants from running off these areas into the storm drain system.

The techniques illustrated in this example are:

- benign roofings materials
- catch basin runoff directed to infiltration area
- permeable pavement parking stalls
- concave landscape areas to infiltrate runoff
- notched curb to direct runoff from parking area into swale
- covered maintenance yard/service areas

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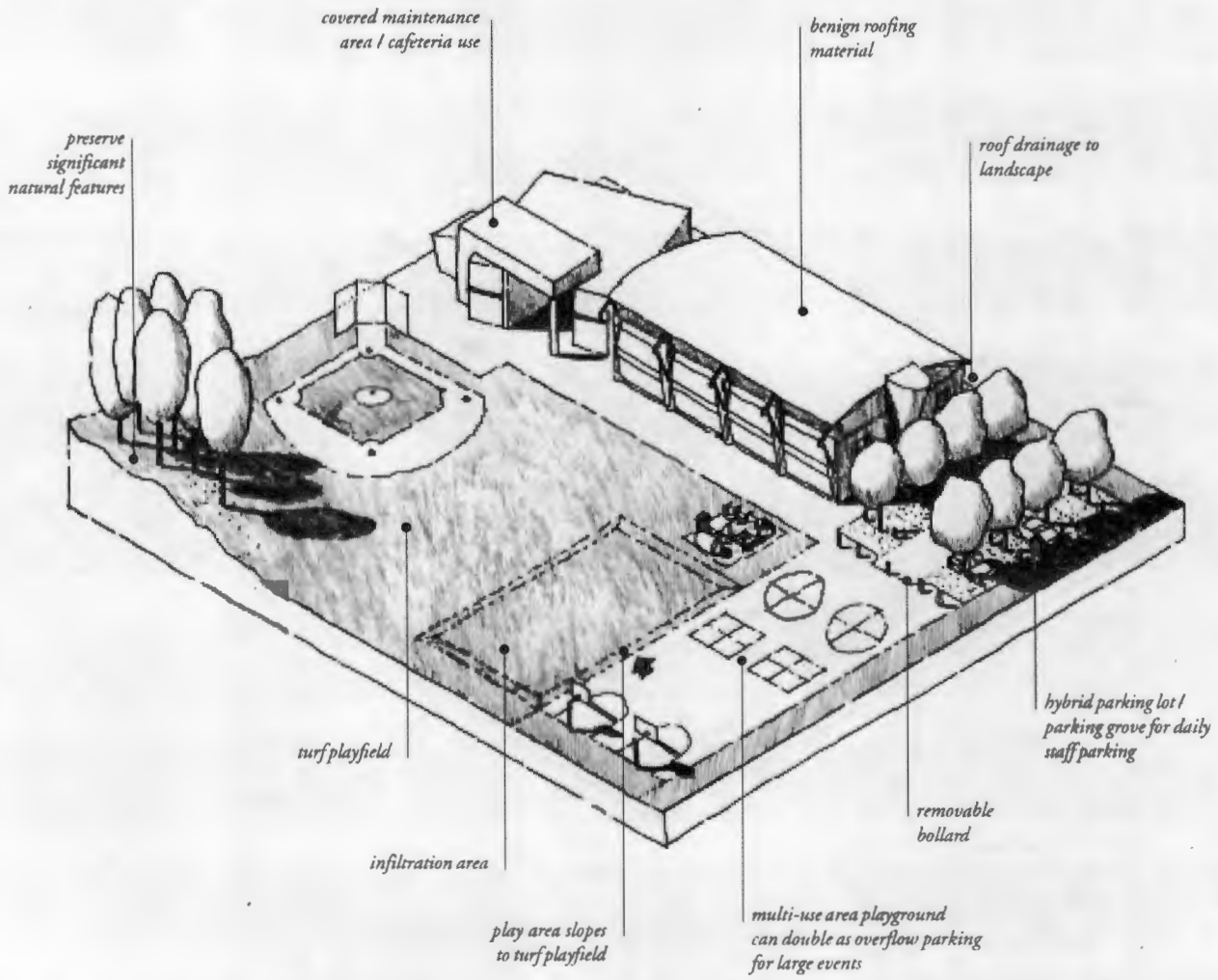
Case Study

7.2d *Schools and parks*



7.2d Schools and parks. Schools and parks present a wide range of opportunities for stormwater management techniques. Large landscape areas for passive and active recreation can be designed as extended detention (dry) ponds to infiltrate and detain runoff, while drying up shortly after rains.

At schools, staff parking can be located in parking groves, since the teaching staff generally parks for long periods. Paved areas, such as basketball courts, can be designed as parking or other multi-use space for special events, thus reducing the need for additional impervious land coverage. Buildings can be designed from benign building materials with appropriately designed outdoor work areas for service, cafeteria, and utility needs.

In large subdivisions, land is often reserved for future schools and parks. Land can be reserved in the lower portion of the site for these uses and designed to receive stormwater from the entire subdivision watershed. This approach illustrates how stormwater management can influence overall site planning and design.

The techniques illustrated in this example are:

- benign roofings materials
- catch basin runoff directed to infiltration area
- parking grove for staff use
- multi-use paved areas
- concave landscape areas to infiltrate runoff
- preservation of significant natural areas
- covered maintenance yard/service areas

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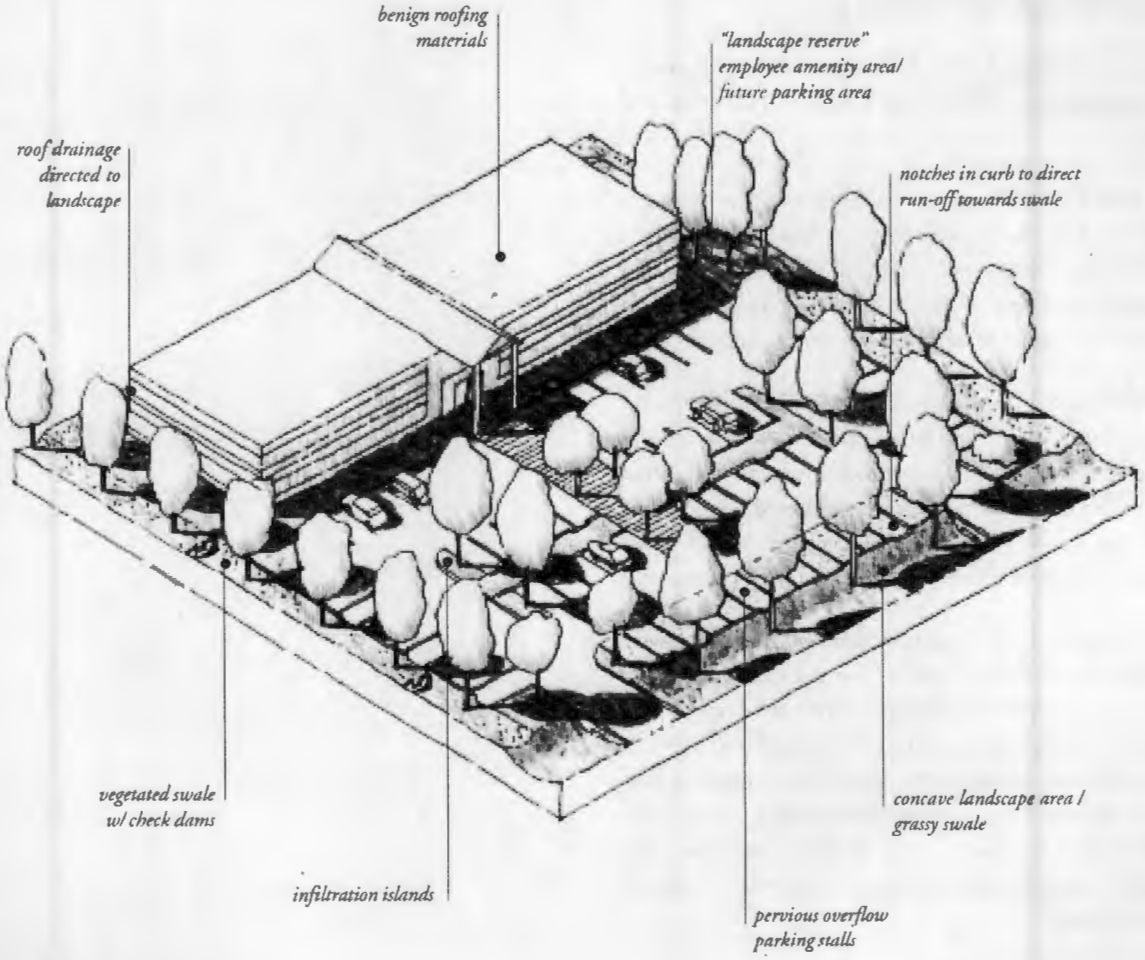
Case Study

7.2e

Office building



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7.2e Office buildings. Office buildings can integrate stormwater management techniques in many ways.

Buildings can be designed from benign materials with appropriately designed outdoor work areas for service, cafeteria, and utility needs.

Landscape areas for employee use and perimeter screening can be designed as extended detention (dry) basins or biofilters (grassy swales) to infiltrate and detain runoff, while drying up shortly after rains. These areas can also be designed as fountains or entry statements to add aesthetic enhancement .

Parking can be treated in a variety of ways, with overflow parking accommodated on permeable pavement. Impervious parking stalls can be designed to drain onto landscape infiltration areas. Alternative transportation can be promoted by providing bicycle lockers, showers and clothes lockers for bicycle commuters, and company sponsored van- and carpool programs.

Finally, many jurisdictions allow a portion of the required parking to be held in "landscape reserve," until a need for the full parking supply is established. This means that the original construction only builds parking to meet anticipated staff needs. If the parking demand increases, the area held in landscape reserve can be modified to accommodate parking. In this way, parking is held to a minimum based on actual use, rather than by a zoning formula that may not apply to the office building's actual parking need.

The techniques illustrated in this example are:

- benign building materials
- catch basin runoff directed to infiltration area
- vegetated swale with check dams
- landscaped "parking reserve"
- concave landscape areas to infiltrate runoff
- pervious overflow parking stalls
- roof drainage directed to landscape

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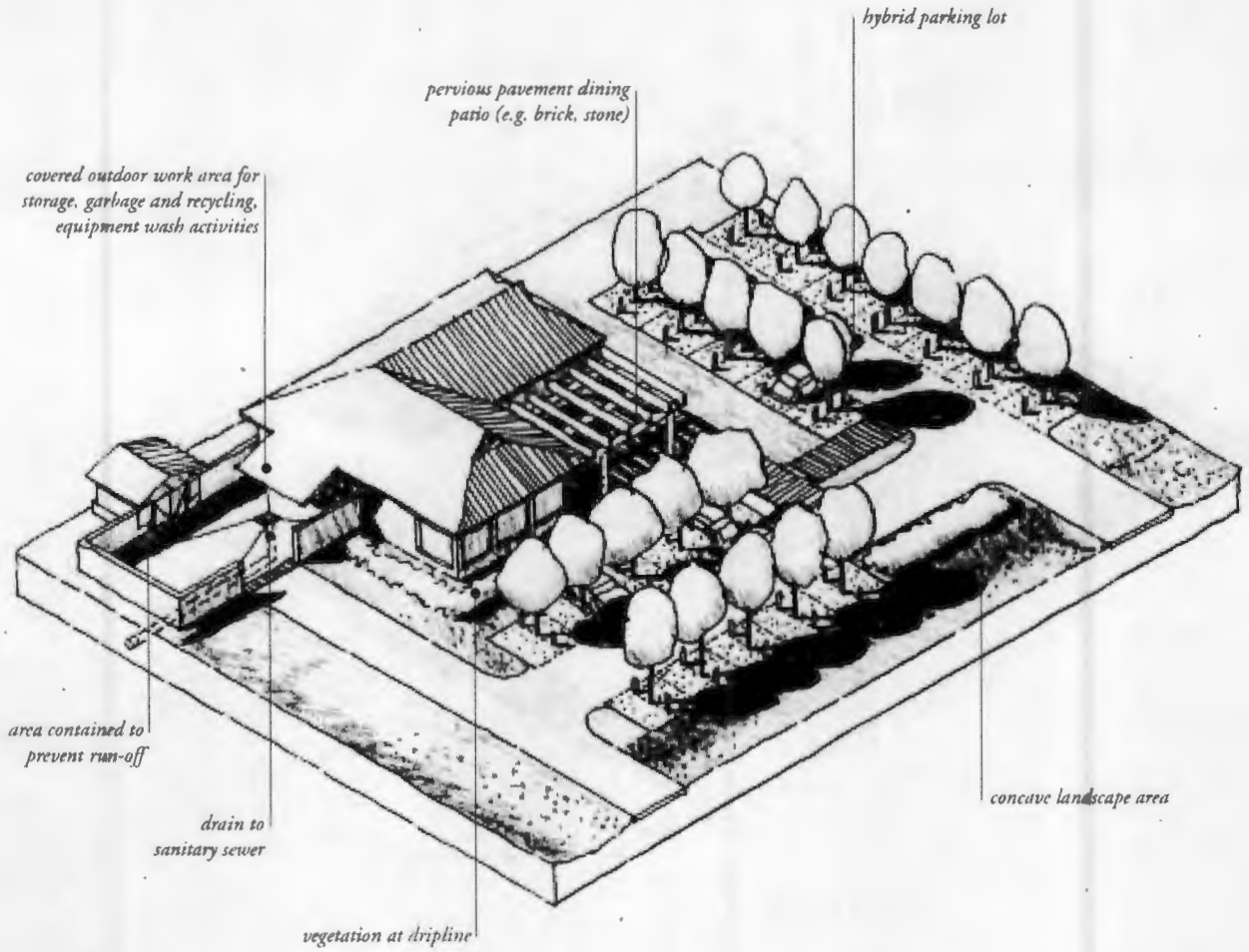
Case Study

7.2f

Restaurant



7.2f Restaurant. Restaurants offer a strong contrast between infiltration opportunities and special activity areas. Careful selection of materials such as brick or stone paving for outdoor patios can enhance the restaurant's aesthetic while allowing for infiltration. Landscape plantings can also be selected for stormwater infiltration.

Parking can be provided in a variety of ways, with hybrid parking lots for staff, who stay for long shifts, or with landscaped infiltration islands in lots with conventional paving for patrons, who stay for shorter periods.

In contrast to these infiltration opportunities, restaurants have special activity areas that need to be isolated from the storm drain system. Grease, stored items, trash, and other food waste must be kept in properly designed and maintained special activity areas. Local ordinances may have design guidelines for allowable square footage of covered and uncovered areas.

The techniques illustrated in this example are:

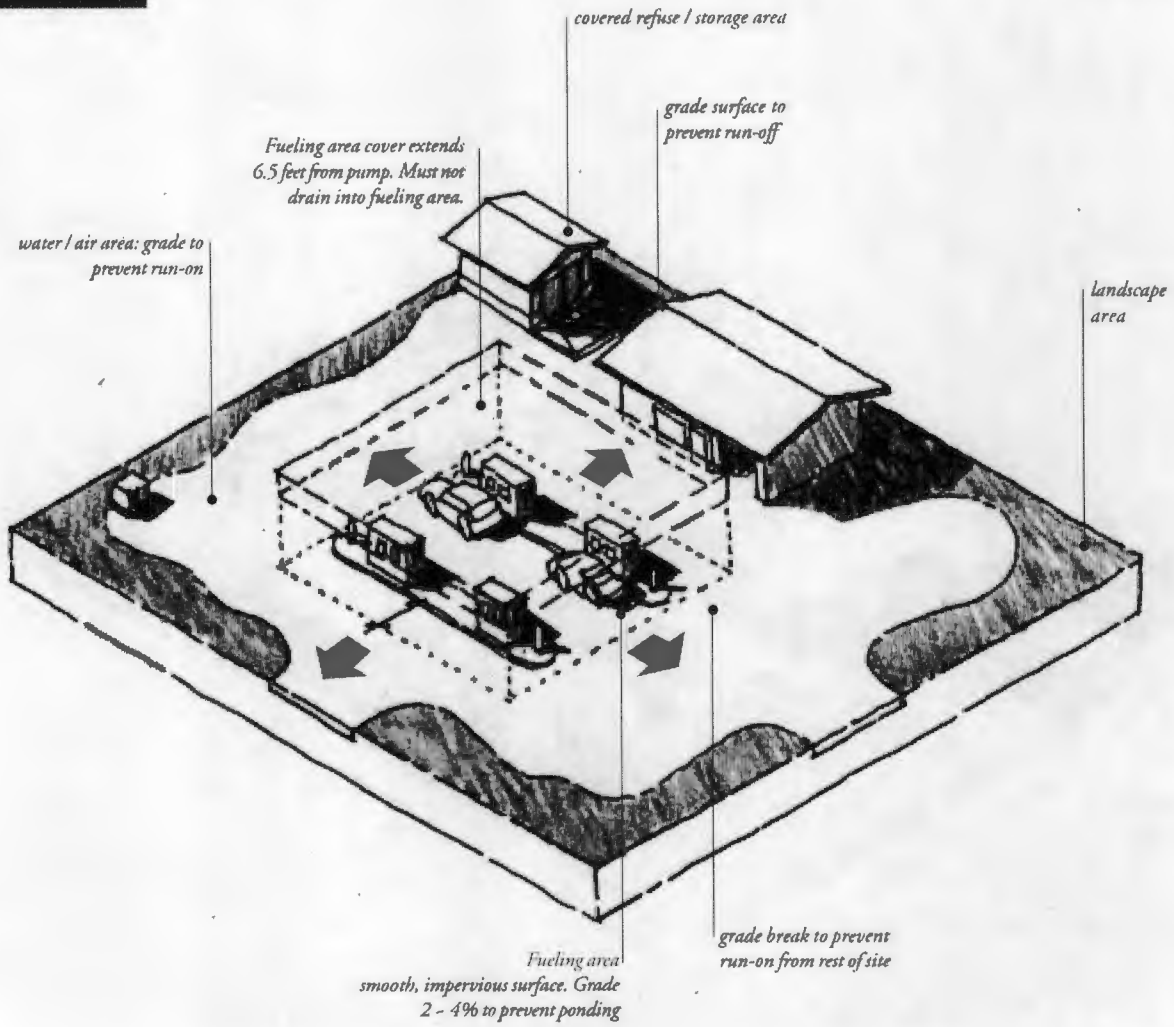
- permeable pavement patio
- benign building materials
- catch basin runoff directed to infiltration area
- hybrid parking lot
- vegetation at dripline
- concave landscape areas to infiltrate runoff
- covered outdoor work area (trash, food waste, storage, equipment wash)

SARB_009613

Case Study

7.2g

Gas station



7.2g Gas station. Gas stations and vehicle fueling areas have specific design guidelines. These are described in a Best Management Practice Guide for retail gasoline outlets developed by the California Stormwater Quality Task Force, in cooperation with major gasoline corporations. Designing for prevention is the first step. Plans must be developed for cleaning near fuel dispensers, emergency spill cleanup, and routine inspections to prevent leaks and ensure properly functioning equipment.[1]

The practice guide addresses standards for existing, new, or substantially remodeled facilities, and is available from www.blymyer.com/swqtf.

Some of these features are illustrated in the case study above:

- fueling area cover
- flat impervious surface fueling area (2%-4% slope to prevent ponding,
- grade break (e.g., curb, berm) that prevents run-on of stormwater
- separate water / air area graded to prevent run-on
- covered refuse / storage area

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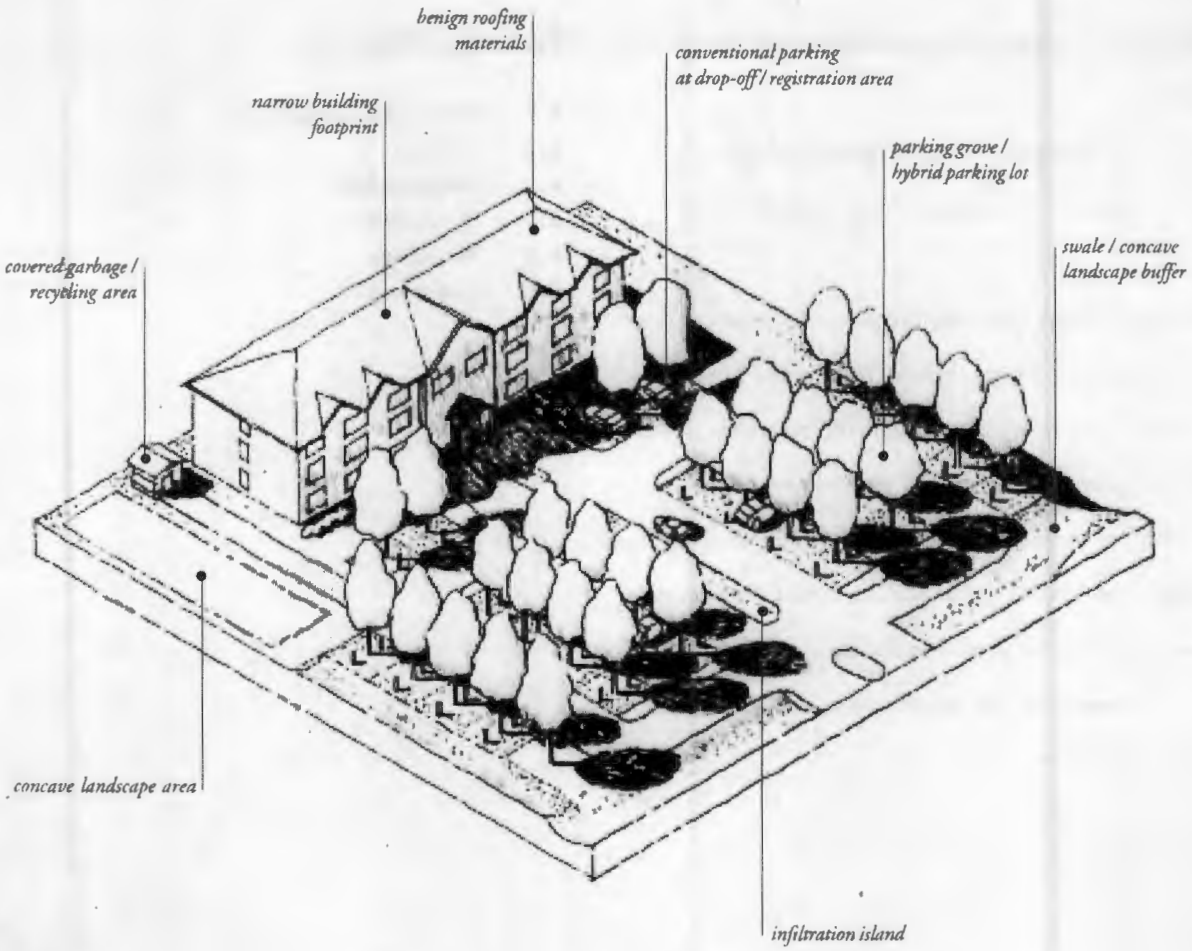
Case Study

7.2h *Hotel/motel*



7.2h Hotel/motel. Hotels and motels present many opportunities for stormwater management designs. Because guests park for long periods of time, such as overnight, parking areas can be designed as parking groves or hybrid lots. This increases the aesthetic appeal of the hotel, reduces heat island effect, and minimizes the impact of parking when the hotel is not highly occupied. However, it is important to retain some conventional parking for more heavily used drop-off and loading areas.

Landscape areas for guest use can be designed as infiltration/ detention areas to hold water briefly after rains. Perimeter areas also can provide opportunities for stormwater management.

The building can be designed from benign materials with a narrow multistory footprint, rather than a sprawling single floor. Rainwater can be directed in gutters and downspouts into landscape areas.

The techniques illustrated in this example are:

- permeable pavement patio
- benign building materials, narrow building footprint
- catch basin runoff directed to infiltration area
- parking grove
- vegetation at dripline
- concave landscape areas to infiltrate runoff
- covered special activity area (trash, food waste, storage)

SARB_009615

8 Technical Section

The site design and landscape details illustrated here have two purposes:

- *to minimize the creation of new runoff, and,*
- *to infiltrate or detain runoff in the landscape.*

The techniques presented here illustrate an approach to design and construction for maximizing infiltration, providing retention, slowing runoff, and minimizing impervious land coverage. They are not all-inclusive, and may not be appropriate for every site or condition. Each detail is given in a generic or typical form– particular site and soil conditions must be assessed by a qualified professional to determine which details are appropriate and what modifications are required for their proper application.

Technical Section

8.1 Permeable pavements
8.2 Streets
8.3 Parking lots
8.4 Driveways
8.5 Buildings
8.6 Landscape

SARB_009616

8.1 Permeable Pavements

Permeable pavements are a method of reducing impervious land coverage while simultaneously providing a stable load-bearing surface. While forming a surface suitable for walking and driving, permeable pavements also contain sufficient void space to infiltrate runoff into soil. By making pavements permeable, impervious surface coverage can be reduced without sacrificing intensity of use.

There are three main categories of permeable pavements: poured-in-place, unit pavers-on-sand, and granular materials. A typical component of these permeable pavements is a reservoir base course. This base course provides a stable load-bearing surface as well as an underground reservoir for water storage. The base course must meet two requirements:

- *it must be open graded, meaning that the particles are of a limited size range, with no fines, so that small particles do not choke the voids between large particles. Open-graded crushed stone of all sizes has a 38 to 40% void space, allowing for substantial subsurface water storage.*
- *it must be crushed stone, not rounded river gravel. Rounded river gravel will tend to rotate under pressure, causing the surface structure to deform. The angular sides of the crushed stone will form an interlocking matrix, keeping the surface stable.*

Permeable pavements must be laid on a relatively flat slope, generally 5% or flatter. If permeable pavements are laid on steep slopes, the underlying base course tends to migrate downhill, causing the surface to deform.

Permeable Pavements

Pervious concrete

Porous asphalt

Turf block

Brick

Natural stone

Unit pavers on sand

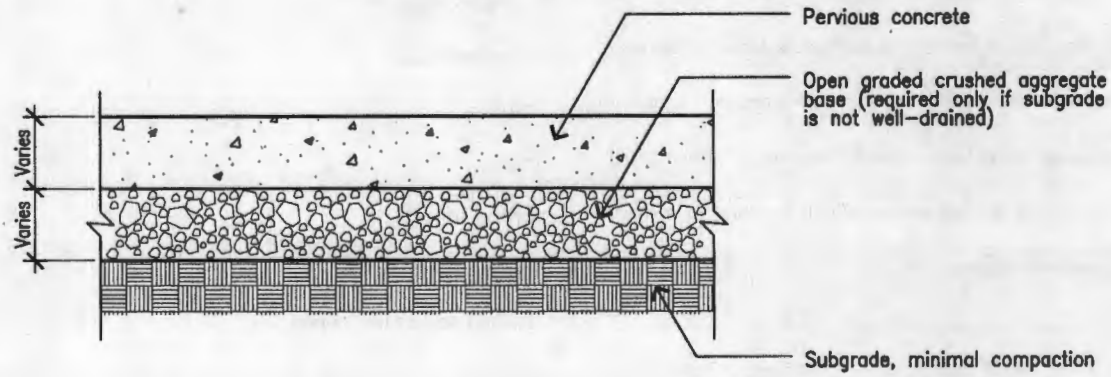
Crushed aggregate (gravel)

Cobbles

SARB_009617

Permeable Pavements

Pervious concrete



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Pervious Concrete is a discontinuous mixture of coarse aggregate, hydraulic cement, and other cementitious materials, admixtures, and water, which has a surface-void content of 15-25%, allowing water and air to pass through the pavement.

Characteristics

- Rigid, poured-in-place slab.
- Appearance similar to exposed aggregate.
- Curb and gutter system may not be necessary to control low flow.
- Runoff coefficient: very low to nil (can infiltrate up to 140 cm/h [56"/h]).
- Reduces impervious land coverage.

Applications

- Flat sites (slope ≤ 5%) with uniform, permeable subgrade (or appropriate depth to construct deep base).
- Low traffic volume bikeways, streets, travel lanes, parking stalls, residential driveways, patios.
- Not appropriate for gas stations, truck stops, areas in which high concentrations of hydrocarbons can be leached into the soil.

Design

- Subgrade and base rock design must be determined by a qualified professional according to soil conditions and intended use or anticipated loads.
- Subgrade must be uniform, well-drained (infiltration rate ≥ 5"/hr). Top 6" of subgrade should be granular/gravely soil, predominantly sandy, with low to moderate amount of clay or silt.
- Base of open graded, crushed (not rounded) stone, no fines. Must be designed to support surface uses, allow water to flow through, and prevent migration of subbase soils.
- Special attention and tools required for installation.

Maintenance

- Inspect for clogging after installation and annually; remove spot clogs.
- Some installers recommend quarterly vacuum sweeping or high pressure hosing.
- Maintenance can be high first few years, until site is fully stabilized.

Economics

- Installation costs up to 50% greater than conventional concrete.
- Costs can be offset by savings in not installing curb and gutter drainage system.
- Maintenance cost up to 1-2% of construction cost annually.

Examples/resources

- Drain cover at Stanford Shopping Center, Palo Alto, CA.
- Tree grates in city sidewalks, Los Angeles, CA.
- Florida Concrete and Products Association (407) 423-8279.

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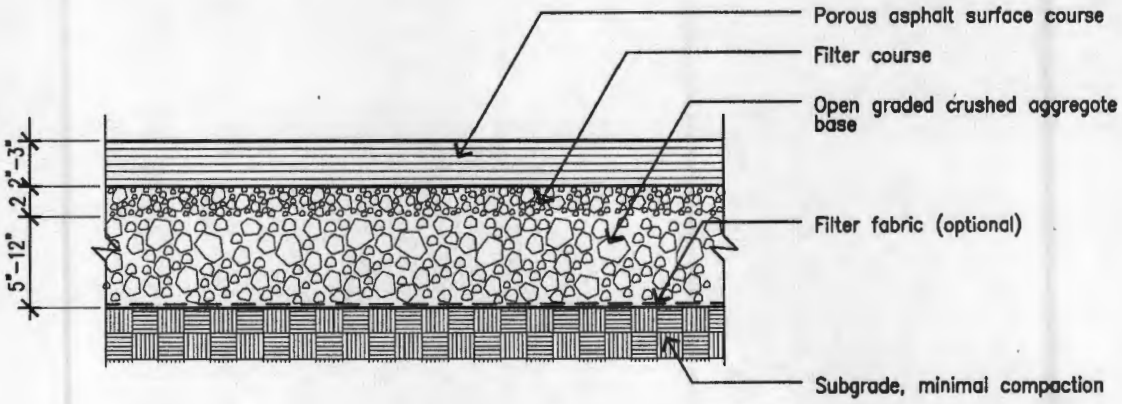
Permeable pavements

Porous asphalt



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Porous Asphalt is an open graded asphalt concrete over an open graded aggregate base and a draining soil. It is composed almost entirely of stone aggregate and an asphalt binder. Porous asphalt is widely used as a top lift on state highways to minimize water ponding and hydroplaning. In this case it does not create a permeable pavement, because the porous ("open graded") asphalt is lain over a conventional asphalt lift.

Characteristics

- Flexible, poured-in-place slab.
- Appearance similar to conventional asphalt, though rougher surface.
- Rough, coarse surface improves traction in wet conditions, but may result in a rough ride.
- Curb and gutter system may not be necessary to control low flow.
- Runoff coefficient: very low to nil (can infiltrate 50-150 cm/h [20-60"/h])
- Reduces impervious land coverage.

Applications

- For use in areas with low traffic use, such as parking lots, travel lanes, parking stalls (surface may be too rough for bicycle path).
- Flat sites (slope ≤ 5%) with uniform, permeable subgrade (or appropriate depth to construct deep base).
- Not appropriate for gas stations, truck stops, areas in which hydrocarbons can be leached into the soil.
- May not be appropriate in areas where children are at play (pavement may cause abrasion injuries).

Design

Asphalt mix void content of 12 - 20%.

Surface composition 4.5 - 6.5% asphalt aggregate, 2.5 - 3.0% asphaltic cement.

Base composition 5" to 12" depth open graded crushed (not rounded) 1/2 - 1" stone, having infiltration rate ≥ 5" per hour.

- Filter fabric may be required below base course.

Subgrade and base rock design must be determined by a qualified professional according to soil conditions and intended use or anticipated loads.

- Special tools required for installation.

SARB_009619

Maintenance

- Most failures occur when substantial quantities of sediment erode onto pavement surface. This can happen if pavement is located downhill from an erosive and sediment is allowed to wash over the surface, or during construction due to a lack of erosion/sediment control measures. Void spaces then become clogged, either requiring wet-vacuuming or reducing the permeability of the surface.
- Some installers recommend quarterly vacuum sweeping and high pressure hosing, though installations are known that have had no special maintenance and remain permeable for 20 years.
- Inspect for clogging after installation and annually; remove spot clogs.
- Take measures to ensure that future property managers do not use top-coat or slurry seal, as this will clog the asphalt pores.

Economics

- Up to 50% more than conventional asphalt pavement.
- Costs can be offset by savings in reducing or eliminating curb and gutter drainage system.
- Maintenance cost up to 1-2% of construction cost annually.

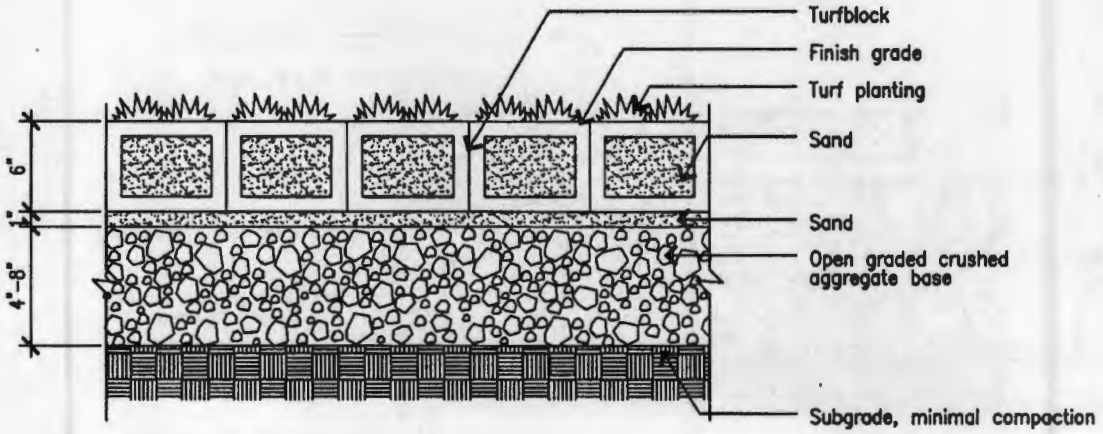
Examples/resources

- Asphalt Institute (805) 373-5130.
- Metropolitan Transportation Commission, pavement management div. (510) 464-7700.
- CalTrans Specifications, Section 39, Asphalt Concrete "Open Graded" type.

SARB_009620

Permeable pavements

Turf block



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Turf block is an open-celled unit paver in which the cells are filled with soil and planted with turf. Sometimes the cells are filled with crushed rock only.

Characteristics

- Units vary in size, weight, surface characteristics, strength, durability, proportion of open area, interlocking capability, runoff characteristics, and cost.
- Original turf block was made solely of concrete, newer plastic styles are available. Concrete block is bulkier, with smaller openings for soil and infiltration. The concrete draws the moisture out of the soil, tending to dry out the grass in hot, dry weather. Plastic open-celled pavers eliminate this problem and have a greater void/soil space.
- Requires deep rooted grass species that can penetrate reservoir base course. Frequent watering may be required because the bulk of root and soil mass are located in the top 3"-4".
- Curbs and gutters generally not necessary to control low flow.
- Runoff coefficient: similar to grass, 0.15-0.60.
- Permeability is directly related to the permeability of the subgrade.
- Reduces impervious land coverage.

Applications

- Areas of low flow traffic and infrequent parking such as: residential driveways, overflow parking areas, the outer 1/3 of commercial and retail developments where parking space is used less often and for shorter periods of time, fire/emergency access roads, utility roads, street shoulders.
- Not suitable for all day parking, heavy use or areas with turning movements because the grass gets insufficient sun for optimal growth, or is suppressed by constant abrasion.
- Swales in urban areas. Turf block prevents mowers from getting stuck or creating grooves in the swale.

Design

- Flat sites (slope ≤ 5%)
- Base course: open-graded and composed of crushed rock (not rounded).
- Subgrademust be designed for anticipated loads.
- Provide underdrain system where there are no deep permeable soils.
- Irrigation required to maintain turf.

Maintenance

- May need occasional reseeding.
- Similar to maintenance of regular lawn, requiring mowing, fertilization, and irrigation.

Economics

- $4-6 per square foot, installed.

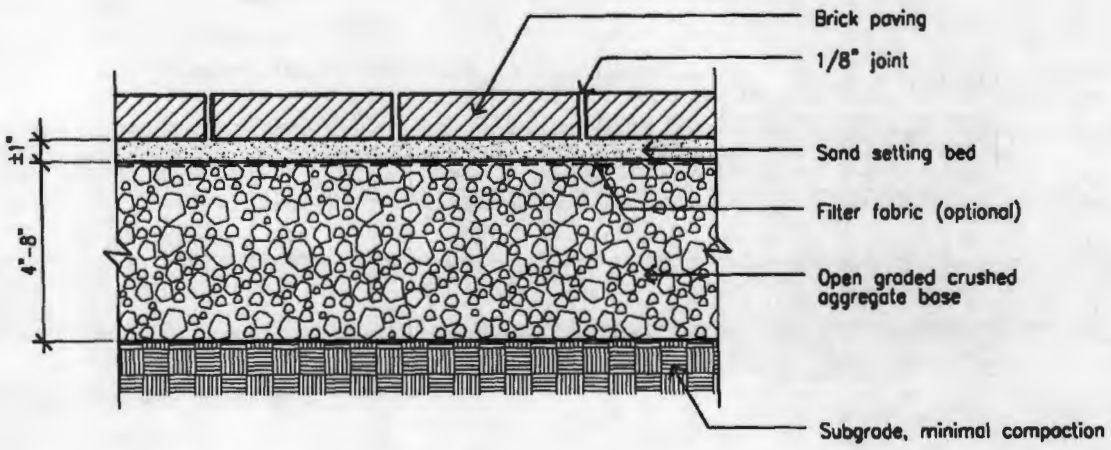
Examples/resources

- Emergency access/fire lane. Guadalupe River Project, San José, CA.
- Parking lot with asphalt aisles, turf block stalls, University of Miami Orange Bowl Stadium, Miami, FL.
- Shopping mall expansion overflow parking, NEMO Project, CT.

SARB_009621

Permeable pavements

Brick



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Brick is a solid unit paver available in a variety of colors and sizes, and a traditional building material with a long history. Brick are typically lain either with sand joints on a crushed rock base, or with mortared joints on a concrete base. Only sand joints on a crushed rock base form a permeable pavement.

Characteristics

- Available in a variety of materials and finishes. Typically, bricks are rectangular in shape and made of a fired clay. Concrete bricks are also commonly available.
- Runoff coefficient: 0.13 to 0.76, depending on rainfall intensity and joint spacing. Brick pavement is more permeable in light rains and with wider joints.

Applications

- Driveways, walkways, patios, public sidewalks, plazas, low volume streets.
- Flat sites (slope ≤ 5%).
- Reduces impervious land coverage.

Design

- Because the bricks are lain loose, the field must be enclosed by a rigid frame. Concrete, mortared brick on a concrete grade beam, redwood header, and metal edging are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- In areas with pedestrian traffic, make joints not larger than 1/4".
- Subgrade must be designed for anticipated loads.

Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.
- Easy to repair, since units are easily lifted and reset.
- Periodically add joint material (sand) to replace material that has been moved/worn by traffic or weather.
- Occasional weed suppression may be required.

Economics

- $6–10 per square foot. Generally more expensive than concrete or asphalt, less expensive than brick on concrete.

Examples/resources

- Widely used as patios, plazas, sidewalks, driveways.

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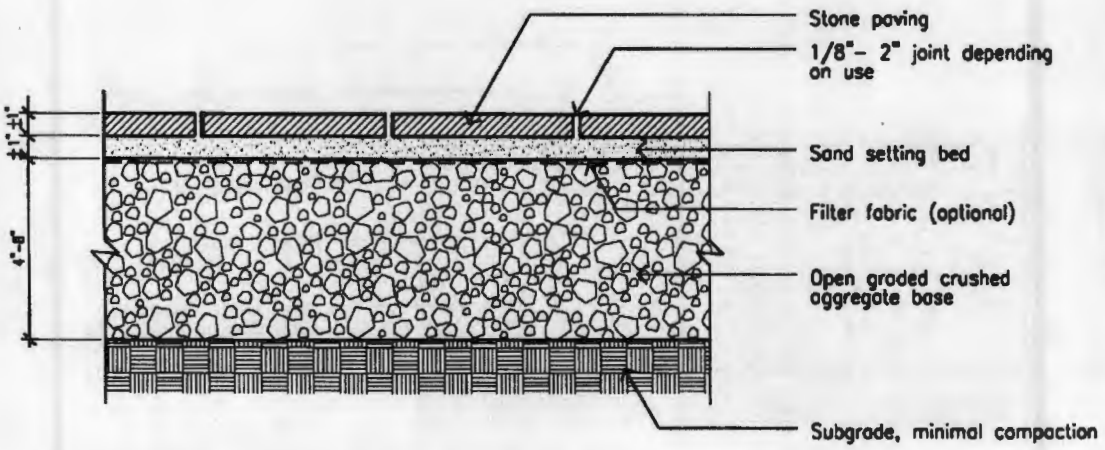
Permeable pavements

Natural stone



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Natural stone paving is made of discrete units set in a pattern on a prepared base. A traditional building material with a long history, natural stone is typically lain either with sand joints on a crushed rock base, or with mortared joints on a concrete base. Only sand joints on a crushed rock base form a permeable pavement.

Characteristics

- Available in a variety of natural materials of varying colors, textures, shapes, and finishes. These include flagstone, slate, granite, and bluestone. For sand-set permeable pavement, the stone must be at least 1" thick– thinner pieces suitable for mortar-setting will crack if sand-set.
- Shapes range from random broken pieces of irregular patterns to cut stone of geometric patterns.
- Permeability is determined by the size of the joints. Large joints in patio or light traffic areas can be filled with plant material such as moss or turf.
- Runoff coefficient: 0.25 - 0.8 depending on joint size. Natural stone pavement is more permeable in light rains and with wider joints.
- Reduces impervious land coverage.

Applications

- Driveways, walkways, patios, low-use parking stalls.
- Flat sites (slope ≤ 5%).

Design

- Because the stone is laid loose, the field must be enclosed by a rigid frame. Concrete, mortared stone on a concrete grade beam, redwood header, and metal edging are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- Subgrade must be designed for anticipated loads.

Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.
- Easy to repair, since units are easily lifted and reset.
- Periodically add joint material (sand) to replace material that has been moved/worn by traffic or weather.
- Occasional weed suppression may be required.

Economics

- Unit cost varies from $10–25 per square foot, depending on material selected.

Examples/resources

- Parking lot stalls, La Casitas del Arroyo community building, Pasadena, CA.
- Widely used as patios, plazas, sidewalks, driveways.

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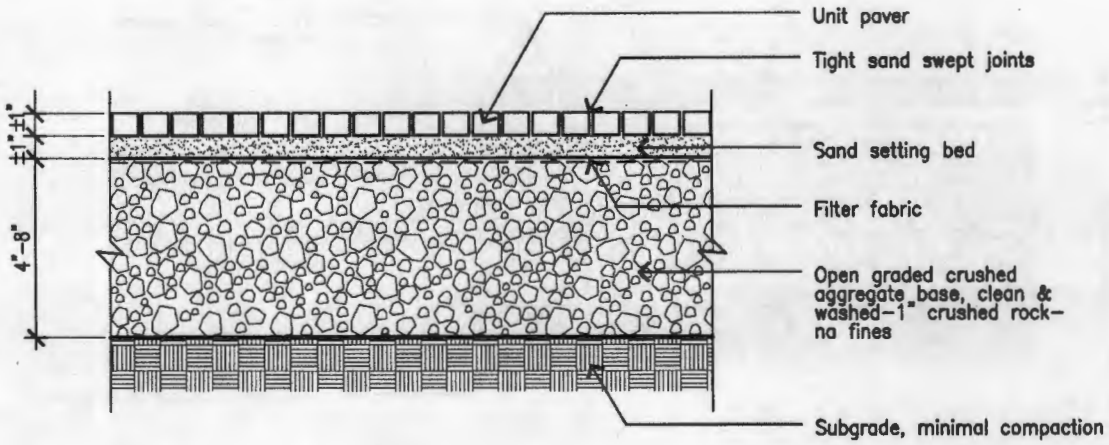
Permeable pavements

Unit pavers on sand



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Unit pavers on sand are discrete units that are set in a pattern on a prepared base. A variation on traditional brick technology, unit pavers are typically made of pre-cast concrete in shapes that form interlocking patterns. Some of these shapes form patterns that include an open cell to increase permeability.

Characteristics

- Widely used as patios, plazas, sidewalks, driveways.
- Open celled unit pavers are designed with precast voids to allow water to pass through.
- Solid unit pavers can form a permeable surface when spaced to expose permeable joints and set on a permeable base.
- Available in a variety of materials, colors and shapes.
- Runoff coefficient: 0.1 - 0.35 (more permeable with open cells or larger joints).
- Reduces impervious land coverage.

Applications

- Parking stalls, private driveways, walkways, patios.
- Can be used for low volume streets, travel lanes, bikeways.
- Flat sites (slopes ≤ 5%).

Design

- Because the unit pavers are lain loose, the field must be enclosed by a rigid frame. Concrete bands, metal or plastic edgings are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- May not be suitable on expansive soils without special subgrade preparation.

Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.
- Easy to repair, since units are easily lifted and reset.
- Periodically add joint material (sand) to replace material that has been moved/worn by traffic or weather.
- Occasional weed suppression may be required.

Economics

- Installation cost $9-15 per square foot
- More expensive than conventional concrete or asphalt, less expensive than unit pavers on slab.

Examples/resources

- Ecostone, SF RIMA are two manufacturers of open-celled concrete unit pavers.
- St. Andrews Church, Sonoma CA. uses uses Ecostone in drop-off area near entrance.
- 3170 Porter Drive, Palo Alto, uses Ecostone in parking lot stalls to increase permeability near heritage oak trees.

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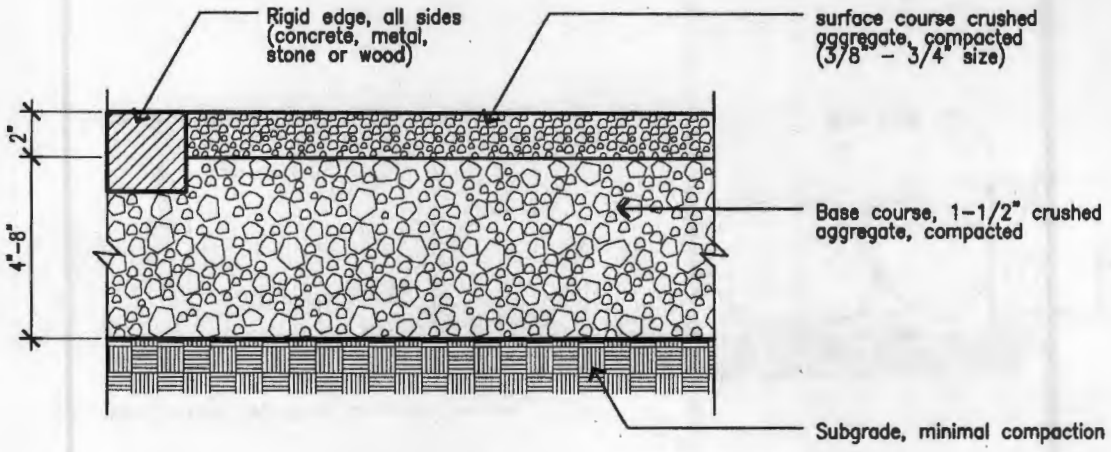
Permeable pavements

Crushed aggregate



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Crushed aggregate is crushed stone ranging from sand-sized "fines" to 2" diameter stone.

Characteristics

- A granular material, crushed aggregate can be laid in any shape field or configuration.
- Runoff coefficient 0.10 – 0.40. Pavements of fine crushed stone (e.g. decomposed granite fines) is relatively impermeable. Permeability increases with larger aggregate sizes. Open graded mixes are more permeable than mixes that include fines.
- Easy to install.
- Reduces impervious land coverage.

Applications

- Low volume, low speed vehicle traffic areas.
- Parking stalls, private driveways, walkways, patios.
- Areas of low erosion.
- Not appropriate for ADA-compliant accessible paths of travel.

Design

- Because the aggregate is laid loose, the field must be enclosed by a rigid frame in most applications. Concrete, mortared brick on a concrete grade beam, redwood header, and metal edging are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- In areas with pedestrian traffic, use smaller aggregate (3/8" size). Larger aggregate (3/4" size) makes a better driving surface.

Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.
- Easy to repair, since aggregate is easily regraded and replenished.
- Occasional weed suppression may be required.
- To maximize permeability, minimize compaction of subgrade.
- Periodic and/or replenishing, raking of displaced gravel may be required.

Economics

- Less expensive than conventional asphalt or concrete pavement.
- Least expensive of all pavements, ranging from $1 to $3 per square foot.
- Reduced impervious land coverage reduces or eliminates need for catch basins/underground storm drain system.

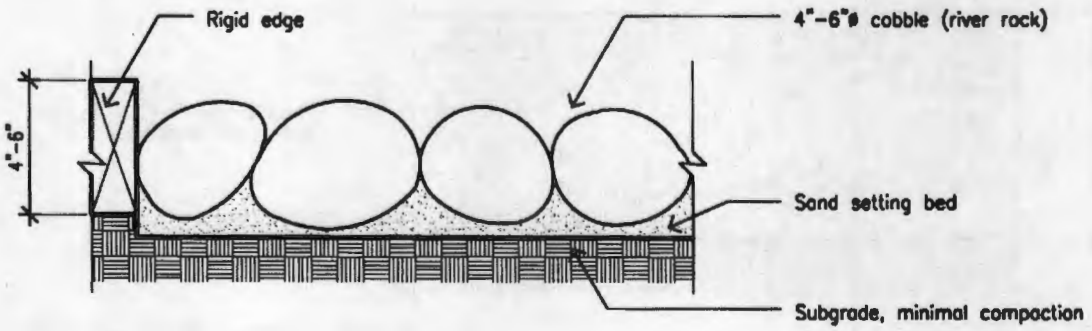
Examples/resources

- Widely used as patios, plazas, driveways.

SARB_009625

Permeable pavements

Cobbles



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Cobbles are natural stones of various sizes. River rock is rounded, other cobbles can be angular in shape. Cobbles are typically set in native soil with soil joints or on a mortar bed with mortared joints. Only soil set cobbles are a permeable pavement.

Characteristics

- Can be laid in a fields of any shape or configuration, with or without base.
- Material varies in color, shape, and size.
- Runoff coefficient 0.60 – 0.90; higher for larger sizes.
- Easy to install.
- Reduces impervious land coverage.

Applications

- Garden areas.
- Not suitable for walkway surface.

Design

- Rigid edge such as concrete, brick, wood or metal band is useful to keep cobbles in place.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- Diameters range from 4" to 8".
- A permeable filter fabric may be provided under the cobbles to suppress weeds and minimize migration of soil.

Maintenance

- Periodic weed suppression may be required.
- Resetting or replacement of cobbles may be required periodically.

Economics

- Easy to remove/reinstall
- Cost varies widely depending on material. Washed river rock is less costly than angular granite cobbles.

Examples/resources

- Commonly used around bases of trees in lawn areas.
- Commonly used in parkway planter strips and median islands.
- Commonly used as decorative mulch in landscaped areas.

SARB_009626

8.2 Streets

More than any other single element, street design has a powerful impact on stormwater quality. Streets and other transport-related structures typically can comprise between 60 and 70% of the total impervious area, and, unlike rooftops, streets are almost always directly connected to an underground stormwater system.

From a technical point of view, streets present many complex design challenges. First, their design must respond to a variety of traffic loads, ranging from the most heavily travelled highway to the least travelled access street or lane. Second, street design is often mandated by a wide array of industry and government standards, many of which may conflict with current stormwater management practice.

The intent of the technical details that follow is two-fold:

- *to reduce the impervious surface area by "right-sizing" streets to fit the transportation demand, and*
- *to disconnect the street as far as possible from the underground stormwater system by incorporating infiltration/detention areas and swales into their design.*

Streets

Access street: urban neo-traditional standard

Access street: rural standard

Urban curb/swale system

Rural swale system

Dual drainage system

Concave median

Cul-de-sac

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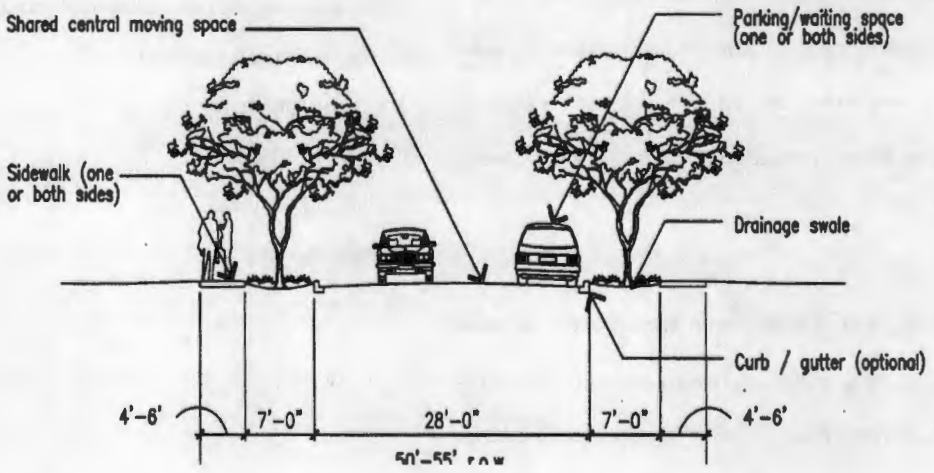
Streets

Access street: urban neo-traditional standard



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Urban neo-traditional standard access streets have a typical pavement width of 20 to 30' for vehicular movement and parking, as compared to conventional local streets, that typically require 36 to 40' of pavement.

Characteristics

- Central shared space for traffic in both directions.
- Sidewalks provided on one or both sides of the street depending on adjacent land uses, pedestrian needs.
- Parkway on one or both sides can be used for planting and surface drainage.
- Generally utilize curbs and gutters, though the gutter may be tied to a biofilter or swale rather than an underground storm drain.
- Reduces impervious land coverage by up to 50 percent.
- Reduces sediment, oil and grease, hydrocarbons when combined with biofilters and swales.

Applications

- Appropriate for areas where traffic volumes are at or below 500-750 ADT and speeds between 15 to 25 mph.
- Most appropriate for grid street systems.
- May not be appropriate for long cul-de-sac streets or hillside sites with high fire risks (because of the potential of shared moving space to be blocked by a single vehicle, with no alternate emergency route).

Design

- Construction detailing same as typical street standard.
- Coordinate with local and regional zoning ordinances and public works standards.
- Streets with special uses, such as bike routes, may require additional pavement width.
- Depending on topography, parkway strip can be designed as a linear swale/biofilter, with curb openings directly into swale (see 6.2c Urban curb/swale system).

Maintenance

- Standard street maintenance practices required.
- Parkway strip between curb and sidewalk requires mowing, tree care. This can be the responsibility of the local jurisdiction or the adjacent property owner, depending on local codes and ordinances.

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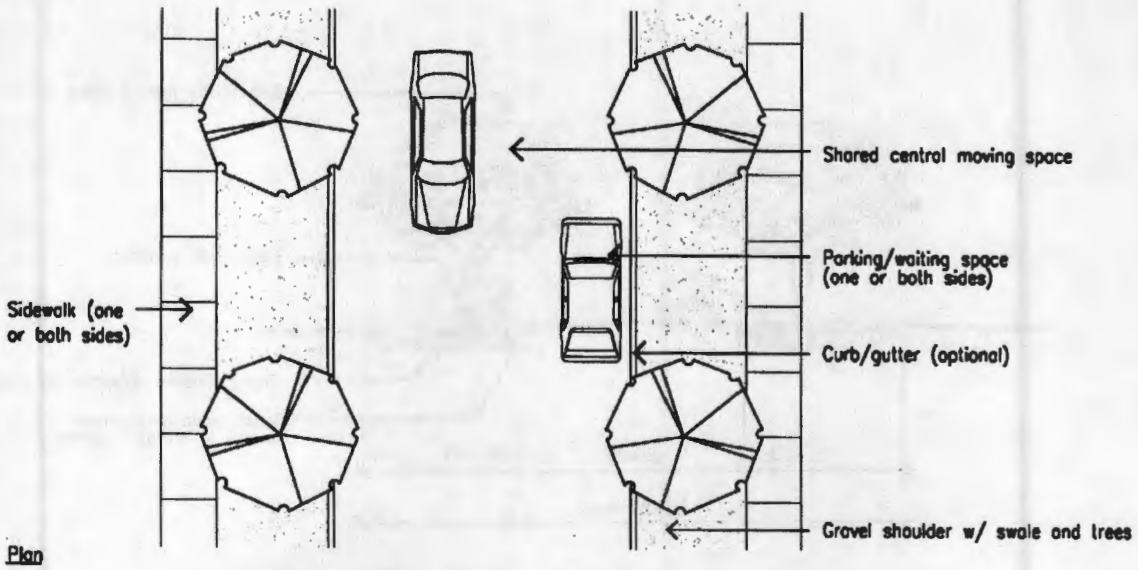
Access street: urban neo-traditional standard, continued



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Economics

- Narrower street section reduces initial construction costs.
- Increased parkway adds additional landscape maintenance cost, especially compared with conventional street section without a parkway strip.
- Properties on narrower streets with tree-lined landscaped parkways typically command higher values than those on wider treeless streets.

Examples/resources

- Institute of Transportation Engineers (ITE) "Traditional Neighborhood Development Street Design Guidelines," 1997.
- Skinny Streets program, Portland, OR.
- Velarde, Loreto Streets, Mountain View, CA.
- Typical of neighborhoods built before WWII.

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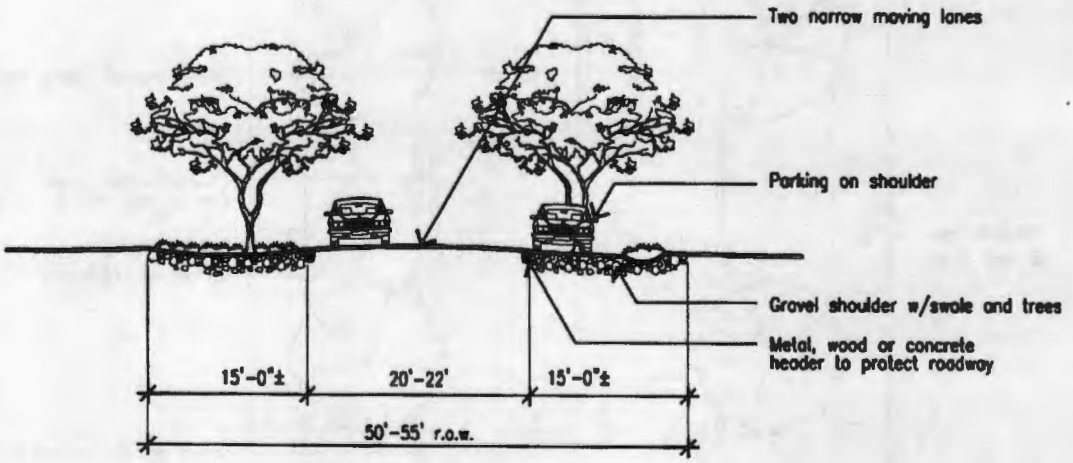
Streets

Access street: rural standard



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Rural standard access streets have an 18'–22' two-lane paved roadway, with no curb or gutters. Gravel or crushed aggregate shoulders act as drainageway and parking area.

Characteristics

- Vehicles tend use the center of the narrow paved roadway. When two cars are present moving in opposite directions, drivers reduce speeds and move towards the right hand shoulder.
- Permeability: Road is crowned to the gravel shoulders on each side. Reduced pavement width allows for shoulder on one or both sides that can be used for planting and surface drainage.
- Reduces impervious land coverage.
- Reduces sediment, oil and grease, hydrocarbons when combined with biofilters and swales.

Applications

- Appropriate for areas where traffic volumes are at or below 500-750 ADT and speeds between 15 to 25 mph.
- May not be appropriate for long culde-sac streets or hillside sites with high fire risks (because of the potential of shared moving space to be blocked by a single vehicle, with no alternate emergency route).
- Rural standard presents a more informal aesthetic and is suitable for less urban locations.

Design

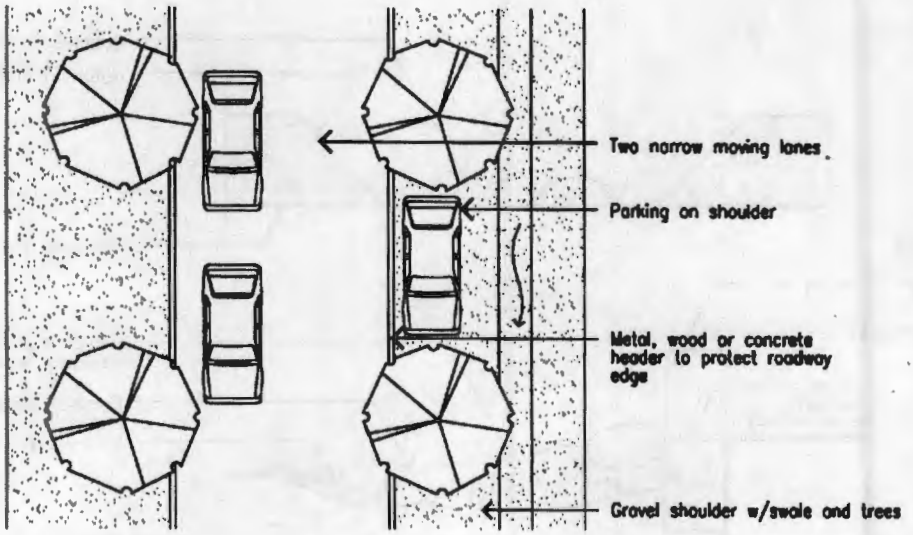
- Roadway edge protection can be achieved by flush concrete bands, steel edge, or wood headers.
- Depending on topography, gravel shoulder can be designed as a linear swale/biofilter, with water sheet flowing directly into swale.
- Parking can be organized by bollards, trees, or allowed to be informal.
- Parking can be allowed only on one side to preserve a wider moving space for emergency vehicles.
- On very low volume, low speed, access streets, sidewalks may not be required, as pedestrians walk in the street or on the shoulder.
- If catch basins are used, provide settlement basin before inlet, or raise inlet above bottom of swale, to prevent sediment from filling catch basin.

Maintenance

- Gravel shoulders require periodic regrading and replenishing.
- Elimination of curb means that conventional street sweeper machinery cannot be used.

SARB_009630

Access street: rural standard, continued



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

- Landscaped shoulder with surface stormdrain elements requires maintenance. This can be the responsibility of the local jurisdiction or the adjacent property owner, depending on local codes and ordinances.

Economics

- Narrower street section and elimination of curb and gutter reduces initial street construction costs significantly.
- Reduced roadway pavement width and increased infiltration in gravel shoulders reduces or eliminates need for underground stormdrain system.
- Landscaped shoulder with surface stormdrain elements adds moderate landscape maintenance cost.
- Properties on narrower streets with tree-lined landscaped parkways typically command higher values than those on wider treeless streets.

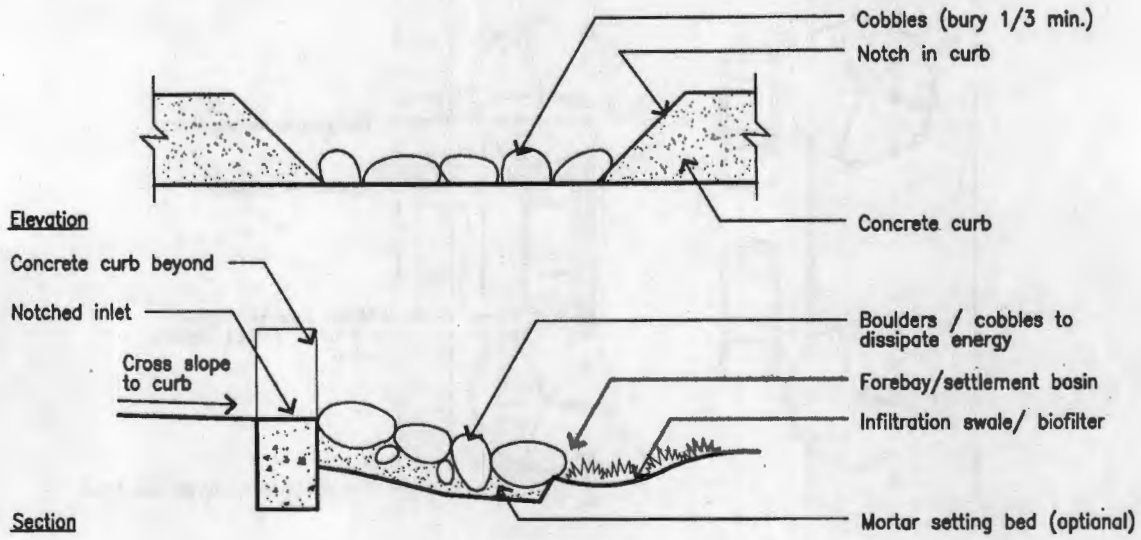
Examples/resources

- Institute of Transportation Engineers (ITE) "Traditional Neighborhood Development Street Design Guidelines," 1997.
- Skinny Streets program, Portland, OR.
- Residential streets, Atherton, CA.
- Neighborhoods built before WWII.

SARB_009631

Streets

Urban curb/swale system



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Urban curb/swale systems are a hybrid of standard urban curb and gutter with a more rural or suburban swale drainage system. It provides a rigid pavement edge for vehicle control, street sweeping, and pavement protection, while still allowing surface flow in landscaped areas for stormwater quality protection.

Characteristics

- Runoff travels along the gutter, but instead of being emptied directly into catch basins and underground pipes, it flows into surface swales.
- Stormwater can be directed into swales either through conventional catch basins with outfall to the swale or notches in the curb with flowline leading to the swale.
- Swales remove dissolved pollutants, suspended solids (including heavy metals, nutrients), oil and grease by infiltration.

Applications

- Residential developments, commercial office parks, arterial streets, concave median islands.
- Swale system can run either parallel to roadway or perpendicular to it, depending on topography and adjacent land uses.

Design

- Size curb opening or catch basin for design storm.
- Multiple curb openings closely spaced are better than fewer openings widely spaced because it allows for greater dissipation of flow and pollutants.
- Provide energy dissipators at curb notches or catch basin outfall into swale.
- Provide settlement basin at bottom of energy dissipator to allow for sedimentation before water enters swale.

Maintenance

- Annual removal of built-up sediment in settlement basin may be required.
- Catch basins require periodic cleaning.
- Inspect system prior to rainy season and during or after large storms.

Economics

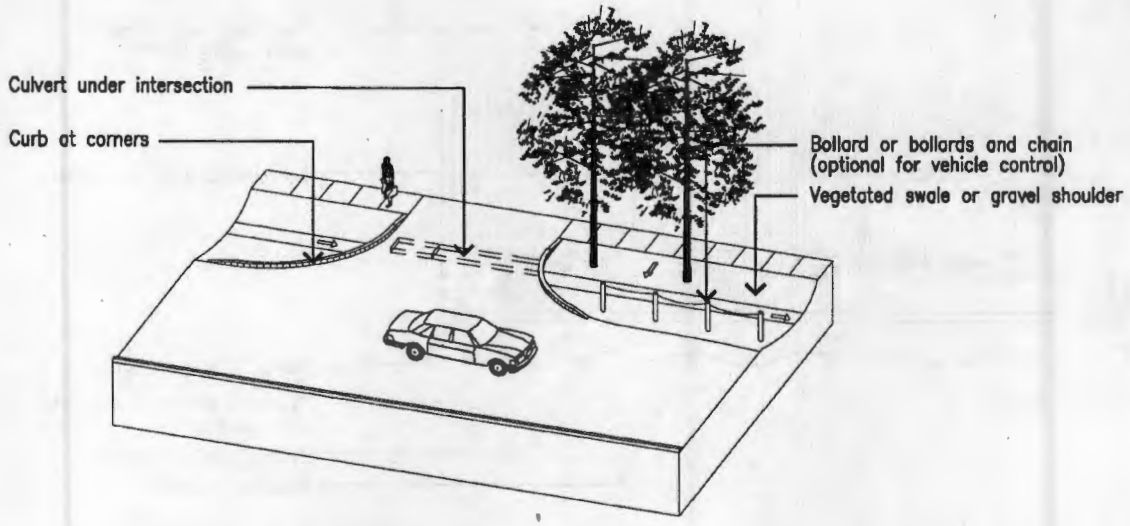
- Cost savings through elimination of underground storm drain network.
- Cobble-lined curb opening may add marginal cost compared to standard catch basin.
- Swale system requires periodic landscape maintenance.

Examples/resources

- Residential street network, Village Homes subdivision, Davis, CA.
- Dual-drainage system, Folsom, CA.

SARB_009632

Rural swale system



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Rural swale systems are a combination of street design elements that allow for surface drainage while simultaneously protecting the roadway edge, organizing parking, and allowing for driveway access and pedestrian circulation.

Characteristics

- Shoulder can be designed to accommodate parking or to serve as a linear swale, permitting infiltration of stormwater along its entire length.
- Runoff from the street is not concentrated, but dispersed along its entire length, and build-up of pollutants in the soil is minimized.

Design

- Concrete curb and gutter not required.
- Ensure that culverts under intersections drain, to avoid standing water and resulting septic condition.
- Provide concrete curb at intersection radii to protect roadway edge and landscape area from turning movements.
- Crown street to direct runoff to shoulders. If drainage is provided on one side only, then provide cross-slope towards swale.
- Protect pavement edge with rigid header of steel, wood or a concrete band poured flush with the street surface.
- If parking is not desired on the shoulder, or if it needs to be organized, install bollards, trees or groundcovers along the shoulder to prevent vehicle trespass.
- Central medians can be used to divide traffic for safety or aesthetics.

Maintenance

- Surface systems require periodic maintenance and inspection.
- Maintenance for surface systems is different than most urban Public Works Departments currently practice, and employee retraining may be required.
- Surface drainage systems are easier to monitor and clear than underground systems, because problems, when they occur, are visible and on the surface. This eliminates the need for subsurface inspection or street excavation.

Economics

- Surface swales are less costly to install than underground pipe systems, but may have higher on-going maintenance costs.

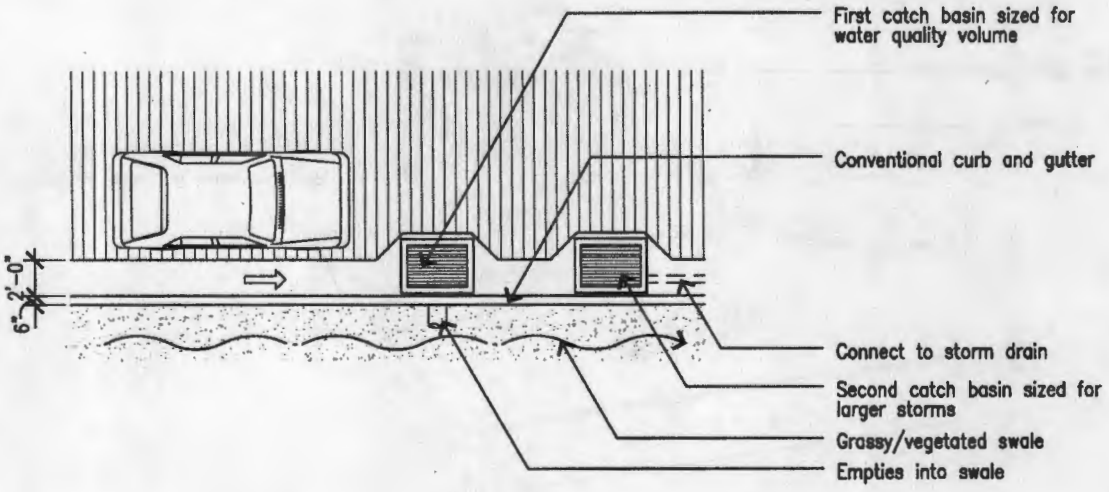
Examples/resources

- City of Folsom, CA.

SARB_009633

Streets

Dual drainage system



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Dual drainage systems provide a pair of catch basins at each inlet point– the first is sized to direct the water quality volume into a landscaped infiltration area, and the second collects the overflow of larger storms and directs it to the storm drain system.

Characteristics

- "Treatment train" approach provides for both water quality and flood protection.
- Separation of water quality volume from larger storms provides a bypass that prevents flushing of sediment and pollutants in vegetated swale during larger storms.
- Appearance of typical urban street.

Applications

- Streets in residential or commercial developments, arterial streets.
- Swale can be located on shoulder or in concave median.
- Not appropriate for industrial areas due to the potential of spills.

Design

- Locate two catch basins adjacent to each other.

First (uphill) catch basin Design outlet pipe to accommodate the water quality volume and direct to adjacent grass or vegetated swale. When first catch basin is full (because inflow exceeds volume of outlet pipe), water will flow past first basin inlet and enter second catch basin.

Second (downhill) catch basin Design to accommodate larger volumes and connect outlet to underground storm drain system or to detention pond.

- Culverts must be provided to carry swale under cross streets and driveways.
- Design swale to accommodate water quality volume.
- If swale is planted with turf grass, provide supplemental irrigation to maintain turf.
- For additional information on swale design, see Technical Detail 6.6a Grass/vegetated swales.

Maintenance

- Perform standard maintenance practices on swale and catch basins.

Economics

- Dual drainage system is more expensive to install and maintain than other solutions because of multiple elements.

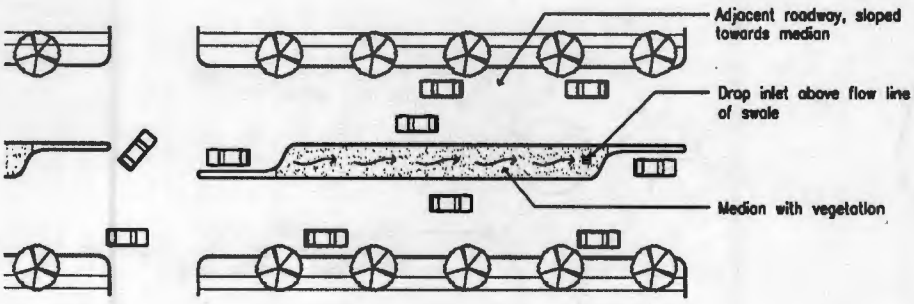
Examples/resources

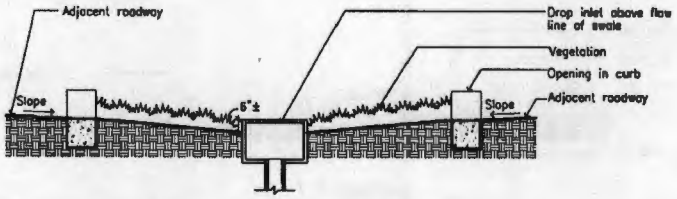
- City of Folsom, CA, Highway 50 at Folsom exit. Contact City Engineer.

SARB_009634

Streets

Concave median





Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Concave medians. Conventional medians are normally designed as a convex surface to shed water onto adjacent pavement and into a curb and gutter system. Concave medians reverse this relationship by depressing the median surface slightly depressed below the adjacent pavement section and designing the median to receive runoff.

Characteristics

- Provides safety and aesthetic functions of traditional convex medians while accommodating stormwater infiltration.
- Helps to disconnect impervious street surface from storm drain system by directing street runoff into landscaped or aggregate-filled median for infiltration.
- Can be designed as a landscaped swale or turf-lined biofilter to treat first-flush runoff, which carries a high concentration of oils and other pollutants off the street.

Design

- Adjacent roadway design must provide cross-slope into medians.
- Runoff from street can be directed into swale by sheet flow or curb inlets.
- Concave medians must be sized to accommodate the water quality volume, and planting must be designed to withstand periodic inundation.
- Catch basin and underground storm drain system may be required for high flows, depending on the available area for infiltration and retention.
- Set catch basin rim elevations just below the pavement elevation, but above the flow line of the infiltration area so that the water quality volume will collect in the swale before overflowing into the underground system.

Maintenance

- Landscaped concave medians have maintenance requirements similar to landscaped convex medians.
- Some maintenance staff retraining may be required to facilitate maintenance of swales or other stormwater detention elements.

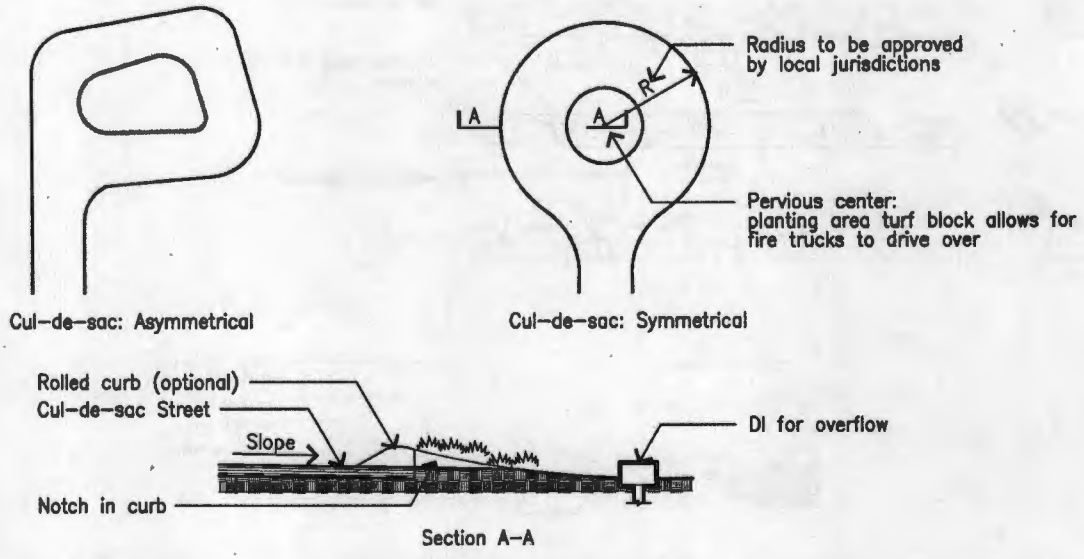
Economics

- Costs are similar to convex landscaped medians.

SARB_009635

Streets

Cul-de-sac



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Cul-de-sac streets are dead-end streets that require turnaround areas large enough to accommodate large trucks and emergency access vehicles.

Characteristics

- Conventional cul-de-sacs are paved across their entire diameter. This large impervious area adds to environmental degradation by increasing runoff and creating a heat island at the front of adjacent land uses.
- A turnaround with a central concave landscaped space or other pervious surface can meet fire department access requirements and create an opportunity for stormwater infiltration or detention.
- A landscaped area in the center of a cul-de-sac can reduce impervious land coverage by 30 to 40%, depending on configuration, while maintaining the required turning radius.

Applications

- Appropriate for cul-de-sac streets in residential, commercial, and institutional settings.

Design

- Street termination requires turnaround area large enough to accommodate large trucks, such as occasional moving vans and emergency access vehicles (fire departments often require 60 feet or greater diameter turnarounds).
- Some local fire departments may require the center landscaped area to accommodate fire trucks. This can be achieved by providing a permeable load bearing surface such as turf-block, and eliminating woody plant materials such as trees from the planting area.
- Asymmetrical cul-de-sac design is more rural than conventional round cul-de-sac design.
- Curb with slots may be needed to allow run-on from the street while keeping vehicles off landscaping.

Maintenance

- Similar to other planted medians.

Economics

- Cost of extending storm drain the length of the cul-de-sac may outweigh the savings gained from reduction of paved area.
- Landscaping in center island may add costs for irrigation, planting, and periodic maintenance.

SARB_009636

8.3 Parking Lots

In any development, storage space for stationary automobiles can consume many acres of land area, often greater than the area covered by streets or rooftops.

The standard parking stall occupies only 160 square feet, but when combined with aisles, driveways, curbs, overhang space, and median islands, a parking lot can require up to 400 square feet per vehicle, or nearly one acre per 100 cars. Since parking is usually accommodated on an asphalt or concrete surface with a conventional underground storm drain system, parking lots typically generate a great deal of directly-connected impervious area. Because the cars sitting in these lots shed hydrocarbons, heavy metals and other pollutants, parking lots are a primary collector and conveyor of urban runoff pollution.

There are many ways to both reduce the impervious land coverage of parking areas and to filter runoff before it reaches the storm drain system.

Parking Lots

Hybrid parking lot

Parking grove

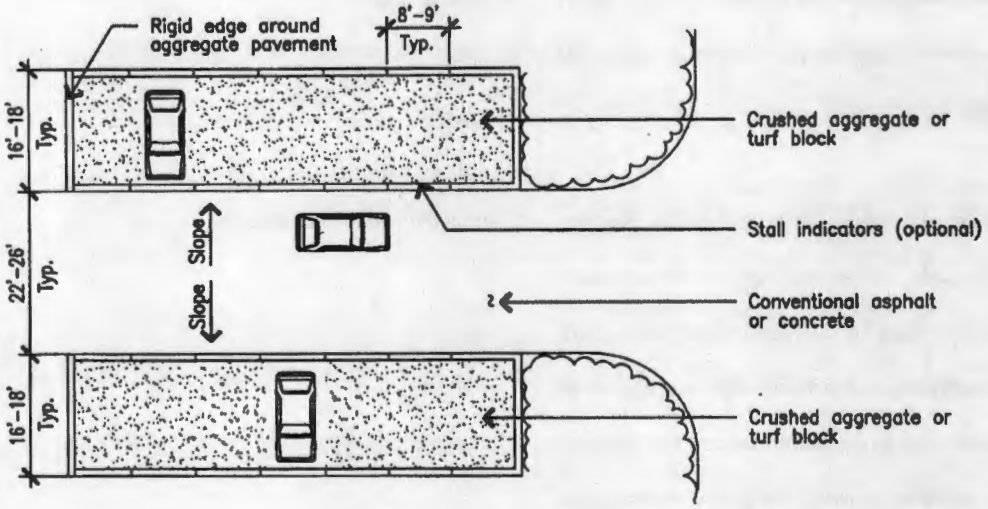
Overflow parking

Porous pavement recharge bed

SARB_009637

Parking lots

Hybrid parking lot



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Hybrid parking lots differentiate paving, combining impervious aisles with permeable stalls. Impervious aisles are designed to carry moving vehicle traffic and accommodate turning movements. Permeable stalls are designed for stationary or very slow moving cars. There are many possible combinations of materials.

Characteristics

- Hybrid lot can reduce the overall impervious surface coverage of a typical double-loaded parking lot by 60%, and avoid the need for an underground drainage system.
- Differentiation between aisles and stalls can mitigate the overall visual impact of the parking lot.

Applications

- Commercial areas, offices, multi-family housing, hotels, restaurants.
- Selection of permeable pavement material depends on use. Porous asphalt, pervious concrete or unit pavers are recommended for stalls in areas with high turnover, such as restaurants. Areas with low turnover, such as hotels, office buildings, and housing can use crushed aggregate for stalls.
- Variable permeability, depending on pavements chosen.
- High ground water or lack of deep, permeable soils may limit applications.

Design

- Keep permeable pavement areas relatively flat (slope ≤ 5%). See Section 6.1 Permeable pavements.
- Aisles are constructed of conventional asphalt or concrete suitable for heavier traffic use, speeds between 10 and 20 mph, and designed to support the concentrated traffic of all vehicles using the lot.
- Stalls are constructed of a permeable pavement, such as open-graded crushed aggregate, open-celled unit pavers, turfblock, porous asphalt, or pervious concrete.
- Slope aisles into adjacent permeable stalls.
- Subdrain or overflow drainage may be required depending on design storm and underlying soils.
- Stall markings can be indicated with wood headers laid in field of permeable pavement, change in unit paver color, concrete bands or pavement markers ("botts dots"), depending on the material used.
- Designated handicapped stalls must be made of an ADA compliant pavement.

Maintenance

- Periodic weed control, sweeping, and regrading required for gravel stalls.
- Irrigation, fertilizer, weed control, and mowing required for turf block stalls.
- Pressure hosing or vacuum sweeping may be required for pervious concrete or porous asphalt stalls.

SARB_009638

Hybrid parking lot, continued

Economics

- Reduction of overall impervious surface coverage may eliminate or reduce need for underground drainage system.
- Construction cost will depend on materials chosen. A hybrid lot of conventional asphalt aisles with crushed aggregate stalls will be lower cost than a lot entirely paved in asphalt. A hybrid lot of conventional asphalt aisles with unit pavers stalls will be higher cost than a lot entirely paved in asphalt.

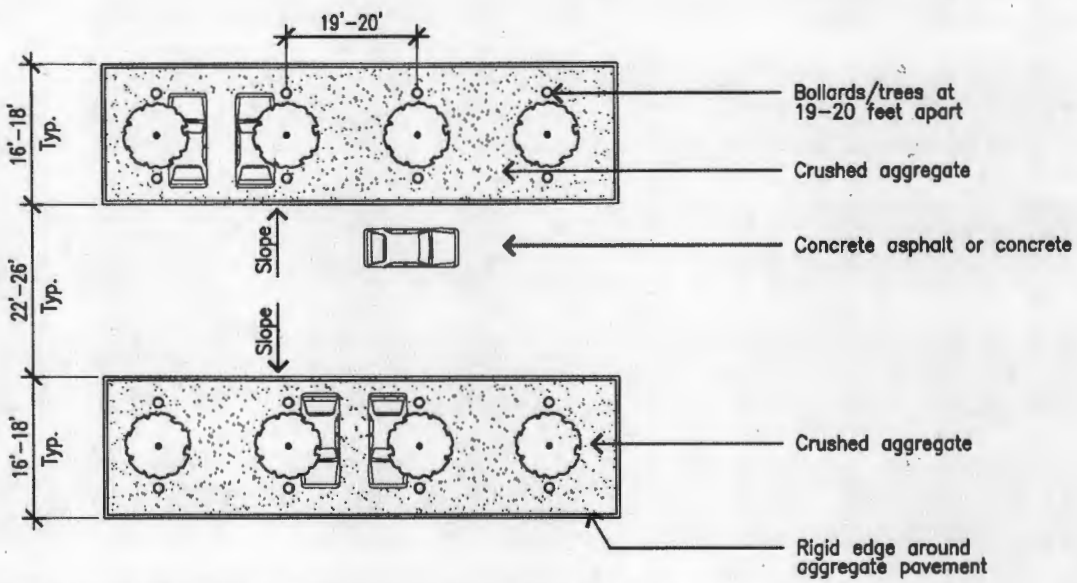
Examples/resources

- Parking lot. Medford Village, NJ.

SARB_009639

Parking lots

Parking grove



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Parking groves, a variation on the hybrid parking lot design (See 6.3a), use a grid of trees and bollards to delineate parking stalls and create a shady environment. The permeable stalls reduce impervious land coverage while the trees reduce heat island effect and improve soil permeability.

Characteristics

- Parking grove not only shades parked cars, but presents an attractive open space when cars are absent.
- Permeability depends on the type of pavement used.
- Reduces impervious land coverage.

Applications

- Best in locations where the users of the parking lot are a consistent group of people (such as multi-family housing or an office building) who become familiar with parking between the trees.
- Best in situations where vehicles park for long periods of time, such as hotels, housing, offices.
- Not recommended for high turnover lots, such as restaurants and commercial areas because of additional care needed to navigate around trees.

Design

- Parking stalls must be oversized to accommodate thickness of bollards and trees. A grid of trees/bollards spaced approximately 19 feet apart allows two vehicles to park between each row of the grid (9.5 foot space per stall, compared to the standard 8.5 to 9 foot space per stall). A grid of 28 to 30 feet allows for three cars between each pair of trees.
- Set trees/bollards at least three feet in from end of stall to allow for turning movements into and out of stall.
- Trees should be protected during the establishment period with double staking of 3" diameter wood stakes. Align stakes along implied stall line.
- Bollards may be omitted if proper tree staking is provided during establishment period.
- Metal tree cages are not recommended because they are easily damaged and can scratch cars.
- Trees should be selected for high, horizontal branching structure, and should not be prone to limb breakage (such as Eucalyptus spp. and Grevillea robusta), or insects that secrete honeydew (such as Celtis).
- Provide irrigation to trees as required.

Maintenance

- Requires tree pruning and maintenance to ensure clearance of vehicles.
- Trees may occasionally be hit by cars, but will heal themselves under normal circumstances.

Economics

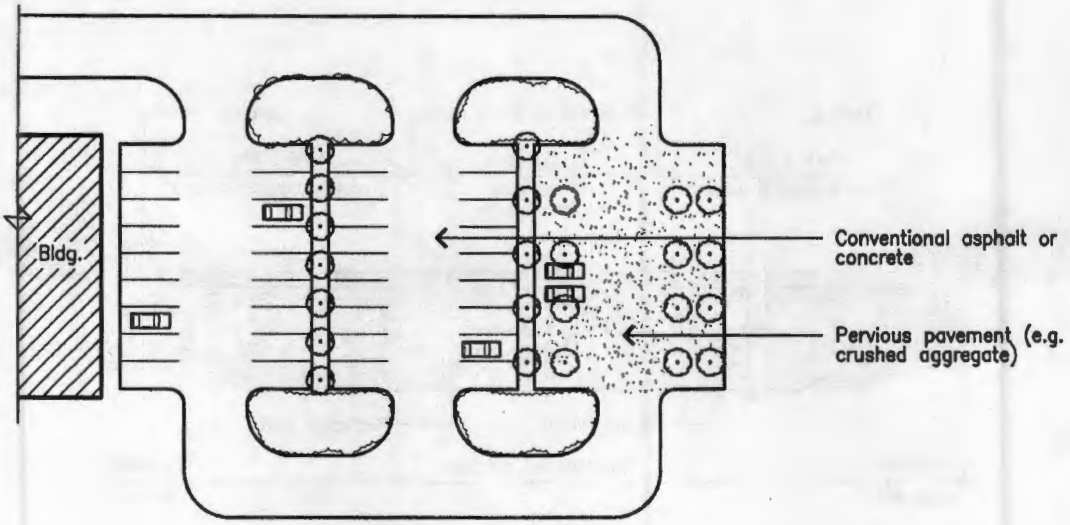
- More expensive to construct and maintain than standard parking lots.

Examples/resources

- Seaside Motel Auto Court, Seaside, FL.

SARB_009640

Overflow parking



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Overflow parking design differentiates between regular and peak parking demands, constructing the regular demand parking stalls with traditional impervious materials and constructing peak parking stalls of a different, more permeable, material.

Characteristics

- Overflow area can be pervious materials such as turf block, crushed stone, unit pavers on sand, and can be designed to break up an expanse of continuous parking lot.
- Permeability depends on pavement used.

Applications

- Large parking lots with variable capacity needs such as shopping malls, conference centers, office complexes, amusement parks, sport facilities.
- Visitor parking areas in multifamily residential developments or office complexes.
- Facilities with infrequent but extensive peak parking needs, such as churches, sports arenas, and conference centers.

Design

- Must be designed to accommodate volume of overflow parking.
- In many uses, regular parking demand accounts for approximately two-thirds of total, with one-third accommodated as overflow.
- Irrigation may be necessary if overflow parking is turf block.

Maintenance

- Maintenance depends on pavement selected.

Economics

- Cost depends on pavement selected and overall design.

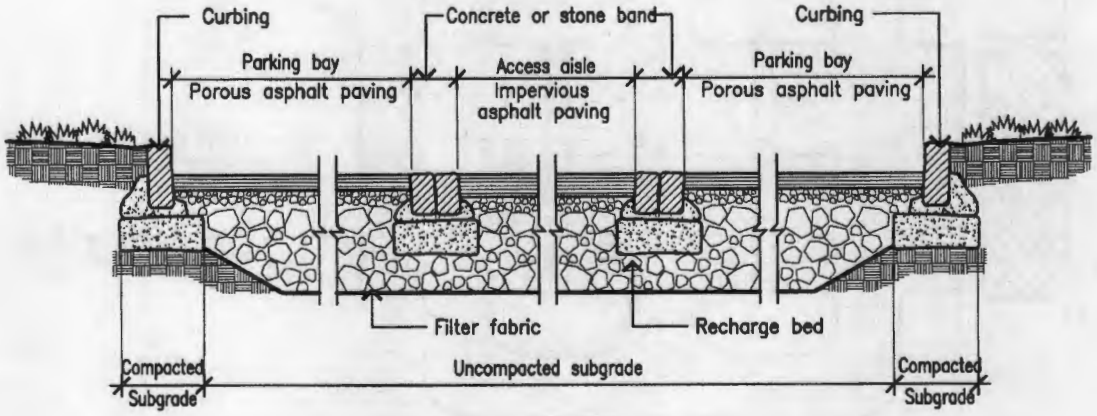
Examples/resources

- Gravel overflow parking at Nordstrom parking lot. Corte Madera, CA.
- Orange Bowl parking lot, FL.

SARB_009641

Parking lots

Porous pavement recharge bed



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional. Detail adapted from Andropogon Associates.

Porous pavement recharge beds underneath parking lots are gravel beds that receive and store infiltration.

Characteristics

- Underground system eliminates the possibilities of mud, mosquitoes and safety hazards sometimes associated with ephemeral surface drainage.
- Provides for storage of large volumes of runoff, which is directed underground by means of perforated distribution pipes.
- Constraints include soil infiltration rates, depth to water table and bedrock, and traffic type and volume.

Applications

- Underneath parking lots generally in areas where land values are high and the need to control runoff is great.

Design

- 2-1/2" porous asphalt paving on clean gravel topcourse.
- Recharge and storage basin of clean open-graded crushed stone with 40% void space.
- Filter fabric placed on floor and sides of recharge bed following excavation allows water to pass readily, but prevents soil fines from migrating up into rock basin, reducing effective storage area of recharge bed.
- Design an unpaved edge of porous pavement, and top off with stone (such as river stone), place wheelstops at edge. This functions as an emergency overflow inlet around perimeter of parking bay.
- Limit porous surfaces to parking areas receiving least wear and tear.
- Soil layer of 4 feet or more with percolation rate of 0.5 inches per hour or more required; must be field tested.
- Direct all sediment-laden runoff from impervious surfaces (e.g., roof tops, roads, parking areas, walkways, etc) away from porous pavement/recharge bed or pretreat to eliminate sedimentation.
- Prevent failures by implementing strict erosion/sediment control during construction (sediment that erodes or is tracked on to the surface can clog void spaces in pavement and prevent stormwater from entering the recharge bed below).

Maintenance

- Vacuum sweeping or pressure hosing recommended twice per year under normal circumstances.

Economics

- Expensive, requires extensive engineering.

Examples/resources

- Morris Arboretum, Philadelphia, PA.
- Automatic Data Processing corporate offices, Philadelphia, PA.

SARB_009642

8.4 Driveways

Driveways can comprise up to 40% of the total transportation network in a conventional residential development, with streets, turn-arounds and sidewalks comprising the remaining 60%.

There are several ways to reduce the impact of driveways on water quality. These include directing runoff from an impervious driveway to a landscaped infiltration area, constructing the driveway from a permeable pavement, and reducing the overall amount of pavement provided.

Driveways

Not directly-connected impervious driveway

Gravel driveway

Unit pavers on sand

Paving only under wheels

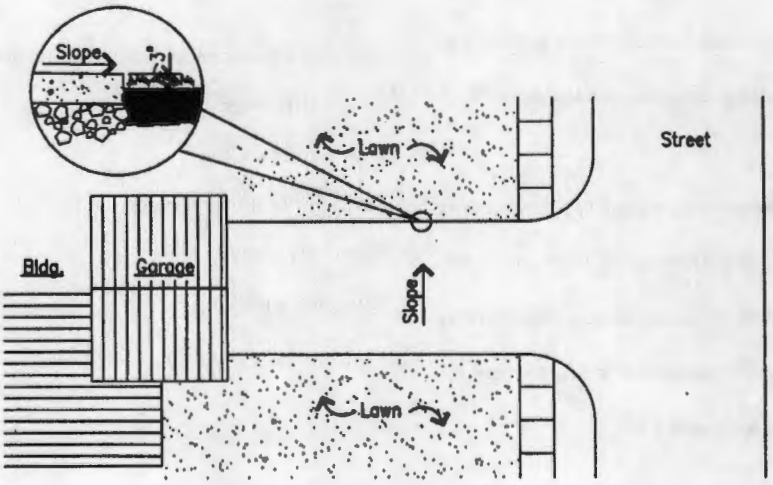
Flared driveways

Temporary parking

SARB_009643

Driveways

Not-directly connected impervious driveway



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Not directly-connected impervious driveway slopes the surface to drain into an adjacent turf or groundcover area, rather sloping towards the curb and gutter in the street as commonly done.

Characteristics

- Appearance is the same as conventional driveway.
- Pollutants are dispersed and cleansed in the soil as driveway runoff passes through a permeable landscaped area.

Applications

- Suitable for all driveways with sufficient adjacent landscape areas.

Design

- Cross slope must be greater than longitudinal slope to direct runoff into adjacent landscape
- Adjacent landscaped area must be sized to accommodate the water quality volume.
- Edge of driveway must be approximately 3 inches above the vegetated area, so that vegetation or turf doesn't block sheet flow from driveway onto soil.

Maintenance

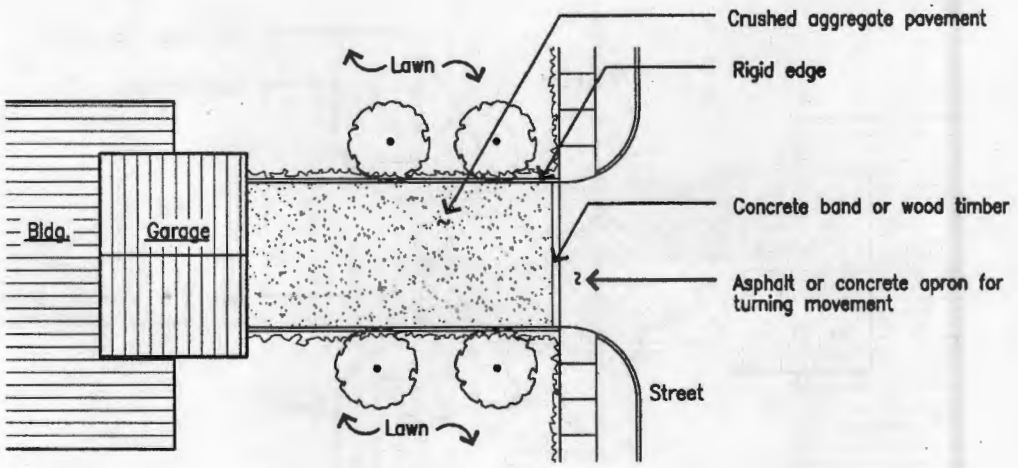
- Edging of adjacent lawn is important to allow unimpeded flow of runoff from driveway onto lawn.

Economics

- Cost is same as conventional driveway.

SARB_009644

Crushed aggregate driveway



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Crushed aggregate driveway. Crushed stone and other granular materials can make a relatively smooth permeable pavement suitable for the low speeds and volumes of typical residential driveways.

Characteristics

- Aesthetic can be formal or rural depending on design and materials.
- Crushed aggregate driveways have a distinctive "crunchy" sound reminiscent of traditional country estates and homes.

Applications

- For driveways that are lightly used by very slow moving vehicles, and those that serve single family homes.
- Not suitable for multi-use driveways such as those that accommodate children's play.
- Flat sites (slope ≤ 5%).

Design

- Rigid edge such as wood header, concrete, metal, or brick band desirable to contain aggregate material and to maintain surface strength.
- Provide a non-granular apron at intersection of driveway with street to accommodate turning movements.
- Provide a concrete band or wood timber at transition between apron and crushed aggregate driveway to absorb impact of repeated wheel crossings.
- Use open-graded crushed aggregate (such as 3/8" to 3/4" granite) rather than rounded stones such as pea gravel. Angles of the crushed stone form a matrix that holds the granular material in place, able to bear the load traffic without substantial displacement.
- Minimize compaction of finished grade and subgrade. Roll surface of aggregate sufficiently to stabilize the stone.
- Open-celled plastic matrix can be used to provide added stability of crushed aggregate.

Maintenance

- Weed control may be needed periodically.
- Periodic replenishment of aggregate may be required.

Economics

- Least cost of all pavement materials.
- $1 to $3 per square foot, depending on design.

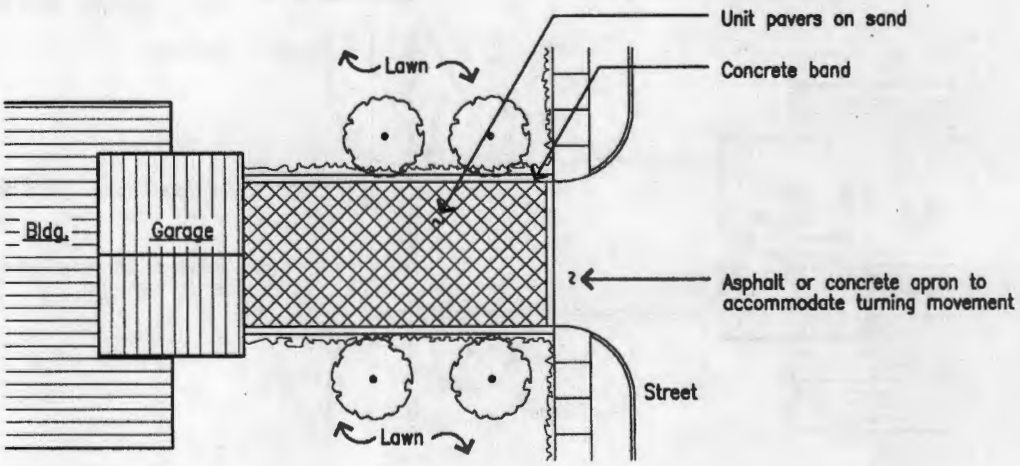
Examples/resources

- Open-celled matrixes are available from Gravelpave, GeoWeb by Presto.

SARB_009645

Driveways

Unit pavers on sand driveway



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Unit pavers on sand are discrete units that are set in a pattern on a prepared base and bound by a rigid edge to form a pavement suitable for a driveway.

Characteristics

- A pavement of brick or unit pavers on sand can make the driveway more integrated with the garden rather than an extension of the street penetrating deep into the garden space.
- Available in a variety of natural and synthetic materials, such as brick, natural stone, cast concrete.
- Runoff coefficient of open celled units: 0.10-0.35 (more permeable if larger voids, solid units: 0.10-0.20. Infiltration rates are higher during lighter, lower intensity rains.

Applications

- Residential driveways.
- Accent to traditional asphalt in low volume commercial driveway.
- Flat sites (slope ≤ 5%).

Design

- Because the unit pavers are lain loose, the field must be enclosed by a rigid frame. Concrete bands, metal or plastic edging are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- May not be suitable on expansive soils without special subgrade preparation.

Maintenance

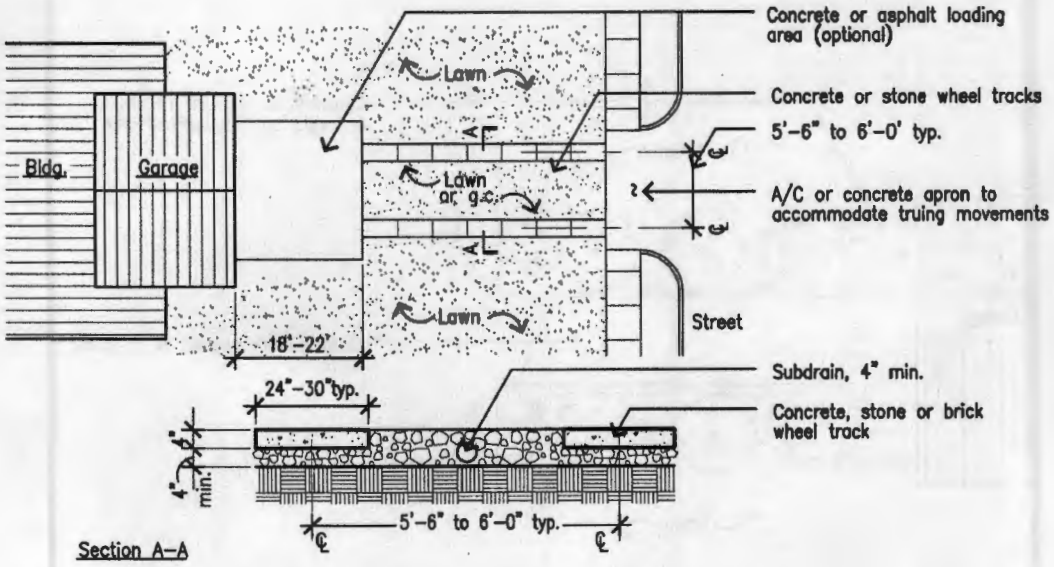
- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.
- Easy to repair, since units are easily lifted and reset.
- Periodically add joint material (sand) to replace material that has been moved/worn by traffic or weather.
- Occasional weed suppression may be required.

Economics

- Installation cost $9-15 per square foot
- More expensive than conventional concrete or asphalt, less expensive than unit pavers on slab.
- Increased construction and maintenance costs can be offset by improved aesthetic and market appeal compared to conventional asphalt or concrete driveways.

SARB_009646

Paving only under wheels



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Paving only under wheels. Paving only under the wheel tracks, with the area between landscaped reduces impervious land coverage, also called a "Hollywood driveway."

Characteristics

- Center strip planted with grass, groundcovers, or filled with gravel.
- A driveway of two paved wheel tracks can reduce impervious surface coverage by 60 to 70% compared with a single lane paved driveway.

Applications

- Residential, low density single family, duplex, mobile home.
- Best in straight driveways, not recommended for curving driveways.

Design

- Wheel tracks should be wide enough to accommodate variability in driving and vehicle widths.
- Wheel tracks must be designed to support vehicle loads, usually concrete or mortar-set unit pavers such as stone or brick.
- A perforated drain line buried between wheel tracks to collect and direct runoff may be added in soils with low infiltration rates.
- If ground cover or grass is selected for center strip, irrigation system must be provided, and parked vehicles must be moved periodically so that a single location is not continuously shaded.

Maintenance

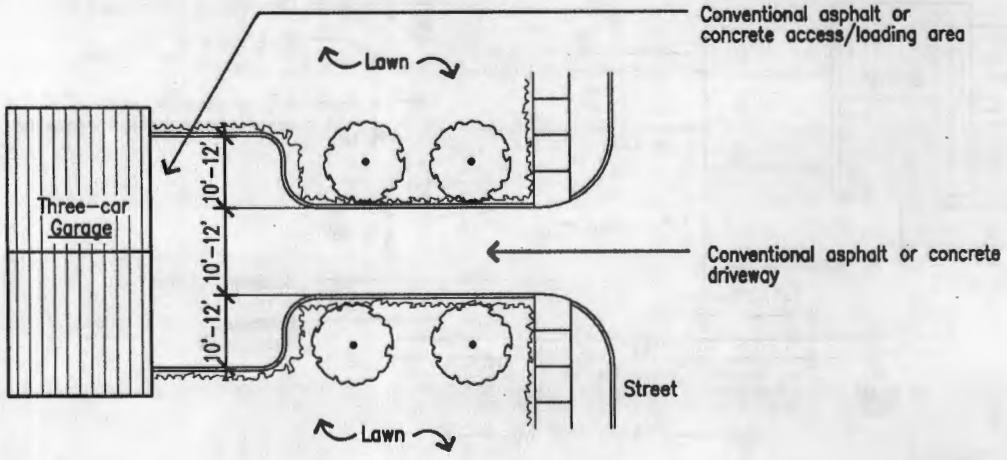
- Area between wheel tracks requires maintenance.
- If area between tracks is planted with lawn, additional edging will be needed.

Economics

- Reduced pavement area reduces construction costs.
- Complex detailing, inclusion of landscape planting and irrigation can add significant costs.

SARB_009647

Flared driveways



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Flared driveways use a single lane to provide access to multiple-car garages by flaring the area in front of the garage.

Characteristics

- The approach to the garage from the street is a single lane, adequate to accommodate the relatively infrequent vehicle trips, while the portion of the driveway at the garage is widened to provide access to all garage doors.
- Reduces impervious surface area compared to multi-lane driveway extending entire length from garage to street.

Applications

- Appropriate for multi-car garages or single family homes with adjacent garages that do not require the full multi-lane width along their entire length.

Design

- Typical driveway design, single lane width at street, and flare to serve garages that are shared.
- Provide adequate depth in front of multi-car garage for vehicle parking and maneuvering.

Maintenance

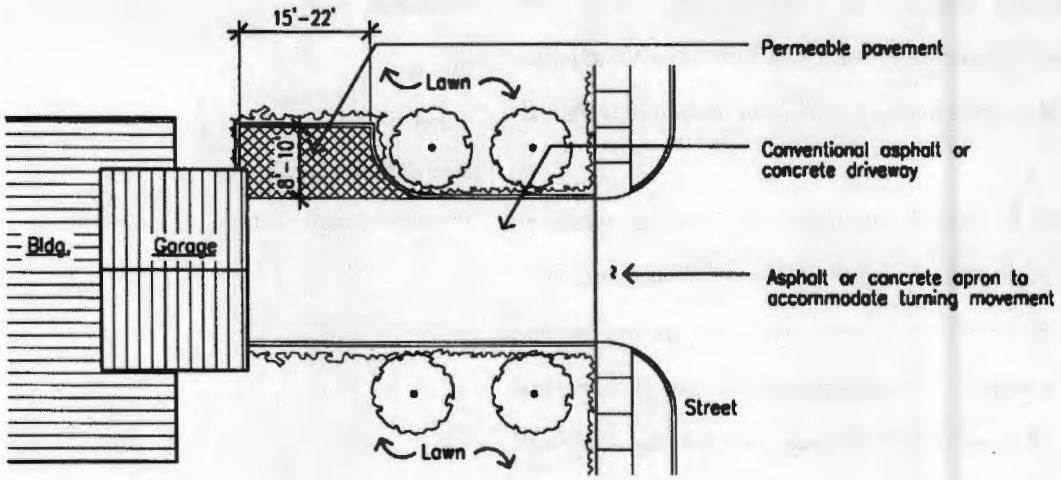
- Same as standard driveway.

Economics

- Reduces overall pavement cost.

SARB_009648

Temporary parking



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Temporary parking is paved with a permeable surface, such as turf-block or open-celled unit paver, and maintained as a landscaped surface.

Characteristics

- Appears and functions as green space or patio for the majority of the time when not used for parking.
- Runoff coefficient depends on the type of pavement used.
- Reduces impervious surface area.

Applications

- Residential driveway applications, such as RV or trailer parking.
- Areas where parking or loading access is required infrequently.
- Guest parking areas.

Design

- Must be designed to support vehicle loads.

Maintenance

- Turf-block requires similar maintenance as conventional lawn.
- Brick or unit pavers require periodic weed supression.

Economics

- Higher initial cost than asphalt or concrete parking areas.
- Increased construction and maintenance costs can be offset by improved aesthetic and market appeal compared to conventional asphalt or parking areas.

SARB_009649

8.5 Buildings

By definition, buildings create impervious land coverage. There are, however, techniques to treat runoff from individual buildings and to collect rooftop runoff for infiltration into the soil.

Roof runoff is typically either channeled in gutters and downspouts or allowed to sheetflow off the roof. Downspouts focus runoff, concentrating the entire watershed of the roof into one or a few points. This concentrated flow can be stored and slowly infiltrated into the soil in a controlled manner through dry-wells, cisterns, or by directing flow into landscape infiltration/detention areas.

Sheet runoff from roofs can be directed and infiltrated onto adjacent landscape areas through grading, mulching, and plant selection.

Buildings

Dry-well

Cistern

Foundation planting

Pop-up drainage emitters

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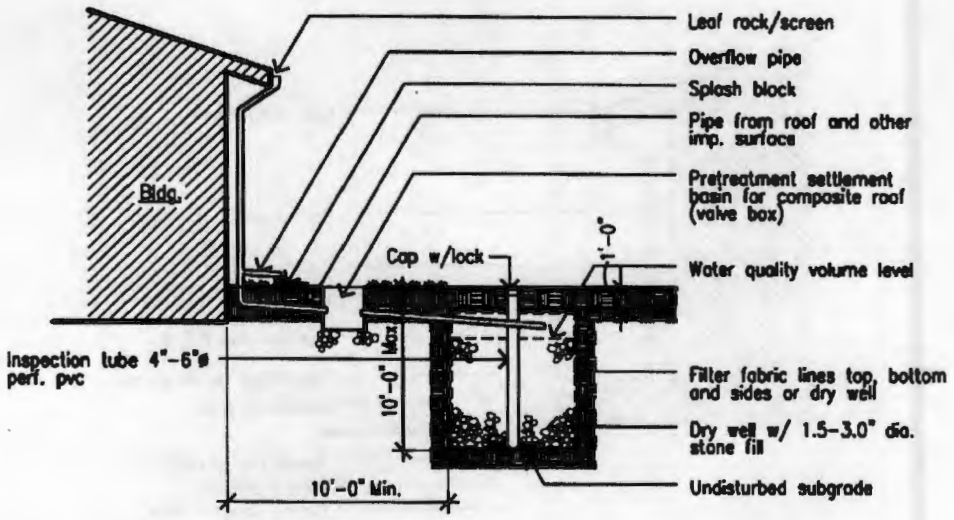
Buildings

Dry-well



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Dry-well. A dry-well is a subsurface basin to which runoff is diverted for infiltration. The roof downspout is connected to the dry-well, allowing runoff to be stored and slowly infiltrated.

Characteristics

- Compact.
- Hidden from view, has no effect on aesthetics.

Applications

- Not appropriate for slopes >40% or areas with expansive soils.
- Many agencies have policies regarding dry wells because of concerns that include migration of pollutants into groundwater, or dumping of pollutants into drywell. Most jurisdictions permit drywells that are connected directly to roof downspouts and are less than ten feet deep. Check local regulations.

Design

- Confirm requirements with local municipal ordinances. These may include overall depth, as well as setbacks from structures, property lines, water supply wells, groundwater level, septic drainfields, and sensitive areas.
- Dimension calculations assume:

  1) Total volume runoff generated by roof in a design storm (e.g. 10 year, 24-hour, etc.) must be stored or infiltrated by the system during the storm.

  2) Infiltration system empty at beginning of storm and full at end.

  3) Rainfall and infiltration rates constant for duration of storm, including a safety factor.
- Subgrade must be relatively permeable (not appropriate for clay).
- Requires excavation filled with drain rock and wrapped top, sides and bottom with filter fabric. Excavation is sized to accommodate water quality volume storm, accounting for 38-40% void space of gravel fill.
- A buried catch basin (concrete, plastic, or metal) or large diameter pipe with open bottom set on end can be used to contain drain rock.
- Roof downspouts are attached to the dry well, an overflow pipe is provided for runoff in excess of water quality volume.
- Provide perforated observation pipe (such as a 6" diameter PVC) to allow for inspection and maintenance.
- Provide pre-treatment sedimentation basin for composite roofs. This can be a small plastic valve box with open bottom.

Maintenance

- Requires inspection at beginning of rainy season.
- Remove sediment from sedimentation basin prior to rainy season.

Economics

- Relatively inexpensive to construct and maintain.

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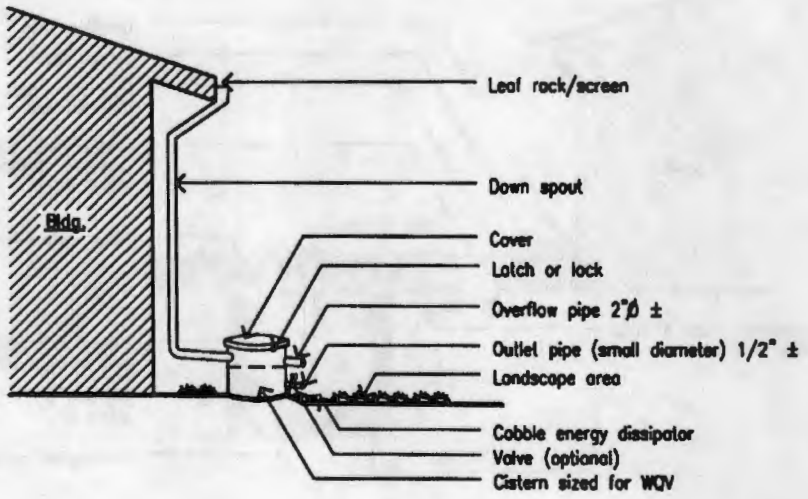
Buildings

Cistern



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Cistern. A cistern is an above ground storage vessel that is directly connected with the roof downspout. Water is slowly released with either a manually operated valve or a permanently open outlet.

Characteristics

- Cisterns can be incorporated into the aesthetics of the building and garden. Japanese, Mediterranean and American southwest architecture provide many examples of attractive cisterns made of a variety of materials.
- Reduces peak runoff and allows sediment to settle.
- Provides more infiltration benefits than connecting directly to storm drain.

Applications

- Residential, commercial, office buildings.

Design

- Manually operated valve can be closed to store stormwater for irrigation use or infiltration between storms.
- Cistern must be covered to prevent mosquitoes from breeding.
- Permanently open outlet must be sized appropriately. If it is significantly smaller than the size of the downspout inlet (approx. 1/4 to 1/2 inch diameter), runoff will build up inside the cistern during storms, and will empty out slowly after peak intensities subside, mitigating the peak flow runoff from impervious rooftops, especially for the frequent, small storms.
- Size cistern for water quality volume, provide overflow for larger storms.
- Provide secure cover or ≤ 4" top opening if holding more than 6" depth of water, to prevent small children from gaining access to the standing water.
- Provide screen on gutter and intake of outlet pipe to minimize clogging by leaves and other debris.

Maintenance

- System requires regular monitoring and cleaning.
- Maintenance required to ensure that system is not clogged by leaves or other debris.

Economics

- Low installation cost.

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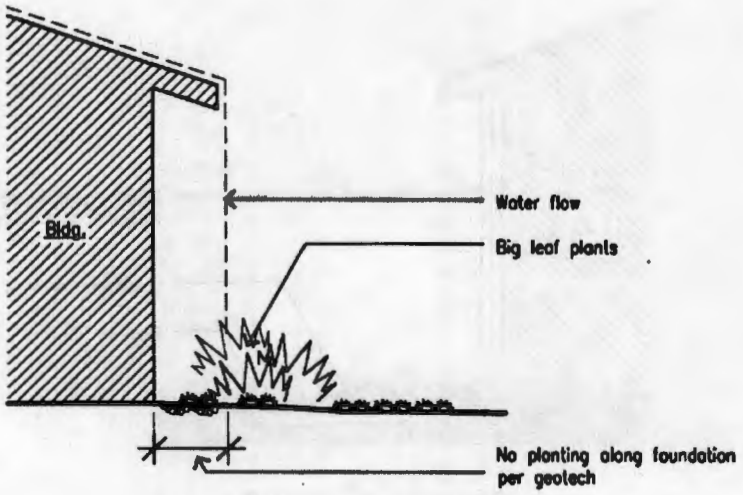
Buildings

Foundation planting



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Foundation planting. Landscape planting around the base of the eaves can reduce the physical impact of water on the soil and provide a subsurface matrix of roots that encourage infiltration.

Characteristics

- Foundation planting serves function of to provides increased opportunities for stormwater infiltration.
- Planting protects the soil from erosion caused by concentrated sheet flow coming off the roof, reducing the amount of sediment in urban runoff.

Applications

- For buildings that do not use a gutter system.

Design

- Locate plants at the roof drip-line.
- Select plants with high capacity for vertical water storage.
- Select plants with leaf architecture that intercepts rainwater and traps it for eventual evaporation.
- Select plants sturdy enough to tolerate the heavy runoff sheet flows, and periodic soil saturation.
- Provide mulch cover in planting bed to protect soil from impact of falling rainwater and to increase soil water-holding potential.
- Protect perimeter of foundation as required by local soil conditions.

Maintenance

- Regular garden maintenance.

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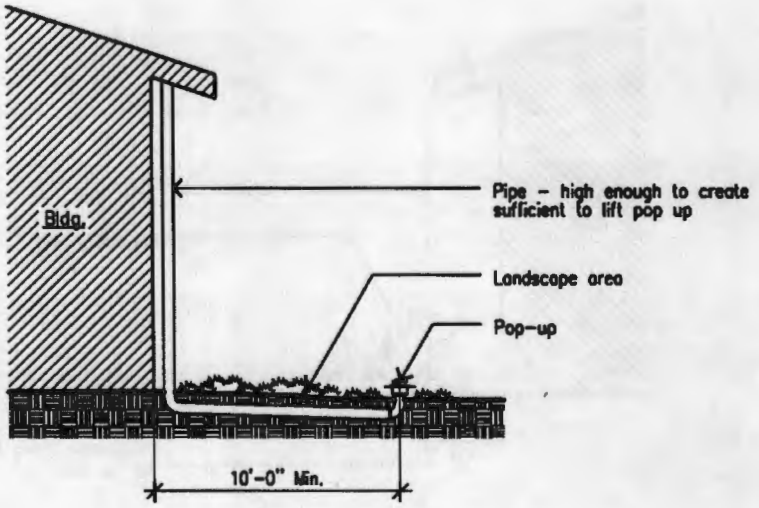
Buildings

Pop-up drainage emitter



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Pop-up drainage emitters allow water collected by downspouts and roof gutter systems to flow through a drainage pipe away from structural foundations, and "pop-up" to disperse in lawn or landscaped areas.

Characteristics

- Emitter is opened by the hydrostatic pressure flowing through the drain pipe. As flow diminishes, the emitter closes again.
- Blends into the surrounding landscape; appearance similar to standard pop-up sprinkler.
- Sheet flow of runoff allows for infiltration.

Applications

- Can use for water captured by standard gutter and downspout system, grates, catch basins, grates and drains.
- Can use to divert water away from erosion-prone or poor drainage areas.
- May be more effective in certain soil types.

Design

- Size emitter(s) according to downspout and watershed (roof area) size.
- Design pipe riser to height required to create head sufficient enough to lift pop-up.
- Design outfall to sheetflow onto vegetated area (such as lawn or groundcover) or suitable landscaped or paved infiltration and drainage system.

Maintenance

- Standard maintenance practices can be used.
- Emitter is only open when water is flowing through the drain pipe, minimizing the risk of debris and rodents entering the pipes.

Economics

- Emitter unit cost $12-20 each plus pipe.

Examples/resources

- City of Milpitas has info. on the sq. ft. of landscape required per sq. ft. roof.

SARB_009654

8.6 Landscape

Landscape solutions for stormwater quality combining site engineering – grading and drainage – with landscape architecture. This presents an opportunity for civil engineers and landscape architects to cooperate on the designs for integration of function and aesthetics.

One concern among developers and property owners is that landscape stormwater infiltration and detention areas will become subject to government regulation as wetlands after they are established.

According to the California Regional Water Quality Control Board, these landscape areas are not classified as jurisdictional wetlands *subject to mitigation if their land use is later changed, as long as:*

- *the design elements (e.g., swales, ponds) are clearly identified on plans and documentation as stormwater treatment areas (BMPs),*
- *the design elements are not used as mitigation for impacts to other wetlands, and*
- *the design elements do not impact or replace existing wetlands.*

Landscape

Grass/vegetated swales

Extended detention (dry) ponds

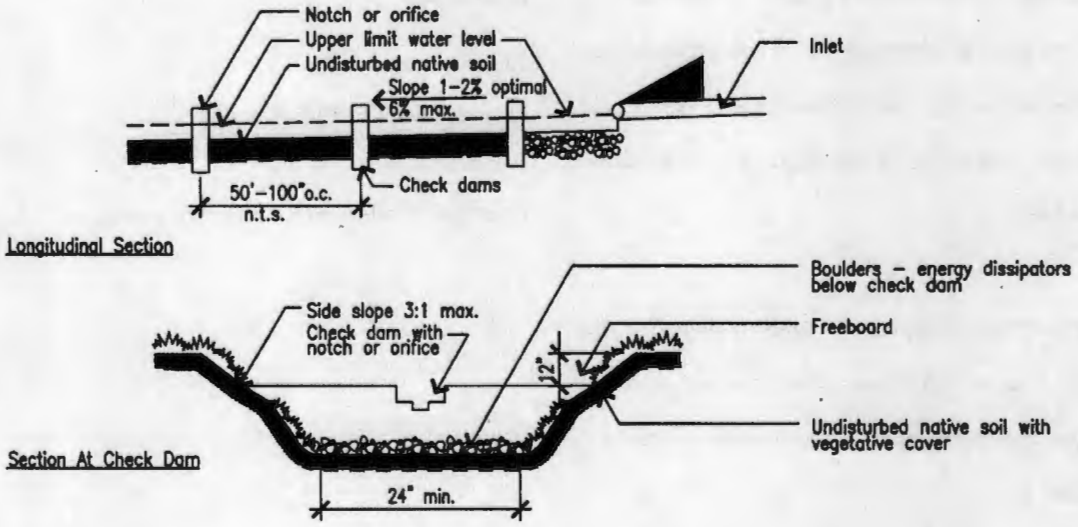
Wet ponds

Plant species selection for infiltration areas

SARB_009655

Landscape

Grass/vegetated swales



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Grass/vegetated swales. An alternative to lined channels and pipes, grass and vegetated swales are vegetated earthen channels that convey and infiltrate water and remove pollutants.

Characteristics

- If properly designed and maintained, swales can last for at least 50 years.
- Can be used in all types of soil. In clay or impermeable soils, swale may require an underdrain to keep maximum water residence time below 24 hours. In sandy or highly permeable soils, swale may require soil amendments to maintain dense turf or vegetation.
- When swales are not holding water, they appear as a typical landscaped area.
- Pollutants and water are filtered by grass/vegetation and removed by infiltration into soil.
- Swales remove suspended solids, the pollutants that are adsorbed onto the solids (including heavy metals and nutrients), oil and grease.

Applications

- Swales require approx. 1200 square feet minimum per impermeable acre (i.e., they will occupy an area equal to at least 2.75% of site's total impermeable area)
- A single grassy swale can drain approximately 4 acres of land. Multiple swales would be required to drain a larger site.
- Parking lot medians, perimeters of impervious pavements.
- Street and highway medians, edges (in lieu of curb and gutter, where appropriate).
- In combination with constructed treatment systems or sand filters.

Design

- Grass swales move water more quickly than vegetated swales. A grass swale is planted with turf grass; a vegetated swale is planted with bunch grasses, shrubs or trees.
- Pollutant removal effectiveness can be maximized by increasing residence time of water in swale.
- Incorporate systems that temporarily divert flows to allow for maintenance.

Longitudinal slope Optimal longitudinal slope is approximately 2% at bottom of the swale. Low slopes reduce public hazards and limit erosion by reducing water velocities and increase pollutant removal by increasing residence time.

For slopes ≤1%, install an underdrain to limit standing water in swale.

Install check dams approximately every 50 to 100 feet on slopes between 4% and 6% to reduce velocity.

Do not use swales on slopes greater than 6%.

Installing turf block bottoms on grass swales can minimize wet, muddy con-

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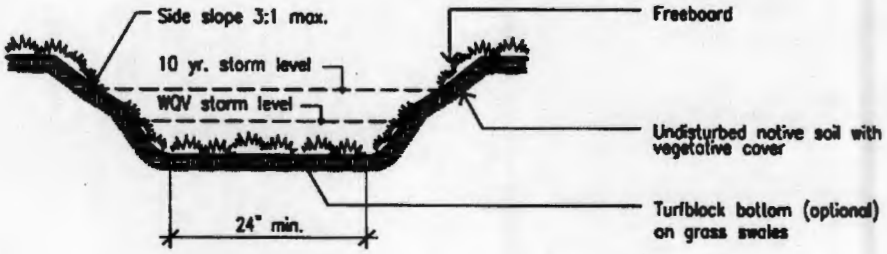
Grass/vegetated swales, continued



Typical Section

Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

ditions that hinder maintenance activities.

Side slope 3:1 (horizontal:vertical) or shallower, to limit erosion and to improve maintainability.

Residence time 9 minutes achieves approximately 80% removal of total suspended solids (TSS).

Inlet Sheet flow or multiple dispersed inlets are better than a single inlet.

If a single inlet (pipe or curb cut) is necessary, design an energy dissipator and flow spreader (such as cobbles or gravel) where water enters the swale to reduce erosion and maintenance.

Planting Select plant species that can survive through both periods of inundation and periods of drought.

A variety of grass species, including native and non-native, can together produce a swale turf that is adapted to varying site environments (see table).

Both trees and shrubs can be located adjacent to swales, and on the banks of larger swales.

If planted with turfgrass, provide supplemental irrigation, to keep swale green year round.

Establishment If establishing vegetation during the dry season, it must be planted at least one month prior to the beginning of the rainy season and irrigated to promote establishment until regular rains begin.

If establishing vegetation during the wet season, divert stormwater runoff from the swale during the first rainy season in which the vegetation is being established.

Erosion control measures such as netting or blankets may be used to aid establishment.

Mosquito prevention Design for maximum residence time of 24 hours (mosquitoes generally require 48 hours to breed and hatch).

Maintenance

- Grass swale maintenance includes mowing and removing clippings and litter; vegetated swales may require additional maintenance of plants.
- Periodically remove sediment accumulation at top of bank, in swale bed, or behind check dams.
- Monitor for erosion and reseed grass or replace plants, erosion control netting and mulch as necessary.
- Fertilize and replace turf well in advance of rainy season to minimize water quality degradation.

Economics

- Grass swale construction cost per linear foot $4.50-$8.50 (from seed) to $15-20 (from sod), compare to $2 per inch of diameter underground pipe

SARB_009657

e.g., a 12" pipe would cost $24 per linear foot).

- $0.75 annual maintenance cost per linear foot

Examples/resources

- 10.9 acre site drains parking lot and roof runoff into swales. BT Office Supply Warehouse, 6601 Overlake Place, Newark, CA.
- Parking lot and roof runoff drains to swale at office building. 3150 Porter Drive, Palo Alto, CA.
- Santa Clara Valley Water District offices. 5750 Almaden Blvd., San José, CA.
- Landscape Architecture Technical Information Series (LATIS), *Vegetated Swales*, 1999.

Grass species for swales

There are many alternatives to conventional turfgrass suitable for use in vegetated swales.

Scientific Name Common Name	*Festuca rubra* † Molate/Red fescue
Agrostis exerata † Bentgrass	*Hordeum brachyantherum* † Meadow barley
Bromus carinatus † California Brome	*Hordeum brachyantherum salt* † Meadow barley salt
Buchloe dactyloides Buffalo Grass	*Juncus spp.* Rushes
Elymus triticoides Creeping wildrye	*Stipa pulchra* † Purple needle grass
Festuca idahoensis Idaho fescue, Blue bunchgrass	*Vulpia myuros v. hirsuta* † Zorro annual fescue

† *California native*

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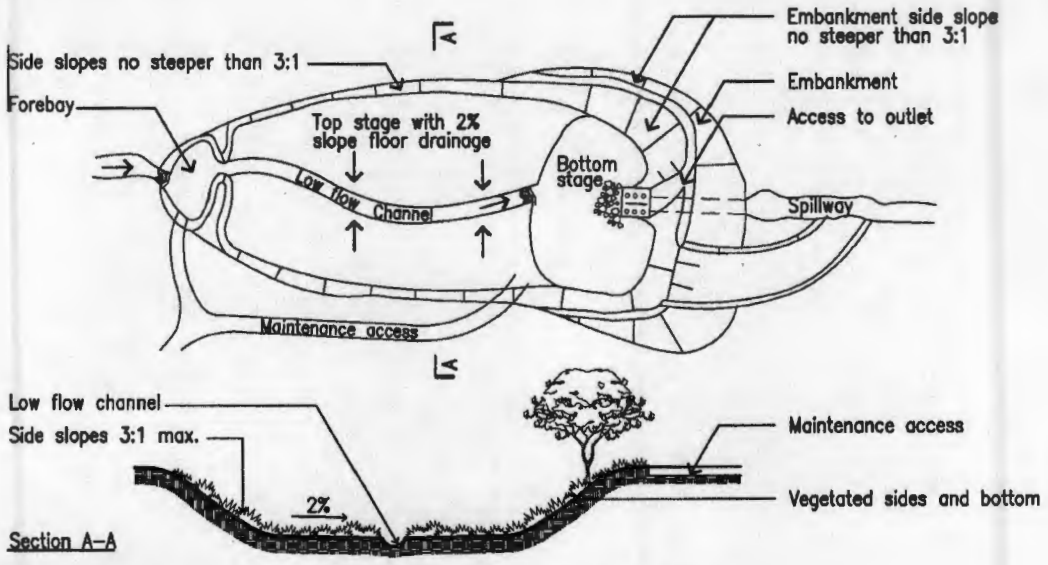
Landscape

Extended detention (dry) ponds



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Extended detention (dry) ponds store water during storms for a short period of time (from a few hours up to a few days), and discharge water to adjacent surface waters. They are *dry* between storms, and do *not* have a permanent pool of water.

Characteristics

- If properly designed, ponds can have a lifetime of 50 years.
- Clay or impervious soils should not affect pollutant removal effectiveness, as the main removal mechanism is settling.
- Pollutants removed primarily through gravitational settling of suspended solids, though a small portion of the dissolved pollutant load may be removed by contact with the pond bottom sediments and/or vegetation, and through infiltration.
- Moderate to high removal of suspended solids (sediment) and heavy metals.
- Low to moderate removal of nutrients and Biological Oxygen Demand (B.O.D.).
- Pollutant removal can be maximized by increasing residence time (average 24 hours); two-stage pond design, with the addition of wetland vegetation to lower stages of the pond; sediment-trapping forebay to allow efficient maintenance; regular maintenance and sediment cleanout; installing adjustable gate valves to achieve target detention times; designing pond outlet to detain smaller treatment volumes (less than two-year storm event).

Applications

- May be initially used as construction settling basins, but must be regraded and cleaned out before used as a post-construction wet pond.
- May be designed for both pollutant removal and flood control.
- May be appropriate for developments of 10 acres or larger.
- Potential for multiple uses including flood control basins; parks, playing fields, and tennis courts; open space; overflow parking lots.

Design

- Coordinate pond design, location, and use with local municipal public works department and/or county flood control department to reduce potential downstream flooding.
- Default conditions for safety have been to fence basins with chain link. Consider aesthetic design elements with safety analyst to address pond barriers, such as fencing and/or vegetation, and shallow side slopes (8:1 to 12:1).

Residence time Design pond for an average residence time of 24 hours, with a maximum of 40 hours.

Slopes Inside basin slopes should be not greater than 3:1 (horizontal:vertical), to minimize erosion and allow heavy equipment access for periodic cleanout.

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Inlet Design energy dissipation at the inlet to minimize erosion and promote settling in the forebay. A trash rack can be installed at the inlet to capture large debris before it enters the basin.

Outlet Vertical risers, negatively sloped pipes, and perforated pipes in a gravel bed are all methods of discharging water from the pond. Vertical risers have the advantage of being less susceptible to clogging.

Vegetation Vegetation can enhance pollutant removal and the aesthetic appearance of extended detention ponds. Specify emergent wetland vegetation and non-wetland plants tolerant of inundation.

Mosquito prevention Minimize pond area that has a depth less than 18 inches.

Use foundation aeration to limit periods of still water during detention.

Plant emergent vegetation with minimal submerged growth.

Apply *Bacillus* (Bti) or other bacteria.

Maintenance

- Regular inspection during wet season for sediment buildup and clogging of inlets and outlets (designing forebay to trap sediments can decrease frequency of required maintenance, as maintenance energy is concentrated towards a smaller area of the basin, and less disruptive than complete cleaning).
- Clean inlet trash rack and outlet standpipe as necessary.
- Clean out basin sediment approximately once per year (this may vary depending on pond depth and design, and if forebay is used). Once site is stabilized, annual cleaning will not likely be needed.
- Mow and maintain pond vegetation, replant or reseed as necessary to control erosion.

Economics

- Least expensive stormwater quality pond option available. 0-25% additional cost when added to conventional stormwater detention facilities.
- Construction cost $0.10-$5.00 per cubic foot of storage (savings from preparing silt basins used during construction for use as extended detention ponds).
- Maintenance cost 3-5% of construction cost annually.

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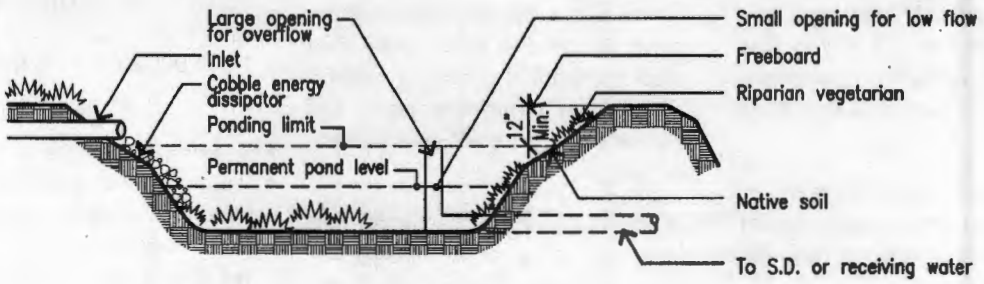
Landscape

Wet ponds



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Wet ponds are permanent pools of water that detain and treat stormwater runoff. They can be enhanced by designing a forebay to trap incoming debris and sediment, and by establishing a fringe wetland at the pond edge to increase pollutant removal and enhance the aesthetic, economic, and habitat value of the pond.

Characteristics

- If properly designed, wet ponds can last indefinitely.
- Clay or impervious soils should not affect pollutant removal effectiveness, as the main removal mechanism is settling.
- Can increase property values by providing a significant landscape amenity.
- Wet ponds provide moderate to high removal of most urban stormwater pollutants, including total suspended solids, sediment, heavy metals, phosphorus, nitrogen, and B.O.D. Removal rates are dependent on residence time of water in pond, amount of wetland vegetation fringing the pond, and other factors.
- Pollutants are removed by settling suspended solids, uptake by wetland plants and algae, and bacterial decomposition.

Applications

- Wet ponds are appropriate for stormwater drainage in a development or project with a drainage area greater than approximately 2 acres, but are more cost effective for drainage areas greater than 10 acres.
- Landscape amenity in residential or commercial development with opportunities for passive recreation (e.g., birdwatching, fishing, boating), and can be combined with consideration to pedestrian and bicycle circulation to provide active recreation.
- May be initially used as construction settling basins, but must be regraded and cleaned out before used as a post-construction wet pond.

Design

- Coordinate pond design, location, and use with local municipal public works department and/or county flood control department to reduce potential downstream flooding.
- Pretreatment may be needed to remove trash, debris and sediments and to reduce maintenance.
- For risk management, basins area often fenced. Other alternatives to minimize risk include screening vegetation and shallow side slopes (8:1 to 12:1).

Area Surface area must equal 1% of the drainage area for high pollutant removal (e.g. 100 acre drainage area would require a 1 acre wet pond).

Storage volume Design permanent pool to store 0.5-1.0" of runoff per contributing watershed area (a storage volume of 1.0" of runoff per contributing watershed area in the Bay Area will capture and treat the runoff from about 75-85% of the rainstorms each year).

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Residence time In general, pollutant removal increases as residence time increases. Pollutant removal can be accomplished with a few days of residence time. The California Stormwater BMP Handbook: Municipal recommends that removal of very fine sediments and removal of dissolved nutrients by plants requires a minimum residence time of 14 days.

Side slopes Forebay side slopes 4:1 to allow access for heavy equipment for periodic cleanout and sediment removal.

Permanent pool side slope 4:1 or shallower if wetland vegetation will be planted around the edge. Shallower slopes will also increase safety and wildlife habitat value.

Depth Range from 3 to 9 feet maximum. A depth greater than 9 feet may produce odor generated from depletion of oxygen in bottom sediments.

Length to width ratio Minimum 3:1 length:width ratio, baffles separating inflow and outflow pipes, and small islands will help avoid flow short circuiting.

Inlet and Outlet Energy dissipation should be used to minimize erosion and promote settling in the forebay.

A weir overflow should be used to pass high-return period (50- or 100- year) flows through the pond and to avoid erosion and flooding.

Vegetation Wet ponds may be constructed with or without a fringe wetland. If fringe wetland is not used, inundation-tolerant grass or other vegetation may be used on the banks. However, this will lower pollutant removal and wildlife value. Wet pond vegetation should consist of wetland plants, including emergent plants, and non-wetland plants tolerant of inundation.

Where fringe wetlands are used, wetland vegetation should occupy 25-50% of the pond surface area to enhance pollutant removal.

Establish vegetation with irrigation 6 months prior to the rainy season, to stabilize the wet pond prior to the rainy season. If this is impossible, appropriate erosion control measures such as blankets, matting, or mulch may be used.

Maintenance

- Check facility annually and after each major storm for erosion and debris.
- Approximately every 2-5 years (when 10-15% of storage volume has been lost), remove sediment from forebay and main pool. Studies generally indicate that pond sediments meet sludge toxicity limits and can be safely disposed of as normal landfill.
- Replant or reseed as necessary to control erosion.
- Provide supplemental water in summer, if required.

Economics

- Construction cost: $0.50-$1.00 per cubic foot of storage.
- Annual maintenance cost is approximately 5% of capital cost for <100,000 cubic feet of storage; 3% for 100,000-1,000,000 cu. ft.; 1% for >1,000,000 cu. ft.

Examples/resources

- Ponds planned to receive summer dry weather flows from landscape irrigation and car washing uses in residential development. Basking Ridge, San José CA.
- West Davis Ponds, Davis, CA.
- Parking lot and structure runoff drain to wet pond in strip mall development. South Napa Marketplace, Napa CA.

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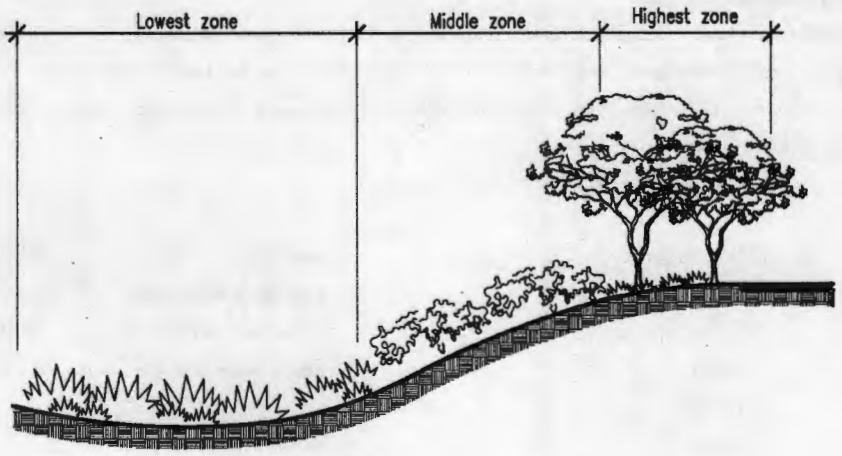
Landscape

Plant species selection for infiltration areas



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Plant species selection for infiltration areas can improve the infiltration potential of landscape areas as well as improve the aesthetics of design.

Characteristics

- Deep rooted plants help to build soil porosity.
- Leaf surface-area helps collect rainwater before it lands on the soil, especially in light rains, increasing the overall water holding potential of the landscape.
- Select species that are tolerant of moist soils or periodic inundation, as well as drought if planted without supplemental irrigation.

Applications

- Applicable to all treatment devices that incorporate plant materials.

Design

- Select appropriate plant species depending on zone of innundation: lowest, middle, and highest.
- Most plants and grasses require initial irrigation during establishment period, as well as during dry periods.
- Select the appropriate plant for the use, water cycle, and aesthetic goals.
- Consider sight-line and other requirements for parking lots and street-side plantings.
- Include mulch cover in planting areas.

Maintenance

- Maintenance can have a significant impact on soil permeability and its ability to support plant growth. If the soil is exposed or bare, it can become so hot that surface roots will not grow in the upper 8 to 10 inches, where the majority of small absorbing roots lie. The common practice of removing all leaf litter and detritus with leaf blowers creates a hard crusted soil surface of low permeability and high heat conduction. Proper mulching of the soil surface improves water retention and infiltration, while protecting the surface root zone from temperature extremes.
- Slightly more attention to maintenance and care of plant material may be required than in non-infiltration areas.

Economics

- Riparian and native plant material species are approximately 20% more expensive to purchase than common landscape species.
- Changing from the leaf blower maintenance practice to more manual practices may increase labor cost.

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Plant Species for Infiltration Areas

Most infiltration and detention basins are designed to remain inundated for less than 48 hours (drawdown time). The following trees and shrubs tolerate wet soil and periodic inundation, and may be suitable for planting in basins and biofilters depending on regional hardiness and other factors. This list is not all-inclusive, and draws from both native and exotic species. Local riparian habitats may provide additional native species suitable for wet locations.

Highest Zone

Acer negundo	Box Elder
Acer rubrum	Red Maple
Acer saccharinum	Silver Maple
Alnus spp.	Alder
Betula spp.	Birch
Carya illinoensis	Pecan
Carya ovata	Buttonbush
Casuarina spp.	She-Oak
Clethra arborea	Lily-of-the-Valley
Cornus stolonifera	Redtwig Dogwood
Diospyros virginiana	Persimmon
Eucalyptus camalduensis	Red Gum
E. citriodora	Lemon Gum
E. erythrocorys	Red-Cap Gum
Fraxinus latifolia	Oregon Ash
Gleditsia triacanthos	Honey Locust
Liquidambar styraciflua	Liquidambar
Liriodendron tulipifera	Tulip Tree
Magnolia grandiflora	Southern Magnolia
M. virginiana	Sweet Bay
Melaleuca quinquenervia	Cajeput Tree
Nyssa sylvatica	Tupelo
Picea sitchensis	Sitka Spruce
Platanus x acerifolia	London plane
Platanus occidentalis	Sycamore
P. racemosa	California Sycamore
Populus deltoides	Cottonwood
Pterocarya stenocarpus	Wingnut
Quercus macrocarpa	Bur Oak
Q. palustris	Pin Oak
Salix spp.	Willow
Sequoia sempervirens	Coast Redwood
Taxodium distichum	Bald Cypress
Thuja occidentalis	Arborvitae

Middle Zone

Cornus stolonifera	Redtwig Dogwood
Gaultheria shallon	Salal
Equisetum hyemale	Horsetail
Ferns (many spp.)	Fern
Iris (many spp.)	Iris
Mimulus	Monkeyflower
Miscanthus sinensis	Japanese Silver Grass
Myoporum parvifolium 'Putah Creek'	Myoporum
Myrica	Pacific Wax Flower
Salix spp.	Willow
Vaccinium	Huckleberry

Lowest Zone

Acorus gramineus	Acorus
Carex spp.	Sedge
Deschampsia caespitosa	Tufted Hairgrass
Iris (many spp.)	Iris
Leucothoe davisiae	Sierra Laurel
Scirpus cernuus	Bulrush
Juncus spp.	Rush
Tradescantia virginiana	Spiderwort
Typha latifolia	Common Cattail

Table adapted from Harris (1992), Sunset Western Garden Book (1988), and ABAG (1995b)

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9 Next Steps

This document illustrates an approach and philosophy towards site planning and design for stormwater management. The design details and site planning principles presented here are proven, practical methods for reducing the impact of new development on environmental quality.

This approach seeks to restore the hydrologic cycle by infiltrating runoff into the soil as close to its source as possible. It proposes simple site planning principles to cluster development, preserve natural areas, and avoid development on fragile lands. It accepts impervious land coverage as an environmental indicator, and seeks to maximize the permeability of new development. It aims to achieve all these objectives economically while creating communities that are more beautiful and desirable places to live.

The document has one goal: to create better projects. Because of the complex nature of development, this goal can only be achieved if developers, regulatory agencies, local governments, designers, contractors, maintenance staff, and others in the real estate industry work cooperatively.

Each group active in development can take a series of steps to create better projects.

Next Steps

9.1 Frequently asked questions
9.2 Getting started
9.3 Keys to success
9.4 Resources

Communities can be built that reward investment, are kind to the natural environment, and make better places for people to live.

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Next Steps

9.1 *Frequently asked questions*

9.1 Frequently asked questions. The techniques described in this document have three basic goals:

– to minimize or reduce overall impervious land coverage,
– to ensure that remaining impervious areas are not directly connected to a storm drain system as far as feasible, and
– to slow runoff within a drainage system.

Because this approach is different than the conventional stormwater management approach of conveying water offsite as quickly as possible – "getting rid of the water" – it often raises questions. A few of the most frequently asked questions are addressed below.

If pollutants infiltrate into the soil, will there be a problem with contaminated soil or groundwater in the long term?

Not usually, especially in residential areas. The risk of contamination is a function of a compound's relative mobility, concentration, and solubility. In residential areas, the concentrations of most pollutants are generally low, and capturing them in the ground where they will eventually degrade is usually the best way to manage them. A recent study published by the U.S. EPA found that residential areas pose the least risk of groundwater contamination from infiltration practices. This study found that the risk from compounds with greatest potential for groundwater pollution – nitrate-nitrogen, pesticides, organic compounds and heavy metals – was generally low provided that runoff percolates through the soil layer. Runoff from some sites in residential communities with higher concentrations of pollutants, such as car wash facilities and service stations, may not be suitable for infiltration.

If water is standing in pools, won't they breed mosquitoes?

Not if the pools are properly designed. All of the techniques described in this document that utilize surface drainage – such as infiltration basins, biofilters, and detention basins – can be designed to dry up within 48 hours of a storm. Even an extended retention basin, which is a semi-permanent pool that holds water for two or three weeks, should be designed to dry up in the spring before temperatures are warm enough to breed mosquitoes.

What about expansive clay soils that don't infiltrate?

The Bay Area's expansive clay soils – with their high runoff potential and low infiltration rates – present special challenges. Also, because these soils have a high swelling potential, care must be taken to prevent damage to foundations from saturated soils. Though infiltration may not be feasible, retention and detention strategies that hold water for later release are often practical. Minimizing impervious land coverage and directly-connected impervious areas are also viable strategies, even in expansive clay soils.

You recommend reducing street widths by adopting "neo-traditional" standards. How is that going to help?

The street is the single most important design element in site planning. Reducing street widths can reduce overall impervious land coverage significantly. For example, most Bay Area municipal street standards mandate between 80 and 100% impervious surface coverage in the right-of-way for streets, curb, gutter and sidewalk. If new standards are adopted for the most lightly traveled local streets, impervious surface coverage can be reduced by 25 to 60%. This alone helps to reduce the generation of "new" runoff from a proposed development. If the street design includes alternative stormwater collection strategies, such as linear biofilters and infiltration basins rather than standard catch basins and storm drains, the pollution generated by vehicles can be controlled near its source.

What about cost? Aren't these designs expensive to build?

These designs emphasize source control because it's the cheapest form of pollution control. Treatment control systems – collecting pollutants and treating them at the end of a pipe before the outfall – are more expensive to build and maintain, and require treating greater quantities of runoff.

Of the source control designs illustrated here, costs vary. Some designs, like concave vegetated surfaces or sloping driveways towards adjacent landscape rather than towards curbs and gutters, are cost neutral. Others, like gravel parking aisles, are less costly than conventional pavements. Cluster development, a

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Next Steps

9.1 *Frequently asked questions, continued*

strategy for minimizing overall impervious land coverage, can be less expensive than conventional development because of reductions in roadway and utility requirements. Some of the techniques, such as pervious concrete, do add cost when compared to conventional materials, but these costs can sometimes be offset by savings generated by not having to install an underground drainage system.

Aren't these designs more expensive to maintain? And who's responsible for maintaining them, anyway?

Though some of the design details need special maintenance, many of them don't. For example, a lawn with a gently sloping concave surface requires the same maintenance as one that is convex. Yet the concave lawn holds water, making it a stormwater management device, while the convex lawn sheds water, making it a contributor to "new" runoff. Overall, the maintenance requirements of the designs recommended here can be comparable to conventional practice, though they may require a different kind of maintenance.

Maintenance responsibility will depend on the control's design and location. Some controls located on private property, such as a dry well or concave lawn near a home, will be maintained by the homeowner. Other controls, such as swales or basins along streets or in parks, may be maintained by a public agency. Still others may be the responsibility of a homeowner's association or management company. In all cases adequate maintenance and proper education are critical to the long-term viability of each control. Once people understand the design intent of a control, and are given guidance on its proper maintenance, acceptance increases and maintenance effort can be optimized.

What about liability?

Compared to building large, single detention basins, the approach described in these pages minimizes risk. By minimizing impervious surface coverage and creating multiple, small basins in the landscape, overall runoff is reduced, and the runoff that remains is held in small, shallow pools for limited periods of time. These small source controls, if properly designed and maintained, present very limited risk.

For example, Village Homes, in Davis, California was built in the mid-1970s using a surface drainage system that includes infiltration basins in private gardens, community lawns and children's playgrounds connected by a continuous network of seasonal swales and pools. For over twenty years this system has functioned successfully in a residential environment with no injuries or litigation associated with the storm drain system.

Where can I get more copies of this manual?

Call your local stormwater program (see Resources, p. 154). They can get you more copies of this manual and help you to implement its design philosophy into your project.

I need more technical information. Where can I get it?

This document contains general technical information and design guidance. For more technical information, see the Resources section and the bibliography.

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Next Steps

9.2 *Getting started*

9.2 Getting Started. The following lists illustrate the wide range of options available that each of the groups active in development can take to begin implementing guidelines for better site planning and design. The lists are not meant to be mandates or all-inclusive, but to serve as a menu for each community to select from depending upon priorities, resources, and local conditions.

Regulatory agencies

- promote education and exchange of information on stormwater management
- create a regulatory environment that facilitates the implementation of better stormwater management practices
- assist local governments in the monitoring and evaluation of alternative stormwater management practices
- recognize and reward projects that take risks and that embrace better stormwater management practices.

Local governments

- adopt standards and alternatives for design and stormwater management, such as impervious surface reduction and on-site stormwater infiltration or detention
- establish an incentive program to encourage alternatives that achieve water quality goals
- establish a penalty program for projects that do not achieve water quality goals
- adopt access street standards for low volume, access streets
- adopt drainage standards and details that permit surface drainage and infiltration/retention systems in combination with conventional underground conveyance systems
- review zoning and other ordinances for driveways, setbacks, lot coverage, and other factors to accommodate more environmentally responsible land use
- modify maintenance practices on public lands and in the public right-of-way to accommodate stormwater infiltration/detention systems
- build a culture of environmental stewardship across all departments and offices
- use these principles and techniques in siting and designing government facilities.

The building industry

- think of water as an amenity to be featured rather than a liability to be gotten rid of or a hazard from which the public must be protected
- market the stormwater system as a landscape feature that can improve product competitiveness
- explore techniques that have proven successful elsewhere, but have not yet been widely used in the Bay Area
- work cooperatively with local governments to build prototype projects that demonstrate better stormwater management practices
- invest in designs and materials that may have a higher initial cost, but that yield long-term value
- educate landscape crews on maintenance practices for stormwater infiltration systems and soil health
- exhibit a willingness to take risks in order to advance the industry and improve the environment.

Design professionals

- invest in continuing education to learn about better stormwater management practice and design
- educate clients and approval bodies on the principles and advantages of designing developments for better stormwater management
- test designs and approaches to ensure successful implementation
- conceive of the drainage system as a fundamental design element to be creatively explored
- complete post-construction review of built projects to evaluate long-term performance of stormwater system designs
- practice continuous incremental improvement of stormwater system designs and detailing.

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Next Steps

9.3 *Keys to success*

9.3 Keys to success. Site planning and design for stormwater management involves the coordination of many disciplines and activities. Building successful projects requires careful follow-through from concept to design to construction and maintenance.

Conceptual stage

- o be sure to understand site constraints, local microclimates, and soil conditions
- o determine regulatory environment and which particular design strategies are favored by regulatory agencies
- o have a preliminary meeting between the development team and local government officials to discuss overall stormwater management goals and strategies
- o consult local stormwater program to learn what has worked (and what hasn't) in a local area.

Design stage

- o establish a stormwater management awareness among all disciplines in the design team
- o hold regular cross-discipline coordination meetings to evaluate overall stormwater management solutions as design develops
- o consult with local nurseryperson or horticulturist to determine appropriate plant material selection for the site's microclimate
- o verify that stormwater systems are sized appropriately for the given water quality volume, and that residence time will be within acceptable limits
- o carefully coordinate related design elements, especially
  - – underground utilities and surface drainage
  - – curb cuts and catch basins
  - – materials and pavement selection
  - – downspouts, area drains and roof drains
  - – grading of roads, parking and adjacent landscape areas
- o check proposed stormwater solutions with geotechnical engineer to verify suitability given site soil conditions

Construction documents stage

- o ensure details and specifications are coordinated across disciplines (e.g. civil engineering and landscape architecture)
- o if plans call for unconventional detailing, such as notched curbs or porous asphalt, be sure they are clearly and boldly identified on the drawings as different from conventional details (or contractor may not notice the difference)
- o double-check all calculations for proper sizing and function
- o if using manufactured products, such as turf block or catch basin inserts, take advantage of manufacturer's design consultation services, if available

Construction stage

- o hold a pre-bid meeting with all contractors to review principal design elements and site conditions
- o hold a pre-construction meeting with selected contractor to review construction documents in detail, especially details that differ from those conventionally used
- o explain to the contractor the design intent of the various stormwater management designs– if they understand why something is designed a certain way, they are more likely to build it the way it's designed
- o insist on meeting with the job foreman, not just the contractor's estimator or client service representative– the foreman will be the one actually supervising the work
- o make periodic site visits during construction to ensure that designs are being correctly implemented

Post-construction stage

- o hold a project closing meeting with the contractor to verify that designs were correctly implemented and to learn how they could be improved
- o hold a meeting with the owner or the owner's maintenance staff to explain the stormwater system
- o provide the owner and the maintenance staff with a Management Handbook describing how the stormwater system is designed to work and how to maintain it
- o make post-occupancy visits to evaluate long-term performance

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Next Steps

9.4 *Resources*

9.4 Resources. The following resources are available for further information and assistance with particular aspects of site planning and design for stormwater management protection.

Regional water resources and pollution prevention

Bay Area Stormwater Management Agencies Association (BASMAA)
1515 Clay Street, Suite 1400
Oakland, California 94612
voice: 510 622.2300
www.basmaa.org

Alameda Countywide Clean Water Program
510 670.5543

Contra Costa Clean Water Program
925 313.2360

San Mateo Countywide Stormwater Pollution Prevention Program
650 599.1406

Vallejo Sanitation and Flood Control District
707 644.8949

Fairfield-Suisun Urban Runoff Management Program
707 429.8930

Marin County Stormwater Pollution Prevention Program
415 485.3363

Santa Clara Valley Urban Runoff Pollution Prevention Program
800 794.2482

California Regional Water Quality Control Board
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, California 94612
510 622.2300

Central Valley Region
3443 Routier Road, Suite A
Sacramento, California 95827
916 255.3000

California Environmental Protection Agency
State Water Resources Control Board
901 P Street
Sacramento, California 95814
voice: 916 657.1025
fax: 916 657.2127

Local planning and development

Association of Bay Area Governments (ABAG)
P.O. Box 2050
Oakland, California 94604-2050
voice: 510 464.7900
fax: 510 464.7970
info@abag.ca.gov

Out-of-state planning and pollution prevention

Site Planning for Urban Stream Protection
available from Department of Environmental Programs
Metropolitan Washington Council of Governments
777 N. Capitol Street N.E., Suite 300
Washington, DC 20002
voice: 202 962.3200

The Center for Watershed Protection
8391 Main Street
Ellicott City, Maryland 21043
voice: 410 461.8323
New document for planning and zoning: *Rapid Watershed Planning Handbook: A Comprehensive Guide for Managing Urbanizing Watersheds.* October 1998.

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Next Steps

9.4 *Resources, continued*

Nonpoint Education for Municipal Officials (NEMO)
Univ. of Connecticut Cooperative Extension System
1066 Saybrook Road, Box 70
Haddam, Connecticut 06438
voice: 860 345.4511
fax: 860 345.3357

Technical documents

California Storm Water Best Management Practice Handbooks
Stormwater Quality Task Force (Roesner, Walker, et. al.).
available through Blue Print Service, Oakland, CA.
510 287.5485

Design and Construction of Urban Stormwater Management Systems
American Society of Civil Engineers Manuals and Reports of Engineering Practice No. 77
Water Environment Federation Manual of Practice FD-20
jointly published by ASCE and WEF, 1992

Urban Runoff Quality Management
WEF Manual of Practice No. 23
ASCE Manual and Report on Engineering Practice No. 87
jointly published by American Society of Civil Engineers (ASCE) and the Water Environment Federation (WEF)
voice: (WEF) 703 684.2400
www.wef.org
www.asce.org

Stormwater Infiltration
by Bruce K. Ferguson
CRC Press
Boca Raton, FL

Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality
Environmental Protection Agency (EPA-440/5-87-001)
Washington, DC

Economic Benefits of Runoff Controls
Environmental Protection Agency. (EPA 841-S-95-002)
Washington, DC

Low-Impact Development Design Manual
Department of Environmental Resources
Prince George's County, Maryland

On-site Residential Stormwater Management Alternatives
Dept. of Civil Engineering
University of Washington
3201 Fremont Avenue North
Seattle, Washington 98103
206 543.5539

Impervious Surface Reduction Study
City of Olympia Public Works Department
P.O. Box 1967
Olympia, Washington 98507-1967
voice: 360 753.8598
fax: 360 753.8087

Time-Saver Standards for Landscape Architecture, second ed.
by Charles W. Harris & Nicholas T. Dines, co-editors
McGraw-Hill Publishing Company, New York, 1998.

Traffic Engineering for Neo-Traditional Neighborhood Design
Institute of Transportation Engineers (ITE)
525 School Street, S.W., Suite 410
Washington, DC 20024-2729
voice: 202 544.8050
fax: 202 863.5486
www.ite.org

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A Appendices

The following pages provide supplementary information for those seeking more detail on residential site planning and design guidance for stormwater quality.

The appendices were adapted from a variety of technical sources drawn from throughout the United States.

Appendices

A.1 Glossary. Relevant terms and acronyms used in the text and common to stormwater management issues.

A.2 Bibliography. A listing of relevant documents on site planning and design for stormwater management. These documents address a wide range of approaches to current practice, including engineering, environmental science, landscape arcitecture, planning, horticulture, real estate marketing and development.

A.3 Footnotes. References for information cited in the text.

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Appendix A.1 *Glossary*

Access streets The lowest order street in the hierarchy of streets, it conducts traffic between individual dwelling units and higher order streets (such as collector and subcollector streets). Access streets convey the lowest traffic volume, and are prime candidates for reduced street widths.

Alternative modes of transportation Modes of transportation other than the single passenger automobile, such as transit, bicycling, carpooling, and walking.

Alternative surfaces Pavement types other than conventional asphalt or concrete. Examples include porous pavement and pavers.

Amenity Something that increases material or physical comfort.

Aquifer The underground layer of rock or soil in which groundwater resides. Aquifers are replenished or recharged by surface water percolating through soil. Wells are drilled into aquifers to extract water for human use.

Arterial street A street that provides a direct route for long-distance travel within the region and also to different parts of the city. Traffic on an arterial street is given preference at intersections, and some access control may be considered in order to maintain capacity to carry high volumes of traffic.

Average daily traffic (ADT) The average total number of vehicles that traverse a road or highway on a typical day. Often used to classify and design roadway systems.

Best Management Practice A method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a water body. The term originated from the rules & regulations developed pursuant to the federal Clean Water Act (40 CFR 1 30).

Bioretention A technique that uses parking lot islands, planting strips, or swales to collect and filter urban stormwater, that includes grass and sand filters, loamy soils, mulch, shallow ponding and native trees and shrubs.

Buffer A zone created or sustained adjacent to a shoreline, wetland or stream where development is restricted or prohibited to minimize the negative effects of land development on animals and plants and their habitats.

Building footprint Commonly used term to describe the ground area that a building covers.

Catchment The smallest watershed management unit, defined as the area of a development site to its first intersection with a stream, usually as a pipe or open channel outfall.

Check dam (a) A log or gabion structure placed perpendicular to a stream to enhance aquatic habitat. (b) An earthen or log structure, used in grass swales to reduce water velocities, promote sediment deposition, and enhance infiltration.

Cluster Development A development pattern for residential, commercial, industrial, institutional, or combination of uses, in which the uses are grouped or "clustered," through a density transfer, rather than spread evenly throughout the parcel as in conventional lot-by-lot development. A local jurisdiction's Critical Area Program may authorize such development by permitting smaller lot sizes if a specified portion of the land is kept in permanent open space to provide natural habitat or open space uses through public or private dedication.

Collector street Acts as the primary traffic route within a residential or commercial area.

Constructed wetland An artificial wetland system designed to mitigate the impacts of urban runoff.

Contamination. The impairment of water quality by waste to a degree that creates a hazard to public health through poisoning or through the spread of disease.

Cul-de-sac A circular section located at the end of an access street that permits vehicles to turn around.

Curbs A concrete barrier on the margin of a road or street that is used to direct stormwater runoff to an inlet, protect pavement edges, and protect lawns and sidewalks from encroachment by vehicles.

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Density The average number of families, persons, or housing units per unit of land, usually density is expressed "per acre".

Design storm A rainfall event of specified size, intensity, and return frequency (e.g., a storm that occurs only once every 2 years) that is used to calculate runoff volume and peak discharge rate.

Detention The temporary storage of storm runoff which is used to control discharge rates sufficiently to provide gravity settling of pollutants.

Detention time The amount of time water actually is present in a basin. Theoretical detention time for a runoff event is the average time parcels of water reside in the basin over the period of release from the basin.

Drainage basin (see Watershed) A land area bounded by high points, which drains all surface water into a single stream or other body of water.

Effective Impervious Surface The portion of impervious surface that generates stormwater runoff which must be managed or directed to a stormwater conveyance system, rather than infiltrating into the ground.

Ephemeral stream A stream or waterway that holds water only for a few hours or days, and dries up shortly after rain storms.

Erosion The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road, building, or timber cutting.

Evapotranspiration The loss of surface water into the atmosphere, through plants and evaporation.

Excess parking Parking spaces that are constructed over and above the number required or predicted based on the parking demand ratio for a particular land use or activity

Excess stormwater runoff Any increase in stormwater resulting from: an increase in the imperviousness of a site, including all additions to buildings, roads, and parking lots; changes in permeability caused by compaction during construction or modifications in contours, including the filling or drainage of small depression areas; the alteration of drainageways, or regrading of slopes; the destruction of forest; or the installation of collection systems to intercept street flows or to replace swales or other drainageways.

Filter fabric Textile of relatively small mesh or pore size that is used to (a) allow water to pass through while keeping sediment out (permeable), or (b) prevent both runoff and sediment from passing through (impermeable).

Filter strips A vegetated area that treats sheetflow and/or interflow to remove sediment and other pollutants. Used to treat shallow concentrated stormflows over very short contributing distances in urban areas.

First flush The delivery of a disproportionately large load of pollutants during the early part of storms due to the rapid runoff of accumulated pollutants. The first flush of runoff has been defined several ways (e.g., one-half inch per impervious acre).

Forebay An extra storage space provided near an inlet of a wet pond or constructed wetland to trap incoming sediments before they accumulate in the pond.

Grassed channel A long, open, and grassed channel used to convey stormwater runoff to a downstream point. It is designed to filter out pollutants during water quality storms, and also convey large storm events.

Green space The proportion of open space in a cluster development that is retained in an undisturbed vegetative condition.

Groundwater Water stored underground that fills the spaces between soil particles or rock fractures. A zone underground with enough water to withdraw and use for drinking water or other purposes is called an aquifer.

Habitat The specific area or environment in which a particular type of plant or animal lives. An organism's habitat must provide all of the basic requirements for life and should be free of harmful contaminants.

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Appendix A.1 *Glossary, continued*

Hammerhead A "T" shaped turnaround option for lightly traveled residential streets. Creates less impervious cover compared to a circular cul-de-sac.

Headwater stream A term for the smaller first and second order tributary streams in a drainage network.

Heat island effect The increase in ambient temperatures generated by heat radiating from paved surfaces exposed to sunlight.

Hydrology The science of the behavior of water in the atmosphere (air), on the surface of the earth, and underground.

Impermeable Not able to be infiltrated by water.

Impervious surface Any surface which cannot be effectively (easily) penetrated by water. Examples include pavement, buildings, compacted soils, and rock outcrops.

Imperviousness The percentage of impervious cover within a development site or watershed.

Infill Developing vacant parcels or redeveloping existing property to achieve higher density in urban areas as an alternative to development in outlying rural areas.

Infiltration The downward entry of water into the surface of the soil, as contrasted with percolation which is movement of water through soil layers.

Infiltration basin A concave vegetated surface (e.g., pond, swale) designed to hold water so that it can gradually infiltrate into the soil.

Interconnected streets Street system that allows traffic to circulate within neighborhoods instead of creating cul-de-sacs and dead end streets that result in disconnected residential areas. A grid pattern of blocks is a typical example.

Nonpoint source pollution Pollution that enters water from dispersed and uncontrolled sources, such as rainfall or snowmelt moving over and through the ground rather than single, identifiable sources. A nonpoint source is any source of water pollution that does not meet the legal definition of point source in section 502(14) of the Clean Water Act (e.g., forest practices, agricultural practices, on site sewage disposal, automobiles, and recreational boats). While individual sources may seem insignificant, they may contribute pathogens, suspended solids, and toxicants which result in significant cumulative effects.

Non-renewable resources Resources that are not naturally regenerated or renewed.

Nonstructural control A practice that does not require construction of a facility to control urban runoff.

NPDES National Pollutant Discharge Elimination System, a provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or another delegated agency.

Open space A portion of a cluster development that is set aside for public or private use and is not developed with homes. The space may be used for active or passive recreation, or may be reserved to protect or buffer natural areas (see also green space)

Perennial streams A stream channel that has running water throughout the year.

Performance criteria Technical standards that govern the development process that are based on meeting general objectives for design, rather than prescribing rigid, uniform and detailed design requirements.

Permeable A type of soil or other material that allows passage of water or other liquid.

Permeable surfaces Areas characterized by materials that allow stormwater to infiltrate the underlying soils (e.g., soil covered or vegetated areas)

Pervious A soil or material that has the specific quality of allowing the passage of water or other liquid.

Point Source Pollution A source of pollutants from a single point of conveyance, such as a pipe. For example, the discharge from a sewage treatment plant or a factory is a point source.

Pollutants A chemical or other additive that adversely alters the

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physical, chemical, or biological properties of the environment.

Porous pavement Asphalt or concrete paving material consisting of a coarse mixture cemented together with sufficient interconnected voids to provide a high rate of permeability.

Premium An additional charge for real estate property with an amenity such as a water view or a view of wooded land.

Receiving waters Lakes, rivers, wetlands, and coastal waters that receive runoff.

Recharge Area A land area in which surface water infiltrates soil and reaches to the zone of saturation, such as where rainwater soaks through the earth to reach an aquifer.

Recharge Infiltration of surface water to groundwater.

Retrofit To provide or add new equipment, parts, or techniques unavailable at the time of original construction.

Riparian Area Habitat found along the bank of a natural and freshwater waterway, such as a river, stream, or creek, that provides for a high density, diversity, and productivity of plant and animal species.

Runoff Water from rain, melted snow, or agricultural or landscape irrigation that flows over the land surface.

Runoff coefficient The runoff coefficient determines the portion of rainfall that will run off the watershed. It is based on the permeability and water-holding capacity of the various surfaces in the watershed. The runoff coefficient value, expressed as *C*, can vary from close to zero to up to 1.0. A low *C* value indicates that most of the water is retained for a time on the site, as by soaking into the ground or forming puddles, whereas a high *C* value means that most of the rain runs off rapidly.

Setback A zone designated to protect sensitive areas from negative impacts associated with development.

Shared parking A parking strategy designed to reduce the total number of parking spaces needed within an area, by allowing adjacent users to share parking areas during non competing hours of operation (e.g., a shared lot for a theater and an office building).

Sheetflow A flow condition during a storm where the depth of stormwater runoff is very shallow in depth and spread uniformly over the land surface. This sheet flow quickly changes into concentrated channel flow within several hundred feet.

Steep slope An area of a development site that is too steep to (a) safely build on or (b) has a high potential for severe soil erosion during construction.

Stormwater conveyance A system of gutters, pipes, or ditches used to carry stormwater from surrounding land areas to constructed or natural drainage systems.

Stormwater runoff Rain that flows off the surface of the land without entering the soil.

Structural control A practice that involves design and construction of a facility to mitigate the adverse impact of urban runoff, and often requires maintenance.

Subdivision The process (and the result) of dividing a parcel of raw land into smaller buildable sites, streets, open spaces, and public areas, and the designation of utilities and other improvements. Critical Area regulations govern the density and design of new subdivisions.

Subwatershed A watershed management unit whose boundaries are typically defined as all of the land draining to the point where two second order streams combine together to form a third order stream. A subwatershed may be a few square miles in area, and are the key geographic unit for urban stream classification and watershed- based zoning,

Surface water Water on the surface of the land that has not infiltrated the soil including streams, lakes, rivers, and ponds.

Swale An open drainage channel that has been explicitly designed to detain or infiltrate the entire runoff volume associated with a water quality storm event.

Trip generation rate A statistic that indicates the number of vehicular trips that are taken from an average dwelling unit in a

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Appendix A.1 *Glossary, continued*

particular land use category on a typical day. For example, studies have shown that one single family home generates about 10 trips per day.

Unbuildable lands The portions of a development site where structures cannot be located for physical or environmental reasons (e.g., easements, open water, steep slopes, floodplains, wetlands and stream buffers).

Unit Pavers Concrete grid and modular pavement whose spaces are filled with pervious materials such as sod, sand, or gravel.

Water table The upper surface of groundwater or the level below which the soil is saturated with water. The water table indicates the uppermost extent of ground water.

Watershed (see Drainage basin) The geographic region within which water drains into a particular river, stream or body of water. A watershed includes hill, lowlands, and the body of water into which the land drains. Watershed boundaries are defined by the ridges of separating watersheds.

Wet pond Pond for urban runoff management that is designed to detain urban runoff and always contains water.

Zoning A set of regulations and requirements which govern the use, placement, spacing, and size of land and buildings within a specific area (zone).

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Finding that the way we design and build communities has a direct effect on water quality, the Bay Area Stormwater Management Agencies Association (BASMAA) has prepared **Start at the Source,** *a manual that aims to help designers, developers, and municipal agencies create communities that achieve water quality goals.*

The ***Site Planning & Design Guidance Manual*** *contains introductory information on hydrology, watersheds, the importance of minimizing impervious land coverage, zoning and planning strategies for stream protection, and conceptual examples of dozens of methods for integrating stormwater management into all kinds of projects, including new development, infill, and redevelopment.*

A ***new technical section*** *presents detailed information on a wide variety of designs that can be adapted to residential, commercial, industrial and institutional projects.*

This document recognizes that the one of the best opportunities to reduce the generation of urban runoff or nonpoint source pollution is through planning and design.

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"The more we study stormwater runoff, the more we realize the critical role site planning and design play in our ability to reduce the impacts of development on the quality of our nation's waters. This manual is a significant step in teaching planners and developers to plan for water quality."

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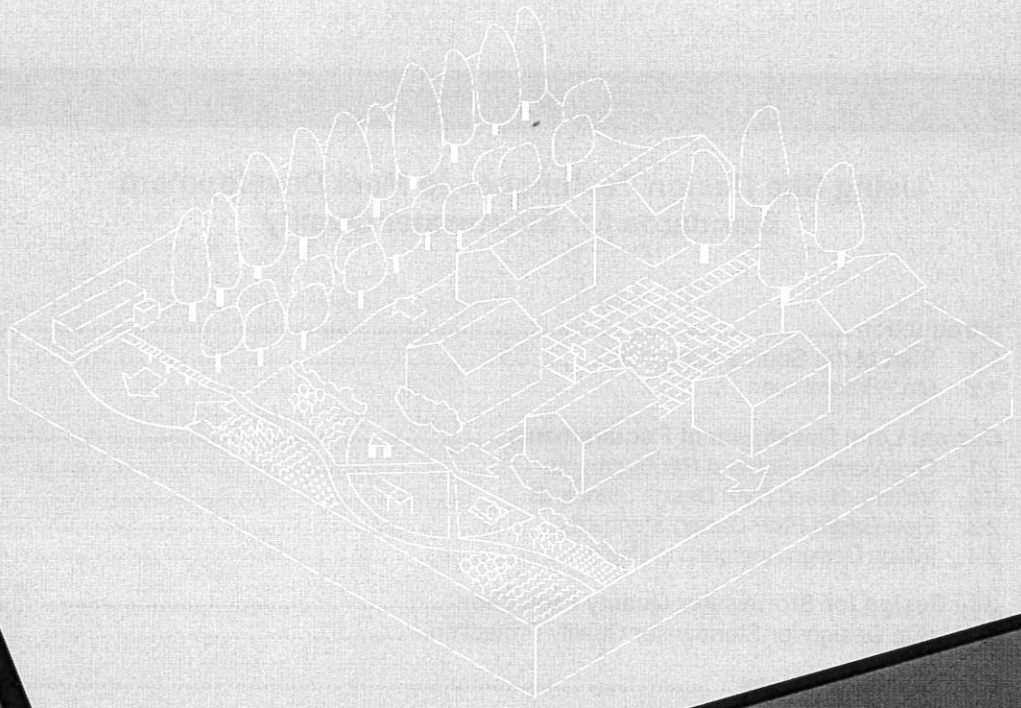

Using Site Design Techniques to Meet Development Standards for Stormwater Quality

A Companion Document to Start at the Source

May 2003

Bay Area Stormwater Management Agencies Association

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Bay Area Stormwater Management Agencies Association

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1 Introduction

1.1 Start at the Source Approach

To address stormwater quality during the planning and design phase of new development and redevelopment projects, the Bay Area Stormwater Management Agencies Association (BASMAA) developed *Start at the Source – Residential Site Planning and Design Guidance Manual for Stormwater Quality Protection* (BASMAA, 1997). This first edition introduced design concepts that could reduce the impact of new development and redevelopment on water quality by addressing pollutants at their source. The manual focused on implementation of Best Management Practices (BMPs) for complying with *qualitative* land development requirements contained within first and second generation NPDES stormwater permits. In 1999, BASMAA prepared a second edition titled *Start at the Source – Design Guidance Manual for Stormwater Quality Protection*. This second edition expanded on the first edition in two ways - by covering industrial/commercial and institutional development, and by providing more detailed technical information.

Recent stormwater permits have evolved to include more specific *quantitative* requirements regarding development and redevelopment. This document demonstrates ways to utilize the techniques described in BASMAA's second edition of *Start at the Source* to help comply with these quantitative permit requirements.

The development and redevelopment planning process involves not only planning, engineering, and landscape architect professionals, but also staff and elected and appointed officials from cities, counties, and local agencies. To address stormwater quality issues during the process, the *Start at the Source* approach aims to convey basic stormwater management concepts that can be adapted to site and project specific conditions.

Development and redevelopment projects that incorporate site design techniques such as detention, retention, and infiltration of runoff, like concave medians, permeable pavements, and conservation of natural areas, exhibit reduced runoff volumes and rates when compared to projects of similar magnitude where the techniques are not utilized. The runoff volume and rate reductions achieved with site design techniques translate directly to reductions in the amount of runoff that must be treated to comply with permit requirements and managed to protect streams from erosion. See Figure 1-1.

1.2 More Information

This manual does not provide detailed information on how to select or size specific site design techniques or other stormwater treatment measures. Sources for stormwater quality design information to supplement this manual include:

- California Stormwater Best Management Practice Handbooks (California Stormwater Quality Association, 2003)
- Urban Runoff Quality Management, WEF Manual of Practice No. 23, ASCE Manual and Report on Engineering Practice No. 87, 1998

These sources will help you complete the design calculations discussed in this document.

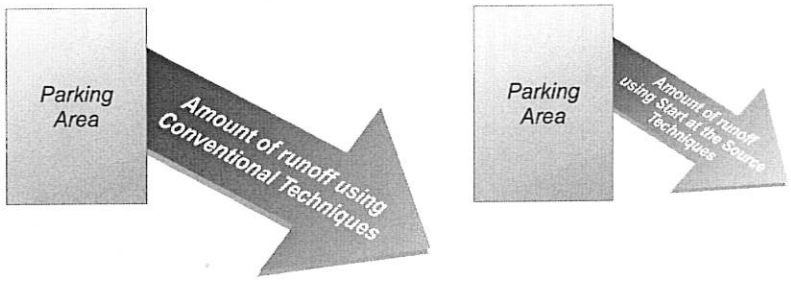

Figure 1-1
***Start at the Source* Reduces Post Development Runoff Volumes**

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2 Current Land Development Requirements

2.1 Overview of General Requirements

Recently issued municipal stormwater discharge permits now contain quantitative requirements regarding stormwater controls for new development and redevelopment. Most new development and redevelopment projects must now treat runoff prior to being discharged to storm drains. The requirements set forth minimum standards for sizing newly constructed treatment controls. Sizing standards are prescribed for both:

- Volume-Based BMPs
- Flow-Based BMPs

Volume-based BMP design standards generally call for the capture and infiltration and/or treatment of the 80th to 85th percentile runoff volume. While this requirement may seem as if it calls for capturing the runoff from large, infrequent storms, in most areas it merely amounts to capturing the runoff from relatively small storms that occur several times per year. Such small storms produce more total runoff than larger more infrequent storms. See Figure 2-1. Local development requirements should be referenced for the specific percentile runoff volume that must be addressed.

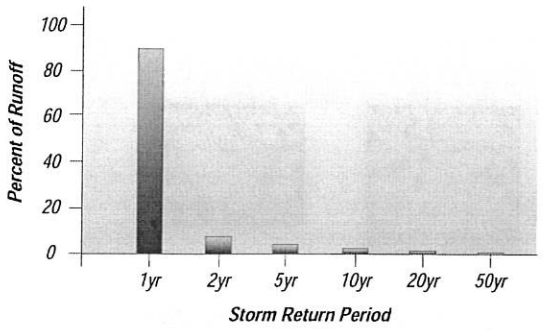


Figure 2-1
Small Storms Add Up

Flow-based BMP design standards generally call for the capture and infiltration and/or treatment of runoff flows produced by the 85th percentile hourly rainfall intensity plus a safety factor. As mentioned above, this requires treating flows from only small, frequent storm events.

Start at the Source provides many site design techniques directly applicable to meeting these land development requirements.

2.2 Volume-Based BMP Design Standards

According to current municipal permits, treatment BMPs whose primary mode of action depends on volume capacity to remove pollutants, such as retention or infiltration structures, shall be designed to treat a volume of stormwater runoff equal to:

- The maximized stormwater quality capture volume for the area, based on historical rainfall records, determined using the formula and volume capture coefficients set forth in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998), pages 175-178; or
- 80 percent of the volume of annual runoff, determined by using local rainfall data in accordance with methodology set forth in Appendix D of the California Stormwater Best Management Practices New Development and Redevelopment Handbook (2003). The BMP Handbooks have recently been revised.

2.3 Flow Based BMP Design Standards

Current municipal stormwater permits also require that treatment BMPs whose primary mode of action depends on flow capacity, such as swales, sand filters, or wetlands, be sized to treat:

- 10% of the 50-year design flow rate; or
- The flow of runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the applicable area, based on historical records of hourly rainfall depths; or
- The flow of runoff resulting from a rain event equal to at least 0.2 inches per hour intensity.

2.4 Which Design Approach to Use?

Some BMPs are designed based on volume, flow, or a combination of both. The design basis is dependent upon the primary mode of action for the specific BMP. For example, the design of extended detention (dry) ponds requires a volume-based design approach, vegetated swales require a flow-based design approach, and concave medians require a combination of volume-based and flow-based design approaches. Table 3-1 lists various site design and landscape techniques and indicates whether a volume-based approach, flow-based approach, or both, is appropriate for the design of each technique.

In determining which design approach to use, apply the locally approved design standards to the BMP design guidance found in the references noted in Section 1.2.

SARB_009689

3 Site Design for Stormwater Quality Protection

3.1 Site Design for Stormwater Quality Protection

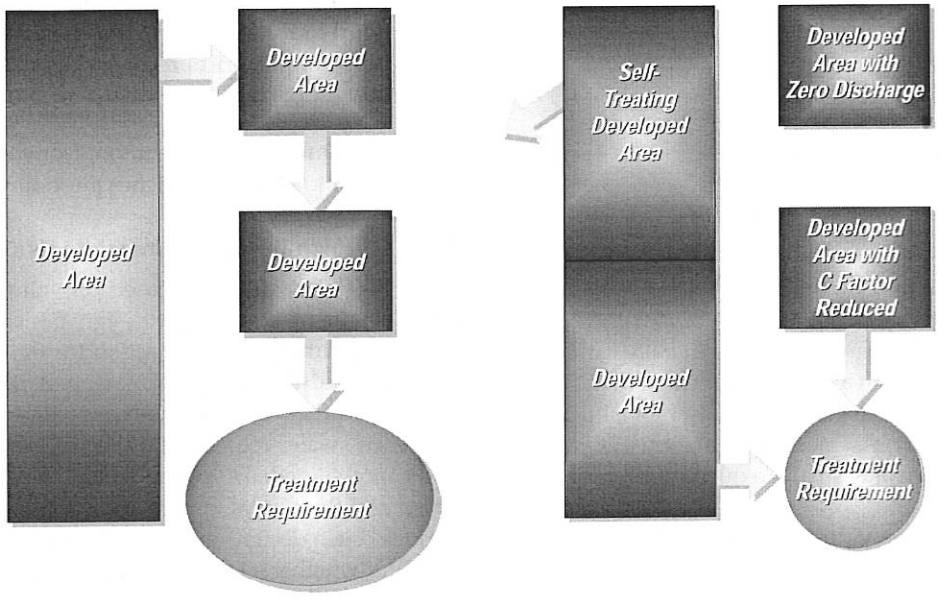
Reducing the amount of runoff required to be captured and infiltrated and/or treated may be achieved by applying the following design philosophies during the planning and design stage of development:

- **Zero Discharge Areas** – areas that have been designed to infiltrate or retain the volume of runoff requiring treatment
- **Self-Treating Areas** – areas that have been designed to provide "self-treatment" without additional BMPs
- **Runoff Reduction Areas** – areas that have been designed using alternative materials or surfaces that may reduce the volume of runoff

Figure 3-1 conceptually illustrates how these philosophies may be used to reduce treatment requirements during development and redevelopment. The design philosophies are explained in detail in the following sections.

The site design techniques do not require radical changes in design methods or development planning. The techniques may simply be incorporated into the standard features of a development, requiring only small changes or refinements in design. For example, an area reserved to meet landscaping requirements can also be used to meet stormwater treatment requirements. The key is to incorporate these changes early on in the planning and design process. Appropriately applied, these techniques can reduce runoff volume and flow rate, which reduces the infrastructure necessary to treat and convey stormwater.

Table 3-1 presents a list of site design and landscaping techniques and indicates whether they are applicable for use in Zero Discharge Areas, Self-Treating Areas, and Runoff Reduction Areas. Several different techniques may be implemented within the same design philosophy. Some techniques may be used to implement more than one design philosophy. Where feasible, combinations of multiple techniques may be incorporated into new development and redevelopment projects to minimize the amount of treatment required.



Conventional Design Approach **_Start at the Source_ Design Approach**

Figure 3-1
Reducing the Size of Treatment Requirements

SARB_009690

Table 3-1
Site Design and Landscaping Techniques

	Design Criteria		Design Philosophy [1,2]		
Site Design and Landscape Techniques	**Volume-Based Design**	**Flow-Based Design**	**Zero Discharge**	**Self – Treating**	**Runoff Reduction**
Permeable pavements					
Pervious concrete	X				X
Pervious asphalt	X				X
Turf block	X			X	X
Un-grouted brick [3]	X				X
Un-grouted natural stone [3]	X				X
Un-grouted concrete unit pavers [3]	X				X
Unit pavers on sand	X				X
Crushed aggregate	X				X
Cobbles	X				X
Wood mulch	X				X
Streets					
Urban curb/swale system	X	X			X
Rural swale system	X	X			X
Dual drainage systems	X	X			X
Concave median	X	X	X	X	X
Pervious island	X	X		X	X
Parking lots [4]					
Hybrid surface parking lot	X				X
Pervious parking grove	X				X
Pervious overflow parking	X			X	X
Driveways [4]					
Not directly connected impervious driveway		X			X
Paving only under wheels	X			X	X
Flared driveways	X				X
Buildings					
Dry-well	X		X	X	X
Cistern	X	X	X	X	X
Foundation planting	X	X			X
Pop-up drainage emitters		X			X
Blue roofs [5]	X		X	X	X
Green roofs [5]	X		X	X	X
Landscape					
Grass/vegetated swales	X	X		X	X
Extended detention (dry) ponds	X		X	X	X
Wet ponds	X		X	X	X
Bio-retention areas	X		X	X	X
Fountains	X		X		

Notes:
(1) The above site design and landscape techniques may be applicable to more than one design philosophy; for example, turf block may be used as part of a self-treating area or runoff reduction area.

(2) These techniques must be designed and located properly to achieve the desired treatment requirement reduction.

(3) The open area between brick, stone, and pavers design techniques is critical, as the spaces provide perviousness.

(4) Options for parking lot and driveway surface treatments are covered under permeable pavements. See Start at the Source for details.

(5) Green roofs are vegetative, landscaped rooftops. Blue roofs are rooftops designed to detain or retain stormwater.

SARB_009691

4 Zero Discharge Areas

4.1 Design Philosophy

An area within a development or redevelopment project can be designed to infiltrate or retain the volume of runoff requiring treatment from that area.

The term "zero discharge" in this philosophy applies at stormwater treatment design storm volumes. For example, consider an area that functionally captures and then infiltrates the 80th percentile storm volume. If permits require treatment of the 80th percentile storm volume, the area generates no *treatment-required* runoff.

Site design techniques available for designing areas that produce no treatment-required runoff include:

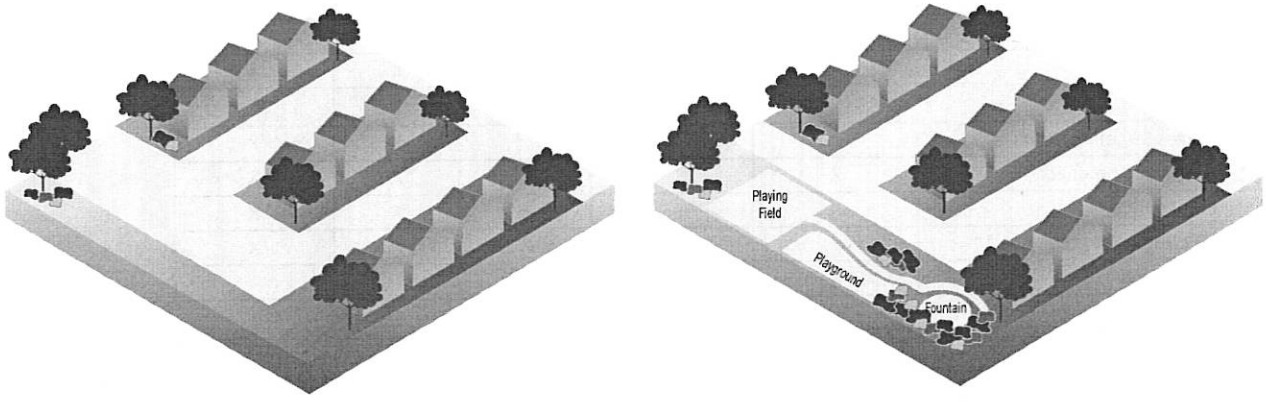
- Retention Ponds
- Wet Ponds
- Infiltration Areas
- Large Fountains
- Retention Rooftops
- Green and/or Blue Roofs

Infiltration areas, ponds, fountains, and green/blue roofs can provide "dual use" functionality as stormwater retention measures and development amenities. Retention ponds and infiltration areas can double as playing fields or parks. Wet ponds and infiltration areas can serve dual roles when meeting landscaping requirements.

When several "zero discharge" areas are incorporated into a development design, significant reductions in volumes requiring treatment may be realized.

"Zero discharge" areas such as wet ponds, retention ponds, and infiltration areas can be designed to provide treatment over and above the storm volume captured and infiltrated. For example, after a wet pond area has captured its required storm volume, additional storm volume may be treated via settling prior to discharge from the pond. In this case, the "zero discharge" area converts automatically into a treatment device for runoff from other areas, providing settling for storm volumes beyond treatment requirements. Another example is a grassy infiltration area that converts into a treatment swale after infiltrating its area-required treatment volume. The grassy infiltration area in this example becomes a treatment swale for another area within the development.

Figure 4-1 illustrates a residential tract, and a tract incorporating Zero Discharge Area techniques (infiltration areas). The Zero Discharge Area designed tract represents a design to infiltrate (i.e., achieve zero discharge from) a portion of the tract's runoff, reducing total runoff from the tract.



Conventional Design Approach **Start at the Source Design Approach**

Figure 4-1
Zero Discharge Area Usage

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4.2 Zero Discharge Area Example

The following example problem compares sizing a retention basin using conventional design methods, to sizing the basin using *Start at the Source* design techniques. Figure 4-2 represents a conventionally designed residential tract with a retention basin.

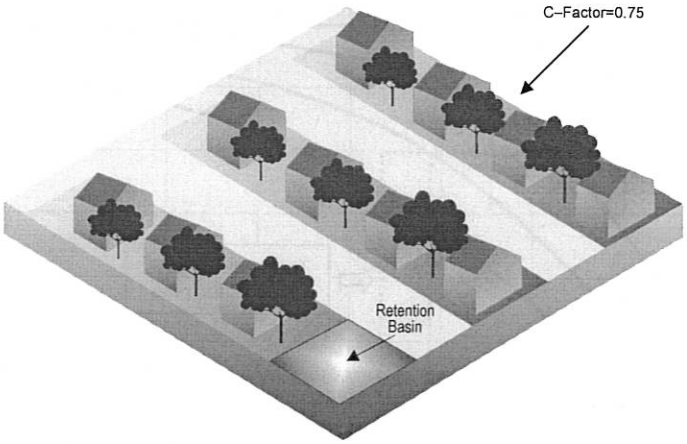

Figure 4-2
Conventional Design

Conventionally Designed Residential Tract:
Assume a 10-acre residential tract has a coefficient of runoff (C-Factor) of C=0.75

Start at the Source Designed Residential Tract:

- Redesign the 10-acre residential tract using the Zero Discharge Area *Start at the Source* technique. Figure 43 represents the residential tract with a 2-acre Zero Discharge Area incorporated into the development. To accommodate the Zero Discharge Area, the residential units were constructed at a higher density, resulting in a C-factor increase in the remaining 8-acre portion of the tract. Assume the redesign is comprised of:

- 2-acre portion with Zero Discharge Areas (fountains, playgrounds, wetlands, parks) with a runoff coefficient of C = 0.00

- 8-acre portion with a runoff coefficient of C = 0.85

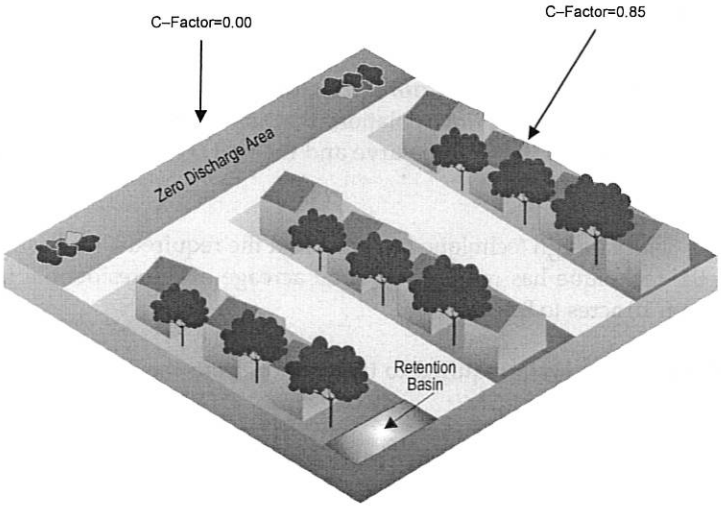

Figure 4-3
Start at the Source Design Approach

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Calculating Retention Basin Size – Conventional Design:
Using Figure 4-4, San Jose Capture Curve developed using techniques set forth in the California Storm Water BMP Handbooks (CDM, et al. 2003):

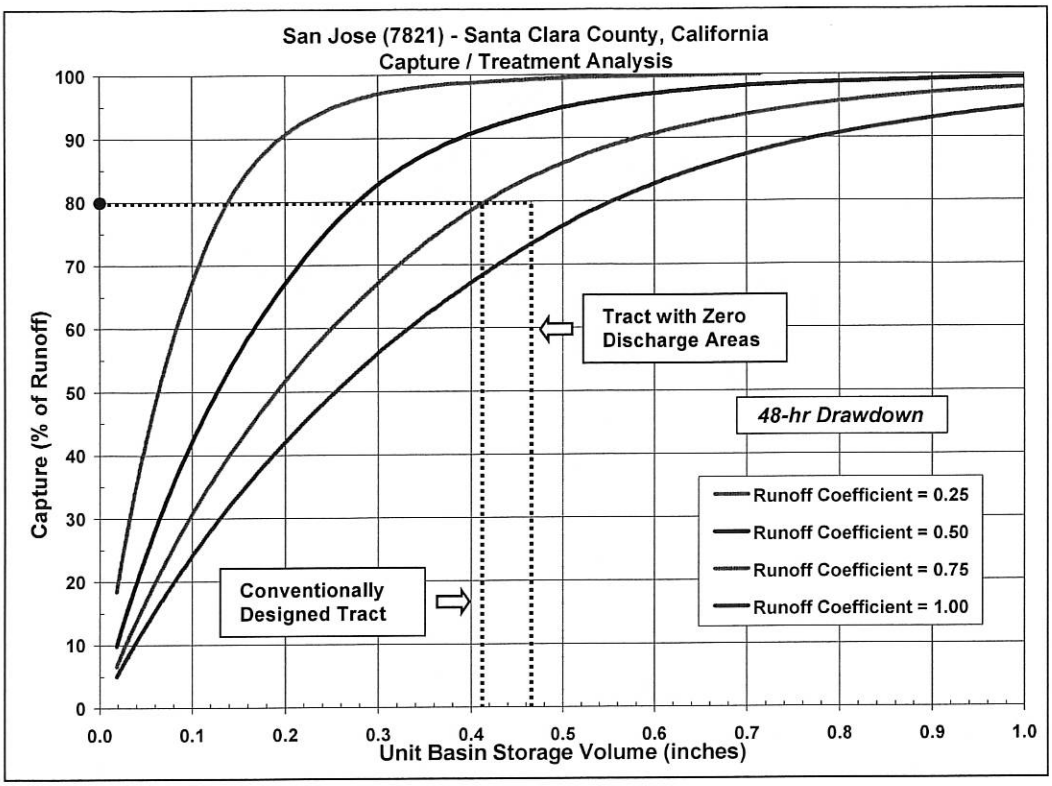

Figure 4-4
San Jose Capture Curve (California Stormwater BMP Handbooks)

By choosing the curve corresponding to a runoff coefficient of C=0.75, the Unit Basin Storage Volume is determined to be 0.41 inches, at the 80th percentile capture. Calculate the capacity of the retention basin required to treat runoff from the 10-acre residential tract:

Volume: $\forall_{Basin}$ = 10 acres × 0.41 inches = 4.10 acre -inches

Calculating Retention Basin Size – *Start at the Source* Design:
Using Figure 4-4 San Jose Capture Curve, by interpolation, the appropriate curve corresponding to a runoff coefficient of C = 0.85, would lie between the C=0.75 curve and the C=1.0 curve. For the 80th percentile capture, the Unit Basin Storage Volume is 0.46 inches.

Though use of the *Start at the Source* design technique has increased the required Unit Basin Storage Volume from 0.41 inches to 0.46 inches, the technique has reduced the total acreage of the residential tract that will produce treatment-required runoff from 10 acres to 8 acres.

Calculate the capacity of the retention basin required to treat runoff from the 8-acre portion of the tract (2-acres has zero treatment-required runoff).

Volume: $\forall_{Basin}$ = 8 acres × 0.46 inches = 3.68 acre -inches

By designing the 10-acre residential parcel using the *Start at the Source* design approach, a **10.2% reduction in treatment requirement** can be achieved.

SARB_009694

5 Self-Treating Areas

5.1 Design Philosophy

Developed areas may provide "self-treatment" of runoff if properly designed and drained.

Self-treating site design techniques include:

- Conserved Natural Spaces
- Large Landscaped Areas (including parks and lawns)
- Grass/Vegetated Swales
- Turf Block Paving Areas

The infiltration and bio-treatment inherent to such areas provides the treatment control necessary. These areas therefore act as their own BMP, and no additional BMPs to treat runoff should be required.

As illustrated in Figure 5-1, site drainage designs must direct runoff from self-treating areas away from other areas of the site that require treatment of runoff. Otherwise, the volume from the self-treating area will only add to the volume requiring treatment from the impervious area.

Likewise under this philosophy, self-treating areas receiving runoff from treatment-required areas would no longer be considered self-treating, but rather would be considered as the BMP in place to treat that runoff. These areas could remain as self-treating, or partially self-treating areas, if adequately sized to handle the excess runoff addition.

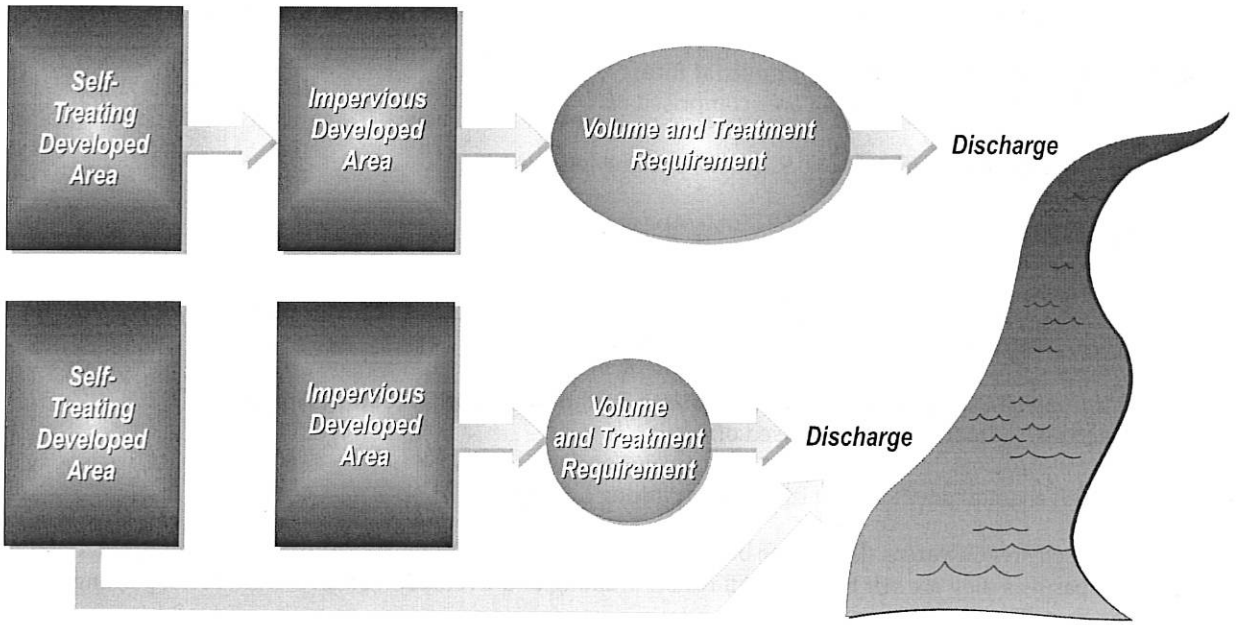

Figure 5-1
Self-Treating Area Usage

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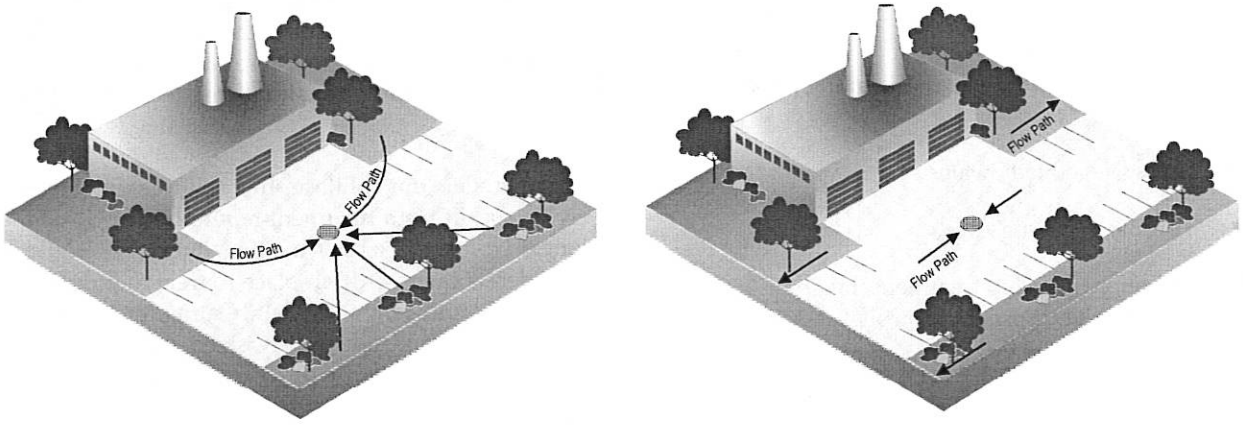
5.2 Self-Treating Area Example

The following example problem compares sizing a retention basin using conventional design methods, to sizing the basin using *Start at the Source* design techniques. Figure 5-2 represents a conventionally designed commercial/industrial lot and a commercial/industrial lot designed using the Self-Treating Area *Start at the Source* design approach. Assume the example lot is one of many similar lots making up a 100-acre commercial industrial site.



Conventional Design Approach **Start at the Source Design Approach**

Figure 5-2
Commercial/Industrial Site vs. Commercial/Industrial Site with Self-Treating Areas

Conventionally Designed Commercial/Industrial Site:

Assume a 100-acre commercial/industrial area comprised of:

- 80 acres with a runoff coefficient of 0.95 (roofs, parking lots, etc.)
- 20 acres with a runoff coefficient of 0.50 (landscape areas)

$$C_{combined} = \frac{(80 \text{ acres} \times 0.95) + (20 \text{ acres} \times 0.50)}{100 \text{ acres}} = 0.86$$

Commercial/Industrial Site Using *Start at the Source* Techniques (Self-Treating Areas):

100-acre commercial/industrial area comprised of:

- 80 acres with a runoff coefficient of 0.95 (roofs, parking lots, etc.)
- 20 acres of self-treating areas (landscape buffers, grassy areas, etc.) Note: These 20-acres do not drain to the retention basin as they are self treating. All runoff draining to the retention basin is from roofs, parking lots, etc.

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Calculating Retention Basin Size – Conventional Design:
Using Figure 5-3, San Jose Capture Curve developed using techniques set forth in the California Storm Water BMP Handbooks (CDM, et al. 2003):

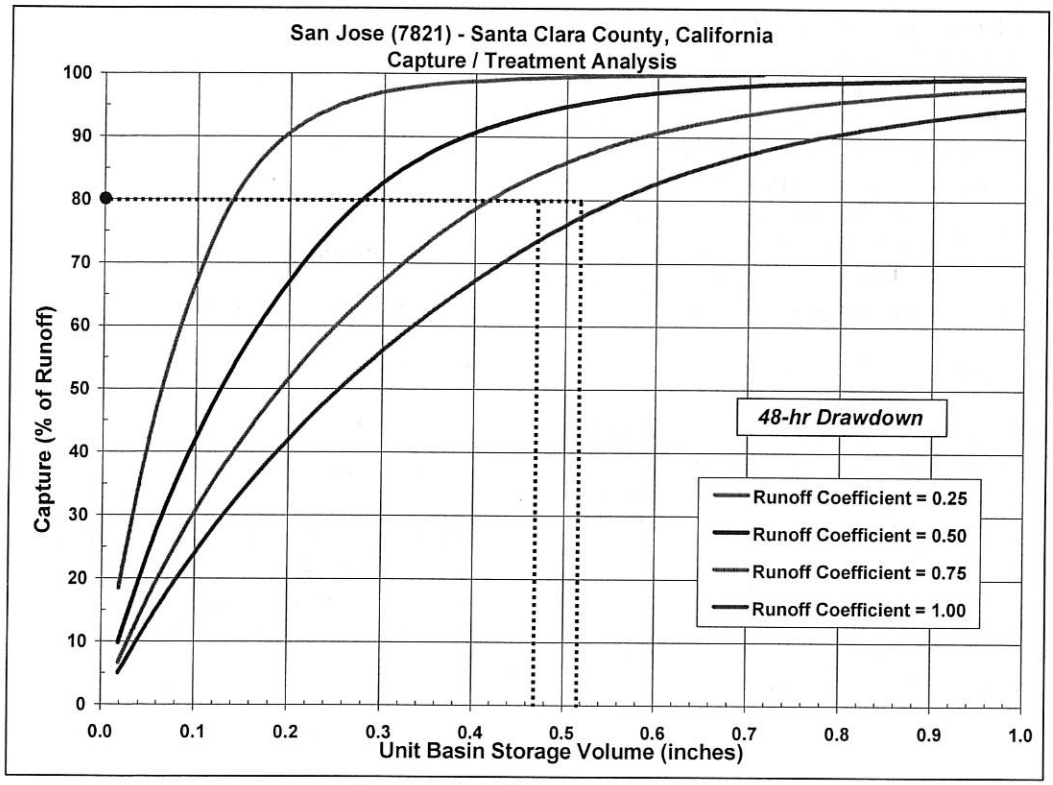

Figure 5-3
San Jose Capture Curve (California Stormwater BMP Handbooks)

By interpolation, the appropriate curve corresponding to a runoff coefficient of C combined = 0.86, would lie between the C=1.0 curve and the C=0.75 curve. For the 80th percentile runoff capture, the Unit Basin Storage Volume is 0.47 inches.

The capacity of the retention basin required to treat runoff from the 100-acre commercial/industrial area is calculated as follows:

$$\forall_{Basin} = 100 \text{ acres} \times 0.47 \text{ inches} = 47 \text{ acre-inches}$$

Calculating Retention Basin Size – *Start at the Source* Design:
Using Figure 5-3, San Jose Capture Curve:

By interpolation, the appropriate curve corresponding to a runoff coefficient of 0.95, would lie between the C=1.0 curve and the C=0.75 curve. For the 80th percentile runoff capture, the Unit Basin Storage Volume is 0.52 inches.

The capacity of the retention basin required to treat runoff from the 80-acre commercial/industrial area (excludes the 20-acres of self-treating areas) is calculated as follows:

$$\forall_{Basin} = 80 \text{ acres} \times 0.52 \text{ inches} = 41.6 \text{ acre-inches}$$

By designing the 100-acre commercial/industrial area using the *Start at the Source* design approach, an **11.5% reduction in treatment requirement** can be achieved.

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6 Runoff Reduction Areas

6.1 Design Philosophy

Using alternative surfaces with a lower coefficient of runoff or "C-Factor" helps reduce runoff from developed areas. The C-Factor is a representation of a surface's ability to produce runoff. Surfaces that produce higher volumes of runoff are represented by higher C-Factors, such as impervious surfaces. Surfaces that produce smaller volumes of runoff are represented by lower C-Factors, such as more pervious surfaces. See Table 6-1 for typical C-Factor values for various surfaces during small storms.

Table 6-2 compares the C-Factors of conventional paving surfaces to alternative, lower C-Factor paving surfaces. By incorporating more pervious, lower C-Factor surfaces into a development, lower volumes of runoff are produced. Lower volumes and rates of runoff translate directly to lower treatment requirements.

Site design techniques may be used to reduce the C-Factor of a developed area, reducing the amount of runoff requiring treatment, including:

- Pervious Concrete
- Pervious Asphalt
- Turf Block
- Brick (un-grouted)
- Natural Stone
- Concrete Unit Pavers
- Crushed Aggregate
- Cobbles
- Wood Mulch

Other site design techniques such as disconnecting impervious areas, preservation of natural areas, and designing concave medians may be used to reduce the overall C-Factor of development areas.

Table 6-1
Estimated C-Factors for Various Surfaces During Small Storms

Paving Surface	*C-Factor*
Concrete	0.80
Asphalt	0.70
Pervious Concrete	0.60
Cobbles	0.60
Pervious Asphalt	0.55
Natural Stone without Grout	0.25
Turf Block	0.15
Brick without Grout	0.13
Unit Pavers on Sand	0.10
Crushed Aggregate	0.10
Grass	0.10
Grass Over Porous Plastic	0.05
Gravel Over Porous Plastic	0.05

Note: C-Factors for frequent small storms used to size water quality BMPs are likely to differ (be lower) than C-Factors developed for infrequent, large storms used to size flood control facilities. The above C-Factors were produced by selecting the lower end of the best available C-Factor range for each paving surface. These C-Factors are only appropriate for small storm treatment design, and should not be used for flood control sizing. Where available, locally developed small storm C-Factors for various surfaces should be utilized.

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Table 6-2
Conventional Paving Surface Small Storm C-Factors vs. Alternative Paving C-Factors

Conventional Paving Surface C-Factors	*Reduced C-Factor Paving Alternatives*
Asphalt Parking Area (0.70)	Crushed Aggregate (0.10)
Concrete Patio/Plaza (0.80)	Decorative Unit Pavers on Sand (0.10)
	Turf Block Overflow Parking Area (0.15)
	Pervious Asphalt (0.55)
	Pervious Concrete (0.60)

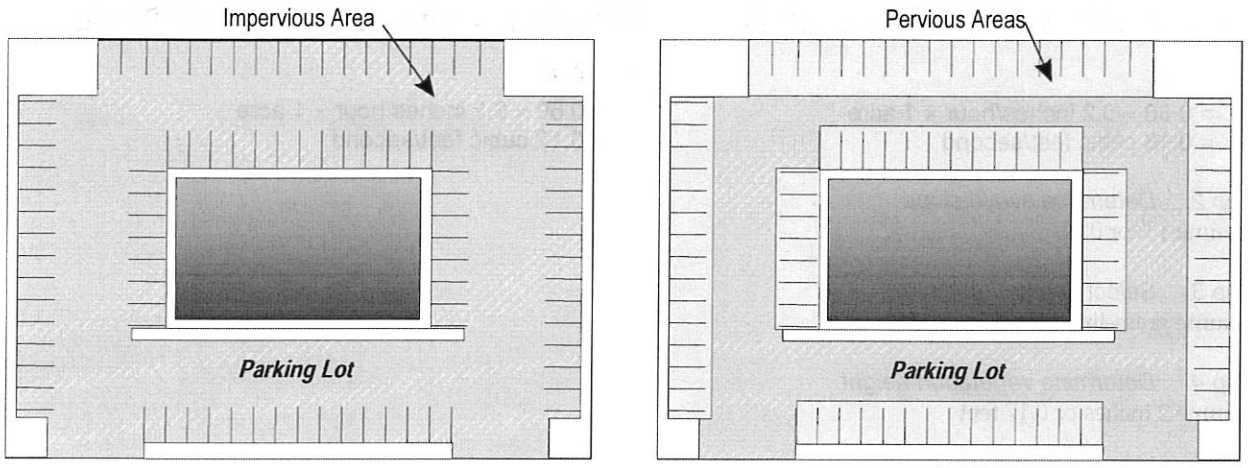

Figure 6-1
Impervious Parking Lot vs. Parking Lot with Some Pervious Surfaces

6.2 Runoff Reduction Area Example

The following example problem compares sizing a treatment swale using conventional design methods, to sizing the swale using *Start at the Source* design techniques.

Conventionally Designed Paved Parking Lot:
1-acre parking lot with a C-Factor of 0.80

Paved Parking Lot Using *Start at the Source* Techniques (Porous Pavement – See Figure 6-2):
1-acre parking lot with a C-Factor of 0.60

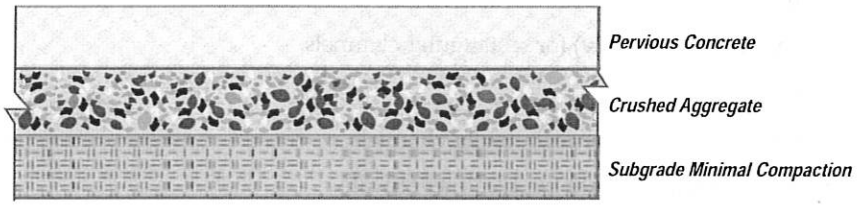

Figure 6-2
Porous Pavement

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Calculating Swale Size:
Using the Urban Runoff Quality Management ASCE/WEF Manual guidelines for Selection and Design of Passive Treatment Controls:

Step 1: Determine Runoff
Using the Rational Method Q = CIA to solve for Q, given a rainfall intensity of 0.2 inches/hour

Where Q = Flow (cubic feet/second, cfs)

C = Runoff Coefficient

I = Rainfall Intensity (inch/hour)

A = Total Site Area (acres)

Calculating Runoff – Conventional Design:

Q = CIA
= 0.80 × 0.2 inches/hour × 1 acre
= 0.16 cubic feet/second

Calculating Runoff – *Start at the Source* Design:

Q = CIA
= 0.60 × 0.2 inches/hour × 1 acre
= 0.12 cubic feet/second

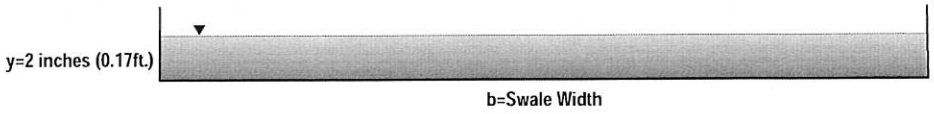
Step 2: Determine swale slope
Assume 1% or 0.01

Step 3: Select vegetation cover
Assume grass-lined swale

Step 4: Determine vegetation height
Assume 2 inches or 0.17 feet

Step 5: Select Manning's n value
Manning's n = 0.20, for routinely mowed grass-lined channels

Step 6: Select cross-sectional shape of swale
A typical swale cross-section is parabolic or trapezoidal in shape. The 2-inch (0.17 ft) flow depth in this example allows a rectangular cross-sectional approximation.



Step 7 Use Manning's equation to determine swale width
Manning's equation: $Q = 1.49/n \times R^{2/3} \times S^{1/2} \times A$

Where Q = Flow

n = Manning's n

R = Hydraulic Radius = A / (b + 2y) for rectangular channels

S = Slope of swale

A = Cross-sectional Area = b × y for rectangular channels

y = Flow Depth = Vegetation Height for Treatment Swale

b = Swale Width

Using Manning's equation to solve for Swale Width, b:

Swale Width = 4.3 feet (Conventional Design)

Swale Width = 3.3 feet (*Start at the Source* Design)

Step 8: Determine flow velocity

Flow Velocity – Conventional Design:

Velocity = Runoff / Cross-sectional Area
= Q / A
= 0.16 cfs / (0.17 feet × 4.3 feet)
= 0.22 feet/second

Flow Velocity – *Start at the Source* Design:

Velocity = Runoff / Cross-sectional Area
= Q / A
= 0.12 cfs / (0.17 feet × 3.3 feet)
= 0.21 feet/second

Step 9: Determine swale length

Using Urban Runoff Quality Management Manual guidelines (p195), assume swale detention time of 7 minutes = 420 seconds

Swale Length – Conventional Design:

Length = Velocity × Detention Time
= 0.22 feet/second × 420 seconds
= 92.4 feet

Swale Length – *Start at the Source* Design:

Length = Velocity × Detention Time
= 0.21 feet/second × 420 seconds
= 88.2 feet

Step 10: Determine swale size (surface area)

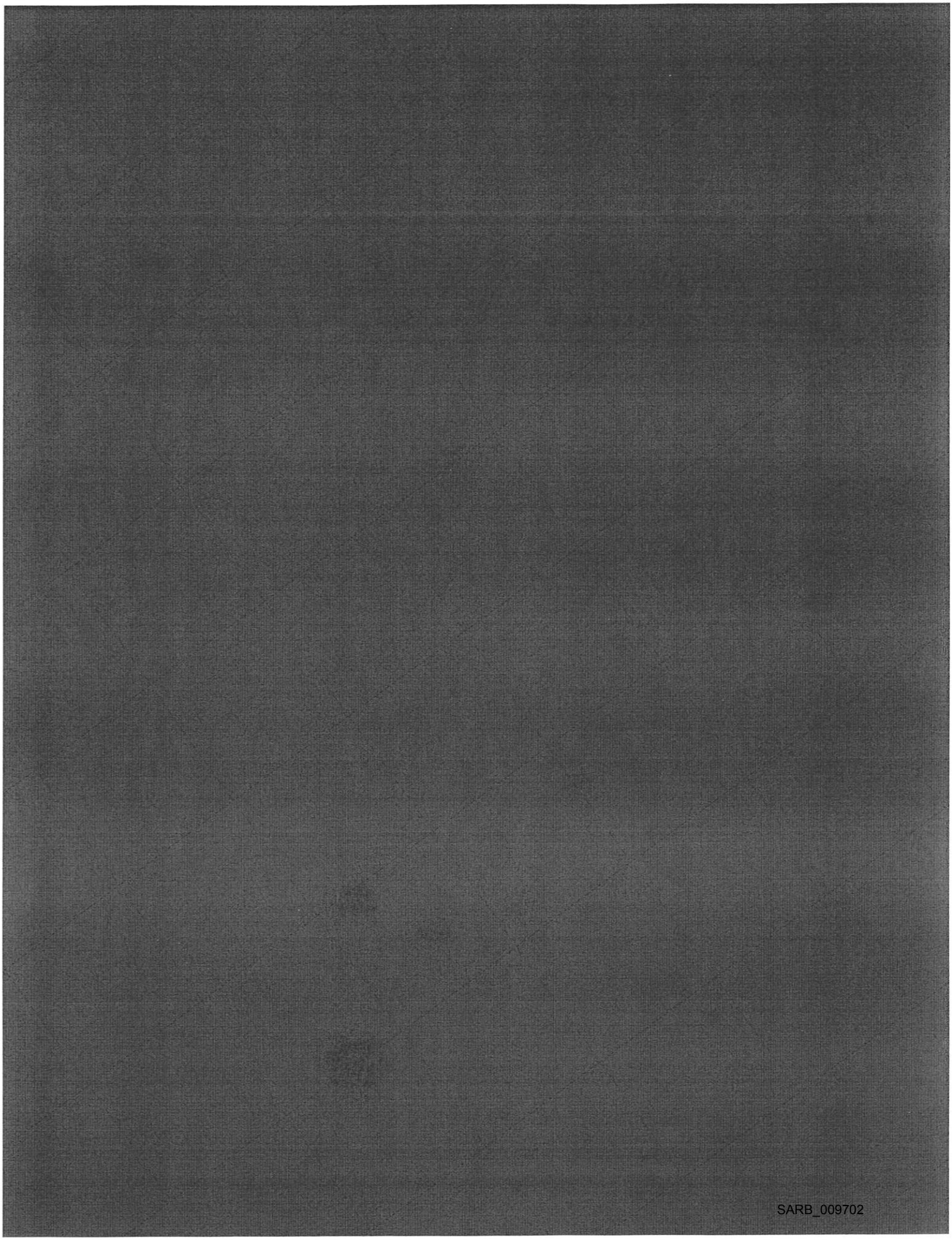
Swale Size – Conventional Design:

Swale Size = Swale Length × Swale Width
= 92.4 feet × 4.3 feet
= 397 square feet

Swale Size – *Start at the Source* Design:

Swale Size = Swale Length × Swale Width
= 88.2 feet × 3.3 feet
= 291 square feet

By designing the parking lot using the *Start at the Source* design approach, a **27% reduction in treatment requirement** can be achieved.



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Storm Water Quality Handbook:
Project Planning and Design Guide

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May 2007

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1.1 OVERVIEW

This Project Planning and Design Guide (PPDG) provides guidance on the process and procedures for evaluating project scope and site conditions to determine the need for and feasibility of incorporating Best Management Practices (BMPs) into projects, and also provides design guidance for incorporating those stormwater quality controls into projects during the planning and design phases. This document supersedes prior stormwater design guidance manuals and has been prepared in support of the Statewide Storm Water Management Plan (SWMP). The PPDG addresses key regulatory, policy and technical requirements by providing direction on the procedures to implement the stormwater BMPs into the design of all Caltrans projects.

The key objective of this PPDG is to provide the overall process for selecting and designing BMPs within the Caltrans planning and design processes and incorporating those BMPs into the appropriate documents. These documents include the Project Initiation Document (PID), the Project Approval/Environmental Document (PA/ED), and the Plans, Specifications and Estimates (PS&E). The planning and design approach described herein has been developed to fit within the appropriate Work Breakdown Structure (WBS) codes and activities identified in the Caltrans Project Development Procedures Manual (PDPM) updated March 2006) and the Guide to Project Delivery Workplan Standards, Release 8.0A. These documents can be found on the web at the following sites:

http://www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm

http://www.dot.ca.gov/hq/projmgmt/documents/wsg/workplan_standards_guide_8.0a.doc

Also, the Storm Water Data Report (SWDR), which summarizes the stormwater quality issues of a project, and its corresponding checklists are described in this manual. These documents are provided in Appendix E, and are used for guidance in evaluating BMPs considered during the PID, PA/ED, and PS&E processes.

This PPDG is organized as follows:

Section 1 – Introduction: Provides an overview of the BMP selection and design process, the history of the existing stormwater guidance documents, regulations and permits, SWMP implementation, design compliance monitoring and annual reporting requirements.

Section 2 – Best Management Practice Selection: Provides designers with background information and guidance necessary for the appropriate selection of permanent and temporary BMPs.

Section 3 – Design Program Responsibilities: Identifies specific staff responsibilities.

Section 4 – Permanent Treatment Consideration: Provides guidance for evaluating whether a project must consider incorporating Treatment BMPs based upon project-specific criteria.

Section 5 – Project Initiation Document Process: Describes the overall PID process, including the identification of stormwater quality issues, evaluation of potential BMPs, the estimating of

BMP costs, the preparation of a PID-level SWDR, and the development of a Preliminary Environmental Assessment Report (PEAR).

Section 6 – Project Approval/Environmental Document Process: Describes the overall PA/ED process, including the evaluation of potential stormwater quality impacts, the preparation of environmental and engineering studies for project alternatives, the selection of the preferred project alternative and its associated permanent BMPs, the development of a cost estimate, the completion of the PA/ED level SWDR, and the completion of a Project Report.

Section 7 – Plans, Specifications and Estimates Process: Describes the overall PS&E process, including the final design of the project, permanent BMPs, and temporary BMP strategy. Also describes the process for obtaining environmental permits, the steps necessary for completion of a PS&E level SWDR, and the completion of the PS&E package.

Section 8 – Final Project Development Procedures – Construction: Provides Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Control Program (WPCP) information and Notification of Construction (NOC) information for the project construction phase.

Appendix A – Approved Design Pollution Prevention BMPs. Describes the Design Pollution Prevention BMPs that are considered during the planning and design phases of projects. These BMPs are then incorporated into the design of new facilities and the reconstruction or expansion of existing facilities.

Appendix B – Approved Treatment BMPs. Describes the Treatment BMPs that are considered during the planning and design phases of projects. Appendix B also identifies BMP selection procedures (the Targeted Design Constituent Approach).

Appendix C – Approved Construction Site BMPs. Describes and lists the Construction Site BMPs that should be considered for use during construction activities to reduce pollutants in stormwater discharges throughout construction.

Appendix D – Relevant Storm Water Documents and Web Sites. Provides a summary of the relevant stormwater related documents and their purpose, and the web sites that are referenced in this document.

Appendix E – Water Quality Summary Forms and Checklists. Provides Process Summary Forms for the PID, PA/ED and the PS&E processes, the Evaluation Documentation Form that correlates to Section 4, the SWDR that documents decisions made regarding stormwater quality, Checklist SW-1 that lists categories of pertinent information required for stormwater planning and design, Checklist SW-2 which provides a guide to collecting information relevant to project stormwater quality issues, Checklist SW-3 which provides direction to the designer during the project planning phase to avoid or reduce potential stormwater impacts, and Checklists DPP-1, T-1, and CS-1 which are used for guidance in selecting Design Pollution Prevention, Treatment BMPs and Construction Site BMPs.

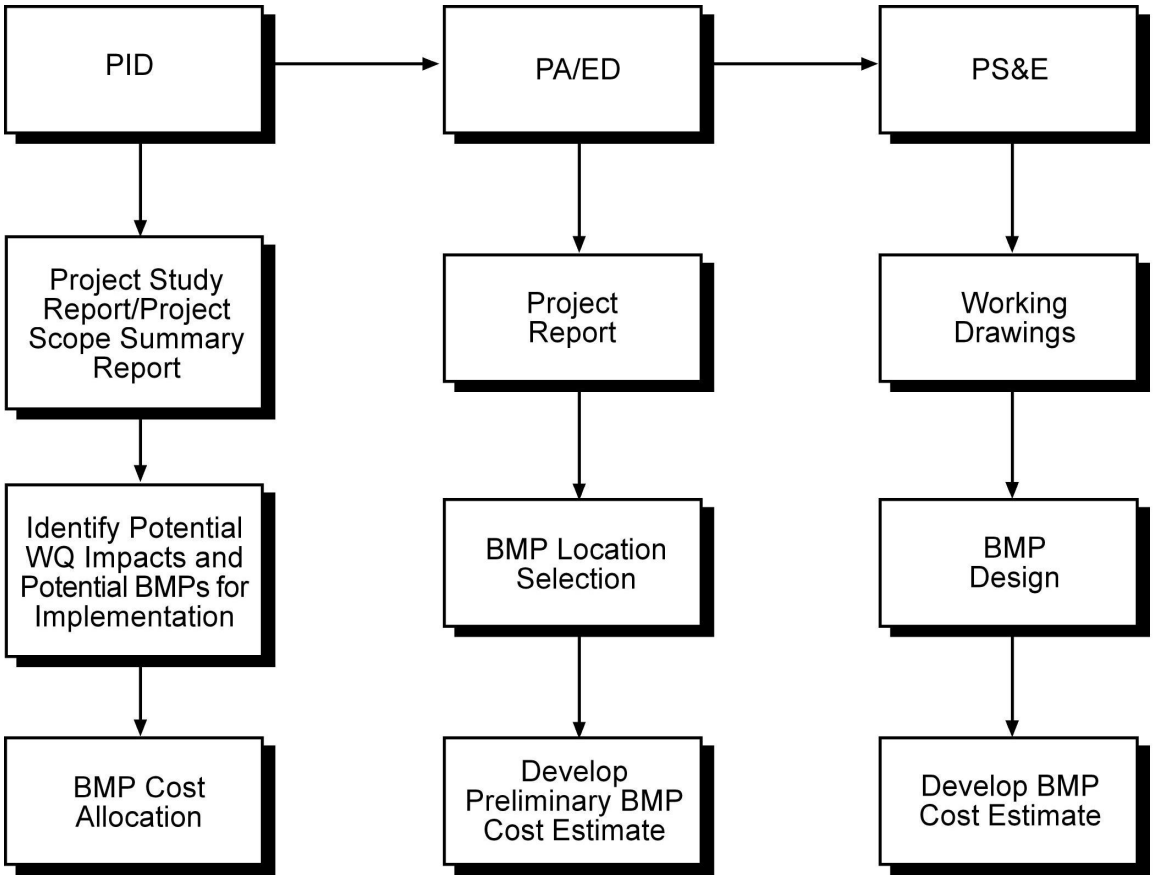
Appendix F – Cost Estimates. Provides guidance on how to estimate the cost of stormwater BMPs into the overall project cost.

Appendix G – Abbreviations, Acronyms, Definition of Terms and References.

1.2 BMP SELECTION AND DESIGN PROCESS

The overall process to select BMPs as part of each of the project phases, PID, PA/ED, and PS&E, is shown in Figure 1-1. This figure presents the procedure for BMP implementation throughout the design process from securing funds in the PID, to selecting the preferred BMP alternative in the PA/ED and preparing detailed design in the PS&E. Each phase of the project is individually described in Sections 5, 6 and 7 of this PPDG. Implementation activities generally follow the procedures presented in the PDPM.

Figure 1-1: Design Process Summary



It is important to note that this document provides minimum guidelines and that additional requirements may have to be incorporated on a project-by-project basis to comply with special requirements from a Regional Water Quality Control Board (RWQCB), specific District guidelines, environmental laws, or as a result of other studies. Other stormwater quality elements that designers may have to consider are included as a result of each District's Work Plan (DWP).

Special site conditions may warrant variations from the guidance provided herein. The Project Engineer (PE) is responsible for recognizing site conditions that warrant variations in procedures, and for securing appropriate approvals for these variations before proceeding with design.

1.3 STORM WATER GUIDANCE DOCUMENTS

In order to meet the demands of the stormwater management process in regards to controlling pollutant discharges and meeting permit requirements, several documents have been developed. Appendix D provides a list and a brief summary of these documents and their purposes.

1.4 REGULATIONS AND PERMITS

1.4.1 Federal Regulations

Federal regulations for controlling discharges of pollutants from municipal separate storm sewer systems (MS4s), construction sites, and industrial activities were incorporated into the National Pollutant Discharge Elimination System (NPDES) permit process by the 1987 amendments to the Clean Water Act (CWA) and by the subsequent 1990 promulgation of federal stormwater regulations issued by the U.S. Environmental Protection Agency (EPA). The EPA regulations require municipal, construction and industrial stormwater discharges to comply with an NPDES permit. In California, the EPA delegated its authority to the State Water Resources Control Board (SWRCB) to issue NPDES permits.

1.4.2 Caltrans NPDES Statewide Storm Water Permit

The SWRCB issued an NPDES Statewide Storm Water Permit (Caltrans Permit) to Caltrans in 1999 (Order No. 99-06-DWQ) (CAS000003), to regulate stormwater discharges from Caltrans facilities. The Caltrans Permit contains three basic requirements:

1. Caltrans must comply with the requirements of the Construction General Permit (General Permit) described in Section 1.4.3;
2. Caltrans must implement a year-round program in all parts of the State to effectively control stormwater and non-stormwater discharges; and
3. Caltrans stormwater discharges must meet water quality standards through implementation of permanent and temporary (construction) BMPs and other measures.

The Caltrans Permit regulates stormwater discharges from Caltrans rights of way during and after construction, as well as from existing facilities and operations. The Caltrans Permit gives RWQCBs the option to specify additional requirements they may consider necessary to meet water quality standards. Copies of the Caltrans Permit can be downloaded from the SWRCB web site, at http://www.swrcb.ca.gov/stormwtr/docs/caltranspmt.pdf.

Discharges from Caltrans rights of way that are not composed entirely of stormwater are prohibited unless the non-stormwater discharges are from a source authorized under the SWMP. Therefore, appropriate BMPs must be installed to remove pollutants to the Maximum Extent Practicable (MEP). The permit language is “Any discharge from Caltrans right-of-way or Caltrans properties, facilities, and activities within those rights of way that is not composed entirely of ‘Storm Water’ to waters of the United States is prohibited unless authorized pursuant to…this NPDES Permit.”

1.4.3 Construction General Permit

Recognizing the substantial administrative burden associated with permitting individual construction sites throughout California, the SWRCB elected to adopt a single statewide general permit for construction activities (General Permit) (Order No. 99-08-DWQ) (CAS000002) that applies to all stormwater discharges from land where clearing, grading, and excavation result in soil disturbance of at least one (1) acre or more. Construction activity that results in soil disturbances of less than one (1) acre is subject to this General Permit if the construction activity is part of a larger Common Plan of Development totaling one (1) acre or more of soil disturbing activities, or if there is the potential for significant water quality impairment resulting from the activity as determined by the RWQCB. The General Permit requires owners of land where construction activity occurs to develop a SWPPP (see Section 1.4.6).

In some areas of the state, the RWQCBs have issued permits directly to Caltrans Districts. The requirements for construction sites in these permits are generally similar and supersede the General Permit requirements. Copies of the General Permit can be downloaded from the SWRCB web site, at http://www.swrcb.ca.gov/stormwtr/construction.html.

1.4.4 Waste Discharge Requirements and Other Permits

In addition to implementing the Caltrans Permit, a RWQCB may issue separate Waste Discharge Requirements (WDRs) or additional permits. Some of the additional permits that may apply to Caltrans projects include, but are not limited to, the following:

- Ø California General Construction Permit (see Section 1.4.3);
- Ø Waste Discharge Requirements (WDR);
- Ø Permit for Re-Use of Soil Containing Aerially Deposited Lead (ADL);
- Ø 1601 and 1603 Permits from the California Department of Fish & Game;
- Ø 404 Permit from the Army Corps of Engineers (ACOE);
- Ø 401 Certification from the RWQCB; and
- Ø Coastal Permits

An example of an additional permit requirement that may be applicable for a project would be work that involves the reuse of soils that contain aerially deposited lead. Caltrans has applied for and received variances from the California Department of Toxic Substances Control (DTSC) for the reuse of some soils that contain lead. Under the Caltrans Permit, the District will provide written notification to the RWQCB at least 30 days prior to advertisement for bids of projects that involve soils subject to this variance. This notification period will allow a determination by the RWQCB(s) of the need for development of Waste Discharge Requirements (WDRs) or written conditional approvals by RWQCB staff. Other situations that may require WDRs or permits include dewatering discharges, disposal of concrete wastes, etc.

1.4.5 Caltrans Statewide Storm Water Management Plan

The Caltrans Permit directs Caltrans to implement and maintain an effective SWMP. The SWMP is the Caltrans policy document that describes how Caltrans conducts its stormwater management activities (i.e., procedures and practices), provides descriptions of each of the major management program elements, discusses the processes used to evaluate and select appropriate

BMPs, and presents key implementation responsibilities and schedules. The SWMP also contains a list of the approved BMPs that have been evaluated and selected to manage stormwater discharges from Caltrans properties, facilities, and activities.

1.4.6 Storm Water Pollution Prevention Plan

Section A of the General Permit outlines the required contents of a SWPPP. A SWPPP is a document that addresses water pollution controls for a specific project during construction. The General Permit requires that all stormwater discharges associated with construction activities that result in soil disturbance of at least one (1) acre of total land area must comply with the provisions specified in the Caltrans Permit, including development and implementation of an effective SWPPP. Designers are required to include pertinent SWPPP related information in the project file. In some cases, the RWQCB may view two or more small projects (individually less than one [1] acre of soil disturbance, but together totaling one [1] acre or more) in the same corridor to be part of a larger Common Plan of Development, thus making the small projects subject to the requirements of the General Permit to develop and implement a SWPPP. The Project Manager (PM) should therefore be aware of other projects in the corridor.

At least 30 days prior to the start of construction, Caltrans will submit a Notification of Construction (NOC) to the appropriate RWQCB for all construction projects that disturb more than one (1) acre of soil. A project's SWPPP must include a copy of the NOC. The SWPPP is normally prepared by the contractor, and shall be approved by the Resident Engineer (RE) prior to commencement of soil-disturbing activities. When construction is complete and the construction site is stabilized, Caltrans will submit a Notice of Completion of Construction (NOCC) to the appropriate RWQCB.

1.4.7 Water Pollution Control Program

Generally, construction projects with a disturbed soil area of less than one (1) acre are not covered under the General Permit and do not require a SWPPP. The exceptions to this rule would be (i) in the case of a Common Plan of Development, or (ii) if the RWQCB requires a SWPPP for a smaller project based upon water quality concerns. For all projects that do not require preparation of a SWPPP, Caltrans requires that a Water Pollution Control Program (WPCP) be prepared. The WPCP is normally prepared by the contractor and shall be approved by the RE prior to commencement of soil-disturbing activities. Details on the preparation of the SWPPP or WPCP are found in the supplementary Storm Water Quality Handbook, "SWPPP and WPCP Preparation Manual, March 2003."

1.5 PERMIT AND SWMP IMPLEMENTATION

The Headquarters (HQ) Environmental Program coordinates implementation of the SWMP with each District or Region and with other HQ functional units including Design, Maintenance, and Construction. Each District is responsible for implementing the SWMP within the District and complying with the Caltrans Permit and General Permit requirements and any District- or Region-specific requirements. Program responsibility matrices have been developed specifically for each District or Region and are available from District/Regional Storm Water Coordinators.

1.5.1 District Work Plans

The Caltrans Permit requires the submittal of District Work Plans (DWPs) as part of the Annual report. Caltrans, in coordination with the SWRCB and the RWQCBs, has developed a standard format for the development and submittal of these DWPs. Each RWQCB is provided a copy of the DWPs relevant to their jurisdiction.

Caltrans will develop and submit DWPs to the SWRCB each year, as part of the Annual Report. The DWPs will also be forwarded to the appropriate RWQCB Executive. The DWPs describe activities that will be conducted by the Districts during the upcoming fiscal year to implement the SWMP. These work plans are organized as follows:

- Section 1 – Introduction;
- Section 2 –Personnel and Responsibilities;
- Section 3 – District Facilities and Water Bodies;
- Section 4 – Drinking Water Reservoirs and Recharge Facilities;
- Section 5 – Implementation.

The Districts will coordinate and meet with the appropriate RWQCBs to discuss the proposed DWPs at least 30 days prior to their submittal due date each year.

1.6 PROJECT DESIGN COMPLIANCE EVALUATION

Project Design Compliance Evaluation (PDCE) is a SWMP element that will be developed by the HQ Project Design Storm Water Advisory Team (PD-SWAT) and will be implemented by the Districts with the following objectives:

- Evaluate compliance of project planning and design activities with requirements of the Caltrans Permit and the approved SWMP;
- Identify activities needing improvement, changes or revisions;
- Report compliance status to Caltrans management, the SWRCB and the RWQCBs.

Currently, each District is responsible for implementing a design review process based on local requirements and project needs. Elements of each District's compliance review program, and the implementation of that program, will be unique due to individual District organizational structures and staff responsibilities. The PDCE that will be implemented through the SWMP is intended to address this variability. It will be developed by the PD-SWAT, implemented through the Districts, and will require documentation and reporting of the review findings to HQ and in the Annual Report.

The key elements of the proposed PDCE are:

- Design Evaluation Selection Criteria;
- Compliance Review Method;

- Compliance Rating Criteria;
- Treatment BMP Evaluation;
- Feedback and Program Improvement

The results of the Project Design Evaluation Activities for each fiscal year will be provided in the Annual Report.

1.7 ANNUAL REPORTING REQUIREMENTS

The information to be included in the Annual Report will be first reviewed by the PD-SWAT as part of the process to annually update the SWMP. A summary of Design Compliance Monitoring activities will be provided in the Annual Report including:

- The design checklists used during the previous year;
- A new checklist for the upcoming year, if needed;
- A summary of the review findings; and
- A summary of lessons learned, trends, challenges encountered, and proposed program changes.

In protecting water quality, each RWQCB:

- Adopts a region-specific Water Quality Control Plan or Basin Plan that contains water quality standards specific to the region's waters;
- Issues waste discharge requirements (WDRs) and water quality monitoring and reporting programs that implement the SWRCB's statewide policy and regulations along with the region-specific water quality standards specified in its Basin Plan; and
- Implements enforceable orders against violations of statewide and region-specific requirements

2.1 INTRODUCTION

This section of the Project Planning and Design Guide (PPDG) provides designers with background information and guidance on the process and procedures for evaluating project scope and site conditions to determine the need for and feasibility of incorporating Best Management Practices (BMPs) into projects, and also provides guidance necessary for the appropriate selection of Best Management Practices (BMPs). The following sections describe how the designer can identify pollutants of concern, define BMP placement and use considerations, and describe the various approved BMPs that can be used by designers.

2.2 APPROVED BEST MANAGEMENT PRACTICES

The Caltrans Statewide Storm Water Management Plan (SWMP) identifies permanent and temporary BMPs that have been approved for statewide application. The BMPs fall into four categories as shown in Table 2-1:

Table 2-1: BMP Categories and Responsible Divisions

BMP	Description	Responsible Division for BMP Implementation
Design Pollution Prevention BMPs	Permanent soil stabilization systems, etc.	Division of Design
Treatment BMPs	Permanent treatment devices and facilities	Divisions of Design, Construction and Maintenance
Construction Site BMPs	Temporary soil stabilization and sediment control, non-stormwater management, and waste management	Divisions of Design and Construction
Maintenance BMPs	Litter pickup, toxic controls, street sweeping, etc.	Division of Maintenance

BMPs must be considered throughout the planning and design process. Both Design Pollution Prevention and Construction Site BMPs must be considered for every project. Treatment BMPs must be evaluated for all projects meeting the criteria presented in Section 4. Consideration for the implementation of BMPs must begin in the planning process, and continue through the design process.

The descriptions, appropriate applications, siting criteria, and design factors for the approved Design Pollution Prevention and Treatment BMPs are provided in Appendices A and B of this document. Additional information regarding the selection process for these BMPs is provided in Sections 2.4.1 and 2.4.2 of this manual.

2.2.1 Incorporation of Non-Approved Treatment Best Management Practices

Only BMPs that have been approved for statewide use should be incorporated into projects. If project conditions prohibit the use of approved BMPs, then the designer should consult with the District/Regional Storm Water Coordinator (either the National Pollutant Discharge Elimination System [NPDES] or Design Storm Water Coordinator). The District does have the option of proposing the incorporation of a non-approved BMP as a pilot project. The Storm Water

Advisory Teams (SWATs) and the appropriate Headquarters' (HQ) functional units must approve this proposal. The District's proposal for a pilot project should include the following information:

- Description of project (including why approved BMPs cannot be implemented);
- Description of proposed BMP (including anticipated costs and benefits);
- Anticipated life-cycle maintenance requirements;
- Monitoring Program;
- Evaluation criteria; and
- Commitment by the District to prepare a final report on the pilot technology.

If the SWATs and the HQ functional units approve the pilot project, the District would be allowed to incorporate the non-approved BMP into their project. It should be noted that a pilot technology is normally approved only for deployment in a limited quantity within a given project. Pilot technologies are not deployed in large numbers within a single project, or deployed within multiple projects unless these multiple deployments are required to evaluate a pilot technology's performance under varying site conditions. The purpose of the pilot project is to evaluate the feasibility of that particular pilot technology, with further deployment being dependent upon the outcome of the pilot project (reference SWMP, Section 4). This process applies to Design Pollution Prevention BMPs, Treatment BMPs, and Construction Site BMPs.

If it is found that a project cannot incorporate an approved Treatment BMP, and no pilot treatment technologies can be identified by the District or by HQ, then the Project Engineer (PE) shall prepare a technical report explaining why this is so. The Technical Data Report must be submitted to the Regional Water Quality Control Board (RWQCB) at a minimum of 60 days prior to PS&E submittal date of the project. This submittal should be made through the District/Regional NPDES Storm Water Coordinator.

2.3 IDENTIFICATION OF WATER QUALITY REQUIREMENTS FOR PROJECT PLANNING PURPOSES

The appropriate selection of BMPs requires the PE to have an understanding of the process used to identify water quality requirements and pollutants of concern for specific water bodies. The RWQCBs play an important role in identifying the pollutants of concern. Water quality standards, Clean Water Act Section 303(d) list, Total Maximum Daily Loads (TMDLs) and Basin Plans developed by the RWQCBs are important references for the identification of pollutants that need to be addressed.

The process of identifying water quality requirements includes close coordination with the District Environmental Unit. The PE should initiate the process of compiling information regarding water quality requirements as identified in the checklists provided in Appendix E, and should share this information with the Environmental Unit. The Environmental Unit and the PE shall exchange information necessary to (1) prepare documents regarding the assessment of water quality impacts, (2) determine whether Treatment BMPs should be considered, and (3) select and design BMPs, which is the responsibility of the PE. This information exchange

continues to take place throughout the Project Initiation Document (PID), the Project Approval/Environmental Document (PA/ED) and the Plans, Specifications and Estimates (PS&E) processes. The Environmental Unit will use the shared information to prepare a Water Quality Assessment Technical Report (WQR), as determined by the Water Quality Impact Questionnaire (Appendix A of the Water Quality Assessment Guidelines (WQAG). The WQAG (Volume 5 of the Caltrans Standard Environmental Reference [website: http://www.dot.ca.gov/ser/]), WQAG Appendices and associated Templates for the WQR, provide direction on format, content, and methods for preparing WQRs, which are technical water quality assessment documents. The PE uses the information to complete the Storm Water Data Report (SWDR) as described in Appendix E.

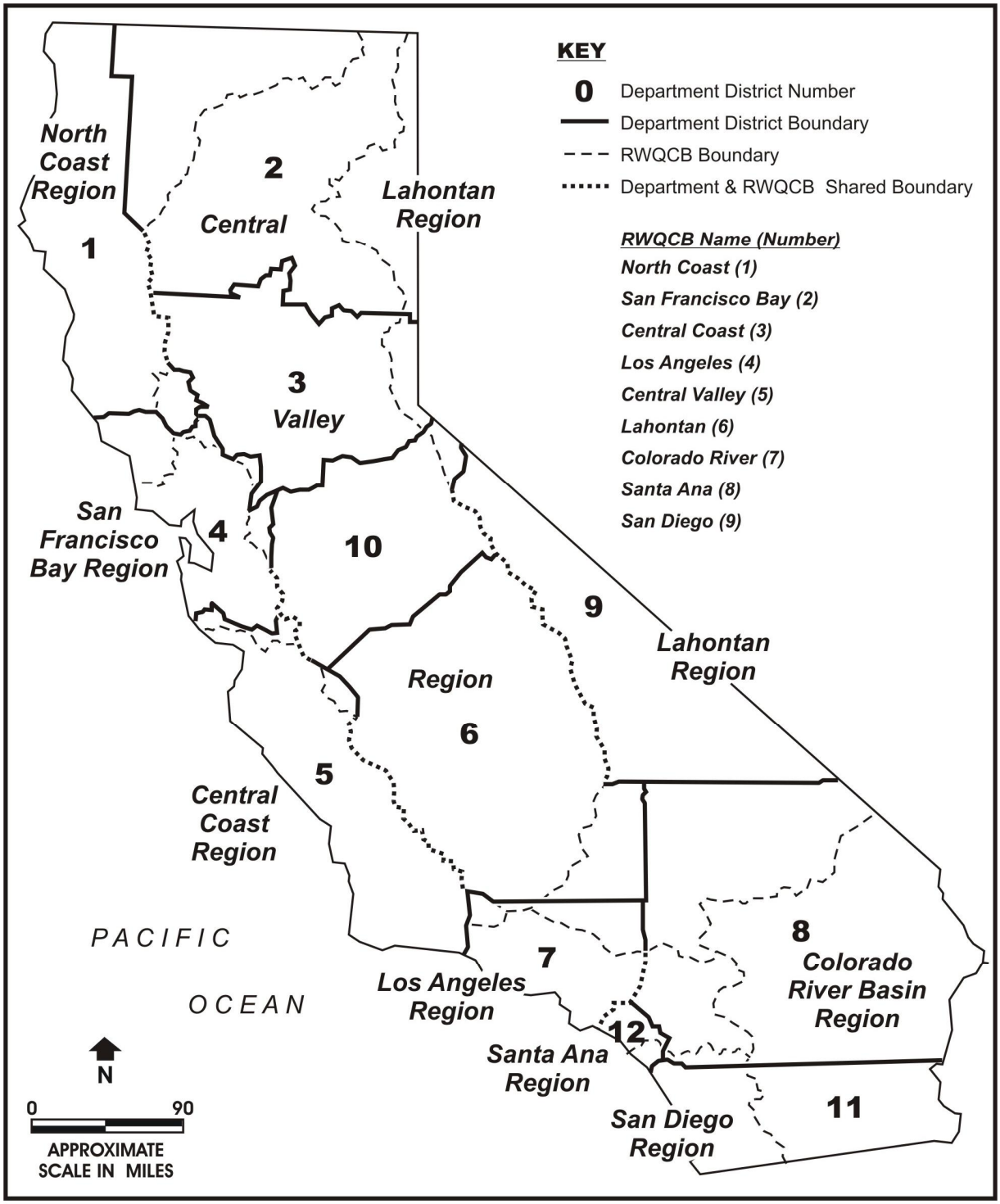
2.3.1 State Water Resources Control Board and Regional Water Quality Control Boards

The State Water Resources Control Board's (SWRCB's) mission is to preserve, enhance and restore the quality of California's water resources, and ensure their proper allocation and efficient use for the benefit of present and future generations. The **California Water Code** divides the state of California into nine RWQCBs, based on major drainage areas. Nine RWQCBs act to protect water quality within these regions. The nine regional boards and their offices are:

- Region 1- North Coast (Santa Rosa);
- Region 2- San Francisco Bay (Oakland);
- Region 3- Central Coast (San Luis Obispo);
- Region 4- Los Angeles (Los Angeles);
- Region 5- Central Valley (Redding);
- Region 5- Central Valley (Fresno);
- Region 5- Central Valley (Sacramento);
- Region 6- Lahontan (Victorville);
- Region 6- Lahontan (South Lake Tahoe);
- Region 7- Colorado River (Palm Desert);
- Region 8- Santa Ana River (Riverside); and
- Region 9- San Diego (San Diego).

Figure 2-1 is a map showing the RWQCB jurisdictions.

Figure 2-1: Map of California with RWQCB and District Boundaries



In protecting water quality, each RWQCB:

- Adopts a region-specific Water Quality Control Plan or Basin Plan that contains water quality standards specific to the region's waters;
- Issues waste discharge requirements (WDRs) and water quality monitoring and reporting programs that implement the SWRCB's statewide policy and regulations along with the region-specific water quality standards specified in its Basin Plan; and
- Implements enforceable orders against violations of statewide and region-specific requirements.

2.3.2 Resources for Identifying Pollution Control Requirements

Proper selection and design of BMPs requires an understanding of the applicable pollution control requirements. Designers should coordinate with the District/Regional Storm Water Coordinators to ensure that all relevant water quality requirements are identified. Water quality requirements come from a variety of sources, including:

- RWQCB Basin Plans;
- TMDLs and 303(d) lists; and
- Standard Urban Storm Water Mitigation Plans (SUSMPs).

The following sub-sections provide a brief description of these sources of pollution control requirements. While the designer normally obtains this information from the District/Regional Storm Water Coordinator, designers should be aware that Basin Plans, TMDLs, and SUSMPs can change over time and that it may be necessary to reconfirm the pollution control requirements at different stages in the design process.

2.3.2.1 Regional Water Quality Control Board Basin Plans

Each RWQCB has developed a Basin Plan to identify designated beneficial uses and water quality objectives for their jurisdictional regions. The Basin Plans are available online by accessing the SWRCB web site at www.swrcb.ca.gov and selecting the link for the appropriate RWQCB. Each individual RWQCB web page includes a link to access the corresponding Basin Plan.

A comprehensive database of all of the beneficial uses, water quality objectives and water quality data can also be accessed using the **Water Quality Planning Tool** available at www.stormwater.water-programs.com.

2.3.2.2 Total Maximum Daily Loads and 303(d) Lists

Section 303(d) of the 1972 Federal Water Pollution Control Act requires priority rankings for water bodies for which the beneficial uses are listed as impaired by pollution, and also requires the establishment of TMDLs to protect water quality of these impaired water bodies from specific pollutants. In response to this requirement, the U.S. Environmental Protection Agency

(EPA) has developed a 303(d) list for each state that identifies specific pollutants causing impairment of specific receiving waters. A water quality planning tool, including 303(d) list information, has been developed for Caltrans and is available at www.stormwater.water-programs.com. Projects discharging to receiving waters on the Clean Water Act 303(d) list and/or with TMDLs may have to comply with additional discharge criteria. Response to TMDL and/or 303(d) listed water body criteria should be coordinated with the District/Regional Storm Water Coordinator.

2.3.2.3 Standard Urban Storm Water Mitigation Plans

Projects in urban areas may be subject to additional water quality requirements or additional BMP requirements if there is an applicable SUSMP. These plans contain special local requirements and are currently applicable in Los Angeles, Ventura, and San Diego counties; however, other urban areas may develop SUSMPs in the future.

2.3.3 Storm Water Documents

The WQR and the Storm Water Data Report (SWDR) are the two project-specific Storm Water Documents prepared by a District. The District Environmental Unit prepares the WQR, while the Project Engineer (PE) prepares the SWDR. These documents are prepared concurrently, and require extensive coordination between the PE, the Environmental staff person preparing the WQR, and the District/Regional Storm Water Coordinator.

A WQR will identify applicable stormwater regulations and stormwater impacts to be addressed. The WQR also identifies the receiving water, evaluates the existing surface water quality, identifies potential project-related stormwater discharges, and evaluates the potential project-related stormwater impacts on the receiving water quality. The WQR is typically prepared by the Environmental Unit as support documentation during the California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA) environmental review phase of a project.

The SWDR documents decisions made regarding project compliance with the NPDES permit. The SWDR also may be used to provide key project information to environmental personnel responsible for preparing the WQR. The preliminary information in the SWDR prepared during the PID phase will be reviewed, updated, and confirmed by environmental personnel, and if required, will be revised in the SWDR prepared during the later phases of the project. The information contained in the SWDR and the WQR may be used to make more informed decisions regarding the selection of BMPs and/or recommended avoidance, minimization or mitigation measures to address water quality impacts for California Environmental Quality Act (CEQA) compliance.

2.3.4 Types of Pollutants

Selection of BMPs requires an understanding of the types of pollutants that the BMPs are designed to remove. Brief descriptions of commonly encountered pollutants are provided in the following sub-sections.

Table 2-2 provides a list of theses pollutants and the types of Treatment BMPs that can be used to reduce the discharge of these pollutants. To determine if the BMP addresses pollutants of

concern and will meet pollution control requirements, use Section 15 of the *BMP Retrofit Pilot Program Final Report* (California Department of Transportation, January 2004) and consult with your District/Regional Storm Water Coordinator.

2.3.4.1 Total Suspended Solids

Solids can be present in the water column in a dissolved phase (Total Dissolved Solids [TDS]) or a suspended phase (Total Suspended Solids [TSS]). In general, suspended solids are considered a pollutant when they significantly exceed natural concentrations and have a detrimental effect on the beneficial uses designated for the receiving water.

Possible sources of TSS from Caltrans facilities include natural erosion, runoff from construction sites, and other operations where the surface of the ground is disturbed. In addition, increased runoff from new impervious surfaces can accelerate the process of channel erosion, which in turn can increase TSS (and TDS) in runoff.

2.3.4.2 Nutrients

Excessive inputs of nutrients such as phosphorus and nitrogen to receiving waters can over-stimulate the growth of aquatic plants to the detriment of other aquatic life and to some beneficial uses of the receiving water. Nutrients generally have more adverse effects in water bodies with slow flushing rates, such as slow moving streams and lakes. Also, nutrients attached to suspended solids in stormwater runoff can cause problems where they settle out downstream.

Sources of phosphorus that may be present in highway runoff include tree leaves, surfactants and emulsifiers, and natural sources such as the mineralized organic matter in soils. Phosphorus may be present in stormwater discharges as dissolved or particulate orthophosphate, polyphosphate, or organic phosphorous.

Potential sources of nitrogen in highway runoff include atmospheric fallout, nitrite discharges from automobile exhausts, fertilizer runoff, and natural sources such as mineralized soil organic matter. Nitrogen may be present in stormwater discharges as nitrate, nitrite, ammonia/ammonium, or organic nitrogen.

2.3.4.3 Pesticides

A pesticide is a chemical agent designed to control pest organisms. The most common forms of pesticides are organic chemicals designed to target insects (insecticides) or vascular plants (herbicides). Pesticides have been repeatedly detected in surface waters and precipitation in the United States. Water is one of the primary media in which pesticides are transported from targeted applications to other parts of the environment. As the use of pesticides has increased, concerns about the potential adverse effects of pesticides on the environment and human health have also increased.

Table 2-2: Pollutants of Concern and Applicable Treatment BMPs

	Biofiltration Systems	Infiltration Devices	Detention Devices	Dry Weather Flow Diversions[1]	Gross Solids Removal Devices	Multi-Chambered Treatment Train	Media Filters	Wet Basins	Traction Sand Traps
Total Suspended Solids	ü	ü	ü	ü		ü	ü	ü	ü
Nutrients		ü	ü [2]	ü			ü [3]	ü [4]	
Pesticides		ü		ü					
Particulate Metals	ü	ü	ü	ü		ü	ü	ü	
Dissolved Metals	ü	ü		ü			ü		
Pathogens		ü		ü				ü	
Litter	ü	ü	ü	ü	ü	ü	ü	ü	
Biochemical Oxygen Demand		ü		ü				ü	
Total Dissolved Solids		ü		ü					

[1] Dry Weather Flow Diversions address non-stormwater flows only.

[2] Phosphorus only.

[3] Phosphorus and Nitrogen for the Austin Sand Filter; Phosphorus only for the Delaware Sand Filter.

[4] Reductions observed for dry weather flow only.

2.3.4.4 Metals (Particulate and Dissolved)

Metals in stormwater runoff may be in a dissolved phase or a particulate form adsorbed to suspended solids. Some Treatment BMPs are effective for removing specific particulate metals, but not for removing dissolved metals.

Possible sources of metals in highway runoff include the combustion products from fossil fuels, the wearing of brake pads, and the corrosion of metals, paints and solder. Metals can also reach receiving waters through the natural weathering of rock and soil erosion.

2.3.4.5 Pathogens

Pathogenic microorganisms including viruses, bacteria, protozoa, and helminth worms are of concern in stormwater runoff. The direct measurement of specific pathogens in water is extremely difficult. For that reason, the coliform group of organisms is commonly used as an indicator of the potential presence of pathogens of fecal origin.

Sources of total and fecal coliforms in stormwater runoff are ubiquitous (e.g., soil particles, droppings of wild and domestic animals, etc.). Human sources could include illicit sewer connections and seepage from septic tanks.

2.3.4.6 Litter

Litter in stormwater is defined as manufactured objects made from paper, plastic, cardboard, glass, metal, etc. This definition does not include materials of natural origin such as gravel or vegetation. Litter is quantified by 24-hour air-dried volume and weight measurements. Litter within stormwater is considered to be a significant problem in the municipal areas of Southern California as evidenced by the current listing of many water bodies as impaired due to trash on the EPA 303(d) list. Litter in surface waters can inhibit the growth of aquatic vegetation, harm aquatic organisms by ingestion or entanglement, convey other pollutants, such as toxic substances, and cause aesthetic problems on shorelines.

2.3.4.7 Biochemical Oxygen Demand

The Biochemical Oxygen Demand (BOD) is a measure of quantity of oxygen required to biologically stabilize the organic matter present in a pollutant. Biochemical oxidation is a slow process, and theoretically takes an infinite time to reach 100% completion. Therefore, a 5-day BOD (BOD_5) test, wherein the oxidation reaches about 60 to 70% completion, is commonly used for practical purposes. The BOD_5 test measures the rate of oxygen required by microorganisms (i.e., a laboratory inoculation) to oxidize the biodegradable matter in a sample under controlled laboratory test conditions. High BOD values (usually the result of organic contamination) suggest that the dissolved oxygen levels in receiving water may be depleted.

2.3.4.8 Total Dissolved Solids

The TDS in water consist of inorganic and organic molecules and ions that are in solution. Elevated levels of dissolved solids can deleteriously affect surface water quality in a number of

ways, most often because of the increased concentration (and perhaps increased number) of constituents that may be toxic to aquatic organisms.

2.3.5 Targeted Design Constituents

A Targeted Design Constituent (TDC) is a pollutant that has been identified during Departmental runoff characterization studies to be discharging with a load or concentration that commonly exceeds allowable standards and which is considered treatable by currently available Department-approved Treatment BMPs. The Targeted Design Constituent approach is the Department's statewide design guidance to address the "Primary Pollutants of Concern" (see Appendix B.1.1).

Targeted Design Constituents are: phosphorus; nitrogen; total copper; dissolved copper; total lead; dissolved lead; total zinc; dissolved zinc; sediments; and general metals [unspecified metals]. A project must consider treatment to target a TDC when an affected water body within the project limits (or with the sub-watershed as defined by the Water Quality Planning Tool) is on the 303(d) list for the one or more of these constituents.

2.4 BEST MANAGEMENT PRACTICES

As used in this document, the term BMP refers to operational activities or physical controls that control, prevent, remove, or reduce pollution and minimize potential impacts upon receiving waters. Accordingly, the term BMP refers to both structural and nonstructural controls that have direct effects on the release, transport or discharge of pollutants.

Federal stormwater regulations call for the implementation of both operational and technology-based BMPs to reduce the discharge of pollutants to the Maximum Extent Practicable (MEP) in municipal-type stormwater systems. Caltrans drainage facilities are considered a municipal separate storm sewer system under the Caltrans permit and are, therefore, held to the MEP requirement. For construction projects that disturb areas of one acre or more, the technology-based requirements include the use of Best Conventional Technology (BCT) and Best Available Technology (BAT).

Four categories of BMPs (Design Pollution Prevention, Treatment, Construction Site, and Maintenance) are described in Table 2-3. Design Pollution Prevention BMPs, Treatment BMPs and Construction Site BMPs are discussed in further detail in Sections 2.4.1 through 2.4.3 of this document.

Table 2-3: BMP Descriptions

BMP	Description
Design Pollution Prevention BMPs	Preservation of existing vegetation, concentrated flow conveyance, slope/surface protection, etc.
Treatment BMPs	Permanent treatment devices and facilities.
Construction Site BMPs	Temporary soil stabilization and sediment control, non-stormwater management, and waste management. Refer to the Construction Site BMP Manual.
Maintenance BMPs	Litter pickup, waste management, street sweeping, etc.

Designers should consider BMPs throughout the development of their project. Design Pollution Prevention and Treatment BMPs should be selected and designed to minimize life-cycle maintenance costs and resources. Adequate site access and maximum worker safety should be considered for maintenance of Design Pollution Prevention and Treatment BMPs. Construction Site BMPs should consider staging and other aspects of construction activities when developing the BMP strategy for the project. All BMPs should be considered when estimating the cost of a project so that adequate cost is projected and enough funding is allocated. Maintenance BMPs are related to typical maintenance activities and equipment, but are not otherwise discussed within this document. In addition to the above BMP categories, the designer must also be aware of, and address, non-stormwater discharges associated with a project, such as pumping stations, tunnel washing, etc. The designer should coordinate with the District/Regional Storm Water Coordinator if there are present and persistent non-stormwater discharges associated with a project.

2.4.1 Design Pollution Prevention Best Management Practices

Design Pollution Prevention BMPs are permanent measures to reduce pollution discharges (e.g., reduce erosion, manage non-stormwater discharges, etc.) after construction is completed. The Design Pollution Prevention BMPs that are to be incorporated, as appropriate, into the design of new facilities and reconstruction or expansion of existing facilities are listed in Table 2-4. Design guidelines for Design Pollution Prevention BMPs are included in Appendix A.

Table 2-4: Design Pollution Prevention BMPs

Consideration of Downstream Effects Related to Potentially Increased Flow
Peak Flow Attenuation Basins
Preservation of Existing Vegetation
Concentrated Flow Conveyance Systems
Ditches, Berms, Dikes and Swales
Overside Drains
Flared Culvert End Sections
Outlet Protection/Velocity Dissipation Devices
Slope/Surface Protection Systems
Vegetated Surfaces
Hard Surfaces

For all Caltrans projects, Caltrans will maximize vegetation-covered soil areas of a project.

A flow chart illustrating the Design Pollution Prevention BMP selection process for projects is shown in Figure 2-2.

2.4.2 Treatment Best Management Practices

Treatment BMPs are permanent measures to improve stormwater quality after construction is completed. The Treatment BMPs listed in Table 2-5 will be considered for all projects identified pursuant to Section 4 of this PPDG. These BMPs have been approved for statewide use. Appendix B provides a general description and design guidelines for the approved Treatment BMPs, and criteria for considering existing roadway features as Treatment BMPs (see Section B.1.4). Appendix E includes an Evaluation Documentation Form for Treatment BMPs that designers are to use to determine if a project is required to consider incorporating Treatment BMPs (see discussion of evaluation process in Section 4).

Table 2-5: Approved Treatment BMPs

Biofiltration Systems
Infiltration Devices
Detention Devices
Traction Sand Traps
Dry Weather Flow Diversion
Gross Solids Removal Devices (GSRDs)
Media Filters
Multi-Chamber Treatment Train
Wet Basins

A flowchart illustrating the Treatment BMP selection process for projects required to consider Treatment BMPs is shown in Figure 2-3. Designers are encouraged to consider combining approved BMPs (e.g., overflow from a Detention Device may be discharged to a Bioswale or an Infiltration Basin could be preceded by a Traction Sand Trap). These considerations shall be utilized at all phases of the project delivery process (PID, PA/ED, and PS&E).

Figure 2-2: Decision Process for Selecting Design Pollution Prevention BMPs

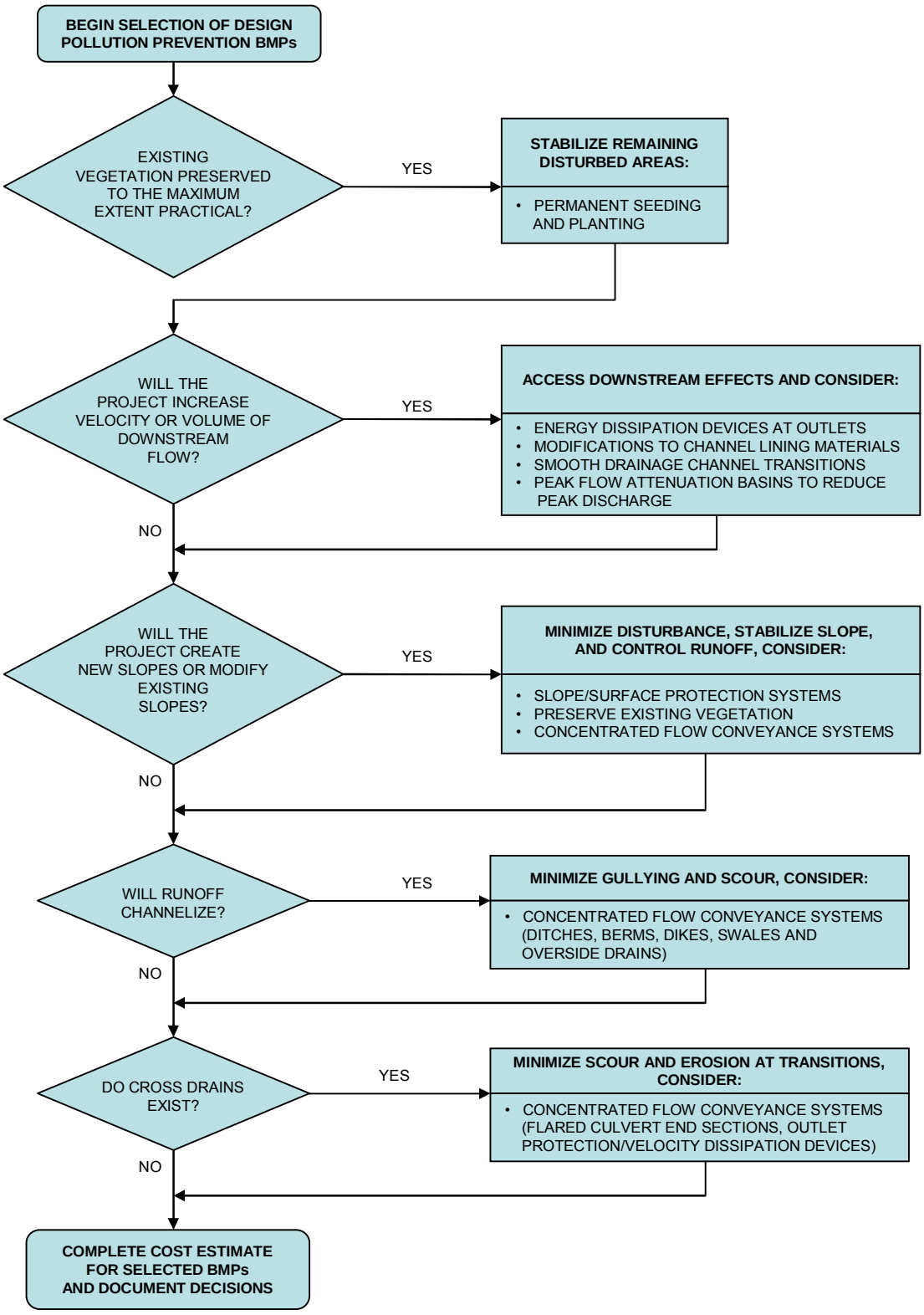
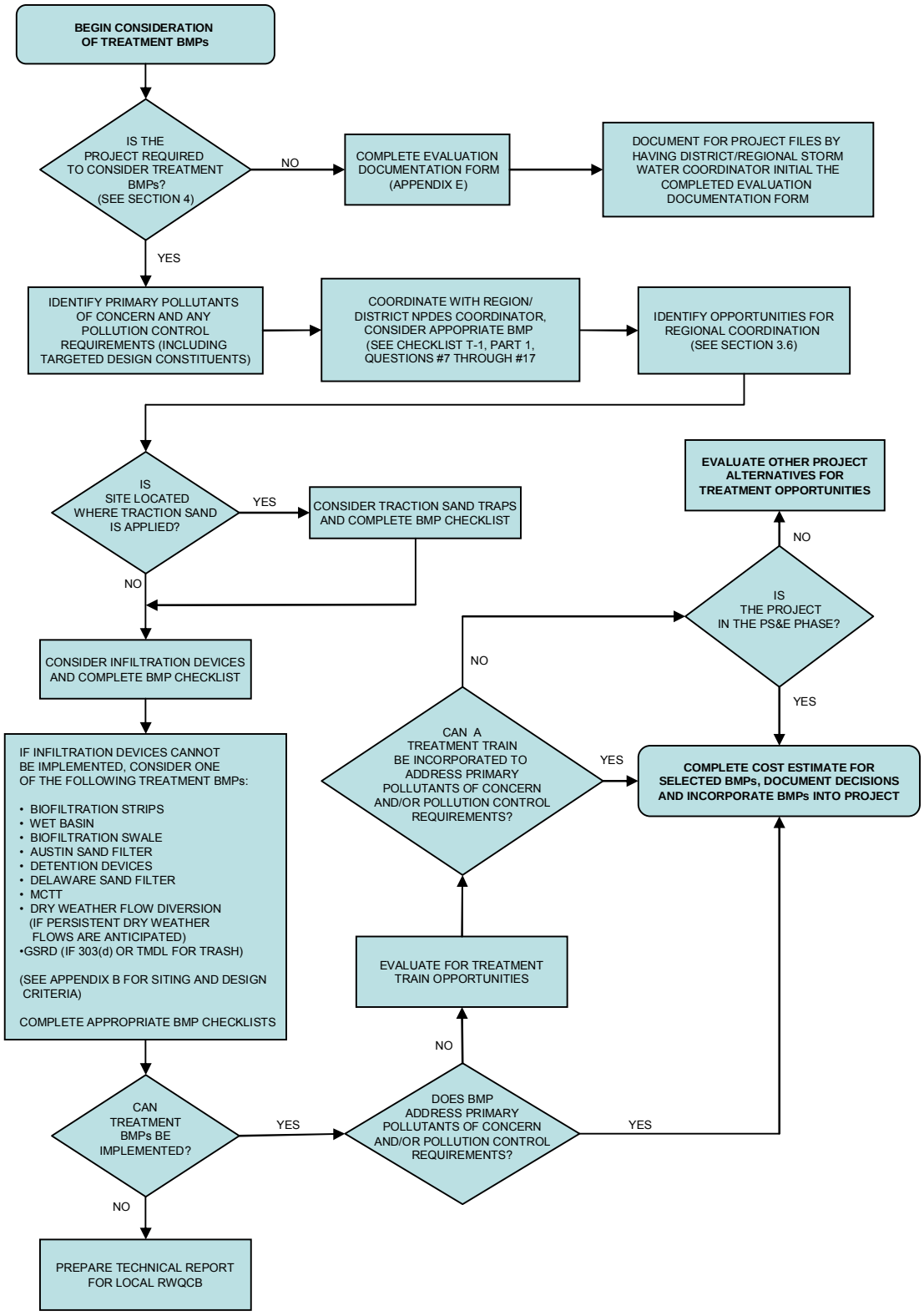


Figure 2-3: Decision Process for Selecting Treatment BMPs at Specific Sites



Biofiltration Strips and Swales are vegetated surfaces that remove pollutants by filtration through grass, sedimentation, sorption to soil or grass, and infiltration through the soil. Strips and swales are mainly effective at removing debris and solid particles, although some constituents are removed by sorption to the soil. Biofiltration Swales are vegetated channels that receive directed flow and convey stormwater. Biofiltration Strips, also known as vegetated buffer strips, are vegetated sections of land over which stormwater flows as overland sheet flow.

Biofiltration Strips and Swales are to be implemented at all sites to the extent that implementation is consistent with existing Caltrans policies, as described herein. In practice, this means maximizing the use of vegetation in the right-of-way wherever site conditions and climate allow vegetation to establish and where flow velocities are not high enough to cause scour.

Infiltration Devices are basins or trenches that store runoff and allow it to infiltrate into the ground. Infiltration prevents pollutants in the captured runoff from reaching surface waters. In areas of high sediment loads, pretreatment may be required. Infiltration Devices are permanent Treatment BMPs, and should be considered wherever site conditions allow, and shall be sited and designed according to the criteria presented in Appendix B of this PPDG.

Detention Devices are basins or tanks that temporarily detain runoff under quiescent conditions to allow particles to settle out. A Detention Device is a permanent Treatment BMP designed to reduce the sediment and particulate loading in runoff from the Water Quality design storm.

Traction Sand Traps are sedimentation devices that temporarily detain runoff and allow traction sand that was previously applied to snowy or icy roads to settle out. Traction Sand Traps are permanent Treatment BMPs, and should be considered at sites where traction sand or other traction-enhancing substances are commonly applied (more than twice per year) to the roadway.

Dry Weather Flow Diversions are devices that direct flow through a pipe or channel to nearby municipal sanitary sewer systems for treatment at a local wastewater treatment plant during dry weather or during periods of dry weather. Dry Weather Flow Diversions may be feasible if dry weather flow from Caltrans activities is persistent, and the sanitary sewer authority is willing to accept the flow. They should only be considered if dry weather flow from Caltrans activities is persistent or the result of an ongoing Caltrans activity. Additionally, Dry Weather Flow Diversions should only be considered if connection to a nearby sanitary sewer would not involve excessive measures to implement.

Gross Solids Removal Devices (GSRDs) are devices that remove litter from stormwater runoff using various screening technologies. GSRDs should be considered for areas where receiving waters are on the 303(d) list for trash or areas for which TMDLs have been adopted that require trash removal.

Media Filters are devices that remove sediment, particulate-associated pollutants, and sometimes dissolved pollutants from stormwater runoff by filtration. The normal configuration of such a device consists of two chambers, an initial sedimentation basin or vault followed by a filtering basin or vault that incorporates a filtering media.

Multi-Chamber Treatment Trains (MCTT) are devices that utilize three chambers to remove sediment, particulate-associated pollutants, and sometimes dissolved pollutants from stormwater runoff using media filter materials. MCTTs use three different treatment mechanisms in three separate chambers. These include a grit chamber with a sump, a sedimentation chamber with tube settlers and sorbent pads, and a filtering chamber provided with a filtering media.

Wet Basins are permanent pools of water designed to mimic naturally occurring wetlands. The main distinction between Wet Basins and natural wetlands is that Wet Basins are placed in upland areas and are not subject to wetland protection regulations.

Wet Basins should be considered when the site is located in a location where the visual aesthetics of the permanent pool is considered a benefit (such as a roadside rest area or vista point). Potential sites must have a high water table or another source of water must be present to provide base flow sufficient to maintain the plant community year-round.

Total Wet Basin volume shall be at least four times the Water Quality Volume (WQV). Permanent pool volume shall have a 3:1 permanent pool to WQV ratio and an additional temporary storage capacity greater than or equal to the WQV. The WQV is determined by the procedure described in Section 2.4.2.2.

2.4.2.1 Site-Specific Determination of Feasibility

General criteria used during the evaluation of Treatment BMPs include relative effectiveness, technical feasibility, costs and benefits, and legal and institutional constraints.

Relative Effectiveness: A recommended BMP should generally demonstrate greater pollution control benefits than a design without any BMP. Effectiveness may be assessed in terms of specific pollutants of concern. For further information, see Section 15 of the *BMP Retrofit Pilot Program Final Report*, California Department of Transportation, January 2004, and consult with the District/Regional Storm Water Coordinator.

Technical Feasibility: A recommended BMP must be technically feasible. Caltrans must be able to implement the BMP within the context of the state highway system. Feasibility also includes health and safety concerns. BMPs that substantially increase the risk to Caltrans workers or the public will be considered infeasible.

Costs and Benefits: The pollution control benefits must have a reasonable relationship to the costs. The costs and benefits analysis will consider the impacts to the receiving waters that are being reduced or eliminated through implementing the BMP.

Legal and Institutional Constraints: The recommended BMP cannot compromise Caltrans compliance with other laws. For example, Caltrans must provide drainage under roadways at regular intervals to prevent water from accumulating up gradient and threatening the integrity of the roadbed and to limit encroachment of captured water on the traveled way. Caltrans cannot legally block historic drainage patterns or systems (e.g., runoff from farmland).

Feasibility Assessment: The first step in assessing the feasibility of incorporating a potential BMP into a project is to gather the data needed to both determine the size and to estimate the

cost of that specific BMP. In addition, it should be determined whether the site characteristics, particularly the soil characteristics, are appropriate (checklists are provided in Appendix E for this purpose).

The second step is to determine the WQV or Water Quality Flow (WQF) that must be treated. (See Section 2.4.2.2 for guidance.)

Next, for all BMPs except GSRDs and Traction Sand Traps, calculate the size of the proposed BMP needed to treat the WQV (or anticipated flow). Use the procedures defined in Appendix B to evaluate the appropriate BMP, giving proper consideration to recovery zones, setbacks from structures, hydraulic head, and maintenance access roads and ramps. In very small drainage areas, it may be impractical to construct a BMP to treat the resulting small WQV (or flow).

For siting and evaluation criteria for all of the approved Treatment BMPs, see Appendix B.

During the planning and design process, multiple project alternatives may be evaluated. If a project requires the consideration of Treatment BMPs, yet the preferred alternative cannot incorporate Treatment BMPs, then the designer should re-evaluate the other alternatives that may provide greater opportunities for incorporating Treatment BMPs and reducing impacts to receiving waters. This consideration of project alternatives shall be documented in the Storm Water Data Report. If it is ultimately found not feasible to incorporate Treatment BMPs within the project, then the designer shall document the reasons in a technical report submitted to the RWQCB. This technical report must be submitted at a minimum of 60 days prior to PS&E submittal date of the project.

Sites requiring extraordinary plumbing to collect and treat runoff (e.g., jacking operations under a highway, bridge deck collection systems, etc.) may be considered infeasible due to their associated costs. Sites requiring extraordinary features or construction practices, such as retaining walls and shoring, may also be infeasible due to their associated costs relative to the cost of the BMP itself. Extraordinary plumbing, features, or construction practices should be brought to the attention of the District/Regional Storm Water Coordinator for consideration on a project-by-project basis; all decisions shall be documented accordingly.

If a BMP is too large to fit at a site, several options should be considered: (1) cooperation with another jurisdiction contributing drainage to obtain sufficient additional space; (2) purchase of additional land; and (3) installing a BMP that is smaller than what normal sizing procedures would dictate, if agreeable to the RWQCB. Again, these are issues to be brought to the attention of the District/Regional Storm Water Coordinator so that decisions can be made on a project-by-project basis.

2.4.2.2 Treatment BMP Use and Placement Considerations

Several factors must be considered to determine which BMPs are suitable for a given application. Site-specific conditions can affect operations, maintenance, construction costs, safety and aesthetics. The designer must determine if sufficient right-of-way is available for the desired BMP, or if the benefits associated with a potential BMP justify the consideration of acquiring additional right-of-way.

The physical dimensions of a BMP may have an important bearing on the factors identified in this section. The size of many BMPs is determined by the amount of runoff the system will be required to treat. The amount of runoff is affected by the location, land use, drainage area, storm intensity, topography, soil characteristics and the extent of impervious areas. For the design of Treatment BMPs that have the potential to affect drainage, the District's hydraulics staff should be consulted.

Both storm volume and peak flow rates must typically be considered in the design of highway drainage facilities. The "Design Storm" is the particular event that generates runoff rates or volumes that the drainage facilities are designed to handle. Determining the "Design Storm" involves the selection of an appropriate design storm frequency for the specific project, location or site under consideration. In order for a design frequency to be a meaningful criterion for roadway drainage design, it must be tied to an acceptable tolerance of flooding. Design water spread involving encroachment upon the roadbed or adjacent property determines the tolerance of flooding directly related to roadway drainage design. The Highway Design Manual (HDM) Chapter 831 provides a detailed discussion on how the probability of exceedance of the design storm and the acceptable tolerance to flooding depends on the importance of the highway and risks involved. For the purposes of this PPDG, the term "Design Storm" used in reference to designing drainage facilities will refer to the peak drainage facility design event as determined in accordance with the HDM.

Unlike flood control measures that are typically designed to store or convey the peak volumes or flows of infrequent (i.e. return period typically > 5 years) storm events, Treatment BMPs are designed to treat the lower volume or flow of more frequent (i.e. return period < 1 year) storm events. The volume or flows associated with the frequent events are commonly referred to as the WQV for BMPs designed based on volume, and WQF for BMPs designed based on flow. Treatment BMPs are sized to accommodate the WQF or WQV from the contributing drainage area. Flows in excess of these values (i.e. those larger runoff volumes or rates associated with the "Design Storm") are diverted around or through the Treatment BMP. Methods for determining the WQV are generally tied to an analysis of rainfall depths generated over 24-hour periods although the WQV may be determined by the drawdown time of certain Treatment BMPs.

The WQV of Treatment BMPs is based on using either of the following methods:

1. Where they are established, sizing criteria from the RWQCB or local agency (whichever is more stringent) will be used; or
2. Where the RWQCB or local agency does not have an established sizing criterion, Caltrans will use the following method:
   - The maximized detention volume determined by the 85th percentile runoff capture ratio. This method is described in Chapter 5 of the *Urban Runoff Management WEF Manual of Practice No. 23,* 1998, published jointly by the Water Environment Federation (WEF) and the American Society of Civil Engineers (ASCE). Designers should note, however, that the information presented in the WEF manual cannot be directly applied to Caltrans facilities because it is based on large watersheds and

oversimplified hydrologic data for California. This method requires the designer to assume a drawdown time. Any drawdown time between 24 and 72 hours can be used (the 24-hour limit provides adequate settling and the 72-hour maximum addresses vector concerns). A design tool (Basin Sizer) that uses data from more than 700 California rainfall stations, has been created for Caltrans use. It is available at:

http://www.owp.csus.edu/research/stormwatertools/

A detailed description of the method can also be found in: Guo, C.Y., and B.R. Urbonas (1996), "Maximized Detention Volume Determined by Runoff Capture Ratio," *Journal of Water Resources Planning and Management*, v. 122, n. 1, pp. 33-39.

Alternatively, the District and the appropriate RWQCB may discuss the potential need for modification of the criteria on a case-by-case basis if one of the following situations applies:

- The site area is limited and cannot accommodate a Treatment BMP sized according to either of the methods for determining WQV; or
- Sizing a Treatment BMP using either method in areas of the State with significant annual precipitation results in excessively large treatment units.

The WQF is the primary design criteria used for various types of flow-based Treatment BMPs (e.g. Biofiltration Swales). Caltrans, the SWRCB and the nine RWQCBs worked cooperatively to establish these values.

The following WQFs negotiated with the SWRCB and RWQCBs should be used as the basis for designing the approved flow-based Treatment BMPs. Where there are special circumstances or conditions, the PE, the District/Regional Storm Water Coordinator and the related RWQCB should discuss the potential need for modification of the criteria on a case-by-case basis.

In addition to designing for the WQF, the designer must also insure that the flow-based Treatment BMPs include a bypass or an overflow device to convey peak discharges from larger design storms consistent with Section 861.3 of the Highway Design Manual.

The listed values of rainfall intensity would be used in the Rational Formula (Q=CiA) to estimate runoff from areas that would discharge flow to flow-based Treatment BMPs. The resulting runoff rate would be the design WQF to be used at any specific site.

1. Region 1 (North Coast) – 0.22 inches/hour ("/hr) for Siskiyou and Modoc Counties, 0.27 "/hr for Trinity and Mendocino Counties and 0.36 "/hr for Del Norte, Humboldt and Sonoma Counties.
2. Region 2 (San Francisco) –0.20 "/hr regionwide.
3. Region 3 (Central Coast) –0.22 "/hr for Santa Cruz County and for that portion of San Mateo County within the region; 0.20 "/hr for Santa Clara County, 0.18 "/hr for San Benito, Monterey and San Luis Obispo Counties and 0.26 "/hr for Santa Barbara County and that portion of Ventura County within the Region.

4. Region 4 (Los Angeles) –0.20 "/hr region wide.
5. Region 5 (Central Valley) –0.16 "/hr for portions of Lassen and Modoc Counties within the Region, all areas of Region below 1,000' elevation north of and including Sacramento and Amador Counties and below 2,000' elevation south of Sacramento and Amador Counties, and all elevations on the west side of the Region (rain shadow side of the Coast Range), 0.20 "/hr for elevations in the Sierra Nevadas between 1,000' and 4,000' in the north and between 2,000' and 4,000' in the south, and 0.24 "/hr for all elevations above 4,000' in the Sierra Nevadas.
6. Region 6 (Lahontan) –

   Where there are location-specific requirements (Truckee River, East and West Forks Carson River, Mammoth Creek, and Lake Tahoe), the WQF will conform to the Basin Plan requirement for runoff from impervious areas. Where runoff from pervious areas contributes to the flow to the treatment device, the WQF value to be used will be as specified in the following two items:

   a) The WQF to be used for that portion of the Lahontan Region including Inyo County and areas southward will be 0.16 "/hr. The WQF to be used for pervious surface areas within the Mammoth Creek watershed above 7,000' elevation will be 0.16 "/hr.

   b) For all other areas of the Lahontan Region other than as indicated in item a) above, the WQF to be used will be 0.20 "/hr. This includes pervious surface areas of the Truckee River, Carson River East and West Forks and Lake Tahoe Hydrologic units.

7. Region 7 (Colorado River) –0.16 "/hr regionwide.
8. Region 8 (Santa Ana River) –0.20 "/hr regionwide.
9. Region 9 (San Diego) –0.20 "/hr regionwide.

2.4.3 Construction Site Best Management Practices

Construction Site BMPs (also called temporary control practices) are deployed during construction activities to reduce pollutants in stormwater discharges. Table C-1 in Appendix C is a matrix of approved Construction Site BMPs that are consistent with the BMPs and control practices required under the General Permit and the SWMP. The Department's construction site BMPs are divided into six categories as shown in Table 2-6:

Table 2-6: Approved Construction Site BMP Categories

Temporary Soil Stabilization
Temporary Sediment Control
Wind Erosion Control
Tracking Control
Non-Stormwater Management
Waste Management and Materials Pollution Control

Additional information on design, placement, and applicability of Construction Site BMPs can also be found in Appendix C of this document, or in the Construction Site BMP manual.

2.4.4 Maintenance Best Management Practices

Maintenance BMPs are water quality controls used to reduce pollutant discharges during highway maintenance and activities conducted at maintenance facilities. One example of a Maintenance BMPs is the Department's practice of stenciling messages at storm drain inlets located at highway facilities such as park and ride lots, rest areas and vista points to assist in educating the public about stormwater runoff pollution. Additionally, all new inlets located within cities, towns, and communities with populations of 10,000 or more, or within designated MS4 areas, shall be stenciled when constructed. Designers should contact the District Maintenance Storm Water Coordinator to identify stencil types, specifications and details for projects falling within these areas.

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3.1 INTRODUCTION TO DESIGN PROGRAM RESPONSIBILITIES

The Caltrans design staff responsibilities regarding implementation of the stormwater management program are described in the following sections. All Caltrans Districts have developed responsibility matrices to identify staff and divisional responsibility for duties assigned under the Storm Water Management Plan (SWMP).

The Caltrans Project Delivery Storm Water Management Program includes the Design Division, the Construction Division, and their associated functional units. Project Delivery Program provides guidance and direction to the District Design and Construction Divisions.

3.2 MANAGEMENT

The role of the Design Storm Water Management Program includes:

- **Coordination:** In coordination with the Water Quality Program, the Design Storm Water Management Program provides general guidance to the Districts on the implementation of stormwater quality management practices;
- **Program Evaluation:** The Design Storm Water Management Program assesses District incorporation of stormwater quality management features into facility designs;
- **Reporting:** The Design Storm Water Management Program assists the Water Quality Program in the preparation of the Annual Report to the State Water Resources Control Board (SWRCB), as it relates to Design activities.

The Design Program Manager is responsible for statewide implementation policies and procedures and management of the personnel of the Design program. This includes the responsibility for ensuring compliance with all elements of the SWMP that are required to be implemented by the Design Division.

3.3 STORM WATER ADVISORY TEAMS

Caltrans design staff provide valuable input and consultation to the Storm Water Advisory Teams (SWATs) as follows:

- The Maintenance SWAT (M-SWAT) is composed of District Maintenance Storm Water Coordinators and representatives from each of the affected Headquarters Divisions. The M-SWAT provides any necessary review and/or evaluation of proposed and existing BMPs used by the Division of Maintenance. In addition, the M-SWAT reviews and assists in the development of training classes and guidance documents for implementing stormwater activities described in the SWMP for maintaining highways, bridges, facilities, and other appurtenances related to transport.

- The Project Design SWAT (PD-SWAT) is composed of District/Regional Design Storm Water Coordinators and related functional units and representatives from each of the affected Headquarters Divisions. The PD-SWAT provides review of proposed

and existing BMPs utilized in the planning and design of projects. BMPs include construction BMPs, design pollution prevention BMPs, and Treatment BMPs. In addition, the PD-SWAT reviews and assists in the development of training classes and guidance documents for implementing stormwater activities relevant to project design.

- The Construction SWAT (C-SWAT) is composed of District Construction Storm Water Coordinators and representatives from each of the affected Headquarters Divisions. The C-SWAT provides review of proposed and existing construction BMPs and measures used for stabilization of soils. In addition, the C-SWAT reviews and assists in the development of training classes and guidance documents for implementing stormwater activities relevant to construction activities.

- The Encroachment Permits SWAT (EP-SWAT) is composed of District Permit Coordinators and representatives from each of the affected Headquarters Divisions. The EP-SWAT reviews existing procedures to ensure that they integrate the appropriate stormwater BMPs into the requirements of encroachment permits. The EP-SWAT reviews and assists in the development of training classes and guidance documents for implementing stormwater activities for issuing and administering encroachment permits.

- The Water Quality SWAT (WQ-SWAT) is composed of the District NPDES Storm Water Coordinators and representatives from each of the affected Headquarters Divisions. The WQ-SWAT provides review of proposed and existing treatment BMPs, and prioritizes research or studies of Treatment BMPs. The WQ-SWAT is a forum for discussing stormwater coordination activities underway or planned with other municipalities, reviewing and recommending public education efforts, sharing technical information, providing advice on compliance issues, and resolving issues of dispute on stormwater. Many of these activities result in recommendations for changes to the SWMP or policies and other documents on stormwater. The WQ-SWAT discusses stormwater budget allocations for the Districts and HQ Divisions. The WQ-SWAT reviews data and findings from compliance-monitoring and evaluation activities, and recommends changes in practices to improve compliance efforts.

3.4 STORM WATER COORDINATORS

All Districts/Regions have designated NPDES Storm Water Coordinators. Other functional-unit Storm Water Coordinators exist in the Planning, Design, Construction and Maintenance Divisions. Also, depending upon the complexity of the district, additional Storm Water Coordinators may be identified to represent other functional units or special needs (e.g. TMDLs); these roles are described in the District Work Plan (DWP). The functional unit coordinators assist the District Divisions in implementing stormwater management activities. The District/Regional NPDES Storm Water Coordinators serve as liaisons with the Water Quality Program. Liaison activities also include regular communications with representatives of the Regional Water Quality Control Board (RWQCB).

3.5 RESPONSIBILITIES AS THEY RELATE TO ENCROACHMENT PERMITS AND THIRD-PARTY ACTIVITIES

Districts control third-party activities on Caltrans rights of way (e.g., utility construction) through the conditions associated with encroachment permits. These conditions require compliance with Caltrans standard plans and specifications. Encroachment permits require environmental compliance, including implementation of BMPs comparable to those required of Caltrans. For larger encroachments, project design is overseen by District Design and construction activities by District Construction. Smaller projects are managed by the Encroachment Permit Unit.

3.6 RESPONSIBILITIES FOR COORDINATION WITH MUNICIPAL STORM WATER PERMITTEES (LOCAL AGENCIES)

Coordination with Municipal Separate Storm Sewer System (MS4) permit holders and other municipalities (cities and counties) must take place whenever a proposed project would result in stormwater discharges from the Department's stormwater drainage systems to stormwater drainage systems owned and operated by the MS4 or municipality, and vice versa. This coordination includes attending meetings, participating in special studies, identifying stormwater run-on issues, etc. The Project Engineer (PE) should consult with the District/Regional Storm Water Coordinator to identify any MS4 permit requirements that may affect the project.

3.7 CONSULTATION WITH REGIONAL WATER QUALITY CONTROL BOARDS AND LOCAL REGULATORY AGENCIES

Consultation with the RWQCBs and local regulatory agencies is strongly recommended to coordinate project issues and develop consensus. The number of coordination meetings may vary depending upon the complexity of the stormwater quality issues, stormwater pollutants involved, and project site constraints. The District/Regional NPDES Storm Water Coordinators are the liaisons between the RWQCBs and the Districts.

3.8 STAFF AND FUNCTIONAL UNITS

3.8.1 Staff

Project Manager

Typically, the Project Manager (PM) is responsible for all project development phases from project initiation to closeout of the construction contract. The PM has full authority, delegated from the District Division Chief for Program and Project Management, to produce the results that were intended, meet schedules, stay within budget and keep the sponsors and customers satisfied. The PM retains these responsibilities over the entire life of the project.

During project initiation, the PM identifies the needs and expectations of the project sponsors, including the need for permanent stormwater BMPs. The PM also leads the Project Development Team (PDT) in the development of a "Project Work Plan" that defines the project scope, schedule, cost, and resource needs. Finally, the PM ensures that the Project Work Plan includes all the work required. Resources are assigned to a project based upon the Project Work Plan developed by the PM and the PDT.

During the design phase of a project, the PM monitors project performance and resolves problems that affect project scope, cost or schedule. This includes the BMP evaluation and selection process for incorporation into the project. The PM coordinates the efforts of the overall team, and typically chairs the PDT meetings. During the entire process, the PM controls the project budget (both support and capital).

Project Engineer

The Project Engineer (PE) is responsible for the preparation of a Project Initiation Document (PID) and a Project Report (PR) during the project-planning phase. The PE is also responsible for preparing plans, specifications and estimates (PS&E) documents (otherwise known as contract plans or bid documents) during the design phase. The PE determines whether a Storm Water Pollution Prevention Plan (SWPPP) or a Water Pollution Control Program (WPCP) is required for the construction project. Where the re-use of soils that contain aerially deposited lead is proposed, the PE and the District/Regional NPDES Coordinator will ensure that written notification is provided to the RWQCB 30 days prior to advertisement for bids.

The PE considers, and where appropriate, incorporates Design Pollution Prevention, Treatment and Construction Site BMPs into the project plans and specifications. The PE prepares and updates the Storm Water Data Report (SWDR) throughout the life of the project. In addition, the PE is responsible for assembling information necessary to assist the Resident Engineer (RE) and contractor in preparing and reviewing the SWPPP/WPCP.

Project Development Team

For most projects, the Department uses a formalized Project Development Team (PDT) that acts as a steering committee in directing the course of studies required to evaluate the various project alternatives during the early phases of the project life cycle. The PDT uses an interdisciplinary approach that draws upon different disciplines in planning, developing, and evaluating alternatives. The PDT advises and assists the PM in directing the course of studies, makes recommendations to the PM and district management, and works to carry out the Project Work Plan. The PDT is responsible for the completion of studies and the accumulation of data throughout project development to PS&E.

The primary functions of the PDT are listed as follows:

- To determine logical project limits;
- To recommend studies, timetables, alternatives, type of environmental documentation, and the feasibility of project impact mitigation measures;
- To ensure thorough analysis of the social, economic, environmental (including visual and aesthetic) and engineering aspects of the project. The PDT calls upon representatives of various disciplines as needed;
- To ensure that state and federal requirements for project development studies have been met;

- To use information in reports (PSR, Draft Project Report – Draft Environmental Document [DPR-DED], etc.) when recommending a preferred alternative to District Management for project approval; and
- To document the project history and decisions.

Functional Managers

Functional Managers supervise the Department functional units that provide technical data and plans to the PE, and schedule and resource data to the PM. Functional Managers are responsible for assigning staff to work on a project, and for ensuring the delivery of product(s) within the schedule agreed upon in the Project Work Plan. Functional Managers also ensure that the products comply with all applicable standards, regulations, and policies.

3.8.2 Functional Units

Design

The District's Design Unit is responsible for the implementation of Caltrans policies, programs, and procedures concerning design of Caltrans facilities. This includes ensuring compliance with all design elements of the Highway Design Manual (HDM), the SWMP, the Project Development Procedures Manual (PDPM), the PPDG and other guidance documents. The Design Unit is responsible for the following stormwater quality related activities:

- Preparation of a Project Initiation Document (PID) and a Project Report (PR) during the project planning phase, including evaluation and selection of potential BMPs that may be incorporated into the project;
- Preparation of plans, specifications and estimates (PS&E) documents during the design phase. This includes the selection and design of Design Pollution Prevention BMPs, Treatment BMPs and appropriate Construction Site BMPs into the plans and specifications;
- Determining whether an SWPPP or a WPCP is required for the project;
- Ensuring that written notification is provided to the RWQCB 30 days prior to advertisement for bids for projects that include the re-use of soils that contain lead; and
- Ensuring that a Notification of Construction is submitted to the appropriate RWQCB at least 30 days prior to the start of construction for projects that require a SWPPP.

Environmental

The District's Environmental Unit is responsible for the implementation of Caltrans policies, programs, and procedures concerning environmental considerations, analysis, and compliance with environmental laws and regulations under California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA) as well as other state and federal regulations. Key responsibilities of the Environmental Unit include the following:

- Define stormwater quality issues in coordination with the PE and the District/Regional Storm Water Coordinator;

- Identify receiving water bodies and their beneficial uses, 303(d) listed water bodies, project-related stormwater discharges and quality;
- Prepare the Preliminary Environmental Assessment Report (PEAR) and the Water Quality Impact Questionnaire;
- Evaluate potential water quality impacts to the water quality of receiving waters;
- Prepare the Water Quality Assessment Technical Report (WQR), as determined by the Water Quality Impact Questionnaire;
- Provide input to the PE regarding information to be incorporated into the Storm Water Data Report (SWDR); and
- Make recommendations to the PDT regarding the avoidance, minimization and mitigation measures relating to compliance with the California Environmental Quality Act (CEQA).

This functional unit is known by various names in different Districts, including, but not limited to, Environmental, Environmental Planning, Environmental Analysis, Environmental Technical Studies, Environmental Engineering, Environmental Oversight, and Environmental Reports. A representative from this unit is a required member of the PDT.

Surveys

The District's Surveys Unit is responsible for the implementation of Caltrans policies and procedures concerning surveys and for conducting surveys. The Surveys Unit is a liaison between the Geometronics Branch of the Office of Engineering Technology in the Engineering Service Center and the PE.

Survey needs should be evaluated and identified early in the project initiation process and throughout the entire project development process when needed. After the first evaluation of survey needs, the PE should submit the initial survey request accompanied by a strip map. The extent of the survey will depend on the type of project, existing information available, sensitivity of the area of potential effect, and the number of viable project alternatives. The Right-of-Way Branch and the Environmental Unit require accurate mapping in order to properly carry out their functions, so their needs must be carefully considered when evaluating surveys.

Right-of-Way

The District's Right-of-Way Branch is responsible for the implementation of Caltrans policies, programs and procedures concerning right-of-way and utility considerations and compliance with state and federal laws and regulations. This function consists of various branches in the Districts under a District Division Chief for Right-of-Way, except for the Right-of-Way Engineering Unit which generally reports to another District Division Chief.

Since most transportation projects in California require right-of-way, utility easements, rights of entry, or some other right-of-way activity, the project development process requires close coordination between the PE, the PM, and representatives from the Right-of-Way Engineering

Unit and the Right-of-Way Branch to determine schedules and cost estimates, and to assure the acquisition of all necessary property rights.

The Right-of-Way Branch provides valuable information at the initiation of studies. Once the project limits have been tentatively determined, property ownership maps can be developed by the Right-of-Way Engineering Unit. Preliminary right-of-way estimates are required to properly develop and analyze project alternatives. Adequate mapping is required, as well as realistic project scope. A representative of the Right-of-Way Branch is a required member of the PDT.

Materials and Geotechnical

Materials information is required for almost all projects, usually related to pavement design, culvert selection, corrosion studies, and material sites. The District Materials Unit is involved throughout the project development process; after the project has been initiated, requests are made of the District's Materials Unit to update materials information.

If projects are located in areas where there are critical unanswered concerns such as gross slope stability, foundation problems, seismic, percolation, etc, preliminary evaluation should be made by DES Geotechnical Design unit. After the project has been initiated, requests should be directed to the DES Geotechnical Design unit to provide geotechnical information such as side slope recommendations, slide locations, etc. It is essential that sufficient geotechnical information be developed so that all viable project alternatives are evaluated at all stages of the design process. If a project includes new slope ratios steeper than 1:2 (v:h), then a Geotechnical Design Report should be prepared. Projects including slopes between 1:4 and 1:2 (v:h) should be coordinated with DES Geotechnical Design unit.

The PE uses the recommendations from these units to develop and analyze alternatives and estimate costs for use in project initiation and approval documents, and to prepare estimates, plans and specifications for both new construction and rehabilitation projects.

It is essential that enough materials information is available so that all viable project alternatives are evaluated at all stages of the design process.

Hydraulics

The District Division of Design is responsible for hydraulic design policies and procedures. The Design unit that performs the project drainage design is responsible for the implementation of these policies and procedures. District organizations differ, but for the purpose of this document, it is assumed that the PE is responsible for ensuring that proper project drainage design is performed. This will typically require the active participation in, or the review of, the design by the Hydraulics Unit.

Detailed drainage design, such as accurate sizing and location of culverts, storm drains, Treatment BMPs and roadway drainage, does not begin until after selection of the preferred alternative and approval of a project. However, the Hydraulics Unit should be involved during the entire project planning process. Their input in the project initiation process is invaluable, particularly in recommending facility types and estimating costs of large facilities.

The Hydraulics Unit should also be involved in the environmental studies. Early coordination between the two functional groups is important. Many projects, by necessity, will include water quality enhancement features or encroach on wetlands, floodplains, etc. When floodplain encroachment is involved, the Hydraulics Unit should be involved in preparing location hydraulic studies. Historical drainage maps often depict the extent of the encroachment and help determine which project alternatives should be considered. Documentation of these features must be included in the Draft Project Report (DPR).

Construction

The Construction Unit is responsible for administering contracts for the construction of projects by contractors to ensure that the final products are in accordance with the plans and specifications, and to deal with any problems that may arise in the process. The Construction Unit should review the project and BMP alternatives to determine if they are biddable and buildable. During environmental and project studies, the Construction Unit should be involved in the determination of measures to reduce or mitigate construction impacts.

During the design stage, the Construction Unit should review the project plans and specifications for such things as construction safety, logical staging, an analysis of the number of working days, supplemental funds, and special provisions usability. Also, the Construction Unit provides advice and concurrence to the PE for strategy, development and inclusion of temporary Construction Site BMPs into the project plans.

Prior to start of construction, the PE, along with other involved District units, will go over the project with the RE. The review at this stage will aid in clearing up reasons for design decisions and commitments such as; right-of-way obligations, signing and traffic handling, materials sites, selected material, foundation treatment, potential slides, environmental commitments, drainage, potential maintenance problems, erosion control, public notification, proprietary materials, special considerations in contract provisions, etc.

On almost all construction projects, developments in the field will necessitate some design changes. For early resolution of these changes, the RE, the PM, and the PE must coordinate with other functional units as needed to accommodate these changes without affecting scope, schedule and budget.

Maintenance

The Maintenance Unit will be responsible for maintaining the highway and BMP facilities once the project is complete. It is essential that the Maintenance Unit be involved in the project development process from conception through construction.

The Maintenance Unit should also review the proposed geometric layouts, typical sections, and final plans. Maintenance Units may have input on shoulder backing materials, drainage concerns, areas with existing erosion problems, access to buildings, access for Treatment BMPs, access for landscape facilities, access to encroachments for utility facilities, access for maintenance of noise barriers, fence and excess land review, etc. Maintenance Units should also participate in the preparation of maintenance agreements (setting maintenance control limits).

The Maintenance Unit field representatives have a unique insight into local problems and maintenance and safety concerns. This insight must be utilized in the project development process. Coordination with maintenance staff during the design process can minimize future maintenance problems and the potential for future lawsuits.

Typical Maintenance Unit involvement would be to comment on features such as the following:

- Drainage patterns – particularly known areas of flooding, debris, etc.;
- Stability of slopes and roadbed: Help determine if the project can be built and maintained economically;
- Possible material borrow or spoil sites;
- Concerns of the local residents;
- Existing and potential erosion problems;
- Facilities within the right-of-way that would affect alternative designs;
- Special problems such as deer crossings, endangered species, etc.;
- Traffic operational problems such as unreported accidents, etc.;
- Facility that is safe to maintain;
- Providing concurrence on any slopes steeper than 1:2 (v:h);
- Known environmentally sensitive areas; and
- Frequency of traction sand use and estimate of quantity applied annually.

Landscape Architecture

The Chief of the Office of Landscape Architecture is responsible for the development of Caltrans policies, programs, procedures, and standards for all aspects of landscape architecture (i.e., highway planting, highway planting restoration, replacement planting, revegetation, vegetative erosion control), safety roadside rest areas, vista points, scenic corridors, and noise barriers.

The Landscape Architect evaluates the implementation of mandatory stormwater Design Pollution Prevention BMPs into the overall landscaping plan for the project. Erosion prevention and stormwater pollution prevention BMPs are incorporated into the project's landscaping and revegetation plan. Additionally several approved Treatment BMPs require the establishment of vegetation. The Landscape Architect will provide recommendations for vegetation establishment when these BMPs are considered. All projects incorporating new slopes steeper than 1:4 (v:h) must have an erosion control plan developed or approved by the District Landscape Architect.

3.9 REPORTING REQUIREMENTS

Environmental

The Preliminary Environmental Assessment Report (PEAR) is prepared by the Environmental Unit. The purpose of the PEAR is to determine whether there are any potentially significant environmental issues that could affect the viability of the project alternatives. The PEAR identifies the environmental documents and supporting technical studies that would be required

in subsequent project development processes to address potential environmental impacts. Based upon the potential for significant impacts, the PEAR would identify whether a California Environmental Quality Act (CEQA) Initial Study or Environmental Impact Report is needed and/or whether a National Environmental Policy Act (NEPA) Environmental Assessment or Environmental Impact Statement is needed. The Water Quality Impact Questionnaire identifying potential water quality impacts is incorporated into the PEAR. The Water Quality Impact Questionnaire has been developed to assist in early identification and consideration of the broadest range of potential water quality effects, and to scope the PEAR analysis with respect to water quality issues. The Questionnaire asks a series of questions about the project description and alternatives, the project setting, and potential project impacts on water quality. Answers developed in response to these questions should be coordinated with the PE and the District/Regional NPDES Coordinator.

The Water Quality Assessment Technical Report (WQR), at different levels of detail, describes existing water quality conditions, identifies potential project impacts and proposed BMPs and/or avoidance/minimization measures. This information will be utilized by Caltrans Design, Construction and Maintenance staff to develop and implement specific BMPs to mitigate any potential water quality impacts associated with stormwater discharges from the proposed project. The information from the PEAR and the WQR would be utilized to update the SWDR and associated checklists.

Surveys & Mapping

During a project evaluation, areas are identified as possible locations for Treatment BMPs. Therefore, surveys and vicinity mapping should be developed for these areas.

Right-of-Way

The right-of-way data sheet should be requested from the Right-of-Way functional unit as soon as possible after project alternatives have been developed. The right-of-way data sheet is prepared during the PID process and updated throughout the Project Approval/ Environmental Document (PA/ED) process, and is a required attachment to the PSR, the PR, and most other project initiation and project approval documents. The information in the right-of-way data sheet is vital to the project development process since it details all types of parcel information and the right-of-way estimate. The information from the right-of-way data sheet is also used to evaluate the feasibility of acquiring additional land for the incorporation of Treatment BMPs or drainage easements.

Hydraulics

Following project approval, a Drainage Report is typically prepared by the Hydraulics Unit. This report covers rainfall, runoff, existing flood records, gauging stations, debris, and any other pertinent drainage information. This report is transmitted to the PE so that pertinent drainage design can be started. The information in the Drainage Report is also used to evaluate and design stormwater BMPs.

Maintenance

In addition to participating on the PDT, the Maintenance Unit should review all major engineering reports such as the PSR, DPR, PR, etc. The review shall include the evaluation of

all proposed BMPs, including the maintainability of those BMPs. Maintenance is also required to sign the SWDR at the conclusion of the PID, the PA/ED, and the PS&E phases. Additionally, Maintenance concurrence must be obtained on any new slope steeper than 1:2 (v:h).

Landscape Architecture

Landscape Architecture is required to sign the SWDR at the conclusion of the PID, the PA/ED, and the PS&E phases. The District Landscape Architect must either prepare or approve an Erosion Control Plan for any project incorporating new slopes steeper than 1:4 (v:h).

Construction

The Construction Unit should review the project and BMP alternatives to determine if they are biddable and buildable. After completion of the construction contract, the PM is responsible for gathering the construction contract records from the RE and the project planning and design data from the PE to put in the Project History File. During the design phase, the construction unit will also provide input and concurrence to the Project Engineer (PE) on the strategy for Construction Site BMPs.

District Materials Unit

The District Materials Unit provides a Materials Report for all projects that involve any of the following components:

- Pavement structure recommendations and/or pavement studies;
- Culverts (or other drainage materials);
- Corrosion studies;
- Materials disposal sites; or
- Slide prone areas with erosive soils.

Geotechnical Services

Geotechnical Services either prepares or approves a Geotechnical Design Report for all projects incorporating new cut slopes or embankments steeper than 1:2 (v:h), retaining walls, groundwater studies and any other studies involving geotechnical investigations and engineering geology.

District/Regional Design Storm Water Coordinator

The District/Regional Design Storm Water Coordinator is required to sign the SWDR at the conclusion of the PID, the PA/ED, and the PS&E phases. The District/Regional Design Storm Water Coordinator may delegate this authority to the District/Regional NPDES Storm Water Coordinator.

District/Regional NPDES Storm Water Coordinator

The District/Regional NPDES Storm Water Coordinator verifies that the water quality issues are identified in the Water Quality Impact Questionnaire and later in the WQR (if one is prepared for the project).

Project Manager

The Project Manager (PM) is required to sign the SWDR at the conclusion of the PID, the PA/ED, and the PS&E phases. The PM also signs the PSR and the PR.

Project Engineer

The Project Engineer (PE) is responsible for the preparation of PSRs and PRs during the planning phase, and PS&E documents (otherwise known as contract plans or bid documents) during the design phase. Where the re-use of soils that contain lead is proposed, the PE will ensure that written notification is provided to the RWQCB 30 days prior to advertisement for bids, as discussed in Section 1.4.4. The PE determines whether a SWPPP or a WPCP is required for the construction project and incorporates appropriate permanent BMPs in the project.

The PE incorporates permanent Design Pollution Prevention, Treatment and temporary Construction Site BMPs into the project plans and specifications.

The PE also prepares and signs the SWDR at the conclusion of the PID, the PA/ED, and the PS&E phases.

4.1 INTRODUCTION AND OBJECTIVES

The Caltrans Statewide Storm Water Management Plan (SWMP) requires Project Development personnel to assess the need for stormwater Best Management Practices (BMPs) and incorporate these BMPs as appropriate during the initial planning and design phases of all Caltrans projects. Design Pollution Prevention BMPs and temporary Construction Site BMPs must be considered for every project. Additionally, every project must evaluate the maintainability of all permanent BMPs incorporated into the project. This section, however, focuses on evaluating whether a project must consider incorporating Treatment BMPs. If a project must consider incorporating Treatment BMPs, then a site-by-site determination of Treatment BMP feasibility is required, and Appendix B and Checklists T-1, Parts 1 through 10 of this document should be consulted.

4.2 PROJECT EVALUATION PROCESS

The attached decision tree, Figure 4-1, provides general guidance to determine when a project is required to consider implementing Treatment BMPs. The corresponding Evaluation Documentation Form is included in Appendix E of this document. The information in the following sub-sections supplements the attached decision tree by providing further detailed descriptions of the steps in the decision tree. The numbers in the descriptions correspond to the steps in the decision tree.

Step 1 - Begin

Caltrans construction projects may require the consideration of permanent Treatment BMPs. The projects required to consider permanent Treatment BMPs are identified based upon certain criteria as shown in Figure 4-1. The Project Engineer (PE) should use Figure 4-1, the detailed guidance provided in this Section 4, and the Evaluation Documentation Form in Appendix E to determine if a specific project requires the consideration of permanent Treatment BMPs.

Step 2 - Is this an Emergency Project?

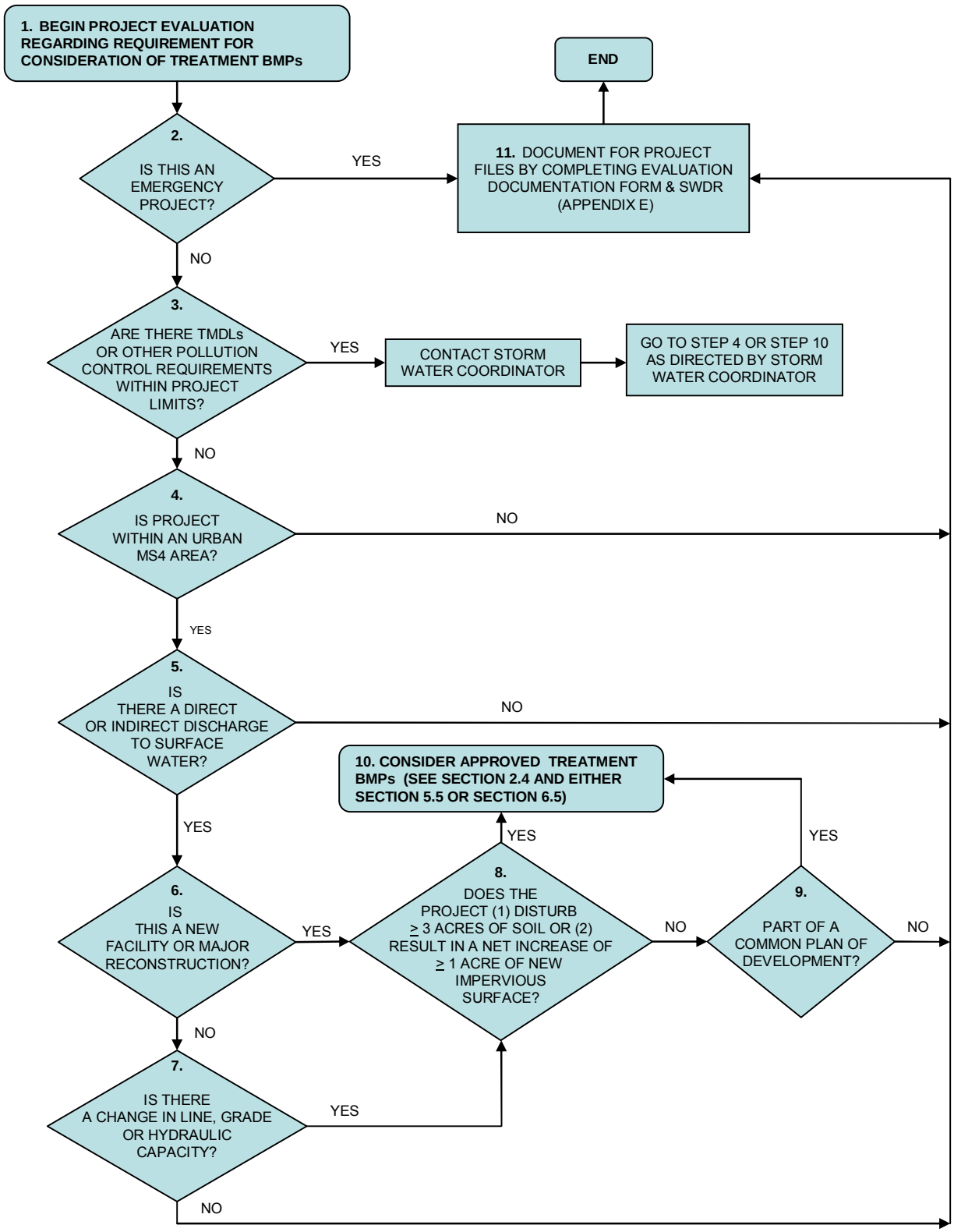
Certain Departmental projects are considered Emergency projects. Throughout the year conditions may arise that require Caltrans to conduct emergency projects to protect public health, safety and property.

Conditions during the emergency projects result in Caltrans being exempt from the requirement to implement Treatment BMPs due to the fact that adding Treatment BMPs could jeopardize the funding and expedient delivery of the project.

These projects may be retrofitted with Treatment BMPs after the objective to restore public health, safety and property has been completed.

Regardless of whether the project falls under an emergency project status, Design Pollution Prevention and Construction Site BMPs need to be considered in project design.

Figure 4-1: Project Evaluation Process for Consideration of Permanent Treatment BMPs



Step 3 – Have TMDLs or other Pollution Control Requirements been established for surface waters within the project limit?

All new construction and major reconstruction projects that discharge into a receiving water for which a TMDL or other Pollution Control Requirement has been established must consider whether Treatment BMPs are required to address the Department's obligations. Pollution Control Requirements include, but are not limited to Basin Plan requirements, TMDLs, 303(d) listings and numeric effluent limits. Contact the District/Regional NPDES Storm Water Coordinator to determine if there are any Pollution Control Requirements or TMDLs within the project limits.

Step 4 – Is the project within an urban MS4 area?

Projects and activities within urban areas subject to MS4 permits may require the consideration of incorporating Permanent Treatment BMPs Coordinate with the District/Regional NPDES and/or Design Storm Water Coordinator to determine if your project limits are within a currently designated urban MS4 area.

Step 5 - Is the project directly or indirectly discharging to Surface Waters?

Surface Waters are known as Waters of the United States and/or Waters of the State. In general, these include creeks, streams, rivers, oceans, reservoirs, wetlands, estuaries and lakes.

A direct discharge means a discharge of surface runoff directly to the surface water body without first flowing through a municipal separate storm sewer system (MS4). An indirect discharge means the discharge of surface runoff to the surface water body through an MS4 stormwater conveyance system, unlisted tributary to the surface water, or a stormwater discharge that otherwise reaches the water body.

If a project directly or indirectly discharges to surface water, the Project Engineer (PE) should consider the additional evaluation criteria in the decision tree, step numbers 3-12. If not, the project is not required to consider the incorporation of Treatment BMPs, and the PE should prepare the appropriate documentation to be attached to the Storm Water Data Report (SWDR).

Step 6 - Does the project constitute a new facility or major reconstruction of an existing facility?

New construction and major reconstruction includes new routes, route alignments, and route upgrades. New construction activity does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of the facility, nor does it include emergency construction activities required to protect public health and safety.

New Construction and major reconstruction projects may include, but are not limited to:

- New highways and freeways;
- Highway-related facilities, including new or reconstructed maintenance facilities, safety roadside rest areas, toll plazas and inspection and weigh stations;
- Adding one or more lanes;

- Adding HOV lanes;
- Construction activities conducted within highway rights-of-way in conjunction with a new facility;
- New or reconstructed interchanges, including on-ramps, off-ramps, and connectors;
- New or reconstructed bridges;
- Tunnels; and
- Drainage system improvements, including changes to pipes, conduits, channels, etc.

Projects containing the elements listed in this section are classified as new facilities or major reconstruction for stormwater purposes.

Step 7 - Will there be a change in line/grade or hydraulic capacity?

Projects that propose a change to the original line, grade, hydraulic capacity, or original purpose of the facility may be required to consider permanent Treatment BMPs. Changes to line, grade or hydraulic capacity include any changes made within the project limits that would alter the hydrologic/hydraulic behavior of stormwater discharges. The following changes would be considered a change in line, grade or hydraulic capacity:

- A change in the time of concentration, peak flow, volume or velocity of stormwater discharges;
- Modifying or creating new drainage ditches, swales, culverts, or storm drain facilities; or
- Changing historic drainage patterns.

Modifying drainage ditches, swales, culverts, or storm drain facilities does not include repairs or grading to re-establish the original line, grade or hydraulic capacity of a ditch or swale, nor does it include minor improvements such as adding culvert flared end sections, energy dissipation, or replacing pipe sections "in-kind."

Examples of activities that would not be considered a change in line, grade or hydraulic capacity include:

- Overlaying a roadway surface;
- Re-grading a ditch to the original line and grade;
- Culvert lining; or
- Replacing a culvert in-kind.

Step 8 - Is the Disturbed Soil Area (DSA) created by the project greater than or equal to 3.0 acres or does the project result in a net increase of one acre or more of new impervious surface?

Both projects that will disturb a soil area of three (3) acres or more and projects that result in a net increase of one acre or more of new impervious surface must consider incorporating approved Treatment BMPs. The District/Regional Storm Water Coordinator should be consulted

if there is any ambiguity or question regarding the determination of the extent of the disturbed area or the applicable Treatment BMPs.

Step 9 - Is the project part of a Common Plan of Development?

Projects that are part of a larger Common Plan of Development whose total land disturbing activities disturb three (3) acres or more and/or projects that result in a net increase of one acre or more of new impervious surface must consider Treatment BMPs. In addition, projects designated as part of a Common Plan of Development by the permitting authority must also consider Treatment BMPs. A Common Plan of Development is broadly defined as any announcement on a piece of documentation or physical demarcation indicating that construction activities may occur on a specific plot. This requirement remains in effect regardless of any lapse in time between the initial grading or clearing of the area and the actual construction on a portion of the land that was graded.

Step 10 - Consider Approved Treatment BMPs for the Project

Checklist T-1, Part 1 provides guidance on which Treatment BMP(s) to consider. Checklist T-1, Parts 2 through 10 also contains design questions that lead the designer through an evaluation of each approved Treatment BMP. See Section 2.4 and either Section 5.5, Section 6.5, or Section 7.4.

Step 11 - Project is not Required to Consider Treatment BMPs

All supporting data used to determine whether a project must consider incorporating Treatment BMPs should be summarized for inclusion in the Project Files. A copy of the completed Evaluation Documentation Form and the supporting data shall be attached to the Storm Water Data Report (SWDR).

If it is determined that a project is not required to consider Treatment BMPs, permanent Design Pollution Prevention BMPs and Construction Site BMPs shall still be considered.

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5.1 INTRODUCTION AND OBJECTIVES

The purpose of this section is to provide a consistent approach in the preparation of the Project Initiation Document (PID) as it relates to incorporating stormwater Design Pollution Prevention, Treatment, and Construction Site Best Management Practices (BMPs) into a project. Although there are several types of PIDs (for a complete list of PIDs, see Chapter 9 of the Project Development Procedures Manual [PDPM], updated September 2005), the most common is the Project Study Report (PSR). Instructions for preparing PSRs are provided in PDPM Appendix L, "Preparation Guidelines for Project Study Reports." This section has been incorporated directly from Appendix L of the PDPM and is to be used only as a supplement to the PDPM.

This section also relates the Work Breakdown Structure (WBS) codes and the Storm Water Data Report (SWDR) and checklists, to the PID process. WBS codes are provided in Appendix E for specific stormwater related tasks during the PID process. These codes are organized in the process form titled "Summary Process for Storm Water Activities for the PID" (included in Appendix E). These codes follow the "Guide to Project Delivery Workplan Standards – Release 8.0A" document. The SWDR and its corresponding checklists are described in this section and are included in Appendix E. These documents should be used for guidance in evaluating BMPs considered during the PID process.

5.2 PROJECT INITIATION DOCUMENT

The purpose of a PID is to develop consensus on the scope, schedule, and estimated cost of a project. The PID is used for programming the project, for proceeding to the environmental evaluation, and for selection of project alternatives. The overall objective of a PID is to gather pertinent information and to clearly define the design concept and design scope of project alternatives. Specific objectives of the PID process as it relates to stormwater quality are listed as follows:

- Define need and purpose of the project;
- Estimate and program the design resources needed to prepare the Plans, Specifications and Estimates (PS&E) and project management costs;
- Define stormwater quality issues and pollutants of concern;
- Form the Project Development Team (PDT), including a District/Regional Storm Water Coordinator;
- Develop project alternatives and evaluate potential stormwater impacts for each alternative;
- Develop a list of potentially feasible permanent stormwater Design Pollution Prevention and Treatment BMPs to be evaluated during later phases of project design;
- Develop the preliminary costs for BMPs and the associated right-of-way costs for incorporating BMPs, and include these costs in the PID;
- Discuss the stormwater quality elements of the project with the Regional Water Quality Control Board (RWQCB) and/or local agencies, if necessary, as determined

by the District/Regional National Pollutant Discharge Elimination System (NPDES) Storm Water Coordinator or if requested by the RWQCB;

- Program the project construction costs, costs for right-of-way associated with construction, and stormwater quality related costs;
- Perform and document the field review and research of other projects in the same general area;
- Identify and document any existing Treatment BMPs within the project limits (e.g. contact Maintenance for an inventory of existing Treatment BMPs) or existing features that provide water quality benefits (see Appendix B.1.4);
- Develop an initial Construction Site BMPs strategy appropriate for the PID phase; and
- Prepare the Preliminary Environmental Assessment Report (PEAR) and Water Quality Impact Questionnaire.

5.3 PROJECT INITIATION DOCUMENT PROCESS

The PID process is intended to obtain management approval of candidate projects, identify right-of-way acquisition needs and determine costs for programming. Therefore, it is essential that all work incidental to the project, including stormwater quality items, be included in the scope and cost estimates. The outcome of the PID process is a well-defined, proposed project scope tied to a reliable cost estimate and schedule that is suitable for programming or local commitment, as well as for proceeding to the Project Approval/Environmental Document (PA/ED) process. It is understood, however, that a project's scope may change as environmental or other studies are completed.

A PEAR is prepared by the Environmental Unit when requested by the Design Unit, and is used to provide necessary information for the completion of a PID. The purpose of a PEAR is to determine whether there are any potentially significant environmental issues that could affect the viability of any project alternatives. When it is concluded that there are water quality issues raised by a proposed project (and its alternatives) and that a potential for one or more substantive water quality impacts exists, then a comprehensive Water Quality Assessment Technical Report (WQR) is prepared during the PA/ED phase of a project. The need for a WQR is determined by the Water Quality Impact Questionnaire completed as part of the PEAR.

The Project Engineer (PE) should use the information from the PEAR during the PID process as a resource to prepare the SWDR when defining the stormwater quality issues for the project. The PE should provide the SWDR to the designated Environmental Staff who prepared the PEAR to verify the information included in the SWDR.

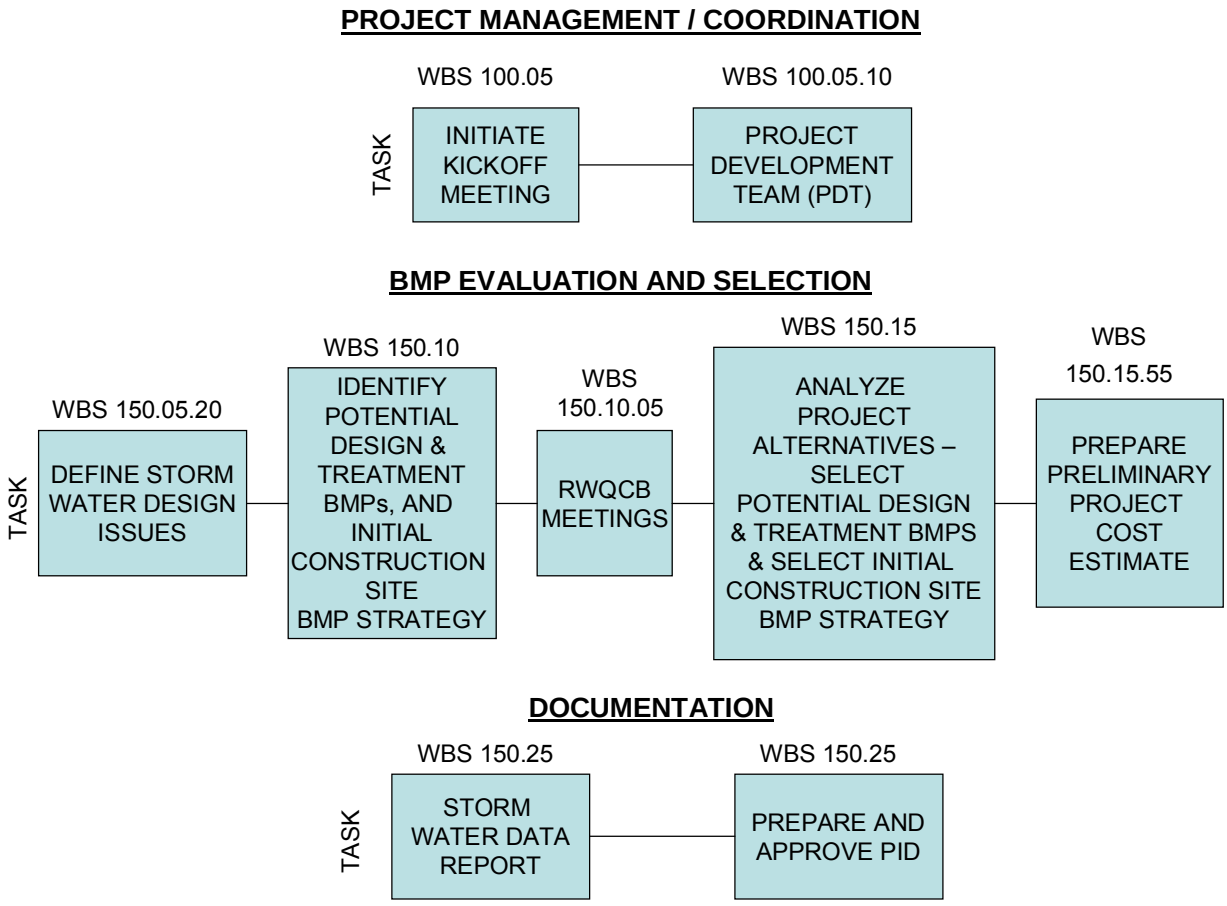
If the PEAR determines that a WQR is required for the project, the PE should coordinate with the Environmental Unit and District/Regional NPDES Storm Water Coordinator during its preparation to update the SWDR as part of the PA/ED process.

Figure 5-1 is a flowchart that illustrates the overall primary task categories for the PID process. Included in the flowchart are WBS Codes for each task. Appendix E includes a process form

titled "Summary of Storm Water Activities for the PID" that provides a step-by-step process of the tasks described in this section.

The sub-sections that follow correspond to the task categories shown in Figure 5-1 and the PID Process Summary Form in Appendix E. Additional information is provided on the following pages detailing the recommended participants, discussion and decision topics, documentation, and verifications for each task to obtain final PID approval and funding for a project.

Figure 5-1: Project Initiation Document - Storm Water Task Categories



5.4 PROJECT MANAGEMENT / COORDINATION

This section describes the primary task categories involved with project management and the coordination in the PID process needed to obtain consensus between the different functional units regarding stormwater issues.

Initiate Kickoff Meeting, WBS 100.05

Narrative: The kickoff meeting is typically initiated by the Project Manager (PM) to discuss the need and purpose of the project.

Responsible: Project Manager (PM)

Recommended Participants:
Project Manager
Project Engineer
District/Regional Storm Water Coordinator
Appropriate functional units
Environmental Engineering Representative
Environmental Planning Representative

Discussion Topics: Project Definition**:** Discuss the project purpose, type, location, schedule, size, and project alternatives.

Project cost estimate**:** Discussion is included early so that the necessary funds can be estimated as soon as possible. Obtain Preliminary Project Cost Estimate (PPCE) form for items to be included.

Discuss the potential need for additional right-of-way to incorporate Treatment BMPs.

Discuss any environmental concerns and/or issues**.**

Decisions/actions: Determine if additional functional units should be involved.

Documentation: Meeting minutes
Start PID

Verification: There is no verification required at this phase.

Project Development Team (PDT), WBS 100.05.10

Narrative: The PDT advises and assists the PE in directing the course of studies, makes recommendations to the PE and District management, and works to carry out the project work plan. Members of the PDT participate in major meetings, public hearings, and community involvement. The PDT is responsible for conducting studies and accumulating data throughout the project's development, from the beginning of the PID process through the PS&E process. The PDPM, Chapter 8, Section 4 (July 1999), provides a thorough description of the PDT and its functions.

Responsible: Project Manager

Recommended Participants:
Project Manager
Project Engineer
District/Regional NPDES Storm Water Coordinator
District/Regional Design Storm Water Coordinator
District Landscape Architect or Project Landscape Architect
Environmental Engineering Representative

Environmental Planning Representative

Construction Storm Water Coordinator

Maintenance Storm Water Coordinator

Right-of-Way Representative

Hydraulics Representative

District Materials Engineer

Geotechnical Representative

Traffic Representative

Local MS4 Representative (if applicable)

RWQCB Representative (at discretion of District/Regional NPDES Storm Water Coordinator)

Others as needed.

All Districts are not organized the same; therefore, the suggested PDT members may have different titles depending upon the District in which the project is located. The PM and the PE should consult the specific District Work Plan (DWP) to obtain the contacts listed in this section or the equivalent title or function in the District.

Discussion Topics: The PDT should meet throughout the entire project in order to maintain communication and to obtain consensus between the functional units.

The following stormwater quality issues are examples of what should be discussed:

- Viable alternatives for projects including location and alignments;
- Evaluate approved BMPs for potential implementation;
- Evaluate whether Treatment BMPs are required to be considered (see Section 4);
- Estimated project cost and BMP costs for various alternatives;
- Environmental issues;
- Site conditions and design constraints;
- Stormwater quality requirements/Basin Plan objectives;
- Storm Water Pollution Prevention Plan (SWPPP) versus Water Pollution Control Program (WPCP);
- Identifying the appropriate RWQCB jurisdiction;

- Identifying water bodies potentially affected by the project;
- Any special requirements established by the RWQCB for those water bodies, including numeric effluent limits, TMDLs, or other requirements;
- Water quality volume and flow;
- Right-of-way impacts, location and size of Design Pollution Prevention and Treatment BMPs;
- Need for permanent or temporary dewatering;
- Presence of aerially deposited lead or other contaminants;
- Evaluation of slope stability;
- Initial Construction Site BMPs strategy;
- Presence of Drinking Water Reservoirs and/or Recharge Facilities; and
- Public access and need for drain inlet stenciling.

Decisions/actions: Document any decisions made during PDT meetings.

Documentation: Meeting minutes

Evaluation Documentation Form

Checklists SW-1, SW-2, DPP-1 and T-1.

Verification: The PE verifies that all documentation is completed.

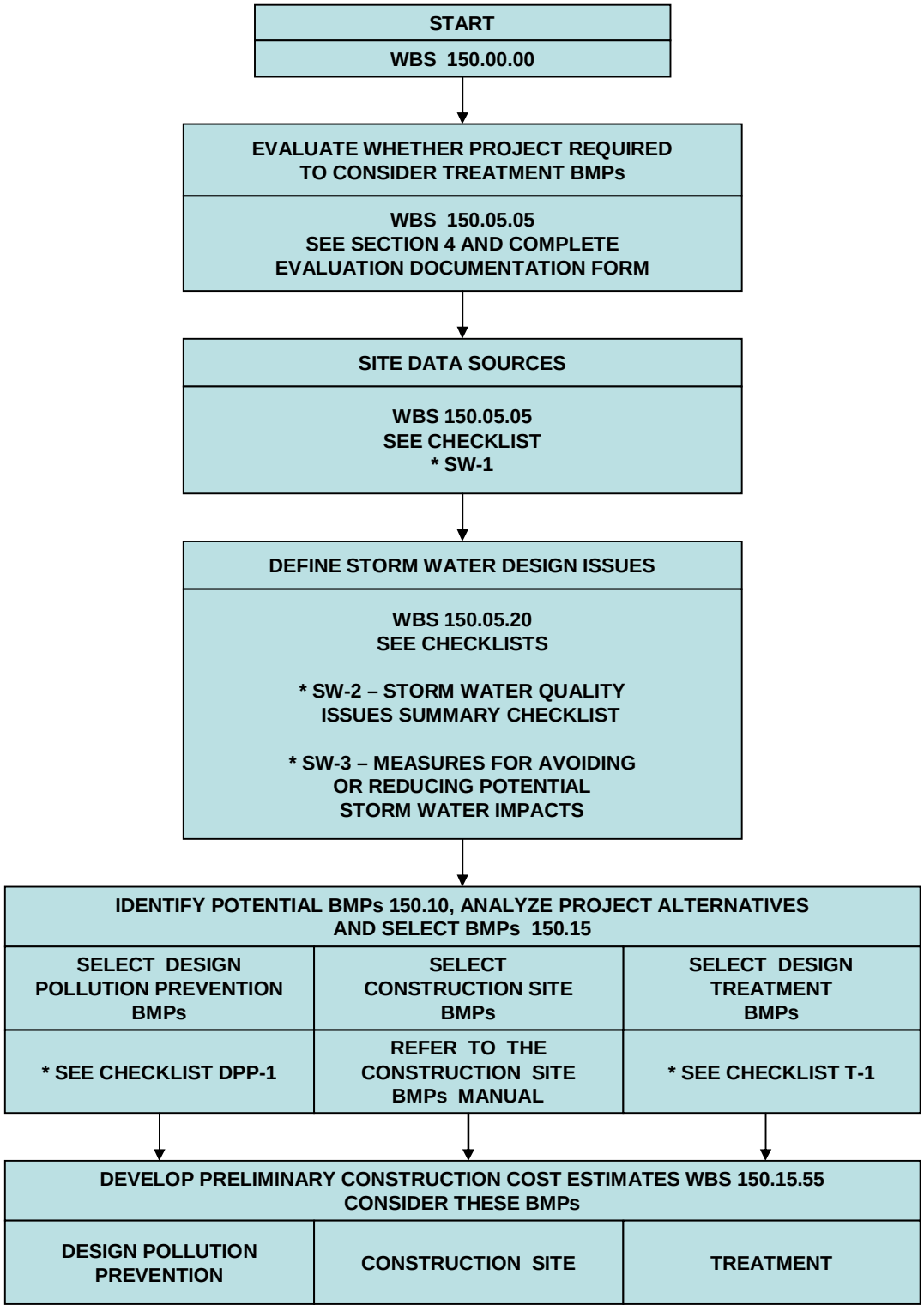
5.5 BMP EVALUATION AND SELECTION PROCESS

This section describes the primary task categories for the Design Pollution Prevention and the Treatment BMP selection procedures associated with the PID process. For information regarding the initial Construction Site BMPs strategy, consult with Construction Storm Water Coordinator and refer to Manual for Construction Site BMPs (see Appendix D for web address). Figure 5-2 is a flowchart that illustrates the process development of considering BMPs in a project. A description of the corresponding checklists listed in Figure 5-2 is provided in Section 5.5.1.

There are three goals for the evaluation and selection process. They are:

1. To obtain consensus between the different functional units regarding preliminary BMP selection;
2. To facilitate the consideration of the BMPs during the PID process; and
3. To provide sufficient information regarding BMP consideration, and if appropriate, evaluation and selection once the PA/ED process is initiated.

Figure 5-2: Flowchart for Consideration of Storm Water BMPs for the PID



*** LOCATED IN APPENDIX E**

5.5.1 Storm Water Data Collection

Define Storm Water Design Issues, WBS 150.05.20

Narrative: Checklists provided in Appendix E and described below are tools for designers to evaluate potential Design Pollution Prevention, Treatment, and Construction Site BMPs for incorporation into a project.

The checklists can be attached to the SWDR, which is also described herein. The SWDR and the checklists are refined during the PA/ED and PS&E processes.

Responsible: Project Engineer

Recommended Participants:
Project Manager
Project Engineer
District/Regional Storm Water Coordinator
Primary functional units

Discussion Topics: The following items 1 – 5 are initiated during the PID Process.

1. **Evaluation Documentation Form for Treatment BMPs, WBS 150.05.05**

   Following the directions provided in Section 4 of this document, determine whether or not the project is required to consider incorporating Treatment BMPs. Complete the Evaluation Documentation Form in Appendix E. If it is determined that the project is not required to consider incorporating Treatment BMPs, then attach the Evaluation Documentation Form and tabulated supporting data to the SWDR. Continue with the selection of Design Pollution Prevention BMPs.

2. **Storm Water Data Report, WBS 150.25**

   The SWDR summarizes the information found in Checklists SW-1, SW-2 and SW-3 (described as follows). The checklists and the SWDR are initiated during the PID process, updated during the PA/ED process and updated again and completed during the PS&E process. During each process, the SWDR is signed by the PE, District Design Storm Water Coordinator, designated Landscape Representative, designated Maintenance Representative, and by the PM to verify that stormwater quality design issues have been addressed and the data are complete, current and accurate. The PE stamp is required at PS&E. This report is to be included in the final PS&E package (see Section 7). Checklists SW-1, SW-2 and SW-3 should be included as a Supplemental Attachment to the SWDR during the review process.

3. Site Data Resources: Checklist SW-1, WBS 150.05.05

Checklist SW-1 lists categories of pertinent information required for stormwater planning and design. Checklist SW-1 should be completed citing the source and date of the information collected for each entry where appropriate.

The five main categories for site data collections are topographic, hydraulic, soils, climatic and water quality. These data should be collected from the various functional units. Field visits should also be conducted to gather pertinent data. The following provides some examples of data that can be collected pertaining to the aforementioned categories:

Topographic Data:

- United States Geological Survey (USGS) Quad Maps;
- Survey Reports and Maps – Survey needs should be evaluated and identified early in the PID process and throughout the entire project development process when needed. After the first evaluation of survey needs, the PE should submit the initial survey request accompanied by a location map;
- Aerial Mapping/Photo Mosaics;
- Vegetation – Existing cover and types of vegetation present should be documented; and
- Landscape/Aesthetic Analysis – The PE requests information from the Landscape Architect to Perform Landscape/Aesthetic Analysis. This helps to evaluate the implementation of mandatory stormwater Design Pollution Prevention BMPs into the overall landscaping plan for the project. Erosion prevention and stormwater pollution prevention BMPs should be incorporated into the project landscaping and revegetation plan.

Soils Data:

- Natural Resources Conservation Service (NRCS) Soil Survey Reports and Maps – Potential areas of serious erosion problems should be identified and provided; and
- Geotechnical Design Reports and Well Records – Well records and Geotechnical Design Reports can provide information regarding the depth from surface to seasonal high groundwater. The local Maintenance Supervisor should be consulted to identify existing drainage and/or erosion problems.

Hydraulic Data

- Groundwater Data;
- Stream Flow Data;
- Drainage Area – Routes and patterns (define sub-basins); and
- Identification of drainage areas affecting or tributary to Drinking Water Reservoirs and/or Recharge Facilities.

Climatic Data

- Rainfall Intensities (as required under HDM for drainage design and as necessary for sizing potential BMPs).

Water Quality Data

- The PE should coordinate with the Environmental Unit and the District/Regional NPDES Storm Water Coordinator during the preparation of the PEAR. This coordination enables the PE to share project-specific information, and to ensure consistency between the evaluation of project alternatives, the completion of the Storm Water Checklists, and the water quality assessments included in the PEAR;
- Receiving water bodies;
- Hazardous Material/Waste Information;
- RWQCB Jurisdiction and Basin Plan;
- Identifying TMDLs within project limits; and
- Water Quality Volume (WQV) and Water Quality Flow (WQF).

4. Storm Water Quality Issues Summary: Checklist SW-2

Checklist SW-2 provides a guide to collecting information relevant to project stormwater quality issues. The PE should coordinate with the Environmental Unit when compiling and reviewing the information required by Checklist SW-2. This information is critical in facilitating the selection and design of the preferred BMPs. This activity includes the following tasks:

- Compile and review existing background information that may impact the alternatives or the scope of the alternatives under consideration, including existing stormwater quality issues. Such background information will help identify specific District and RWQCB requirements as well as the possibility of sensitive receiving waters or valuable habitats; and
- Analyze future requirements to determine the project's need and purpose. This task requires the analysis of site-specific conditions or potential sources of pollution for effective soil stabilization and

sediment control. This task includes discussion with internal and external stakeholders.

5. Measures for Avoiding or Reducing Potential Storm Water Impacts: Checklist SW-3

Checklist SW-3 provides direction to the designer during the project planning phase to avoid or reduce potential stormwater impacts. The planning phase represents the greatest opportunity to avoid adverse water quality impacts as alignments and right-of-way requirements are developed and refined. Avoiding impacts may reduce or eliminate the need for mitigation measures. The PE should coordinate with the Environmental Unit when compiling and reviewing the information required by Checklist SW-3.

Table 5-1 identifies many of the project features and potential stormwater impacts that should be considered. The PE should obtain or develop this information for each project or alternative. The PE must confer with other functional units, such as Landscape Architecture, Hydraulics, Environmental, Materials, Construction, Maintenance, Right-of-Way, and the NPDES office when necessary. This will usually be accomplished by submitting layouts/base maps, in conjunction with other information required by the functional units, to determine impacts and BMP requirements.

Decisions/actions: Identify potential stormwater quality impacts or issues.

Estimate project cost of the potential BMPs.

Documentation: Evaluation Documentation Form

Preliminary Checklists SW-1, SW-2, SW-3 and the SWDR. These will be first drafts since not all information will be available.

Verification: District/Regional Design Storm Water Coordinator or designated functional unit verifies that the SWDR and checklists are being completed appropriately.

Table 5-1: Project Features and Potential Impacts to Be Considered During Project Planning

Features and Potential Impacts to be Considered	Reason Why They Must be Considered
Identify which RWQCB will have jurisdiction over the project(s). Does the RWQCB have any special requirements?	Requirements may vary by RWQCB. May impact permanent and temporary control requirements.
Identify receiving waters and all other waters that may affect or may be affected by the project. Consider aquifers, wells, streams, lakes, reservoirs, wetlands, and waters both fresh and saline. Consider impacts throughout the project lifecycle, including construction, maintenance, and operation.	First step in identifying impacts and potential control measure requirements.
Are any of the receiving waters impaired [303(d) listed] or have TMDLs been established? (Discharges to impaired water bodies may be subject to strict numeric water quality standards and prescribed treatment controls.)	Supplemental controls may be required to further reduce pollutants to meet numeric water quality standards, waste load allocations or requirements of an adopted watershed plan.
Will construction require work in, above, or directly adjacent to the water bodies listed in this section?	Could require additional environmental permits/agreements and control measure requirements.
Are any sensitive fishery, wildlife, recreational, agricultural, or industrial aquatic resources located in the vicinity of the project?	Could require additional environmental permits/agreements and control measure requirements.
What is the unit cost for additional right-of-way should it be needed for Treatment BMPs or other control measures or requirements?	Used for budgeting and cost estimating.
Will the project increase the potential for downstream erosion by adding impervious surfaces, decreasing the time of concentration, or redirecting flows?	May need to implement Peak Flow Attenuation Basins or stabilized conveyance systems to prevent damage to off-site streambanks or channels.
Does the project discharge to lined, engineered drainage facilities or unlined, natural channels?	Will need to consider implementing Peak Flow Attenuation Basins or stabilized conveyance systems for streambank protection.
Identify general soil types and vegetation within the project site.	Basic information needed for slope design, slope protection plans and infiltration BMPs.
How difficult will it be to re-establish vegetation following construction?	May affect slope stabilizations plans.
How long will it take for the new vegetation to establish? What vegetation, if any, can be preserved?	Used to determine the need for separate vegetation establishment contract.
Are any slopes steeper than 1:4 vertical:horizontal (v:h)?	Slopes steeper than 1:4 require an erosion control plan prepared or approved by the District Landscape Architect.
Are any slopes as steep as or steeper than 1:2 (v:h) ?	If yes, a Geotechnical Design Report must be prepared by Geotechnical Services. Additionally, the District Landscape Architect should prepare or approve an erosion control plan and Maintenance must concur with the proposed slope.
Determine the general climate, annual rainfall, and typical seasonal rainfall patterns for the project area.	Basic information needed for slope design, slope protection plans, BMP feasibility, plus conveyance system design and sizing of treatment controls.
Determine the proposed project slopes, and areas of cut and fill.	Basic information needed for slope design and slope protection plans.
Does the project include contaminated or hazardous soils as identified in the initial site assessment (ISA) and environmental documents?	May impact project construction activities and deployment of temporary controls during construction. May affect whether soil can be re-used.

Table 5-1: Project Features and Potential Impacts to Be Considered During Project Planning (Continued)

Features and Potential Impacts to be Considered	Reason Why They Must be Considered
Will the contractor's yard be located within the State's right-of-way or otherwise be arranged for or provided by Caltrans? If so, what are the potential impacts?	May impact responsibility for deployment of temporary controls during construction.
Do the regulatory agencies have seasonal construction restrictions?	May impact project construction activities and deployment of temporary controls during construction.
Identify Drinking Water Reservoirs and/or Recharge Facilities that fall within or are adjacent to project limits.	Could require additional features to minimize spills or intercept spills.

5.5.2 Identify Potential BMPs, WBS 150.10

Narrative: This activity includes identifying potential Design Pollution Prevention and Treatment BMPs for implementation.

Responsible: Project Engineer

Recommended Participants:
Project Manager
Project Engineer
District/Regional NPDES Storm Water Coordinator
District/Regional Design Storm Water Coordinator
District Landscape Architect or Project Landscape Architect
Environmental Engineering Representative
Environmental Planning Representative
Construction Storm Water Coordinator
Maintenance Storm Water Coordinator
Right-of-Way Representative
Hydraulics Representative
District Materials Engineer
Geotechnical Representative
Traffic Representative

Discussion topics:
Potential BMPs
Checklists, SW-1, SW-2, SW-3
Environmental Impacts

Decisions/actions: Develop general scope and study limits of the potential BMPs selected for further evaluation. These potential BMPs are now ready for further analysis to determine project features, cost, and feasibility.

Documentation: Completed PID level Checklists SW-1, SW-2, SW-3

Project descriptions for potential BMPs (including maps of areas with potential impact)

Verification: The PE must verify that consensus is reached with internal/external stakeholders on the potential BMPs that will be addressed in the PID.

Regional Water Quality Control Board Meetings, WBS 150.10.05

Narrative: Consultation with the RWQCB, local regulatory agencies and MS4 Permit Holders is strongly recommended to coordinate project issues and develop consensus for controversial or complex stormwater quality issues. The number of coordination meetings is dependent upon the complexity of the stormwater quality issues, stormwater pollutants involved, and project site constraints.

Responsible: PE and the District/Regional NPDES Storm Water Coordinator. The PE should consult with the District/Regional NPDES Storm Water Coordinator regarding the complexity of the project and the need to consult with the RWQCB at this early stage in the project.

Recommended Participants: Project Manager

Project Engineer

District/Regional NPDES Storm Water Coordinator (primary point of contact with the RWQCB)

RWQCB, MS4, and/or local agency representatives

Department of Fish and Game, if necessary

The Army Corps of Engineers, if necessary

County Health Department, if necessary

Discussion Topics: Present Project Information

- Site Conditions
- Project Alternatives
- Consider Approved Treatment BMPs
- Implement Design Pollution Prevention BMPs
- Storm Water Quality Impacts and Issues
- Right-of-Way Impacts

Decisions/actions: Complete project alternatives

Identify preliminary site conditions and stormwater concerns

Complete preliminary evaluation of permanent BMPs

Documentation: Meeting minutes

Verification: The PE must verify that all comments are recorded and resolved.

5.5.3 Analyze Project Alternatives / Select BMPs, WBS 150.15

Narrative: The purpose of this activity is to develop a general overview of the estimated costs for BMPs for different project alternatives. It is anticipated that a general discussion of each BMP alternative will be included for each project alternative that is presented in the PID. Thus, analysis of the project alternatives is required for this activity.

One of the variables considered when selecting a preferred project alternative may be the potential BMPs required for that alternative. Thus, it is anticipated that BMPs must be considered as early as possible. Costs developed in this activity will be used for programming purposes; consequently, the analysis should be of sufficient detail to identify all potential BMP costs.

Note: Appendix C of the SWMP is the design reference for all approved Construction Site BMPs. Appendices A and B of this PPDG contains specific information on Design Pollution Prevention BMPs and Treatment BMPs, respectively.

As described in Section 4 of this document, a project may not be required to consider incorporating approved Treatment BMPs based on the established criteria displayed in Figure 4-1. If a project is not required to consider Treatment BMPs, continue with the selection of Design Pollution Prevention BMPs. If it has been determined that a project is required to consider incorporating Treatment BMPs, the feasibility of the approved Treatment BMPs must be evaluated. If no approved Treatment BMPs can be deployed within a specific project and no pilot BMP has been identified, then the PE, in consultation with the District/Regional NPDES Storm Water Coordinator, will prepare a technical report documenting why Treatment BMPs could not be incorporated into the project (prepared during PS&E).

Responsible: Project Engineer

Recommended Participants:

Project Manager

Project Engineer

District/Regional NPDES Storm Water Coordinator

District/Regional Design Storm Water Coordinator

Hydraulics Representative

District Landscape Architect or Project Landscape Architect

Geotechnical Representative

Environmental Branch for coordination

- Coordination through the Environmental Branch includes NPDES review as part of the environmental process.

Maintenance Storm Water Coordinator

District Materials Engineer

Construction Storm Water Coordinator

Discussion Topics: Discuss Checklists DPP-1 and T-1 (all Checklists are located in Appendix E). These Checklists are used for guidance in selecting Design Pollution Prevention and Treatment BMPs. The following is a description of each Design Checklist.

- **Checklist DPP-1, Design Pollution Prevention BMPs**

  All projects must incorporate certain minimum design elements with respect to water quality. The design goals for the Design Pollution Prevention BMPs include the following:

  – Minimize Impervious Surfaces: The intent of this goal is to reduce the volume of runoff.

  – Prevent Downstream Erosion: Stormwater drainage systems will be designed to avoid causing or contributing to downstream erosion.

  – Stabilize Disturbed Soil Areas: Disturbed soil areas will be appropriately stabilized to prevent erosion.

  – Maximize Vegetated Surfaces: Vegetated surfaces prevent erosion, promote infiltration (which reduces runoff), and remove pollutants from stormwater.

  Part 1 of Checklist DPP-1 is a list of questions that will help the PE determine which Design Pollution Prevention BMPs to consider. Once Part 1 is completed, the PE can refer to Parts 2 – 5 for design questions regarding the specific Design Pollution Prevention BMPs.

- **Checklist T-1, Treatment BMPs.**

  Part 1 of the checklist provides guidance on which Treatment BMPs to consider. Once Part 1 is completed, the PE can refer to Parts 2 – 10 for design questions regarding the specific Treatment BMPs.

Other discussion topics include:

- General overview of estimated scope and cost for BMP deployments for different project alternatives;
- The location of permanent BMPs;
- Every SWPPP project is required to include separate bid items for Construction Site BMPs. See Appendix D for the most current Standard Special Provisions (SSP) web site;
- Acquisition of right-of-way, considered for funding allocation;
- Initiate Geotechnical Report, Materials Report and Drainage Report; and
- Determine quantities for BMPs, if possible. If quantities cannot be estimated at the PID stage, planning-level cost information (provided in Appendix F) is to be included in the PID to reference BMPs and their anticipated costs.

Decisions/actions: Establish project scope, cost, and feasibility for presentation in the PID and programming.

Determine all potentially feasible BMPs.

Documentation: Checklists DPP-1 and T-1

Preliminary Project Cost Estimate (PPCE), see Section 5.5.4

Preliminary Geotechnical Report

A final report on materials and geotechnical issues is not required at this stage, but a draft report would be appropriate

Preliminary SWDR

Verification: District/Regional Design Storm Water Coordinator or other designated person must verify documentation

5.5.4 Prepare Preliminary Project Cost Estimates, WBS 150.15.55

Narrative: A preliminary cost estimate is a required attachment for most PIDs. Because the PID cost estimate will most likely be used as the current PPCE, the importance of a reliable estimate at this stage cannot be overemphasized. The PPCE form to be filled out is located in Appendix L (2/18/00) and Appendix AA of the PDPM (7/1/99). It is the initial base against which following estimates are measured and has extremely high visibility. Chapter 20 of the PDPM provides guidance on the current method of cost estimating, the responsibilities of staff and functional units. Appendix F of this document provides greater detail on methods for cost estimating in order to include stormwater BMPs as part of the overall project cost.

Responsible: Project Engineer

Recommended Participants:
Project Manager
Project Engineer
Hydraulics Representative
Environmental Engineering Representative
Environmental Planning Representative
District/Regional NPDES Storm Water Coordinator
District/Regional Design Storm Water Coordinator
Construction Storm Water Coordinator
Maintenance Storm Water Coordinator
District Landscape Architect or Project Landscape Architect

Discussion Topics:
Bid data from similar projects
Sampling and Analysis Plans
Potential Construction Site BMPs to be incorporated into the project.
Sensitive Environments (such as 303(d) listed water bodies)
Highway Planting contracts
Supplemental funds
Costs for SWPPP or WPCP development and implementation
Costs for potential permanent stormwater BMPs
Available cost options (i.e., historical sample projects, percent of total project costs (see Appendix F)

Decisions/actions:
Prepare, revise and update project cost estimates.
Incorporate new or revised cost data from functional units in project cost estimate.
Provide revised or updated current cost estimates and their respective dates for inclusion in the project management data base in a timely manner.
Complete the PPCE

Documentation: Completed PPCE

Verification: The following functional units shall verify the completed PPCE:
NPDES
Landscape

Hydraulics

Environmental

Maintenance

Construction

5.6 DOCUMENTATION REQUIRED FOR PROJECT INITIATION DOCUMENT

This section describes the documents necessary for completion of a PID.

Prepare and Approve PID, WBS 150.25

Narrative: The overall purpose of a PID is to develop a purpose and need statement that solves a transportation problem. Areas under consideration are right-of-way needs, environmental impacts, accurate cost estimates and required scheduling. As mentioned earlier, the PSR is the most common PID. Preparation guidelines of the PSR are included in Chapters 2 and 3 of Appendix L of the PDPM, 2/18/00. These guidelines are available on-line at http://www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm

The purpose of this section is to ensure that stormwater quality issues are identified, and that all appropriate BMPs are being considered in the PID.

This activity includes all tasks required to develop the PID text and exhibits, as well as the effort required to circulate, review and update the PID (includes appropriate "constructability review" for project initiation process). This activity also includes development and approval of any required design exceptions and/or a Federal Highway Administration (FHWA) access modification request. This WBS also includes the development and approval of any supplemental PIDs.

Responsible: Functional Manager overseeing preparation of the PID. The final PID is submitted to the Division Chiefs. The PE is required to route for signature and approval of PID.

Recommended Participants:

Project Manager

Division Chiefs

Project Engineer

Contents: The following should be included in the PID package. Also refer to the PDPM, Appendix L, for the format and contents required.

- A brief discussion of the applicable stormwater treatment goals, including descriptions of the anticipated permanent and Construction Site BMPs plus their anticipated cost estimates
- Descriptions of the anticipated permanent and Construction Site BMPs including their anticipated cost estimates;

- Evaluation Documentation Form;
- General Overview of the Treatment BMPs considered by each viable alternative. That description shall include the anticipated location and size of any considered Treatment BMP. See Appendix L of the PDPM, page L-25 No. 4, Alternatives (2/18/00);
- A summary of the engineering features for each alternative used to satisfy stormwater pollution prevention measures described in Section 2;
- PEAR – The PE shall include a copy of the PEAR and the Water Quality Impact Questionnaire which identify potentially significant project-related water quality impacts and determines whether a WQR will need to be prepared.
- Right-of-Way Data Sheet. The PE shall also identify the additional right-of-way and consider costs related to stormwater treatment;
- SWDR;
- Storm Water Checklists SW-1, SW-2, and SW-3 should be included as a Supplemental Attachment to the SWDR during the approval process.

Documentation: The PID package includes a copy of the PID, PEAR, Right-of-Way Data sheets, Advanced Planning Study (APS), the PPCE, and the SWDR cover sheet. Incorporate "Storm Water Pollution Prevention Discussion (under "Considerations" heading) of planning document. See the "Summary Process for Storm Water Activities for PID" in Appendix E.

Verification: The following Division Chiefs shall approve the completed PID:

- The Functional Manager responsible for production of the PID;
- Program/Project Manager.

The District Division Chiefs are responsible for approving the project's scope, schedule, and cost within these established guidelines, and may exercise engineering judgment and flexibility in approving the PID. PIDs are to be approved by the District Director after review by the Division Chiefs, Functional Manager and the PDT.

Project Managers are to endorse the decision by "Approval Recommended By" or "Approved By" where such authority has been delegated.

The SWDR shall be signed by the PE, the District/Regional Design Storm Water Coordinator, the designated Landscape Representative, the designated Maintenance Representative, and the PM to verify that stormwater quality design issues have been addressed, and the data is complete, current, and accurate. The District/Regional Design Storm Water Coordinator should be the last person to sign the SWDR to ensure that all appropriate reviews have been completed.

This activity is complete with the approval and distribution of the PID.

6.1 INTRODUCTION AND OBJECTIVES

The purpose of this section is to provide a consistent approach in the Project Approval/Environmental Document (PA/ED) process as it relates to incorporating stormwater Design Pollution Prevention, Treatment, and Construction Site Best Management Practices (BMPs) into a project. The PA/ED process results in a Project Report (PR). Instructions for preparing PRs are provided in Appendix K, "Preparation Guidelines for Project Reports" of the Project Development Procedures Manual (PDPM). The described process has been incorporated directly from Appendix K of the PDPM and is to be used only as a supplement to the PDPM.

This section also relates the Work Breakdown Structure (WBS) codes and the Storm Water Data Report (SWDR), and checklists to the PA/ED process. WBS codes are provided in Appendix E for specific stormwater related tasks during the PA/ED process. These codes are organized as a process form, which is titled "Summary Process for Storm Water Activities for the PA/ED" (included in Appendix E). These codes follow the "Guide to Project Delivery Workplan Standards – Release 8.0A" document. The SWDR and its corresponding checklists are described both in this section and in Section 5 of this document and are included in Appendix E. These can be used for guidance in selecting BMPs for inclusion in the PA/ED process.

6.2 PROJECT APPROVAL/ENVIRONMENTAL DOCUMENT

The purpose of the PA/ED is to summarize the studies of the scope, cost, and overall environmental impact of alternatives so that the decision maker can make an informed decision about whether or not to proceed with the project, and also select appropriate Design Pollution Prevention, Treatment, and Construction Site BMPs.

The objective of a PA/ED process is to clearly refine the design concept and design scope of the project alternatives listed in the Project Initiation Document (PID), and to obtain the necessary environmental documents. As mentioned earlier, the PA/ED results in a PR. For a complete list of PRs, see the PDPM, Chapter 12, Section 4 (September 2005). PIDs and PRs require similar information, acquired at different points in time. The PID is preliminary in nature and does not benefit from knowledge acquired from detailed environmental studies. When preparing a PR, appropriate PID data should be updated prior to its insertion in the PR; appropriate data from the environmental studies should be included.

The water quality goal of the PA/ED phase is to utilize updated and more detailed engineering and environmental data to continue the BMP selection process that was initiated during the PID process. The design team should also review the BMPs previously identified to determine whether they are still appropriate and whether they represent the best application of the BMPs approved for statewide use. The PE should investigate whether new stormwater BMPs were approved for statewide use subsequent to the approval of the PID.

Specific objectives of the PA/ED process are listed as follows:

- Review and update project scope in the PID;
- Refine scope, estimate and Project Development Resources;

- Prior to initiating the environmental studies, prepare geometric plans and right-of-way maps in greater detail to identify the areas of potential effects;
- Begin the environmental studies to prepare and process the appropriate environmental document(s) and permits for the project;
- Complete detailed environmental and engineering studies for project alternatives;
- Select the preferred alternative and further define stormwater pollution impacts. Chapter 12 of the PDPM describes the project development policies and procedures for selecting and approving the preferred alternative and for project approvals. Selection of the preferred alternative authorizes the completion of the PR for project approval;
- Develop General Cost Estimate for potential BMPs to be incorporated into the project;
- Initiate and complete PR after environmental studies and costs estimates are completed;
- Continue coordinating the project with the Regional Water Quality Control Board (RWQCB) and local agencies; and
- Complete the Water Quality Assessment Technical Report (WQR), as determined by the Water Quality Impact Questionnaire or updated water quality information. The information presented in the WQR will be utilized by Caltrans Design, Construction and Maintenance staff to develop and implement specific BMPs to mitigate any potential water quality impacts associated with stormwater discharges from the proposed project.

6.3 PROJECT APPROVAL/ENVIRONMENTAL DOCUMENT PROCESS

The PA/ED process is generally initiated after the PID is approved, and the project is programmed. It is intended to obtain management approval of a selected preferred alternative project, identify right-of-way acquisition needs, further define costs, and develop the necessary environmental documents, in accordance with the California Environmental Quality Act and National Environmental Policy Act (CEQA/NEPA).

A WQR is prepared by the Environmental Unit, as determined by the Water Quality Impact Questionnaire as part of the PEAR, which is completed during the PID process. The WQR would typically be a technical appendix to the CEQA/NEPA document.

The Water Quality Impact Questionnaire identifies potential water quality impacts, and is incorporated into the PEAR. The Water Quality Impact Questionnaire was developed to assist in early identification and consideration of the broadest rage of potential water quality effects, determine whether a detailed WQR is appropriate, and to scope the PEAR analysis with respect to water quality issues. The Questionnaire asks a series of questions about the project description and alternatives, the project setting, and potential project impacts on water quality.

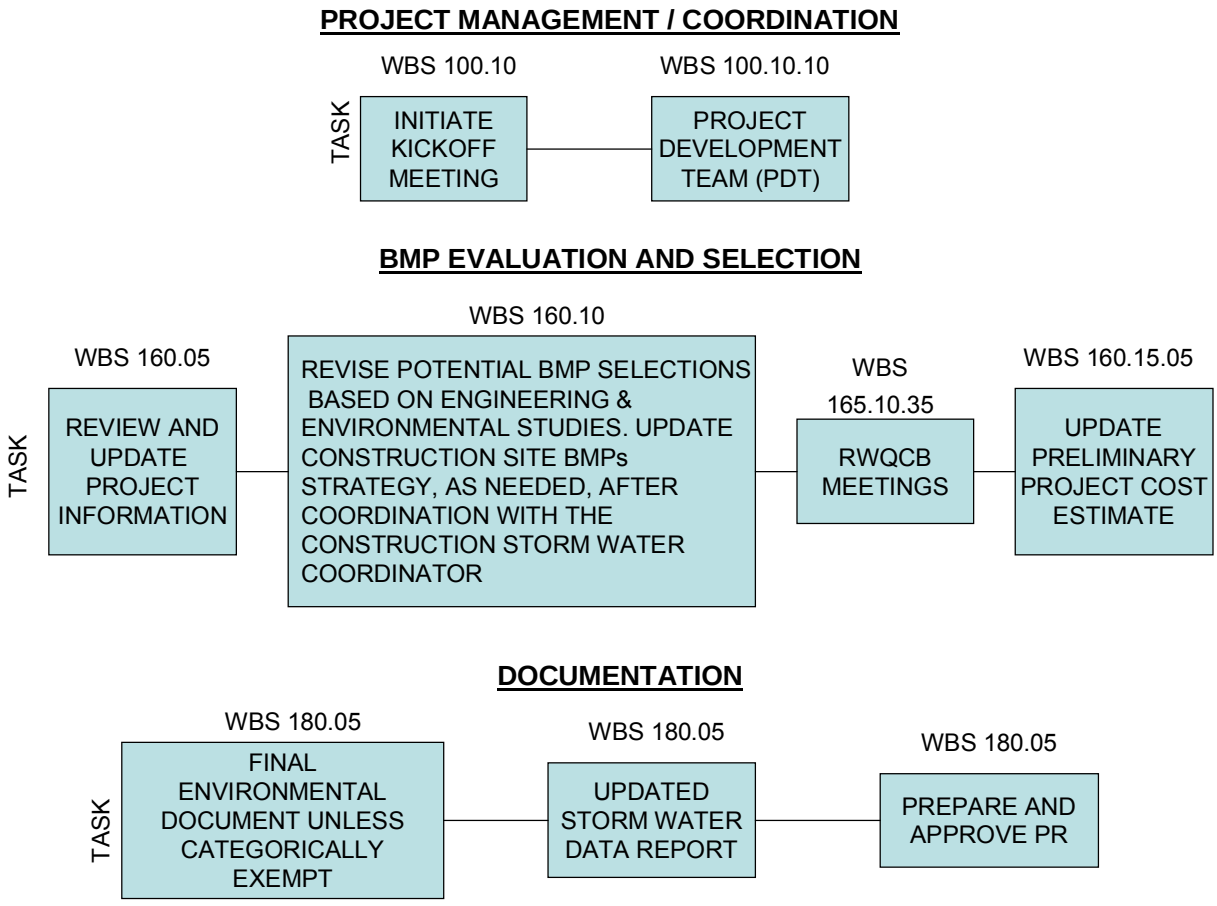
During the PA/ED process, the PE should coordinate with Environmental Unit staff to identify potential stormwater impacts associated with the project. The PE should update the SWDR

based on the detailed information provided in the WQR, and as appropriate, incorporate Design Pollution Prevention and Treatment BMPs. The PE should also update Construction Site BMPs strategy, as needed, after coordination with the Construction Storm Water Coordinator.

Figure 6-1 illustrates the overall primary task categories for the PA/ED process. Included in the flow chart are WBS codes for each task. Appendix E includes the form titled "Summary Process for Storm Water Activities for the PA/ED" that provides a step-by-step process of the tasks described in this section.

The sub-sections that follow correspond to the task categories provided in Figure 6-1 and the PA/ED Process Summary Form in Appendix E. Additional information is provided on the following pages detailing the recommended participants, discussion and decision topics, documentation, and verifications for each task to obtain final PID approval and funding for a project.

Figure 6-1: Project Approval/Environmental Document - Storm Water Task Categories



6.4 PROJECT MANAGEMENT / COORDINATION

This section describes the primary task categories involved with project management and the coordination during the PA/ED process needed to obtain consensus between the different functional units and the RWQCB regarding stormwater issues.

Initiate Kickoff Meeting, WBS 100.10

Narrative: The initial kickoff meeting is initiated by the PM to review and discuss the PID. This is particularly important for projects that have been on hold. Major scope changes may require a supplemental or new PID.

Responsible: Project Manager

Recommended Participants: Project Manager

Project Engineer

District/Regional National Pollutant Discharge Elimination System (NPDES) Storm Water Coordinator

District/Regional Design Storm Water Coordinator

Appropriate functional units

Environmental Engineering Representative

Environmental Planning Representative

Construction Storm Water Coordinator

Discussion Topics: Project Definition**:** Review PID. Refine type of project, scope, and schedule.

Review the Preliminary Project Cost Estimate (PPCE).

Environmental Studies: Determine status of the Environmental Document.

Right-of-way requirements.

Right-of-entry requirements.

Findings of the Water Quality Impact Questionnaire and WQR;

Possible compliance avoidance/minimization measures required by permits other than the Caltrans NPDES Permit (i.e. not required by SWMP);

Specific RWQCB requirements;

SWDR; and

Update Construction Site BMPs strategy, as needed.

Decisions/actions: Determine additional functional units to be involved.

Determine if right-of-way concerns have changed since the PID process.

Confirm PID is still valid. If not, a supplemental or new PID will be needed.

Initiate the PR.

Documentation: Meeting Minutes

Initial PR

Verification: Project Development Team (PDT) verifies that the PID is still valid.

Project Development Team, WBS 100.10.10

Narrative: The PDT has the responsibility to direct and evaluate the project studies to determine if any project re-scoping is needed, and to develop new alternatives, if required. When consensus is reached, the PDT determines the appropriate level of environmental evaluation. If an environmental document is required, the PDT directs its preparation. The PDPM, Chapter 8, Section 4, provides a thorough description of the PDT and its functions.

Responsible: Project Manager

Recommended Participants:

Project Manager

Project Engineer

District/Regional NPDES Storm Water Coordinator

District/Regional Design Storm Water Coordinator

District Landscape Architect or Project Landscape Architect

Environmental Engineering Representative

Environmental Planning Representative

Construction Storm Water Coordinator

Maintenance Storm Water Coordinator

Right-of-Way Representative

Hydraulics Representative

District Materials Engineer

Geotechnical Representative

Traffic Representative

Local MS4 Representative (if applicable)

RWQCB Representative (at discretion of District/Regional NPDES Storm Water Coordinator)

Others as needed.

All Districts are not organized the same and some of the suggested PDT members may have different titles depending upon the District in which the project is located. The PE should consult with the specific District Work Plan (DWP) to obtain the contacts listed in this section or the equivalent title or function in the District.

Discussion Topics: The PDT should meet throughout the entire project in order to maintain communication and to obtain consensus between the functional units. The following stormwater quality issues should be discussed:

- Viable alternatives for projects including location and alignments;
- Potential Design Pollution Prevention BMPs;
- Consider approved Treatment BMPs;
- Environmental issues;
- Site conditions and design constraints, including Construction Site and Maintenance BMPs;
- Stormwater quality BMP design criteria;
- Water quality volume and flow;
- Permanent BMP Locations: Identifying right-of-way impacts, utility conflicts and geotechnical issues;
- Landscape conflicts with conceptual plan;
- Permit requirements;
- Other agencies involved;
- BMPs to meet a prescribed Waste Load Allocation (WLA) and/or Total Maximum Daily Load (TMDL) for an impaired (303d listed) water body;
- Significant, unavoidable impacts to receiving waters;
- Mitigation measures prescribed by a Department of Fish & Game 1602 Streambed Alteration Agreement;
- Post Construction dewatering requirements. The RWQCB requires a separate Dewatering Permit under most conditions;
- Variance for lead contaminated soils, emphasizing the reuse of soils containing aerially deposited lead (ADL) due to vehicle emissions;
- Discharges of dredged or fill material into navigable waters (404 Permit/401 Certification);
- Potential impacts associated with spills, especially near municipal or domestic water supply reservoirs or potable water recharge facilities (i.e., Driving Water Reservoirs and Recharge Facility);
- Specific RWQCB requirements; and
- SWDR.

Decisions/actions: Tentatively select Design Pollution Prevention, Treatment and Construction Site BMPs for each project alternative.

Begin preliminary design of BMPs.

Determine necessary Environmental Documents (ED) and Permits.
Determine other agencies that should be involved.
Determine if an ED already exists. If not, the PDT initiates one.
Determine if project re-scoping is necessary.
Update PR and ED
Document any decisions made during the PDT meetings.

Documentation: Meeting minutes
Updated PR and ED

Verification: The PE verifies that all documentation is completed

6.5 BMP SELECTION PROCESS

This section describes the primary task categories for the Design Pollution Prevention and Treatment BMP selection processes associated with the PA/ED process (see Figure 6-2). For information regarding initial Construction Site BMPs strategy, consult with Construction Storm Water Coordinator and refer to Manual for Construction Site BMPs (see Appendix D for web address). There are three goals for the BMP identification process. They are: (1) to obtain consensus between the different functional units and the RWQCB regarding water quality issues; (2) to tentatively select Design Pollution Prevention and Treatment BMPs for each project alternative and incorporate them into the PA/ED, and (3) to provide sufficient information for the Plans, Specifications & Estimate (PS&E) process.

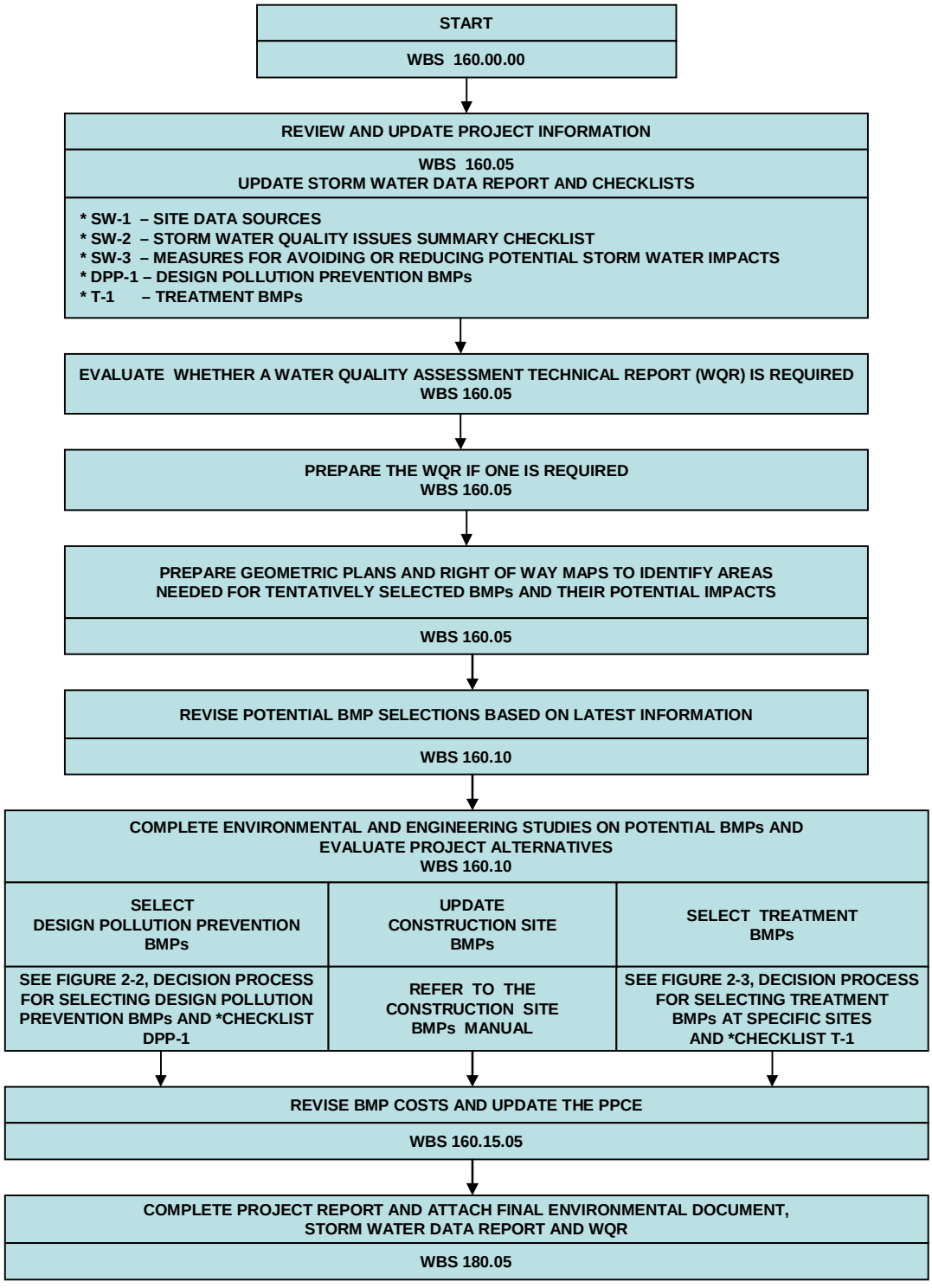
Review and Update Project Information, WBS 160.05

Narrative: Decisions for selecting the preferred project alternative, including the BMP alternatives, are the focus of the PA/ED process. Project alternatives, the Storm Water Data Report and Checklists SW-1, SW-2 and SW-3 that were initiated in the PID process are revisited and updated. The checklists should be updated continuously to provide documentation of stormwater quality issues and decisions.

Responsible: Project Manager

Recommended Participants: Project Manager
Project Engineer
District/Regional NPDES Storm Water Coordinator
District/Regional Design Storm Water Coordinator
District Materials Engineer

Figure 6-2: Project Approval/Environmental Document – BMP Selection Process



* LOCATED IN APPENDIX E

Discussion Topics: Review of the Checklists for DPP-1 and T-1 and the SWDR that were initiated in the PID process.

Stormwater quality impacts for each project alternative identified in the WQR.

Project Evaluation Documentation Form for Treatment BMPs.

Update to Construction Site BMPs strategy.

Decisions/actions: Review Project Alternatives, SWDR, Checklists for DPP-1 and T-1, and the PPCE.

Review the Evaluation Documentation Form. If the project was not required to consider incorporating Treatment BMPs in the PID process, confirm that this is still the proper determination pursuant to Section 4 of this PPDG.

Evaluate potential stormwater quality impacts and options for avoiding or reducing these impacts for the various project alternatives:

- Update Checklist SW-1, Site Data Sources;
- Update Checklist SW-2, Storm Water Quality Issues Summary; and
- Update Checklist SW-3, Measures for Avoiding or Reducing Potential Storm Water Impacts.

Prepare WQR.

Perform Field Review of the area.

Determine if the scope has changed since the PID and if so, how stormwater quality issues are affected.

Begin environmental studies and permit process to evaluate the tentatively selected BMPs.

Evaluate project for types of stormwater quality impacts.

Based on the SWDR, checklists and the WQR, evaluate Design Pollution Prevention, Treatment and Construction Site BMP applications.

Materials Unit updates materials information and provides other information, such a side slope recommendations, wetland locations, slide locations, etc.

Prepare Geometric Plans and Right-of-way maps to identify areas needed for tentatively selected BMPs and their potential impacts.

Documentation: Updated SWDR and Checklists SW-1, SW-2 and SW-3Evaluation Documentation Form.

A final report on materials and geotechnical issues is still not required at this stage, but an updated draft report would be appropriate.

Verification: The PE verifies that all documentation is completed.

Revise BMP Selections Based on Engineering Studies, WBS 160.10

Narrative: Final decisions are made in regard to alternatives, costs, location, alignments, etc. Potential stormwater BMPs that were identified during the PID process are developed in more detail through additional technical studies in the PA/ED process. The costs of the potential BMPs should be estimated and prepared in accordance with Appendix F.

Responsible: Project Engineer

Recommended Participants:
Project Manager
Project Engineer
District/Regional NPDES Storm Water Coordinator
District/Regional Design Storm Water Coordinator
District Landscape Architect or Project Landscape Architect
Environmental Engineering Representative
Environmental Planning Representative
Construction Storm Water Coordinator
Maintenance Storm Water Coordinator
Right-of-Way Representative
Hydraulics Representative
District Materials Engineer
Geotechnical Representative
Traffic Representative

Discussion topics:
Engineering studies and checklists
Environmental impacts of proposed BMPs
Potential permanent BMPs
Construction Site BMPs

Decisions/actions: Revise the preferred project alternative(s) and the tentative selection of potential BMPs to be incorporated into the project.

Review engineering studies and completed stormwater checklists.

Complete environmental and engineering studies on potential BMPs and evaluate project alternatives.

Review potential BMP selections, evaluating the pros and cons of each, including the WQR and the SWDR to evaluate potential environmental impacts, and how those impacts are addressed during BMP selection and design.

Identify anticipated Construction Site BMPs.

Documentation: Descriptions of project alternatives, including those under consideration, those withdrawn from consideration and the "no-action" alternative. Describe tentative BMP strategies for the project alternatives under consideration. These descriptions will be the basis for the "Description of Alternatives" section of the environmental document.

Updated Checklists DPP-1, parts 1 through 5, and T-1, parts 1 through 10, for selecting BMPs at specific sites.

Updated SWDR.

Verification: PDT verifies the preferred project alternative(s) and preferred BMP selection(s) are feasible. The District/Regional Storm Water Coordinator must be in concurrence on BMP feasibility.

Regional Water Quality Control Board Meetings, 165.10.35

Narrative: Consultation with the RWQCB, local regulatory agencies and Municipal Separate Storm Sewer System (MS4) Permit Holders is strongly recommended to coordinate project issues and develop consensus for controversial or complex stormwater quality issues. The number of coordination meetings is dependent upon the complexity of the stormwater quality issues, stormwater pollutants involved, and project site constraints.

Responsible: Project Engineer and District/Regional NPDES Storm Water Coordinator

Recommended Participants:

Project Manager

Project Engineer

District/Regional NPDES Storm Water Coordinator (primary point of contact with the RWQCB)

Other regulatory agency representatives

Discussion Topics: Present Project Information

- Site Conditions;
- Project Alternatives;
- Potential Implementation of Approved BMPs;
- Storm Water Quality Impacts and Issues; and
- Right-of-way Impacts.

Decisions/actions: Determine preliminary site conditions and stormwater concerns

Documentation: Meeting minutes

Verification: The PE must verify that all comments are recorded and resolved.

Update Preliminary Project Cost Estimate, WBS 160.15.05

Narrative:

The PR cost estimate is prepared as part of the project approval process. This generally occurs after completion of the public hearing, selection of the preferred project alternative, and completion of the environmental document.

The PR cost estimate is prepared using the same format as used for the other project planning cost estimates (see Appendix AA of the PDPM, 7/1/99 for current methods of cost estimating). However, since the initial preferred alternative(s) has been selected, the project cost estimate can now be more definitive.

Cost estimates for stormwater BMP alternatives can now also be more definitive. The PPCE for the BMP alternatives are now updated to provide a more detailed cost estimate in helping to select the preferred BMP alternative. Appendix F in this document provides greater detail on methods for cost estimating to include stormwater BMPs as part of the overall project cost.

Responsible: Project Engineer

Recommended Participants:

Project Manager
Project Engineer
Hydraulics Representative
Environmental Engineering Representative
Environmental Planning Representative
District/Regional Design Storm Water Coordinator
Construction Storm Water Coordinator
Maintenance Storm Water Coordinator
District Landscape Architect or Project Landscape Architect
Right-of-Way Representative

Discussion Topics:

PPCE developed during the PID process.

Bid data from actual projects

Sampling and Analysis Plans

Temporary items listed and the costs for SWPPP or WPCP development and implementation.

Sensitive Environments

Highway Planting contracts

Supplemental funds

Costs for a SWPPP or WPCP

Costs for potential alternative stormwater BMPs

Available cost options (see Appendix F)

Decisions/actions: Update and refine PPCE

Documentation: Completed PPCE

Verification: The following functional units shall verify the completed PPCE:
NPDES
Landscape
Hydraulics
Environmental
Maintenance
Right-of-Way

6.6 DOCUMENTATION REQUIRED FOR PROJECT APPROVAL/ENVIRONMENTAL DOCUMENT

This section describes the documents necessary for completion of a PA/ED package.

Prepare and Approve PR, WBS 180.05

Narrative: The purpose of the PR is to recommend approval of the selected preferred project alternative. Preparation Guidelines for a PR are included in Appendix K of the PDPM (2/18/00). The PID contained basic project data necessary for programming the project. These data have now been updated with the information that was developed during the environmental studies and included in the PR. The PR summarizes the studies of the scope, cost and overall impact of alternatives so that the decision maker can make an informed decision of whether or not to continue into the PS&E process.

Responsible: The final PR is submitted to the Division Chiefs by the Functional Manager responsible for production of the PR.

Recommended Participants: Project Manager

Division Chiefs

Contents: The following should be included in the PR. Also refer to the PDPM, Appendix K, 2/18/00, for the format, outline and contents.

- Final Environmental Document (FED) or CE if required;
- WQR;
- The Cover Sheet of the approved SWDR at the PA/ED phase.
- Evaluation Documentation Form;

- Right-of-Way Data Sheet;
- Discussion of stormwater quality issues under "Other Consideration.";
- PPCE;
- Description of project alternatives; and
- Recommendation for approval of the project.

Documentation: The PA/ED package includes a copy of the PR, the WQR, the SWDR, the FED or CE, the Evaluation Documentation Form, Right-of-Way Data Sheets, and the PPCE.

Verification: The following Division Chiefs shall approve the completed PR:

- The Functional Manager of PA/ED Production;
- The Program/Project Management; and
- The Functional Manager responsible for the next phase, which is the PS&E process.

The SWDR shall be signed by the PE, the District/Regional Design Storm Water Coordinator, the designated Landscape Representative, the designated Maintenance Representative and the PM. The PE's signature will verify that stormwater quality design issues have been addressed, and the data is complete, current and accurate. The District/Regional Design Storm Water Coordinator should be the last person to sign the SWDR to ensure that all appropriate reviews have been completed.

The Caltrans District Division Chiefs are responsible for approving the project's scope, schedule, and cost within these established guidelines, and may exercise engineering judgment and flexibility in approving the PA/ED document. PA/EDs are to be approved by the District Director after review by Division Chiefs, Functional Managers and the PDT.

Project Managers are to endorse the decision by "Approval Recommended By" or "Approved By" where such authority has been delegated.

7.1 INTRODUCTION AND OBJECTIVES

The purpose of this section is to provide a consistent approach in the Plans, Specifications and Estimates (PS&E) process as it relates to incorporating stormwater Design Pollution Prevention, Treatment, and Construction Site Best Management Practices (BMPs) into a project. This section has been incorporated directly from Chapter 14 of the Project Development Procedures Manual (PDPM), (7/1//99) and is to be used only as a supplement to the PDPM.

This section also relates the Work Breakdown Structure (WBS) codes and the Storm Water Data Report (SWDR) and checklists, to the PS&E process. WBS codes are provided in Appendix E for specific stormwater related tasks during the PS&E process. These codes are organized as a process form, which is titled "Summary Process for Storm Water Activities for PS&E" (included in Appendix E). These codes follow the "Guide to Project Delivery Workplan Standards – Release 8.0A" document. The SWDR and its corresponding checklists are described in Sections 5 and 6 and are included in Appendix E. These can be used for guidance in selecting BMPs for inclusion in the PS&E process.

7.2 PLANS, SPECIFICATIONS & ESTIMATES PROCESS

The purpose of the PS&E is for eventual contract advertising and bidding on a project. The PS&E process is generally initiated after the Project Report (PR) approval. Base maps, plan sheets, accurate cost estimates and specifications are developed for the selected preferred project alternative including selected BMPs within the project limits. The objective of this section is to present how stormwater quality issues are addressed within the overall PS&E process by the District functional unit personnel.

Figure 7-1 illustrates the primary task categories for the PS&E process. The "Summary Process for Storm Water Activities for PS&E" form in Appendix E provides a step-by-step process of these tasks.

The sub-sections that follow correspond to the task categories provided in Figure 7-1 and the PS&E process summary form in Appendix E. Additional information is provided on the following pages detailing the recommended participants, discussion and decision topics, documentation and verifications for each task to develop the final PS&E package.

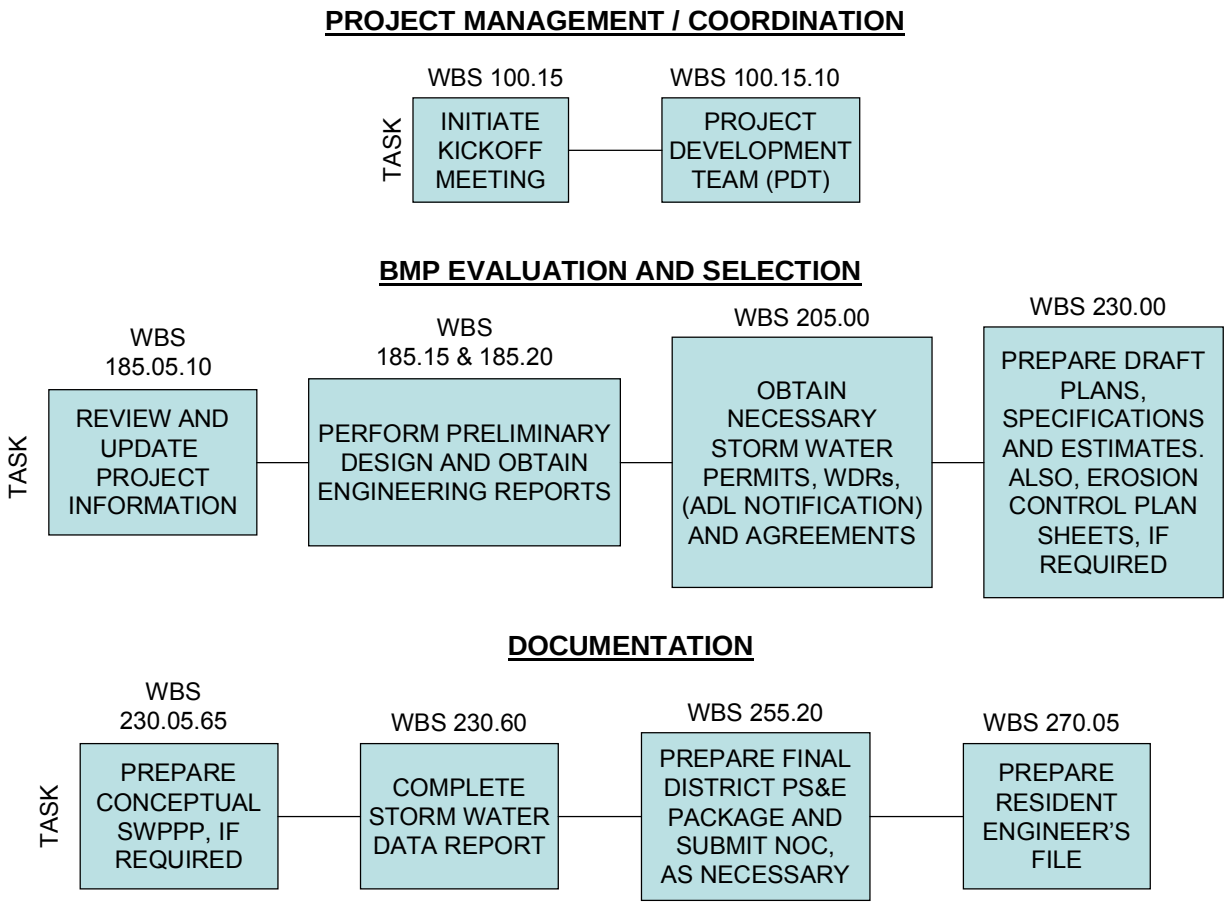
7.2.1 Conceptual Storm Water Pollution Prevention Plans and Water Pollution Control Plans

The designer may elect to prepare a Conceptual Storm Water Pollution Prevention Plan (CSWPPP) for a project. The CSWPPP will provide additional direction and convey specific BMP expectations to the contractor. However, the CSWPPP shall not be considered a complete SWPPP, and shall not replace the contractor's SWPPP, since CSWPPPs are prepared assuming standard construction practices, and may not reflect the contractor's actual methods of construction, access requirements, or project phases.

The designer may also elect to provide Water Pollution Control Plans showing the locations of appropriate Construction Site BMPs, or construction site BMPs that are designated as a separate

bid line item in the Preliminary Project Cost Estimate (PPCE). These engineer-identified Construction BMPs must be deployed by the contractor to provide a minimal level of protection at specific locations within a project. The purpose of these Water Pollution Control Plans is to identify the deployment of appropriate Construction Site BMPs such as contractor staging areas, locations for concrete washouts, designated locations for storage of materials, etc. The Water Pollution Control Plans should be included as part of any Conceptual Storm Water Pollution Prevention Plan (CSWPPP) if provided, and as part of the contractor's Storm Water Pollution Prevention Plan (SWPPP) or Water Pollution Control Program (WPCP).

Figure 7-1: Plans, Specifications, and Estimates Document - Storm Water Task Categories



7.3 PROJECT MANAGEMENT/COORDINATION

This section describes the primary task categories involved with project management and the coordination in the PS&E process needed to obtain consensus between the different functional units as well as with the Regional Water Quality Control Board (RWQCB) regarding stormwater quality issues and BMP deployment.

Initiate Kickoff Meeting, WBS 100.15

Narrative: The purpose of the initial kickoff meeting is to review the Project Initiation Document (PID) and the PR. It is the first step in the process of formally recognizing that the project should continue through the PS&E process.

Responsible: Project Manager (PM)

Recommended Participants:
- Project Manager
- Project Engineer (PE)
- District/Regional National Pollutant Discharge Elimination System (NPDES) Storm Water Coordinator
- District/Regional Design Storm Water Coordinator
- Appropriate functional units
- Environmental Engineering Representative
- Environmental Planning Representative

Discussion Topics:
- Data gathered during the PID and Project Approval/Environmental Document (PA/ED) process.
- WQR
- SWDR and its corresponding checklists.

Decisions/actions:
- Determine if the project should continue into the PS&E process.
- Review PID and PR.
- Review the SWDR and its corresponding checklists.
- Coordinate Schedule.

Documentation: Meeting minutes

Verification: There is no verification required at this phase.

Project Development Team, WBS 100.15.10

Narrative: The Project Development Team (PDT) has the responsibility to direct and evaluate the project studies to determine if any project re-scoping is

needed. The PDPM, Chapter 8, Section 4 (7/1/99) provides a thorough description of the PDT and its functions.

Responsible: Project Engineer

Recommended Participants:

Project Engineer

District/Regional NPDES Storm Water Coordinator

District/Regional Design Storm Water Coordinator

District Landscape Architect or Project Landscape Architect

Environmental Engineering Representative

Environmental Planning Representative

Construction Storm Water Coordinator

Maintenance Storm Water Coordinator

Right-of-Way Representative, Hydraulics Representative

District Materials Engineer, Geotechnical Representative

Traffic Representative, Local MS4 Representative (if applicable)

RWQCB Representative (at discretion of District/Regional NPDES Storm Water Coordinator)

Others as needed.

All Districts are not organized the same and some of the suggested PDT members may have different titles depending upon which District the project is located. The PE should consult with the specific District Work Plan (DWP) to obtain the contacts listed in this section or the equivalent title or function in the District.

Discussion Topics: Engineering Reports that must be prepared by different functional units of the PDT. This requires the functional units to develop project design reports needed to establish design parameters and complete design. Those related to stormwater quality issues are:

- Hydrology and Hydraulic Reports;
- Geotechnical Design Report;
- Materials Report;
- Environmental Document (ED) (Completed during PA/ED process); and
- WQR.

Decisions/actions: Update data gathered in the PID and PA/ED processes. Update Checklists SW-1, SW-2 and SW-3 and the Evaluation Documentation Form (EDF).

Review Geometric Base Maps - The appropriate functional unit in the PDT should identify problems that are easier to correct at early stages of

design and to establish a foundation for skeleton layouts. Comments from Maintenance, Hydraulics, Landscape Architecture, Structures (to determine railroad involvement and easement requirements) and Traffic are particularly useful.

Documentation: Checklists and EDF

Meeting minutes

Any decisions made during PDT meetings should be documented.

Verification: The PE verifies that all documentation is completed.

7.4 BMP DESIGN PROCESS

Figure 7-2 is a flowchart outlining the BMP design process. This section describes the primary task categories listed in this flowchart.

Review and Update Project Information, WBS 185.05.10

Narrative: Project design requires the continuous review and update of data from the PID and PA/ED processes. During the PA/ED process, a preferred project alternative was selected. The SWDR and checklists that were initiated in the PID and PA/ED are revisited and updated to further define the stormwater quality issues. The checklists should continue to be used to provide documentation of these stormwater quality issues and decisions. A field review should have also been completed during the PID and PA/ED processes as well. Continue to arrange site investigations and screening for Treatment BMPs as needed.

Responsible: Project Engineer

Recommended Participants: Project Manager

Project Engineer

District/Regional NPDES Storm Water Coordinator

District/Regional Design Storm Water Coordinator

Environmental Unit and other appropriate functional units

Discussion Topics: The SWDR and Checklists SW-1, SW-2, and SW-3 that were initiated in the PID and updated in the PA/ED.

Project Scope

Stormwater impacts

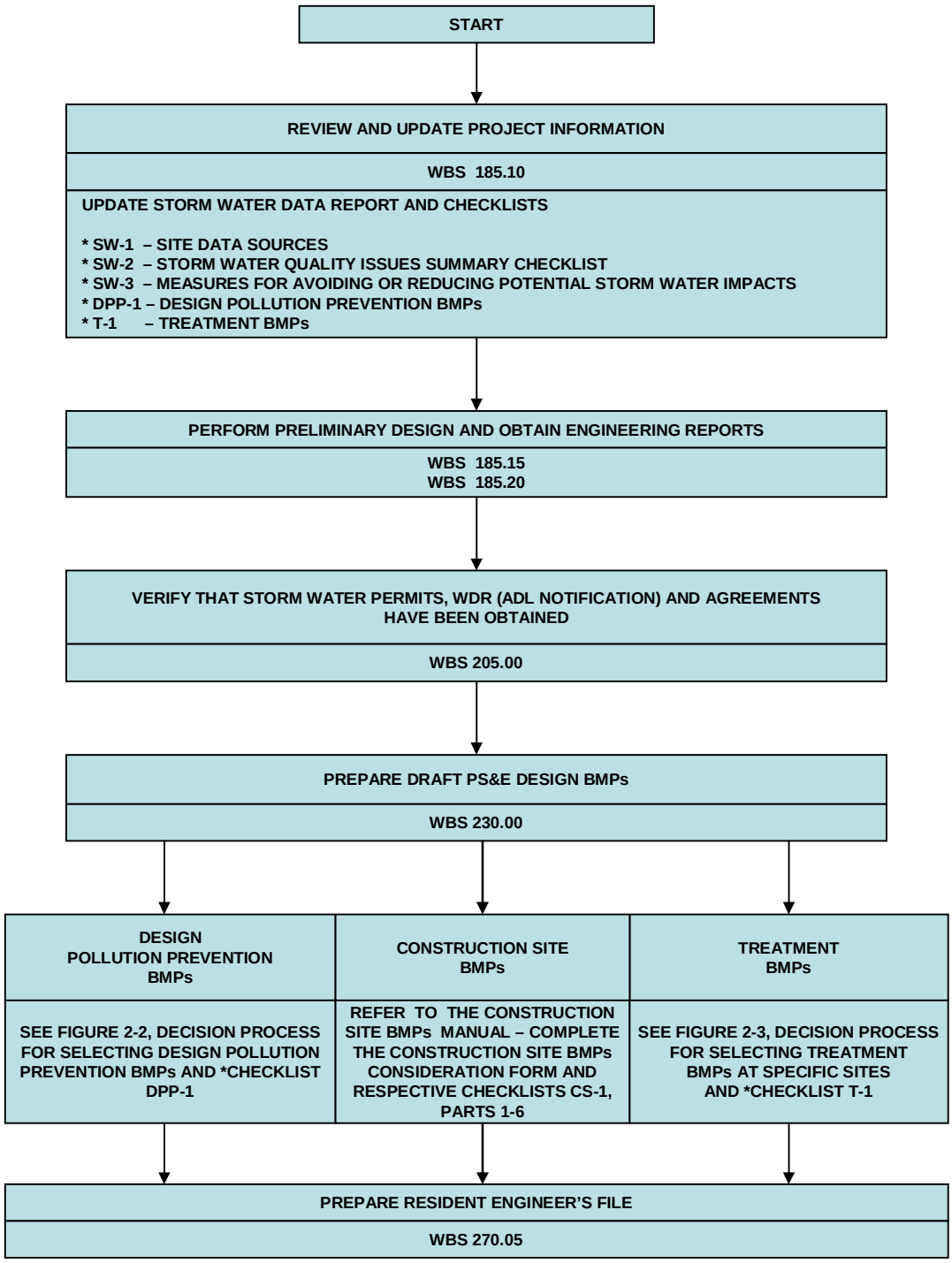
BMP deployment strategy plus siting and design criteria

Preliminary Project Cost Estimate (PPCE)

Design surveys and photogrammatric mapping

Utilities

Figure 7-2: BMP Design Process Flowchart



* LOCATED IN APPENDIX E

Screening for Treatment BMP installations

Site investigations for design of Treatment BMPs

Necessary Permits and Agreements (i.e., 1601, 1604, 404/401)

Decisions/actions: Review the SWDR, EDF and Checklists SW-1, SW-2, and SW-3 that were initiated in the PID and updated in the PA/ED.

Review selected project alternative.

Determine if the project scope has changed since the PA/ED and, if so, how stormwater quality issues are affected.

Evaluate project for types of stormwater impacts.

Evaluate BMP applications plus design and siting criteria.

PPCE: Determine if the budget has changed since the PA/ED and if so, how stormwater quality issues are affected.

Obtain updated design surveys and photogrammatric mapping.

Coordinate necessary agreements, permits, or actions.

Coordinate Utilities - Work involves identification, potholing, protection, removal and/or relocation of utility facilities as necessary to clear and certify right-of-way for deployment of stormwater BMPs.

Complete site investigations and screening for Treatment BMP installations.

Review Final ED for any non-SWMP compliant water quality impact avoidance, minimization or mitigation measures.

Documentation: N/A

Verification: There are no verifications required at this phase.

Perform Preliminary Design, WBS 185.15

Narrative: Many projects have revisions that may affect the project scope, length and description. Before starting detailed design, the project data should be updated to reflect the selected project alternative and selected BMPs within the project limits, as well as other revisions that may have occurred.

Responsible: Project Engineer

Recommended Participants:

Project Manager

Project Engineer

District/Regional NPDES Storm Water Coordinator

District/Regional Design Storm Water Coordinator

District Landscape Architect or Project Landscape Architect

Environmental Engineering Representative
Environmental Planning Representative
Maintenance Storm Water Coordinator
Right-of-Way Representative
Hydraulics Representative
District Materials Engineer
Geotechnical Representative
Traffic Representative

Discussion Topics: Preferred selected alternative from the PA/ED

Applicable stormwater regulations

Decisions/actions: Analyze horizontal and vertical alignments, site data and stormwater data, including depth to groundwater, infiltration rates, available right-of way, soils, utilities, etc. Much of the data are included in the Checklists SW-1, SW-2, SW-3, DPP-1 and T-1.

Review any changes to stormwater regulations that may affect the project.

Perform or request additional field investigations as required.

Analyze any existing drawings, reports, checklists.

Update the SWDR, as needed.

Review the PA/ED. Determine if the preferred selected BMP alternative in the PA/ED is still valid.

Documentation: SWDR

Verification: The PE verifies that all documentation is completed.

PE and District/Regional Design Storm Water Coordinator to verify that selected BMP alternative is still valid.

Obtain Engineering Reports, WBS 185.20

Narrative: Several engineering reports must be prepared. This involves various functional units to develop project design reports needed to establish design parameters and complete design.

Responsible: Project Engineer

Recommended Participants: Project Manager
Project Engineer
District/Regional NPDES Storm Water Coordinator
District/Regional Design Storm Water Coordinator
District Landscape Architect or Project Landscape Architect
Environmental Engineering Representative

Hydraulics Representative
District Materials Engineer
Right-of-Way Representative
Geotechnical Representative

Discussion Topics: Reports required and the information contained within those reports (e.g., site data, site investigations, soil analysis, vegetation, contamination, right-of-way, right-of-entry, discharge conditions, Drinking Water Reservoirs and/or Recharge Facilities, stormwater drainage before and after construction, water bodies, vegetation issues, depth to groundwater, infiltration rates, etc.).

Decisions/actions: The functional units begin preparing the previously mentioned engineering reports as applicable.

Documentation: Hydrology and Hydraulic Report
Geotechnical Design Report
Materials Report

Verification: PE and District/Regional Design Storm Water Coordinator to verify that required stormwater reports are prepared.
Each functional unit verifies that the project issues pertained to their functional specialty have been completely addressed.

Obtain Necessary Storm Water Permits, WDRs and Agreements, WBS 205.00

Narrative: This activity involves all work involved in obtaining permits. This work includes: Filing the Notification of Construction (NOC) for coverage under the Caltrans Permit and the General Permit; determining other necessary permits or agreements; discussions and negotiations with the permitting agencies, especially in regards to dewatering and other known discharges; preparation of the permit and attachments such as exhibits, maps, etc.; obtaining funds for any required permit fee; and submitting the permit application. Send notification to RWQCB regarding the reuse of soil containing aerially deposited lead (ADL). Consultation with the RWQCB, local regulatory agencies and Municipal Separate Storm Sewer System (MS4) Permit Holders is strongly recommended to coordinate project issues and develop consensus for controversial or complex stormwater quality issues.

Responsible: Recommended Project Engineer

Participants: Project Engineer
District/Regional NPDES Storm Water Coordinator
District/Regional Design Storm Water Coordinator
District Landscape Architect or Project Landscape Architect

Environmental Engineering Representative
Engineering Planning Representative
Construction Storm Water Coordinator
Maintenance Storm Water Coordinator
Right-of-Way Representative
Geotechnical Representative

Discussion Topics: Significant, unavoidable impacts to receiving waters.

BMPs to meet a prescribed Waste Load Allocation (WLA) and Total Maximum Daily Load (TMDL) for an impaired 303(d) listed water body.

Mitigation measures prescribed by a Department of Fish & Game 1601 Streambed Alteration Agreement.

Dewatering requirements. The RWQCB requires a separate dewatering permit under most conditions.

Variance for lead-contaminated soils, emphasizing the reuse of soils containing ADL due to vehicle emissions.

Discharges of dredged or fill material into navigable waters (404 Permit/401 Certification).

Potential impacts associated with spills, especially near municipal or domestic water supply reservoirs or potable water recharge facilities.

Specific RWQCB requirements.

Potential impacts of unique maintenance activities or known discharges.

Decisions/actions: Obtain required permits and agreements. These permits may include but are not limited to the following:

U.S. Army Corps of Engineer Permit (404)
U.S. Coast Guard Permit
Department of Fish & Game (1601/1603)
Coastal Development Permit
U.S. Fish and Wildlife Service approval
RWQCB Permit (401)
National Marine Fisheries Permit

Other permits and agreements: Bay Conservation and Development Commission (BCDC) permit, Tahoe Regional Planning Agency (TRPA) permit, and flood control District permits.

Documentation: Permit Applications
Request for funding permit fee
Completed permits

Verification: Environmental Branch obtains the 401, 404, 1601, etc.

Completed Permits.

PE, District/Regional NPDES Storm Water Coordinator and District Environmental Office verify that required stormwater permits are identified and obtained.

Prepare Draft Plans, Specifications and Estimates, WBS 230.00

Narrative: The main activities in producing a draft set of plans are the completion of geometric base maps, the submittal of structure site data, the submittal of right-of-way maps, and the circulation of skeleton layouts. The PE's responsibilities during the design process are to; prepare quality plans that meet Caltrans standards, practices, and policies; include stormwater BMPs into the project; prepare project and BMP cost estimates and monitor costs to keep the project within budget; utilize available resources to maintain project schedules; monitor the project scope to ensure consistency with previous approvals; and inform the PM of any cost, scope, or schedule changes that may be required for the project.

Responsible: Project Engineer

Recommended Participants:
Project Engineer
District/Regional NPDES Storm Water Coordinator
District/Regional Design Storm Water Coordinator
District Landscape Architect or Project Landscape Architect
Environmental Engineering Representative
Construction Storm Water Coordinator
Maintenance Storm Water Coordinator
Right-of-Way Representative
Hydraulics Representative
District Materials Engineer
Geotechnical Representative

Discussion Topics: Plans to be obtained from the functional units include the following:

Traffic – Draft Roadway Plans

Landscape – Highway Planting Plans

Utility – Utility Relocation Plans

Hydraulics – Drainage Plans

Right-of-Way

Discuss drainage area information about the project site in order to select, locate, and design appropriate stormwater BMPs. This is extremely important information during the PS&E.

Decisions/actions: Review stormwater related activities to consider during project design, and complete the process form "Summary Process for Storm Water Activities for PS&E" found in Appendix E.

Review Checklist DPP-1 and determine Design Pollution Prevention BMPs.

Review Checklist T-1 and design Treatment BMPs.

Design Construction Site BMPs:

- See Storm Water Quality Handbook – Construction Site Best Management Practices Manual for additional guidance;
- Complete Construction Site BMPs Consideration Form and respective checklists CS-1, Parts 1-6;
- Division of Construction - Storm Water Quality webpage (http://www.dot.ca.gov/hq/construc/stormwater/stormwater1.htm) contains links to resources for developing a Storm Water Pollution Prevention Plan (SWPPP), a Water Pollution Control Program (WPCP), and stormwater quality information to be included in the Information Handout. It is important to note that the PE is not responsible for preparing a Conceptual SWPPP (CSWPPP) for every project. The PE must provide tabular data identifying anticipated Construction Site BMP items and quantities, and provide the available Standard Special Provisions (SSPs) for those items;
- Include Erosion Control Plan Sheets, at discretion of Districts. These are developed by the Landscape Architect;
- Document concurrence with Construction – initial and date Construction Site BMP Consideration Form, include concurrence information in Section 6 of the SWDR
- Include rainy season data - The average rainfall in California varies greatly from region to region. To account for the various rainfall patterns (i.e., time frame, intensities, and amounts) the state is separated into several rainy seasons. These rainy seasons are used to identify the appropriate level of soil stabilization and sediment control protection.

Prepare Standard Special Provisions – More information can be obtained from the Web site located at:
http://www.dot.ca.gov/hq/esc/oe/specs_html/index.html

Identify physical attributes of site drainage areas that may affect the selection, siting, and design of BMPs (use Table 7-1). Attributes with an * in Table 7-1 are optional depending on the particular controls being considered for application. Required data can be gathered first, leaving

optional data for later in the design process when the specific BMP is selected.

Table 7-1: Drainage Area Attributes and Their Effect on Storm Water BMPs

Attribute	Information Source	Effect on Design and Use of BMPs
Tributary Drainage Area Size	Topographic Maps Grading Plans Aerial Photos Survey Data	Used to select suitable Treatment BMPs and size them. Also used to determine need for and the design of stabilized conveyance systems, interception ditches, Biofiltration Swales, and to establish the need for energy dissipaters.
Slopes	Vicinity Map Aerial Photographs Field Reconnaissance Contour Grading Plan	Used to identify slopes that require controls to prevent erosion. Limits use of certain controls on or adjacent to slopes.
Site permeability (runoff coefficients)	Aerial Photographs Satellite Imagery Field Reconnaissance Geographic Information Systems (GIS) Map Geotechnical Design Report	Used to determine runoff flows and therefore sizing of many controls. The percentage of the drainage area covered by pavement, buildings, concrete, or other impermeable materials significantly affects the size of controls.
Soil Texture and Saturated Soil Infiltration Rate *	Materials Report Geotechnical Design Report Natural Resources Conservation Service (NRCS) Soil Survey	Used to size the surface area of Infiltration Devices.
Depth to Seasonal High Groundwater *	Well Records Geotechnical Design Report Environmental Site Investigation for Hazardous Wastes	Limits use of infiltration at sites with shallow groundwater tables. In areas with shallow groundwater tables consider Detention Devices.
Existing Vegetation/Ground Cover *	Aerial Photographs Field Reconnaissance Landscape Record Drawings GIS Map Satellite Imagery	Used to identify drainage areas with significant amounts of unstabilized soil, which limits use of infiltration and retention basins. An Infiltration Basin can be used in an area where there is unstabilized soil, but it may require soil stabilization (vegetation or mechanical), and/or a preceding forebay for the basin.

* These data are applicable to many of the Treatment BMPs considered during this phase.

If Infiltration or Detention Devices are being considered, then data regarding soil texture and saturated soil infiltration rate may be determined from a Soil Survey report. Aerial photographs and Geographic Information Systems (GIS) maps may provide information regarding the identification of drainage areas with significant amounts of unstabilized soil.

Documentation: From Traffic - Roadway Plans, WBS 230.05 – Includes all activities, from base maps (skeletons), such as design, delineation, field reviews, and

internal/external coordination necessary to develop draft roadway plan sheets for the construction contract.

Conceptual Storm Water Pollution Prevention Plan (CSWPPP) and Water Pollution Control Plan (WPCP) Sheets

From Landscape - Highway Planting Plans, WBS 230.10 – All activities (such as design, field reviews, delineation, and internal/external coordination) necessary to develop highway planting plan sheets for construction contract.

From Utilities - Utility Relocation Plans, WBS 230.25.10

From Hydraulics - Draft Drainage Plans, WBS 230.30

Geometric Base Maps – A preferred alternative was selected during the PR approval process and must now be refined to produce geometric base maps, typical sections, and profiles. Preferably, the development of alternatives was performed using controlled aerial mapping, which can easily be transformed into geometric base maps. The geometric base maps must show existing topography and proposed engineering features. Accurate mapping is needed for all subsequent design activities, such as right-of-way needs, designing drainage facilities, etc.

Verification: PE, Hydraulics, Geotechnical, Structural and other appropriate members of the PDT verify that plans are being developed per Caltrans standards and that all necessary information is included in the plans.

Prepare Draft Specifications, WBS 230.35

Narrative: These activities are necessary to develop the project draft Standard Special Provisions (SSPs). SSPs must be incorporated into PS&E for all projects to ensure that the contract documents clearly set forth the contractor's responsibilities with respect to preparation and implementation of either a SWPPP or WPCP as required for the project.

Responsible: Project Engineer

Recommended Participants:

Project Manager

Project Engineer

Hydraulics Engineer

Environmental Engineering Representative

Environmental Planning Representative

District/Regional Design Storm Water Coordinator

Construction Storm Water Coordinator

Maintenance Storm Water Coordinator

District Landscape Architect or Project Landscape Architect

Discussion Topics: SSPs to make sure the most recent ones are being used.

CSWPPP**.** The PE is not responsible for preparing a Conceptual SWPPP for every project. The PE must provide tabular data identifying anticipated Construction Site BMP items and quantities, and provide the available SSPs and if available, include details and estimate codes for those items.

Decisions/actions: Complete Specifications.

Review the specifications to make sure they are complete and that they match the cost estimates and the plans.

Documentation: Standard Specifications including the following:

From Hydraulics – Hydraulic Specifications, WBS 230.35.30

From Landscape - Highway Planting Specifications, WBS 230.35.10

Water Pollution Control Specifications, WBS 230.35.35

Erosion Control Specifications, WBS 230.35.40

Verification: PE confirms that the Specifications are complete and are consistent with the cost estimate and plans.

Prepare Draft Estimates, WBS 230.40

Narrative: Project design cost estimates are initiated after the PR approval and are updated until completion of the PS&E process. These estimates are categorized as either preliminary or final. Project design cost estimates focus on the construction costs of the project and the stormwater BMPs, and are input into the Basic Engineering Estimating System (BEES). BEES has two components: (1) the District Cost Estimate, and (2) Structures (Bridge) Cost Estimate, that, when combined, equal the total construction cost for the project. See Appendix AA of the PDPM, 7/1/99 for current methods of cost estimating.

Project design cost estimates, including stormwater BMPs, should be considerably more detailed than project planning cost estimates. As engineering and environmental studies progress, more information, such as final contour mapping, materials and drainage information, and structure studies, becomes available. These data increase the ability to prepare a more detailed cost estimate. Appendix F of this document provides greater detail on methods for cost estimating to include stormwater BMPs as part of the overall project cost.

Responsible: Project Engineer

Recommended Participants: Project Manager

Project Engineer

Hydraulics Engineer
Environmental Engineering Representative
Environmental Planning Representative
District/Regional Design Storm Water Coordinator
Construction Storm Water Coordinator
Maintenance Storm Water Coordinator
District Landscape Architect or Project Landscape Architect

Discussion Topics: Storm water related quantities and estimates

Decisions/actions: PPCE developed during the PA/ED process.
Calculate Drainage Quantities and Estimate, WBS 230.40.15
Calculate Water Pollution Control Quantities and Estimate, WBS 230.40.35
Calculate Erosion Control Quantities and Estimate, WBS 230.40
Update quantities and estimates
Costs for stormwater BMPs
Designate appropriate Construction Site BMPs as separate contract bid line items as required per checklist CS-1
Available cost options (see Appendix F)

Documentation: Summary of Quantities

Verification: The following functional units shall verify the completed Cost Estimate:
NPDES
Landscape
Hydraulics
Environmental
Maintenance

7.5 DOCUMENTATION REQUIRED FOR PLANS, SPECIFICATIONS & ESTIMATES PACKAGE

This section describes the documents necessary for completion of a PS&E package. Preparation guidelines for the PS&E submittal are included in the PDPM, Chapter 14 (7/1/99). The PE works with the District Office Engineer to prepare the PS&E package. The following is a list of the stormwater documentation items included in the PS&E package.

Storm Water Data Report, WBS 230.60

The SWDR is updated and completed. Checklists SW-1, SW-2 and SW-3 should be included as a Supplemental Attachment to the SWDR during the approval process. The SWDR cover sheet is to be included in the final PS&E package.

Final District PS&E, WBS 255.20

Narrative: The PS&E is submitted to the Office Engineer for most projects. Guidance to PS&E submittal and documentation is located in the PDPM, Chapter 14, Section 3, dated 7/1/99.

Responsible: The final PS&E is submitted to the Division Chiefs by the Functional Manager overseeing the production of the PS&E.

Recommended Participants:

Division Chiefs

PE

PM

District/Regional NPDES Storm Water Coordinator

District/Regional Design Storm Water Coordinator

Other functional units as required.

Contents: The following should be included in the PS&E package. Also refer to the most current PDPM, Chapter 14 for the format and contents required.

- Final Standard Plans, including Water Pollution Control Plan Sheets identifying appropriate Construction Site BMPs and BEES designating appropriate Construction Site BMPs as separate bid line items.
- Quantities and Estimates;
- Right-of-Way Certification;
- Copy of NOC, WDR and other permits;
- SWDR - finalized and completed. Required Attachments are affixed to the report. Copy of Required Attachments, along with Supplemental Attachments (both listed in Appendix E) included in Resident Engineer (RE) File;
- SSPs and any non-standard special provisions required for the water quality BMPs or other contract items must be incorporated into PS&E for all projects, to ensure that the contract documents clearly set forth the contractor's responsibilities with respect to preparation and implementation of the SWPPP or WPCP as required for the project;
- Layout sheets showing locations and limits for the BMPs identified in the PS&E; and
- A brief explanation of both the permanent and Construction Site BMPs that will be specified;

Documentation: The PS&E package should include copies of the final plans, quantities and estimates, Right-of-Way Certification, updated SWDR, SSPs, copies of

permits, and any additional information the designer feels is necessary for the contractor to bid the project accurately.

Verification: District/Regional Design Storm Water Coordinator or other designated person verifies the PS&E package is complete, in relation to stormwater quality, with appropriate documentation and signatures on the SWDR.

The SWDR shall be signed by the PE, the District/Regional Design Storm Water Coordinator, a designated Landscape Representative, a designated Maintenance Representative, and by the PM to verify that stormwater quality design issues have been addressed, and the data is complete, current, and accurate. The District/Regional Design Storm Water Coordinator should be the last person to sign the SWDR to ensure that all appropriate reviews have been completed. The PE shall stamp the final SWDR.

The full PS&E package is circulated throughout the District to the functional units for comments and questions to make sure that each functional unit agrees with the package. After circulation and changes have been made, the PS&E goes to Headquarters (HQ) for final reviews before it is advertised for bidders. HQ will approve, make changes, or discuss with the District to make sure the project is "biddable" and "buildable."

Resident Engineer's File, WBS 270

This work involves preparing the District RE File/Structures RE File. It includes contacts with construction to transmit the file and determining what additional information may be required. Place information regarding stormwater quality issues in the RE File. See Section 8.1, Table 8-1 for a typical list of information to be included in the RE File.

8.1 INFORMATION FOR THE CONSTRUCTION PHASE OF THE PROJECT

The Caltrans Statewide National Pollutant Discharge Elimination System (NPDES) Permit requires a Storm Water Pollution Prevention Plan (SWPPP) for every project that meets the definition of Construction as outlined in the Construction General Permit. Specifically, a SWPPP is required when one of the following conditions exists:

- The project involves one (1) acre or more of soil disturbance;
- The project involves less than one (1) acre of soil disturbance but is considered part of a Common Plan of Development (see Section 4.2, Step #9); or
- The Regional Water Quality Control Board (RWQCB) designates the project as requiring a SWPPP based upon water quality concerns, even if the project does not meet the preceding requirements.

All projects that do not require a SWPPP must have a Water Pollution Control Program (WPCP). The purpose of both the SWPPP and the WPCP is to identify construction/contractor activities that could discharge pollutants in stormwater, and provide descriptions of measures or practices to control these pollutants. Both the SWPPP and the WPCP are the responsibility of the contractor to prepare, although the designer may elect to prepare a Conceptual SWPPP under certain circumstances (See the SWPPP and WPCP Preparation Manual, March 2003, Section 2.1.3).

In order to provide information for contractors to both bid on projects and prepare the SWPPP/WPCP, the design staff must supply certain water quality-related information. This information is incorporated into the Resident Engineer (RE) File (reference the Project Development Procedures Manual, Chapter 15, Section 2 and Section 7.5 of this manual) and may be included in the contractor's Information Handout. This information is in addition to any Construction Site Best Management Practices (BMPs) identified during the Plans, Specifications and Estimates (PS&E) process and included in the plans and specifications.

Typical water quality information that must be in the RE File and may be included in the Information Handout is listed in Table 8-1.

Table 8-1: Water Quality Information to be Included in the Resident Engineer File and/or Information Handout

• Vicinity map of the project area.
• Soils/geotechnical report, project materials report and/or other reports for description of soils types, nature of fill materials and known buried hazardous or toxic materials.
• List of pre-construction (existing) control practices.
• List of and/or narrative description of permanent (post-construction) stormwater control measures.
• Layout sheets showing locations and limits for the Construction Site BMPs identified in the PS&E.
• A brief explanation of permanent and Construction Site BMPs bid items and implementation strategy. The explanation shall identify locations for BMP deployment and substantiate the quantity estimates (may be in tabular format).
• Copy of drainage report or other documentation for identifying flow patterns and tributary areas.
• Rainfall total from a 25-year, 24-hour event and rainfall intensity for a 2-year, 1-hour event.
• Construction site estimates such as area calculations, runoff coefficients and pervious area calculations.
• Copy of the submitted NOC for the project.
• Copy of any WDR or permits
• Any additional information the designer determines is necessary for the contractor to bid the project accurately and implement BMPs during the construction of the project.
• Listing or cross-reference of special (atypical) conditions and/or mitigations, if any, associated with permits and environmental document.

Most of the information listed in Table 8-1 may be taken directly from the Storm Water Data Report (SWDR). **However, the SWDR itself should not be provided to the contractors, as it is not appropriate to justify design decisions or provide construction cost estimates to the contractor.** The following sub-sections provide a description of the items listed in Table 8-1 and where to collect them.

8.1.1 Vicinity Map of the Project Area

Provide a vicinity map extending approximately one-quarter mile beyond the property boundaries of the construction site showing: the construction site, surface water bodies (including known springs and wetlands), known wells, an outline of off-site drainage areas that discharge into the construction site, general topography, and the anticipated discharge location(s) where the construction site's stormwater discharges to a municipal storm drain system or other water body. It is recommended that a U.S. Geological Survey (USGS) quadrangle map be used for showing the project site and a one-quarter mile extension beyond the property boundaries of the construction site. USGS maps display much of the required information; however, the map will need to be slightly modified to show anticipated drainage paths (onto and off the construction site) and construction site boundaries.

The following are additional recommended items that should be provided on the vicinity map:

- Legend;
- Measurement of the construction site area;
- Flow directions of nearby creeks, streams, and rivers; and
- North arrow and Scale.

8.1.2 Soils/Geotechnical Report, Project Materials Report and/or Other Reports

Toxic History of the Site: To the extent information is available from the soils/geotechnical report, include the project materials report, site investigation report developed by the Hazardous Waste Section, or other regulatory or environmental compliance documentation. Include any Waste Discharge Requirements (WDRs) issued from the RWQCB related to toxic materials.

The Nature of Fill Material and Existing Data Describing the Soil: Include a copy of the project materials report (and/or the geotechnical report). The Information Handout package must describe the conditions of the fill material and the soil that can be found at the construction site (i.e., types of soils, groundwater location and conditions, dewatering operations that may be necessary, etc.) A general description can usually be found in the project materials report or geotechnical report. Fill material should be described as whether it is native or non-native, contaminated or uncontaminated, and its coverage technique (i.e., native soil coverage, asphalt or concrete coverage, and/or landscape).

Show and/or describe existing site features that, as a result of known past usage, may contribute pollutants to stormwater (e.g., toxic materials that are known to have been treated, stored, disposed, spilled, or leaked onto the construction site.) Review the contract documents and associated environmental documents to determine the known site contaminants.

8.1.3 Pre-Construction (Existing) Control Practices

Provide written descriptions of existing pre-construction practices, if any, which are already in place to reduce sediment and other pollutants in stormwater discharges. These permanent control practices may consist of rock slope protection, Infiltration Devices, Detention Devices, etc. If there are no pre-construction control practices, then this should be indicated. Existing features, structures, facilities, or practices that may be used by the contractor during construction should be clearly indicated. Conversely, if some or all may not be used, this likewise should be indicated (and consideration should be given to including such restrictions in the contract special provisions).

8.1.4 Permanent (Post-Construction) Storm Water Control Measures

Post-construction BMPs are permanent erosion and sediment control measures (i.e., Design Pollution Prevention BMPs) or Treatment BMPs that have been incorporated into the project plans. They include the minimization of land disturbance, minimization of impervious surfaces, treatment of stormwater runoff using approved Treatment BMPs, and appropriately designed and constructed energy dissipation devices. Provide a list containing narrative descriptions of

post-construction permanent BMPs that have been included in the project to reduce pollutants in stormwater discharges after construction is completed.

In some cases, these permanent BMPs will be designed to meet the requirements of other agencies, permit conditions, or other agreements. Any BMP to be included at the request of another agency should be discussed in the information presented in the RE File, and listed in the Information Handout. For example, if the Department of Fish & Game required the construction of a permanent Detention Basin, then this basin and its purpose would be described in this section. In addition, if a local agency were to require hard surfacing for the purpose of controlling erosion in a particular area, then the purposes and requirements of that agency would be described.

8.1.5 Layout Sheets Showing Suggested Construction Site BMP Locations

The designer may elect to provide layout sheets showing the suggested locations of Construction Site BMPs. The purpose of these sheets is to show the contractor the designer's anticipated placement of Construction Site BMPs such as contractor staging areas, approximate location of concrete washouts, approximate locations for storage of materials, and preferred locations for vehicle and equipment maintenance. These are not intended to be highly detailed drawings. Typically, these layouts can be drawn on l:200 and l:500 scale drawings. Where multiple stages of construction are anticipated, the designer should use the stage construction sheets to show how deployment of the BMPs is expected to change over time. These locations and layouts will be, in most cases, subject to the contractor's phasing of the work and timing of operations. As a result, many of the suggested locations will be modified by the contractor in the SWPPP/WPCP. If provided, the layout sheet must also contain a disclaimer stating that the temporary BMP locations are suggestions only, and that the Contractor is ultimately responsible for developing a SWPPP that complies with the Permit.

8.1.6 Explanation of Permanent BMPs Used as Temporary BMPs During Construction

The purpose of this section is to provide a brief explanation of the permanent BMPs that may be utilized to prevent pollutant discharges during construction. The designer should identify both existing permanent BMPs within the project limits, and any new permanent BMPs that could be constructed as a first order of work for use as a temporary BMP during construction. An example of this may be the deployment of a Detention Device as a first order of work to treat construction site discharges. All requirements listed in this section should be included in the contract special provisions.

8.1.7 Drainage Information

Include a copy of the drainage information, such as the drainage report, hydrology maps, delineation of drainage boundaries, concentrations of runoff, and runoff coefficients sufficient to determine peak discharges or run-on flowcharts.

8.1.8 Construction Site Estimates

Provide the following information to the RE File:

- An estimate of the construction site area in acres;
- An estimate of the percentage of the area of the construction site that is impervious (e.g., pavement, building, etc.) before and after construction;
- An estimate of the runoff coefficient of the construction site before and after construction (The form shown in Table 8-2 may be used to develop the necessary information for runoff coefficients. Tables 8-3 and 8-4 provide supporting information for the calculation of runoff coefficients.); and
- An estimate of the total disturbed area in acres.

Table 8-2: Computation Sheet for Determining Runoff Coefficients

Total Site Area	=		(A)
Existing Site Conditions			
Impervious Site Area[1]	=		(B)
Impervious Area Runoff Coefficient[2,4]	=	0.95	(C)
Pervious Site Area[3]	=		(D)
Pervious Site Area Runoff Coefficient[4]	=		(E)
Existing Site Area Runoff Coefficient = $\frac{(B \times C) + (D \times E)}{A}$	=		(F)
Proposed Site Conditions (After Construction)			
Impervious Site Area[1]	=		(G)
Impervious Site Runoff Coefficient[2,4]	=	0.95	(H)
Pervious Site Area[3]	=		(I)
Pervious Site Area Runoff Coefficient[4]	=		(J)
Proposed Site Area Runoff Coefficient = $\frac{(G \times H) + (I \times J)}{A}$	=		(K)

Note: For sites with dissimilar drainage sub-areas, calculate the equivalent runoff coefficients for pervious and impervious areas by $C = (C_1A_1+C_2A_2+...+C_iA_i) / (A_1+A_2+....A_i)$ Refer to the HDM Section 819.2(1) for additional information.

[1] Includes paved areas, areas covered by buildings, and other impervious surfaces.

[2] Use 0.95 unless lower or higher runoff coefficients can be verified.

[3] Includes areas of vegetation, most unpaved or uncovered soil surfaces, and other pervious areas.

[4] See Tables 8-3 and 8-4 for runoff coefficients.

Table 8-3: Runoff Coefficients for Undeveloped Areas
Watershed Types

	Extreme	High	Normal	Low
Relief	0.28 -0.35 Steep, rugged terrain with average slopes above 30%	0.20 - 0.28 Hilly, with average slopes of 10 to 30%	0.14 -0.20 Rolling, with average slopes of 5 to 10%	0.08 - 0.14 Relatively flat land, with average slopes of 0 to 5%
Soil Infiltration	0.12 - 0.16 No effective soil cover, either rock or thin soil mantle of negligible infiltration capacity	0.08 - 0.12 Slow to take up water, clay or shallow loam soils of low infiltration capacity, imperfectly or poorly drained	0.06 - 0.08 Normal; well drained light or medium textured soils, sandy loams, silt and silt loams	0.04 - 0.06 High; deep sand or other soil that takes up water readily, very light well drained soils
Vegetal Cover	0.12 - 0.16 No effective plant cover, bare or very sparse cover	0.08 - 0.12 Poor to fair; clean cultivation crops, or poor natural cover, less than 20% of drainage area over good cover	0.06 - 0.08 Fair to good; about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	0.04 - 0.06 Good to excellent; about 90% of drainage area in good grassland, woodland or equivalent cover
Surface Storage	0.10 - 0.12 Negligible surface depression few and shallow; drainage-ways steep and small, no marshes	0.08 - 0.10 Low; well defined system of small drainage ways; no ponds or marshes	0.06 - 0.08 Normal; considerable surface depression storage; lakes and basin marshes	0.04 - 0.06 High; surface storage, high; drainage system not sharply defined; large flood plain storage or large number of ponds or marshes

Reference: Caltrans Highway Design Manual, Section 819.2, Figure 819.2A, November 1, 2001

Example Determination of Runoff Coefficient for a watershed:

Given: An undeveloped watershed consisting of:
1) rolling terrain with average slopes of 5%,
2) clay type soils,
3) good grassland area, and
4) normal surface depressions.

Solution:

Relief	0.14
Soil Infiltration	0.08
Vegetal Cover	0.04
Surface Storage	0.06
C =	0.32

Find: The runoff coefficient, C, for the above watershed

Table 8-4: Runoff Coefficients for Developed Areas

Type of Drainage Area	Runoff Coefficient
Business:	
Downtown areas	0.70 - 0.95
Neighborhood areas	0.50 - 0.70
Residential:	
Single-family areas	0.30 - 0.50
Multi-units, detached	0.40 - 0.60
Multi-units, attached	0.60 - 0.75
Suburban	0.25 - 0.40
Apartment dwelling areas	0.50 - 0.70
Industrial:	
Light areas	0.50 - 0.80
Heavy areas	0.60 - 0.90
Parks, Cemeteries:	0.10 - 0.25
Playgrounds:	0.20 - 0.40
Railroad yard areas:	0.20 - 0.40
Unimproved areas:	0.10 - 0.30
Lawns:	
Sandy soil, flat, 2%	0.05 - 0.10
Sandy soil, average, 2-7%	0.10 - 0.15
Sandy soil, steep, 7%	0.15 - 0.20
Heavy soil, flat, 2%	0.13 - 0.17
Heavy soil, average, 2-7%	0.18 - 0.25
Heavy soil, steep, 7%	0.25 - 0.35
Streets:	
Asphaltic	0.70 - 0.95
Concrete	0.80 - 0.95
Brick	0.70 - 0.85
Drives and walks	0.75 - 0.85
Roofs:	0.75 - 0.95

Reference: Caltrans Highway Design Manual, Section 819.2, Table 819.2B, November 1, 2001

8.1.9 Other Information

Include any other information that would explain the decisions or rationale behind the selection and deployment of both permanent and Construction Site BMPs chosen by the designer. Examples include the designer's estimated staging of the project and estimated time of year for those stages; any scheduling modifications included in the Order of Work specifications that were included to enhance water pollution control; and any specific BMP deployments that are considered to be critical to the success of the contractor's SWPPP/WPCP. The designer should verify that all requirements listed herein would be reflective of the contract special provisions.

Other Plans/Permits: Other agencies may have issued permits or have plan requirements for the construction of the project or imposed certain conditions. If so, a written description of the permit conditions and a copy of the permit must be provided for inclusion in an appendix to the SWPPP. For example, hazardous materials must be handled in accordance with specific laws and regulations and disposed of properly. If during the preparation of the PS&E, it is known that special permits for hazardous waste disposal are required, a written explanation must be provided

to the contractor to be incorporated within this section and it must be consistent with other specifications in the contract. In addition, information regarding other related permits such as California Department of Fish & Game or U.S. Army Corps of Engineers permits should also be included.

Information/Guidance for Maintenance Staff: Many of the permanent control measures will require ongoing inspection and maintenance once construction is completed and the project is operational. This information should include project-specific O&M procedures for the permanent BMPs. The design staff should assemble information to be included in the RE File to be turned over to District Maintenance upon project close-out.

8.2 CONCEPTUAL STORM WATER POLLUTION PREVENTION PLAN/WATER POLLUTION CONTROL PROGRAM

The Caltrans permit allows any RWQCB to request submission of a SWPPP up to 30 days prior to the start of construction. In order not to delay the start of construction, the District/Regional NPDES Coordinator should determine, through consultation with the local RWQCB, if the submittal of a "Conceptual SWPPP" (CSWPPP) would satisfy this requirement. In this case, the submission of the CSWPPP would be prior to the submittal of the PS&E package to the Office Engineer. This CSWPPP may be prepared by the District/Regional Storm Water Coordinator, the Project Engineer (PE), or by other designated personnel. If required, the Conceptual SWPPP should be developed and included with the Information Handout to the bidders. The District may also decide to develop a CSWPPP on any project for reasons other than a 30-day prior submittal request by a RWQCB.

The CSWPPP should contain all of the elements of a contractor prepared SWPPP, but it will not replace the contractor's SWPPP. The term conceptual is used because the designer does not know all aspects of the eventual contractor's actual methods of construction, access requirements, planned order of operations, or other items, processes, equipment, etc. that are under the purview and control of the contractor. When a CSWPPP has been prepared, the designer should make that information available to the contractor through the Construction Duty Senior and include the information in the RE File and in the Information Handout. The contractor may use the CSWPPP as a guide and reference tool to develop and submit the contract SWPPP.

8.3 PREPARATION AND SUBMITTAL OF THE NOTIFICATION OF CONSTRUCTION

The Permit requires that a NOC be submitted to the appropriate RWQCB for projects with a disturbed soil area (DSA) of at least one (1) acre of total land area. This NOC must be submitted at least 30 days prior to the start of construction. A copy of the NOC is contained in Attachment F of the SWPPP/WPCP Preparation Manual (this manual can be downloaded from the following web site: http://www.dot.ca.gov/hq/construc/stormwater1.htm). A copy of the NOC is included at the end of this section.

Designers should also be aware of the following information:

- The NOC form should be completed by the PE or Project Manager (PM), Environmental Unit or District/Regional Storm Water Coordinator, as determined by District procedure;
- The signed NOC shall be submitted to the appropriate RWQCB at a minimum of 30 days prior to construction. It is recommended that the NOC be submitted to the RWQCB when the PS&E package is transmitted to the Office Engineer;
- No filing fees are required to submit an NOC to the RWQCB;
- A signed copy of the NOC should be transmitted to the District Construction Division, and a copy should also be sent to the PE for the project file;
- At the time of the first submittal to the RWQCB, the District may elect to leave blank the information in Section IV, Construction Field Office, and resubmit a copy of the form with that information filled in at the time the RE is assigned, and the field office address and phone number are known. Alternatively, the District may wish to fill in a contact name of someone other than the RE, such as the Area Senior Construction Engineer or PM. This person will remain the contact for that project until the NOC is resubmitted with the new contact information, or until the Notice of Completion of Construction (NOCC) is filed;
- In some cases, the RWQCB may deem two or more small projects (less than one [1] acre of soil disturbance) in the same corridor as part of a larger Common Plan of Development. The PM should be aware of other projects in the corridor. If needed, the other projects may be mentioned in the NOC;
- Caltrans has applied for and received a variance from the Department of Toxic Substances Control for the reuse of some soils that can contain lead. The Caltrans permit requires written notification to the RWQCB at least 30 days prior to advertisement for bids for projects that involve soils subject to this variance. The PE is encouraged to submit the notification early in design as the RWQCB may take as long as 180 days to issue WDRs. This notification period will allow a determination by the RWQCB(s) of the need for development of WDRs or written conditional approvals by RWQCB staff; and
- For areas in RWQCB-Regions 6 and 7 below 3,937 feet in elevation, the following additional requirements apply: (1) The Department will notify the RWQCB staff of construction projects in these areas at least 30 days prior to the start of construction, (2) During the 30-day notification period, RWQCB staff may request to review the SWPPP or meet with the Department to discuss the project, and (3) If Board staff does not respond within the 30-day review period, then the Department can proceed with its construction activities.

NOTIFICATION OF CONSTRUCTION

IN COMPLIANCE WITH CALTRANS STATEWIDE NPDES STORM WATER PERMIT Order No. 99-06 DWQ, NPDES No. CAS000003

I. IDENTIFICATION-Attach Vicinity Map, ½ size copy of Title Sheet

Project	*Check One:* ☐First Submittal or ___Amendment No. __	*Contract Number EA*	*Date MM/DD/YY*
City(if applicable)	*County*	*Tentative Start Date*	*Tentative End Date*
Route	*Post Mile*	*Kilometer Post*	*Tentative Date SWPPP Available*

II. CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARDS

☐Region 1, North Coast	Region 5, Central Valley	Region 6, Lahontan	☐Region 7, Colorado River
☐Region 2, San Francisco Bay	☐Sacramento	☐South Lake Tahoe	☐Region 8, Santa Ana
☐Region 3, Central Coast	☐Fresno	☐Victorville	☐Region 9, San Diego
☐Region 4, Los Angeles	☐Redding		

III. CALTRANS DISTRICT

Name/Number	*Project Contact*
Address	*Position Title*
City *Zip*	*Phone* ( )

IV. CONSTRUCTION FIELD OFFICE- Attach Location Map

Street Address	*Construction Contact*
Physical Location if Different than address above	*Position Title*
City *State* *Zip*	*Phone* ( )

V. CONSTRUCTION SITE INFORMATION

Description and Type of Work

Additional related required approvals: ☐ *DTSC Variance* ☐ *CWA 404/401* ☐ *DFG 1601* ☐ *NPDES/WDRs* ☐ *Other*
Describe:

Total Construction Area: *Acres* *Hectares*	*Total Disturbed Area:* *Acres* *Hectares*
Receiving Water Name:	*Project In Or Adjacent to Receiving Water?:* ☐ *Yes* ☐ *No*
Project Discharges to?: ☐ *Groundwater Infiltration* *Basin Location:*	☐*Municipal/Other System Name:*

VI. CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is true, accurate, and complete to the best of my knowledge and belief. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment of knowing violations.

Signature: _____ Date:

Print/Type Name: Title:

Appendix A
Approved Design Pollution Prevention BMPs

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A.1 REQUIRED MINIMUM DESIGN ELEMENTS FOR STORM WATER CONTROL

The PE must consider, and as appropriate, incorporate certain Design Pollution Prevention Best Management Practices (BMPs) into a project to minimize impacts to water quality. These BMPs were developed in response to the three following design objectives:

- *Prevent Downstream Erosion:* Stormwater drainage systems will be designed to avoid causing or contributing to downstream erosion;
- *Stabilize Disturbed Soil Areas:* Disturbed soil areas will be appropriately stabilized to prevent erosion after construction; and
- *Maximize Vegetated Surfaces Consistent with Existing Caltrans Policies:* Vegetated surfaces prevent erosion and promote infiltration (which reduces runoff).

The Design Pollution Prevention BMPs listed in Table A-1 and described in the following sections are designed to accomplish these objectives.

Table A-1: Design Pollution Prevention BMPS

Consideration of Downstream Effects Related to Potentially Increased Flow
Peak Flow Attenuation Basins
Preservation of Existing Vegetation
Concentrated Flow Conveyance Systems
Ditches, Berms, Dikes and Swales
Overside Drains
Flared Culvert End Sections
Outlet Protection/Velocity Dissipation Devices
Slope/Surface Protection Systems
Vegetated Surfaces
Hard Surfaces

A.2 CONSIDERATION OF DOWNSTREAM EFFECTS RELATED TO POTENTIALLY INCREASED FLOW

Description:

Changes in the velocity or volume of runoff, the sediment load or other hydraulic changes from stream encroachments, crossings or realignment may affect downstream channel stability.

Caltrans will evaluate the effects on downstream channel stability and the applicability of the mitigation measures described under Implementation for this BMP.

Appropriate Applications:

During the design of both new and reconstructed facilities, Caltrans may include new road surfaces or additional surface paving to enhance the operational safety and functionality of the facility. The designer must also consider the effect of collecting and concentrating flows in roadside ditches, storm drain systems, or the effect of re-directing flows to Treatment BMPs. Diversions or overflows from large storm events in these instances may create concentrated discharges in areas that have not historically received these flows.

Implementation:

If these changes result in an increased potential for downstream effects in channels, Caltrans will consider the following:

- Modifications to channel lining materials (both natural and man-made), including vegetation, geotextile mats, rock and riprap;
- Energy dissipation devices at culvert outlets;
- Smoothing the transition between culvert outlets/headwalls/wingwalls and channels to reduce turbulence and scour; and
- Incorporating peak flow attenuation facilities into designs to reduce peak discharges.

Caltrans will implement appropriate measures to ensure that runoff from Caltrans facilities will not significantly increase downstream effects.

A.3 PRESERVATION OF EXISTING VEGETATION

Description:

Preservation of existing vegetation involves the identification and protection of desirable vegetation that provides erosion and sediment control benefits.

Appropriate Applications:

Caltrans will preserve existing vegetation at areas on a site where no construction activity is planned or will occur at a later date.

Implementation:

The following general steps should be taken to preserve existing vegetation:

- Identify and delineate in contract documents all vegetation to be retained;
- Delineate the areas to be preserved in the field prior to the start of soil-disturbing activities;
- Minimize disturbed areas by locating temporary roadways to avoid stands of trees and shrubs and to follow existing contours to reduce cutting and filling; and

- When removing vegetation, consider impacts (increased exposure or wind damage) to the adjacent vegetation that will be preserved.

A.4 CONCENTRATED FLOW CONVEYANCE SYSTEMS

Concentrated flow conveyance systems consist of permanent design measures that are used alone or in combination to intercept and divert surface flows, and convey and discharge concentrated flows with a minimum of soil erosion. Concentrated flow conveyance systems may be used both within Caltrans rights-of-way (on-site) and downstream outside Caltrans rights-of-way.

Ditches, Berms, Dikes and Swales

Description:

These are permanent devices typically used to intercept and direct surface runoff to an overside (or slope) drain or stabilized watercourse.

Appropriate Applications:

Ditches, berms, dikes and swales are typically implemented:

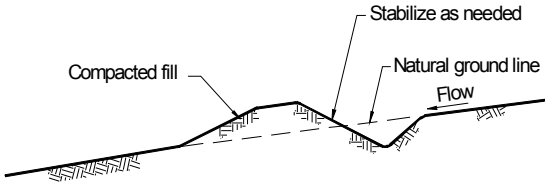
- At the top of slopes to divert run-on from adjacent slopes and areas;
- At bottom and mid-slope locations to intercept sheet flow and convey concentrated flows;
- At other locations to convey runoff to overside drains, stabilized watercourses, and stormwater drainage system inlets (catch basins), pipes and channels;
- To intercept runoff from paved surfaces; or
- Along roadways and facilities subject to flooding.

Implementation:

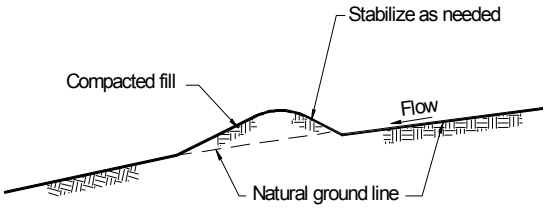
- Design must be in accordance with Chapter 800 of the Highway Design Manual (see Chapter 813, Topic 836 and Chapter 860);
- Select design flow based on careful evaluation of risks due to erosion, overtopping, flow backups or washout;
- Consider outlet protection where localized scour is anticipated;
- Examine the site for run-on from off-site sources;
- Consider order of work provisions to install and utilize permanent dikes, swales and ditches early in the construction process;
- Conveyances must be lined when velocities exceed allowable limits for soil (see Table 862.2 of the Highway Design Manual). Consider use of Rock Slope Protection (RSP), engineering fabric, vegetation, asphalt concrete or concrete (see Table 873.3E of the Highway Design Manual);

- Riprap should not be used where there is a high probability that traction sand or abrasives may enter the channel; and
- Ditches, berms, dikes and swales are shown in Figure A-1.

Figure A-1: Ditches, Berms, Dikes and Swales



Conceptual Diversion Ditch/Drainage Swale
Not to Scale



Conceptual Diversion Dike/Berm
Not to Scale

Note: Actual layout determined by design.

Overside Drains

Description:

Overside drains are conveyance systems used to protect slopes against erosion. Overside Drains may take the form of pipe downdrains, flumes or paved spillways, and protect slopes against erosion by collecting surface runoff from the roadbed, the tops of cuts or from benches in cut or fill slopes, and conveying it down the slope to a stabilized drainage ditch or area.

Appropriate Applications:

Overside drains are typically used at sites where slopes may be eroded by surface runoff.

Implementation:

- Design must be in accordance with Chapter 830 of the Highway Design manual (see Topic 834.4);

- Pipe downdrains are metal pipes adaptable to any slope. They are recommended where side slopes are 1:4 (V:H) or steeper;
- Flume downdrains are rectangular corrugated metal flumes with a tapered entrance. They are best adapted for low flow rates on slopes that are 1:2 (V:H) or flatter;
- Pipe and flume downdrains shall be securely anchored to the slope;
- Paved spillways are recommended on side slopes flatter than 1:4 (V:H). On steeper slopes, pipe downdrains should be used; and
- Drainage from benches in cut and fill slopes should be removed at intervals ranging from 300 to 500 feet.

An overside drain is shown in the Standard Plans, May 2006, Figure D87D.

Flared Culvert End Sections

Description:

These are devices typically placed at inlets and outlets of pipes and channels to improve the hydraulic operation, retain the embankment near pipe conveyances, and to help prevent scour and minimize erosion at these inlets and outlets.

Appropriate Applications:

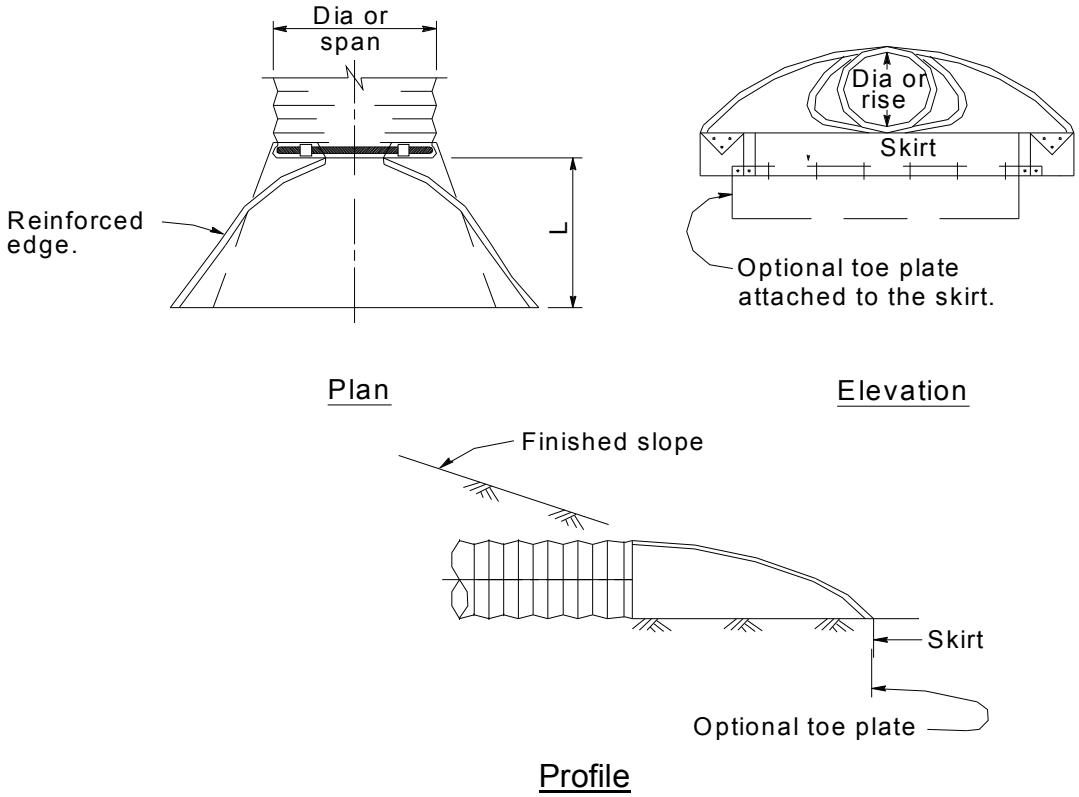
Use flared culvert end sections at outlets and inlets of overside drains and culverts.

Implementation:

- Design must be in accordance with Chapter 800 of the Highway Design Manual (see Topics 826 and 827); and
- Use with other outlet protection/velocity dissipation devices as appropriate.

A flared culvert end section is shown in Figure A-2 (see Standard Plans, May 2006, Figures D94A and D94B, Pages 181 and 182).

Figure A-2: Flared Culvert End Section



Outlet Protection/Velocity Dissipation Devices

Description:

These devices are typically placed at pipe outlets to prevent scour and reduce the outlet velocity and/or energy of exiting stormwater flows.

Appropriate Applications:

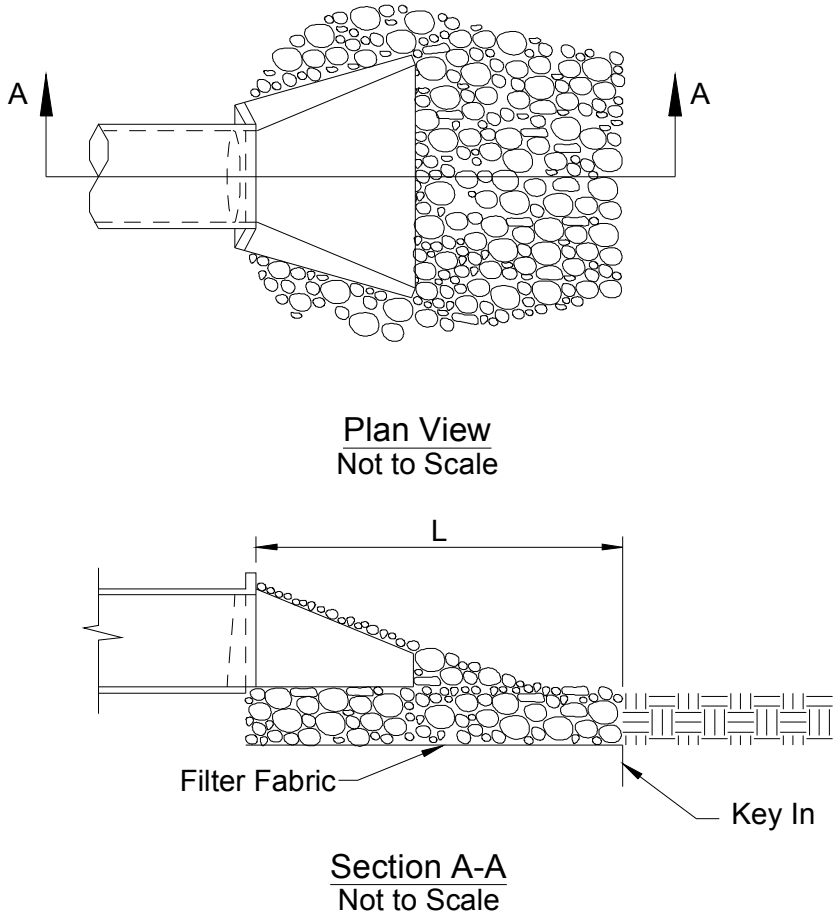
These devices are typically used at the outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits or channels, where localized scouring is anticipated.

Implementation:

- Design must be in accordance with Chapter 800 of the Highway Design manual (see Topic 827 and Chapter 870);
- Install riprap, grouted riprap, or concrete apron at selected outlet;
- Apron length (L) is related to outlet flow rate and tailwater level; and
- For proper operation of apron, align apron with receiving stream and keep straight throughout its length.

An outlet protection/velocity dissipation device is shown in Figure A-3.

Figure A-3: Outlet Protection/Velocity Dissipation Device



A.5 SLOPE/SURFACE PROTECTION SYSTEMS

Surface protection consists of permanent design measures that are used alone or in combination to minimize erosion from completed, disturbed surfaces. Vegetated surfaces may offer several advantages to paved surfaces, including lower runoff volumes and slower runoff velocities, increased times of concentration and lower cost. However, where site or slope-specific conditions would prevent adequate establishment and maintenance of a vegetative cover, hard surfacing should be considered.

Vegetated Surfaces

Description:

A vegetated surface is a permanent perennial vegetative cover on areas that have been disturbed. The purpose of a vegetated surface (from a water quality perspective) is to prevent erosion and may additionally remove pollutants in stormwater and non-stormwater runoff.

Appropriate Applications:

Vegetated surfaces should be established on areas of disturbed soil after construction related activities in that area are completed, and after the slope has been prepared. Vegetated surfaces should only be considered for areas that can support the selected vegetation long-term. Consult the District's Landscape Architect regarding vegetated surfaces and appropriate applications.

Implementation:

The following steps are typically implemented by the Landscape Architect:

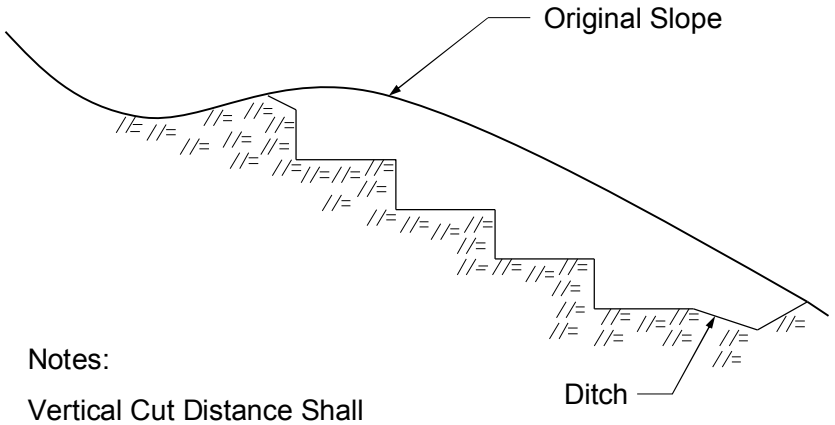
- The site should first be evaluated to select the appropriate vegetation and planting strategy. The site evaluation should consider soil type and condition; site topography; climate and season; types of appropriate native and adapted vegetation suited to the site; and maintenance;
- Vegetated surfaces shall be designed to minimize overland and concentrated flow depths and velocities, and maximize contact time between water and vegetated surfaces. This will enhance infiltration and pollutant removal opportunities; and
- When determined feasible, strip and stockpile topsoil (duff) and removed vegetation during construction. Use stockpiled materials in the surface preparation prior to seeding operations.

Slope Roughening/Terracing/Rounding/Stepping:

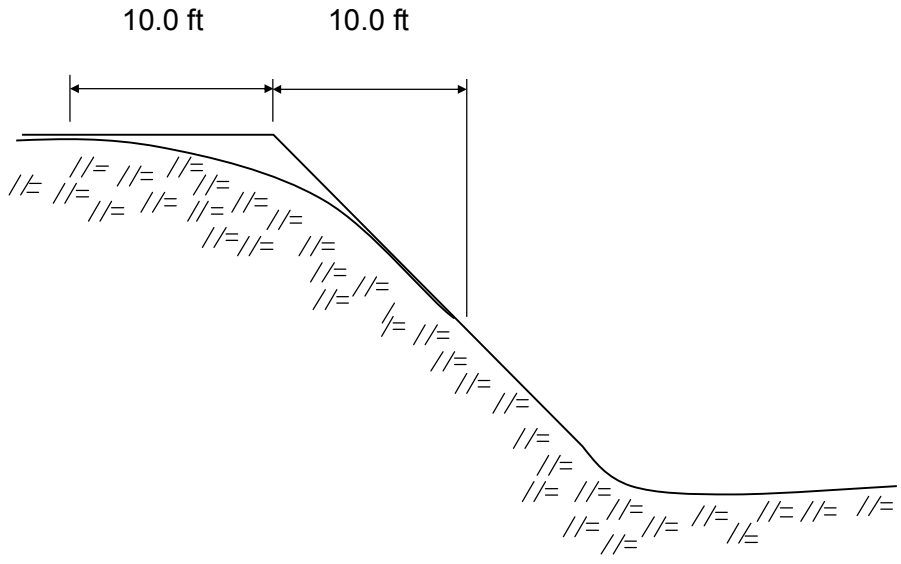
- Roughening and terracing are techniques for creating furrows, terraces, serrations, stair-steps or track-marks on the soil surface to increase the effectiveness of temporary and permanent soil stabilization practices. Slope rounding is a design technique to minimize the formation of concentrated flows; and
- Use on embankment or cut slopes, prior to the application of temporary soil stabilization or permanent seeding.

Slope roughening, terracing, rounding, and stepping, should be implemented as shown in Figure A-4.

Figure A-4: Slope Rounding, Stepping, Terracing and Contouring

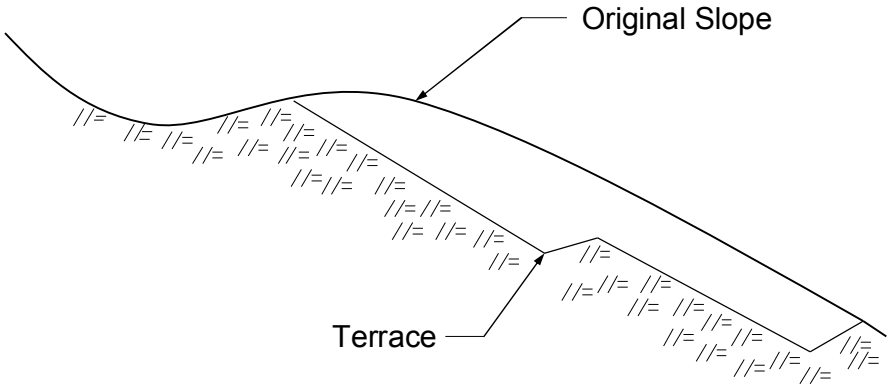


Stepped Slope (Not to Scale)

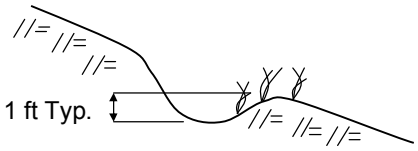


Slope Rounding

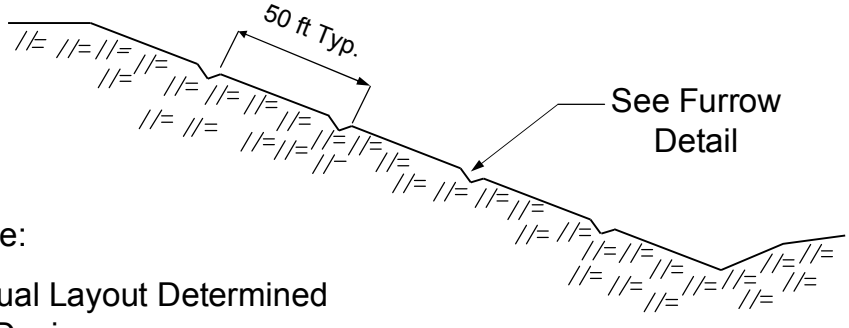
Figure A-4: Slope Rounding, Stepping, Terracing and Contouring
(Continued)



Terraced Slope (Not to Scale)



Furrow Detail



Note:

Actual Layout Determined by Design

Contour Furrows (Not to Scale)

Hard Surfaces

Description:

Hard surfaces consist of placing concrete, rock, or rock and mortar slope protection. The designer needs to consider the effects of increased runoff from impervious areas.

Appropriate Applications:

Apply on disturbed soil areas where vegetation would not provide adequate erosion protection. Hard surfaces are also considered where it is difficult to maintain vegetation.

Implementation:

- **Rock Slope Protection** (RSP) (See the California Bank and Shore Rock Slope Protection Design Manual. Web site: http://www.dot.ca.gov/hq/oppd/hydrology/hydroidx.htm
  - Angular rock of specified size is placed over fabric and used as rip rap to armor slopes, steambanks, etc.;
  - RSP consists of placing revetment-type rock courses;
  - Remove loose, sharp, or extraneous material from the slope to be treated;
  - Place underlayment fabric loosely over the surface so that the fabric conforms to the surface without damage. Equipment or vehicles should not be driven directly on the fabric;
  - Excavate a footing trench along the toe of the slope; and
  - Local surface irregularities should not vary from the planned slope by more than 1.0 feet (ft) as measured at right angles to the slope.

- **Concreted RSP**:
  - Angular rock of specified size is placed over fabric;
  - Concrete is placed into the rock interstices by gravity flow and a minimum of brushing and troweling; and
  - Used to armor streambanks.

- **Rock Blanket**:
  - Consists of round cobble rock placed as a landscape feature in areas often inundated with water.

- **Sacked Concrete Slope Protection**:
  - Bags are filled with concrete mix and stacked against the slope to cure. Rebar can be driven into the wet mix and bags.
  - Used to create revetment or bank protection. (This is aesthetically less desirable.)

- **Slope Paving**:
  - Used almost exclusively below bridge decks at abutments.
  - Provides erosion control and soil stabilization in areas too dark for vegetation to establish.
  - May be constructed of finish poured Portland Cement Concrete (PCC), shotcrete, or masonry paving units.
  - Foundation areas should be evenly graded and thoroughly compacted, with moisture sufficient to allow a firm foundation and to prevent absorption of water from the concrete or mortar. Work should be scheduled so that the work (including placing, finishing, and application of curing compound) between timber borders is started and completed in the same day. There should not be any construction joints between timber spacers.

- **Articulated Revetments**:
  - Mattresses composed of concrete units that are interlocked or interconnected with cables.

- **Gabions**:
  - Wire cages filled with rock. These units are then constructed into structures of various configurations.

Appendix B
Approved Treatment BMPs

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B.1 TREATMENT BMPS

This Appendix provides design guidelines for the Caltrans-approved Treatment Best Management Practices (BMPs) listed in Table 2-5. These BMPs have been approved for statewide use and should be considered for all projects that meet the criteria for incorporating Treatment BMPs, as described in Section 4 of this handbook.

B.1.1 Targeted Design Constituent

A Targeted Design Constituent (TDC) is defined as a pollutant that has been identified during Departmental runoff characterization studies to be discharging with a load or concentration that commonly exceeds allowable standards and which is considered treatable by currently available Department-approved Treatment BMPs. The Targeted Design Constituent approach is the Department's statewide design guidance to address the "Primary Pollutants of Concern" as listed in Figure 2-3.

Targeted Design Constituents are: phosphorus; nitrogen; total copper; dissolved copper; total lead; dissolved lead; total zinc; dissolved zinc; sediments; general metals [unspecified metals]. A project must consider treatment to target a TDC when an affected water body within the project limits (or with the sub-watershed as defined by the Water Quality Planning Tool) is on the 303(d) list for the one or more of these constituents. Infiltration Devices, being the approved Treatment BMP capable of treating all the constituents listed in Table 2-2, Pollutants of Concern and Applicable Treatment BMPs, should be considered as the desired Treatment BMP for all watersheds in projects that are required to consider Treatment BMPs. However, if Infiltration Devices cannot be incorporated, or if the proposed Infiltration Device(s) cannot accept all of the WQV runoff, Biofiltration Systems, Detention Devices, Multi-Chambered Treatment Trains, Media Filters (Austin Sand Filter and Delaware Filter), and Wet Basins must be considered based on the Targeted Design Constituent approach. The remaining Caltrans-approved Treatment BMPs, Dry Weather Flow Diversion, Gross Solids Removal Devices, and Traction Sand Traps, are applicable for specific situations as described in this Appendix and in this handbook.

B.1.2 Interaction with other Caltrans Functional Units

Besides Design, many other functional units may play a significant role in the implementation of the various Treatment BMPs into a project. These units should be consulted during the selection and design of Treatment BMPs. For example, District Landscape Architecture will select vegetative cover for many of the Treatment BMPs (e.g., Biofiltration BMPs), and should be consulted on siting issues for all the Treatment BMPs. District Maintenance must be consulted to insure that they can safely access and maintain the deployed BMPs. Proper hydraulic design is critical to the safe and efficient operation of all of the Treatment BMPs; this task is performed by either the Project Engineer or by District Hydraulics depending upon the District and level of complexity of the design. Geotechnical Services will conduct site investigations for Infiltration Devices and other Treatment BMPs. District Traffic Operations should be consulted when considering placement of Treatment BMPs in or near Clear Recovery Zones. The District Environmental unit plays a significant role in the environmental assessment of the project, and in the environmental clearance of sites for proposed Treatment BMPs. The District NPDES and/or the Design Storm Water Coordinator plays a significant role by assisting in the interpretation of

the PPDG, and by reviewing Storm Water Data Reports produced for the PID, PA/ED, and PS&E phases of the project. District Construction will help to identify potential constructability issues with proposed Treatment BMPs. Other units may have a role in developing appropriate Treatment BMP strategies; therefore, the designer must identify key project information and coordinate with other Functional Units throughout each Project Phase.

B.1.3 Hydraulic Issues Related to Treatment BMPs

Treatment BMPs are designed for water quality purposes, but they must also operate safely and effectively as part of the overall highway drainage system; because of this, hydraulic design issues must be carefully evaluated during the consideration and design processes for Treatment BMPs, especially with regard to any upstream effects that would impact highway drainage. While some aspects of hydraulic engineering are presented in this handbook, those presented will focus on the site-specific design of a Treatment BMP, and not on all aspects of hydraulic or hydrologic engineering. Instead, the Project Engineer is referred to the Highway Design Manual - Section 800, Highway Drainage Design, and the Project Engineer may require the assistance of the District Hydraulics Unit (e.g., when a Treatment BMP is used for the dual purposes of peak flow attenuation and water quality treatment).

B.1.3.1 Treatment BMPs as a Component of the Drainage System

Several of the Treatment BMPs can be designed to work either online or offline; for convenience, within this handbook it is assumed that online placement will be chosen.[1] There are potentially different impacts and design issues associated with online versus offline placement, and these should be discussed with District Hydraulics.

Those WQV- and WQF-based Treatment BMPs that are designed for online placement must also safely pass events that are larger than the WQ event assumed in the design of that Treatment BMP; for all except the Biofiltration Swale, the release of larger events is usually accomplished as overflow through a weir, with the weir set at an elevation related to the WQV. The overflow event used in the design of the weir must be consistent with the intensity, duration and frequency of the rainfall event used in the roadway drainage design for that tributary area contributing runoff to the Treatment BMP (and from other sources that cannot be redirected around the Treatment BMP) as discussed in Highway Design Manual – Topic 831. Overflow weirs must also be considered for offline placement of Treatment BMPs in the event that clogging or other unusual conditions occur.

Associated with the overflow event, a minimum freeboard of 12 inches should be provided between the surface water elevation during the overflow event and the lowest elevation of the confinement (e.g. the lowest elevation at the top of berm or vault) in order to provide assurance

[1] When placed 'online', the BMP would be located in the drainage flow path of the runoff and the BMP must convey runoff from any storm that occurs by passing all flows through the BMP itself. Flows up to the WQV (or WQF, depending upon the Treatment BMP selected) are treated by the BMP, while larger storm events are safely passed through the BMP without adversely impacting the upstream drainage systems, but without treatment. In contrast, 'offline' Treatment BMPs systems primarily receive runoff from storm events up to and including the Water Quality event, while larger events are diverted around the Treatment BMP by an upstream flow splitter device. Treatment BMPs which use WQV as the design basis must make an estimate of an equivalent flow rate to capture the 85th percentile runoff when designing the flow splitter for the offline configuration.

of the physical integrity of the Treatment BMP and downstream facilities. This distance is referred to as the "Water Quality Freeboard."

B.1.3.2 Use of WQV-Based Treatment BMPs as Peak Flow Attenuation Devices

Usually a Treatment BMP is placed only for stormwater quality purposes; however, when a WQV-based Treatment BMP is proposed with the added purpose of a Peak Flow Attenuation Device (accomplished by delayed release of the runoff), District Hydraulics should be consulted to select the inflow hydrograph and runoff storage requirements within the Treatment BMP.

B.1.4 Incorporation of Existing Features as Treatment BMPs

Some existing features may be considered as Treatment BMPs even if they were not originally designed with that intent, provided that the existing features meet the guidelines in this handbook. These features (e.g. vegetated swales or detention basins, etc.) may perform the same functions as Treatment BMPs, but were not classified as Treatment BMPs at the time they were constructed. These features should be evaluated for possible classification as Treatment BMPs, considering the following:

- Determine the tributary area to the existing feature, and determine the associated Water Quality Volume or Water Quality Flow;
- Verify that the Applications/Siting criteria for the Treatment BMP listed in Appendix B is met at the existing location;
- Verify that the Design Factors of the Treatment BMP listed in Appendix B are met at the existing location.

Once these items are considered, the features that are under consideration for classification as Treatment BMPs should be discussed with the District Storm Water Coordinator and the entire Project Development Team (PDT). A final decision should be made after examining all the issues (e.g., Water Quality benefits versus changes in maintenance practices, future projects affecting the proposed Treatment BMP location).

If an existing feature is determined to be the functional equivalent of an approved Treatment BMP and classification as a Treatment BMP is accepted, then document the location in Section 2 and Section 5 of the Storm Water Data Report that this feature qualifies as an existing Treatment BMP and claim credit on the appropriate Treatment BMP Summary Spreadsheet.

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B.2 BIOFILTRATION STRIPS AND SWALES

(VEGETATED TREATMENT SYSTEMS)

B.2.1 Description

Biofiltration Strips are vegetated land areas, over which stormwater flows as sheet flow. Biofiltration Swales are vegetated channels, typically configured as trapezoidal or v-shaped channels, that receive and convey stormwater flows while meeting water quality criteria and other flow criteria.

Pollutants are removed by filtration through the vegetation, sedimentation, adsorption to soil particles, and infiltration through the soil. Strips and swales are effective at trapping litter, Total Suspended Solids (soil particles), and particulate metals.

B.2.2 Appropriate Applications and Siting Criteria

Biofiltration Strips and Swales should be considered wherever site conditions and climate allow vegetation to be established and where flow velocities will not cause scour. Vegetative cover of about 70% is required for treatment to occur. Biofiltration Strips and Swales should also be considered upstream of Treatment BMPs that would benefit from pretreatment by reducing sediment loading, such as Infiltration Devices, Detention Devices, and Wet Basins.

B.2.3 Factors Affecting Preliminary Design of Biofiltration Swales and Strips

B.2.3.1 Biofiltration Swales

Biofiltration Swales have two design goals: 1) to meet treatment criteria under Water Quality Flow (WQF) conditions, and 2) to provide adequate hydraulic function for conveyance and scour prevention for the peak drainage facility design event. Treatment is maximized by designing the swale to be as gently sloped and as long as the site constraints allow.

For a swale to be designated as a Treatment BMP, criteria relating depth, velocity, and Hydraulic Residence Time (HRT) as presented in the formula below must be met:

$$(HRT \times 60)/(depth \times velocity) \geq C \qquad \text{(Eq. 1)}$$

where:

HRT	=	Hydraulic Residence Time during WQF, minutes ($\geq$ 5 minutes)
60	=	conversion factor from minutes to seconds
depth	=	depth of flow at WQF (varies with velocity selected, up to 0.5 ft)
velocity	=	velocity of flow at WQF (varies with depth selected, up to 1.0 fps)
C	=	A constant: 1,300 (sec^2/ft^2)

Note that the Hydraulic Residence Time is that time during which the WQF travels in the Biofiltration Swale, and has no relation to the Time of Concentration term as used in hydrologic calculations.

The Rational Formula should be used to calculate the runoff entering the bioswale as described in Topic 819.2 of the Highway Design Manual, using the appropriate Water Quality storm

intensity from Section 2.4.2.2, *Treatment BMP Use and Placement Considerations*, of this handbook to calculate the WQF. Calculation of the depth of flow and velocity in the bioswale should be made using the Manning's equation, with the Manning's number under the WQF for preliminary calculations taken as n = 0.20 for "routinely mowed" strips and swales, or at WQF Manning's n = 0.24 for "infrequently mowed" strips and swales. HEC 22, Tables 5-2 and 5-3 can also be consulted to determine an appropriate Manning's n for the site-specific depth if more rigorous calculations are deemed warranted.[2] In the situation where the WQF enters the proposed bioswale at a single upstream point, and only minor additional flow enters along the length of the swale, the calculation of Equation 1 is relatively simple. However, if the flow enters the Biofiltration Swale continuously along the length of the swale or at multiple discrete locations, other rational methods should be employed. In the case of continuous flow entering the swale, the designer may wish to initially calculate the depths and velocities at selected points along the swale to verify that the depth or velocity has not exceeded the maximum allowed values. This same calculation could also be used if there is a change of grade. The length of the swale that would qualify as a Biofiltration Treatment BMP must be upstream of the location where either the maximum depth or velocity was exceeded. The calculation of the HRT when the WQF enters at multiple (actual entry points or discretized from continuous flow) entry points could be done by calculating the HRT for the flow from each of the discrete entry points, and then taking a weighted average of the HRTs for the entire flow over the length that qualifies as a Biofiltration Treatment BMP; velocity and depth criteria would still need to be met.

To provide adequate hydraulic function, a swale should also be sized as a conveyance system calculated according to criteria and procedures for conveyance of design storm flows and scour associated with the peak drainage facility design event.

B.2.3.2 Biofiltration Strips

Biofiltration Strips should be designed to be as long and as flat as the site will allow, which maximizes treatment efficiency. The maximum strip length under which sheet flow conditions exist (and therefore treatment is obtained as a Biofiltration Strip) is dependent on site conditions; an upper limit for maximum strip length of approximately 100 ft in the direction of flow should be used, although there may be a greater opportunity for infiltration using longer lengths.

A study by Caltrans [Roadside Vegetated Treatment Sites (RVTS) Study, CTSW-RT-03-028] indicated that for Biofiltration Strips in certain slope and soil conditions, reductions were noted in the concentrations of copper, lead, zinc and TSS after flow passed through as little as 15 feet of Biofiltration Strip, and that little additional treatment was achieved after approximately 30 feet of flow length.

Areas with limited opportunity to sustain vegetative cover (i.e. sustain less than 70% coverage) provide little effective treatment, and should be considered unsuitable for Biofiltration Strips. The area to be used for the Biofiltration Strip should be free of gullies or rills that can concentrate overland flow and cause erosion.

[2] As a bioswale usually also conveys the HDM storm event (a much larger event than the WQF event), a more precise determination of Manning's n is usually unnecessary for water quality purposes.

Table B-1 summarizes preliminary design factors for Biofiltration Strips and Swales.

Table B-1: Summary of Biofiltration Strips and Swales Siting and Design Factors

Description	Applications/Siting	Preliminary Design Factors
Strips are vegetated land areas over which stormwater flows as sheet flow. Swales are vegetated channels that receive and convey storm water as a concentrated flow. Biofiltration treats the WQF. Treatment Mechanisms: • Filtration through the vegetation • Sedimentation • Adsorption to soil particles • Infiltration Pollutants primarily removed: • Litter • Total Suspended Solids • Particulate metals	• Site conditions and climate allow vegetation to be established – 70% minimum vegetation coverage will allow treatment, with better effects at higher coverage. • Consider locations for swales where flow velocities will not cause scour • Consider swales to provide pretreatment for other Treatment BMPs (Infiltration Devices, Detention Devices, and Wet Basins) • If proposed location is above hazardous soils or contaminated groundwater plumes, coordinate with District/Regional NPDES Storm Water Coordinator and RWQCB for clear direction	• Strips and Swales: vegetation mix appropriate for climates and location • Strips and Swales: Use the Rational Method to determine the Water Quality Flow (WQF) and peak flows for the peak drainage facility design event • Swales designed as a conveyance system for the peak drainage facility design event per HDM Chapters 800 to 890 • Swales: after designing to convey flows from the peak drainage facility design event, check swale against biofiltration criteria at WQF • Swales: design criteria under WQF: Hydraulic Residence Time of 5 minutes or more; maximum velocity of 1.0 ft/s; maximum depth of flow of 0.5 ft, and Eqn. 1 relationship among these variables. • Swales: slope in direction of flow: minimum 0.25%, maximum 6%, with 1 to 2% preferred; • Swales: A minimum width (in the direction of flow) at the invert of a trapezoidal bioswale typically 2.0 ft; maximum bottom typically up to 10 ft; side slope ratio should be 1:4 (V:H) or flatter; discuss bottom width and side slope ratio with District Maintenance. • Swales: if flow velocity under the peak drainage facility design event exceeds 4.0 ft/s, consult with Hydraulics to determine if geosynthetic reinforcement of the bioswale would be helpful to prevent erosion. • Swales: freeboard: Refer to HDM Topic 866 to determine if freeboard is required • Strips: sized as long (in direction of flow) and flat as the site will reasonably allow up to sheet flow boundaries (maximum length of Biofiltration Strip is approximately 100 ft); an HRT is not required. • Strips: should be free of gullies or rills

B.2.4 Vegetative Factors

Apart from meeting the hydraulic parameters presented above, vegetation is the critical component in the effectiveness of Biofiltration Treatment BMPs. The District Landscape Architecture Office should be consulted for each project to recommend appropriate vegetation

species. Every effort should be made to assure the successful establishment of vegetation, including consideration of the topics discussed below.

B.2.4.1 Soils

Soils with favorable infiltration characteristics promote successful vegetative cover by allowing healthy root development, thereby promoting the effectiveness of the Biofiltration BMP. The Landscape Architect may recommend the following practices that foster infiltration and vegetation establishment:

- Stockpiling topsoil or duff prior to construction and replacement of topsoil in areas that will serve as Biofiltration Strips and Swales;
- Cultivating and ripping of existing soils along the areas to be converted into Biofiltration BMPs, to relieve compaction; and
- Incorporating soil amendments, including granular soils and organic material.

B.2.4.2 Selection of Plant Materials

Selection of plant materials for the Biofiltration BMP should be based on the following:

- Tolerance to varying soil moisture, and an ability to survive during dry season without irrigation (unless irrigation is already in place or has been proposed with highway planting in adjacent areas);
- Long-term survivability that includes a mix of long-lived perennial species and annual species that successfully reseed;
- Dense, continuous root mass; and
- Dense, continuous top growth that includes grasses and grass-like species, forbs, and some broad-leafed species.

B.2.4.3 Plant Establishment

Seeded Biofiltration Strips and Swales may require specific measures be incorporated in the design to ensure success. Consideration should be given to:

- Mulches, bark, straw, etc., on slopes that are steeper than 1:4 (V:H) to improve infiltration and protect against surface erosion when under sheet flow conditions;
- Erosion control blankets to protect against surface erosion when concentrated flow is present;
- Turf Reinforcement Mat (TRM) or a suitable geosynthetic fabric as a bioswale lining for flows from the peak drainage facility design event

(design with assistance of Regional/District Hydraulics using methods listed in HDM Chapter 870);

- Temporary flow diversion to direct concentrated flow around newly seeded areas until vegetation is established;
- The use of sod may be preferred over seeding;
- If sod is used, supplemental water/temporary irrigation may be required during an establishment period; and
- An appropriate plant establishment period to ensure plant survivability.

B.2.4.4 Resources about Plant Materials

For additional information about native plant species suited to varied hydrologic conditions within specific ecological subregions of California, consult:

- Ecological Subregions of California Section and Subsection Descriptions, USDA, Forest Service, USDA, Natural Resources Conservation Service, published May 1998

  (online at: http://www.fs.fed.us/r5/projects/ecoregions/);
- Calflora Database (online at: http://www.calflora.org); and
- Caltrans native grass database (online at: http://www.dot.ca.gov/hq/LandArch/grass.html).

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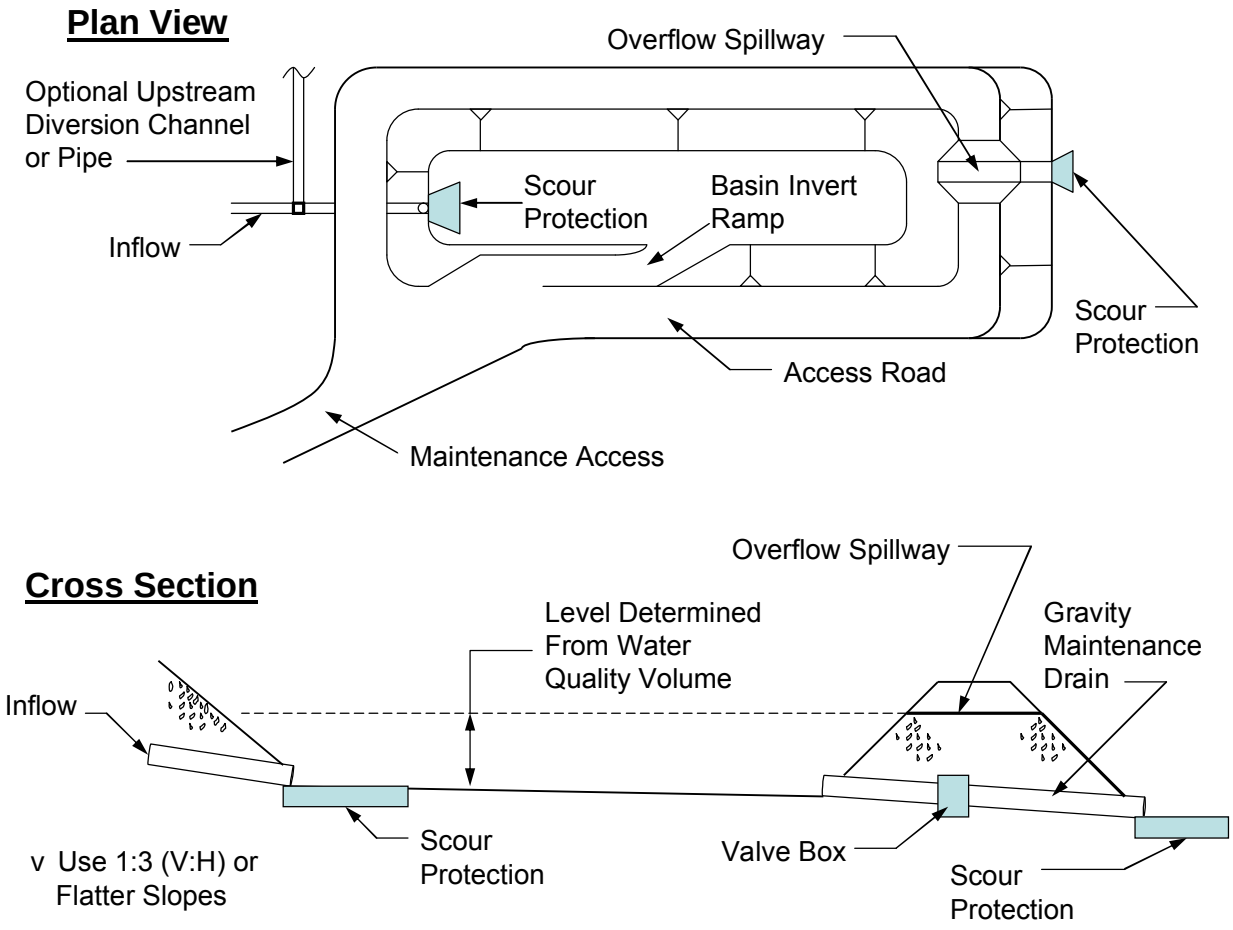
B.3 INFILTRATION DEVICES

An Infiltration Device is designed to remove pollutants from surface discharges by capturing the Water Quality Volume (WQV) and infiltrating it directly to the soil rather than discharging it to surface waters. Infiltration devices may be configured as basins or trenches.

B.3.1. Description

An Infiltration Basin temporarily stores the WQV while it infiltrates through the invert. An Infiltration Basin may be constructed in any shape to meet right-of-way restrictions. Runoff enters the basin under gravity flow. Storms producing runoff greater than the WQV will overflow through a spillway if the Infiltration Device is placed in an online configuration. However, an Infiltration Basin must always incorporate an overflow spillway whether placed online or offline. A schematic illustration of an Infiltration Basin is shown in Figure B-1.

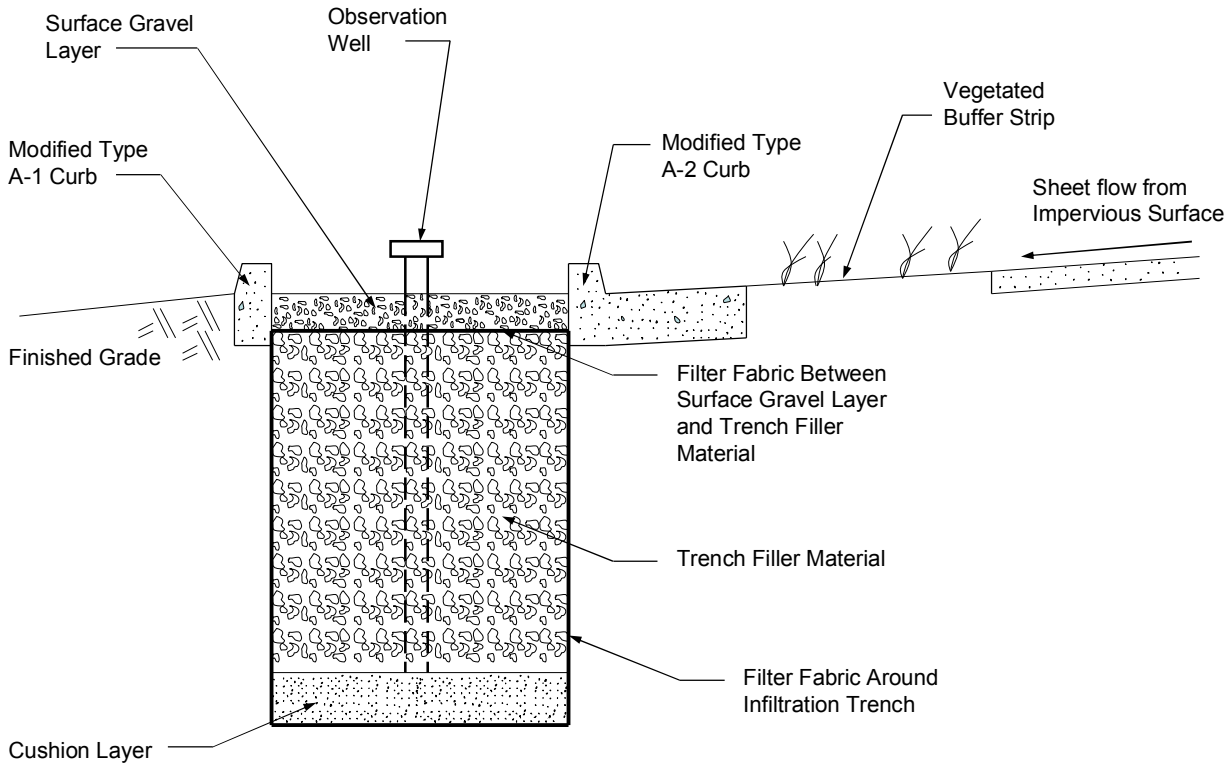
Figure B-1: Schematic of an Infiltration Basin



By contrast, an Infiltration Trench temporarily stores the WQV below ground in the void spaces between the rock or other material placed in the trench while it infiltrates through the invert.

Infiltration Trenches are often elongated, allowing them to be used in constricted areas, but there is no shape restriction. A schematic illustration of an Infiltration Trench is shown in Figure B-2.

Figure B-2: Schematic of an Infiltration Trench



In order to avoid the classification of an Infiltration Trench as a regulated injection well, the Infiltration Trench should be designed as follows: a) the WQV should be directed to the Infiltration Trench by gravity flow in an open channel or as sheet flow; b) the captured volume should flow downward within the trench by the action of gravity, and without vertical piping for distribution to lower depths of the trench; and c) the greater dimension (length or width) at the surface must exceed the depth of the trench.

Installation of an upstream bypass or flow splitter device should be considered for Infiltration Trenches.

Performance of the Infiltration Trench is monitored using an observation well placed within the Infiltration Trench; this observation well can also be used to access the trench if maintenance is required (e.g. using a hose and pump to remove standing water).

The required volume of the Infiltration Trench is roughly three times the WQV because only the void space within the rock backfill holds the WQV, and that void space is typically only 35% of the total volume of the rock. Other high porosity backfill materials are available, thus reducing the volume of the trench; consult with the Headquarters Division of Environmental Analysis – Policy, Planning and Permitting, and Headquarters Design Office of Storm Water Management if such materials are under consideration for a site.

The typical configuration uses a filter-fabric lined trench (i.e., the trench is formed against bare earth with a fabric as a separator, rather than concrete walls) with a curb or dike at its perimeter at the ground surface; the filter fabric is employed between the rock and the native ground to prevent soil intrusion into the void space.

B.3.2 Appropriate Applications and Siting Criteria: Infiltration Basins and Trenches

Infiltration Devices should be considered wherever site conditions allow and the design WQV exceeds 0.1 acre-feet; an Infiltration Trench may be considered whenever the WQV is between 0.065 and 0.1 acre-feet with concurrence of District/Regional Storm Water Coordinator. Appropriate sites for Infiltration Devices should have:

a) Sufficient soil permeability;

b) A sufficiently low water table;

c) The influent would not present a threat to local groundwater quality; and

d) Sufficient elevation to allow gravity drainage of the device when needed for maintenance purposes (Infiltration Basin only).

The Regional Water Quality Control Board (RWQCB) having jurisdiction may impose additional requirements for water protection purposes. Other physical siting conditions are discussed under Table 2, Applications/Siting. One other important siting requirement is that water stored in the Infiltration Basin, when constructed online, does not cause an objectionable backwater condition upstream in the storm drain system that would adversely impact its ability to convey flows generated by peak drainage facility design events as required in the HDM.

Infiltration Basins will function more effectively over the long-term if vegetated on the invert and side slopes. Consult the District Office of Landscape Architect for types of vegetation that can function effectively in Infiltration Basins in each of the various ecological subregions of a District. Additional information about grasses that have been successful within specific ecological subregions of California may be found in Ecological Subregions of California Section and Subsection Descriptions (as referenced in Appendix B, Biofiltration Strips and Swales).

Because an Infiltration Trench relies on flow through a filter fabric, the device is prone to clogging if excessive sediment loads are allowed to enter the device. Rehabilitation of a clogged Infiltration Trench is difficult, especially compared to the relative ease to rehabilitate an Infiltration Basin. Because of this, pretreatment to capture sediment in the runoff is required upstream of the Infiltration Trench to increase longevity of the system (by using Biofiltration devices or a forebay). To further minimize the clogging potential, the design may employ an upper layer of permeable material, typically about 0.5 feet in thickness, below which would be placed filter fabric; this upper layer would act as an initial filter, and could be periodically removed and replaced as conditions warrant rather than removing the entire rock volume.

Infiltration Trenches would likely be considered inappropriate for placement in close proximity to Drinking Water Reservoirs and/or Recharge Facilities due to the difficulty in cleaning in the event of a spill; consult the District/Regional NPDES Coordinator if an Infiltration Trench is being considered adjacent to a Drinking Water Reservoir or Recharge Facility.

B.3.3 Factors Affecting Preliminary Design

The following steps are recommended for determining the feasibility of an Infiltration Device. The major components are Pre-screening, Site Screening, Site Investigation and Preliminary Design. Siting and design criteria are summarized in Table B-2.

Table B-2: Summary of Infiltration Device Siting and Design Criteria

(Applicable to both Infiltration Basins and Infiltration Trenches unless noted)

Applications/Siting	Preliminary Design Factors
• Infiltration Basin and Trench: Ability to treat a WQV ≥ 0.1 acre-feet; consult District/Regional Storm Water Coordinator if an Infiltration Trench is being considered for a WQV between 0.065 and 0.1 acre-feet (between 2,833 ft^3 and 4,356 ft^3). • Runoff quality must meet or exceed standards for infiltration to local groundwater • Infiltration Devices should not be sited in locations over previously identified contaminated groundwater plumes • Separation from seasonally high water table > 10 ft, (or ≥ 4 ft if justified by adequate groundwater observations for a minimum of 1 year); for most projects, the minimum clearance of 10 ft should be provided; consult with District NPDES and Headquarters *Office of Storm Water Management Design* if < 10 ft of clearance is being considered. • Soil types restricted to HSG A, B, or C (for Infiltration Basins) or HSG A or B (for Infiltration Trenches) having an infiltration rate ≥ 0.5 in/hr; maximum infiltration rate is 2.5 in/hr unless a higher rate is approved in writing by RWQCB. For preliminary estimates of soil infiltration rate, consult Table B-3. • Soil should have a clay content < 30% and a combined silt/clay content < 40% • Site should not be located in area containing fractured rock within 10 ft of invert [Table continues on next page]	• Infiltration Basins: Infiltrate WQV within 40 to 48 hours; Infiltration Trenches: Infiltrate WQV up to 72 hours • Use representative infiltration or permeability rate to size the device • Provide maintenance access (for an Infiltration Basin, provide a road entirely around the basin or at least to the overflow spillway. Also provide a ramp to the basin invert, or provide an access road to an Infiltration Trench) • Infiltration Devices should not be placed in service within a construction contract until all upstream runoff is stabilized, or shall be protected from sediment-laden runoff. • Infiltration Basins: Optional upstream diversion channel or pipe for storm events > WQV; mandatory downstream overflow outlet as part of the Basin flow control device sized to pass the peak drainage facility design event (see HDM Chapter 830) that will enter the basin, minimum outlet length 3.0 ft, as overflow weir or outlet riser • Infiltration Basins: Provide a minimum 12 inch Water Quality freeboard (the difference between the surface water elevation during the overflow event and the lowest elevation of the confinement) • Infiltration Basin: Scour protection on inflow and overflow outlet • Infiltration Basins: Use as flat an invert as possible (3% maximum); Infiltration Trenches: flat invert (no slope) • Infiltration Basins: Provide maintenance gravity drain, if practicable • Infiltration Basins: Use 1:4 (V:H) side slope ratios or flatter for interior side slopes, unless approved by District Maintenance, with 1:3 (V:H) maximum • Infiltration Basins: Provide vegetation, typically grasses at invert and side slopes • Infiltration Basin: Provide a maintenance gravity drain, minimum 8-inch diameter [Table continues on next page]

Table B-2: Summary of Infiltration Device Siting and Design Criteria (cont.)

(Applicable to both Infiltration Basins and Infiltration Trenches unless noted)

Applications/Siting	Preliminary Design Factors
• Locate where sloping ground < 15%, and where infiltrated water is unlikely to affect the stability down gradient of structures, slopes, or embankments • Locate at least 1,000 ft from any municipal water supply well; at least 100 ft from any private well, septic tank or drain field; and at least 200 ft from a Holocene fault zone • Locate > 10 ft down gradient and 100 ft up gradient from structural foundations, when infiltrating to near surface groundwater. • Infiltration Trenches: installed down gradient from the highway structural section, and should not be placed closer horizontally than the Trench depth to the roadway if in a location subject to frost • Infiltration Trenches: would likely be considered inappropriate for placement in close proximity to a Drinking Water Reservoir and/or Recharge Facility due to the difficulty in cleaning in the event of a spill; consult District/Regional Storm Water Coordinator if an Infiltration Trench is being considered in close proximity to a Drinking Water Reservoir and/or Recharge Facility. • Locate outside the Clear Recovery Zone (HDM Topic 309.1), or consult with Traffic Operations to determine if guard railing is required	• Infiltration Trenches: total volume ≥ 2.85x WQV • Infiltration Trenches: Provide one observation well in the Trench, minimum diameter of 6 inches, with weatherproof cap; may be used to drain the trench if necessary. • Infiltration Trenches: maximum depth of trench is 13 feet, depth less than the widest surface dimension, and WQV should be directed to trench as surface flow, and allowed to gravity-flow downward to the invert of the trench. • Infiltration Trench: use rock specified elsewhere in this section; a 6 inch layer of Permeable Material (Standard Specification 68-1.025) is usually placed at the invert to protect the filter fabric from the rock during its placement. • Pretreatment to capture sediment in the runoff (such as with Biofiltration or a forebay): required for Infiltration Trenches, and recommended for Infiltration Basins. Only approved BMPs should be considered. • Infiltration Trenches often have a perimeter curb for delineation, and to limit vehicle wheel loads from encroaching upon the trench; may use A1-150 (Standard Plan sheet A87). • Wetting front water level should not cause groundwater to rise within 0.7 ft of the roadway subgrade;

Drain rock conforming to Rock Slope Protection, Method B Placement, Class 3 (Standard Specification 72-2.02, "Materials") should be used in Infiltration Trenches with the following gradation.[3]

Sieve Size, inches	Per cent passing
4	100
3	50 - 100
2	20 - 85
1.5	10 - 75
1	5 - 40

B.3.4 Pre-Screening for the Infiltration Device

Pre-screening for the Infiltration Device involves collecting site-specific information necessary to determine whether infiltration is an appropriate stormwater treatment method and to ensure the site meets criteria established by the local RWQCB. Consult with the District/Regional

[3] Minor variation from these gradations will have little effect on the void space available.

Storm Water Coordinator to obtain RWQCB criteria. No field testing is anticipated during this early investigation.

The steps involved in pre-screening include:

- Information collection; and
- Preliminary determination of infiltration appropriateness.

Sub-sections (*B.3.4.1 Information Collection* and *B.3.4.2 Preliminary Determination for Appropriateness of Infiltration*) describe the steps involved in Pre-Screening; these steps are usually conducted by the Project Engineer as early in the project as feasible, often during the PID phase. The Project Engineer could discuss the proposed site with the Geotechnical services representative, and a Preliminary Geotechnical Report might be deemed beneficial at this stage of the project.

B.3.4.1 Information Collection

Some of the basic site-specific data required for the determination of the appropriateness of an Infiltration Device are found in the sources listed below. Additional data may be required for local conditions. Data collected by Caltrans project engineering staff and Caltrans District/Regional Storm Water Coordinators include, but may not be limited to:

- Outfall inventory data available through District/Regional Storm Water Coordinators, project alignment, right-of-way, annual average daily traffic (ADT), Caltrans outfall locations, and other basic project maps and data;
- Tributary drainage areas and surrounding land uses (from outfall inventory, as-built drawings, aerial photographs, Geographic Information System (GIS) data from Caltrans and local planning agencies, etc.);
- Site surface hydrology data: tributary drainage area, runoff coefficients, drainage network, travel times, etc., needed to design facilities to Caltrans hydrologic/hydraulic criteria;
- Basin Plan groundwater beneficial uses and known impairments (RWQCB).
- Caltrans runoff quality data appropriate for the Caltrans land use in the tributary area (Caltrans Annual Report or Caltrans Discharge Characterization Study Report (CT SW-RT-03-065.51.42) htpp://www.dot.ca.gov/hq/env/stormwater/special/newsetup/index.htm); and
- WQV calculated in accordance with Section 2; the program Basin Sizer satisfies the requirements of Section 2 and is available at:

  http://www.owp.csus.edu/research/stormwatertools/

Site soil characteristics:

- Indigenous soil types: Natural Resources Conservation Services (NRCS) soil maps and corresponding hydrologic soil classes, USCS classifications, or similar;

- Soil infiltration rates (estimated and from any existing on-site testing in the vicinity); and
- Caltrans project grading plans or as-built plans (if retrofit), if available.

Existing groundwater and hydrogeology information:

- Maps of local aquifers underlying the alignment or location of the proposed Caltrans project; and
- Aquifer groundwater quality and seasonal groundwater levels: monitoring well data, U.S. Geological Survey (USGS), Department of Water Resources (DWR), and local public agency maps and databases (e.g., http://wdl.water.ca.gov/gw/)

Local groundwater quality concerns: Consult RWQCB, California Department of Toxic Substances Control (DTSC), local environmental/health department (city/county);

- Site hydrogeology (from any existing boring logs: lenses, hardpan, etc.);
- Known contaminated groundwater plumes (RWQCB);
- Groundwater rights data: adjudicated groundwater basins, other rights (RWQCB, DHS); and
- State Water Information Management System data for project area (State Water Resources Control Board [SWRCB]).

B.3.4.2 Preliminary Determination for Appropriateness of Infiltration

Once the data have been collected and placed in the context of the alignment and/or location of the Caltrans facility being considered for Infiltration Devices, the Project Engineer and the District/Regional Storm Water Coordinator will use the data and follow the procedure outlined in Figure B-3 (page B-17). Project Engineers shall also follow the procedures outlined in Figures B-22 and B-23 for an Infiltration Device being considered for District 7.

Applicable steps for determination of appropriateness of infiltration include:

1. Estimate the quality of runoff from the Caltrans facility draining into the proposed Infiltration Device using data from the Caltrans stormwater database and annual research summaries.

2. Determine if local Basin Plan or other local ordinances provide limits on quality of water that can be infiltrated. Compare with Caltrans runoff quality, and determine if infiltration is permissible. If not, document inapplicability of infiltration and continue to step 5 for consideration of other approved Treatment BMPs.

3. Determine if local agencies, public health authorities, legal restrictions, or other concerns preclude consideration of infiltration of stormwater runoff. Consult with District/Regional Storm Water Coordinator and representatives of appropriate authorities as needed. If infiltration into the aquifer is not acceptable to local authorities, document

inapplicability of infiltration, and continue to step 5 for consideration of other approved Treatment BMPs.

4. Compare the estimated Caltrans runoff water quality with available groundwater quality data, using receiving water quality objectives from the RWQCB Basin Plan, for each groundwater beneficial use. Determine if the separation between the maximum anticipated seasonal high groundwater table and the proposed device invert is at least 10 ft (or greater than or equal to 4 ft if justified by adequate groundwater observations for a minimum of one year). Tabulate the results and make a preliminary determination of the appropriateness of the Infiltration Device.
5. If the determination is negative (i.e., infiltration *not* appropriate), consider other approved treatment BMPs according to the Targeted Design Constituents (TDC) approach as defined in the Storm Water Data Report (SWDR). If determination is positive (i.e., infiltration potentially appropriate), proceed to infiltration site screening.

B.3.5 Infiltration Device Site Screening

Using data gathered in the pre-screening process, perform an initial screening of sites to narrow the number of potential sites to those that can be considered for field investigations within the project limits. As needed, collect additional information, and follow these procedures:

- Identify soil type (consider NRCS Hydrologic Soil Groups [HSG] A, B, or C only for Infiltration Basin, HSG A or B only for Infiltration Trench, as shown in Table B-3) from soil maps and/or U.S. Department of Agriculture (USDA) soil survey tables and/or background information. In areas where septic systems are in widespread use, the County Environmental Health Department may have information on appropriate soil types for infiltration of on-site wastewaters;
- Review other key available data: percent silt and clay, presence of a restrictive layer, permeable layers interbedded with impermeable layers, and seasonal high water table. Other geotechnical considerations that may prohibit usage include: location in seismic impact zones, unstable areas such as landslides and Karst terrains, and areas with soil liquefaction and differential settlement potential, or highly expansive/collapsible soils. Generally, Infiltration Devices should not be constructed in fill, or on any slope greater than 15 percent; and
- The minimum acceptable spacing between the proposed Infiltration Device invert and the maximum seasonal high groundwater table is 10 ft. If a separation of less than 10 ft is proposed, the approval of the local RWQCB is required.

Figure B-3: Pre-screening for the Infiltration Devices

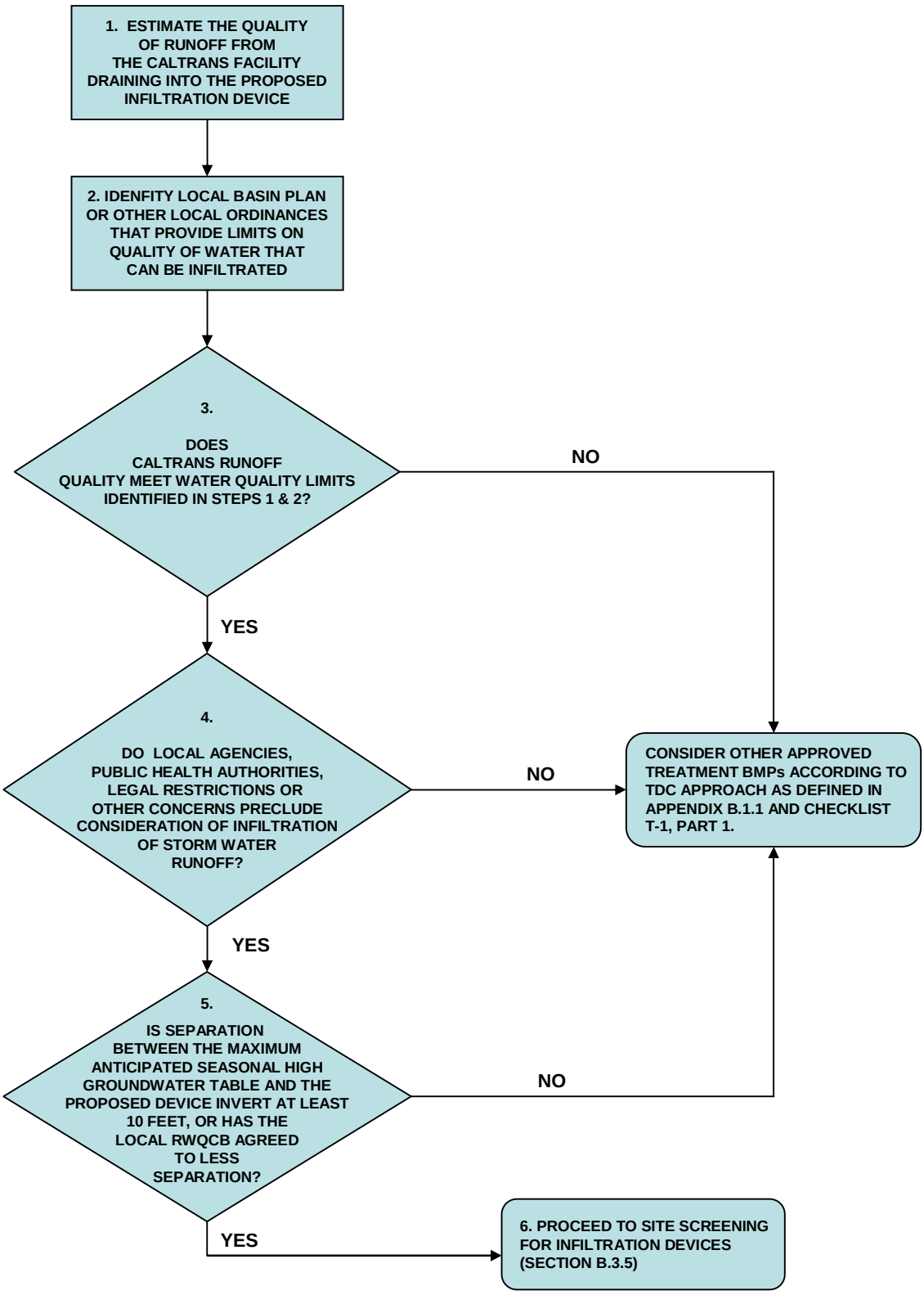


Table B-3: Typical Infiltration Rates for NRCS Type, HSG, and USCS Classifications

NRCS Soil Type	HSG Classification	USCS Classifications	Typical Infiltration Rates (inches/hour) See Notes 2 & 3
Sand	A	SP, SW, or SM	8
Loamy Sand	A	SM, ML	2
Sandy Loam	A	SM, SC	1
Loam	B	ML, CL	0.3
Silt Loam and Silt	B	ML, CL	0.25
Sandy Clay Loam	C	CL, CH, ML, MH	0.15
Clay Loam, Silty Clay Loam, Sandy Clay, and Silty Clay	D	CL, CH, ML, MH	< 0.05
Clay	D	CLM CH, MH	< 0.05

Note 1: USCS classifications are shown as approximation to the NRCS classifications. Note that the NRCS textural classification does not include gravel, while the USCS does. Note also that the gradation criteria (particle diameter) for the three soil types as used in the NRCS and the USCS, while agreeing in large part, are not congruent. Dual classifications in the USCS omitted. Infiltration estimates for USCS found in standard geotechnical references may vary from those shown for NRCS classifications, especially if significant gravel is present.

Note 2: Infiltration Basins should be placed at locations with soils classified as HSG A or B, although C soils can be acceptable if geotechnical investigations demonstrate minimum infiltration rate of 0.5 in/hr. Infiltration Trenches should be placed at locations with soils classified as HSG A or B and that have a minimum infiltration rate of 0.5 in/hr. Maximum infiltration rate allowed for any Infiltration Device is 2.5 in/hr unless RWQCB approval is received.

Note 3: When estimating the invert area for Infiltration Basins and Trenches placed in HSG Group B and C soils using the equations below, use the minimum infiltration rate of 0.5 in/hr to size the Infiltration Device until geotechnical investigation provides a field rate for the proposed location.

Infiltration Devices should not be sited in locations over previously identified contaminated groundwater plumes; setback distance should be determined in coordination with the RWQCB.

Estimate infiltration rate for the soil type at the site using Table B-3.

Estimate the area required for an Infiltration Basin as follows:

$$A_{est} = (C \times SF \times WQV)/(k_{est} \times t) \quad \text{(Eq. 2)}$$

where:

A_{est} = estimated area of invert of Infiltration Basin (ft^2)
C = conversion factor (12 for inches to ft)
SF = safety factor of 2.0
WQV = Water Quality Volume calculated from the Water Quality design storm (ft^3)
k_{est} = estimated or representative infiltration rate from Table B-3 (inches/hr)
t = drawdown time, 40 to 48 hours

Infiltration Trenches are intended for use in areas with limited right-of-way. For this reason, an Infiltration Trench is typically designed using the minimum allowable invert area and the maximum allowable depth (not to exceed 13 ft) while still providing 10 ft separation between the trench invert and seasonally high ground water. To design an Infiltration Trench with a minimum invert area, first calculate the depth, D, as follows:

$$D = (k_{est} \times t)/(C \times SF \times 0.35) \quad \text{(Eq. 3)}$$

Where:

D = depth of the Infiltration Trench (ft), [maximum depth = 13 ft]
k_{est} = permeability from Table B-3, (ft/hr)
t = drawdown time, up to 72 hours
C = conversion factor (12 to convert from inches to ft)
SF = safety factor of 2.0
0.35 = porosity of void material (value for rock shown)

Next calculate the required excavated volume for the Infiltration Trench:

$$EV = WQV / 0.35 \quad \text{(Eq. 4)}$$

Where:

EV = excavated volume (ft^3)
WQV = Water Quality Volume calculated from the Water Quality design storm (ft^3)
0.35 = porosity of void material (value for rock shown)

Once the depth and excavated volume are obtained then calculate the invert area of the Infiltration Trench:

$$A = EV / D \quad \text{(Eq. 5)}$$

Where:

A = estimated or calculated area of invert of Infiltration Trench (ft^2)
EV = excavated volume (ft^3)
D = depth of the trench ($\leq$13ft)

The final step is to calculate the invert dimensions for the Infiltration Trench:

$$A = L \times W \quad \text{(Eq. 6)}$$

Where:
A = estimated or calculated area of invert of Infiltration Trench (ft^2)
L = length of Infiltration Trench (ft)
W = width of Infiltration Trench (ft)

Adjust length "L" and width "W" to meet site constraints.

Notes: a) The invert area of the Infiltration Trench having vertical sides is identical to the surface area.

b) To avoid classification as an underground injection well, the Infiltration Trench at its greatest surface dimension (length or width) must exceed its depth.

The efforts in B.3.5 Infiltration Device Site Screening usually occur in the PA/ED phase, but sometimes in the PID or even the PS&E phase depending upon the project. If it has not already been done, the Project Engineer should discuss the site with the Geotechnical Services representative and request a Preliminary Geotechnical Report if the information evaluated during Pre-Screening indicates that placement of Infiltration Devices appears favorable; the Preliminary Geotechnical Report would usually be completed without conducting field-testing, but other information could be developed that would produce indications whether the site conditions are favorable for infiltration.

B.3.6 Site Investigation

This step is usually conducted during the PS&E phase of the project. After the desktop screening of sites has been completed (including those sites outside of existing Caltrans right-of-way), proceed with field investigations of the remaining potential sites. Under *B.3.6 Site Investigation* a two-stage approach to the geotechnical investigation is proposed, *B.3.6.1 Procedure for Preliminary Infiltration Device Site Investigation* and *B.3.6.2 Detailed Investigation*. However, due to potential difficulties in scheduling geotechnical fieldwork, those activities might be conducted jointly.

- Perform site investigation to identify any: (a) Regulatory permit required, (b) Major underground utility interference, (c) Transportation improvement plan conflicts, or (d) General plan land use data for tributary area;
- If considering a parcel outside of the right-of-way, Caltrans must generate greater than 50% of the total tributary runoff directed toward that parcel; otherwise investigate opportunities for a cooperative agreement to share stormwater treatment facilities with the other agency, county, or city responsible for the additional flow;
- Assess the feasibility (e.g., degree of plumbing, features or construction practices required and available area) of directing runoff from additional tributary area to the device; additional Caltrans area would have priority; other off-site areas are secondary. Consider potential downstream impacts from diversions and cost of diverting additional flow. Diversions of runoff from outside the tributary area of the Infiltration Device to unimproved conveyances (creeks/streams) are prohibited due to the increased potential for erosion. Diversions to improved conveyances may be permitted if it can be demonstrated that the conveyance has sufficient capacity to accommodate the additional flow, and other environmental considerations are favorable or neutral. If such diversion is being considered, consult with District/Regional Environmental and Hydraulics units;
- Investigate feasibility of infiltration using criteria and the procedure in Section B.3.4.1. Recalculate and verify area requirements using the collected field data. Use Equation 2 (see Section B.3.5) and the lowest measured or anticipated infiltration rate, or value considered representative of by the geotechnical professional, to calculate area of the Infiltration Device; and
- If an Infiltration Device is feasible, proceed to Section B.3.7, Preliminary Design.

B.3.6.1 Procedure for Preliminary Infiltration Device Site Investigation

The following scope of work defines the steps for Infiltration Device studies necessary to determine if an Infiltration Device may be feasible on the subject site. The screening procedure is terminated if the site does not meet the criteria for any step, and assessment of the site would continue for other approved Treatment BMPs.

The depth to groundwater must be known as a first step in determining feasibility because a high groundwater table can lead to infiltration failure and potential contamination of the groundwater table. The *in situ* infiltration rate at the device invert must also be known or reasonably estimated to ensure that infiltration of the calculated WQV is possible within 48 hours for an Infiltration Basin or within 72 hours for an Infiltration Trench. Due to the potential variability of site conditions, field investigation is almost always required to determine the depth to groundwater and to provide an evaluation of the *in situ* infiltration rate.

Initial Investigation

The initial investigation comprises two parts: A) Initial technical field screening and determination of groundwater elevations, and B) Geotechnical investigation for soil lithology and select chemical testing. To streamline the initial investigation phase, Part A will be performed first, followed by Part B if the Part A criterion of at least 10 ft clearance for the groundwater elevation below the device invert is satisfied and the site is deemed appropriate for further consideration. Consult the local RWQCB for approval of proposed groundwater separation less than 10 ft.

Part A: Initial Technical Field Screening and Determination of Groundwater Elevation

A local or regional groundwater review will be performed based on the available data, including, but not necessarily limited to:

- Previously compiled databases on potential BMP sites (such as outfall inventory databases);
- Data and maps available from regional government databases, DWR, other local agencies and internal Caltrans sources;
- Local soil survey data from the NRCS and other sources;
- Soil lithology, infiltration rate and groundwater depth data from the county or other specialists that approve septic system installations in the local area;
- Information on local groundwater beneficial uses and groundwater quality issues from the RWQCBs and other water resource agencies; and
- Information on local groundwater-related drinking water issues from DHS.

An initial indication of the seasonal high groundwater water table elevation will be determined by using a piezometer, previous studies, or other accepted geotechnical means. The piezometer will be installed to a depth of at least 20 ft below the proposed device invert using the direct push or other suitable method. Initial groundwater levels will be recorded at least 24 hours after installation.

The geotechnical professional will make a determination on a site-by-site basis, whether the groundwater elevation determined after 24 hours can be considered to be a reasonable indication of the seasonal high water table for the purposes of the evaluation of the groundwater depth criterion, described as follows. If such determination cannot be made reasonably based on the available data, the site will be recommended for a longer period of water table elevation monitoring, as necessary.

If the initial seasonal high groundwater elevation indication is within 10 ft of the invert of the proposed Infiltration Device then the site will be eliminated from further consideration unless the local RWQCB requires installation of an Infiltration Device with less than 10 ft separation to groundwater. If there is not a reliable indication that the seasonal high water table is at least 10 ft below the invert of the proposed Infiltration Device (i.e., if there is reason to believe the water table may rise to within 10 ft of the proposed invert), a more extensive groundwater table elevation investigation will be performed as described in Section B.3.6.2 Part C. If the groundwater elevation at the site is clearly deeper than 10 ft from the proposed device invert and all other criteria in the initial investigation are satisfied, a detailed groundwater elevation determination will not be required.

Part B. Geotechnical Investigation for Soil Lithology and Select Chemical Testing

An initial soil investigation will be performed to adequately evaluate soil lithology and determine:

- If there are potential problems in the soil structure that would inhibit the rate or quantity of infiltration desired; or
- If there are potential adverse impacts to structures, slopes or groundwater that could result from locating the Infiltration Device at the site to structures, slopes or groundwater.

Geotechnical trenches (a boring may be used at the option of the geotechnical professional) will be dug using a backhoe at one or two locations within each site, depending on the site conditions. Clearance of the site for hazardous contaminants through the appropriate District should be done prior to drilling by the geotechnical professional conducting the work; Underground Service Alert (USA) clearance will also be obtained. The trenches will be at least 6 ft long and 6 ft deep below the proposed device invert. The soil profiles will be carefully logged to determine variations in the subsurface profile. Of greatest importance is the presence of fine-grained materials such as silts and clays, which should be determined by direct measurement of particle size distribution. Two to four soil samples should be collected for determination of the soil particle size distribution at each site. Samples should be collected from the soil profiles at different horizons and transported to a laboratory for soil indices testing, plasticity, and chemical testing described as follows:

- Soil textures or classifications that are conducive to infiltration include sands, loamy sands, sandy loams, loams, silt loams, and silt in the NRCS classification system, or GW, GM, SP, SW, GC, SC, SM, and ML (in the Unified Soil Classification System [USCS]) as long as the soil does not have more than 30 percent clay or more than 40 percent of clay and silt combined; and

- The soil in the first 12 inches below the basin invert will be tested for organic content (OC), pH, and cation exchange capacity (CEC) only if required by the local approving agency (notify Geotechnical Services prior to site investigation for this testing). Values that promote pollutant capture in the soil are: OC > 5%, pH in the range of 6-8, and CEC > 5 meq/100 g of soil (however, soils that have this CEC value are typically fine-grained, and often would be rejected for infiltration based on permeability considerations).

In addition, the trenches or samples from borings should be examined for other characteristics that may adversely affect infiltration. These include evidence of significant mottling (indicative of high groundwater), restrictive layer(s), and significant variation in soil types, either horizontally or vertically. A summary report will be prepared addressing the issues noted in this section, with recommendations on the suitability of the site for infiltration and the necessity of carrying out the next phase of the investigation. (All the site reports will ultimately be combined in a single report.) The geotechnical professional will develop the detailed investigation phase for the sites deemed acceptable from the initial investigation.

B.3.6.2 Detailed Investigation

If the site conditions still appear favorable to infiltration after the geotechnical review and soil investigations, a detailed field investigation will be undertaken, which includes Part A, Detailed Subsurface Soil Investigation, Part B, Permeability Testing, and Part C, Detailed Groundwater Elevation Determination (if required by the geotechnical professional).

Part A. Detailed Subsurface Soil Investigation

Borings will be drilled to a maximum depth of 50 ft (or refusal in rock or rock-like material at a lesser depth) below the invert of the proposed basin, and to a minimum depth of 3 times the depth of water when in the basin (at the WQV depth) for each detailed investigation location. Samples will be obtained at 5-ft intervals for soil characterization and/or laboratory testing. Bulk samples will also be collected at shallow depths (i.e., just below the invert elevation) to verify information collected in Parts A and B of the Initial Investigation.

Part B. Permeability Testing

No single test method is appropriate for the variety of subsurface conditions that might be encountered, as, for example a percolation test at the invert elevation might not disclose the existence of layers of either highly permeable or low permeability within the depth of interest. Rather, a permeability evaluation below the invert of the proposed Infiltration Device will be made using infiltration rate tests or other method(s) selected by the geotechnical professional.

The minimum acceptable infiltration rate for an Infiltration Device is 0.5 in/hr. If any test hole shows less than the minimum value, the site will be disqualified from further consideration unless strong local geotechnical evidence exists to predict the successful performance of the device. If the infiltration rate at the site is greater than 2.5 in/hr, the RWQCB must be consulted, and the RWQCB must conclude that the groundwater quality will not be compromised before approving the site for infiltration.

If the site is constructed in fill or partially in fill, it will be excluded from consideration unless no silts or clays are present in the soil boring within 13 ft of the device invert; fill tends to be compacted, with clays in a dispersed, rather than flocculated state, greatly reducing permeability.

The geotechnical investigation will be sufficient to develop an adequate understanding of how the stormwater runoff will move in the soil (horizontally or vertically), and if there are any geological conditions that could inhibit the movement of water.

Part C. Detailed Groundwater Elevation Determination

If a detailed investigation to determine the groundwater elevation is required per the guidance and, in the opinion of the geotechnical professional, the seasonal high groundwater elevation may come within 10 ft of proposed device invert, at least one groundwater monitoring well will be installed at a representative location. The well(s) will be observed over a wet and dry season. This observation period will be extended to a second wet season (at the direction of Caltrans) if the first wet season produces regional rainfall less than 80% of the historical average. The minimum acceptable spacing between the proposed Infiltration Device invert and the seasonal high water table is 10 ft, unless, in coordination with the RWQCB, it can be demonstrated that the groundwater will not be adversely impacted. A geotechnical professional will oversee the detailed investigation and must also consider other potential factors that may influence the groundwater elevation, such as local or regional groundwater recharge projects, future urbanization, or agricultural practices. The geotechnical professional should also examine the soil borings for indications of previous high water.

A final geotechnical report, overseen by a geotechnical professional, summarizing the findings of the investigation will be prepared. The report will include all results from the initial as well as detailed investigation phases of the feasibility study.

B.3.7 Preliminary and Final Design

Table B-2 summarizes preliminary design factors for Infiltration Devices. Preliminary design includes the following:

- Obtain site topography (one-half meter contours, 1:500 scale). Extend topography 80 ft beyond the Infiltration Device perimeter to show where runoff enters or leaves Caltrans right-of-way, enters a drainage channel owned by others, or enters a receiving water;
- Develop a conceptual grading plan for improvements showing the device, maintenance access, device outlet and extent of right-of-way requirements to accommodate the improvements. An Infiltration Basin invert must not have a slope of greater than 3%, while the invert for an Infiltration Trench must have a slope of 0%;
- Develop unit cost-based cost estimate to construct the Infiltration Device. Include allowances for traffic management and storm drain system improvements as needed and determined by the PE; and
- Develop single paragraph assessments of: nonstandard design features; impact on utilities; hydrology (WQV, peak flow, land use); right-of-way total area needed;

current ownership; highway planting and lighting; permits, hazardous materials, environmental clearance; and traffic management.

Final design efforts involve completing all required activities for which only preliminary assessments had been made, and developing the complete PS&E package for the Infiltration Devices.

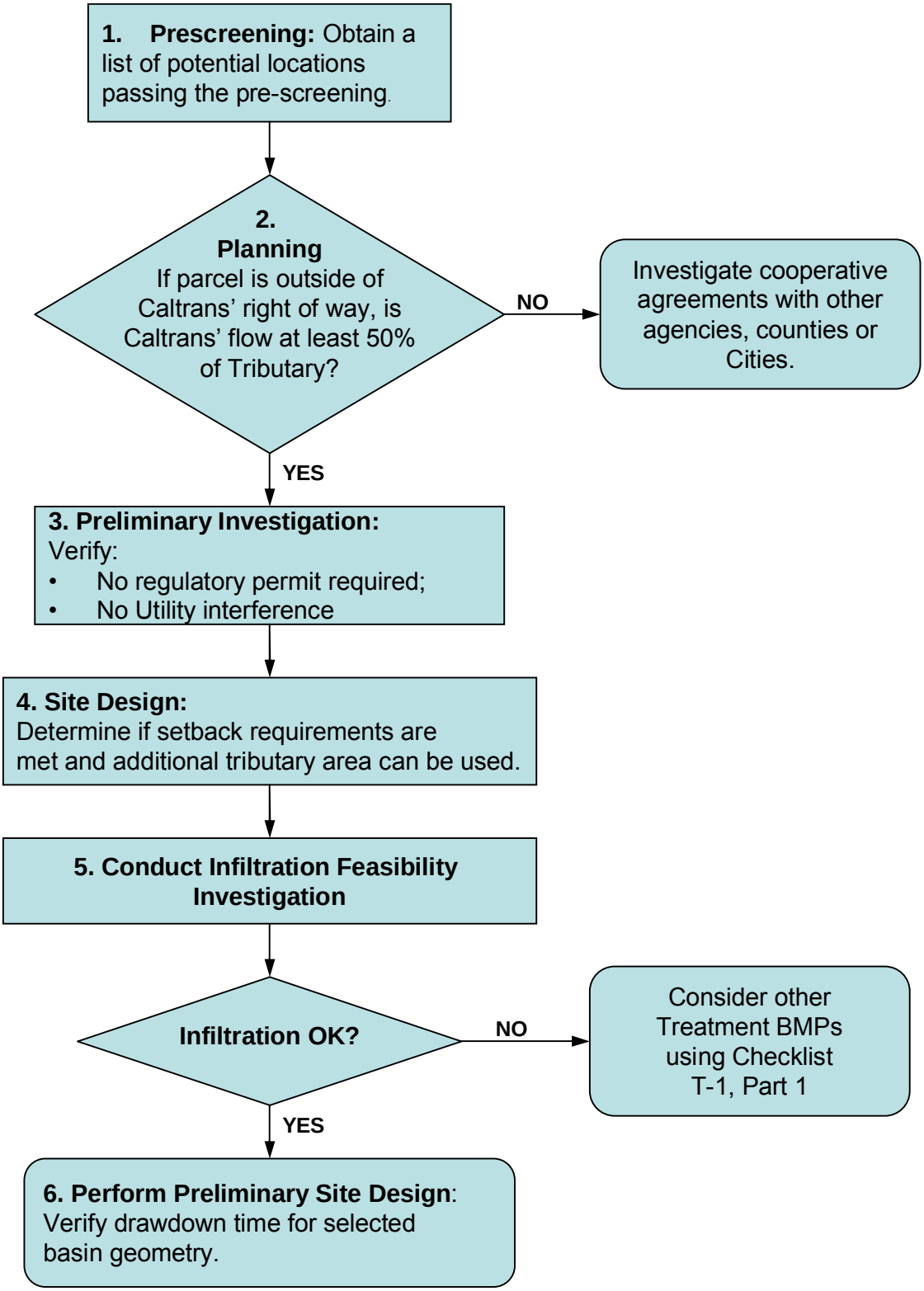
Figure B-5 summarizes the BMP siting procedure for Infiltration Devices for all Districts except District 7, for which the procedures in Figures B-22 and B-23 apply.

Figure B-4: Caltrans' Pilot Infiltration Trenches





Figure B-5: BMP Siting Procedure for Infiltration Devices



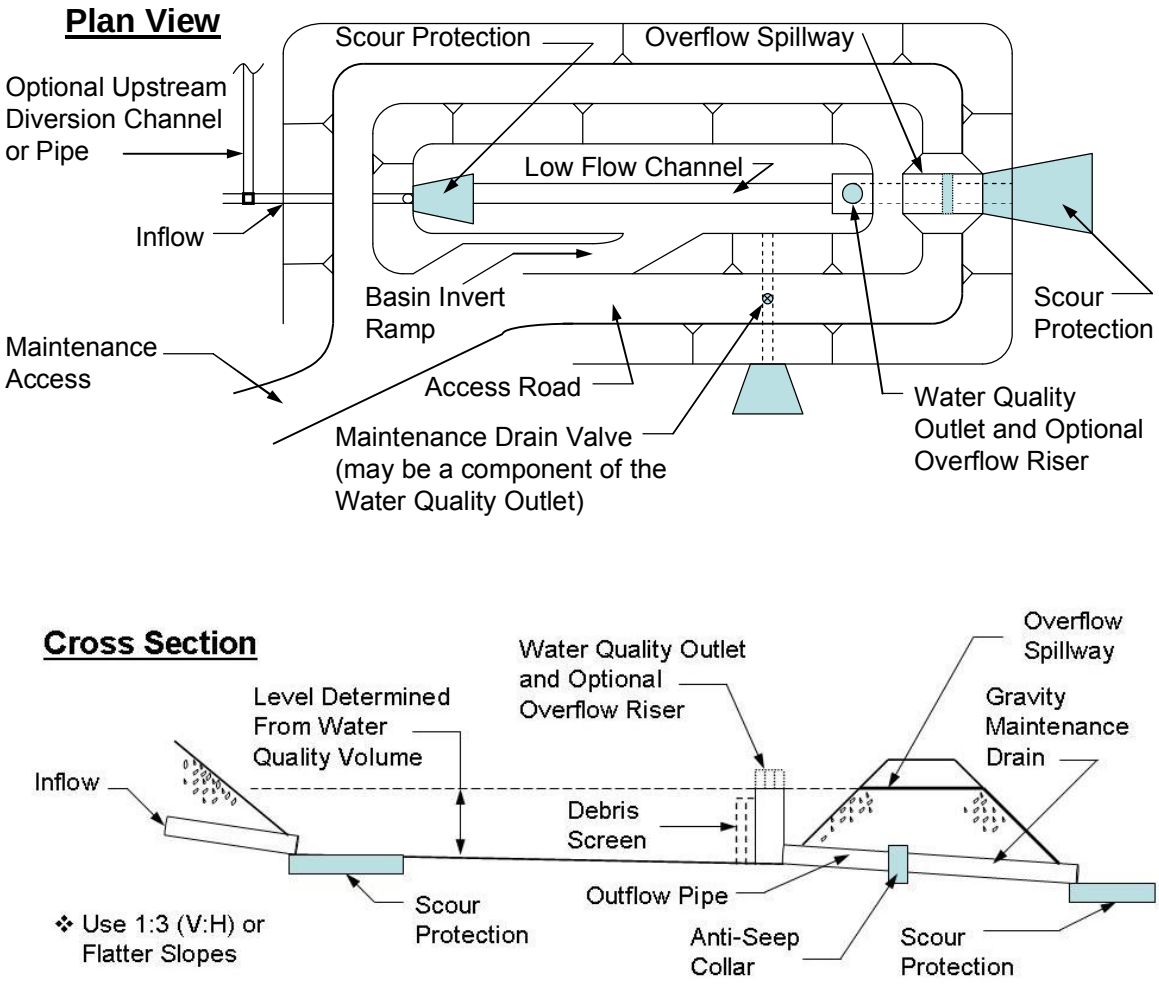
B.4 DETENTION DEVICES

B.4.1 Description

A Detention Device is a permanent treatment BMP designed to reduce the sediment and particulate loading in runoff from the water quality design storm (Water Quality Volume [WQV]). While the WQV is temporarily detained in the device sediment and particulates settle out under the quiescent conditions prior to the runoff being discharged. A Detention Device is typically configured as a basin. A schematic of a Detention Basin is shown in Figure B-6.

Detention Devices remove litter, total suspended solids (TSS), and pollutants that are attached (adsorbed) to the settled particulate matter.

Figure B-6: Schematic of a Detention Basin



B.4.2 Appropriate Applications and Siting Criteria

Detention Devices and other approved Treatment BMPs should be considered for implementation wherever Infiltration Devices are not feasible. For Detention Devices, the WQV

should be at least 0.1 acre-foot and site conditions must meet criteria. Refer to Checklist T-1, Part 1 in Appendix E. See Table B-4 for siting and design criteria.

One important siting requirement is that sufficient hydraulic head is available so that water stored in the device does not cause an objectionable backwater condition in the storm drain system, which would adversely impact the system's ability to convey flows generated by the peak drainage facility design event as required in the HDM. A second siting requirement is that seasonally high groundwater cannot be higher than the bottom elevation of the device for reasons described in the section below.

B.4.3 Factors Affecting Preliminary Design

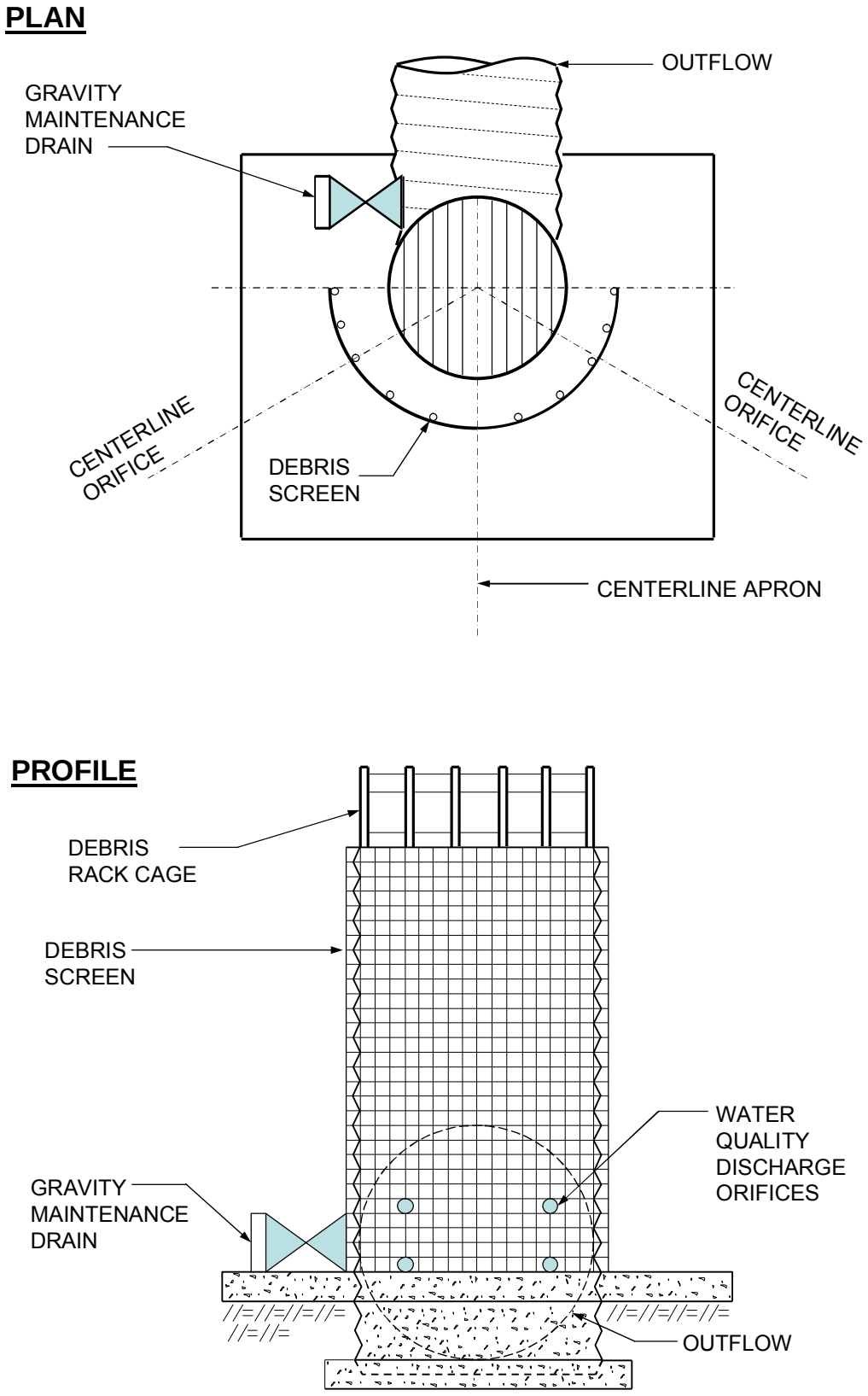
Detention Devices should be designed with a volume equal to at least the WQV determined using the methods described in Section 2.4.2.2, Treatment BMP Use and Placement Considerations. The maximum water level in the Detention Device should not cause seepage of water under the roadway to within 8 inches of the roadway subgrade. The flow-path-to-width ratio within the Detention Device at the elevation of the WQV is recommended to be $\geq$ 2:1; if needed, this ratio can be accomplished by baffles or interior berms to accommodate the geometry of the site.

Liners are not generally required for Detention Basins. However, they may be used to facilitate maintenance and to protect groundwater. Limited infiltration is permissible if the infiltrated water does not surface in an undesirable place off-site or threaten the stability of a slope or embankment down gradient of the basin. However, to protect groundwater quality and to ensure dry conditions for maintenance of unlined basins, the distance between the basin invert and seasonally high groundwater should be at least 10 ft; use a liner for an earthen Detention Basin if the groundwater separation distance between the basin invert and seasonally high groundwater is between 1.0 and 10 feet or if located over a known contaminated groundwater plume unless approved by the local RWQCB due to the presence of low permeability soils (Hydrologic Soil Groups C or D).

Entering flows should be distributed uniformly at low velocity to prevent re-suspension of settled materials and to encourage quiescent conditions. Low flow channels are often used to ensure conveyance to the outlet and to limit erosion during low flows.

Discharge should be accomplished through a water quality outlet; an example is shown in Figure B-7 (page B-31). A rock pile or rock-filled gabions can serve as an alternative to the debris screen around the outlet although the designer should be aware of the potential for extra maintenance involved should the pore spaces in the rock pile clog. Proper hydraulic design of the outlet is critical to achieving good performance of the Detention Device. The water quality outlet should be designed to empty the device within 24 to 72 hours (also referred to as "drawdown time"), with 40-hrs the preferred design drawdown time. The 24-hour limit is specified to provide adequate settling time; the 72-hour limit is specified to mitigate vector control concerns.

Figure B-7: Schematic of Water Quality Outlet Structure



The two most common outlet problems that occur are: a) the capacity of the outlet is too great resulting in only partial filling of the device and drawdown time less than designed for; and b) the outlet clogs because it is not adequately protected against trash and debris. To avoid these problems, the following outlet types are recommended for use: (1) a single orifice outlet with or without the protection of a riser pipe, and (2) riser perforated vertically (orifices in multiple rows). Use of a V-notch weir as an outlet is not recommended because this design is susceptible to clogging. Design guidance for single orifice and for perforated riser outlets is presented in the following text.

Flow Control Using Orifices at The Bottom of the Device: The outlet control orifice should be sized using the following equation:

$$a = \frac{2A(H - Ho)^{0.5}}{3600CT(2g)^{0.5}} \qquad \text{(Eq. 7)}$$

where:

a	=	total area of orifice (ft^2) [4]
A	=	surface area of the device at mid elevation (ft^2)
C	=	orifice coefficient (see discussion on following page)
T	=	drawdown time of full device (Recommended 40 hrs)
g	=	gravity (32.2 ft/s^2)
H	=	elevation when the device is full (ft)
Ho	=	final elevation when device is empty (ft)

For a riser perforated vertically (orifices in single or multiple columns (see Figure B-7), use:

$$a_t = [2A \times h_{max}]/[3600 \times C \times T(2g\{h_{max} - h_{centroid\ of\ orifices}\})^{0.5}] \qquad \text{(Eq. 8)}$$

with terms as shown in Eqn. 7 except:

a_t	=	total area of orifices in the perforated riser, (ft^2);
h_{max}	=	maximum vertical distance from lowest orifice to the maximum water surface (ft);
$h_{centroid\ of\ orifices}$	=	vertical distance from the lowest orifice to the centroid of the orifice configuration (ft).

Allocate the orifices evenly on two rows; separate the holes by 3x hole diameter vertically, and by 120 degrees horizontally. If more than two orifice rows are used, a special design is required.

If the WQV (specifically Methods 1 and 2 in Section 2.4.2.2, Treatment BMP Use and Placement Considerations) was determined using an assumed drawdown time, then use the same

[4] In the 'single orifice' design, the total orifice area is placed at one elevation, and may be configured using one or several orifices, at the designer's option.

value for drawdown time (T) in equations 2 and 4. Because Detention Devices are not maintained for infiltration, water loss by infiltration should be disregarded when designing the hydraulic capacity of the outlet structure.

Assuming an average release rate at one half the basin depth (a common approach in several design manuals) may lead to considerable error if the device has a significant variation of surface area with depth. If this is true, consult HEC-22, Chapter 10, for the design of detention facilities.

Care must be taken in the selection of "C"; 0.60 is most often recommended and used. However, based on actual tests, GKY (1989), "Outlet Hydraulics of Extended Detention Facilities for Northern Virginia Planning District Commission", recommends the following:

C = 0.66 for thin materials; where the thickness is equal to or less than the orifice diameter, or

C = 0.80 when the material is thicker than the orifice diameter

Drilling the orifice into an outlet structure that is made of concrete can result in considerable impact on the coefficient, as does the beveling of the edge. For steel outlet structures, it is recommended that outlet specifications require drilled and de-burred holes for any orifice incorporated into steel pipe.

Three alternative outlet structures that use single orifice outlets may be considered: a) A concrete block structure located in the containment berm for large devices. b) A riser pipe for small to large devices to prevent orifice clogging as shown in the equations above. c) Placing the outlet control downstream of the facility in the berm or in a manhole located may be considered for small devices as long as other outlets/spillways are provided for storms larger than the water quality design storm (consult District Hydraulics). For small facilities, place the control orifice in the outlet manhole downstream of the debris screen, or use a "T-pipe" to submerge the orifice. Variations of this alternative may include gates, valves, or weirs. The PE should consult with both the District Maintenance Storm Water Coordinator and the District Hydraulics Branch regarding these outfall structures.

Flow Control Using the Perforated Riser: For outlet control using the perforated riser as the outlet control, as shown on Figure B-7 (page B-30). This design incorporates flow control for the small storms in the perforated riser, and also provides an overflow outlet for large storms. If properly designed, the perforated riser can be used for both water quality and overflow control by: (1) sizing the perforated riser as indicated for water quality control; (2) sizing the top of the outlet riser pipe to function as an overflow weir to control peak outflow rate from the design storm (reference HDM Chapter 830).

If possible, an upstream flow-splitter should be provided to divert the peak hydraulic flow (calculated for the design storm); this minimizes scouring of previously deposited materials. Alternatively, an overflow spillway sized to accommodate the design storm can be provided in one of the downstream walls or berms. A third alternative is to include an overflow outlet in the top of the water quality outlet, as described in a preceding paragraph. In this case, an additional

outlet (riser or spillway) is often still supplied to prevent overtopping of the walls or berms should blockage of the riser occur, based on a downstream risk assessment.

A Detention Device must be designed to allow for regular maintenance. Consideration should be made for a perimeter access road, safe access to and from the site from local streets or access roads, and an access ramp to the basin invert. Any diversion from these requires the concurrence from the Maintenance Storm Water Coordinator.

Preliminary design factors for Detention Devices are summarized in Table B-4. A Detention Device designed for dual purposes of water quality and attenuation of peak flows requires additional design considerations not included in this table.

Detention Basins will appear more aesthetic to the traveling public and function more effectively if vegetated on the invert rather than having a 'hard bottom' and/or side slopes; this will also eliminate the erosion from the side slopes of the basin.[5] Consult the District Office of Landscape Architect for types of vegetation that can function effectively in Detention Basins in each of the various ecological subregions of a District. Additional information about grasses that have been successful within specific ecological subregions of California, in grassland and wetland conditions, may be found in Ecological Subregions of California Section and Subsection Descriptions (as referenced in Appendix B, Biofiltration Strips and Swales).

[5] If a vegetated invert is used, consider adding a low-flow channel between the influent pipe and the outlet device, to reduce erosion caused under the initial flows into the basin.

Table B-4: Summary of Detention Device Siting and Design Criteria

Description	Applications/Siting	Preliminary Design Factors
Impoundments where the WQV is temporarily detained during treatment Treatment Mechanisms: • Sedimentation • Infiltration (if basin unlined) Pollutants primarily removed: • Sediment (TSS) • Particulate metals • Litter • Sorbed pollutants (heavy metals, oil and grease [O&G]) to some degree	• WQV ≥ 0.1 acre-feet • Sufficient head to prevent objectionable backwater condition in the storm drain system • Separation between seasonally high groundwater and basin invert > 10ft; use liner if separation between 1.0 foot and 10 ft. unless approved by the local RWQCB due to the presence of low permeability soils (Hydrologic Soil Groups C or D) • Use liner if basin is located over a known contaminated groundwater plume unless approved by the local RWQCB due to the presence of low permeability soils (Hydrologic Soil Groups C or D). • If significant sediment is expected (e.g., from erosion-prone cut slopes) consider increasing the volume of the Detention Device an amount equivalent to the annual loading (or more, if less frequent cleanout is expected); consult with District Maintenance. • Locate outside the Clear Recovery Zone (HDM Topic 309.1), or consult with Traffic Operations to determine if guard railing is required	• Size to capture the WQV according to Section 2.4.2.2. • Outlet designed to empty device within 24 to 72 hrs (consistent with device sizing method), with 40 hrs recommended, using debris screen (or equivalent). • Flow-path-to-width ratio of at least 2:1 recommended. • Maximum water level should not cause groundwater to occur under the roadway within 0.7 ft of the roadway subgrade. • Maintenance access (road around device and ramp to basin invert). • Upstream diversion channel or pipe (see Figure B-6), if possible. • Downstream spillway or overflow riser: sized to pass the design storm (see HDM Chapter 830); minimum spillway length of 3 feet, and/or minimum riser diameter of 36 in., or per District practice. Use local criteria for overflow design if more stringent. • Provide Water Quality freeboard ≥ 12 inches (distance between the elevation of water in the basin when passing the design storm and the elevation at the top of the confinement). • Provide a maintenance gravity drain. Use 8 inch diameter pipe for gravity drain; connect gravity drain to base of outlet riser. • Flows should enter at low velocity. Use scour protection on inflow, outfall and spillway if necessary • If a vegetated invert is used, consider adding a low-flow channel between the influent pipe and the outlet device, to reduce erosion caused under the initial flows into the basin. • Use 1:4 (V:H) slope ratios or flatter for interior slopes, unless approved by District Maintenance, with 1:3 (V:H) maximum. • Provide vegetation on (earthen) invert and on non-paved side slopes. • Minimum orifice size of 0.5 in

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B.5 TRACTION SAND TRAPS

B.5.1 Description

Traction Sand Traps are sedimentation devices that temporarily detain runoff and allow traction sand that was previously applied to snowy or icy roads to settle out. In this handbook, traction sand refers to sand and other traction enhancing substances. These traps may take the form of basins, tanks, or vaults.

B.5.2 Appropriate Applications and Siting Constraints

Traction Sand Traps should be considered at sites where traction sand are commonly applied to the roadway. If traction sand is used only rarely (less than twice a year) then Traction Sand Traps need not be considered for installation.

Vault-style Traction Sand Traps should be considered only where Detention Basins or Basin-style Traction Sand Traps are infeasible.

Consult the District/Regional NPDES coordinator to ensure that a Traction Sand Trap which receives water from a pipe and discharges through the invert of the device is not classified as a regulated underground injection well.

B.5.3 Factors Affecting Preliminary Design

Traction Sand Traps are sized to convey the design peak flow while holding one year's worth of traction sand (or some other period of time chosen by the District). However, provisions should be made to divert the peak hydraulic flow (calculated for the peak drainage facility design event) and to prevent scouring if possible. Traction Sand Traps should have sufficient volume to store the settled sand with enough depth over the stored sand to prevent scouring and to promote relatively calm pool conditions.

The volume required to store traction sand is calculated by starting with the estimated amount of traction sand spread in a tributary area and applying reduction factors to account for sand that has been recovered by other means or that cannot be captured. The equation for calculating the volume of traction sand storage is:

$$V = (S \times R \times L \times E)/F \qquad \text{(Eq. 9)}$$

where:

V = The total volume of traction sand that must be stored (ft^3).
S = The estimated volume of sand applied (ft^3/yr).
R = A factor to account for sand recovered by roadway sweeping.
L = A factor to account for other miscellaneous losses/accumulations.
E = A factor to account for recovery efficiency.
F = The number of times the trap will be cleaned (times/yr).

Guidelines for defining the variables in this equation are as follows:

S: Typical sand application rates range from 100 $yards^3$/lane/mile/yr for areas with average application rates to 200 $yards^3$/lane/mile/yr for areas with high application rates. To

estimate the total volume of traction sand applied, select an appropriate application rate from the range listed in this section, and multiply it by the total number of lanes (e.g., one lane in each direction equals two lanes) and the length of highway tributary to the Traction Sand Trap. Because some areas track sand usage by post mile, a more accurate estimate may be obtained by consulting with District Maintenance staff. In any event, consider the following guidelines when estimating the volume of sand that is spread annually in the tributary area:

Exposure: Roadways on north facing slopes generally require more traction sand than similar south facing slopes. The surrounding vegetation may also significantly affect exposure and traction sand application.

Roadway grade: Steeper grades generally receive more traction sand than flatter grades.

Other climatic and geographic factors, such as elevation, will affect the traction sand application rate for a specific area.

Other sources of similar material: Adjacent cut slopes and other non-paved tributary areas may contribute similar-sized sediment or other debris that will be retained in the trap.

R: This is a factor to account for traction sand that is recovered through roadway sweeping. Estimate a value between 1.0 (no roadway sweeping) and 0.6 (aggressive winter roadway sweeping) based on interviews with District maintenance staff. If actual sweeping records are available, these may provide a more accurate estimate.

L: This is a factor to account for traction sand that has been carried into or out of the tributary area by miscellaneous means such as wind (smaller particles), sand thrown out of the tributary area by snow clearing equipment, and sand splashed or carried by vehicles. Estimate an appropriate value in the range of 0.8 (high losses from known sources such as snow blowers) to 1.2 (high accumulation from known sources). Use a factor of 1.0 for no miscellaneous losses/accumulations.

E: This factor is provided to account for traction sand that passes through the Traction Sand Trap without settling out. Because of particle size limitations, settling inefficiencies, and other factors, it may not be realistic or practicable to recover all of the traction sand that reaches the Traction Sand Trap. Until empirical information is obtained from pilot studies, a value of 1.0 should be used for this factor.

F: This is the number of times the sand trap will be cleaned each year. Usually, the value for F is 1 as most Traction Sand Traps are cleaned once per year, usually in the summer. If obtaining the required storage volume is difficult, it may be possible to implement mid-season cleaning (F greater than 1), but District Maintenance staff should be consulted to make sure this is practicable. Mid-season cleaning requirements will also likely affect trap design, as maintenance equipment will have to access the trap under wet or snowy conditions.

Other design issues: Traction Sand Traps configured as vaults require a small hydraulic head for gravity flow operation. The inlet and outlet devices should be arranged or baffled to minimize short-circuiting of the flow through the device. Provide if possible at least 0.5 ft between top of captured sand and outlet pipe. Weep holes should be provided and the trap invert should be

sufficiently high above groundwater 3 to 6 ft to allow for proper drainage. Traction Sand Traps that do not drain may create vector problems in the spring.

Maintenance needs: Traction Sand Traps require sufficient space and/or access ramps for maintenance by large equipment to remove the accumulated sand. Traction Sand Traps should also be located so that water is not infiltrated above the roadway subgrade should the Traction Sand Trap become blocked or fail to drain so as not to affect expected life of the pavement.

Preliminary design factors for Traction Sand Traps are summarized in Table B-5.

Table B-5: Summary of Traction Sand Trap Siting and Design Criteria

Description	Applications/Siting	Preliminary Design Factors
Sedimentation devices that temporarily detain runoff and allow traction sand to settle out. May be basins, tanks, or vaults. Designed for peak hydraulic flow. Treatment Mechanisms: • Sedimentation Pollutants removed: • Sand or other traction-enhancing substances	• Sites where sand or other traction-enhancing substances are commonly applied to the roadway • Not considered where sand is used only rarely (less than twice a year) • Use Detention Basins or forebays as Traction Sand Traps whenever feasible; if they are not feasible, then consider tanks or vaults • Consult District/Regional NPDES Storm Water Coordinator to ensure device not classified as a regulated underground injection well • Locate device so water is not introduced above the roadway subgrade in case of blockage	• Design for anticipated sand recovery and cleanout interval • To the extent possible, stabilize areas within the tributary area to control sediment loads • Divert peak hydraulic flow if practical • Design to avoid or minimize scour • Provide, if possible, temporary storage volume (for sedimentation) using a minimum of 0.5 ft between top of sand (just prior to scheduled cleanout) and outlet pipe • Sufficient hydraulic head for gravity flow • Inlet and outlet arrangement to minimize short-circuiting of the flow • Weep holes to allow proper drainage • Invert 3 to 6 ft above groundwater if drainage is allowed through base (CMP riser type) • Maximum depth of tank or vault of 10 ft below ground surface (varies with equipment – consult District Maintenance) • Maintenance space and/or access ramps for large equipment (a maintenance vehicle access shoulder of up to 16 ft may be required; consult with District Maintenance)

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B.6 DRY WEATHER FLOW DIVERSION

B.6.1 Description

Dry Weather Flow Diversion devices provide permanent treatment by directing non-stormwater flow through a pipe or channel to a local municipal sanitary sewer system (publicly owned treatment works [POTWs]) during the dry season or dry weather. This flow must be generated by Caltrans activities or from Caltrans facilities.

B.6.2 Appropriate Applications and Siting Criteria

Dry Weather Flow Diversions should only be considered when all of the following conditions apply:

- Dry weather flow is persistent (i.e., present over a significant length of time at a relatively consistent flow rate, or having significant quantities that are periodically developed on-site), and contains pollutants;
- An opportunity for connecting to a sanitary sewer is reasonably close and would not involve extraordinary plumbing, features or construction practices to implement (e.g., jacking under a freeway);
- The POTW is willing to accept the flow during the dry season or dry weather.

An example of dry weather flow that could be considered for diversion is the runoff from a Caltrans tunnel generated during cleaning using water spray and scrubbing.

B.6.3 Factors Affecting Preliminary Design

Typically, a berm or wall is constructed across the dry weather flow drainage channel and the dry weather flows are diverted to a pipe or channel leading to the sanitary sewer. A gate, weir, or valve should be installed to stop the diversion during the wet season or during storms during the wet season (if the diversion will be made year-round). Accordingly, the conveyance to the sanitary sewer should be sized for the dry weather (non-storm) flows only. Wet weather flow is diverted (or remain undiverted, depending upon the design) back to the stormwater conveyance system.

If possible, a screen or trash rack should be installed at the diversion to reduce the likelihood of clogging the diversion pipe or channel. Maintenance vehicle access should be provided, especially if a screen is installed.

Preliminary design factors for Dry Weather Flow Diversions are summarized in Table B-6.

Table B-6: Summary of Dry Weather Flow Diversion Siting and Design Criteria

Description	Applications/Siting	Preliminary Design Factors
Direct flow during dry weather (or non-storm periods) to a POTW. Treatment flow rate determined on a site-specific basis (not the WQF). Treatment Mechanisms: • Wastewater treatment plant Pollutants removed: • All constituents	Only when the conditions below apply: • Dry weather flow is persistent (consistent flow rate and significant length of time) • Connection would not involve extraordinary plumbing, features or construction practices to implement • POTW willing to accept dry weather flow	• Berm or wall across channel to divert dry weather flow to the sanitary sewer • Gate, weir, or valve to stop diversion during wet season • Conveyance to sanitary sewer sized only for dry weather flow • Consider a screen or trash rack to limit debris conveyed to the POTW • Maintenance vehicle access

B.7 GROSS SOLIDS REMOVAL DEVICES: LINEAR RADIAL DEVICE AND INCLINED SCREEN DEVICES

B.7.1 Description

Gross Solids Removal Devices (GSRDs) include physical or mechanical methods to remove litter and solids 0.20 inch nominal[6] and larger from the stormwater runoff, usually done using various screening technologies. GSRDs should be considered for projects in watersheds where a TMDL allocation or 303(d) listing for litter has been made. The design should be coordinated through the Headquarters – Office of Storm Water Management – Design. GSRDs should be designed to handle flows generated by the peak drainage facility design event, unless placed in an offline configuration. The devices also have an overflow feature in the event of clogging.

B.7.2 Appropriate Applications and Siting Criteria

There are currently two approved types of GSRDs that can be considered:

- The Linear Radial – this device requires very little head to operate and is well suited for narrow and relatively flat rights-of-way.
- The Inclined Screen – this device requires about 5.5 ft of head and is better suited for fill sections of the highways.

GSRDs require sufficient space and/or access ramps for maintenance and inspection including the use of vacuum trucks or other large equipment to remove accumulated trash.

B.7.3 Styles of Devices

B.7.3.1 Linear Radial Device

The Linear Radial Device (Figure B-8, page B-42) utilizes modular 2-ft diameter, stainless steel well casings with 0.20 inch by 2.5 inch nominal louver slots to remove gross solids, litter and debris from stormwater runoff. The louvered well casings are usually contained in a concrete vault. Flows pass radially through the louvers trapping litter and solids in the casing and passing flows through the screens for discharge via an outlet pipe. The bottom of the casing is smooth to allow trapped litter to move to the downstream end of the well casing. The Linear Radial Device is designed to work inline with the existing storm drain system or could be placed in an offline configuration; either placement will incorporate an overflow/bypass that will operate if the unit becomes plugged.

Detail sheets for construction are available for the Linear Radial GSRD for flows up to 21.91 cfs and debris volumes up to 47.5 cubic feet., A Linear Radial GSRD may be placed on a grade with slopes up to 1:4 (V:H). Other highlights of the Linear Radial GSRD include:

- Long and narrow shape, well-suited for narrow right-of-ways;
- Minimal hydraulic head needed for operation;

[6] The 0.20 inch dimension is based on requirements set forth in TMDLs applicable to certain District 7 watersheds; other sizes may be necessary if required to meet TMDLs issued by other RWQCBs.

- Overflow/Bypass opening at the upstream end;
- Multiple wall heights to accommodate varying pipe depths;
- Graded with slopes up to 1:4 (V:H)
- Six lengths to accommodate varying flow rates and debris areas;
- Sloped floor for self-draining without permanent pool of water;
- Solids storage volume to accommodate a once per year maintenance cycle;
- Circular louvered sections have access doors that can be easily opened to facilitate cleaning with a vacuum truck or other equipment if necessary;
- Grated cover for safety.

There are two Linear Radial configurations. One model (referred to as "Linear Radial") is used for influent runoff velocities up to 8.2 feet per second; as shown in Figure B-8, the first half-meter of the Linear Radial well casing is non-louvered with an open top to allow for influent bypass should the device become clogged with litter. The other model (referred to as "Linear Radial (HV)") is for influent velocities greater than 8.2 feet per second, and is shown in Figure B-9. The Linear Radial (HV) has an energy dissipation vault separate from the main vault, and overflows occur by overtopping the initial vault into the second chamber.

Rendered images of the Linear Radial (HV) are presented in Figures B-8 and B-9.

Figure B-8: Schematic of Linear Radial Device

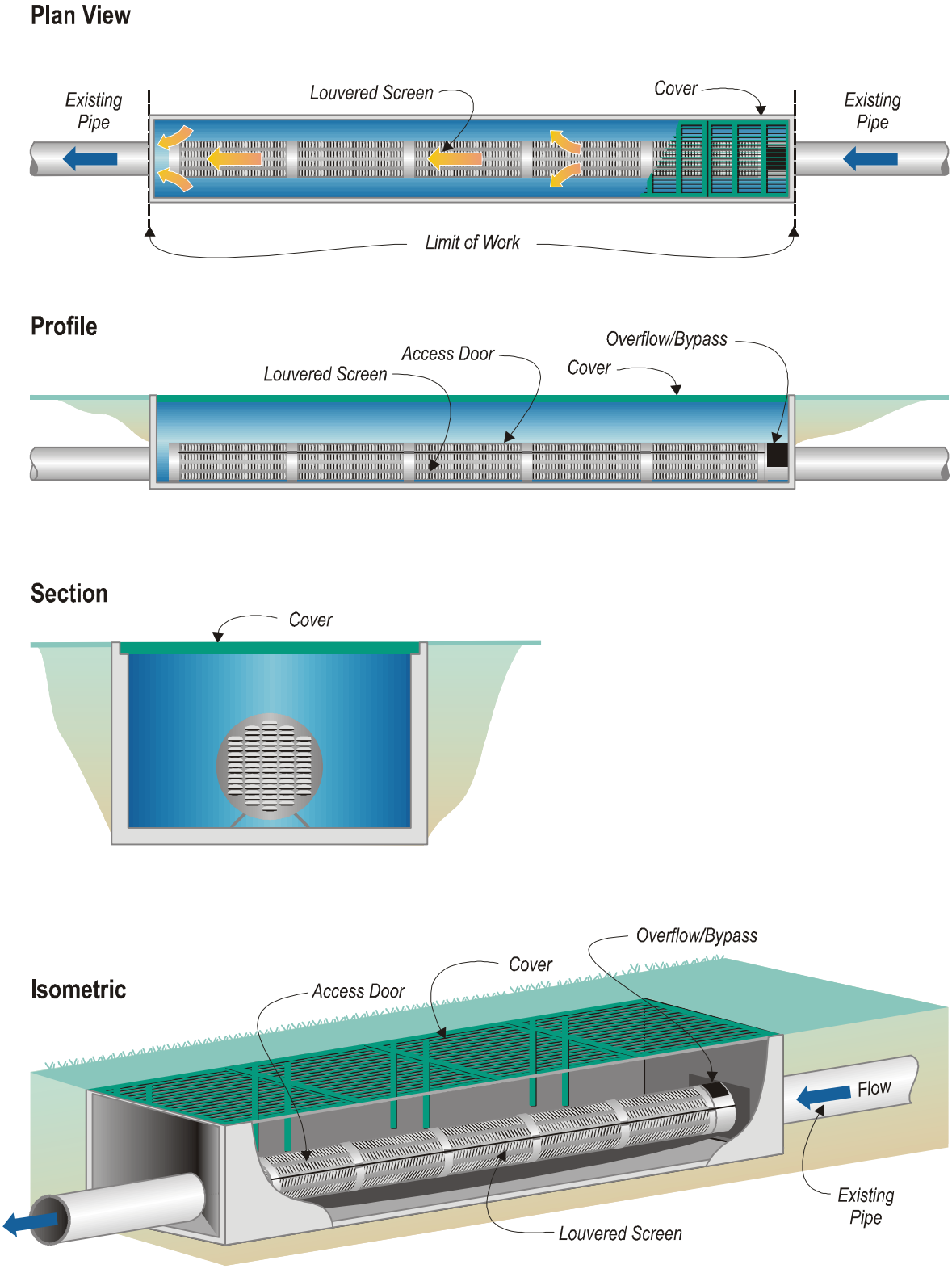
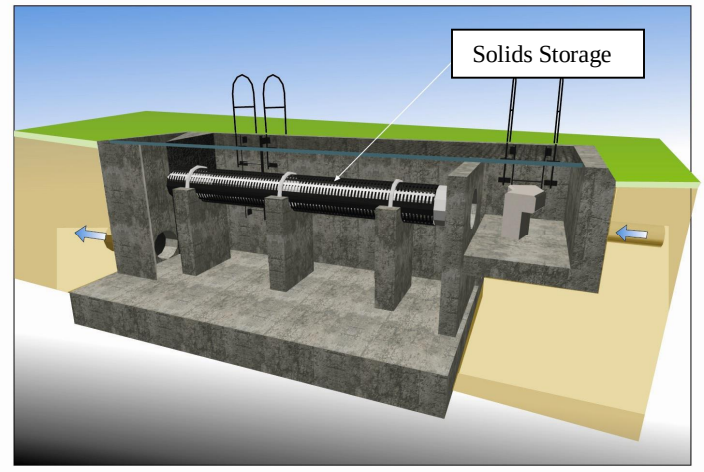
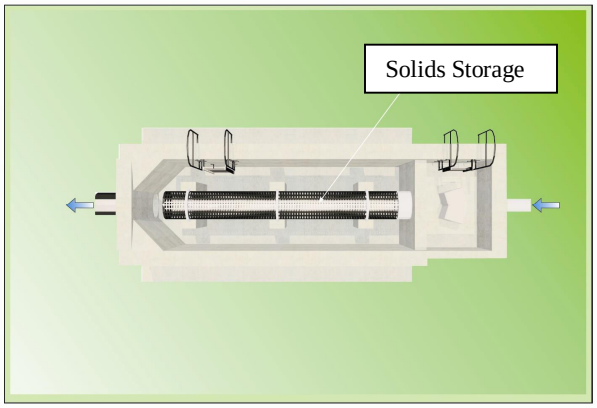
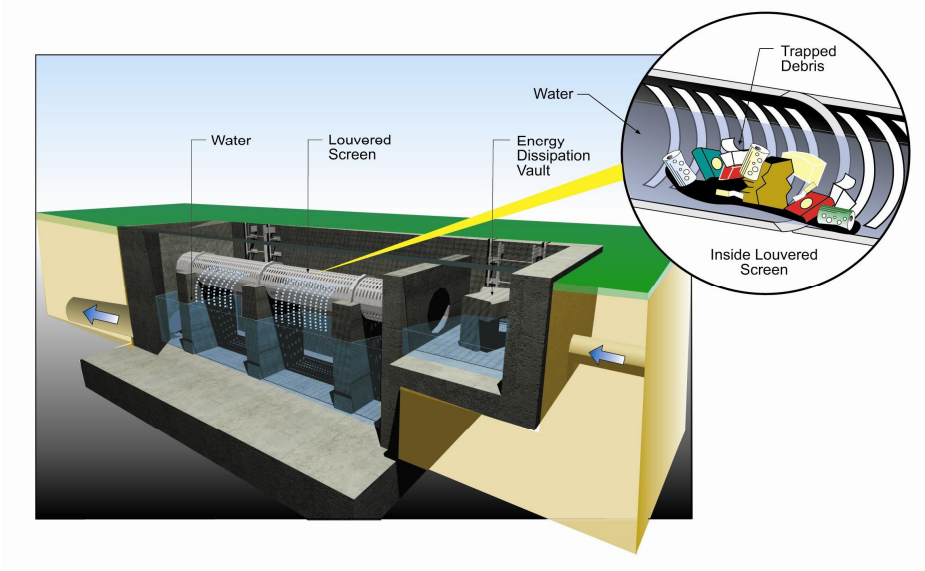


Figure B-9: Schematic of Linear Radial Device (HV)[7]







[7] Schematics shown represent one configuration; other configurations exist that operate with lower available hydraulic head.

Figure B-10: Linear Radial Device (partially full)





B.7.3.2 Inclined Screen Devices

Two versions of the Inclined Screen Device have been tested, and for which details sheets are available from HQ Office of Storm Water Management. In one the incoming flow overtops a weir and falls through an inclined bar rack (wedge-wire screen) with a 0.20-inch nominal maximum spacing between the bars, located after the influent trough. After passing through the rack, the flow exits the device via the discharge pipe. A distribution trough is provided to allow influent to be distributed along the length of the Inclined Screen. The litter captured by the bar rack is pushed down toward the litter storage area by the stormwater runoff. This version employs a parabolic wedge-wire screens inclined at 60 degrees and 3 ft high. The gross solids storage area is sloped and is provided with a drain to prevent standing water. As shown in Figure B-11 (page B-47), an opening above the litter storage area is provided to allow for overflow/bypass if the device becomes plugged. The device should be designed for litter and debris storage for a period of one year.

A second version uses a straight screen, and incoming flow is not required to overtop a weir to reach the screen (see Figure B-12).

Figure B-11: Type 1 Inclined Screen Device Schematic

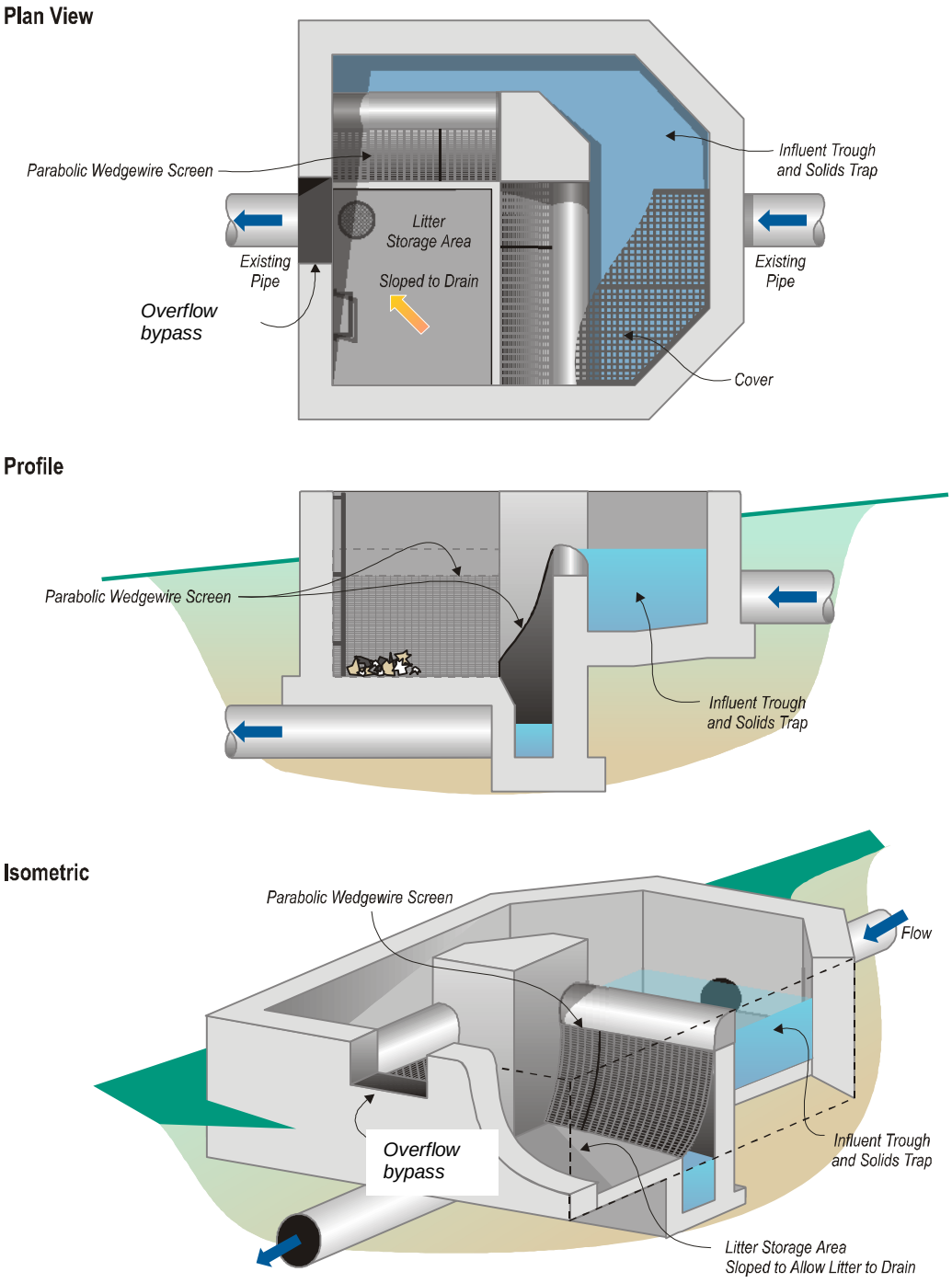


Figure B-12: Type 2 Inclined Screen Device Schematic

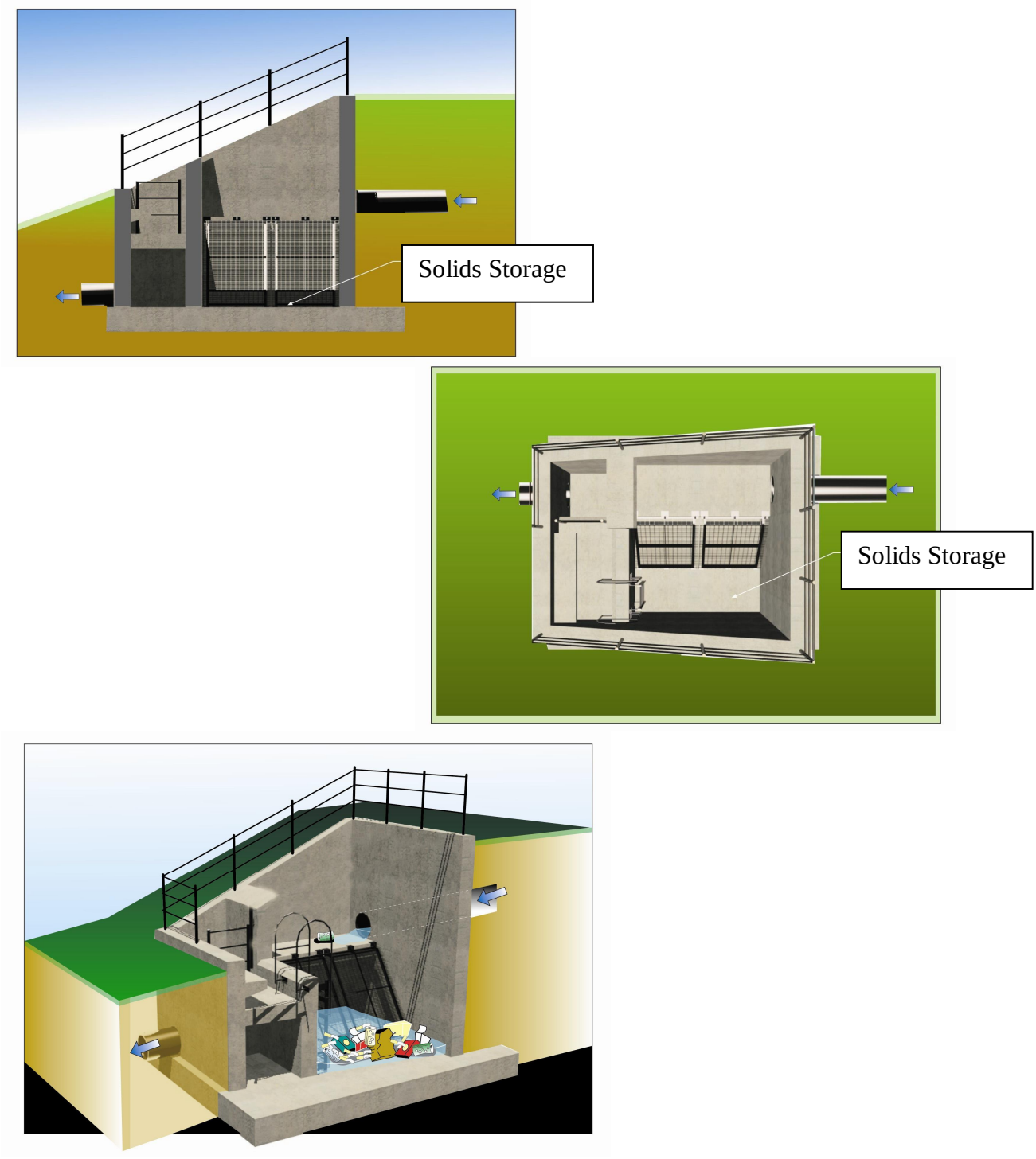


Figure B-13: Inclined Screen GSRD





B.7.4 Factors Affecting Preliminary Design

The two most important factors affecting the design of these devices are: a) sizing to accommodate gross solids storage for a given maintenance period (typically one year), and b) maintaining the hydraulic capacity of the drainage system in which it is to be installed. Litter and debris accumulation data need to be available to properly size the devices for the given drainage area. If regional litter and debris accumulation data are not available, then 10 ft^3/acre/yr may be used. Designers should consult with District Maintenance regarding litter and debris loads, access requirements for cleaning equipment, and District Hydraulics concerning drainage issues. These devices can be designed both online and offline.

Table B-7 provides external GSRD dimensions based on anticipated annual litter and debris accumulation and calculated maximum flow rate.

Table B-7: Summary of Dimensions for Gross Solids Removal Devices[8]

GSRD	Type	Max. Annual Litter/Debris Accumulation (cubic feet)	Max. HDM Flow Rate (cfs)	Out-to-out Dimension: Length (ft)	Out-to-out Dimension: Width (ft)
Linear Radial	LR-1	7.9	3.54	14.5	11.5
Linear Radial	LR-2	15.8	7.07	19.5	11.5
Linear Radial	LR-3	22.5	10.96	24.5	11.5
Linear Radial	LR-4	31.6	14.49	29.5	11.5
Linear Radial	LR-5	39.5	18.38	34.5	11.5
Linear Radial	LR-6	47.5	21.91	39.5	11.5
Linear Radial (HV)	LR(HV)-1	7.9	3.54	17.3	11.5
Linear Radial (HV)	LR(HV)-2	15.8	7.07	22.3	11.5
Linear Radial (HV)	LR(HV)-3	22.5	10.96	27.3	11.5
Linear Radial (HV)	LR(HV)-4	31.6	14.49	32.3	11.5
Linear Radial (HV)	LR(HV)-5	39.5	18.38	37.3	11.5
Linear Radial (HV)	LR(HV)-6	47.5	21.91	42.3	11.5
Type 1 Inclined Screen	1-A	24.6	9.66	17.2	13.5
Type 1 Inclined Screen	1-B	51.3	14.48	20.5	16.8
Type 1 Inclined Screen	1-C	87.7	19.31	23.8	20.2
Type 2 Inclined Screen	2-A	14.2	2.91	13.2	14.5
Type 2 Inclined Screen	2-B	21.2	4.37	14.8	14.5
Type 2 Inclined Screen	2-C	28.3	5.83	16.5	14.5
Type 2 Inclined Screen	2-D	35.4	7.28	18.2	14.5

[8] If HDM flow rate > 22 cfs, then a special design or bypass is required. Contact District Storm Water Coordinator.

A summary of preliminary design factors is presented in Table B-8:

Table B-8: Summary of Gross Solids Removal Devices (Linear Radial and Inclined Screen)

Description	Applications/Siting	Preliminary Design Factors
Devices to capture and remove litter from the stormwater runoff. • Designed to handle up the flow from the peak drainage facility design event (reference HDM Chapter 830) unless placed in an offline configuration Treatment Mechanisms • Filtration through screens Pollutants removed • Litter and solid particles greater than 0.20 inch nominal	• Site conditions must have adequate space for device and maintenance activities. • Sites that drain to litter sensitive receiving waters on 303(d) list for trash or areas where TMDLs require trash removal. • The Linear Radial Device requires little head to operate and is well suited for flat sections of highway. • The Inclined Screen requires approximately 5.5 ft of head measured between the top of the weir above the screen and the flowline of the outflow pipe; it is well suited for fill sections. • Locate outside the Clear Recovery Zone (HDM Topic 309.1), or consult with Traffic Operations to determine if guard railing is required	• Design using regional litter accumulation data if available, otherwise use 10 ft^3/acre/yr. • Devices must be sized for peak design flow while holding design (typically annual) gross solids load. • Some TMDLs also require full capture for events of up to a one-year, one-hour storm event (i.e., runoff should not be bypassed in the GSRD under that flow rate). Determine if this or other specific TMDL requirements apply at the project site. • The standard Linear Radial Device well casing is 24 inch diameter. • Standard designs for the Linear Radial GSRD have been evaluated for flows up to 22 cfs. If design flows exceed 22 cfs, then consider incorporating a flow-splitter device upstream of the GSRD to divert peak flows. • Structure and grate do not support traffic load. Traffic-rated GSRD would require special design. • Determine location and depth of device for maintenance access (coordinate with District Maintenance)

B.8 MEDIA FILTERS

B.8.1 Description

A Media Filter Treatment BMP device primarily removes TSS pollutants (sediments and metals) from runoff by sedimentation and filtering, and also is effective for dissolved metals, litter and potentially some nutrients (depending upon type of Media Filter selected).

There are two types of approved Media Filter devices: The Austin Sand Filter and the Delaware Sand Filter; each is configured using two chambers. An Austin Sand Filter is usually open and at grade, and has no permanent water pool; a Delaware Sand Filter is always configured with closed chambers and below grade, and has a permanent pool of water. An Austin Sand Filter may be configured with earthen or concrete sides and invert; a Delaware Sand Filter is always made using concrete sides and invert.

In both types of Media Filters, stormwater is directed into the first chamber where the larger sediments and particulates settle out, and the partially treated effluent is metered into the second chamber to be filtered through a media. In the Austin Sand Filter, the first chamber may be sized for the entire WQV ('full sedimentation') (see Figure B-15, page B-53) or as a 'partial sedimentation' chamber, holding only about 20% of the WQV (see Figure B-16, page B-54); the Delaware Sand Filter holds the entire WQV in the initial chamber, and is designed to pass the WQV from the second chamber (see Figure B-17, page B-55).

The treated effluent (filtered water) is captured by perforated underdrains (collector pipes) for release downstream. There is a drop in elevation of 3 ft to 6 ft between the invert of the inlet pipe and the invert of the device outflow pipe depending on device type, size or configuration.

The filter media typically consists of sand, which is effective for removal of coarse and fine sediments and particulate metals. Other materials, such as topsoil or organic materials may be added to the sand to increase the treatment capacity for some pollutants (for example, dissolved metals) but these additives often increase the nitrogen and phosphorus concentration levels in the effluent. Design of a Media Filter must be coordinated through the Headquarters Division of Environmental Analysis – Policy, Planning and Permitting, and Headquarters Design – Office of Storm Water Management.



Figure B-14: Caltrans Pilot Media Filters (Austin Sand Filter [left], Delaware Sand Filter [right])

B.8.2 Appropriate Applications and Siting Criteria

The minimum WQV for Media Filters is ≥ 4,356 ft^3 (0.1 acre-ft [a-f])[9]. Medial Filters will perform better if the tributary area has a relatively high percentage of impervious area, and low sediment loading.

Sites proposed for Media Filters must have sufficient hydraulic head to operate by gravity; generally between 3 to 6 ft of elevation drop is needed between the inflow to the initial chamber and effluent outflow from the second chamber.

Unless concurrence for the use of Delaware Sand Filters can be obtained from the local vector control agencies, the placement of a Delaware Sand Filter, which maintains a permanent pool of water in the sedimentation chamber, should be avoided in locations where there are concerns about vector control. It is anticipated that standard details for a vector-proof Delaware Sand Filter will be developed; contact the District/Regional NPDES Coordinator for availability.

For earthen-type Media Filters, at least 10 ft separation from seasonally high groundwater should be provided. For vault-type Media Filters, the level of the concrete base of the vault must be above seasonally high groundwater unless by special design.

B.8.3 Preliminary Design Factors

B.8.3.1 General Factors

Maintenance must have access to both chambers, and the distance below ground surface of the invert must be approved by Maintenance (maximum depth of 13 ft).

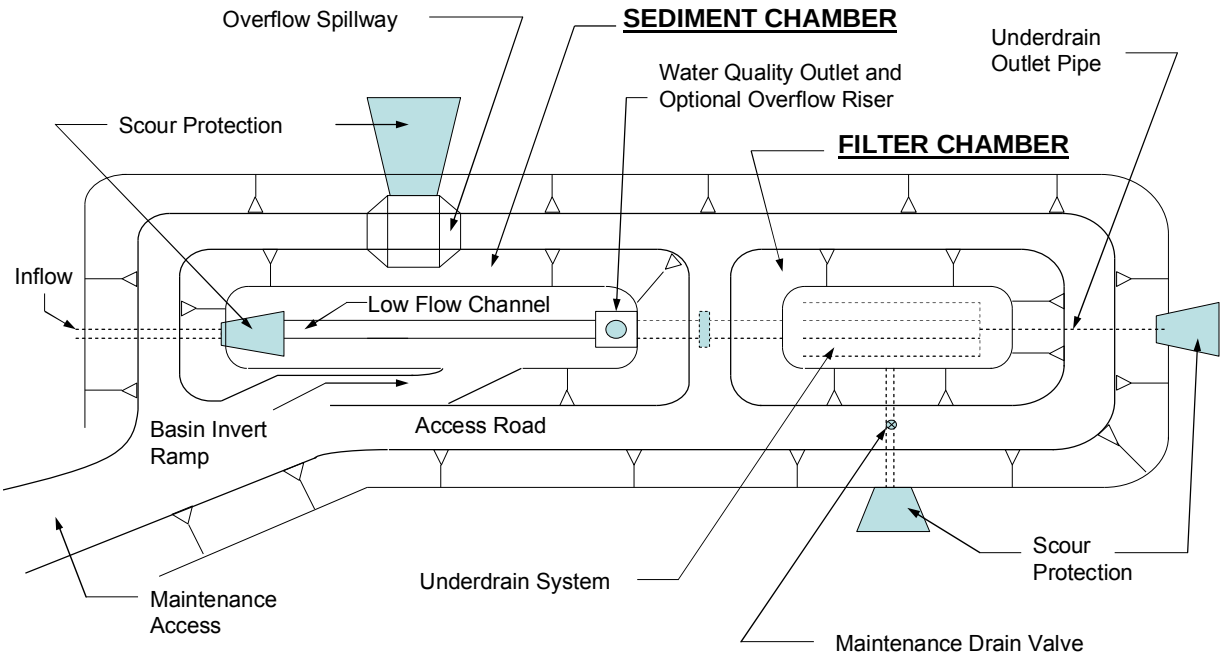
For the Austin Sand Filter designed for full sedimentation (see B.8.1), the following design features should be incorporated: a) the initial chamber should be sized to hold the entire WQV using a 24-hour release time; b) release to the second chamber is usually made using a perforated riser; and c) a minimum length to width ratio of 2:1 for the initial (sedimentation) chamber at the WQV elevation should be provided.

For partial sedimentation Austin Sand Filters the following design features apply: a) the initial chamber should be sized to hold a minimum of 20% of the WQV; b) release from the first chamber is made using a rock-filled gabion wall separating the chambers; c) the length to width ratio does not apply; and d) the sum of the volume of the sedimentation chamber plus the total volume stored in the filtration chamber should be ≥ the WQV. The volume stored in the filtration chamber is equal to the volume above the media material plus 35% of the media volume which accounts for void spaces within the media.

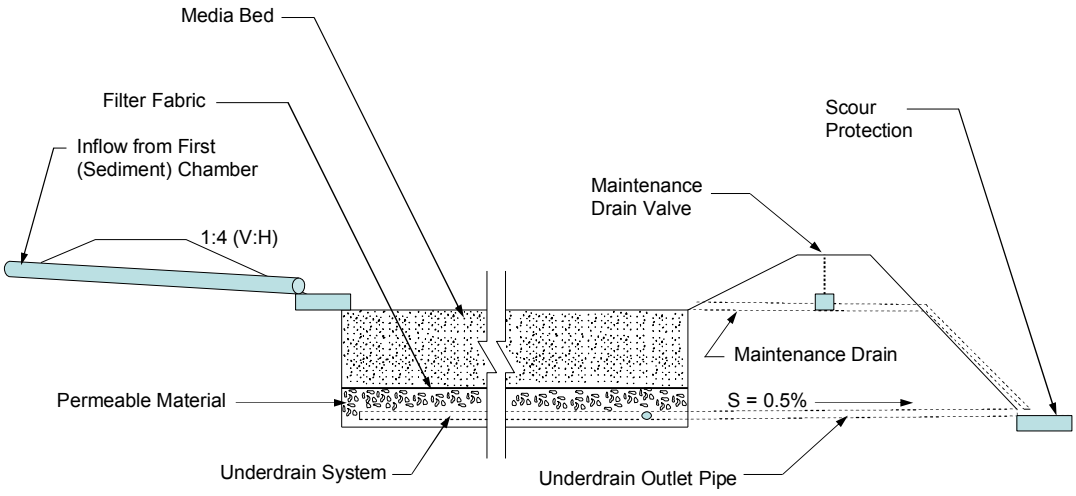
Figure B-15 provides a schematic of a full sedimentation Austin Sand Filter, while Figure B-16 provides a schematic of a partial sedimentation Austin Sand Filter.

[9] Consult with District/Regional NPDES if less than 4,356 ft^3 is under consideration.

Figure B-15: Schematic of a Austin Sand Filter - Full Sedimentation (Earthen Type)



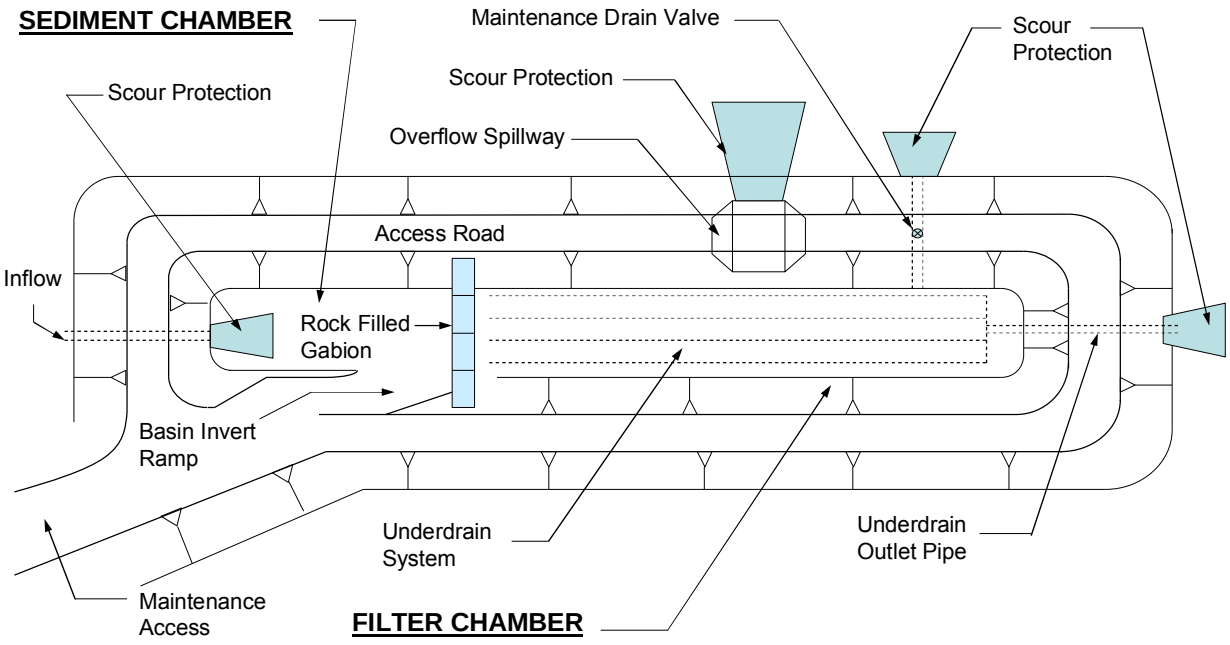
Plan View



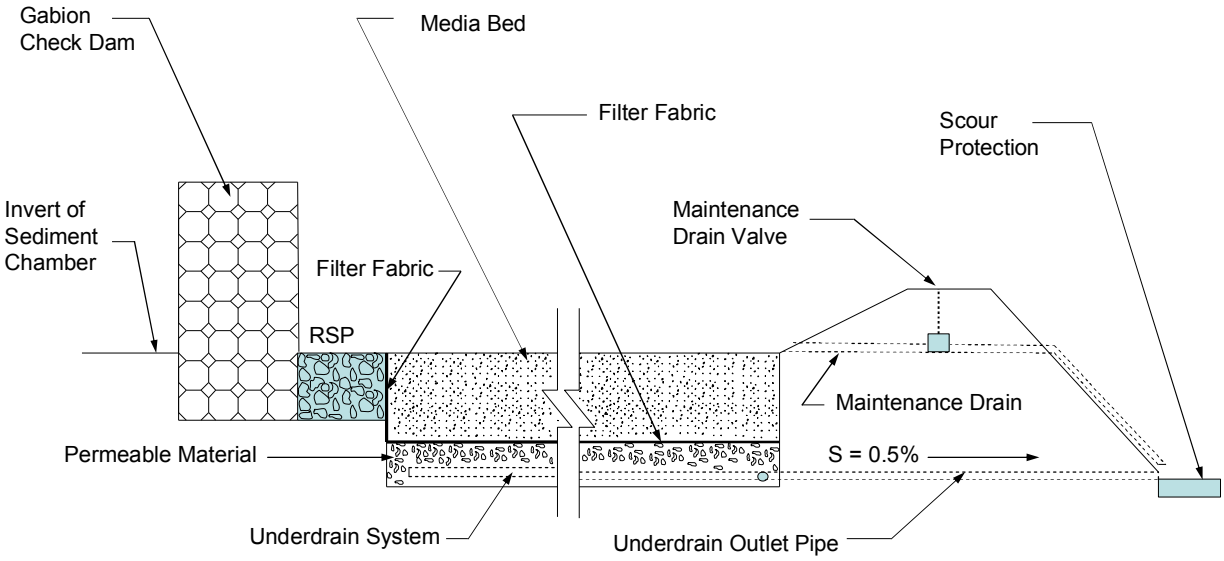
Second (Filter) Chamber Cross Section

NOT TO SCALE

Figure B-16 Schematic of an Austin Sand Filter - Partial Sedimentation (Earthen Type)



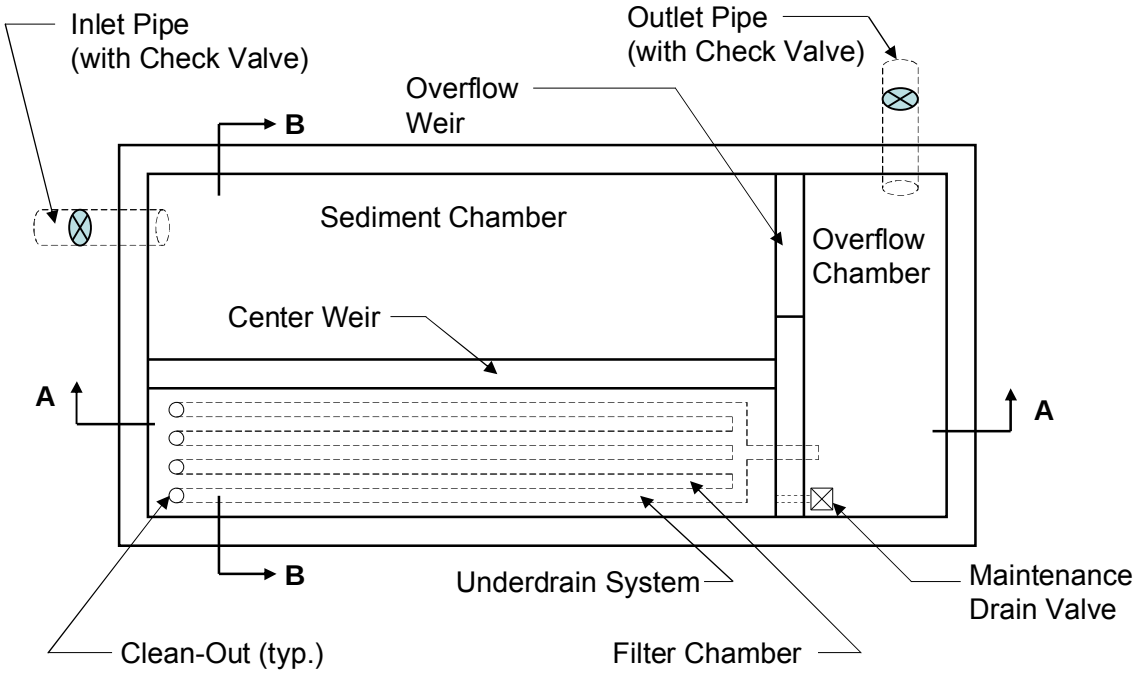
Plan View



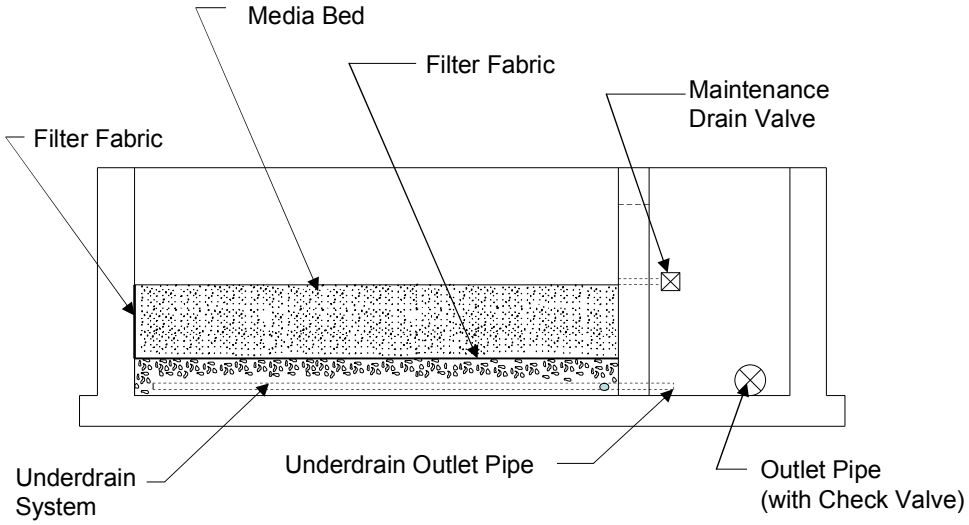
Second (Filter) Chamber Cross Section

NOT TO SCALE

Figure B-17: Schematic of a Delaware Sand Filter

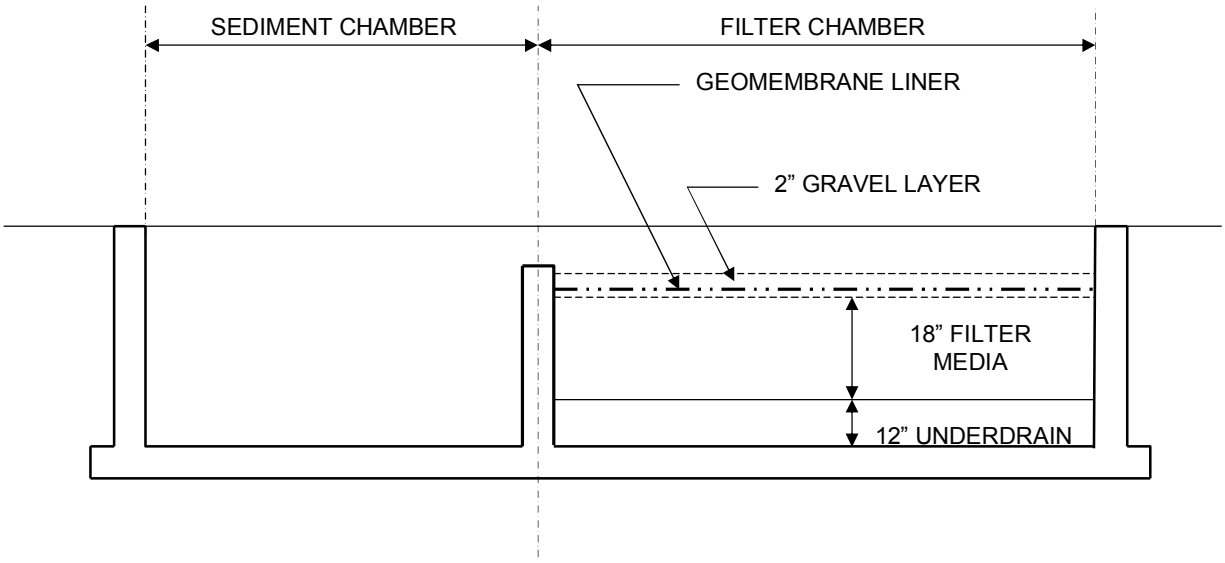


Plan View



Section A-A

Figure B-17 (Continued): Schematic of a Delaware Sand Filter



Section B-B

STANDARD LAYOUT

Other general factors include:

- Austin Sand Filter: Depth of the media layer (sand filter layer) typically 1.5 ft, and the gravel layer (collector layer) is 1.0 ft.

- Austin Sand filter with earthen base and sides, full or partial: side slopes should be 1:3 (V:H) or flatter, and should be stabilized by vegetation. Consult the District Office of Landscape Architect for types of vegetation that can function effectively in each of the various ecological subregions of a District. Additional information about grasses that have been successful within specific ecological subregions of California, in grassland and wetland conditions, may be found in *Ecological Subregions of California Section and Subsection Descriptions* (as referenced in Appendix B, Biofiltration Strips and Swales).

- Delaware: Depth of the media layer (sand filter layer) is 1.5 ft; depths of the two gravel layers are: top layer at 2.0 inches, and lower layer (collector layer) at 1.0 ft. Separate layers using geotextile fabric.

- For all types of Media Filters, upstream bypass for larger storms is preferred for storms > WQV; internal overflow protection also must be provided through the device, typically using weirs from the initial chamber.

- Upstream litter and sediment capture should be provided if possible, e.g., using Biofiltration or a forebay.

Preliminary Design Factors for Media Filters are summarized in Table B-8.

B.8.3.2 Austin Sand Filter Chambers - Full Sedimentation Device

Size the initial chamber to hold the WQV, and use the equation for the outlet riser presented under Detention Devices (Section B.4.1) to determine the diameter of the orifices, using a 24-hour hold time.

The equation for sizing the filter bed in the second chamber is:

$$A_{fc} = [C \times WQV \times d] / [k \times T \times (h + d)] \quad \text{(Eq. 10)}$$

Where:

A_{fc} = area of 2nd chamber filter bed, full sedimentation basin; ft^2
C = conversion factor for units of permeability (12 for inches to ft)
WQV = Water Quality Volume; ft^3
d = depth of sand layer in the Austin-style filter bed, typically 1.5 ft
k = coefficient of permeability of the filtering medium; US Customary units: 2 inches/hr
T = design drain time for WQV, equal to 24 hours
h = average water height above the surface of the media bed, taken as ½ the maximum head of the second chamber (distance to any overflow device from that chamber to the surface of the media bed); ft

B.8.3.3 Austin Sand Filter Chambers, Partial Sedimentation Device

When sizing the two chambers for the Austin Sand Filter - Partial Sedimentation device, the following procedures are recommended:

First, size the filter bed in the second chamber using the following formula:

$$A_{fp} = 1.8A_{fc} \quad \text{(Eq. 11)}$$

Where:

A_{fp} = area of 2nd chamber filter bed for a partial sedimentation device, and A_{fc} is calculated as above.

Note that the filter area is larger in the partial sedimentation version than the full sedimentation version due to the less efficient capture of sediments in the partial sedimentation device.

Then size the initial chamber to hold a minimum 20% of the WQV, subject to increase to meet the requirement that both chambers (including the void space in the filter chamber calculated using Eqn. 14 shown on page B-61) combine to hold the entire WQV.

With these requirements, the area of the Austin Sand Filter - Partial Sedimentation device is usually about 80 to 90% of the Austin Sand Filter - Full Sedimentation device. However, the efficiency of the partial sedimentation design is not greatly different from the full sedimentation version, and the overall maintenance is usually reduced because the release of stormwater from the partial sedimentation chamber to the filter chamber is usually done through a rock-filled gabion wall (and not an outlet riser), and no hold time is assigned to the water in the initial (sedimentation) chamber.

B.8.3.4 Delaware Sand Filter Chambers

When sizing the two chambers for the Delaware Sand Filter, the following procedure is recommended:

The area of the filter chamber is calculated using the following equation:

$$A_{fc} = [C \times WQV \times d] / [k \times T \times (h + d)] \quad \text{(Eq. 12)}$$

where

A_{fc} = area of filter chamber; ft^2
C = conversion factor for units of permeability (12 for inches to ft)
WQV = Water Quality Volume; ft^3
d = depth of sand layer in the Delaware filter bed, typically: US Customary units: 1.5 ft
k = coefficient of permeability of the filtering medium; US Customary units: 1 inches/hr
T = design drain time for WQV, 40 to 48 hours
h = average water height above the surface of the media bed, taken as ½ the maximum head of the second chamber (distance to any overflow device from that chamber to the surface of the media bed); ft

Note that the formula for the Delaware Sand Filter is very similar to that used for the full sedimentation Austin Sand Filter, except for the value assigned to the permeability (even though the same material is used); a more conservative permeability value is assigned to the Delaware Sand Filter, as the device, being underground and not directly visible during the wet season, requires a more conservative design.

Then, series of calculations must be made to verify that the required storage areas are sufficient. Step 1: Select a width for the chambers, normally between 1.5 feet and 2.5 feet, not including the one-foot thick concrete wall between them), and compute the length based on the area calculated above:

$$L_s = L_f = A/W \quad \text{(Eq. 13)}$$

where
L_s = length of the sediment chamber, ft
L_f = length of the filter chamber, ft
A = Area used for individual chambers (A_{sc} or A_{fc}), calculated above, ft^2
W = selected width for individual chamber (not total width), ft

Step 2: Calculate the storage volume available for water in the filter chamber (filter media), V_V:

$$V_V = 0.35A_{fc} \times (d + d_g) \quad \text{(Eq. 14)}$$

where

V_v = available storage volume of the filter chamber; ft^3
A_{fc} = area of the filter chamber; ft^2
d = depth of the filter (sand) layer; US Customary units: 1.5 ft
d_g = depth of the gravel layer(s); US Customary units: 1.0 ft
0.35 = assumed void ratio (dimensionless)

Step 3: Calculate the flow through the filter during filling, V_Q

$$V_Q = (k \times A_{fc} \times [d + d_g] \times t_f) / (C \times d) \quad \text{(Eq. 15)}$$

where

V_Q = volume of water passing through filter during time to fill voids, ft^3
k, A_{fc}, d, d_g, and d_f are terms as defined previously
C = conversion factor for units of permeability
(12 for inches to ft)
t_f = time to fill the voids, take as 1 hour

Step 4: Calculate the net volume required to be stored in chambers awaiting filtration, V_{ST}

$$V_{ST} = WQV - V_V - V_Q \quad \text{(Eq. 16)}$$

Step 5: Calculate available storage in chambers, V_{SF}

$$V_{SF} = 2h \times (A_{fc} + A_{sc}) \quad \text{(Eq. 17)}$$

Step 6: Compare V_{SF} and V_{ST}

If $V_{SF} > V_{ST}$, proceed with the design
If $V_{SF} > V_{ST}$, adjust the length or the width or either chamber, and repeat these Steps 1 through 5.

Table B-9: Summary of Media Device Siting and Design Criteria

(Applicable to both Austin Sand Filter and Delaware Filter unless noted)

Description	Applications/Siting	Preliminary Design Factors
Two-chambered treatment devices designed to treat the WQV. Treatment Mechanisms • Sedimentation • Filtration Pollutants removed • Suspended solids • Particulate metals • Dissolved metals • Litter (although preferred capture is upstream of the device) • Nutrients	• WQV ≥ 4,356 ft^3 (0.1 a-f). For WQV < 0.1 a-f, contact the District/Regional NPDES Coordinator. • Site must have sufficient hydraulic head to operate by gravity between inflow to the initial chamber and effluent outflow from the second chamber, about 3.0 to 6.0 ft. • Delaware Media Filters should avoid locations where there are concerns about vectors because they maintain a permanent pool of water unless concurrence for its use can be obtained from the local vector control agency. • For earthen-type Media Filters, at least 10 ft separation from seasonally high groundwater should be provided. For vault-type Media Filters, the level of the concrete base of the vault must be above seasonally high groundwater unless by special design. • Will perform better if the tributary area has a relatively high percentage of impervious area, and low sediment loading. • Maintenance must have access to both chambers. • Locate outside the Clear Recovery Zone (HDM Topic 309.1), or consult with Traffic Operations to determine if guard railing is required.	• Maximum depth: 13 feet below ground surface; verify with Maintenance • Upstream bypass for larger storms is preferred but bypass for storms > WQV must be provided through the device, typically using weirs from the initial chamber. • Provide if possible upstream litter and sediment capture, e.g., using Biofiltration or a Sediment Forebay. • Collector pipes: minimum 6 inches diameter laterals, and minimum 8 inches diameter collector pipe • Sand media: use Caltrans Standard Specification 90-3.03 for fine aggregate; Gravel: use Caltrans Standard Specification 68-1.025, Permeable Material, Class 1, Type B; separate layers using geotextile.[10] • Austin, full sedimentation design: design the initial chamber to hold the entire WQV and use a 24-hour release time if site constraints allow, release to the second chamber using a perforated riser, and a length to width ratio of 2:1 should be provided for the sedimentation chamber. • For partial sedimentation designs, the initial chamber should be sized to hold ≥ 20% WQV and the volume of the sedimentation chamber plus 35% of the total volume of the filtration chamber (available storage volume of filtration chamber based upon 35% porosity of filter rock) should be ≥ the WQV; provide a rock-filled gabion wall separating the chambers. • For either Austin or Delaware Sand Filters: Drainage over 24 hours from the second chamber (filtering chamber). • Austin Sand Filter: no permanent vegetation is desired on the invert of the second chamber. • Austin Sand Filter with earthen base and sides, full or partial: side slopes should be 1:3 (V:H) or flatter, and should be stabilized by vegetation. Consult the District Office of Landscape Architect for types of vegetation that can function effectively.

[10] Media Filters: The filter fabric should meet the requirements of Caltrans Standard Specification Section 88-1.03, Filter Fabric. The gravel layer can function without an intermediary geotextile, if designed using 'graded filter' criteria (e.g., see Soil Mechanics, DM 7.01, NAVFAC, 1986, page 271ff).

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B.9 MULTI-CHAMBER TREATMENT TRAIN (MCTT)

B.9.1 Description

The MCTT is a stormwater treatment device that uses different treatment mechanisms in each of three sequential chambers. An MCTT device primarily removes TSS pollutants (sediments and metals) from runoff by sedimentation and filtering, and may also be effective for some dissolved metals, litter and nutrients. The MCTT was developed for treatment of stormwater at critical source areas, such as vehicle service facilities, parking areas, paved storage areas and fueling stations. A pilot MCTT installation is presented in Figure B-18, and a schematic of an MCTT is shown in Figure B-19.

The initial chamber, also called a 'grit' chamber, captures the larger sized sediments; this may be configured as a catch basin with a sump. Some variations are employed in this chamber, such as including a trash rack. The second chamber, also called the main settling chamber, is designed to capture fine sediments; this chamber may also be configured with sorbent pads designed to capture hydrocarbons. The third chamber, also called the filter chamber, employs a media bed often configured as a combination of sand and peat moss; it removes even finer sized particles than were captured in the previous chambers and acts as a sorption area for some dissolved constituents.



Figure B-18: Caltrans' MCTT pilot installations

Water flows from the initial chamber to the second chamber via either a weir or an orifice, and this chamber will have a permanent pool of water. Water flows from the second to third chamber via either an orifice or a weir. The effluent leaves the third chamber via an underdrain system located at the base of this chamber. The MCTT may be covered or uncovered, but if uncovered should be protected by a fence. The design of this device should be coordinated through the Headquarters Office of Storm Water Management – Design.

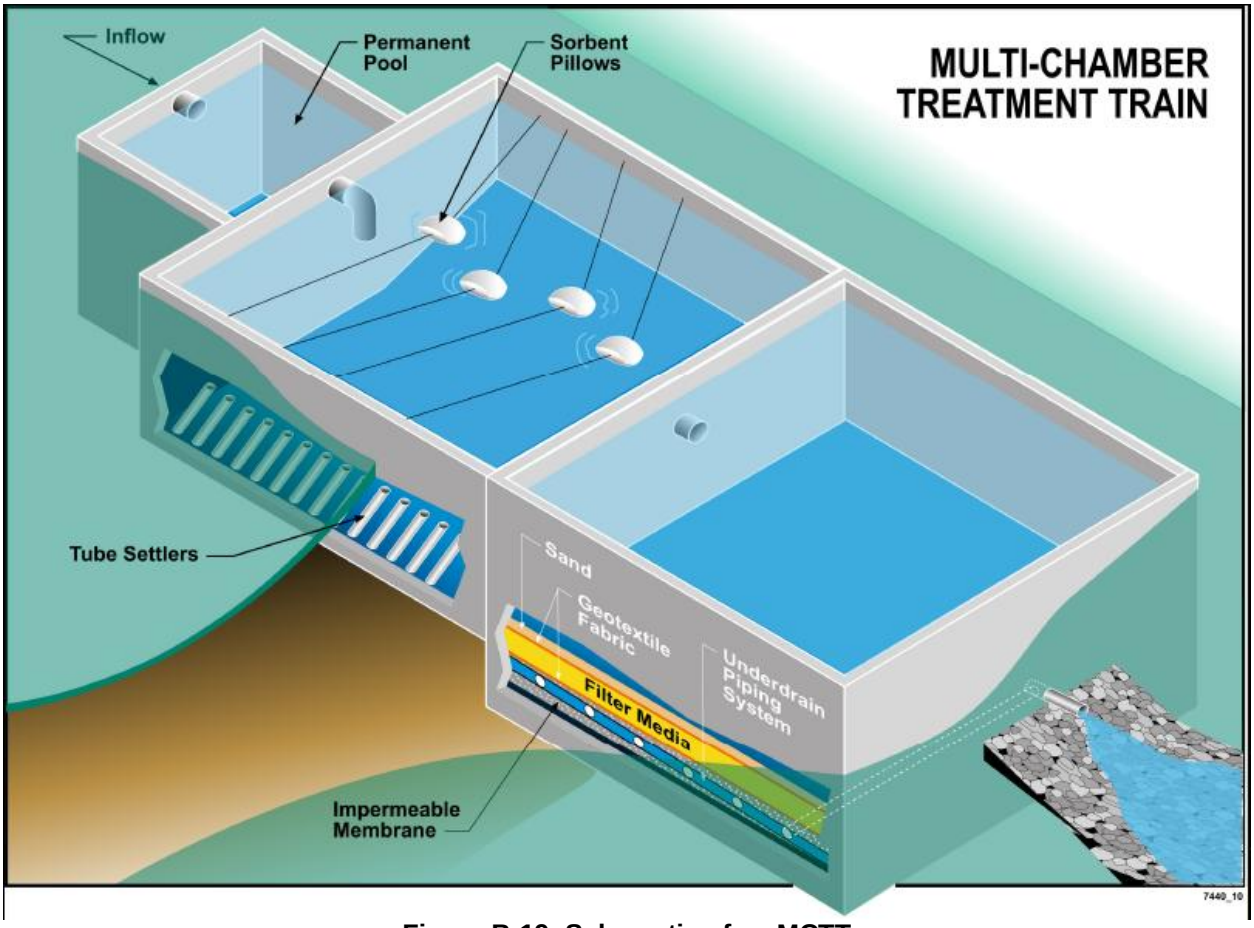


Figure B-19: Schematic of an MCTT

B.9.2 Appropriate Applications and Siting Criteria

The MCTT was developed for treatment of stormwater at critical source areas, such as vehicle service facilities, parking areas, paved storage areas, and fueling stations. To maintain longevity, potential sites should have a relatively high percentage of impervious surfaces contributing to the runoff, and runoff from the remaining area should not contain significant sediment. The WQV should be greater than or equal to 4,356 ft^3 (0.1 acre-foot [a-f]) for the MCTT to be considered.

Sites proposed for MCTTs must have a hydraulic head of approximately 5 ft to allow the device to operate by gravity. MCTTs are easier to place in flat to gently rolling terrain.

Designers should consult with the local vector agency regarding MCTTs proposed for locations having vector concerns due to the permanent pool of water present in the first and second chambers. If necessary, a MCTT may be provided with a permanent cover.

Upstream litter and sediment capture should be provided if possible, e.g., using Biofiltration or a forebay.

B.9.3 Preliminary Design Factors

B.9.3.1 General Factors

Maintenance vehicle access to all chambers is required for inspection, periodic maintenance, and cleanout.

The maximum depth to invert of second chamber is 13 ft below the ground surface; Maintenance must be able to access the invert at this depth.

Bypass overflow: offline placement of MCTTs is preferred, but the device should also have a separate overflow spillway, overflow riser or outlet pipe for events larger than the WQV, even if upstream diversion is provided; the overflow should be capable of passing the HDM design event (see Section B.1.3.1).

The combined storage capacity of all the MCTT chambers should be ≥ 100% of the WQV, excluding the permanent pool volumes in the grit and sedimentation chambers and the volume of the media in the filter chamber (assume a void ratio of 35% for the media bed which can be counted towards storage of the WQV). For 100% WQV storage in the device, the volume should be estimated as:

> *Total (100% WQV) = 10% WQV in grit chamber + live storage volume above the tube settlers in the sedimentation chamber + live storage in filter chamber including volume stored in media voids (assume 35% void ratio).*

If the site conditions allow, the second (sedimentation) chamber can be designed to store 90% of the WQV, with a minimum 24-hour drain time. The filter chamber should be designed to pass 75% to 100% of the WQV with a drain time of 24 to 48 hours.

Preliminary Design Factors for MCTT are summarized in Table B-10.

B.9.3.2 Sizing the MCTT Initial Chamber

The initial (grit) chamber should be sized to hold at least 10% of the WQV, with outflow to the second (sedimentation) chamber accomplished by using a weir or outlet pipes designed to pass a flow rate equal to the WQF (Water Quality Flow) or design flow for the site if bypass is not provided upstream. The weir or pipe outlet design should follow methods presented standard hydraulics texts. The depth of the initial chamber below the weir or outlet pipe invert should be at least 1.0 ft, to minimize re-suspension of sediments.

B.9.3.3 Sizing the MCTT Second Chamber

The size of the second (sedimentation) chamber depends on the site area available. If the site conditions allow, the second chamber can be designed to store 90% of the WQV above the permanent pool, and outflow to the third chamber can be regulated by a water quality outlet or an orifice for a minimum drain time of 24-hours.

If site conditions do not permit, the second and third chambers together may be designed to store a minimum of 90% of the WQV (refer to Equations 18 through 21). The outflow from the second chamber to the third chamber is generally accomplished via pipes located just at the top

elevation of the tube settlers in the second chamber. The second chamber must have an overflow weir or pipe to pass runoff from storms larger than the Water Quality event if no upstream bypass is provided, or to pass volumes in excess of the second chamber storage volume (even if upstream bypass is provided).

B.9.3.4 Sizing the MCTT Third Chamber

The third chamber contains a filter bed. The surface area of this chamber should be sized to pass a minimum of 75% to 100% of the WQV within a drain time of 24 to 48 hours (Equation 18). As noted previously, the total minimum WQV for the filter chamber and sedimentation chamber should be 90% of the WQV. As noted in Section B.9.3.3, the volume of water stored above the media bed plus the volume of water stored within the media bed voids can be counted towards the total WQV, and the combined second and third chamber volume can be designed for a minimum of 90% of the WQV (Equations 19 and 20).The size is first calculated for the area of the filter bed, then the length is determined, as the width is usually set by the width of the second chamber.

The equation for calculating the area of the filter bed (third chamber) is:

$$A_f = (C \times VOL \times d) / (k \times T \times [h + d]) \quad \text{(Eq. 18)}$$

where

A_f	=	area of filter bed in the third chamber, ft^2
C	=	conversion factor for units of permeability 12 for inches to ft
VOL	=	75 to 100% of the Water Quality Volume, ft^3
d	=	depth of filter bed[11], typically about 1.0 to 1.5 ft
k	=	coefficient of permeability of the filtering medium; 2 inches/hr
T	=	design drain time for WQV, typically 24 to 48 hours
h	=	average water height above the surface of the media bed, taken as ½ the maximum head of the second chamber (distance to any overflow device from that chamber to the surface of the media bed); ft

The equation for calculating the length of the third chamber is:

$$L_{3rd\ chamber} = A_f / Width \quad \text{(Eq. 19)}$$

Where:

$L_{3rd\ chamber}$	=	length of the third chamber, ft
A_f	=	area of filter bed in the third chamber, ft^2
Width	=	width of filter bed selected for design, ft

[11] Note that in the final design for the MCTT a gravel layer is placed below the sand layer. This layer has a thickness of 1.0 ft, and it has within it the perforated underdrains.

The equation for determining the storage capacity in the third (filter) chamber is as follows:

$$V_{fc} = (L_{3rd\ chamber} \times Width \times h) + [0.35 \times L_{3rd\ chamber} \times Width \times (d+d_g)] \quad \text{(Eq. 20)}$$

Where:

V_{fc}	=	storage capacity in third (filter) chamber, ft^3
$L_{3rd\ chamber}$	=	length of the third chamber, ft
Width	=	width of filter bed selected for design, ft
h	=	average water height above the surface of the media bed, taken as ½ the maximum head of the second chamber (distance to any overflow device from that chamber to the surface of the media bed); ft
d	=	depth of filter bed, typically about 1.0 to 1.5 ft
d_g	=	depth of gravel under filter bed, typically about 1.0 ft
0.35	=	assumed porosity of media and gravel

The volume of the second (sedimentation) chamber may now be calculated as follows:

$$V_{2nd\ chamber} = \text{WQV} - \text{Volume in first (grit) chamber} - V_{fc} \quad \text{(Eq. 21)}$$

Where:

$V_{2nd\ chamber}$ = storage capacity in second (sedimentation) chamber, ft^3

Table B-10: Summary of Multi-Chamber Treatment Train Siting and Design Criteria

Description	Applications/Siting	Preliminary Design Factors
Vault-type multi-chambered treatment device Treatment Mechanisms: • Sedimentation • Filtration • Adsorption and ion exchange Pollutants removed: • Medium to fine sediments • Litter • Particulate metals • Some dissolved metals • Some nutrients	• WQV ≥ 4,356 ft^3 (0.1 a-f) • Located at a areas as vehicle service facilities, parking areas, paved storage areas and fueling stations • Will perform better if the tributary area has a relatively high percentage of impervious area and/or a low sediment loading • Upstream litter and sediment capture should be provided if possible, e.g., using Biofiltration or a forebay. • Baffle wall or reverse pipe outlets can be used to control litter within the device • Site must have sufficient hydraulic head to operate under gravity flow, minimum 6 ft • MCTTs are not recommended for locations that have vector concerns due to the presence of a permanent pool of water in the second chamber; consult with local vector agency. • More appropriate in flat to gently rolling terrain • Locate outside the Clear Recovery Zone (HDM Topic 309.1), or consult with Traffic Operations to determine if guard railing is required	• Maintenance vehicle access to all chambers is required for inspection, periodic maintenance, and cleanout • Maximum depth to invert of second chamber of 13 ft below ground surface; verify that Maintenance can access invert at this depth. • Bypass overflow: offline placement of MCTTs is preferred, but the device should also have a separate overflow spillway, overflow riser or outlet pipe for events larger than the WQV, even if upstream diversion is provided; the overflow should be capable of passing the HDM design event (see Section B.1.3.1) • The second chamber employs an outlet orifice or weir to pass the runoff to the third chamber • Minimum of 100% WQV combined capacity for all chambers • Third chamber should be sized to pass a minimum of 75% to 100% of the WQV within a drain time of 24 to 48 hours • Third chamber filter media: 50% sand and 50% peat moss; for the sand: use Caltrans Standard Specification 90-3.03 for fine aggregate; Gravel: use Caltrans Standard Specification 68-1.025, Permeable Material, Class 1, Type B; Filter Fabric: Standard Specification Section 88-1.03, • Collector pipes: minimum 6 inches diameter laterals, and minimum 8 inches diameter collector pipe

B.10 WET BASIN

B.10.1 Description

Wet Basins are detention systems comprised of a permanent pool of water, a temporary storage volume above the permanent pool, and a shoreline zone planted with aquatic vegetation. Wet Basins are placed in locations where naturally occurring wetlands do not exist. Wet Basins are designed to remove pollutants from surface discharges by temporarily capturing and detaining the Water Quality Volume (WQV) in order to allow settling and biological uptake to occur. Wet Basins are effective in removing sediments, nutrients, particulate metals, pathogens, litter, and BOD from stormwater runoff. A schematic of a Wet Basin is shown in Figure B-20.

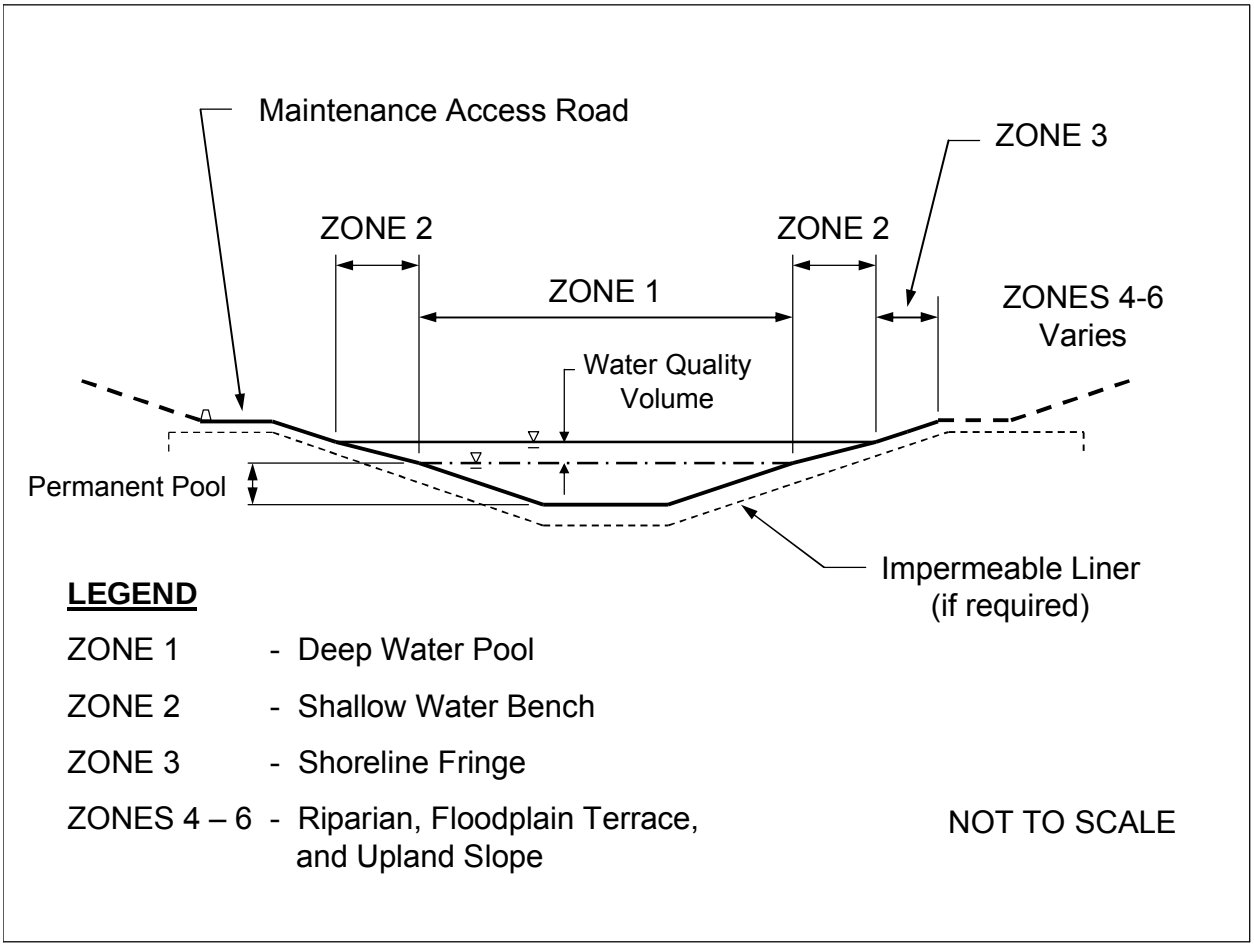


Figure B-20: Schematic of a Wet Basin

As indicated above, a Wet Basin has temporary storage capacity above the permanent pool for the Water Quality Volume. The WQV enters the Wet Basin and commingles with the permanent pool, during which time the water level in the basin rises to inundate the surrounding vegetation during a WQ event. The commingled water is slowly discharged through a water quality riser until the water level returns to the level of the permanent pool. To accommodate storms larger than the WQV design event, an upstream bypass should be considered. Regardless of whether

an upstream bypass is incorporated into the design, an overflow spillway or riser should be provided. If the overflow riser is a component of the water quality riser, an overflow spillway also should be considered to provide additional safety in the event of failure of the overflow riser.

The level of the permanent pool must be maintained year-round to support the plant community in the Wet Basin; this water level is maintained by connecting the Wet Basin to a stream channel, by seepage from springs, or by water from some other source. In arid climates, it can be difficult to maintain the proper level of the permanent pool using natural sources, and augmentation may be required. If 'gray water' is available nearby (gray water is water sold for non-potable use by a wastewater treatment facility, after receiving secondary or tertiary treatment), it could serve as a permanent source of water, but the use of potable water for the permanent pool is considered inappropriate in almost all situations due to its scarcity. As some infiltration might also occur, even for soils with a low infiltration rate, approval from the RWQCB must be obtained if gray water will be considered.

Within the permanent pool, emergent plants provide biological processes that aid in reducing the amount of soluble nutrients and for some dissolved metals; however, the permanent pool of water should also have deeper zones to limit the growth of hydrophytic vegetation within the Wet Basin and also to reduce the plan view of the basin. Specific plant species suitable for inundated conditions are used in the Wet Basin (see the Hydrologic Conditions for Vegetation below).

Wet Basins have the potential to attract and harbor sensitive or endangered species, which may prevent the maintenance activities needed to maintain the proper functioning of the basins and for vector control. Because of the potential for endangered/sensitive species establishment, the Department is required to contact the appropriate state and federal regulatory agencies early in the design phase to discuss the proposed location of every Wet Basin.

Design of a Wet Basin must be coordinated through the Headquarters Division of Environmental Analysis – Policy, Planning and Permitting, and Headquarters Design – Office of Storm Water Management.

B.10.2 Appropriate Applications and Siting Criteria

For Wet Basins to be considered, the design Water Quality Volume must exceed 4,356 ft^3 (0.1 acre-foot [a-f]). The site under consideration for a Wet Basin should if possible be located where the visual aesthetics of the permanent pool is considered a benefit (such as a roadside rest area or vista point).

The proposed site must have a source of water to provide base flow sufficient to maintain a year-round plant community to account for losses due to infiltration and evapo-transpiration. The soil immediately below the invert must be relatively impermeable to limit loss of water by infiltration (NRCS Hydrologic Soils Group [HSG] soils C and D) unless a liner is used. Separation between seasonally high groundwater and basin invert should be > 10 ft; use liner if separation is between 1.0 ft and 10 ft unless approved by the local RWQCB due to presence of low permeability soils [Hydrologic Soil Groups C or D]).

The permanent pool volume should be at least 3x the Water Quality Volume, and additional temporary storage capacity greater than or equal to the Water Quality Volume, giving a minimum total volume of 4x the WQV below the spillway elevation. Consult public health and vector control authorities; mosquito fish may be required in the Wet Basin. [12]

Conditions that do not allow for siting are: a site having hazardous soils or a contaminated groundwater plumes; objectionable backwater conditions in the storm drain system being induced; placement on or near unstable slopes, or slopes steeper than 15 percent.

Note also that if the impounded volume exceeds 15 a-f then the Wet Basin may classify as a jurisdictional dam and be subject to other requirements; consult with District Hydraulics if the volume below the spillway exceeds this threshold.

The maximum width is suggested as 49 ft, although if the width is greater than 23 ft, access to both sides of the Wet Basin may be required; consult with the local vector agency and District Maintenance regarding accessibility requirements around the Wet Basin. A Wet Basin with maintenance access is shown in Figure B-21.



Figure B-21: Wet Basin in District 11

B.10.3 Preliminary Design Factors

The Wet Basin must employ an impermeable liner below the invert if placed in NRCS HSG A and B soils. Flow should enter the Wet Basin at low velocity, or scour protection should be provided at inflow. Outfalls and spillways should also be provided with scour protection as necessary. Maintenance access around basin and paved or unpaved ramp to basin invert must be provided.

[12] The biological agent most commonly used to control mosquitoes is the mosquito fish, *Gambusia affinis*. Mosquito fish are most effective in wet basins that have a depth of 4 to 12 ft and limited shallow shoreline (less than 30 percent of surface area); their effectiveness as a mosquito control agent declines greatly as the density of vegetation increases.

An upstream diversion channel or pipe for storms generating runoff volumes greater than the WQV should be implemented if possible. The Wet Basin should have an upstream forebay to capture coarse sediment and litter if possible having a volume of 10 to 25% of the WQV.

Within the Wet Basin, a flow-path-to-width ratio of at least 2:1 configured in an irregular or meandering configuration is preferred. The invert of the Wet Basin may employ a 'micro topography' (contouring and benching of the invert to vary the water depth); care should be exercised to minimize stagnant areas (areas where incoming water does not displace or commingle with permanent pool). The basin may also be configured to fit the surrounding topography.

For the ground above the WQV elevation: use 1:4 (V:H) side slope ratios or flatter for a minimum 16 ft horizontally, with 1:3 (V:H) side slopes maximum if approved by Maintenance. Below the WQV and the permanent pool elevation, the side slope ratios should be no steeper than 1:3 (V:H), with 1:4 (V:H) preferred along the entire shoreline. Within the Wet Basin, average water depth should be approximately 4.0 to 6.5 ft, and typical maximum depth usually between 8.0 and 10 ft. Usually the shallow area temporarily holding the WQV is limited to between 15 and 30% of the surface water area of the Wet Basin.

The outlet used to discharge the WQV is designed to complete the drawdown within 24 to 72 hrs, but typically within 24 to 48 hrs. The WQ outlet should employ a debris screen (or equivalent) and riser similar to that shown in Figure B-7 on page B-31. The orifice sizes for a WQ outlet using a perforated riser may be calculated using Equation 8, page B-32, taking the ($H-H_o$) term as equal to the height of the WQV above the permanent pool.

While the WQ outlet is designed to discharge the WQV, additionally either the WQ outlet or a separate outlet device must pass the flows generated by a design storm. If a separate outlet device is used, the outlet for an overflow event may be in the form of a weir or a pipe riser having a minimum nominal diameter of 36 in., or larger if District practice, designed using methods found in standard hydraulics references.

The Wet Basin should have a Water Quality freeboard $\geq$ 12 in, where freeboard is defined as the distance between the elevation at the top of the containment forming the basin and the water surface elevation during an overflow event (the Highway Design Manual event as discussed in Section B.1.3.1); note that when runoff from a storm event is passed through the Wet Basin, it is assumed that the initial water surface elevation in the Wet Basin is the Water Quality elevation (i.e. the elevation of the water surface at the top of the temporary pool).

Finally, some local jurisdictions may have more stringent requirements, and these should be consulted.

A drain for maintenance purposes should be placed if possible in a Wet Basin, or a defined sump area constructed for pumping during major maintenance. Consider fencing around the Wet Basin to restrict public access.

The design for the Wet Basin must provide appropriate vegetation for each hydrologic zone. Native soils at invert may require added organics.

Preliminary design factors are shown in Table B-11.

Table B-11: Summary of Wet Basin Siting and Design Criteria

Description	Applications/Siting	Preliminary Design Factors
• Impoundments where the WQV is temporarily detained in a permanent pool. Treatment Mechanisms: • Sedimentation/filtration • Adsorption to soil particles and by vegetation for certain contaminants Pollutants removed: • Total Suspended Solids • Nutrients* • Particulate Metals • Pathogens • Litter • BOD * Reductions observed for dry weather flow only. [End of this column]	• Minimum WQV > 4,356 ft^3 (0.1 a-f) • Volume of water in temporary pool > WQV • Volume of water in permanent pool > 3x WQV • Should if possible be located where the visual aesthetics of the permanent pool is considered a benefit (such as a roadside rest area or vista point). • Permanent source of water must be available, and sufficient for all losses including infiltration and evapo-transpiration • Do not consider for sites with hazardous soils or contaminated groundwater plumes • Sufficient head to prevent objectionable backwater condition in the storm drain system • Preferred maximum width 49 ft; consult with the local vector agency and District Maintenance regarding accessibility requirements around the Wet Basin. • Consult public health and vector control authorities; mosquito fish may be required in the permanent pool of the Wet Basin • If the impounded volume exceeds 15 a-f consult with District Hydraulics to determine if the basin would classify as a jurisdictional dam • Not appropriate on or near unstable slopes, best sited in flat or gentle terrain of up to 15% slopes [This column continues on next page]	• NRCS HSG A and B soils at invert requires the use of an impermeable liner to maintain the permanent pool • Flows should enter at low velocities, otherwise use scour protection on inflow; protect outfall and spillway with scour protection as necessary. • Maintenance access around basin • Upstream diversion channel or pipe for storms > WQV if possible • Place if possible an upstream forebay for sediment and litter, with a volume of 10 to 25% WQV • Flow-path-to-width ratio of 2:1 if possible, configured in an irregular or meandering configuration • The invert may employ a 'micro topography' (contouring and benching of the invert to vary the water depth); care should be exercised to minimize stagnant areas (areas where incoming water does not displace or commingle with permanent pool) • Use 1:4 (V:H) side slope ratios or flatter for area above the WQV for a minimum 16 ft horizontally; 1:3 (V:H) side slopes max. above this area if approved by Maintenance • Internal (below the permanent pool) side slope ratio: no steeper than 1:3 (V:H), and 1:4 (V:H) in Zone 2. [This column continues on next page]

Table B-11: Summary of Wet Basin Siting and Design Criteria (cont.)

Applications/Siting	Preliminary Design Factors
• Separation between seasonally high groundwater and basin invert > 10 ft; use liner if separation 1.0 and 10 ft. • Wet Basins placed in cold climates will have reduced effectiveness • Locate outside the Clear Recovery Zone (HDM Topic 309.1), or consult with Traffic Operations to determine if guard railing is required	• Average water depth should be approximately 4.0 to 6.5 ft, and typical maximum depth usually between 8.0 and 10.0 ft. • A deeper permanent pool is preferred to a shallower one, in order to reduce the area from which emergent vegetation (rooted below the water surface) can grow. • Usually the shallow (vegetated) areas are limited to between 15 and 30% of surface water area. • Outlet design to drawdown the WQV within 24 to 72 hrs, typically 24 to 48 hrs • Downstream spillway or overflow riser: sized to pass flows generated by the peak drainage facility design event (reference HDM Chapter 830); minimum spillway length of 3.0 ft, and/or minimum riser diameter of 36 in., or per District practice. Use local criteria for overflow passage if more stringent. • Provide Water Quality freeboard ≥ 12 in (distance between the elevation of water in the basin when passing the design storm, and the elevation at the top of the confinement) • Discharge the WQV through an outlet riser and include a debris screen (or equivalent) • An 8 inch drain valve should be placed to evacuate water during major maintenance • Provide vegetation appropriate for each hydrologic zone in the Wet Basin • Native soils at invert may require added organics • Consider fencing around the Wet Basin to restrict public access

B.10.4 Hydrologic Conditions for Vegetation

Wet Basins may have up to six specific hydrologic zones, as described in Table B-12. Local or native plant species should be used in all zones of the Wet Basin, if possible. Typically five to seven species of emergent wetland plants are used in the permanent pool. Large woody plants should not be allowed to be established in Zones 1, 2, or 3 of the Wet Basin. The District Office of Landscape Architecture should be consulted early in the design process to consider overall shape of the Wet Basin and plant materials for each hydrologic zone, if the design of the Wet Basin will be produced by the District. See also Caltrans *Technical Memorandum: Constructed Wetland Siting Study*, CTSW-TM-01-013, December 2001, page 5-10, for a list of native plants suitable for the shallow zones of Wet Basins (prepared for Caltrans Division of Environmental Analysis).

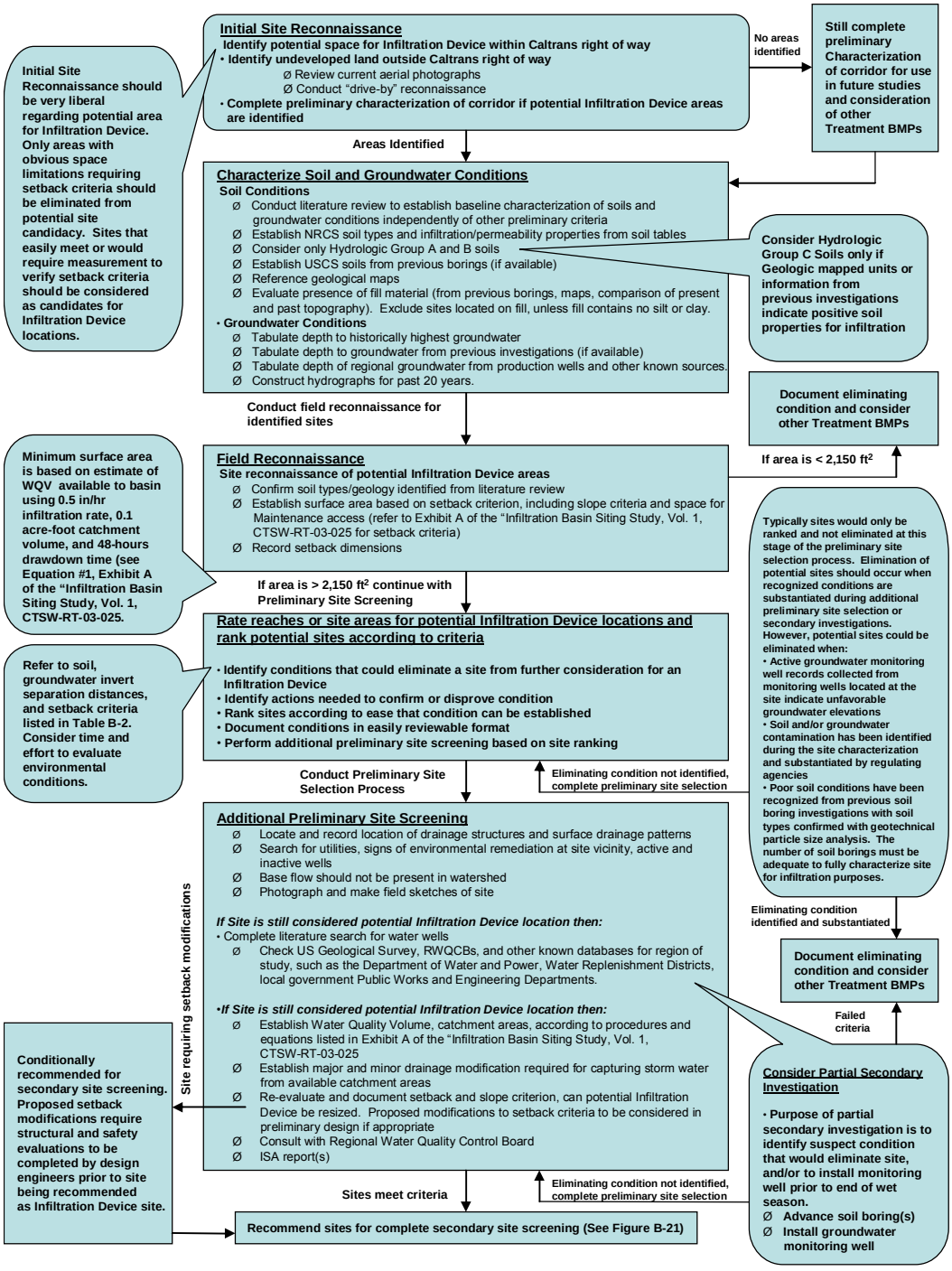
Table B-12: Wet Basin Hydrologic Zones

Zone number	Description and Topography	Hydrologic Condition and Water Depths Between Storm Events
1	Deep water pool (permanent pool): usually accounts for 70% to 85% of the total surface area at the WQV elevation (See Note 1), with a generally flat invert bordered by side slopes up to 1:3 (V:H) where adjoining Zone 2	Permanently inundated. Usually 6.0 to 10.0 ft depth at invert; little or no plant growth in this zone, especially below a depth of 6.0 ft, except for emergent vegetation on the side slopes
2	Shallow water bench (holds the WQV): usually between 15 to 30% of the total surface area at the WQV elevation; side slopes of 1:4 (V:H) preferred, but up to 1:3 (V:H) allowed if approved by maintenance	Portions will be inundated (up to the WQV elevation) during every rainfall event; depth usually between 0.75 and 1.5 ft (varies with design of the Wet Basin). Vegetation able to survive frequent inundation and saturated or nearly saturated soil condition
3	Shoreline fringe (up to the top of the Water Quality Freeboard): side slopes of 1:4 (V:H) preferred, but up to 1:3 (V:H) allowed if approved by maintenance	Occasionally inundated by overflow events (frequency is difficult to quantify, but potentially several times per year); vegetation able to survive occasional inundation and nearly saturated soil conditions in this zone (depending upon soil conditions)
4	Riparian fringe: no set side slopes or distance from preceding zones (see Note 2)	Only inundated during major events; vegetation selection much less influenced by presence of permanent and temporary pool of water
5	Floodplain Terrace: no set side slopes or distance from preceding zones (see Notes 2 and 3)	Only inundated during extreme events; vegetation selection much less influenced by presence of permanent and temporary pool of water.
6	Upland slopes: no set side slopes or distance from preceding zones (see Note 2)	Rarely or never inundated; vegetation selection much less influenced by presence of permanent and temporary pool of water.

Note 1: Surface area is defined as the area below the elevation of Zone 2.
Note 2: Zones 4, 5 and 6 may be omitted depending upon the site-specific design of the Wet Basin.
Note 3: Zone 5 will usually not be part of the typical Caltrans design (with overflow events handled in Zone 3).

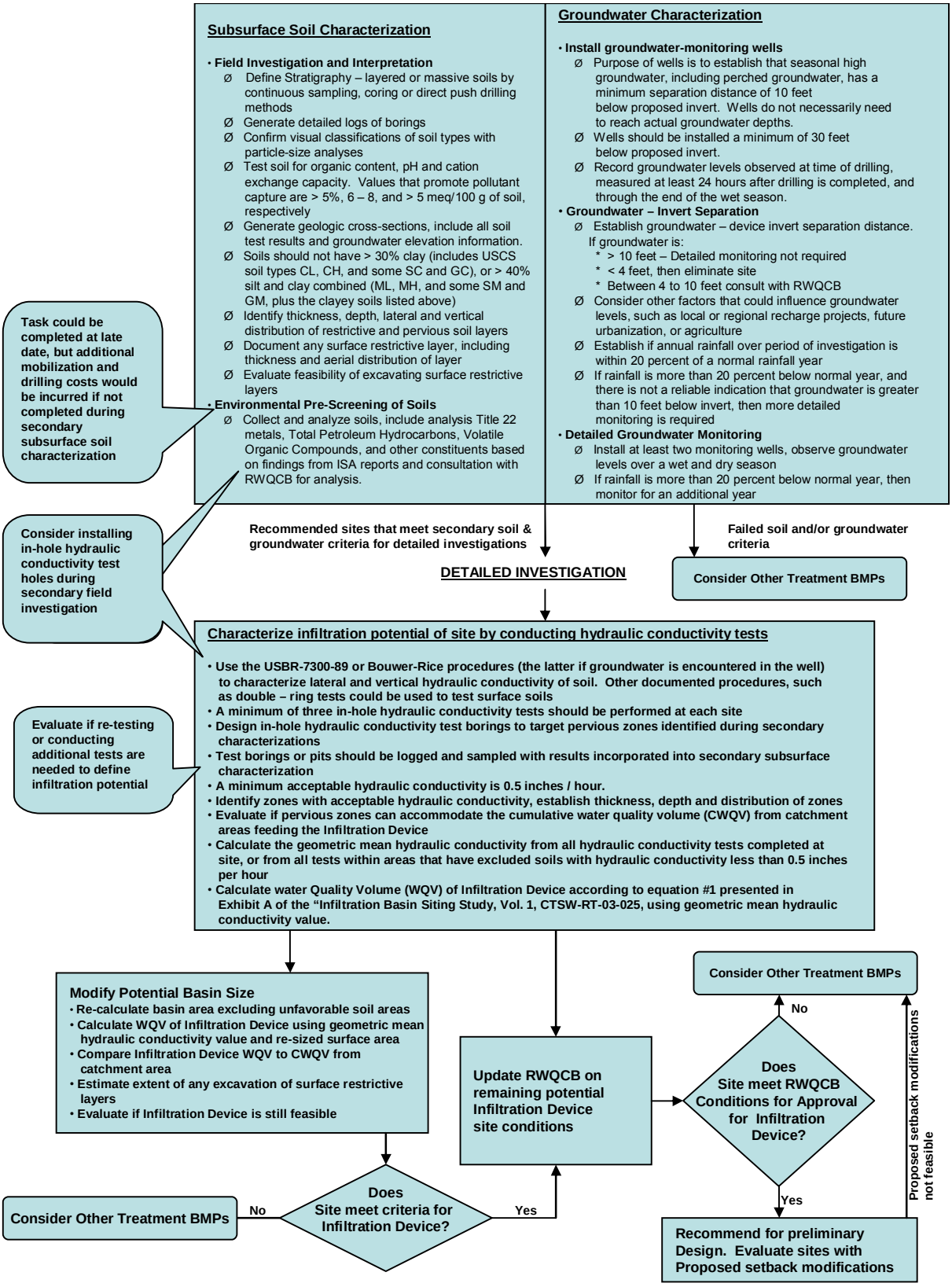
Figure B-22: District 7 Infiltration Device Site Selection Logic Tree (Initial Site Screening)

See Footnote [13]



[13] Figure B-22 from this handbook is taken from the "Infiltration Basin Siting Study, Vol. 1," CTSW-RT-03-025, Caltrans, June 2003, Figure 32. Available online: http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/new_technology/CTSW-RT-03-025/figures/FR_IFB_Figure_32.pdf

Figure B-23: District 7 Infiltration Device Site Selection (Secondary Site Screening)



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Appendix C
Approved Construction Site BMPs

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C.1 CONSTRUCTION SITE BEST MANAGEMENT PRACTICES (BMPS)

Construction Site Best Management Practices (BMPs) are applied during construction activities to reduce the pollutants in stormwater discharges throughout construction. These Construction Site BMPs provide both temporary erosion and sediment control, as well as control for potential pollutants other than sediment. There are six categories of BMPs suitable for controlling potential pollutants on construction sites. They are:

- Soil Stabilization Practices;
- Sediment Control Practices;
- Tracking Control Practices;
- Wind Erosion Control;
- Non-Stormwater Controls; and
- Waste Management and Material Pollution Controls.

It is generally accepted that practices that perform well by themselves can be complemented by other practices to raise the collective level of erosion control effectiveness and sediment retention. Effective erosion and sediment control planning relies on a system of BMPs (e.g., mulches for source control, fiber rolls on slopes for reducing runoff velocities, silt fence at the toe of slopes for capturing sediment, etc.).

To meet regulatory requirements and protect the site resources, every project must include an effective combination of erosion and sediment control measures. These measures must be selected from all of the BMP categories presented in this section: soil stabilization practices, sediment control practices, tracking control practices, and wind erosion control practices. Additionally, the project plan must include non-stormwater controls, waste management and material pollution controls.

Table C-1 is a matrix of the Construction Site BMPs that have been approved for use during construction. Detailed descriptions and guidance regarding implementation of these BMPs may be found in the Construction Site Best Management Practices Manual and Section 4 of the Statewide Storm Water Quality Practice Guidelines (Guidelines).

The individual BMPs, designated by an “X” in Table C-1 as being applicable to a particular typical construction activity, will not necessarily be appropriate for all projects involving the noted activity. For example, not all projects will have on-site vehicle fueling and maintenance operations; however, those that do will be required to conduct those operations in a manner consistent with the intent of the BMP description contained in Appendix B of the Storm Water Management Plan (SWMP) and BMP implementation detailed in the Guidelines.

Table C-1 shows the Construction Site BMPs by construction activity.

Table C-1: Construction Site BMPS By Construction Activity

	Typical Highway Construction Activities																											
	Demolish Pavement/Structures	Clear and Grub	Construct Access Roads	Grading (inc. cut and fill slopes)	Channel Excavation	Channel Paving	Trenching/ Underground Drainage	Underground Drainage Facility Installation	Drainage Inlet Modification	Utility Trenching	Utility Installation	Subgrade Preparation	Base Paving	AC Paving	Concrete Paving	Saw Cutting	Joint Sealing	Grind/Groove	Structure Excavation	Erect Falsework	Bridge/Structure Construction	Remove Falsework	Striping	Miscellaneous Concrete Work	Sound Walls/Retaining Walls	Planting and Irrigation	Contractor Activities	Treatment BMP Construction
Best Management Practices																												
Temporary Sediment Control																												
Silt Fence	X	X	X	X	X		X			X		X							X		X					X		X
Sandbag Barrier	X	X	X	X	X		X			X		X							X		X					X		X
Straw Bale Barrier	X	X	X	X	X		X			X		X							X		X					X		X
Fiber Rolls	X	X	X	X	X		X			X											X					X		X
Gravel Bag Berm	X	X	X	X	X		X			X											X					X		X
Check Dam	X	X		X	X		X																					X
Desilting Basin	X	X	X	X	X																X					X		X
Sediment Trap	X	X	X	X	X		X			X		X							X		X					X		X
Sediment Basin		X		X	X																X					X		X
Temporary Soil Stabilization																												
Hydraulic Mulch	X	X		X	X																X					X		X
Hydroseeding	X	X		X	X																X					X		X
Soil Binders	X	X		X	X														X		X					X		X
Straw Mulch	X	X	X	X	X		X	X		X		X							X		X					X		X
Geotextiles, Mats/Plastic Covers and Erosion Control Blankets	X	X	X	X	X		X	X		X		X							X		X					X		X
Scheduling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X
Preservation of Existing Vegetation		X	X	X			X	X		X									X	X		X			X			
Temporary Concentrated Flow Conveyance Controls																												

Table C-1: Construction Site BMPS By Construction Activity

	Typical Highway Construction Activities																											
	Demolish Pavement/Structures	Clear and Grub	Construct Access Roads	Grading (inc. cut and fill slopes)	Channel Excavation	Channel Paving	Trenching/ Underground Drainage	Underground Drainage Facility Installation	Drainage Inlet Modification	Utility Trenching	Utility Installation	Subgrade Preparation	Base Paving	AC Paving	Concrete Paving	Saw Cutting	Joint Sealing	Grind/Groove	Structure Excavation	Erect Falsework	Bridge/Structure Construction	Remove Falsework	Striping	Miscellaneous Concrete Work	Sound Walls/Retaining Walls	Planting and Irrigation	Contractor Activities	Treatment BMP Construction
Best Management Practices (Cont'd)																												
Earth Dikes/Drainage Swales & Lined Ditches		X	X	X																	X							
Outlet Protection/Velocity Dissipation Devices		X	X	X																	X							
Slope Drains				X																	X							
Temporary Stream Crossing			X				X	X		X	X									X	X	X		X				
Clear Water Diversion	X		X		X	X														X	X	X			X			X
Wind Erosion Control		X	X	X	X		X			X		X	X	X	X												X		X
Sediment Tracking Control	X	X	X	X	X		X	X		X	X	X	X	X	X	X		X	X		X				X	X	X	X	X
Street Sweeping and Vacuuming	X	X	X	X	X		X	X		X	X	X	X	X	X	X		X	X		X				X	X	X	X	X
Stabilized Construction Roadway		X	X	X																								
Entrance/Outlet Tire Wash		X	X	X																						X	X	
Waste Management																												
Spill Prevention and Control	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Solid Waste Management	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hazardous Waste Management	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Contaminated Soil Management	X	X		X			X	X		X	X									X								
Concrete Waste Management	X		X			X		X			X		X		X	X		X	X		X				X	X	X	X
Sanitary/Septic Waste Management	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table C-1: Construction Site BMPS By Construction Activity

	Typical Highway Construction Activities																											
	Demolish Pavement/Structures	Clear and Grub	Construct Access Roads	Grading (inc. cut and fill slopes)	Channel Excavation	Channel Paving	Trenching/ Underground Drainage	Underground Drainage Facility Installation	Drainage Inlet Modification	Utility Trenching	Utility Installation	Subgrade Preparation	Base Paving	AC Paving	Concrete Paving	Saw Cutting	Joint Sealing	Grind/Groove	Structure Excavation	Erect Falsework	Bridge/Structure Construction	Remove Falsework	Striping	Miscellaneous Concrete Work	Sound Walls/Retaining Walls	Planting and Irrigation	Contractor Activities	Treatment BMP Construction
Best Management Practices (Cont'd)																												
Liquid Waste Management														X		X	X		X		X		X				X	X
Materials Handling																												
Material Delivery, and Storage	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Material Use	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vehicle and Equipment Operations																												
Vehicle and Equipment Cleaning	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vehicle and Equipment Fueling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vehicle and Equipment Maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Paving Operations			X			X			X				X	X	X	X	X	X			X							
Stockpile Management	X		X					X		X	X		X	X	X			X										
Water Conservation Practices	X	X	X	X	X	X	X	X	X	X		X				X	X	X	X		X			X		X	X	X
Potable Water/Irrigation																												
Dewatering Operations	X			X	X	X	X	X	X	X	X								X		X			X	X	X		X
Illicit Connection/Illegal Discharge Detection and Reporting	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Storm Drain Inlet Protection	X	X	X	X	X		X	X	X	X		X	X			X	X	X	X								X	X
Stabilized Construction Entrance/Exit		X	X	X																						X		X

X BMP may be applicable to activity

C.1.1 Soil Stabilization BMPs

Examples of Soil Stabilization BMPs include:

- SS-1 Scheduling;
- SS-2 Preservation of Existing Vegetation;
- SS-3 Hydraulic Mulch;
- SS-4 Hydroseeding;
- SS-5 Soil Binders;
- SS-6 Straw Mulch;
- SS-7 Geotextiles, Plastic Covers and Erosion Control Blankets;
- SS-8 Wood Mulching;
- SS-9 Earth Dikes/Drainage Swales and Ditches;
- SS-10 Outlet Protection/Velocity Dissipation Devices; and
- SS-11 Slope Drains.
- SS-12 Streambank Stabilization

Provided in Table C-2 are selection criteria information and ratings for temporary soil stabilization BMPs. The BMPs are described in detail following Table C-2.

Table C-2: Temporary Soil Stabilization Criteria Matrix

CLASS	TYPE	TEMPORARY SOIL STABILIZATION CONTROL CRITERIA													
		Antecedent Moisture	Availability	Ease of Clean-Up	Installed Cost Per Acre	EC Effectiveness (%)	Degradability	Length of Drying Time (hrs)	Time to Effectiveness (days)	Longevity	Mode of Application	Residual Impact	Native	Runoff Effect	Water Quality Impact
CATEGORY: STANDARD BIODEGRADABLE MULCHES (SBM)															
Straw Mulch	Wheat Straw	D	S	H	$12,844	90-95	B	0	1	M	L/M	M		+	M
	Rice Straw	D	S	H	$12,844	90-95	B	0	1	M	L/M	M		+	L
Wood Fiber Mulch	Wood Fiber	D	S	H	$5,434	50-60	B	0-4	1	M	H	L		+	M
Recycled Paper Mulch	Cellulose Fiber	D	S	H	$5,187	50-60	B	0-4	1	S	H	L		+	L
Bonded Fiber Matrix	Biodegradable	D	S	H	$33,592	90-95	B	12-18	1	M	H	M		+	H
CATEGORY: ROLLED EROSION CONTROL PRODUCTS (RECP)															
Biodegradable	Jute Mesh	D	S	H	$39,520	65-70	B		1	M	L	M		+	UNK
	Curled Wood Fiber	D	S	H	$64,220	85-90	P/B		1	M	L	M		+	L
	Straw	D	S	H	$54,340	85-90	P/B		1	M	L	M		+	H
	Wood Fiber	D	S	H	$54,340	85-90	P/B		1	M	L	M		+	L
	Coconut Fiber	D	S	H	$79,040	90-95	P/B		1	L	L	M		+	L
	Coconut Fiber Mesh	D	S	H	$190,190	85-90	B		1	L	L	M		+	UNK
	Straw Coconut Fiber	D	S	H	$66,690	90-95	P/B		1	L	L	M		+	M
Non-Biodegradable	Plastic Netting	D	M	H	$12,350	<50	P		1	L	L	H		+	UNK
	Plastic Mesh	D	M	H	$19,760	75-80	P		1	L	L	H		+	UNK
	Synthetic Fiber with Netting	D	M	H	$212,420	90-95	P		1	L	L	H		+	UNK
	Bonded Synthetic Fibers	D	M	H	$298,870	90-95	P		1	L	L	H		+	UNK
	Combination with Biodegradable	D	M	H	$195,130	85-90	P		1	L	L	H		+	UNK
CATEGORY: TEMPORARY SEEDING (TS)															
High-Density	Ornamentals		S-M	H	$2470 - $9880	50-60			28	M-L	H	L-M	N/E	+	UNK
	Turf species		S	H	$2,223	50-60			28	L	H	M-H	N/E	+	UNK
	Bunch grasses		S-M	H	$1853 - $7904	50-60			28	L	H	L-M	N	+	UNK
Fast-Growing	Annual		S	H	$2223 - $3952	50-60			28	L	H	L-H	N/E	+	UNK
	Perennial		S	H	$1976 - $4940	50-60			28	L	H	M	N/E	+	UNK
Non-Competing	Native		S-M	H	$1729 - $9880	50-60			28	L	H	L-M	N	+	UNK
	Non-Native		S-M	H	$2470 - $2964	50-60			28	L	H	L-H	E	+	UNK
Sterile	Cereal Grain		S	H	$2,964	50-60			28	L	H	L	E	+	UNK
CATEGORY: IMPERVIOUS COVERS (IC)															
Plastic	Rolled Plastic Sheeting		S		$41,990	100	P		1	M	L	H		-	UNK
	Geotextile (Woven)		S		$36,556	90-95	P		1	M	L	H		-	UNK
CATEGORY: HYDRAULIC SOIL STABILIZERS (HSS)															
(PBS) Plant Material Based- Short Lived	Guar	D	S	H	$2,470	80-85	B	12-18	Same as Length of	S	B	L		0/+	M/L
	Psyllium	P	S	H	$2,470	25-35	B	12-18		M	B	L		0	L/H
	Starches	D	S	H	$2,470	25-30	B	9-12		S	H	L		0	L
(PBL) Plant Material Based- Long Lived	Pitch/ Rosin Emulsion	D	S	M	$7,410	60-75	B	19-24		M	B	M		-	H
(PEB) Polymeric Emulsion Blends	Acrylic polymers and copolymers	D	S	M	$7,410	35-70	P/C	19-24		L	B	M		+/-	L/M
	Methacrylates and acrylates	D	M	M	$2,470	35-40	P/C	12-18		S	W	L		0/+	L
	Sodium acrylates and acrylamides	D	M	M	$2,470	20-70	P/C	12-18		S	H	L		+/-	L/M
	Polyacrylamide	D	M	M	$2,470	55-65	P/C	4-8		M	H	L		0/+	L
	Hydro-colloid polymers	D	M	H	$2,470	25-40	P/C	0-4		M	H	L		0/+	L/M
(PRB) Petroleum/ Resin-Based Emulsions	Emulsified Petroleum Resin	D	M	L	$7,410	10-50	P/C	0-4		M	B	M		0/-	H
(CBB) Cementitious Based Binders	Gypsum	D	S	M	$4,940	75-85	P/C	4-8		M	H	L		-	M/H

= not applicable for category, class or type

UNK = unknown

See next page for Legend

Table C-2: Temporary Soil Stabilization Criteria Matrix (continued)

Antecedent Moisture	**D** **P**	Soil should be relatively dry before application Soil should be pre-wetted before application
Availability	**S** **M**	A short turn-around time between order and delivery, usually 3-5 days A moderate turnaround time, between 1-2 weeks
Ease of Clean-Up	**L** **M** **H**	Require pressure washing, a strong alkali solution, or solvent to clean up Requires cleanup with water while wet; more difficult to clean up once dry May be easily removed from equipment and overspray areas by a strong stream of water
Installed Cost		Dollars per acre
Degradability	**C** **P** **B**	Chemically degradable Photodegradable Biodegradable
Length of Drying Time		Estimated hours
Time to Effectiveness		Estimated days
Erosion Control Effectiveness		Percent reduction in soil loss over bare soil condition.
Longevity	**S** **M** **L**	1 - 3 months 3 – 12 months > than 12 months
Application Mode	**L** **W** **H** **B** **M**	Applied by hand labor Applied by water truck Applied by hydraulic mulcher Applied by either water truck or hydraulic mulcher Applied by a mechanical method other than those listed above (e.g., straw blower)
Residual Impact	**L** **M** **H**	Projected to have a low impact on future construction activities Projected to have a moderate impact on future construction activities Projected to have a significant impact on future construction activities
Native	**N** **E**	Plant or plant material native to the State of California Exotic plant not native to the State of California
Runoff Effect	**+** **0** **-**	Runoff is decreased over baseline (bare soil) No change in runoff from baseline Runoff is increased over baseline
Water Quality Impact	**L** **M** **H**	Low potential to impact water quality Moderate potential to impact water quality Higher potential to impact water quality

C.1.1.1 Scheduling (SS-1)

This BMP involves developing, for every project, a schedule that includes sequencing of construction activities with the implementation of Construction Site BMPs such as temporary soil stabilization (erosion control) and temporary sediment control measures. The purpose is to reduce the amount and duration of soil exposed to erosion by wind, rain, runoff and vehicle tracking, and to perform the construction activities and control practices in accordance with the planned schedule.

C.1.1.2 Preservation of Existing Vegetation (SS-2)

Preservation of existing vegetation is the identification and protection of desirable vegetation that provides erosion and sediment control benefits. Whenever practical, existing vegetation should be preserved. Plants and trees act as effective soil stabilization and sediment control devices, particularly around the perimeter of construction sites. Areas that will not be disturbed as part of construction activities should be clearly marked on plans and protected in the field with fencing prior to clearing and grubbing. Access limitations should also be shown on the plans and described in the Special Provisions. Any damage to preservation areas should be repaired immediately.

Items to consider when preserving existing vegetation include:

- Preserve existing vegetation to provide effective erosion control;
- Consider the age, life expectancy, health, aesthetic value, and habitat benefits of vegetation to be preserved;
- Areas containing vegetation to be preserved must be shown on the plans; and
- Preserve native plants on the site wherever possible.

C.1.1.3 Hydraulic Mulch (SS-3)

Hydraulic mulch consists of applying a water-based mixture of wood or paper fiber and stabilizing emulsion with hydro-mulching equipment. This will protect disturbed soil from erosion by raindrop impact or wind. Specifications for mulch can be found in Caltrans Standard Specifications, Section 20-2.08.

Type: Wood Fiber

Wood fiber mulch is generally used as a component of hydraulic applications. It is usually used in combination with seed, fertilizer and other materials, and is typically applied at the rate of 2,010 to 4,020 pounds per acre (lb/acre).

Wood fiber mulch can be specified with or without a tackifier. Previous work has shown that wood fiber mulches with tackifiers have better erosion control performance.

Type: Recycled Paper

Recycled paper mulch is generally used in hydraulic applications. It is usually used in combination with seed and fertilizer and is typically applied at the rate of 2,010 to 4,020 lb/acre.

Type: Cellulose Fiber

Cellulose fiber mulch contains fibers of shorter length than wood fiber mulches and is typically made from recycled newsprint, magazine, or other waste paper sources. It can be specified with or without a tackifier.

Type: Bonded Fiber Matrix

A bonded fiber matrix (BFM) is a hydraulically applied system of fibers and adhesives that upon drying forms an erosion-resistant blanket that promotes vegetation, and prevents soil erosion. BFMs are typically applied at rates from 3,035 to 4,020 lb/acre based on the manufacturer's recommendation.

The biodegradable BFM is composed of materials that are 100% biodegradable. The binder in the BFM should also be biodegradable and should not dissolve or disperse upon re-wetting. Typically, biodegradable BFMs should not be applied immediately before, during or immediately after rainfall so that the matrix will have an opportunity to dry for 24 hours after application.

C.1.1.4 Hydro seeding (SS-4)

Hydro seeding consists of applying a water-based mixture of wood or paper fiber, stabilizing emulsion, and seed with hydro-mulching equipment. This is usually a multi-step process with a layer of straw and tackifier placed over the initial hydraulic application. Often fertilizer and compost are added to the hydraulic mixture. This will protect disturbed soil from erosion by raindrop impact or wind. Hydraulic mulches are typically combined with a seed mixture for achieving longer term temporary soil stabilization than by hydraulic mulching alone. The selection of plant materials to be included in the seed mixture can be based, in part, on the length of time temporary stabilization is required.

Temporary Erosion Control with perennial grasses, especially California native species, is not appropriate for Caltrans projects. The most effective method is to use straw and tackifier with cereal barley (45 lb/acre). Temporary seeding on construction projects should last one to two seasons before the grass is removed and the slopes re-graded.

If a follow-up planting project is to re-vegetate an area, it might be possible to seed with natives and perennials. The key here is that there will be another project. The seeding on the first project would not be temporary; it would be permanent, as it would continue beyond project completion.

C.1.1.5 Soil Binders (SS-5)

Soil binders, also known as soil stabilizers, are adhesives that stabilize soil by binding soil particles together. This will protect disturbed soil from erosion by raindrop impact or wind. Soil binders can also be used in combination with hydraulic mulches to improve their erosion control effectiveness.

There are five types of soil binders:

- Plant Material-Based (Short-Term);
- Plant Material-Based (Long-Term);
- Polymeric Emulsion Blends;
- Petroleum or Resin-Based Emulsions; and
- Cementitious-Based Binders.

Type: **Plant-Material Based (Short-Term)**

Guar

Guar is a non-toxic, biodegradable, natural galactomannan-based hydrocolloid treated with dispersent agents for easy field mixing. It should be applied at the rate of 10.0 to 15.0 lb per 1,000 gallons of water, depending on application machine capacity. Recommended minimum application rates are as follows:

Application Rates for Guar Soil Stabilizer

Slope (V:H):	Flat	1:4	1:3	1:2	1:1
lb/acre:	40	45	50	60	70

Psyllium

Psyllium is composed of the finely ground muciloid coating of plantago seeds that is applied as a dry powder or in a wet slurry to the surface of the soil. It dries to form a firm but re-wettable membrane that binds soil particles together but permits germination and growth of seed. Psyllium requires 12 to 18 hours drying time. Application rates are generally 80 to 200 lb/acre, with enough water in solution to allow for a uniform slurry flow.

Starch

Starch is non-ionic, cold-water soluble (pre-gelatinized) granular cornstarch. The material is mixed with water and applied at the rate of 150 lb/acre. Approximate drying time is 9 to 12 hours.

Type: **Plant-Material Based (Long-Term)**

Pitch and Rosin Emulsion

Generally, a non-ionic pitch and rosin emulsion has a minimum solids content of 48%. The rosin should be a minimum of 26% of the total solids content. The soil stabilizer should be non-corrosive, water-dilutable emulsion that upon application cures to a water insoluble binding and cementing agent. For soil erosion control applications, the emulsion is diluted as follows:

For clayey soil: 5 parts water to 1 part emulsion
For sandy soil: 10 parts water to 1 part emulsion

Application can be by water truck or hydraulic seeder with the emulsion/product mixture applied at the rate specified by the manufacturer.

Type: **Polymeric Emulsion Blends**

Acrylic Copolymers and Polymers

Polymeric soil stabilizers should consist of a liquid or solid polymer or copolymer with an acrylic base that contains a minimum of 55% solids. The polymeric compound should be handled and mixed in a manner that will not cause foaming or should contain an anti-foaming agent. The polymeric emulsion should have a minimum shelf life of one year. Polymeric soil stabilizer should be readily miscible in water, non-injurious to seed or animal life, non-flammable, should provide surface soil stabilization for various soil types without totally inhibiting water infiltration, and should not re-emulsify when cured. The applied compound should air cure within a maximum of 36 to 48 hours. Liquid copolymer should be diluted at a rate of 10 parts water to 1 part polymer and applied to soil at a rate of 1,175 gallons per acre.

Liquid Polymers of Methacrylates and Acrylates

This material consists of a tackifier/sealer that is a liquid polymer of methacrylates and acrylates. It is an aqueous 100% acrylic emulsion blend of 40% solids by volume that is free from styrene, acetate, vinyl, ethoxylated surfactants or silicates. For soil stabilization applications, it is diluted with water and applied with a hydraulic seeder at the rate of 20 gallons per acre. Drying time is 12 to 18 hours after application.

Copolymers of Sodium Acrylates and Acrylamides

These materials are non-toxic, dry powders that are copolymers of sodium acrylate and acrylamide. They are mixed with water and applied to the soil surface for erosion control at rates that are determined by slope gradient:

Slope Gradient (V:H)	lbs per acre
Flat to 1:5	3.0 – 5.0
1:5 to 1:3	5.0 – 10.0
1:2 to 1:1	10.0 – 20.0

Poly-Acrylamide and Copolymer of Acrylamide

Linear copolymer poly-acrylamide is packaged as a dry-flowable solid. When used as a stand-alone stabilizer, it is diluted at a rate of 10 lbs/1,000 gallons of water and applied at the rate of 5.0 lbs per acre.

Hydro-Colloid Polymers

Hydro-colloid polymers are various combinations of dry-flowable poly-acrylamides, copolymers and hydro-colloid polymers that are mixed with water and applied to the soil surface at rates of 54 to 62 lbs per acre. Drying times are 0 to 4 hours.

Type: **Petroleum or Resin-Based Emulsions**

Emulsified Petroleum Resin

This material is a concentrated petroleum hydrocarbon emulsion that is mixed with water and applied to the soil surface at a rate of 2,460 gallons per acre. Dilution rates vary with the type of soil and other site conditions, and should be provided by the manufacturer. They typically range from 12:1 to 20:1 parts water to emulsion.

Type: **Cementitious-Based Binders**

Gypsum

This is a formulated gypsum-based product that readily mixes with water and mulch to form a thin protective crust on the soil surface. It is composed of high purity gypsum that is ground, calcined and processed into calcium sulfate hemihydrate with a minimum purity of 86 percent. It is mixed in a hydraulic seeder and applied at rates 4,000 to 12,000 lbs per acre. Drying time is 4 to 8 hours.

Comparative testing of Hydraulic Soil Stabilizers has been conducted at the Caltrans/SDSU Soil Erosion Research Laboratory for application on two soil types, sandy clay and clayey sand ("Soil Stabilization for Temporary Slopes," URSGWC, October 1, 1999). Both erosion control effectiveness and water quality were evaluated for soil stabilizers representing the available classes and types.

C.1.1.6 Straw Mulch (SS-6)

Straw mulch consists of placing a uniform layer of straw and incorporating it into the soil with a studded roller, or anchoring it with a tackifier. Straw mulch is used for soil stabilization, as a temporary surface cover, on disturbed areas until soils can be prepared for re-vegetation. It is also used in combination with temporary and/or permanent seeding strategies to enhance plant establishment.

Loose straw is the most common mulch material used in conjunction with direct seeding of soil. Straw mulching is generally the second part of multi-step process where seed and fertilizer is first applied, then straw mulch applied as the second step. The final step of the process involves holding the loose straw in place by a) using netting, b) applying a liquid tackifier, or c) punching it into the soil by a process known as "crimping" or "incorporating."

Type: **Wheat or Rice Straw**

Straw can be hand applied or machine applied. The fiber length of the straw should be typically greater than 6 inches.

C.1.1.7 Geotextiles, Mats/Plastic Covers and Erosion Control Blankets (SS-7)

This BMP involves the placement of geotextiles, plastic covers, or erosion control blankets/mats to stabilize disturbed soil areas (DSAs) and protect soil from erosion by wind or water. These measures are typically used when DSAs are particularly difficult to stabilize, around Environmentally Sensitive Areas (ESAs), and as a temporary quick stopgap measure.

Type: Biodegradable Rolled Erosion Control Products

Biodegradable Rolled Erosion Control Products (RECPs) are typically composed of jute fibers, curled wood fibers, straw, coconut fiber, or a combination of these materials. For an RECP to be considered 100% biodegradable, the netting, sewing or adhesive system that holds the biodegradable mulch fibers together must also be biodegradable.

Jute Mesh

Jute is a natural fiber that is made into a yarn that is loosely woven into a biodegradable mesh. It is designed to be used in conjunction with vegetation and has longevity of approximately one year. The material is supplied in rolled strips, which should be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Curled Wood Fiber

Excelsior (curled wood fiber) blanket material should consist of machine produced mats of curled wood excelsior with 80% of the fiber 6 inches or longer. The excelsior blanket should be of consistent thickness. The wood fiber should be evenly distributed over the entire area of the blanket. The top surface of the blanket should be covered with a photodegradable extruded plastic mesh. The blanket should be smolder resistant without the use of chemical additives and shall be non-toxic and non-injurious to plant and animal life. Excelsior blanket should be furnished in rolled strips, a minimum of 48 inches wide, and should have an average weight of 0.1 lbs per square foot (lb/ft^2), ±10 percent, at the time of manufacture. Excelsior blankets should be secured in place with wire staples. Staples should be made of 0.12 inch steel wire and should be U-shaped with 7.9 inch legs and 2 inch crown.

Straw

Straw blanket should be machine-produced mats of straw with a lightweight biodegradable netting top layer. The straw should be attached to the netting with biodegradable thread or glue strips. The straw blanket should be of consistent thickness. The straw should be evenly distributed over the entire area of the blanket. The straw blanket should be furnished in rolled strips a minimum of 6.6 feet (ft) wide, a minimum of 82 ft long and a minimum of 0.055 lb/ft^2. Straw blankets should be secured in place with wire staples. Staples should be made of 0.12 inch steel wire and should be U-shaped with 7.9 inch legs and 2 inch crown.

Wood Fiber

Wood fiber blanket is composed of biodegradable fiber mulch with extruded plastic netting held together with adhesives. The material is designed to enhance revegetation. The material is furnished in rolled strips, which should be secured to the ground with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Coconut Fiber

The coconut fiber blanket should be machine-produced mats of 100% coconut fiber with biodegradable netting on the top and bottom. The coconut fiber should be attached to the netting with biodegradable thread or glue strips. The coconut fiber blanket should be of consistent thickness. The coconut fiber should be evenly distributed over the entire area of the blanket. The coconut fiber blanket should be furnished in rolled strips with a minimum of 6.6 ft wide, a minimum of 82 ft long and a minimum of 0.055 lb/ft^2. Coconut fiber blankets should be secured in place with wire staples. Staples should be made of 0.12 inch steel wire and should be U-shaped with 7.9 inch legs and 2 inch crown.

Coconut Fiber Mesh

Coconut fiber mesh is a thin permeable membrane made from coconut or corn fiber that is spun into a yarn and woven into a biodegradable mat. It is designed to be used in conjunction with vegetation and typically has longevity of several years. The material is supplied in rolled strips, which should be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Straw Coconut Fiber

The straw coconut fiber blanket should be machine-produced mats of 70% straw and 30% coconut fiber with a biodegradable netting top layer and a biodegradable bottom net. The straw and coconut fiber should be attached to the netting with biodegradable thread or glue strips. The straw coconut fiber blanket should be of consistent thickness. The straw and coconut fiber should be evenly distributed over the entire area of the blanket. The straw coconut fiber blanket should be furnished in rolled strips a minimum of 6.6 inch wide, a minimum of 82 ft long and a minimum of 0.055 lb/ft^2. Straw coconut fiber blankets should be secured in place with wire staples. Staples should be made of 0.12 inch steel wire and should be U-shaped with 7.9 inch legs and 2 inch crown.

Type: Non-Biodegradable Rolled Erosion Control Products

Non-biodegradable RECPs are typically composed of polypropylene, polyethylene, nylon or other synthetic fibers. In some cases, a combination of biodegradable and synthetic fibers is used to construct the RECP. Netting used to hold these fibers together is typically non-biodegradable as well.

Plastic Netting

Plastic netting is a lightweight biaxially-oriented netting designed for securing loose mulches like straw or paper to soil surfaces to establish vegetation. The netting is photodegradable. The netting is supplied in rolled strips, which should be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Plastic Mesh

Plastic mesh is an open-weave geotextile that is composed of an extruded synthetic fiber woven into a mesh with an opening size of less than 0.2 inches. It is used with re-vegetation or may be used to secure loose fiber such as straw to the ground. The material is supplied in rolled strips, which should be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Synthetic Fiber with Netting

Synthetic fiber with netting is a mat that is composed of durable synthetic fibers treated to resist chemicals and ultraviolet light. The mat is a dense, three-dimensional mesh of synthetic (typically polyolefin) fibers stitched between two polypropylene nets. The mats are designed to be vegetated and provide a permanent composite system of soil, roots, and geomatrix. The material is furnished in rolled strips, which should be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Bonded Synthetic Fibers

This type of product consists of a three-dimensional, geomatrix nylon (or other synthetic) matting. Typically it has more than 90% open area, which facilitates root growth. Its tough root-reinforcing system anchors vegetation and protects against hydraulic lift and shear forces created by high volume discharges. It can be installed over prepared soil, followed by seeding into the mat. Once vegetated, it becomes an invisible composite system of soil, roots, and geomatrix. The material is furnished in rolled strips that should be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Combination Synthetic and Biodegradable

Combination synthetic and biodegradable RECPs consist of biodegradable fibers, such as wood fiber or coconut fiber, with a heavy polypropylene net stitched to the top and a high-strength continuous-filament geomatrix or net stitched to the bottom. The material is designed to enhance re-vegetation. The material is furnished in rolled strips, which should be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Rolled Plastic Sheeting

Plastic sheeting should have a minimum thickness of 0.24 inch, and should be firmly held in place with sandbags or other weights placed no more than 9.8 ft apart. Seams are typically taped or weighted down their entire length, and there should be at least a 12 inches to 24 inches overlap of all seams. Edges should be embedded a minimum of 6 inches in native soil.

All sheeting should be inspected periodically after installation and after significant rainstorms to check for erosion and undermining. Any failures shall be repaired

immediately. If washout or breakages occurs, the material should be re-installed after repairing the damage to the slope.

Geotextile (Woven)

Woven geotextile material should be a woven polypropylene fabric with a minimum thickness of 0.6 inches, a minimum of 12ft wide and should have a minimum tensile strength of 150 lbs (warp) 80 lbs (fill) in conformance with the requirements in American Society of Testing and Materials (ASTM) Designation: D 4632. The permittivity of the fabric shall be approximately 0.07 sec^{-1} in conformance with the requirements in ASTM Designation: D 4491. The fabric should have an ultraviolet (UV) stability of 70% in conformance with the requirements in ASTM designation: D 4355. Geotextile blankets should be secured in place with wire staples or sandbags and by keying into tops of slopes and edges to prevent infiltration of surface waters under geotextile. Staples should be made of 0.12 inch steel wire and shall be U-shaped with 7.9 inch legs and 2 inch crown.

Geotextile (Non-Woven)

Non-woven geotextile shall be manufactured from polyester, nylon, or polypropylene material, or any combination thereof. The fabric shall be permeable, non-woven, shall not act as a wicking agent. The fabric shall weigh a minimum of 0.25 lbs per square yard (per ASTM Designation: D 3776), have a minimum grab tensile strength of 50 lbs in each direction (per ASTM Designation: D 4632), have a minimum elongation at break of 10% (per ASTM Designation: D 4632), have a minimum toughness of 2900 lbs (percent elongation x grab tensile strength), and a minimum permittivity of 0.5 sec^{-1} (per ASTM Designation: D 4491).

C.1.1.8 Wood Mulching (SS-8)

Wood mulching consists of applying shredded wood, bark, or green material. The primary function of wood mulching is to reduce erosion by protecting bare soil from raindrop impact and reducing runoff. Use is limited to slopes that are less than 1:3 (V:H) and depth of the mulch blanket is typically 3 – 4 inches. The material is typically spread by hand, although pneumatic methods are available. Wood mulching is primarily applicable for landscape projects.

C.1.1.9 Earth Dikes/Drainage Swales and Ditches (SS-9)

The primary function of earth dikes, drainage swales and ditches is to prevent erosion and reduce pollutant loading. They are structures that intercept, divert, and convey surface runoff in a controlled, non-erosive manner. Top, toe, and mid-slope diversion ditches, berms, dikes, and swales should be used to intercept runoff and direct it away from critical slopes without allowing it to reach the roadway.

Typically, mid-slope diversion ditches should have a cross-slope of at least 2%, and should be concrete or rock-lined. Top of slope diversions should be paved along cut slopes where the slope length above the cut is greater than 40 ft. Earthen diversion ditches, berms, dikes, and swales channelize flow and should be stabilized with vegetation or other materials to prevent erosion.

Alternatively, drop structures can be placed along the diversion to maintain a grade sufficiently mild to prevent erosive velocities, or a paved chute can be placed down the side of the fill before the accumulated runoff in the diversion is sufficient to cause erosive velocities.

Design guidelines include:

- Select design flow and safety factor based on careful evaluation of the risk due to erosion of the measure, over topping, flow backups, or wash out;
- Examine the site for run-on from off-site sources. These off-site flows should be diverted from the right-of-way;
- Select flow velocity limit of unlined conveyance systems based on soil types and drainage flow patterns for each project site. Establish a maximum flow velocity for using earth dikes and swales, above which a lined ditch must be used (see Highway Design Manual Table 862.2). Consider use of rip-rap, engineering fabric, vegetation or concrete lining;
- Consider outlet protection where localized scour is anticipated;
- Consider order of work provisions early in the construction process to effectively install and use the permanent ditches, berms, dikes, and swales; and
- A sediment-trapping device should be used in conjunction with conveyances where sediment-laden water is expected.

C.1.1.10 Outlet Protection/Velocity Dissipation Devices (SS-10)

Outlet protection/velocity dissipation devices are rock, riprap, or other materials placed at pipe outlets to reduce flow velocity and the energy of exiting stormwater flows and to prevent scour. They are used where localized scouring is anticipated, such as outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits, or channels. They are also used where lined channels or ditches discharge to unlined conveyances.

Appropriate applications include:

- Outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits, or channels;
- Outlets located at the bottom of mild to steep slopes;
- Discharge outlets that carry continuous flows of water;
- Outlets subject to short, intense flows of water, such as from flash floods; and
- Where lined conveyances discharge to unlined conveyances.

C.1.1.11 Slope Drains (SS-11)

A slope drain is a pipe used to intercept and direct surface runoff or groundwater into a stabilized watercourse, trapping device, or stabilized area. Slope drains are used with lined ditches to intercept and direct surface flow away from slope areas to protect cut or fill slopes.

Slope drains should be sized to convey large, infrequent storms down or around the slope (see the Highway Design Manual for additional information). Design the top and toe of slope diversion ditches/berms/dikes/swales to direct flow into the drain. Provide for outlet protection/velocity dissipation devices at the outlet of the drain, as needed.

C.1.1.12 Streambank Stabilization (SS-12)

Drainage systems including the stream channel, streambank, and associated riparian areas, are dynamic and sensitive ecosystems that respond to changes in land use activity. Streambank and channel disturbance resulting from construction activities can increase the stream's sediment load, which can cause channel erosion or sedimentation and have adverse effects on the biotic system. Best management practices can reduce the discharge of sediment and other pollutants and minimize the impact of construction activities on watercourses. Streams included on the 303(d) list by the State water Resources Control Board (SWRCB) may require careful evaluation to prevent any increases in sedimentation, siltation and/or turbidity to the stream.

C.1.2 Sediment Control Practices

Sediment control is required along the site perimeter at all operational internal inlets and at all times during the rainy season.

Sediment control devices function by:

- Slowing water velocities, thereby allowing soil particles to settle out; and
- Attenuating the flood peak by detaining flow and releasing water at a slower rate.

All sediment control devices require continued maintenance to function properly. Excess sediment not removed reduces capacity and efficiency.

Examples of sediment control practices include:

SC-1 Silt Fence
SC-2 Desilting Basin
SC-3 Sediment Trap
SC-4 Check Dam
SC-5 Fiber Rolls
SC-6 Gravel Bag Berm
SC-7 Street Sweeping and Vacuuming
SC-8 Sand Bag Barrier
SC-9 Straw Bale Barrier
SC-10 Storm Drain Inlet Protection

C.1.2.1 Silt Fence (SC-1)

A silt fence is a temporary linear sediment barrier of permeable fabric designed to intercept and slow the flow of sediment-laden sheet flow runoff. Silt fences allow sediment to settle from runoff before water leaves the construction site.

Silt fences are placed below the toe of exposed and erodible slopes, downslope of exposed soil areas, around temporary stockpiles and along streams and channels. Silt fences should not be used to divert flow or in streams, channels or anywhere flow is concentrated.

C.1.2.2 De-silting Basin (SC-2)

A de-silting basin is a temporary basin formed by excavation and/or constructing an embankment so that sediment-laden runoff is temporarily detained under quiescent conditions, allowing sediment to settle out before the runoff is discharged.

De-silting basins shall be considered for use:

- On construction projects with disturbed areas during the rainy season;
- Where sediment-laden water may enter the drainage system or water courses; and
- At outlets of disturbed soil areas between 5 acres and 10 acres.

C.1.2.3 Sediment Trap (SC-3)

A sediment trap is a temporary basin with a controlled release structure, formed by excavating or constructing an earthen embankment across a waterway or low drainage area. As a supplemental control, sediment traps provide additional protection for a water body or for reducing sediment before it enters a drainage system.

Sediment traps may be used on construction projects during the rainy season when the contributing drainage area is less than 5 acres. Traps would be placed where sediment laden stormwater may enter a storm drain or watercourse, and around and/or up-slope from storm drain inlet protection measures.

C.1.2.4 Check Dam (SC-4)

A check dam is a small device constructed of rock, sand bags, or fiber rolls, placed across a natural or man-made channel or drainage ditch. Check dams reduce scour and channel erosion by reducing flow velocity and encouraging sediment dropout.

Check dams may be installed:

- In small open channels that drain 10 acres or less;
- In steep channels where stormwater runoff velocities exceed 5 feet per second (ft/s);
- During the establishment of grass linings in drainage ditches or channels; and
- In temporary ditches where a short length of services does not warrant establishment of erosion-resistant linings.

C.1.2.5 Fiber Rolls (SC-5)

A fiber roll consists of straw, flax or other similar materials inserted into a tube of netting. Fiber rolls are placed on the face of slopes at regular intervals and/or at the toe of slopes to intercept runoff, reduce its flow velocity, release the runoff as sheet flow, and provide some removal of

sediment from the runoff. Fiber rolls may be used along the top, face and at grade breaks of exposed and erodible slopes to shorten slope length and spread runoff as sheet flow.

C.1.2.6 Gravel Bag Berm (SC-6)

A gravel bag berm consists of a single row of gravel bags that are installed end-to-end to form a barrier across a slope to intercept runoff, reduce runoff velocity, release runoff as sheet flow and provide some sediment removal. The gravel bag berm should be installed along a level contour with the bags tightly abutted.

C.1.2.7 Street Sweeping and Vacuuming (SC-7)

Street sweeping and vacuuming are practices to remove tracked soil particles from paved roads to prevent the sediment from entering a storm drain or watercourse. Street sweeping and vacuuming are implemented anywhere sediment is tracked from the project site onto public or private paved roads, typically at points of egress.

C.1.2.8 Sand Bag Barrier (SC-8)

A sand bag barrier is a temporary linear sediment barrier consisting of stacked sand bags, designed to intercept and slow the flow of sediment-laden sheet flow runoff. Sand bag barriers allow sediment to settle from runoff before water leaves the construction site.

Sand bags can also be used:

- Where flows are moderately concentrated to divert and/or detain flows;
- Along the perimeter of a site;
- Along streams and channels;
- Below the toe of exposed and erodible slopes; and
- Around stockpiles.

C.1.2.9 Straw Bale Barrier (SC-9)

A straw bale barrier is a temporary linear sediment barrier consisting of straw bales, designed to intercept and slow sediment-laden sheet flow runoff. Straw bale barriers allow sediment to settle from runoff before water leaves the construction site.

Typical applications for straw bale barriers include:

- Along the perimeter of a site;
- Along streams and channels;
- Below the toe of exposed and erodible slopes;
- Downslope of exposed soil areas; and
- Around stockpiles.

C.1.2.10 Storm Drain Inlet Protection (SC-10)

Storm drain inlet protection is a practice to reduce sediment from stormwater runoff discharging from the construction site prior to entering the storm drainage system. Effective storm drain inlet protection allows sediment to settle out of water or filters sediment from the water before it enters the drain inlet. Storm drain inlet protection is the last line of sediment control defense prior to stormwater leaving the construction site.

Storm drain inlet protection is used:

- Where ponding will not encroach into highway traffic;
- Where sediment-laden surface runoff may enter an inlet;
- Where disturbed drainage areas have not yet been permanently stabilized; and
- Where the drainage area is 1.0 acre or less.

C.1.3 Tracking Control Practices

Tracking control practices prevent or reduce off-site tracking of sediment by vehicles. Tracking is a common source of complaints, and can result the discharge of sediment to storm drains or watercourses. These measures include:

- TC-1 Stabilized Construction Entrance;
- TC-2 Stabilized Construction Roadway; and
- TC-3 Entrance/Outlet Tire Wash.

C.1.3.1 Stabilized Construction Entrance (TC-1)

A stabilized construction entrance is a designated point of access (ingress and egress) to a construction site that is stabilized to reduce tracking of sediment (mud and dirt) onto public roads by construction vehicles. Stabilized construction entrances are an effective method to limit the migration of sediment from the construction site, especially when combined with street sweeping and vacuuming. The stabilized entrance is typically composed of a crushed aggregate layer over a geotextile fabric or constructed of steel plates with ribs.

C.1.3.2 Stabilized Construction Roadway (TC-2)

A stabilized construction roadway is a temporary access road connecting existing public roads to a remote construction area. It is designed for the control of a dust and erosion created by vehicular traffic. A stabilized construction roadway may be constructed of aggregate, asphalt concrete, or concrete based on the desired longevity.

C.1.3.3 Entrance/Outlet Tire Wash (TC-3)

A tire wash is an area located at stabilized construction access points to remove sediment from tires and undercarriages, and to prevent tracking of sediment onto public roads. The tire wash typically includes a wash rack on a pad of coarse aggregate. The runoff water from the wash area must be conveyed to a sediment trap or basin.

C.1.4 Wind Erosion Control (WE-1)

Wind erosion control consists of applying water or other dust palliatives as necessary to prevent or alleviate wind-blown dust. Dust control must be applied in accordance with Caltrans standard practices. Water or dust palliatives should be applied so no runoff occurs.

The California General Construction Permit (General Permit) requires that special attention be paid to stockpiles. Stockpiles may be covered with plastic, mats, blankets, mulches, or sprayed with water or soil binders. It may also be prudent to surround the base of a stockpile with a row of fiber rolls, silt fence, or other sediment barrier.

Another means to reduce the potential for wind erosion of stockpiles is to keep the height of stockpiles low, and to adjust the shape and orientation of the stockpiles to reduce the area of exposure to the prevailing wind.

C.1.5 Non-Storm Water Controls

The National Pollutant Discharge Elimination System (NPDES) stormwater regulations for construction sites also require that BMPs be included in the project plans for control of non-stormwater discharges. Non-stormwater management measures are source controls that prevent pollution by limiting or reducing potential pollutants at their source before they come in contact with stormwater. These BMPs are also known as "good housekeeping practices." These BMPs must be in place throughout the grading and construction phases. The measures include:

NS-1 Water Conservation Practices

NS-2 Dewatering Operations

NS-3 Paving and Grinding Operations

NS-4 Temporary Stream Crossing

NS-5 Clear Water Diversion

NS-6 Illicit Connection/Illegal Discharge Detection and Reporting

NS-7 Potable Water/Irrigation

NS-8 Vehicle and Equipment Cleaning

NS-9 Vehicle and Equipment Fueling

NS-10 Vehicle and Equipment Maintenance

NS-11 Pile Driving Operations

NS-12 Concrete Curing

NS-13 Material and Equipment Use Over Water

NS-14 Concrete Finishing

NS-15 Structure Demolition/Removal Over or Adjacent to Water

During preparation of the project plans, it is not always possible to know where a contractor will be performing certain activities. To provide the contractor with flexibility, but to assure that proper control measures are implemented, it is appropriate to identify in the project plans that specific BMPs will be implemented for certain activities regardless of where on the site those activities are performed.

C.1.5.1 Water Conservation Practices (NS-1)

Water conservation practices are activities that use water during the construction of a project in a manner that avoids erosion caused by runoff and the transport of pollutants off the site. If less water is used, the potential for erosion decreases and the transport of construction-related pollutants off site is less likely. Water conservation practices must be implemented on all construction sites wherever water is used. It includes preventing water leaks, avoid vehicle washing on site, sweeping in lieu of hosing areas, and applying water for dust control to minimize runoff.

C.1.5.2 Dewatering Operations (NS-2)

This BMP is intended to prevent the discharge of pollutants from construction site dewatering operations associated with stormwater (accumulated rain) and non-stormwater (groundwater, water from a diversion or cofferdam, etc.). Dewatering effluent that is discharged from the construction site to a storm drain or receiving water is subject to the requirements of the applicable NPDES permit. Refer to the Caltrans Field Guide to Construction Site Dewatering for detailed guidance for management of dewatering operations. The District Storm Water Coordinator is also available for assistance.

C.1.5.3 Paving and Grinding Operations (NS-3)

Procedures that minimize pollution of stormwater runoff during paving operations include new paving and preparation of existing paved surfaces for overlays. Paving and grinding operations include handling materials, wastes and equipment associated with pavement removal, paving, surfacing, resurfacing, pavement preparation, thermoplastic striping and placing pavement markers.

C.1.5.4 Temporary Stream Crossing (NS-4)

A temporary stream crossing is a structure placed across a waterway that allows vehicles to cross the waterway during construction without contacting the water, thus reducing erosion and the transport of pollutants into the waterway. Temporary stream crossings are typically conditions of regulatory permits for work near live streams. Installation may require dewatering or temporary diversion of the stream. Types of temporary stream crossings include culverts, fords, and bridges. Their design requires knowledge of stream flows, soils, and wildlife.

C.1.5.5 Clear Water Diversion (NS-5)

Clear water diversion consists of a system of structures and measures that intercept clear surface water runoff upstream of a construction site, transport it around the site, and discharge it downstream with minimal water quality impact. A common example is a temporary creek diversion system that consists of a sandbag cofferdam and a flexible plastic pipe to divert the water around the construction site. Structures commonly used as part of this system include diversion ditches, berms, dikes, slope drains, drainage, and interceptor swales.

C.1.5.6 Illicit Connection/Illegal Discharge Detection and Reporting (NS-6)

These procedures and practices are designed for construction contractors to recognize illicit connections or illegally dumped or discharged materials on a construction site and report incidents to the Resident Engineer (RE).

C.1.5.7 Potable Water/Irrigation (NS-7)

Potable water/irrigation consists of practices and procedures to reduce the discharge of potential pollutants generated from irrigation water lines, landscape irrigation, lawn or garden watering, potable water sources, water line flushing, and hydrant flushing. These practices include reusing discharges for landscaping, automatic shut-off valves, prevention of impacts to downstream drainage systems, leak detection, inspection of equipment and lines, and repair of broken pipes.

C.1.5.8 Vehicle and Equipment Cleaning (NS-8)

This BMP consists of procedures and practices used to minimize or eliminate the discharge of pollutants from vehicle and equipment cleaning operations to storm drains or watercourses. On most construction sites, vehicle and equipment cleaning on site should be discouraged.

If vehicle or equipment cleaning is allowed, then soap, solvents, or steam shall not be used unless approved by the RE. Vehicle and equipment wash water must be contained for percolation or evaporation, and must not be discharged off site.

C.1.5.9 Vehicle and Equipment Fueling (NS-9)

This BMP consists of measures and practices to minimize or eliminate the discharge of fuel spills and leaks into the storm drain system or to watercourses. These measures include containment of fueling areas, spill prevention and control, drip pans or absorbent pads, automatic shut-off nozzles, vapor recovery nozzles, topping off restrictions, and leak inspection and repair.

C.1.5.10 Vehicle and Equipment Maintenance (NS-10)

This BMP consists of procedures and practices to minimize or eliminate the discharge of pollutants to the storm drain system or to watercourses from vehicle and equipment maintenance procedures. Practices include drip pans or absorbent pads, spill kits, dedicated maintenance areas, proper waste disposal, leak repair, and secondary containment.

C.1.5.11 Pile Driving Operations (NS-11)

The construction of bridges and retaining walls often includes driving piles for foundation support. Piles are typically constructed of cast in place concrete, steel, or timber. Driven sheet piles are also used for shoring and cofferdam construction. Proper control and use of equipment, materials, and waste products from pile driving operations will reduce the discharge of potential pollutants to the storm drain system or watercourses. These procedures apply to all construction sites where permanent and temporary pile driving operations take place.

C.1.5.12 Concrete Curing (NS-12)

This BMP consists of procedures that minimize pollution of stormwater runoff during concrete curing. Concrete curing includes the use of both chemical and water methods. Concrete curing is used for the construction of structures such as bridges, retaining walls, and pump houses. Any element of the structure (i.e., footings, columns, abutments, stem and soffit, decks) may be subject to curing requirements.

C.1.5.13 Material and Equipment Use Over Water (NS-13)

This BMP consists of procedures for the proper use, storage, and disposal of materials and equipment on barges, boats, temporary construction pads, or similar locations that minimize or eliminate the discharge of potential pollutants to a watercourse. These procedures shall be implemented for construction materials and wastes (solid and liquid), soil or dredging materials, or any other materials that may be detrimental if released and apply where equipment is used over or adjacent to a watercourse.

C.1.5.14 Concrete Finishing (NS-14)

This BMP consists of procedures to minimize the impact that concrete finishing methods may have on stormwater runoff. Methods include sand blasting, lead shot blasting, grinding, or high pressure water blasting. Concrete finishing methods are used for bridge deck rehabilitation, paint removal, curing compound removal, and final surface finish appearances.

C.1.5.15 Structure Demolition/Removal Over Water (NS-15)

This BMP consists of procedures to protect water bodies from debris and wastes associated with structure demolition or removal over or adjacent to watercourses. These procedures shall be implemented for full bridge demolition and removal, partial bridge removal (i.e., barrier rail, edge of deck) associated with bridge widening projects, concrete channel removal, or any other structure removal that could potentially affect water quality.

C.1.6 Waste Management and Materials Pollution Control

The NPDES stormwater regulations for construction sites also require that BMPs be included in the project plans for waste management and materials pollution control. These are source control BMPs that prevent pollution by reducing pollutants at their source, and require a clean, well-kept site. The measures include:

WM-1 Material Delivery and Storage	WM-6 Hazardous Waste Management
WM-2 Material Use	WM-7 Contaminated Soil Management
WM-3 Stockpile Management	WM-8 Concrete Waster Management
WM-4 Spill Prevention and Control	WM-9 Sanitary/Septic Waste Management
WM-5 Solid Waste Management	WM-10 Liquid Waste Management

As with the non-stormwater management measures, it is important to provide the contractor with flexibility, but to identify that in the plans, that specific BMPs will be implemented for certain activities regardless of where on the site those activities are performed.

C.1.6.1 Material Delivery and Storage (WM-1)

This BMP consists of procedures and practices for the proper handling and storage of materials in a manner that minimizes or eliminates the discharge of these materials to the storm drain system or to watercourses. These procedures include secondary containment, spill prevention and control, product labeling, quantity reduction, proper storage, material covering, training, and inventory control.

C.1.6.2 Material Use (WM-2)

This BMP consists of procedures and practices for use of construction material in a manner that minimizes or eliminates the discharge of these materials to the storm drain system or watercourses. These procedures include proper waste disposal, product labeling, proper cleaning techniques, recycling materials, reducing quantities, and application rates, spill prevention and control, training, and reduction of exposure to stormwater.

C.1.6.3 Stockpile Management (WM-3)

This BMP consists of procedures and practices to eliminate pollution of stormwater from stockpiles of soil and paving materials (such as concrete rubble, aggregate, and asphalt concrete). These procedures include locating stockpiles away from drainages, providing perimeter sediment barriers, and wind erosion control measures.

C.1.6.4 Spill Prevention and Control (WM-4)

This BMP consists of procedures and practices implemented to prevent and control spills in a manner that minimizes or prevents the discharge of spilled material to storm drain systems or watercourses. Spill prevention and prompt appropriate spill response reduce the potential for polluting receiving waters with spilled contaminants. Spills of concern include chemicals and hazardous wastes such as soil stabilizers/binders, dust palliatives, herbicides, growth inhibitors, fertilizers, de-icing products, fuels, lubricants, paints, and solvents. Spill prevention practices include education as well as cleanup and storage procedures that address small spills, semi-significant spills, and significant/hazardous spills.

C.1.6.5 Solid Waste Management (WM-5)

This BMP consists of procedures and practices to minimize or eliminate the discharge of pollutants to storm drain systems or watercourses as a result of the creation, stockpiling or removal of construction site wastes. Solid wastes include such items as used brick, mortar, timber, steel, vegetation/landscaping waste, empty material containers, and litter. Measures include education as well as collection, storage, and disposal practices.

C.1.6.6 Hazardous Waste Management (WM-6)

This BMP consists of procedures and practices to minimize or eliminate the discharge of pollutants from construction site hazardous waste to the storm drain system or watercourses. Hazardous wastes should be collected, stored, and disposed of using practices that prevent contact with stormwater. The following types of wastes are considered hazardous; petroleum products, concrete curing compounds, palliatives, septic wastes, paints, stains, wood preservatives, asphalt products, pesticides, acids, solvents, and roofing tar. There may be additional wastes on the project that are considered hazardous. It is also possible that non-hazardous waste could come into contact with these hazardous wastes, such that they become contaminated and are therefore considered hazardous waste. Measures include education, storage procedures, and disposal procedures.

C.1.6.7 Contaminated Soil Management (WM-7)

This BMP consists of procedures and practices to minimize or eliminate the discharge of pollutants to the storm drain system or watercourses from contaminated soil. Typical soil

contamination is due to spills, illicit discharges, and underground storage tank leaks, or aerially deposited lead (ADL). Contaminated soils tend to occur on projects in urban or industrial areas. Soil contaminants and locations are often identified in the project plans and specifications. Measures include identifying contaminated areas, education, handling procedures for material with ADL, handling procedures for contaminated soils, procedures for underground storage tank removals, and water control.

C.1.6.8 Concrete Waste Management (WM-8)

This BMP consists of procedures and practices that are implemented to minimize or eliminate the discharge of concrete waste materials to the storm drain system or to watercourses. These measures include education, concrete slurry waste handling procedures, on-site concrete washout facility, transit truck washout procedures, and procedures for removal of temporary concrete washout facilities.

C.1.6.9 Sanitary/Septic Waste Management (WM-9)

This BMP consists of procedures and practices to minimize or eliminate the discharge of construction site toilet facilities to the storm drain system or watercourse. Measures include education, and storage and disposal procedures.

C.1.6.10 Liquid Waste Management (WM-10)

This BMP includes procedures to prevent pollutants related to non-hazardous liquid wastes from entering storm drains or receiving waters. Liquid wastes include drilling slurries, drilling fluids, wastewater that is free from grease and oil, dredgings, and other non-storm water liquid discharges not covered by separate permits. This BMP does not apply to the following:

- Dewatering operations (see NS-2);
- Solid wastes (See WM-5);
- Hazardous wastes (See WM-6);
- Concrete slurries (See WM-8);
- Liquid wastes covered by specific laws or permits; and
- Non-stormwater discharges permitted by any Caltrans NPDES permit unless Caltrans determines that the discharge contains pollutants.

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Appendix D
Relevant Storm Water Documents and Web Sites

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Table D-1: Relevant Storm Water Documents and Purpose

Date	Document	Purpose
May 2003	Storm Water Management Plan (SWMP) – approved May 2003 by the State Water Resources Control Board (SWRCB).	Policy Document that ties the functional area activities together and describes the procedures and practices to address stormwater quality statewide. It identifies how Caltrans will comply with the provisions of the National Pollutant Discharge Elimination System (NPDES) permit.
March 2003	Storm Water Quality Handbooks: Construction Site Best Management Practices (BMPs) Manual	Provides instructions for the selection and implementation of Construction Site BMPs. Caltrans requires contractors to identify and utilize these BMPs in the preparation of their SWPPP or WPCP.
March 2003	Storm Water Quality Handbooks: Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Control Program (WPCP) Preparation Manual	Guides contractors and Caltrans staff through the process of preparing a SWPPP and WPCP. This manual provides detailed step-by-step procedures, instructions, examples and a template that contractors shall use to prepare the SWPPP/WPCP.
Pending	Water Quality Assessment Guidelines (WQAG) and Templates for the Water Quality Assessment Technical Report (WQR), Volume 5 Standard Environmental Reference	Provides guidance on preparing WQRs as well as methods for assessing stormwater quality impacts of a project in support of preparing the PA/ED.
Current edition. Updated annually	Regional Work Plans (RWP)	Describes how Caltrans will specifically implement the SWMP within the jurisdiction of each RWQCB as required by the Caltrans Permit. The RWP provides District-specific information on Caltrans facilities, water bodies, BMPs and monitoring programs. It also includes a list of personnel titles and responsibilities.

Table D-2: Storm Water Related Web Sites

Web Sites	Description
http://www.swrcb.ca.gov/stormwtr/docs/caltranspmt.pdf	Caltrans NPDES Statewide Storm Water Permit (Caltrans Permit)
http://www.swrcb.ca.gov/stormwtr/construction.html	Construction General Permit (General Permit)
http://www.owp.csus.edu/research/stormwatertools/	This web site contains a water quality planning tool that provides information on water quality standards, and also contains a Basin Sizer program that calculates the WQV for Treatment BMPs located within California.
http://www.dot.ca.gov/hq/construc/stormwater/stormwater1.htm	A Division of Construction - Storm Water Quality Link. Contains links to resources for developing SWPPP, WPCP, and the Storm Water Quality Information Handout.
http://www.dot.ca.gov/hq/esc/oe/specs_html/index.html	Current Standard Special Provisions (SSPs)
http://www.dot.ca.gov/hq/projmgmt/documents/wsg/workplan_standards_guide_8.0a.doc	Guide to Project Delivery Workplan Standards – Release 8.0A
http://www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm	The Project Development Procedures Manual
http://www.dot.ca.gov/hq/construc/stormwater/manuals.htm	Storm Water Pollution Prevention Plan/Water Pollution Control Program Preparation Manual
http://www.epa.gov	U.S. Environmental Protection Agency (EPA)
http://www.dhs.ca.gov/	California Department of Health Services (DHS)
http://www.epa.gov/epahome/cfr40.htm	Code of Federal Regulations (CFR)
http://www.ceres.ca.gov/ceqa	California Environmental Quality Act (CEQA)
http://ceres.ca.gov/topic/env_law/ceqa/guidelines/art19.html	CEQA web site that lists Categorical Exemptions
http://www.dot.ca.gov/hq/oppd/stormwtr/index.htm	Web site for the Office of Storm Water Management Design.
http://www.dot.ca.gov/hq/env/stormwater/index.htm	Contains links to the 2006 Annual Report, the SWMP, and the 2006 Regional Work Plans
http://wdl.water.ca.gov/gw/	Aquifer groundwater quality and seasonal groundwater levels: monitoring well data, U.S. Geological Survey (USGS), Department of Water Resources (DWR) and local public agency maps and databases.
http://www.dot.ca.gov/ser/	This website is the Standard Environmental Reference (SER) which is an online resource to help state and local agency staff plan, prepare, submit, and evaluate environmental documents for transportation projects. The site includes five Environmental Handbooks, as well as guidance, forms, templates and memos pertaining to the environmental process at Caltrans. Volume 5 of the SER is the Storm Water Quality Assessment document.
http://www.dwr.water.ca.gov	California Department of Water Resources web site that provides data regarding: Water quality; groundwater level; climatology, and surface water.
http://www.dot.ca.gov/hq/oppd/hydrology/hydroidx.htm	California Bank and Shore Rock Slope Protection.

Appendix E

Water Quality Summary Forms

Storm Water Data Report

and

Checklists

- PID Process Summary Forms
- PA/ED Process Summary Forms
- PS&E Process Summary Form
- Storm Water Data Report
  - § Short Form - Storm Water Data Report Template
  - § Long Form – Storm Water Data Report Template
  - § Evaluation Documentation Form
  - § Construction Site BMP Consideration Form
  - § Storm Water Checklist SW-1, Site Data Sources
  - § Storm Water Checklist SW-2, Storm Water Quality Issues Summary
  - § Storm Water Checklist SW-3, Measures for Avoiding or Reducing Storm Water Impacts
  - § Checklist DPP-1, Parts 1–5 (Design Pollution Prevention BMPs)
  - § Checklist T-1, Parts 1–10 (Treatment BMPs)
  - § Checklist CS-1, Parts 1–6 (Construction Site BMPs)

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Summary Process for Storm Water Activities for Project Initiation Document (PID)

WORK BREAKDOWN STRUCTURE (WBS) CODE	ACTIVITY	STORM WATER QUALITY PLANNING ACTIVITY DURING THE PID PHASE	DATE (S) COMPLETED	COMPLETED BY
100.05	Project Management – PID Process	**Invite District/Regional Storm Water Coordinators to project kickoff meeting and to participate in the Project Development Team (PDT).**		
100.05.10	PDT meetings	**The PDT should meet throughout the entire project in order to maintain communication and to obtain consensus between the functional units throughout the project.** Any decisions made during the PDT meetings should be documented.		
150.05.05	Site Data Sources	**Complete Checklist SW-1 (Site Data Sources)** **From Section 4, determine if project is required to consider incorporating Treatment BMPs.** § Complete Evaluation Documentation Form (Appendix E). § If the project is not required to consider Treatment BMPs, verify with District/Regional Storm Water Coordinator. Continue with the PID process with the selection of Design Pollution Prevention and Construction Site Best Management Practices (BMPs). § If the project is required to consider Treatment BMPs, select Treatment, Design Pollution Prevention and Construction Site BMPs.		
150.05.20	Define Storm Water Design Issues	**Obtain any existing available data.** **After obtaining existing data and selecting project alternatives, determine potential stormwater quality impacts and issues. Obtain additional data from the different functional units.** § Complete Checklist SW-2 (Storm Water Quality Issues Summary Checklist) **Perform Field Review of the Area** **Begin Filling out the Storm Water Data Report (SWDR).** **Coordinate with Environmental Unit during preparation of the PEAR and the Water Quality Impact Questionnaire.** **Evaluate options for avoiding or reducing potential impacts.** Begin to fill out Checklist SW-3, Measures for Avoiding or Reducing Potential Storm Water Impacts.		

WORK BREAKDOWN STRUCTURE (WBS) CODE	ACTIVITY	STORM WATER QUALITY PLANNING ACTIVITY DURING THE PID PHASE	DATE (S) COMPLETED	COMPLETED BY
150.10	Identify Potential BMPs	**Determine Potential/Likely BMPs for each site of impact to receiving waters.** § Complete Checklist DPP-1 (including all applicable parts 1-5) and T-1 (including all applicable parts 1-10) for selecting BMPs at specific sites (Appendix E). § Complete decision tree for Pre-Screening for the Infiltration BMP – Appendix B.		
150.10.05	RWQCB Meetings	**Consultation with the Regional Water Quality Control Board (RWQCB) is strongly recommended to coordinate project issues and develop consensus for controversial or complex stormwater quality issues.** Initiate meetings with the RWQCB as necessary. Number of coordination meetings is entirely dependent upon the complexity of the stormwater quality issues, stormwater pollutants involved, and project site constraints. District/Regional NPDES Storm Water Coordinator serves as the single point of contact with the RWQCB.		
150.15	Analyze Project Alternatives	**Discuss BMPs with District/Regional Storm Water Coordinator, Landscape Architecture and Maintenance Storm Water Coordinator**.		
150.15.55	Preliminary Project Cost Estimate (PPCE)	**Develop preliminary BMP costs and incorporate into the PID cost estimate.** **Evaluate for Construction Site BMP costs.** § Refer to cost estimating procedure in Appendix F. § Meet with Construction to obtain concurrence with the Construction Site BMP strategy – cost estimate.		
150.25	Storm Water Data Report (SWDR)	**Route SWDR for functional units' signature.** **Coordinate with the Environmental Unit.** **Complete the SWDR using available data.**		
150.25	Prepare and Approve PID	**Incorporate "Storm Water Pollution Prevention Discussion" under "Considerations" heading of the planning document.**		
150.25.20	Circulate, Review, and Approve PID	**Attach signed SWDR cover sheet to PID and circulate to obtain functional unit concurrence. Original copy of SWDR should be kept in the project file.**		

Summary Process for Storm Water Activities for Project Approval/Environmental Document (PA/ED)

WBS CODE	ACTIVITY	STORM WATER QUALITY PLANNING ACTIVITY DURING THE PA/ED PHASE	DATE (S) COMPLETED	COMPLETED BY
100.10	Project Management Process (PA/ED)	**Invite District/Regional Storm Water Coordinators to project kickoff meeting and to participate in the PDT.**		
100.10.10	PDT meetings	**The PDT should meet throughout the entire project in order to maintain communication and to obtain consensus between the functional units throughout the project.** Any decisions made during the PDT meetings should be documented.		
160.05	Review and Update Project Information	**Confirm whether or not the project is required to consider incorporating Treatment BMPs.** § Complete/Update Evaluation Documentation Form (Appendix E). § If the project is not required to consider Treatment BMPs, verify with District/Regional Storm Water Coordinator. Continue with selection of Design Pollution Prevention and Construction Site BMPs. § If the project is required to consider Treatment BMPs, select Treatment, Design Pollution Prevention and Construction Site BMPs. **Review Information Developed in the PID Process.** **Determine potential stormwater quality impacts and issues for project alternatives.** **Obtain updated data and reports from the different functional units.** § Update Checklist SW-1 (Site Data Sources) § Update Checklist SW-2 (Storm Water Quality Issues Summary). **Consult with Environmental Unit to coordinate the PA/ED Phase - SWDR with the WQR prepared by Environmental (WBS 165.10.35).** **Perform Field Review of the Area.** **Update SWDR.** § **Evaluate options for avoiding or reducing potential impacts.** Update Checklist SW-3, Measures for Avoiding or Reducing Potential Storm Water Impacts.		

WBS CODE	ACTIVITY	STORM WATER QUALITY PLANNING ACTIVITY DURING THE PA/ED PHASE	DATE (S) COMPLETED	COMPLETED BY
160.10	Revise Potential BMP Selections Based on Engineering Studies	**Select Potential/Likely BMPs for each site of unavoidable impact to receiving waters.** § Complete Checklist DPP-1 (including all applicable parts 1-5) and T-1 (including all applicable parts 1-10) for selecting BMPs at specific sites (Appendix E). § Complete decision tree for Pre-Screening for the Infiltration BMP – Appendix B. **Coordinate with Environmental Unit to coordinate the PA/ED – Phase SWDR with the WQR prepared by Environmental.** **Discuss BMPs with District/Regional Storm Water Coordinator, Maintenance Storm Water Coordinator and other functional units (e.g. Hydraulics, LA, etc.) to obtain concurrence.** **Evaluate potential Construction Site BMPs.** § See Construction Site BMPs Manual. § Meet with District/Regional Storm Water Coordinator to discuss BMPs for project required by RWQCB or other agency. § Meet with Construction to obtain concurrence with the Construction Site BMP strategy.		
165.10.35	RWQCB Meetings	**Consult with the RWQCB to coordinate project issues and develop consensus for controversial or complex stormwater quality issues.** Initiate meetings with the RWQCB through the District/Regional NPDES Storm Water Coordinator, as necessary. The number of coordination meetings is entirely dependent upon the complexity of the stormwater quality issues, stormwater pollutants involved, and project site constraints.		
160.15	Prepare Draft Project Report (DPR)	**Incorporate "Storm Water Pollution Prevention Discussion" under "Considerations" heading of the planning document.** (This is done only if the project does not have categorical exemption and has an Environmental Document (ED)) See Figure 6-2 in Section 6.		
160.15	Storm Water Data Report (SWDR)	**Coordinate with the Environmental Unit.** **Complete the SWDR using available data.** **Route SWDR for functional units' signature.**		
160.15.05	Update Preliminary Project Cost Estimates	**Develop preliminary BMP costs and incorporate into PA/ED cost estimate.**		
180.05	Prepare and Approve Project Report (PR)	**Attach signed SWDR cover sheet to PR and circulate to obtain functional unit concurrence. Original copy of SWDR should be kept in the project file.**		

Summary Process for Storm Water Activities for Plans, Specifications & Estimates (PS&E)

WBS CODE	ACTIVITY	STORM WATER QUALITY PLANNING ACTIVITY DURING THE PS&E PHASE	DATE (S) COMPLETED	COMPLETED BY
100.15	Project Management Process (PS&E)	**Invite District/Regional NPDES and Design Storm Water Coordinators to project kickoff meeting and to participate in the PDT.**		
100.15.10	PDT Meetings	**The PDT should meet throughout the entire project in order to maintain communication and to obtain consensus between the functional units throughout the project.** Any decisions made during the PDT meetings should be documented.		
205.10.40	RWQCB Meetings	**Consultation with the RWQCB to coordinate project issues and develop consensus for controversial or complex stormwater quality issues.** Initiate meetings with the RWQCB through the District/Regional NPDES Storm Water Coordinator as necessary. The number of coordination meetings is entirely dependent upon the complexity of the stormwater quality issues, stormwater pollutants involved, and project site constraints.		
185.05.10	Review and update project information	**Review Information Developed in the PID and PA/ED Process.** § Update Checklist SW-1 (Site Data Sources) § Update Checklist SW-2 (Storm Water Quality Issues Summary) **Consult with Environmental Unit to obtain permits.** **Perform Field Review of the Area.** **Review and Update the SWDR; if a WQR is prepared for the project, reference the WQR findings.** **Evaluate options for avoiding or reducing potential impacts.** Update Checklist SW-3, Measures for Avoiding or Reducing Potential Storm Water Impacts.		
185.15	Perform Preliminary Design	**Perform Preliminary Design.** § Delineate drainage areas and define total disturbed area. § Review and update need to consider Treatment BMPs. § Obtain Engineering Reports, WBS 185.20, from the different functional units.		

205.00	Obtain Necessary Permits, WDRs and Agreements	**Obtain NPDES Storm Water Permits and Local Agency Agreements.** § File Notification of Construction (NOC) for coverage under the Caltrans Permit. § Obtain Waste Discharge Requirement (WDR) for Aerially Deposited Lead (ADL) reuses. § Coverage for dewatering activities under separate NPDES permit. Contact your District/Regional NPDES Storm Water Coordinator. § Obtain other agreements with RWQCB and other agencies.		
230.00 230.30 230.40	Prepare Draft PS&E - Design Pollution Prevention BMPs	**Prepare Draft PS&E - Design Pollution Prevention BMPs.** § Update Checklist DPP-1 (and all applicable Parts 2-5) § Incorporate Design Pollution Prevention BMPs in all applicable plans, specifications, and estimates. § Review with District Landscape Architect and Maintenance as necessary. § Calculate quantities, estimates, and prepare Standard Special Provisions (SSPs).		
230.00 230.35 230.40	Prepare Draft PS&E – Treatment BMPs	**Prepare Draft PS&E – Design Treatment BMPs.** § Update Checklist T-1 (and all applicable Parts 2-10) § Incorporate Treatment BMPs in all applicable plans, specifications, and estimates. § Hydraulics to design or review design as per Highway Design Manual (HDM) requirements. § Review Treatment BMPs and future maintenance with District/Regional Storm Water Coordinator and Storm Water Maintenance Coordinator. § Calculate quantities, estimates, and prepare SSPs.		
230.00 230.35 230.40	Prepare Draft PS&E – Construction Site BMPs	**Prepare Draft PS&E - Construction Site BMPs.** § Review Appendix C of the PPDG and the Construction Site BMP Manual. § Complete Construction Site BMPs Consideration Form and respective Checklists CS-1, Parts 1-6 § Meet with District/Regional Storm Water Coordinator to discuss BMPs for project required by RWQCB or other agency. § Meet with Construction on inclusion of Construction Site BMPs. § Document Concurrence with Construction –initial and date Construction Site BMPs Consideration Form § Calculate quantities, estimates, and prepare SSPs.		

230.05.65	Prepare Conceptual SWPPP (if required)	**Prepare Conceptual Storm Water Pollution Prevention Plan (CSWPPP) if required.** § Includes preparing a Water Quality (WQ) information handout for bidders if necessary, Storm Water Pollution Prevention Plan (SWPPP), or Water Pollution Control Program (WPCP). § Includes how to develop estimates and deployment of BMPs.		
230.60	Storm Water Data Report	**Complete and stamp SWDR. Route for functional unit concurrence.**		
255.20	Prepare Final District PS&E Package	**Attach signed SWDR cover sheet for the PS&E package and obtain functional unit signature. Original copy of the SWDR should be kept in the project file.**		
270.05	Prepare RE File	**Submit Storm Water Information to Resident Engineer (RE) File. See Section 7.5.**		

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Storm Water Data Report (SWDR)

In general, a Storm Water Data Report (SWDR) shall be prepared for every project. Depending upon the extent of soil disturbance and degree of stormwater impacts, a "Long Form" or "Short Form" SWDR shall be required. Projects that do not have the potential to create stormwater impacts, and have little or no soil disturbance (less than 0.25 acre) may utilize the "Short Form" SWDR. A Short Form SWDR may be appropriate for (but not limited to) the following types of projects:

- Signing and striping projects;
- Weigh-in-motion projects;
- Traffic monitoring projects (closed-circuit camera installation, etc.);
- Construction of ADA ramps;
- Bridge rail projects;
- Chip seal and/or fog seal projects;
- Pavement marker projects (raised or depressed);
- Metal Beam Guardrail Projects;
- Loop detector installations;
- Median Barrier Projects;
- Extended plant establishment projects,
- Emergency projects* using informal bids (as defined per PDPM); and
- Building remodeling or refurbishment such as painting, tile, or plumbing repair.

Please note that all the aforementioned project types may still be required to utilize a "Long Form" Storm Water Data Report if meeting the following conditions:

1. The Project is required to consider Treatment BMPs.
2. The project disturbs more than 0.25 acres of soil.
3. The project is part of a Common Plan of Development.
4. The project potentially creates permanent water quality impacts.
5. The project requires a notification of ADL reuse.

Any exceptions must be under the direction of the Design District/Regional Storm Water Coordinator.

The Licensed Person in responsible charge of the project (either the Project Engineer or the Licensed Landscape Architect) determines whether a project qualifies and may utilize a Short Form SWDR based upon the previously identified criteria. During the Project Initiation phase, the Design District/Regional Storm Water Coordinator shall confirm that the project may appropriately utilize the Short Form SWDR. The applicability of the Short Form will be reviewed and changed (if necessary) during the Project Approval and PS&E phases.

* Note that an Emergency Project done under Force Account does not require a SWDR.

Dist-County-Route_____

Post Mile (Kilometer Post) Limits:_____

Project Type:_____

EA: _____

RU: _____

Program Identification:_____

Phase: ☐ PID
☐ PA/ED
☐ PS&E

Regional Water Quality Control Board(s): _____

1. Is the project required to consider incorporating Treatment BMPs? Yes ☐ No ☐
2. Does the project disturb more than 0.25 acres of soil? Yes ☐ No ☐
3. Is the project part of a Common Plan of Development? Yes ☐ No ☐
4. Does the project potentially create permanent water quality impacts? Yes ☐ No ☐
5. Does the project require a notification of ADL reuse? Yes ☐ No ☐

If the answer to any of the preceding questions is "Yes", prepare a Long Form - Storm Water Data Report.

Estimated Construction Start Date:_____ Construction Completion Date:_____

Separate Dewatering Permit (if yes, permit number) Yes ☐ Permit # _____ No ☐

This Short Form - Storm Water Data Report has been prepared under the direction of the following Licensed Person. The Licensed Person attests to the technical information contained herein and the data upon which recommendations, conclusions, and decisions are based. Professional Engineer or Landscape Architect stamp required at PS&E.

_____

[Name], Registered Project Engineer/Landscape Architect *Date*

I have reviewed the stormwater quality design issues and find this report to be complete, current, and accurate:

_____

[Stamp Required for PS&E only] *[Name], District/Regional SW Coordinator or Designee* *Date*

1. Project Description

- Clearly describe the type of project and major engineering features, including a brief explanation why project does not have the potential to create water quality impacts.
- Quantify total disturbed soil area and describe how it was calculated.
- Provide any additional information that may be pertinent to the project (e.g. TMDLs, Drinking Water Reservoirs and/or Recharge Facilities, 303(d) water bodies, 401 certifications, etc.).

2. Construction Site BMPs

- Identify whether the project requires a WPCP or SWPPP.
- Coordinate with Construction to determine the appropriate selection of Construction Site BMPs being implemented into the contract documents (e.g. separate line items and/or lump sum).
- Summarize those Construction Site BMPs that have been designated as separate Bid Line Items.
- Describe any pertinent details from the strategy used for estimating Construction Site BMPs.
- Document coordination effort to get concurrence from Construction regarding the Construction Site BMP strategy and associated quantities (provide names of staff and date of meeting(s)). Attach a copy of the Construction Site BMP Consideration Form to the SWDR at PS&E.

REQUIRED ATTACHMENTS

- Vicinity Map
- Evaluation Documentation Form
- Construction Site BMP Consideration Form (required at PS&E only)

Dist-County-Route_____
Post Mile (Kilometer Post) Limits:_____
Project Type:_____
EA: _____
RU: _____
Program Identification:_____

Phase: ☐ PID
☐ PA/ED
☐ PS&E

Regional Water Quality Control Board(s): _____

Is the Project required to consider Treatment BMPs? Yes ☐ No ☐

If yes, can Treatment BMPs be incorporated into the project? Yes ☐ No ☐

If No, a Technical Data Report must be submitted to the RWQCB at least 60 days prior to PS&E Submittal. List Submittal Date: _____

Total Disturbed Soil Area: _____

Estimated: Construction Start Date: _____ Construction Completion Date: _____

Notification of Construction (NOC) Date to be submitted: _____

Notification of ADL reuse (if Yes, provide date) Yes ☐ Date _____ No ☐

Separate Dewatering Permit (if Yes, permit number) Yes ☐ Permit # _____ No ☐

This Report has been prepared under the direction of the following Licensed Person. The Licensed Person attests to the technical information contained herein and the data upon which recommendations, conclusions, and decisions are based. Professional Engineer or Landscape Architect stamp required at PS&E.

_____

[Name], Registered Project Engineer/Landscape Architect *Date*

I have reviewed the stormwater quality design issues and find this report to be complete, current, and accurate:

_____

[Name], Project Manager *Date*

_____

[Name], Designated Maintenance Representative *Date*

_____

[Name], Designated Landscape Architect Representative *Date*

[Stamp Required for PS&E only]

_____

[Name], District/Regional SW Coordinator or Designee *Date*

STORM WATER DATA INFORMATION

1. Project Description

- Clearly describe the type of project and major engineering features.
- Quantify total disturbed soil area and describe how it was calculated.
- Quantify the existing impervious surface, and the impervious surface area after the project is completed.
- Identify all urban MS4 areas within the project limits.

2. Define Site Data and Storm Water Quality Design Issues (refer to Checklists SW-1, SW-2, and SW-3)

Project Engineer (PE) should confer with District/Regional Storm Water Coordinator, Landscape Architecture, Maintenance, Hydraulics, Construction and Environmental Units to define design issues. Provide a narrative that contains pertinent information from source documents identified on SW-1 (e.g. Preliminary Geotechnical Report [PGR]) and a summary of the answers to the questions in SW-2 and SW-3. Use the bullets listed below as examples of information that should be described in the narrative. Note, not all of the information listed is available at each phase of a project (document status of availability, as appropriate). Information to be included will depend on the nature of the project and the site conditions.

- Identify Receiving Water Bodies (including the Hydrologic Area or sub-area [name and/or number]) and distance from the project's outfalls
- Identify if any of the Receiving Water Bodies are on the 303(d) list / describe Pollutants of Concern
- Identify if 401 certification is required
- Identify any Drinking Water Reservoirs and/or Recharge Facilities within project limits
- Describe RWQCB special requirements/concerns, including TMDLs or effluent limits
- Describe local agency requirements/concerns
- Describe project design considerations (climate, soil, topography, geology, groundwater, right-of-way requirements, slope stabilization, etc.)
- Include soil classifications and geology information, if pertinent
- Identify if project involves reuse of soil containing Aerially Deposited Lead (ADL)
- Identify Right-of-way costs for BMPs
- Describe measures for avoiding or reducing potential stormwater impacts
- Identify any existing Treatment BMPs within the project limits and their association with the project

3. Regional Water Quality Control Board Agreements

The District/Regional NPDES coordinator will furnish information and language for this part of the Checklist.

- Summarize any key negotiated understandings or agreements with RWQCB pertaining to this project. This would include any discussions relating to 401 Certifications, Waste Discharge Requirements, or other required permits/certifications.
- Document any specific meeting dates and contact names that reference the negotiated understandings and/or agreements. (Communication with the RWQCB is coordinated through the District/Regional NPDES Storm Water Coordinator.)

4. Describe Proposed Design Pollution Prevention BMPs to be used on the Project.

Summarize responses to Checklist DPP-1, Parts 1-5 in a short narrative. Use the sub-headings shown below for the type of information that should be described in the narrative. Note, not all of the bulleted information listed is required or available at each phase of a project. Information to be included will depend on the nature of the project and the site conditions.

Develop an estimate of quantities and costs for the erosion control/revegetation portion of the Design Pollution Prevention BMPs as part of the for the Storm Water BMP Cost Summary; include right-of-way costs if additional right-of-way is needed for erosion control. Complete for each phase of the project.

Downstream Effects Related to Potentially Increased Flow, Checklist DPP-1, Parts 1 and 2

- Identify velocity or volume of downstream flow
- Describe Existing vs. Post Construction Conditions
- Describe channel condition and design (e.g., will the project discharge to unlined channels)
- Describe potential for increased sediment loading
- Identify hydraulic changes (realignment, encroachment, etc.)

Slope/Surface Protection Systems, Checklist DPP-1, Parts 1 and 3

- Describe cut and fill requirements
- Describe existing and proposed slope conditions
- Identify vegetated surfaces (plants, soils, mulch, blankets, establishment periods, etc.)
- When required, provide date of approval of the Erosion Control Plan by Landscape Architecture and Maintenance
- Summarize any hard surfaces (rock blankets, paving)

Concentrated Flow Conveyance Systems, Checklist DPP-1, Parts 1 and 4

- Briefly describe the Concentrated Conveyance Systems to be implemented for this project

Preservation of Existing Vegetation, Checklist DPP-1, Parts 1 and 5

- Describe area(s) of clearing and grubbing identified and defined in the contract plans
- Describe area(s) that will be placed off-limits to the contractor, if applicable (e.g., ESA areas)
- Consider project changes to increase preservation or preserve/avoid critical areas such as floodplains, wetlands, problem soils, and steep slopes.

5. Describe Proposed Permanent Treatment BMPs to be used on the Project

Summarize responses to Checklist T-1, Parts 1-10 in a short narrative. Use the bullets listed below as examples of information that should be described in the narrative. Note, not all of the information listed is required or available at each phase of a project. Information to be included will depend on the nature of the project and the site conditions.

Develop an estimate of quantities and costs for the proposed Treatment BMPs as part of the Storm Water BMP Cost Summary; include additional right-of-way costs if needed for these BMPs. Complete for each phase of the project.

This section of the SWDR should be used to develop the Technical Report required by the SWMP for projects that must consider Treatment BMPs, but are not able to incorporate them due to siting constraints. At PS&E stage, if the project must consider Treatment BMPs but is not able to incorporate them, document the date of the submittal of the Technical Report to the appropriate RWQCB.

Treatment BMP Strategy, Checklist T-1

- List the Targeted Design Constituent(s), if any.
- List what percentage of the WQV (or WQF depending upon device) will be treated. If less than 100%, describe justification.
- Describe the Treatment BMP strategy for the watershed(s) within the project limits.

Biofiltration Swales/Strips, Checklist T-1, Parts 1 and 2

- Are Biofiltration Swales/Strips incorporated into project? If not, explain reason why not feasible. If yes, list number of Biofiltration Swales and Strips, location(s), approximate total area, and total WQF treated.
- Quantify Tributary Area
- Calculate Design Storm Flow and calculate Water Quality Flow
- Determine depth of flow and velocities at Design Storm and at Water Quality Flow

Dry Weather Diversion, Checklist T-1, Parts 1 and 3

- Are Dry Weather Diversions incorporated into project? If not, explain reason why not feasible. If yes, list number of Dry Weather Diversions, location(s), and total flow rate diverted.
- Describe persistent dry weather flows
- Describe proximity to sanitary sewer
- Document Publicly Owned Treatment Works (POTW) and local health agencies acceptance
- Identify need for existing sanitary sewer pipeline upgrade

Infiltration Devices – Checklist T-1, Parts 1 and 4

- Are Infiltration Devices incorporated into project? If not, explain reason why not feasible (e.g. threat to local groundwater quality, etc.). If yes, list number of Infiltration Devices, location(s), and total WQV treated.
- Quantify approximate tributary area of impervious surface per Infiltration Device
- Calculate Water Quality Volume (WQV) treated per Treatment Infiltration Device
- Document soil type and permeability
- Document groundwater depth
- Identify infiltration rate

Detention Devices, Checklist T-1, Parts 1 and 5

- Are Detention Devices incorporated into project? If not, explain reason why not feasible. If yes, list number of Detention Devices, location(s), and total WQV treated.
- Quantify approximate tributary area of impervious surface per Treatment Detention Basin
- Calculate WQV treated per Treatment Detention Basin
- Discuss Geotechnical Integrity
- Document groundwater depth
- Discuss hydraulic head sufficiency

Gross Solids Removal Devices (GSRDs), Checklist T-1, Parts 1 and 6

- Are GSRDs incorporated into project? If not, explain reason why not feasible or required. If yes, list number of GSRDs, location(s), and total tributary area treated.
- Is receiving water on a 303(d) list for trash or have Total Maximum Daily Loads (TMDLs) for trash been established?
- Calculate Tributary Area for each GSRD
- Estimate volume of each GSRD device
- Identify peak design flow

Traction Sand Traps, Checklist T-1, Parts 1 and 7

- Are Traction Sand Traps incorporated into project? If not, explain reason why not feasible or required. If yes, list number of Traction Sand Traps, location(s), and total WQV treated.
- Is Traction Sand or an abrasive applied to roadway more than twice per year?
- Estimate volume of traction sand applied (S) (ft^3/yr)
- Estimate impact from highway sweeping, snow-blowing operations, or accumulation from other sources
- Discuss Traction Sand Trap cleaning frequency and Maintenance operational needs such as pullouts

Media Filters, Checklist T-1, Parts 1 and 8

- Are Media Filters incorporated into project? If not, explain reason why not feasible. If yes, list number of Media Filters, location(s), and total WQV treated.
- Identify type of Media Filter incorporated: Full Sedimentation Austin Sand Filter, Partial Sedimentation Austin Sand Filter or Delaware Sand Filter
- If an Austin Sand Filter is incorporated into project, identify if earthen configuration or lined
- Is pretreatment provided to capture sediment and litter?
- Quantify approximate tributary area of impervious surface per Media Filter
- Identify Water Quality Volume (WQV) treated per Media Filter
- Identify depth to groundwater
- Discuss local vector agency issues

Multi-Chambered Treatment Trains (MCTTs), Checklist T-1, Parts 1 and 9

- Are MCTTs incorporated into project? If not, explain reason why not feasible. If yes, list number of MCTTs, location(s), and total WQV treated.
- Quantify approximate tributary area of impervious surface per MCTT
- Identify Water Quality Volume (WQV) treated per MCTT
- Discuss local vector agency issues

Wet Basins, Checklist T-1, Parts 1 and 10

- Are Wet Basins incorporated into project? If not, explain reason why not feasible. If yes, list number of Wet Basins, location(s), and total WQV treated.
- Quantify approximate tributary area of impervious surface per Wet Basin
- Identify Water Quality Volume (WQV) treated per Wet Basin
- Identify soil type and permeability
- Document groundwater depth

6. Describe Proposed Temporary Construction Site BMPs to be used on Project

Summarize the selected Construction Site BMPs in a Short Narrative. The narrative should also include any pertinent details from the strategy used for the implementation of Construction Site BMPs (e.g. specific project conditions, construction operations, etc.). It is understood that the level of detail discussed will be different at each phase of the project. Include a brief summary to how the BMPs were estimated.

- Identify those Construction Site BMPs that have been designated as separate Bid Line Items.
- Identify those Construction Site BMPs incorporated as a lump sum.
- Identify if dewatering will be required during the construction of the project. Describe circumstances. (i.e. will a separate dewatering permit be needed?)

- Document the coordination effort to get concurrence with Construction regarding the Construction Site BMP strategy and associated quantities (provide names of staff and date of meeting(s)). Attach a copy of the Construction Site BMP Consideration Form to the SWDR at PS&E.
- Develop an estimate of quantities and costs for Construction Site BMPs as a part of the Storm Water BMP Cost Summary. Complete for each phase of the project.

7. Maintenance BMPs (Drain Inlet Stenciling)

Briefly describe locations where drain inlet stenciling is required, such as within cities, towns, and communities with populations of 10,000 or more, or within designated MS4 areas. Include any specific stencil types and names of contacts that recommended stencil types or locations.

REQUIRED ATTACHMENTS

⇒ **Vicinity Map**
⇒ **Evaluation Documentation Form (EDF)**
⇒ **Construction Site BMP Consideration Form (required at PS&E only)**
⇒ **Treatment BMP Summary Spreadsheets (required, if Treatment BMPs are incorporated into project)**
⇒ **Quantities for Construction Site BMPs (required at PS&E only)**

SUPPLEMENTAL ATTACHMENTS

Note: Supplement Attachments are to be supplied during the SWDR approval process; where noted, some of these items may only be required on a project-specific basis.

⇒ Storm Water BMP Cost Summary
⇒ BMP cost information from: Preliminary Project Cost Estimate (PPCE) during PID and PA/ED project phases; Engineer's Cost Estimate for PS&E project phase
⇒ Plans showing BMP Deployment (i.e. Layout Sheets, Water Pollution Control Sheets, etc)
⇒ Pertinent Correspondence with RWQCB (if requested or recommended by District/Regional NPDES Storm Water Coordinator or Designated Reviewer)
⇒ Checklist SW-1, Site Data Sources
⇒ Checklist SW-2, Storm Water Quality Issues Summary
⇒ Checklist SW-3, Measures for Avoiding or Reducing Potential Storm Water BMPs
⇒ Checklists DPP-1, Parts 1–5 (Design Pollution Prevention BMPs) [only those parts that are applicable]
⇒ Checklists T-1, Parts 1–10 (Treatment BMPs) [only those Parts that are applicable]
⇒ Checklists CS-1, Parts 1–6 (Construction Site BMPs) [only those Parts that are applicable]
⇒ Calculations and cross sections related to BMPs (if requested by District/Regional Storm Water Coordinator)
⇒ 07-340 or 07-345 (if requested or recommended by District/Regional Storm Water Coordinator)
⇒ Conceptual Drainage Map or Drainage Plans, if available (if requested by District/Regional Storm Water Coordinator for review)

DATE: _____

EA: _____

NO.	CRITERIA	YES ü	NO ü	SUPPLEMENTAL INFORMATION FOR EVALUATION
1.	Begin Project Evaluation regarding requirement for consideration of Treatment BMPs	ü		See Figure 4-1, Project Evaluation Process for Consideration of Permanent Treatment BMPs. Go to 2
2.	Is this an emergency project?			If **Yes**, go to 11. If **No**, continue to 3.
3.	Have TMDLs or other Pollution Control Requirements been established for surface waters within the project limits?			If **Yes**, contact the District/Regional NPDES Coordinator to discuss the Department's obligations under the TMDL (if Applicable) or Pollution Control Requirements, go to 10 or 4 (as determined by the NPDES Coordinator). _____ *(Dist./Reg. SW Coordinator initials)* If **No**, continue to 4.
4.	Is the project within an urban area subject to an MS4 permit?			If **Yes**, continue to 5. *(write the MS4 Area here)* If **No**, go to 11.
5.	Is the project directly or indirectly discharging to surface waters?			If **Yes**, continue to 6. If **No**, go to 11.
6.	Is it a new facility or major reconstruction?			If **Yes**, continue to 8. If **No**, go to 7.
7.	Will there be a change in line/grade or hydraulic capacity?			If **Yes**, continue to 8. If **No**, go to 11.
8.	Is the Disturbed Soil Area (DSA) created by the project greater than or equal to 3.0 acres or does the project result in a net increase of one acre or more of new impervious surface?			If **Yes**, continue to 10. If **No**, go to 9. _____ *(Total DSA quantity)* _____ *(Net Increase New Impervious Surface)*
9.	Is the project part of a Common Plan of Development?			If **Yes**, continue to 10. If **No**, go to 11.
10.	Project is required to consider approved Treatment BMPs.		See Sections 2.4 and either Section 5.5or 6.5 for BMP Evaluation and Selection Process. Complete Checklist T-1 in this Appendix E.	
11.	Project is not required to consider Treatment BMPs. _____*(Dist./Reg. SW Coord. Initials)* _____*(Project Engineer Initials)* _____ *(Date)*		Document for Project Files by completing this form, and attaching it to the SWDR.	

See Figure 4-1, Project Evaluation Process for Consideration of Permanent Treatment BMPS

Project Evaluation Process for the Consideration of Construction Site BMPs

DATE: _____
EA: _____

NO.	CRITERIA	YES ü	NO ü	SUPPLEMENTAL INFORMATION
1.	Will construction of the project result in areas of disturbed soil as defined by the Project Planning and Design Guide (PPDG)?			If Yes, Construction Site BMPs for Soil Stabilization (SS) will be required. Complete CS-1, Part 1. Continue to 2. If No, Continue to 3.
2.	Is there a potential for disturbed soil areas within the project to discharge to storm drain inlets, drainage ditches, areas outside the right-of-way, etc?			If Yes, Construction Site BMPs for Sediment Control (SC) will be required. Complete CS-1, Part 2. Continue to 3.
3.	Is there a potential for sediment or construction related materials and wastes to be tracked offsite and deposited on private or public paved roads by construction vehicles and equipment?			If Yes, Construction Site BMPs for Tracking Control (TC) will be required. Complete CS-1, Part 3. Continue to 4.
4.	Is there a potential for wind to transport soil and dust offsite during the period of construction?			If Yes, Construction Site BMPs for Wind Erosion Control (WE) will be required. Complete CS-1, Part 4. Continue to 5.
5.	Is dewatering anticipated or will construction activities occur within or adjacent to a live channel or stream?			If Yes, Construction Site BMPs for Non-Storm Water Management (NS) will be required. Complete CS-1, Part 5. Continue to 6.
6.	Will construction include saw-cutting, grinding, drilling, concrete or mortar mixing, hydro-demolition, blasting, sandblasting, painting, paving, or other activities that produce residues?			If Yes, Construction Site BMPs for Non-Storm Water Management (NS) will be required. Complete CS-1, Parts 5 & 6. Continue to 7.
7.	Are stockpiles of soil, construction related materials, and/or wastes anticipated?			If Yes, Construction Site BMPs for Waste Management and Materials Pollution Control (WM) will be required. Complete CS-1, Part 6. Continue to 8.
8.	Is there a potential for construction related materials and wastes to have direct contact with precipitation; stormwater run-on, or stormwater runoff; be dispersed by wind; be dumped and/or spilled into storm drain systems?			If Yes, Construction Site BMPs for Waste Management and Materials Pollution Control (WM) will be required. Complete CS-1, Part 6. Continue to 9.
9.	End of checklist.		Document for Project Files by completing this form, and attaching it to the SWDR.	

PE to initialize after concurrence with Construction (PS&E only) *Date*

Checklist SW-1, Site Data Sources

Prepared by:_____Date:_____District-Co-Route:_____
PM (KP):_____EA:_____
RWQCB:_____

Information for the following data categories should be obtained, reviewed and referenced as necessary throughout the project planning phase. Collect any available documents pertaining to the category and list them and reference your data source. For specific examples of documents within these categories, refer to Section 5.5 of this document. Example categories have been listed below; add additional categories, as needed. Summarize pertinent information in Section 2 of the SWDR.

DATA CATEGORY/SOURCES	Date
Topographic	
•	
•	
•	
Hydraulic	
•	
•	
•	
Soils	
•	
•	
•	
Climatic	
•	
•	
•	
Water Quality	
•	
•	
•	
Other Data Categories	
•	
•	
•	
•	
•	
•	
•	

Checklist SW-2, Storm Water Quality Issues Summary

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

The following questions provide a guide to collecting critical information relevant to project stormwater quality issues. Complete responses to applicable questions, consulting other Caltrans functional units (Environmental, Landscape Architecture, Maintenance, etc.) and the District/Regional Storm Water Coordinator as necessary. Summarize pertinent responses in Section 2 of the SWDR.

1.	Determine the receiving waters that may be affected by the project throughout the project life cycle (i.e., construction, maintenance and operation).	o Complete	oNA
2.	For the project limits, list the 303(d) impaired receiving water bodies and their constituents of concern.	o Complete	oNA
3.	Determine if there are any municipal or domestic water supply reservoirs or groundwater percolation facilities within the project limits. Consider appropriate spill contamination and spill prevention control measures for these new areas.	o Complete	oNA
4.	Determine the RWQCB special requirements, including TMDLs, effluent limits, etc.	o Complete	oNA
5.	Determine regulatory agencies seasonal construction and construction exclusion dates or restrictions required by federal, state, or local agencies.	o Complete	oNA
6.	Determine if a 401 certification will be required.	o Complete	oNA
7.	List rainy season dates.	o Complete	oNA
8.	Determine the general climate of the project area. Identify annual rainfall and rainfall intensity curves.	o Complete	oNA
9.	If considering Treatment BMPs, determine the soil classification, permeability, erodibility, and depth to groundwater.	o Complete	oNA
10.	Determine contaminated or hazardous soils within the project area.	o Complete	oNA
11.	Determine the total disturbed soil area of the project.	o Complete	oNA
12.	Describe the topography of the project site.	o Complete	oNA
13.	List any areas outside of the Caltrans right-of-way that will be included in the project (e.g. contractor's staging yard, work from barges, easements for staging, etc.).	o Complete	oNA
14.	Determine if additional right-of-way acquisition or easements and right-of-entry will be required for design, construction and maintenance of BMPs. If so, how much?	o Complete	oNA
15.	Determine if a right-of-way certification is required.	o Complete	oNA
16.	Determine the estimated unit costs for right-of-way should it be needed for Treatment BMPs, stabilized conveyance systems, lay-back slopes, or interception ditches.	o Complete	oNA
17.	Determine if project area has any slope stabilization concerns.	o Complete	oNA
18.	Describe the local land use within the project area and adjacent areas.	o Complete	oNA
19.	Evaluate the presence of dry weather flow.	o Complete	oNA

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Checklist SW-3, Measures for Avoiding or Reducing Potential Storm Water Impacts

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

The PE must confer with other functional units, such as Landscape Architecture, Hydraulics, Environmental, Materials, Construction and Maintenance, as needed to assess these issues. Summarize pertinent responses in Section 2 of the SWDR.

Options for avoiding or reducing potential impacts during project planning include the following:

1.	Can the project be relocated or realigned to avoid/reduce impacts to receiving waters or to increase the preservation of critical (or problematic) areas such as floodplains, steep slopes, wetlands, and areas with erosive or unstable soil conditions?	o Yes	o No	o NA
2.	Can structures and bridges be designed or located to reduce work in live streams and minimize construction impacts?	o Yes	o No	o NA
3.	Can any of the following methods be utilized to minimize erosion from slopes:			
	a. Disturbing existing slopes only when necessary?	o Yes	o No	o NA
	b. Minimizing cut and fill areas to reduce slope lengths?	o Yes	o No	o NA
	c. Incorporating retaining walls to reduce steepness of slopes or to shorten slopes?	o Yes	o No	o NA
	d. Acquiring right-of-way easements (such as grading easements) to reduce steepness of slopes?	o Yes	o No	o NA
	e. Avoiding soils or formations that will be particularly difficult to re-stabilize?	o Yes	o No	o NA
	f. Providing cut and fill slopes flat enough to allow re-vegetation and limit erosion to pre-construction rates?	o Yes	o No	o NA
	g. Providing benches or terraces on high cut and fill slopes to reduce concentration of flows?	o Yes	o No	o NA
	h. Rounding and shaping slopes to reduce concentrated flow?	o Yes	o No	o NA
	i. Collecting concentrated flows in stabilized drains and channels?	o Yes	o No	o NA
4.	Does the project design allow for the ease of maintaining all BMPs?	o Yes	o No	
5.	Can the project be scheduled or phased to minimize soil-disturbing work during the rainy season?	o Yes	o No	
6.	Can permanent stormwater pollution controls such as paved slopes, vegetated slopes, basins, and conveyance systems be installed early in the construction process to provide additional protection and to possibly utilize them in addressing construction stormwater impacts?	o Yes	o No	o NA

Design Pollution Prevention BMPs
Checklist DPP-1, Part 1

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Consideration of Design Pollution Prevention BMPs

1. Consideration of Downstream Effects Related to Potentially Increased Flow [to streams or channels]?

(a)	Will project increase velocity or volume of downstream flow?	o Yes	o No	o NA
(b)	Will the project discharge to unlined channels?	o Yes	o No	o NA
(c)	Will project increase potential sediment load of downstream flow?	o Yes	o No	o NA
(d)	Will project encroach, cross, realign, or cause other hydraulic changes to a stream that may affect downstream channel stability?	o Yes	o No	o NA

If Yes was answered to any of the above questions, consider ***Downstream Effects Related to Potentially Increased Flow***, complete the DPP-1, Part 2 checklist.

2. Slope/Surface Protection Systems

(a)	Will project create new slopes or modify existing slopes?	o Yes	o No	o NA

If Yes was answered to the above question, consider ***Slope/Surface Protection Systems***, complete the DPP-1, Part 3 checklist.

3. Concentrated Flow Conveyance Systems

(a)	Will the project create or modify ditches, dikes, berms, or swales?	o Yes	o No	o NA
(b)	Will project create new slopes or modify existing slopes?	o Yes	o No	o NA
(c)	Will it be necessary to direct or intercept surface runoff?	o Yes	o No	o NA
(d)	Will cross drains be modified?	o Yes	o No	o NA

If Yes was answered to any of the above questions, consider ***Concentrated Flow Conveyance Systems***; complete the DPP-1, Part 4 checklist.

4. Preservation of Existing Vegetation

a) It is the goal of the Storm Water Program to maximize the protection of desirable existing vegetation to provide erosion and sediment control benefits on all projects. o Complete

Consider ***Preservation of Existing Vegetation***, complete the DPP-1, Part 5 checklist.

Design Pollution Prevention BMPs
Checklist DPP-1, Part 2

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Downstream Effects Related to Potentially Increased Flow

1.	Review total paved area and reduce to the maximum extent practicable.	o Complete
2.	Review channel lining materials and design for stream bank erosion control.	o Completed
	(a) See Chapters 860 and 870 of the HDM.	o Completed
	(b) Consider channel erosion control measures within the project limits as well as downstream. Consider scour velocity.	o Completed
3.	Include, where appropriate, energy dissipation devices at culvert outlets.	o Completed
4.	Ensure all transitions between culvert outlets/headwalls/wingwalls and channels are smooth to reduce turbulence and scour.	o Completed
5.	Include, if appropriate, peak flow attenuation basins to reduce peak discharges.	o Completed

Design Pollution Prevention BMPs
Checklist DPP-1, Part 3

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Slope / Surface Protection Systems

1. What are the proposed areas of cut and fill? (attach plan or map) o Complete
2. Were benches or terraces provided on high cut and fill slopes to reduce concentration of flows? o Yes o No
3. Were slopes rounded and/or shaped to reduce concentrated flow? o Yes o No
4. Were concentrated flows collected in stabilized drains or channels? o Yes o No
5. Are new or disturbed slopes > 1:4 vertical:horizontal (V:H))? o Yes o No

   If Yes, District Landscape Architecture must prepare or approve an erosion control plan.
6. Are new or disturbed slopes > 1:2 (V:H)? o Yes o No

   If Yes, Geotechnical Services must prepare a Geotechnical Design Report, and the District Landscape Architect should prepare or approve an erosion control plan. Concurrence must be obtained from the District Maintenance Storm Water Coordinator for slopes steeper than 1:2 (V:H).
7. Estimate the change to the impervious areas that will result from this project. _____ acres o Complete

VEGETATED SURFACES

1. Identify existing vegetation. o Complete
2. Evaluate site to determine soil types, appropriate vegetation and planting strategies. o Complete
3. How long will it take for permanent vegetation to establish? o Complete
4. Minimize overland and concentrated flow depths and velocities. o Complete

HARD SURFACES

1. Are hard surfaces required? o Yes o No

   If Yes, document purpose (safety, maintenance, soil stabilization, etc.), types, and general locations of the installations. o Complete

Review appropriate SSPs for Vegetated Surface and Hard Surface Protection Systems. o Complete

Design Pollution Prevention BMPs
Checklist DPP-1, Part 4

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Concentrated Flow Conveyance Systems

Ditches, Berms, Dikes and Swales

1. Consider Ditches, Berms, Dikes, and Swales as per Chapters 813, 836, and 860 of the HDM. o Complete
2. Evaluate risks due to erosion, overtopping, flow backups or washout. o Complete
3. Consider outlet protection where localized scour is anticipated. o Complete
4. Examine the site for run-on from off-site sources. o Complete
5. Consider channel lining when velocities exceed scour velocity for soil. o Complete

Overside Drains

1. Consider downdrains, as per Index 834.4 of the HDM. o Complete
2. Consider paved spillways for side slopes flatter than 1:4 V:H. o Complete

Flared Culvert End Sections

1. Consider flared end sections on culvert inlets and outlets as per Chapter 827 of the HDM. o Complete

Outlet Protection/Velocity Dissipation Devices

1. Consider outlet protection/velocity dissipation devices at outlets, including cross drains, as per Chapters 827 and 870 of the HDM. o Complete

Review appropriate SSPs for Concentrated Flow Conveyance Systems. o Complete

Design Pollution Prevention BMPs
Checklist DPP-1, Part 5

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Preservation of Existing Vegetation

1.	Review Preservation of Property, Standard Specifications 16.1.01 and 16-1.02 (Clearing and Grubbing) to reduce clearing and grubbing and maximize preservation of existing vegetation.	o Complete
2.	Has all vegetation to be retained been coordinated with Environmental, and identified and defined in the contract plans?	o Yes o No
3.	Have steps been taken to minimize disturbed areas, such as locating temporary roadways to avoid stands of trees and shrubs and to follow existing contours to reduce cutting and filling?	o Complete
4.	Have impacts to preserved vegetation been considered while work is occurring in disturbed areas?	o Yes o No
5.	Are all areas to be preserved delineated on the plans?	o Yes o No

Treatment BMPs
Checklist T-1, Part 1

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Consideration of Treatment BMPs

This checklist is used for projects that require the consideration of Approved Treatment BMPs, as determined from the process described in Section 4 (Project Treatment Consideration) and the Evaluation Documentation Form (EDF). This checklist will be used to determine which Treatment BMPs should be considered for each watershed and sub-watershed within the project. Supplemental data will be needed to verify siting and design applicability for final incorporation into a project.

Complete this checklist for each phase of the project, when considering Treatment BMPs. Use the responses to the questions as the basis when developing the narrative in Section 5 of the Storm Water Data Report to document that Treatment BMPs have been appropriately considered.

Answer all questions, unless otherwise directed.

1. Dry Weather Flow Diversion

   (a) Are dry weather flows generated by Caltrans anticipated to be persistent? o Yes o No

   (b) Is a sanitary sewer located on or near the site? o Yes o No

   (c) Is connection to the sanitary sewer possible without extraordinary plumbing, features or construction practices? o Yes o No

   (d) Is the domestic wastewater treatment authority willing to accept flow? o Yes o No

   If Yes was answered to all of these questions consider Dry Weather Flow Diversion, complete and attach Part 3 of this checklist

2. Is the receiving water on the 303(d) list for litter/trash or has a TMDL been issued for litter/trash? o Yes o No

   If Yes, consider Gross Solids Removal Devices (GSRDs), complete and attach Part 6 of this checklist. Note: Biofiltration Systems, Infiltration Devices, Detention Devices, Media Filters, MCTTs, and Wet Basins also can capture litter – consult with District/Regional NPDES if these devices should be considered to meet litter/trash TMDL.

3. Is project located in an area (e.g., mountain regions) where traction sand is applied more than twice a year? o Yes o No
   If Yes, consider ***Traction Sand Traps***, complete and attach **Part 7** of this checklist.

4. (a) Are there local influent limits for infiltration or Basin Plan restrictions or other local agency prohibitions that would restrict the use of the Infiltration Devices? o Yes o No

   (b) Would infiltration pose a threat to local groundwater quality as determined by the District/Regional Storm Water Coordinator? o Yes o No

If the answer to either part of Question 4 is "Yes", then Infiltration Devices are infeasible and the consideration of Infiltration Devices should not be made when completing Questions 5 through 17.

5. (a) Does the project discharge to any 303(d) listed water body or has a TMDL been issued? o Yes o No
If No, go to Question 17, General Purpose Pollutant Removal

(b) If Yes, is the identified pollutant(s) considered a Targeted Design Constituent (TDC) (check all that apply):
___ phosphorus, ___ nitrogen, ___ total copper, ___ dissolved copper,
___ total lead, ___ dissolved lead, ___ total zinc, ___ dissolved zinc,
___ sediments, ___ general metals [unspecified metals].

(c) If no TDC's are checked above, go to Question 17

(d) If only one TDC is checked above, continue to Question 6. o Complete

(e) If more than one TDC is checked, contact your District/Regional NPDES Coordinator to determine priority before continuing with this checklist. o Complete

6. Consult with the District/Regional NPDES Storm Water Coordinator to determine whether Treatment BMP selection will be affected by any existing or future TMDL requirements. o Complete

The following questions list the approved Treatment BMPs in order of preference based on load reduction (performance) for the listed constituent and lifetime costs for the device, excluding right-of-way. Note that a line separates Treatment BMPs into groups of approximately equal effectiveness and within each grouping; any of the Treatment BMPs may be selected for placement if meeting site conditions. In the space provided next to the BMP, use Yes or a check mark to indicate a positive response.

If none of the listed Treatment BMPs for a specific constituent of concern (TDC) can be sited, go to Step #17 (General Purpose Pollutant Removal) to determine whether another Treatment BMP can be incorporated into the project.

For the SWDRs developed for the PID and PA/ED phases of a project: **Consider all approved Treatment BMPs listed that can be reasonably incorporated into the project for each TDC.**

For the SWDR developed for the PS&E phase: **Indicate (Yes or check mark) only those BMPs that will be incorporated into the project.**

7. Is phosphorus the TDC? [Use this constituent if "eutrophic" or "nutrients" is the TDC for the water body.] If Yes, consider: o Yes o No
____ Infiltration Devices
____ Austin Sand Filters

8. Is nitrogen the TDC? If Yes, consider: o Yes o No

____ Infiltration Devices
____ Austin Sand Filter
____ Delaware Filter
____ Detention Device
____ MCTT

9. Is copper (total) the TDC? If Yes for total Copper, consider: o Yes o No

____ Infiltration Devices
____ Wet Basins
____ Biofiltration Strips
____ Detention Devices
____ Biofiltration Swales
____ Austin Sand Filter
____ Delaware Filter
____ MCTT

10. Is copper (dissolved) the TDC? If Yes for dissolved Copper, consider: o Yes o No

____ Infiltration Devices
____ Biofiltration Strips
____ Wet Basin
____ Biofiltration Swale

11. Is lead (total) the TDC? If Yes for total Lead, consider: o Yes o No

____ Infiltration Devices
____ Wet Basin
____ Biofiltration Strips
____ Austin Sand Filter
____ Delaware Filter
____ Detention Devices
____ Biofiltration Swales
____ MCTT

12. Is lead (dissolved) the TDC? If Yes for dissolved Lead, consider: o Yes o No

____ Infiltration Devices
____ Biofiltration Strips
____ Wet Basin
____ Detention Device
____ Biofiltration Swales
____ Austin Sand Filters

13. Is zinc (total) the TDC? If Yes for total Zinc, consider: o Yes o No

____ Infiltration Devices
____ Delaware Filter
____ Wet Basin
____ Biofiltration Strips
____ Biofiltration Swales
____ Austin Sand Filter
____ MCTT
____ Detention Devices

14. Is zinc (dissolved) the TDC? If Yes for dissolved Zinc, consider: o Yes o No
    ____ Infiltration Devices
    ____ Delaware Filter
    ____ Biofiltration Strip
    ____ Biofiltration Swale
    ____ Austin Sand Filter
    ____ MCTT

15. Is sediment (total suspended solids [TSS]) the TDC? If Yes for TSS, consider: o Yes o No
    ____ Infiltration Devices
    ____ Austin Sand Filter
    ____ Delaware Filter
    ____ Wet Basin
    ____ Detention Device
    ____ Biofiltration Strip
    ____ MCTT
    ____ Biofiltration Swale

16. Are "General Metals" or (unspecified) "Metals" the TDC? If Yes for General Metals, consider: o Yes o No
    ____ Infiltration Devices
    ____ Biofiltration Strips
    ____ Wet Basin
    ____ Biofiltration Swale
    ____ Austin Sand Filter
    ____ Delaware Filter
    ____ MCTT

17. General Purpose Pollutant Removal: When it is determined that there are no TDCs, consider the Treatment BMPs in the order listed below. o Yes o No
    ____ Infiltration Devices
    ____ Biofiltration Strips
    ____ Wet Basin
    ____ Biofiltration Swale
    ____ Austin Sand Filter
    ____ Detention Device
    ____ Delaware Filter
    ____ MCTT

18. Biofiltration
    (a) Are site conditions and climate favorable to allow suitable vegetation to be established? o Yes o No

    (b) Have Biofiltration Strips and Swales been considered to the extent practicable? Note: Biofiltration BMPs should be considered for all projects, even if other Treatment BMPs are placed. o Yes o No

    If No to (a) or (b), document justification in Section 5 of the SWDR.

19. After completing the above, complete and attach the checklists shown below for every Treatment BMP under consideration — o Complete

    ____ Biofiltration Strips and Biofiltration Swales: Checklist T-1, Part 2
    ____ Dry Weather Diversion: Checklist T-1, Part 3
    ____ Infiltration Devices: Checklist T-1, Part 4
    ____ Detention Devices: Checklist T-1, Part 5
    ____ GSRDs: Checklist T-1, Part 6
    ____ Traction Sand Traps: Checklist T-1, Part 7
    ____ Media Filter [Austin Sand Filter and Delaware Filter]: Checklist T-1, Part 8
    ____ Multi-Chambered Treatment Train: Checklist T-1, Part 9
    ____ Wet Basins: Checklist T-1, Part 10

20. (a) Estimate what percentage of WQV (or WQF, depending upon the Treatment BMP selected) will be treated by the preferred Treatment BMP(s): _____% — o Complete

    (b) Have Treatment BMPs been considered for use in parallel or series to increase this percentage? — o Yes o No

21. Prepare cost estimate, including right-of-way, for selected Treatment BMPs and include as supplemental information for SWDR approval. — o Complete

Treatment BMPs

Checklist T-1, Part 2

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Biofiltration Swales / Biofiltration Strips

Feasibility

1. Do the climate and site conditions allow vegetation to be established? o Yes o No

2. Are flow velocities from a peak drainage facility design event < 4 fps (i.e. low enough to prevent scour of the vegetated bioswale as per HDM Table 873.3E)? o Yes o No

   If "No" to either question above, Biofiltration Swales and Biofiltration Strips are not feasible.

3. Are Biofiltration Swales proposed at sites where known hazardous soils or contaminated groundwater plumes exist?
   If "Yes", consult with District/Regional NPDES Coordinator about how to proceed. o Yes o No

4. Does adequate area exist within the right-of-way to place Biofiltration device(s)?
   If "Yes", continue to Design Elements section. If "No", continue to Question 5. o Yes o No

5. If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site Biofiltration devices and how much right-of-way would be needed to treat WQF? _____ acres
   If "Yes", continue to Design Elements section. If "No", continue to Question 6. o Yes o No

6. If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of these Treatment BMPs into the project. o Complete

Design Elements

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1. Has the District Landscape Architect provided vegetation mixes appropriate for climate and location? * o Yes o No

2.	Can the bioswale be designed as a conveyance system under any expected flows > the WQF event, as per HDM Chapter 800? * (e.g. freeboard, minimum slope, etc.)	o Yes	o No
3.	Can the bioswale be designed as a water quality treatment device under the WQF while meeting the required HRT, depth, and velocity criteria? (Reference Appendix B, Section B.2.3.1)*	o Yes	o No
4.	Is the maximum length of a biostrip ≤ 300 ft? *	o Yes	o No
5.	Has the minimum width (in the direction of flow) of the invert of the bioswale received the concurrence of Maintenance? *	o Yes	o No
6.	Can bioswales be located in natural or low cut sections to reduce maintenance problems caused by animals burrowing through the berm of the swale? **	o Yes	o No
7.	Is the biostrip sized as long as possible in the direction of flow? **	o Yes	o No
8.	Have Biofiltration Systems been considered for locations upstream of other Treatment BMPs, as part of a treatment train? **	o Yes	o No

Treatment BMPs
Checklist T-1, Part 3

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Dry Weather Flow Diversion

Feasibility

1.	Is a Dry-Weather Flow Diversion acceptable to a Publicly Owned Treatment Works (POTW)?	o Yes	o No
2.	Would a connection require ordinary (i.e., not extraordinary) plumbing, features or construction methods to implement?	o Yes	o No
	If "No" to either question above, Dry Weather Flow Diversion is not feasible.		
3.	Does adequate area exist within the right-of-way to place Dry Weather Flow Diversion devices? If "Yes", continue to Design Elements sections. If "No", continue to Question 4.	o Yes	o No
4.	If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site Dry Weather Flow Diversion devices and how much right-of-way would be needed? _____ (acres) If "Yes", continue to the Design Elements section.	o Yes	o No
	If "No", continue to Question 5.		
5.	If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project.	o Complete	

Design Elements

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Does the existing sanitary sewer pipeline have adequate capacity to accept project dry weather flows, or can an upgrade be implemented to handle the anticipated dry weather flows within the project's budget and objectives? *	o Yes	o No
2.	Can the connection be designed to allow for Maintenance vehicle access? *	o Yes	o No
3.	Can gate, weir, or valve be designed to stop diversion during storm events? *	o Yes	o No
4.	Can the inlet be designed to reduce chances of clogging the diversion pipe or channel? *	o Yes	o No
5.	Can a back flow prevention device be designed to prevent sanitary sewage from entering storm drain? *	o Yes	o No

Treatment BMPs
Checklist T-1, Part 4

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Infiltration Devices

Feasibility

1.	Does local Basin Plan or other local ordinance provide influent limits on quality of water that can be infiltrated, and would infiltration pose a threat to groundwater quality as determined by the District/Regional NPDES Storm Water Coordinator?	o Yes	o No
2.	Does infiltration at the site compromise the integrity of any slopes in the area?	o Yes	o No
3.	Per survey data or U.S. Geological Survey (USGS) Quad Map, are existing slopes at the proposed device site >15%?	o Yes	o No
4.	At the invert, does the soil type classify as NRCS Hydrologic Soil Group (HSG) D, or does the soil have an infiltration rate < 0.5 inches/hr?	o Yes	o No
5.	Is site located over a previously identified contaminated groundwater plume?	o Yes	o No
	If "Yes" to any question above, Infiltration Devices are not feasible; stop here and consider other approved Treatment BMPs.		
6.	(a) Does site have groundwater within 10 ft of basin invert?	o Yes	o No
	(b) Does site investigation indicate that the infiltration rate is significantly greater than 2.5 inches/hr?	o Yes	o No
	If "Yes" to either part of Question 6, the RWQCB must be consulted, and the RWQCB must conclude that the groundwater quality will not be compromised, before approving the site for infiltration.	o Yes	o No
7.	Does adequate area exist within the right-of-way to place Infiltration Device(s)? If "Yes", continue to Design Elements sections. If "No", continue to Question 8.	o Yes	o No
8.	If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site Infiltration Devices and how much right-of-way would be needed to treat WQV? _____ acres If Yes, continue to Design Elements section. If No, continue to Question 9.	o Yes	o No
9.	If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project.	o Complete	

Design Elements – Infiltration Basin

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Has a detailed investigation been conducted, including subsurface soil investigation, in-hole conductivity testing and groundwater elevation determination? (This report must be completed for PS&E level design.) *	o Yes	o No
2.	Has an overflow spillway with scour protection been provided? *	o Yes	o No
3.	Is the Infiltration Basin size sufficient to capture the WQV while maintaining a 40-48 hour drawdown time? (Note: the WQV must be ≥ 4,356 ft^3 [0.1 acre-feet]) *	o Yes	o No
4.	Can access be placed to the invert of the Infiltration Basin? *	o Yes	o No
5.	Can the Infiltration Basin accommodate the Water Quality freeboard above the WQV elevation (reference Appendix B.1.3.1)? *	o Yes	o No
6.	Can the Infiltration Basin be designed with interior side slopes no steeper than 1:4 (V:H) (may be 1:3 [V:H] with approval by District Maintenance)? *	o Yes	o No
7.	Can vegetation be established in the Infiltration Basin? **	o Yes	o No
8.	Can diversion be designed, constructed, and maintained to bypass flows exceeding the WQV? **	o Yes	o No
9.	Can a gravity-fed Maintenance Drain be placed? **	o Yes	o No

Design Elements – Infiltration Trench

* **Required** Design Element – (see definition above)
** **Recommended** Design Element – (see definition above)

1.	Has a detailed investigation been conducted, including subsurface soil investigation, in-hole conductivity testing and groundwater elevation determination? (This report must be completed for PS&E level design.) *	o Yes	o No
2.	Is the surrounding soil within Hydrologic Soil Groups (HSG) Types A or B? *	o Yes	o No
3.	Is the volume of the Infiltration Trench equal to at least the 2.85x the WQV, while maintaining a drawdown time of ≤ 72 hours? (Note: the WQV must be ≥ 4,356 ft^3 [0.1 acre-feet], unless the District/Regional NPDES Storm Water Coordinator will allow a volume between 2,830 ft^3 and 4,356 ft^3 to be considered.) *	o Yes	o No
4.	Is the depth of the Infiltration Trench ≤ 13 ft, and is the depth < the width? *	o Yes	o No
5.	Can an observation well be placed in the trench? *	o Yes	o No
6.	Can access be provided to the Infiltration Trench? *	o Yes	o No
7.	Can pretreatment be provided to capture sediment in the runoff (such as using Biofiltration)? *	o Yes	o No
8.	Can flow diversion be designed, constructed, and maintained to bypass flows exceeding the Water Quality event? **	o Yes	o No
9.	Can a perimeter curb or similar device be provided (to limit wheel loads upon the trench)? **	o Yes	o No

Treatment BMPs
Checklist T-1, Part 5

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Detention Devices

Feasibility

1.	Is there sufficient head to prevent objectionable backwater conditions in the upstream drainage systems?	o Yes	o No
2.	2a) Is the volume of the Detention Device equal to at least the WQV? (Note: the WQV must be ≥ 4,356 ft^3 [0.1 acre-feet])	o Yes	o No
	Only answer (b) if the Detention Device is being used also to capture traction sand.		
	2b) Is the total volume of the Detention Device at least equal to the WQV plus the anticipated volume of traction sand, while maintaining a minimum 12 inch freeboard (1 ft)?	o Yes	o No
3.	Is basin invert ≥ 10 ft above seasonally high groundwater or can it be designed with an impermeable liner? (Note: If an impermeable liner is used, the seasonally high groundwater elevation must not encroach within 12 inches of the invert.)	o Yes	o No

If No to any question above, then Detention Devices are not feasible.

4.	Does adequate area exist within the right-of-way to place Detention Device(s)? If Yes, continue to the Design Elements section. If No, continue to Question 5.	o Yes	o No
5.	If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site Detention Device(s) and how much right-of way would be needed to treat WQV? _____ acres If Yes, continue to the Design Elements section. If No, continue to Question 6.	o Yes	o No
6.	If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project.	o Complete	

Design Elements

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Has the geotechnical integrity of the site been evaluated to determine potential impacts to surrounding slopes due to incidental infiltration? If incidental infiltration through the invert of an unlined Detention Device is a concern, consider using an impermeable liner. *	o Yes	o No
2.	Has the location of the Detention Device been evaluated for any effects to the adjacent roadway and subgrade? *	o Yes	o No
3.	Can a minimum Water Quality freeboard of 12 inches be provided above the WQV? *	o Yes	o No
4.	Is an overflow outlet provided? *	o Yes	o No
5.	Is the drawdown time of the Detention Device within 24 to 72 hours? *	o Yes	o No
6.	Is the basin outlet designed to minimize clogging (minimum outlet orifice diameter of 0.5 inches)? *	o Yes	o No
7.	Are the inlet and outlet structures designed to prevent scour and re-suspension of settled materials, and to enhance quiescent conditions? *	o Yes	o No
8.	Can vegetation be established in an earthen basin at the invert and on the side slopes for erosion control and to minimize re-suspension? Note: Detention Basins may be lined, in which case no vegetation would be required for lined areas.*	o Yes	o No
9.	Has sufficient access for Maintenance been provided? *	o Yes	o No
10.	Is the side slope 1:4 (V:H) or flatter for interior slopes? ** (Note: Side slopes up to 1:3 (V:H) allowed with approval by District Maintenance.)	o Yes	o No
11.	If significant sediment is expected from nearby slopes, can the Detention Device be designed with additional volume equal to the expected annual loading? **	o Yes	o No
12.	Is flow path as long as possible (≥ 2:1 length to width ratio at WQV elevation is recommended)? **	o Yes	o No

Treatment BMPs
Checklist T-1, Part 6

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Gross Solids Removal Devices (GSRDs)

Feasibility

1.	Is the receiving water body downstream of the tributary area to the proposed GSRD on a 303(d) list or has a TMDL for litter been established?	o Yes	o No
2.	Are the devices sized for flows generated by the peak drainage facility design event or can peak flow be diverted?	o Yes	o No
3.	Are the devices sized to contain gross solids (litter and vegetation) for a period of one year?	o Yes	o No
4.	Is there sufficient access for maintenance and large equipment (vacuum truck)?	o Yes	o No

If "No" to any question above, then Gross Solids Removal Devices are not feasible. Note that Biofiltration Systems, Infiltration Devices, Detention Devices, Dry Weather Flow Diversion, MCTT, Media Filters, and Wet Basins may be considered for litter capture, but consult with District/Regional NPDES if proposed to meet a TMDL for litter.

5.	Does adequate area exist within the right-of-way to place Gross Solids Removal Devices? If "Yes", continue to Design Elements section. If "No", continue to Question 6.	o Yes	o No
6.	If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site Gross Solids Removal Devices and how much right-of-way would be needed? _____ acres If "Yes", continue to Design Elements section. If "No", continue to Question 7.	o Yes	o No
7.	If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project.	o Complete	

Design Elements – Linear Radial Device

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Does sufficient hydraulic head exist to place the Linear Radial GSRD? *	o Yes	o No
2.	Was the litter accumulation rate of 10 ft^3/ac/yr (or a different rate recommended by Maintenance) used to size the device? *	o Yes	o No
3.	Were the standard detail sheets used for the layout of the devices? ** If No, consult with Headquarters Office of Storm Water Management and District/Regional NPDES.	o Yes	o No
4.	Is the maximum depth of the storage within 10 ft of the ground surface, or another depth as required by District Maintenance? *	o Yes	o No

Design Elements – Inclined Screen

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Does sufficient hydraulic head exist to place the Inclined Screen GSRD? *	o Yes	o No
2.	Was the litter accumulation rate of 10 ft^3/ac/yr (or a different rate recommended by Maintenance) used to size the device? *	o Yes	o No
3.	Were the standard details sheets used for the layout of the devices? ** If No, consult with Headquarters Office of Storm Water Management and District NPDES.	o Yes	o No
4.	Is the maximum depth of the storage within 10 ft of the ground surface, or another depth as required by District Maintenance? *	o Yes	o No

Treatment BMPs
Checklist T-1, Part 7

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Traction Sand Traps

Feasibility

1.	Can a Detention Device be sized to capture the estimated traction sand and the WQV from the tributary area? If Yes, then a separate Traction Sand Trap may not be necessary. Coordinate with the District/Regional Storm Water Coordinator and also complete Checklist T-1, Part 5.	o Yes	o No
2.	Is the Traction Sand Trap proposed for a site where sand or other traction enhancing substances are applied to the roadway at least twice per year?	o Yes	o No
3.	Is adequate space provided for Maintenance staff and equipment access for annual cleanout?	o Yes	o No
4.	Has the local RWQCB agreed that the proposed Traction Sand Trap would not be classified as a regulated underground injection well?	o Yes	o No
	If the answer to any one of Questions 2, 3 or 4 is No, then a Traction Sand Trap is not feasible.		
5.	Does adequate area exist within the right-of-way to place Traction Sand Traps? If Yes, continue to Design Elements section. If No, continue to Question 6.	o Yes	o No
6.	If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site Traction Sand Traps and how much right-of-way would be needed? _____ acres If Yes, continue to the Design Elements section. If No, continue to Question 7.	o Yes	o No
7.	If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project.	o Complete	

Design Elements

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Was the local Caltrans Maintenance Station contracted to provide the amount of traction sand used annually at the location? * (Detention Device or CMP type) List application rate reported. _____ yd^3	o Yes	o No
2.	Does the Traction Sand Trap have enough volume to store settled sand over the winter using the formula presented in Appendix B, Section B.5? * (Detention Device or CMP type)	o Yes	o No
3.	Is the invert of the Traction Sand Trap a minimum of 3 ft above seasonally high groundwater? * (CMP type)	o Yes	o No
4.	Is the maximum depth of the storage within 10 ft of the ground surface, or another depth as required by District Maintenance? * (CMP type)	o Yes	o No
5.	Has the District/Regional NPDES Storm Water Coordinator been contacted to ensure that the Traction Sand Trap is not classified as a regulated underground injection well? * (CMP type)	o Yes	o No
6.	Can peak flow be diverted around the device? ** (CMP type)	o Yes	o No
7.	Within the tributary area, have the unstabilized areas (that would contribute sediment in addition to traction sand) been minimized as much as possible?**(Detention Device or CMP type)	o Yes	o No
8.	Is 6 inches separation provided between the top of the captured traction sand and the outlet from the device, in order to minimize re-suspension of the solids? ** (CMP type)	o Yes	o No

Treatment BMPs

Checklist T-1, Part 8

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Media Filters

Caltrans has approved two types of Media Filter: Austin Sand Filters and Delaware Filters. Austin Sand filters are typically designed for larger drainage areas, while Delaware Filters are typically designed for smaller drainage areas. The Austin Sand Filter is constructed with an open top and may have a concrete or earthen invert, while the Delaware is always constructed as a vault. See Appendix B, Media Filters, for a further description of Media Filters.

Feasibility – Austin Sand Filter

1. Is the volume of the Austin Sand Filter equal to at least the WQV using a 24 hour drawdown? (Note: the WQV must be ≥ 4,356 ft^3 [0.1 acre-feet]) o Yes o No

2. Is there sufficient hydraulic head to operate the device (minimum 3 ft between the inflow and outflow chambers)? o Yes o No

3. If initial chamber has an earthen bottom, is initial chamber invert ≥ 3 ft above seasonally high groundwater? o Yes o No

4. If a vault is used for either chamber, is the level of the concrete base of the vault above seasonally high groundwater or is a special design provided? o Yes o No

   If No to any question above, then an Austin Sand Filter is not feasible.

5. Does adequate area exist within the right-of-way to place an Austin Sand Filter(s)? o Yes o No
   If Yes, continue to Design Elements sections. If No, continue to Question 6.

6. If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site the device and how much right-of way would be needed to treat WQV? _____ acres o Yes o No
   If Yes, continue to the Design Elements section.

   If No, continue to Question 7.

7. If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project. o Complete

   If an Austin Sand Filter meets these feasibility requirements, continue to the Design Elements – Austin Sand Filter below.

Feasibility- Delaware Filter

1.	Is the volume of the Delaware Filter equal to at least the WQV using a 40 to 48 hour drawdown? (Note: the WQV must be ≥ 4,356 ft^3 [0.1 acre-feet], consult with District/Regional NPDES if a lesser volume is under consideration.)	o Yes	o No
2.	Is there sufficient hydraulic head to operate the device (minimum 3 ft between the inflow and outflow chambers)?	o Yes	o No
3.	Would a permanent pool of water be allowed by the local vector control agency?	o Yes	o No

If No to any question, then a Delaware Filter is not feasible

4.	Does adequate area exist within the right-of-way to place a Delaware Filter (s)? If Yes, continue to Design Elements sections. If No, continue to Question 5.	o Yes	o No
5.	If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site the device and how much right-of way would be needed to treat WQV? _____ acres If Yes, continue to the Design Elements section. If No, continue to Question 6.	o Yes	o No
6.	If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project.	o Complete	

If a Delaware Filter is still under consideration, continue to the Design Elements – Delaware Filter section.

Design Elements – Austin Sand Filter

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Is the drawdown time of the 2nd chamber 24 hours? *	o Yes	o No
2.	Is access for Maintenance vehicles provided to the Austin Sand Filter? *	o Yes	o No
3.	Is a bypass/overflow provided for storms > WQV? *	o Yes	o No
4.	Is the flow path length to width ratio for the sedimentation chamber of the "full" Austin Sand Filter ≥ 2:1? **		
5.	Can pretreatment be provided to capture sediment and litter in the runoff (such as using Biofiltration)? **	o Yes	o No

6. Can the Austin Sand Filter be placed using an earthen configuration? **
   If No, go to Question 9. o Yes o No

7. Is the Austin Sand Filter invert separated from the seasonally high groundwater table by ≥ 10 ft)? *
   If No, design with an impermeable liner. o Yes o No

8. Are side slopes of the earthen chamber 1:3 (V:H) or flatter? * o Yes o No

9. Is maximum depth ≤ 13 ft below ground surface? * o Yes o No

10. Can the Austin Sand Filter be placed in an offline configuration? ** o Yes o No

Design Elements – Delaware Filter

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1. Can the first chamber be sized for the WQV? * o Yes o No

2. Is the drawdown time of the 2nd chamber between 40 and 48 hours? * o Yes o No

3. Is access for Maintenance vehicles provided to the Delaware Filter? * o Yes o No

4. Is a bypass/overflow provided for storms > WQV? ** o Yes o No

5. Can pretreatment be provided to capture sediment and litter in the runoff (such as using Biofiltration)? ** o Yes o No

6. Can the Delaware Filter be placed in an offline configuration? ** o Yes o No

7. Is maximum depth ≤ 13 ft below ground surface? * o Yes o No

Treatment BMPs
Checklist T-1, Part 9

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

MCTT (Multi-chambered Treatment Train)

Feasibility

1.	Is the proposed location for the MCTT located to serve a "critical source area" (i.e. vehicle service facility, parking area, paved storage area, or fueling station)?	o Yes	o No
2.	Is the WQV ≥ 4,346 ft³ [0.1 acre-foot]?	o Yes	o No
3.	Is there sufficient hydraulic head (typically ≥ 6 feet) to operate the device?	o Yes	o No
4.	Would a permanent pool of water be allowed by the local vector control agency? If No to any question above, then an MCTT is not feasible.	o Yes	o No
5.	Does adequate area exist within the right-of-way to place an MCTT(s)? If Yes, continue to Design Elements sections. If No, continue to Question 6.	o Yes	o No
6.	If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site the device and how much right-of way would be needed to treat WQV? _____ acres If Yes, continue to Design Elements section. If No, continue to Question 7.	o Yes	o No
7.	If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project.	o Complete	

Design Elements

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Is the maximum depth of the 3rd chamber ≤ 13 ft below ground surface and has Maintenance accepted this depth? *	o Yes	o No
2.	Is the drawdown time in the 3rd chamber between 24 and 48 hours? *	o Yes	o No
3.	Is access for Maintenance vehicles provided to all chambers of the MCTT? *	o Yes	o No
4.	Is there sufficient hydraulic head to operate the device? *	o Yes	o No
5.	Has a bypass/overflow been provided for storms > WQV? *	o Yes	o No

6. Can pretreatment be provided to capture sediment and litter in the runoff (such as using Biofiltration)? ** o Yes o No

Treatment BMPs
Checklist T-1, Part 10

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Wet Basin

Feasibility

1.	Is the volume of the Wet Basin above the permanent pool equal to at least the WQV using a 24 to 72 hour drawdown (40 to 48 hour drawdown preferred)? (Note: the WQV must be ≥ 4,356 ft^3 [0.1 acre-feet] and the permanent pool must be at least 3x the WQV.)	o Yes	o No
2.	Is a permanent source of water available in sufficient quantities to maintain the permanent pool for the Wet Basin?	o Yes	o No
3.	Is proposed site in a location where naturally occurring wetlands do not exist?	o Yes	o No
	Answer either question 3 or question 4:		
4.	For Wet Basins with a proposed invert above the seasonally high groundwater, Are NRCS Hydrologic Soil Groups [HSG] C and D at the proposed invert elevation, or can an impermeable liner be used? (Note: If an impermeable liner is used, the seasonally high groundwater elevation must not encroach within 12 inches of the invert.)	o Yes	o No
5.	For Wet Basins with a proposed invert below the groundwater table: Can written approval from the local Regional Water Quality Control Board be obtained to place the Wet Basin in direct hydraulic connectivity to the groundwater?	o Yes	o No
6.	Is Water Quality freeboard provided ≥ 1 foot?	o Yes	o No
7.	Is the maximum impoundment volume < 14.75 acre-feet?	o Yes	o No
8.	Would a permanent pool of water be allowed by the local vector control agency? If No to any question above, then a Wet Basin is not feasible.	o Yes	o No
9.	Is the maximum basin width ≤ 49 ft as suggested in Section B.10.2? If No, consult with the local vector control agency and District Maintenance.	o Yes	o No
10.	Does adequate area exist within the right-of-way to place a Wet Basin? If Yes, continue to Design Elements sections. If No, continue to Question 7.	o Yes	o No

11. If adequate area does not exist within right-of-way, can suitable, additional right-of-way be acquired to site the device and how much right-of way would be needed to treat WQV? _____ acres
    If Yes, continue to Design Elements section.
    If No, continue to Question 8.
    o Yes o No

12. Have the appropriate state and federal regulatory agencies been contacted to discuss location and potential to attract and harbor sensitive or endangered species?
    If No, contact the Regional/District NPDES Coordinator
    o Yes o No

13. If adequate area cannot be obtained, document in Section 5 of the SWDR that the inability to obtain adequate area prevents the incorporation of this Treatment BMP into the project.
    o Complete

Design Elements

* **Required** Design Element – A "Yes" response to these questions is required to further the consideration of this BMP into the project design. Document a "No" response in Section 5 of the SWDR to describe why this Treatment BMP cannot be included into the project design.

** **Recommended** Design Element – A "Yes" response is preferred for these questions, but not required for incorporation into a project design.

1.	Can a controlled outlet and an overflow structure be designed for storm events larger than the Water Quality event? *	o Yes	o No
2.	Is access for Maintenance vehicles provided? *	o Yes	o No
3.	Is the drawdown time for the WQV between 24 and 72 hours? *	o Yes	o No
4.	Has appropriate vegetation been selected for each hydrologic zone? *	o Yes	o No
5.	Can all design elements required by the local vector control agency be incorporated? *	o Yes	o No
6.	Has a minimum flow path length-to-width ration of at least 2:1 been provided? **	o Yes	o No
7.	Has an upstream bypass been provided for storms > WQV? **	o Yes	o No
8.	Can pretreatment be provided to capture sediment and litter in the runoff (such as using Biofiltration, or a forebay)? **	o Yes	o No
9.	Can public access be restricted using a fence if proposed at locations accessible on foot by the public? **	o Yes	o No
5.	Is the maximum depth < 10 ft?"	o Yes	o No

Construction Site BMPs
Checklist CS-1, Part 1

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Soil Stabilization

General Parameters

1.	How many rainy seasons are anticipated between begin and end of construction?	_____
2.	What is the total disturbed soil area for the project? (ac)	_____
	(a) How much of the project DSA consists of slopes 1V:4H or flatter? (ac)	_____
	(b) How much of the project DSA consists of 1V:4H < slopes < 1V:2H? (ac)	_____
	(c) How much of the project DSA consists of slopes 1V:2H and steeper? (ac)	_____
	(d) How much of the project DSA consists of slopes with slope lengths longer then 20 ft? (ac)	_____
3.	What rainfall area does the project lie within? (Refer to Table 2-1 of the Construction Site Best Management Practices Manual)	_____
4.	Review the required combination of temporary soil stabilization and temporary sediment controls and barriers for area, slope inclinations, rainy and non-rainy season, and active and non-active disturbed soil areas. (Refer to Tables 2-2, and 2-3 of the Construction Site Best Management Practices Manual for Rainfall Area requirements.)	o Complete

Scheduling (SS-1)

5.	Does the project have a duration of more then one rainy season and have disturbed soil area in excess of 25 acres?	o Yes o No
	(a) Include multiple mobilizations (Move-in/Move-out) as a separate contract bid line item to implement permanent erosion control or revegetation work on slopes that are substantially complete. (Estimate at least 6 mobilizations for each additional rainy season. Designated Construction Representative may suggest an alternate number of mobilizations.)	o Complete
	(b) Edit Order of Work specifications for permanent erosion control or revegetation work to be implemented on slopes that are substantially complete.	o Complete
	(c) Edit permanent erosion control or revegetation specifications to require seeding and planting work to be performed when optimal.	o Complete

Preservation of Existing Vegetation (SS-2)

6. Do Environmentally Sensitive Areas (ESAs) exist within or adjacent to the project limits? (Verify the completion of DPP-1, Part 5) o Yes o No

   (a) Verify the protection of ESAs through delineation on all project plans. o Complete

   (b) Protect from clearing and grubbing and other construction disturbance by enclosing the ESA perimeter with high visibility plastic fence or other BMP. o Complete

7. Are there areas of existing vegetation (mature trees, native vegetation, landscape planting, etc.) that need not be disturbed by project construction? Will areas designated for proposed treatment BMPs need protection (infiltration characteristics, vegetative cover, etc.)? (Coordinate with District Environmental and Construction to determine limits of work necessary to preserve existing vegetation to the maximum extent practicable.) o Yes o No

   (a) Designate as outside of limits of work (or designate as ESAs) and show on all project plans. o Complete

   (b) Protect with high visibility plastic fence or other BMP. o Complete

8. If yes for 6, 7, or both, then designate ESA fencing as a separate contract bid line item, *if not already incorporated as part of design pollution prevention work (See DPP-1, Part 5).* o Complete

Slope Protection

9. Provide a soil stabilization BMP(s) appropriate for the DSA, slope steepness, slope length, and soil erodibility. (Consult with District/Regional Landscape Architect.)

   (a) Select SS-3 (Hydraulic Mulch), SS-4 (Hydroseeding), SS-5 (Soil Binders), SS-6 (Straw Mulch), SS-7 (Geotextiles, RECPs, Etc.), SS-8 (Wood Mulching), other BMPs or a combination to cover the DSA throughout the project's rainy season. o Complete

   (b) Increase the quantities by 25% for each additional rainy season. (Designated Construction Representative may suggest an alternate increase.) o Complete

   (c) Designate as a separate contract bid line item. o Complete

Slope Interrupter Devices

10. Provide slope interrupter devices for all slopes with slope lengths equal to or greater than of 20 ft in length. (Consult with District/Regional Landscape Architect and Designated Construction Representative.)

(a) Select SC-5 (Fiber Rolls) or other BMPs to protect slopes throughout the project's rainy season.	o Complete
(b) For slope inclination of 1:4 (V:H) and flatter, SC-5 (Fiber Rolls) or other BMPs shall be placed along the contour and spaced 20 ft on center.	o Complete
(c) For slope inclination between 1:4 (V:H) and 1:2 (V:H), SC-5 (Fiber Rolls) or other BMPs shall be placed along the contour and spaced 15 ft on center.	o Complete
(d) For slope inclination of 1:2 (V:H) and greater, SC-5 (Fiber Rolls) or other BMPs shall be placed along the contour and spaced 10 ft on center.	o Complete
(e) Increase the quantities by 25% for each additional rainy season. (Designated Construction Representative may suggest alternate increase.)	o Complete
(f) Designate as a separate contract bid line item.	o Complete

Channelized Flow

11. Identify locations within the project site where concentrated flow from stormwater runoff can erode areas of soil disturbance. Identify locations of concentrated flow that enters the site from outside of the right-of-way (off-site run-on).	o Complete
(a) Utilize SS-7 (Geotextiles, RECPs, etc.), SS-9 (Earth Dikes/Swales, Ditches), SS-10 (Outlet Protection/Velocity Dissipation), SS-11 (Slope Drains), SC-4 (Check Dams), or other BMPs to convey concentrated flows in a non-erosive manner.	o Complete
(b) Designate as a separate contract bid line item.	o Complete

Construction Site BMPs
Checklist CS-1, Part 2

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Sediment Control

Perimeter Controls - Run-off Control

1. Is there a potential for sediment laden sheet and concentrated flows to discharge offsite from runoff cleared and grubbed areas, below cut slopes, embankment slopes, etc.? o Yes o No

   (a) Select linear sediment barrier such as SC-1 (Silt Fence), SC-5 (Fiber Rolls), SC-6 (Gravel Bag Berm), SC-8 (Sand Bag Barrier), SC-9 (Straw Bale Barrier), or a combination to protect wetlands, water courses, roads (paved and unpaved), construction activities, and adjacent properties. (Coordinate with District Construction for selection and preference of linear sediment barrier BMPs.) o Complete

   (b) Increase the quantities by 25% for each additional rainy season. (Designated Construction Representative may suggest an alternate increase.) o Complete

   (c) Designate as a separate contract bid line item. o Complete

Perimeter Controls - Run-on Control

2. Do locations exist where sheet flow upslope of the project site and where concentrated flow upstream of the project site may contact DSA and construction activities? o Yes o No

   (a) Utilize linear sediment barriers such as SS-9 (Earth Dike/Drainage Swales and Lined Ditches), SC-5 (Fiber Rolls), SC-6 (Gravel Bag Berm), SC-8 (Sand Bag Barrier), SC-9 (Straw Bale Barrier), or other BMPs to convey flows through and/or around the project site. (Coordinate with District Construction for selection and preference of perimeter control BMPs.) o Complete

   (b) Designate as a separate contract bid line item. o Complete

Storm Drain Inlets

3. Do existing or proposed drainage inlets exist within the project limits? o Yes o No

   (a) Select SC-10 (Storm Drain Inlet Protection) to protect municipal storm drain systems or receiving waters wetlands at each drainage inlet. (Coordinate with District Construction for selection and preference of inlet protection BMPs.) o Complete

   (b) Designate as a separate contract bid line item. o Complete

4. Can existing or proposed drainage inlets utilize an excavated sediment trap as described in SC-10 (Storm Drain Inlet Protection- Type 2)? o Yes o No

   (a) Include with other types of SC-10 (Storm Drain Inlet Protection). o Complete

Sediment/Desilting Basin (SC-2)

5. Does the project lie within a Rainfall Area where the required combination of temporary soil stabilization and sediment control BMPs includes desilting basins? (Refer to Tables 2-1, 2-2, and 2-3 of the Construction Site Best Management Practices Manual for Rainfall Area requirements.) o Yes o No

   (a) Consider feasibility for desilting basin allowing for available right-of-way within the project limits, topography, soil type, disturbed soil area within the watershed, and climate conditions. Document if the inclusion of sediment/desilting basins is infeasible. o Complete

   (b) If feasible, design desilting basin(s) per the guidance in SC-2 Sediment/ Desilting Basins of the Construction Site BMP Manual to maximize capture of sediment-laden runoff. o Complete

   Designate as a separate contract bid item. o Complete

6. Will the project benefit from the early implementation of proposed permanent Treatment BMPs? (Coordinate with District Construction.) o Yes o No

   (a) Edit Order of Work specifications for permanent treatment BMP work to be implemented in a manner that will allow its use as a construction site BMP. o Complete

Sediment Trap (SC-3)

7. Can sediment traps be located to collect channelized runoff from disturbed soil areas prior to discharge? o Yes o No

   (a) Design sediment traps in accordance with the Construction Site BMP Manual. o Complete

   (b) Designate as a separate contract bid line item. o Complete

Construction Site BMPs
Checklist CS-1, Part 3

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Tracking Controls

Stabilized Construction Entrance/Exit (TC-1)

1. Are there points of entrance and exit from the project site to paved roads where mud and dirt could be transported offsite by construction equipment? (Coordinate with District Construction for selection and preference of tracking control BMPs.) — o Yes o No

   (a) Identify and designate these entrance/exit points as stabilized construction entrances (TC-1). — o Complete

   (b) Designate as a separate contract bid line item. — o Complete

Tire/Wheel Wash (TC-3)

2. Are site conditions anticipated that would require additional or modified tracking controls such as entrance/outlet tire wash? (Coordinate with District Construction.) — o Yes o No

   Designate as a separate contract bid line item. — o Complete

Stabilized Construction Roadway (TC-2)

3. Are temporary access roads necessary to access remote construction activity locations or to transport materials and equipment? (In addition to controlling dust and sediment tracking, access roads limit impact to sensitive areas by limiting ingress, and provide enhanced bearing capacity.) (Coordinate with District Construction.) — o Yes o No

   (a) Designate these temporary access roads as stabilized construction roadways (TC-2). — o Complete

   (b) Designate as a separate contract bid line item. — o Complete

Street Sweeping and Vacuuming (SC-7)

4. Is there a potential for tracked sediment or construction related residues to be transported offsite and deposited on public or private roads? (Coordinate with District Construction for preference of including street sweeping and vacuuming with tracking control BMPs.) — o Yes o No

   Designate as a separate contract bid line item. — o Complete

Construction Site BMPs
Checklist CS-1, Part 4

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Wind Erosion Controls

Wind Erosion Control (WE-1)

1. Is the project located in an area where standard dust control practices in accordance with Standard Specifications, Section 10: Dust Control, are anticipated to be inadequate during construction to prevent the transport of dust offsite by wind? o Yes o No
   (Note: Dust control by water truck application is paid for through the various items of work. Dust palliative, if it is included, is paid for as a separate item.)

   (a) Select SS-3 (Hydraulic Mulch), SS-4 (Hydroseeding), SS-5 (Soil Binders), SS-7 (Geotextiles, Plastic Covers, & Erosion Control Blankets/Mats), SS-8 (Wood Mulching) or a combination to cover the DSA subject to wind erosion year-round, especially when significant wind and dry conditions are anticipated during project construction. (Coordinate with District Construction for selection and preference of wind erosion control BMPs.) o Complete

   (b) Designate as a separate contract bid line item. o Complete

Construction Site BMPs
Checklist CS-1, Part 5

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Non-Storm Water Management

Temporary Stream Crossing (NS-4) & *Clear Water Diversion* (NS-5)

1. Will construction activities occur within a waterbody or watercourse such as a lake, wetland, or stream? (Coordinate with District Construction for selection and preference for stream crossing and clear water diversion BMPs.) — o Yes o No

   (a) Select from types offered in NS-4 (Temporary Stream Crossing) to provide access through watercourses consistent with permits and agreements.[1] — o Complete

   (b) Select from types offered in NS-5 (Clear Water Diversion) to divert watercourse consistent with permits and agreements.[1] — o Complete

   (c) Designate as a separate contract bid line item(s). — o Complete

Other Non-Storm Water Management BMPs

2. Are construction activities anticipated that will generate wastes or residues with the potential to discharge pollutants? — o Yes o No

   (a) Identify potential pollutants associated with the anticipated construction activity and select the corresponding BMP such as NS-1 (Water Conservation Practices), NS-2 (Dewatering Operations), NS-3 (Paving and Grinding Operations), NS-7 (Potable Water/Irrigation), NS-8 (Vehicle and Equipment Cleaning), NS-9 (Vehicle and Equipment Fueling), NS-10 (Vehicle and Equipment Maintenance), NS-11 (Pile Driving Operations), NS-12 (Concrete Curing), NS-13 (Material and Equipment Use Over Water), NS-14 (Concrete Finishing), and NS-15 (Structure Demolition/Removal Over or Adjacent to Water).[1] — o Complete

   (b) Verify that costs for non-stormwater management BMPs are identified in the contract documents. Designate BMP as a separate contract bid line item if the requirements in Construction Site Management (SSP 07-346) are anticipated to be inadequate or if requested by Construction. — o Complete

[1] Coordinate with District Environmental for consistency with US Army Corps of Engineers 404 permit and Dept. of Fish and Game 1601 Streambed alteration Agreements.

Construction Site BMPs
Checklist CS-1, Part 6

Prepared by:_____ Date:_____ District-Co-Route:_____
PM (KP):_____ EA:_____
RWQCB:_____

Waste Management & Materials Pollution Control

Concrete Waste Management (WM-8)

1. Does the project include concrete placement or mortar mixing? o Yes o No

   (a) Select from types offered in WM-8 (Concrete Waste Management) to provide concrete washout facilities. In addition, consider portable concrete washouts and vendor supplied concrete waste management services. (Coordinate with District Construction for selection and preference of waste management and materials pollution control BMPs.) o Complete

   (b) Designate as a separate contract bid line item if the quantity of concrete waste and washout are anticipated to exceed 5.2 yd^3 or if requested by Construction. o Complete

Other Waste Management and Materials Pollution Controls

2. Are construction activities anticipated that will generate wastes or residues with the potential to discharge pollutants? o Yes o No

   (a) Identify potential pollutants associated with the anticipated construction activity and select the corresponding BMP such as WM-1 (Material Delivery and Storage), WM-2 (Material Use), WM-4 (Spill Prevention and Control), WM-5 (Solid Waste Management), WM-6 (Hazardous Waste Management), WM-7 (Contaminated Soil Management), WM-9 (Sanitary/Septic Waste Management) and WM-10 (Liquid Waste Management) o Complete

   (b) Verify that costs for waste management and materials pollution control BMPs are identified in the contract documents. Designate BMP as a separate contract bid line item if the requirements in Construction Site Management (SSP 07-346) are anticipated to be inadequate or if requested by Construction. o Complete

Temporary Stockpiles (Soil, Materials, and Wastes)

3. Are stockpiles of soil, etc. anticipated during construction? o Yes o No

   (a) Select WM-3 (Stockpile Management), SS-3 (Hydraulic Mulch), SS-4 (Hydroseeding), SS-5 (Soil Binders), SS-7 (Geotextiles, RECPs etc.), or a combination as appropriate to cover temporary stockpiles of soil, etc. o Complete

(b) Select linear sediment barrier such as SC-1 (Silt Fence), SC-5 (Fiber Rolls), SC-6 (Gravel Bag Berm), SC-8 (Sand Bag Barrier), SC-9 (Straw Bale Barrier), or a combination to encircle temporary stockpiles of soil, etc. (Coordinate with District Construction for selection and preference of BMPs related to stockpiles.) o Complete

(c) Designate as a separate contract bid line item if the requirements in Construction Site Management (SSP 07-346) are anticipated to be inadequate or if requested by Construction. o Complete

4. Is there a potential for dust and debris from construction material (fill material, etc.) and waste (concrete, contaminated soil, etc.) stockpiles to be transported offsite by wind? o Yes o No

(a) Select SS-7, temporary cover, plastic sheeting or other BMP to cover stockpiles subject to wind erosion year-round, especially when significant wind and dry conditions are anticipated during project construction. (Coordinate with District Construction for selection and preference of wind erosion control BMPs.) o Complete

(b) Designate as a separate contract bid line item. o Complete

Appendix F

Cost Estimates

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F.1 INTRODUCTION

The reliability of project cost estimates at every stage in the project delivery process is necessary for responsible fiscal management (see Chapter 20 of the Project Development Procedures Manual (PDPM, July 1999) for additional information). Unreliable cost estimates can result in severe problems in Caltrans programming and budgeting, in local and regional planning, and it results in staffing and budgeting decisions that could impair effective use of resources. This, in turn, affects Caltrans relations with the California Transportation Commission (CTC), the Legislature, local and regional agencies, and the public, and results in loss of credibility. Storm Water Quality Best Management Practices (BMPs) are an integral part of a project, and need to be accurately estimated during the Project Initiation Document (PID), Project Approval/Environmental Document (PA/ED), and Plans, Specifications and Estimates (PS&E) phases.

F.2 OBJECTIVES

Caltrans strives to avoid cost overruns on projects. One objective is to anticipate "unforeseen items of work" before the project concept, scope, and cost have been determined; thus minimizing the differences between cost estimates during the PID process, the PA/ED process and the PS&E process. The objective of this appendix is to provide general guidance on incorporating the cost of stormwater BMPs into the project delivery process; however, it is understood that local district procedures for cost estimating may vary.

F.3 METHODOLOGY

Although cost estimating is not an exact science, Caltrans must strive for reliable project cost estimates so that projects can be delivered "within budget." To this end, it is required that project cost estimates be prepared using a consistent and comprehensive methodology. Even with a consistent and comprehensive methodology, careful attention is needed to ensure a quality cost estimate. The cost estimator needs to research, compare and, above all, use their professional judgment to prepare a quality cost estimate.

F.3.1 Categories of Project Cost Estimates

There are two categories of project cost estimates: Project Planning Cost Estimates (PPCE) and Project Design Cost Estimates (PDCE). PPCEs are used for project justification, analysis of alternatives, approval, and for programming. PDCEs are used to summarize the cost of a project's contract items of work and will be part of the construction contract for the project.

PPCEs are cost estimates prepared in advance of project approval. The initial programmed cost (see PDPM, Chapter 6, Article 2) that appears the first time a project is listed is based on an escalation of a PPCE. PPCEs are categorized as: (1) Project Feasibility; (2) Project Summary Report (PSR); (3) Draft Project Report (DPR); and (4) Project Report (PR).

PDCEs are design cost estimates made after PR approval and until completion of the PS&E process. These estimates are categorized as either preliminary or final. PDCEs focus on the construction costs of the project and are input into the Basic Engineering Estimating System (BEES). BEES has two components: (1) the District (Highway) Cost Estimate, and (2) the

Structures (Bridge) Cost Estimate, that, when combined, equal the total construction cost for the project.

PDCEs should be considerably more detailed than PPCEs. As engineering and environmental studies progress, more information, such as final contour mapping, materials and drainage information, and structure studies, becomes available. This data increases the ability to prepare a more detailed cost estimate.

Cost estimates, in a sense, are never completed. They are not static, but have to be reviewed continually to keep them current. Other functional units (Division of Structures, Right-of-Way, Traffic Operations, Materials, Maintenance, Construction, Environmental, Landscape Architecture, etc.) and local entities should be involved, as appropriate, in the preparation of both PPCEs and PDCEs. The designer should gather as much information as possible for the project and its various alternatives. It is better to have too much information than not enough. Coordination between the PPCEs, the PDCEs, and the Standard Specifications that will be used to construct the project is required.

F.3.2 Systematic Field Reviews

During the planning phase, it is essential that project alternatives be adequately scoped. This is best accomplished by performing systematic field reviews to obtain factual data. This data is used to backup the cost estimates so that the estimates can be used with confidence. In addition, a systematic field review will help to ensure that the project is adequately scoped. Systematic field reviews are an essential part of the project delivery process. They provide an important perspective that supplements the mapping, photos, survey data and other sources of information about the project that are used in the office. Systematic field reviews will minimize the possibility of overlooking significant features that could affect project design.

While in the field, project personnel should be on the lookout for high cost items (i.e., retaining walls, major storm drains, additional rights-of-way required for installation of Treatment BMPs, utility obstructions, traffic handling, etc.). If high cost items are present or need to be designed into the project alternatives, then they must be quantified. The "worse probable case" should always be assumed, particularly on reconstruction projects. Existing facilities thought to be adequate may have become inadequate because of changes to standards, new data, etc. Design feature decisions, project constructability, construction staging, are among a variety of issues that should be evaluated in the field. Notes should be taken to document decisions and to identify limits, boundaries, and other conditions.

F.3.3 Technical Information

Technical information that must be obtained to prepare a PPCE includes, but is not limited to: geotechnical design information (particularly where infiltration is being considered or slope stability problems can be anticipated); materials information; hazardous waste assessment; potential environmental issues and mitigation; right-of-way and utilities data sheets; traffic handling and transportation management plans; etc. The designer should refer to as-built drawings or other references to see what information is available early in the project delivery process. If necessary information is not available, then it should be requested from the appropriate source unit.

F.3.4 Use Groupings from Standard Cost Estimate Format

Individual contract items are difficult to identify at the early project development stages, but it is possible to group basic work functions together to form a systematic approach to project cost estimating. Most projects have Design Pollution Prevention BMPs, Treatment BMPs, and Construction Site BMPs that are relatively easy to recognize and quantify. The standard cost estimating format (see Section F.7) provides for this approach by using such groupings. Coordination between the planning cost estimate and the Standard Specifications is essential, since these elements will directly influence construction of the project. A thorough knowledge of the Standard Specifications is essential.

F.3.5 Contingencies Versus Confidence Factor

Contingency factors for project planning cost estimates vary depending on the cost estimate type. Contingencies are intended to compensate for the use of limited information. The percentage goes down as the project becomes more defined and thus less unknown. Contingencies are not intended to take the place of complete design work. Project alternatives and their associated cost estimates must be thoroughly compiled by diligently using all of the available data, modifying that data with good judgment and using past cost estimating experience so that the cost estimates can be used with confidence.

F.3.6 Construction Seasons

Consideration should be given when a project is anticipated to extend beyond a single construction season. If the project cannot be finished before the end of the construction season and the project needs to be suspended, contractors will increase their bid prices to cover their overhead during the winter (i.e. “rainy” or “wet” season) and repair any damage that may occur. Even if contractors reasonably expect to finish before the winter, they may protect themselves to allow for an early winter. This can especially be true if construction involves work on items that may be affected by winter weather (i.e., drainage channels, earthwork, slope stabilization, etc.), or that requires deployment of additional Construction Site BMPs. Therefore, if a construction project is anticipated to extend over two or more construction seasons, add 25% to the estimated cost for Construction Site BMPs as determined by Section F.6.1 or Section F.6.3.

F.4 SUPPLEMENTAL WORK

Supplemental work is work of an uncertain nature or amount and, therefore, it is not done on a contract item basis. Work that is known but cannot be predetermined and provided for under contract items of work should be included as supplemental work. Supplemental work is not intended to take the place of complete design work, nor is it to be used for contingencies. The designer should not add supplemental work items for "possible additional work" for any major area of work (i.e. drainage, traffic items, etc.). Additional funds for undeterminable changes, such as increased dewatering operations, additional soil stabilization, or increased maintenance of Construction Site BMPs due to unusual weather (i.e. early winter or heavier than normal rainfall), should be included as supplemental work.

Extra work identified in the contract special provisions must be itemized as supplemental work. Contingencies are a percentage of the subtotal of the cost of contract items, supplemental work,

and state-furnished materials and expenses, and are included in the grand total of the District Cost Estimate to allow for unforeseen increases.

F.5 STANDARD SPECIFICATIONS, CONTRACT PLANS AND SPECIAL PROVISIONS

All District Cost Estimates are to be based on the *Standard Specifications*, Contract Plans and Special Provisions. These documents form the basis for determining contract items. The *Standard Specifications*, along with the Contract Plans and Special Provisions for a specific project, prescribe the details for construction and completion of the work that the Contractor undertakes to perform in accordance with the terms of the contract. Coordination between the District Cost Estimate, the *Standard Specifications*, Contract Plans and Special Provisions is required.

F.6 ESTIMATING OPTIONS

There are three estimating options that may be used to establish prices for Storm Water BMPs considered during the PID, PA/ED, and PS&E processes of a project. These options may be used individually or in combination, and are shown in Table F-1:

Table F-1: Options for Estimating Storm Water BMPs

Option	Description
1	Percent of Total Project Cost
2	Historical Project Information
3	Estimated Unit Cost Sample
4	Actual Unit Cost

Although the cost estimating procedures may vary for each District, Table F-2 lists the options that are generally available during the different project delivery processes:

Table F-2: Estimating Options Available During the Project Development Processes

Project Process	Option	Documentation
PID	1 or 2	Storm Water Data Report (SWDR) / Preliminary Project Cost Estimate (PPCE)
PA/ED	2 or 3 or 4	Updated PPCE
PS&E	3 or 4	PDCE

The designer must provide estimates for the following Storm Water – related items:

- Design Pollution Prevention BMPs;
- Treatment BMPs;
- Construction Site BMPs;
- Cost for the contractor to prepare a SWPPP or WPCP; and
- Right-of-way Acquisition.

Design Pollution Prevention BMPs are normally covered under bid line items for excavation, grading, backfill, etc. Treatment BMPs may also be covered under bid line items, but are difficult to estimate during the planning phase. Construction Site BMPs are normally estimated as a percentage of the total project cost due to the uncertainty of the contractor's schedule. In addition, costs for right-of-way acquisitions to accommodate Treatment BMPs or drainage easements need to be incorporated into the estimate. The designer should base the estimated cost for land acquisition upon the unit right-of-way costs established by the District Right-of-Way Branch for the specific project area (see Section F.7.3).

F.6.1 Option 1: Percent of Total Cost Method

The Percent of Total Project Cost method can be used during the PID process when no unit costs or sample historical project costs are available. Table F-3 can be used to determine the percentage of cost for Construction Site BMPs based on the total construction costs (not including right-of-way costs). Typically, the total cost of Construction Site BMPs range from one percent (1%) to two percent (2%) of total project cost.

To use Table F-3, add the adjustments that apply for the particular project and then multiply the total estimated construction cost by the total of adjustments.

Table F-3: Percentage of Extra Cost to Project Due to Construction Site BMPs

Description	Recommended Adjustment (%)
Baseline Cost Percentage	1.25 [1]
Adjustment for Project Magnitude (Cost)	
$0 to $1,000,000	2.00
$1,000,000 to $1,500,000	1.25
$1,500,000 to $12,000,000	0.25
Greater than $12,000,000	0.00
Adjustment for Location (RWQCB)	
Region 9 (San Diego)	0.75
All other Regions	0.00
Adjustment for Type of Project	
Highway Planting (Landscaping)	0.10
All other projects	0.00
Adjustment for Work near 303(d) Water Bodies	
Work near 303(d) Water Bodies	Project Specific[2]
Adjustment for Project Specific Issues	
Project specific issues such as environmental sensitivity, monitoring, dewatering and discharge restrictions, permits, extreme construction conditions (coastal, mountain, urban), etc.	Project Specific[2]
a) Total Adjustments for Water Pollution Control	(sum)

[1] Baseline cost percentage of 0.75 is based upon actual construction costs for projects completed in 2003, 2004 and 2005 as described in the Water Pollution Cost Report prepared in 2005. (CT-SW-RT-05-138-04.1). Increase the baseline percentage to 1.25 or higher as necessary to reflect cost increases since 2005.

[2] Engineer preparing estimate should discuss the cost implications of project specific issues with District Storm Water Coordinator and District Construction Storm Water Coordinator.

Example:

For an interchange modification project consisting of structure widening, ramp realignment, and embankment construction, the estimated cost is $16,000,000. The project is located in San Diego County and is within RWQCB Region 9. The project drains to an unlisted water body. The adjustment factor is based upon the following:

Baseline Cost Percentage	1.25
Greater than $12,000,000	0.00
Adjustment for Location (RWQCB 9))	0.75
Adjustment for Type of Project	0.00
Adjustment for Work near 303(d) Water Bodies	0.00
Adjustment for Project Specific Issues	0.00
Total Adjustments for Water Pollution Control	2.00

The PID phase estimate for water pollution control is $320,000 ($16,000,000 x 2.00%).

As previously mentioned, the Design Pollution Prevention BMPs are normally covered under individual bid line items. The Treatment BMPs, however, are not normally defined enough at the PID stage to estimate as excavation, backfill, etc. For New Construction or Major Reconstruction Projects, an additional $100,000 to $250,000 per lane mile should be added to cover costs associated with incorporating Treatment BMPs. The lower end of this range would apply to projects that are not adjacent to a 303(d) listed water body. Conversely, the higher end of this range would be for projects that are adjacent to 303(d) listed water bodies. This price does not include right-of-way acquisition costs for constructing Treatment BMPs or for establishing drainage easements.

F.6.2 Option 2: Historical Project Method

The Historical Project method uses historical project cost information and updates that information to present day costs using the cost indexes in the Engineering News Record. This method can be generally used during the PID and PA/ED processes.

The following guidelines apply when using Historical Project costs:

- Similar size projects should be used and quantities for individual items should be similar;
- Consider using the average of the five lowest bidders, or possibly applying an increase factor to the low bid;
- Previous bid prices should be revised by the projected change in the California Construction Cost Index between the date of the old bid and the date of the anticipated new bid;
- The reference bid price should be adjusted to reflect different conditions between the reference project and the project for which the cost estimate is being prepared. This would include considerations of differences in type of terrain, geographical location, soil, traffic and specifications; and
- Lump sum bid prices or unit prices for items of work (e.g. culverts) that include varying amounts of other related work should not be used.

Table F-4 is a sample table that may be used to list the project, description of BMP(s), and corresponding unit price (if available) and the total dollar amount of specific BMPs. This table should be used separately to complete cost estimates for Design Pollution Prevention, Treatment and Construction Site BMPs. The total costs for each can then be added together.

Table F-4: Sample Table

Historical Project Name/EA	BMP Description	Unit of Measurement	Unit Price	Total Dollar Amount

F.6.3 Option 3, Unit Costs

The Unit Cost method uses estimated (Option 3) and actual (Option 4) unit costs. Both Options 3 and 4 can be used during the PS&E process. However, Option 4 is preferred.

Sources for estimating unit cost include the following:

- Design Pollution Prevention BMPs – See Table F-5;
- Construction Site BMPs – Table F-5;
- Basic Engineering Estimating System (BEES).

Table F-5 lists a range of unit costs for erosion and sediment control BMPs along with their related effectiveness. This table does not include costs for additional right-of-way acquisitions, if needed.

Table F-5: Installed Costs and Effectiveness of BMPs

BMP	Unit Cost Installed	Estimated Relative Erosion/ Sediment Control Effectiveness
SEDIMENT CONTROL		
Silt Fence	$3.00 – 4.00 per lineal foot	UNK
Fiber Rolls	$3.50 – 4.25 per lineal foot	58%
Gravel/Sand Bags Barrier	$0.45 – 0.90 per linear foot	UNK
Temporary Straw Bale Barrier	$2.30 – 4.50 per linear foot	UNK
TRACKING CONTROL		
Stabilized Construction Entrance/Exit	$1,500 – 2,500 each	UNK
NON-STORM WATER CONTROL		
Temporary Concrete Washout Facility	$1,500 – 3,000 each	UNK
SOIL STABILIZATION		
Vegetative:		
Fertilizer	$450 – 550 per acre	N/A
Seeding	$870 – 2,170 per acre	50%
Stolonizing	$2,200 per acre + cost of stolons	90%
Hydraulic Mulching	$900 – 1,200 per acre	50 – 60%
Compost Application	$900 – 1,200 per acre	40 – 50%
Straw Mulching	$1,800 – 2,100 per acre	90 – 95%
Mulch (Bark/Wood Chips –2 inch layer	$4,000 – 9,000 per acre	UNK
Erosion Control (Type C) {reference application of 110 lb seed, 1,000 lb fertilizer, 660 lb fiber, and 4.5 tons incorporated straw}		
Erosion Control (Type D) {reference application of 110 lb seed, 660 lb fertilizer, 4,400 lb compost, 1,300 lb fiber, 4.5 tons straw, and 300 lb tackifier}		
Non-Vegetative:		
Temporary Cover/Plastic Sheeting	$2.00 – 3.00 per square yard	UNK
Slope Roughening, Trackwalking, Imprinting	$0 – 350 per acre	
Rock Blanket (Cobble)	$12,000 – 28,000 per acre	
Rock Slope Protection (RSP-Light)	$15,600 – 25,700 per acre	
Rock Slope Protection (RSP-1/4 Ton)	$16,200 – 40,500 per acre	
Rock Slope Protection (RSP-1/2 Ton)		
Rock Slope Protection (RSP-1 Ton)		
Soil Binders		
Plant Material-Based (Short-Term)	$700 – 900 per acre	80 – 85%
Plant Material-Based (Long-Term)	$1,200 – 1,500 per acre	60 – 65%
Polymeric Emulsion Blends	$700 – 1,500 per acre	30 – 70%
Petroleum Resin-Based	$1,200 – 1,500 per acre	25 – 20%

Table F-5: Installed Costs and Effectiveness of BMPs

Cementitious Binder-Based		80 – 85%
Bonded Fiber Matrices		90 – 95%
Rolled Erosion Control Products		
Biodegradable:		
Jute	$6,000 – 7,000 per acre	65 – 70%
Curled Wood Fiber	$8,000 – 10,500 per acre	85 – 90%
Straw	$8,000 – 10,500 per acre	85 – 90%
Wood Fiber	$8,000 – 10,500 per acre	85 – 90%
Coconut Fiber	$13,000 – 14,000 per acre	90 – 95%
Coconut Fiber Net		85 – 90%
Straw Coconut		90 – 95%
Non-Biodegradable:		
Plastic Netting	$5,000 – 6,500 per acre	< 50%
Plastic Mesh	$3,000 – 3,500 per acre	75 – 80%
Synthetic Fiber w/Netting	$34,000 – 40,000 per acre	90 – 95%
Bonded Synthetic Fibers		90 – 95%
Combination Synthetic and Erosion Control		85 – 90%
STABILIZED CONVEYANCE SYSTEMS		
Culverts, Ditches, Berms, Dikes, Swales, Bio-strip*, Bio-swales* *Listed in this section for convenience but listed in the SWMP as Treatment BMPs		
TREATMENT BMPs		
Infiltration Device; Detention Device; Gross Solids Removal Device; Dry Weather Flow Diversion; Traction Sand Trap	Estimate using individual components of entire system, e.g.: Infiltration Device would require earthwork, minor concrete, asphalt concrete; various landscape items, various hydraulic items.	
NEW AND/OR UNAPPROVED BMPs		
MISCELLANEOUS		
Dewatering (Sediment Removal Only)	$100 per day per discharge	N/A
Temporary Creek Diversion System	$15,000 – 35,000	N/A

Sources: Unless otherwise noted, information derives from the Erosion Control Pilot Study Report, URS Greiner Woodward Clyde, June 2000, Table 4-1; and Caltrans Costs Data

[1] 2005 Caltrans Contract Cost Data

Prepare Water Pollution Control Program (BEES Item: 074017) & Prepare Storm Water Pollution Prevention Plan (BEES Item: 074019)

Use Table F-6 to estimate the cost of preparing the written document describing the implementation of the project's water pollution controls. Projects with less than one (1) acre of soil disturbance will have Prepare Water Pollution Control Program (WPCP). Projects with one

(1) acre or more disturbed soil area will have Prepare Storm Water Pollution Prevention Plan (SWPPP). Prepare SWPPP will usually include the cost to prepare the Sampling and Analysis Plan (SAP).

Table F-6: Construction Site Water Pollution Control

a) Total Construction Cost	**Prepare SWPPP**	**Prepare WPCP**
$0 to $500,000	$5,000	$3,000
$500,000 to $1,000,000	$6,000	$5,000
$1,000,000 to $1,500,000	$6,000	$5,000
$1,500,000 to $12,000,000	$6,000	-
Greater than $12,000,000	$10,000	-

Construction Site Management (BEES Item: 074016)

Since bid history for Construction Site Management (SSP 07-346) is not yet available, the result from Table F-3 will be used as a starting figure. From this amount, subtract out costs for all separate BMPs bid items included. As a rule-of-thumb, Construction Site Management cost should be no lower than what is estimated for Prepare SWPPP (or Prepare WPCP).

Storm Water Sampling and Analysis (BEES Item: 066597)

Supplemental work items for Storm Water Sampling and Analysis (monitoring) are typically overestimated. It has been suggested that funds should only be included for projects that drain into a 303(d) water body listed for sediment or turbidity. Supplemental Work funds are not needed for non-visible pollutant testing as the conditions requiring testing rarely arise. Since information on what has been paid out for Storm Water Sampling is difficult to obtain, this extra work item should be estimated at the same rate as for Prepare SWPPP. This would be incremented for each rainy season anticipated and only included for sediment and turbidity listed waters.

Additional Water Pollution Control (BEES Item: 066596)

The Supplemental Work item for Additional Water Pollution Control will cover the addition of WPC BMPs suggested by the RE or Contractor. This is expected to be minor for most projects. As such, it is suggested to use the same rate as for Prepare SWPPP (or Prepare WPCP).

Water Pollution Control Maintenance Sharing (BEES Item: 066595)

The Supplemental Work item for Water Pollution Control Maintenance Sharing still exists but has been shifted to the individual separate item BMPs that allow for cost sharing. Water Pollution Control Maintenance Sharing cost should be no lower then the amount estimated for Prepare SWPPP (or Prepare WPCP). The following may be used to estimate BMP maintenance costs based upon input from Districts where this approach was piloted. The aggregate total of estimated maintenance costs would be combined into item WPC Maintenance Sharing:

- Temporary Silt Fence, estimate at 10% of the separate item cost per rainy season.
- Temporary Fiber Roll, estimate at 10% of the separate item cost per rainy season.
- Temporary Erosion Control and other hydraulically applied soil stabilization BMPs, estimate at 10% of the separate item cost per rainy season.
- Temporary Gravel Bag Berm, estimate at 25% of the item cost per rainy season.
- Temporary Drainage Inlet Protection, estimate at 25% of the item cost per rainy season.
- Temporary Construction Entrance, estimate at 25% of the item cost per rainy season.

All other Separate Item BMPs

For the variety of separate contract item BMPs such as hydraulic mulch or silt fence, the Item Cost database on the OE website will be sufficient. The items mentioned previously are not tracked so other methods must be used as tools for guidance. Also refer to Table F-5.

F.7 STANDARD FORMAT FOR PROJECT PLANNING COST ESTIMATES

The standard format included at the end of the PDPM (Appendix AA) may be used for all project planning cost estimates. For many projects, the form can be used as is by completing a cover sheet and "filling-in" the blanks. However, if needed, extra lines are provided for items not listed. Additional lines may be added as necessary.

The standard format is broken into four components:

- Cover Sheet;
- Roadway Items;
- Structure Items; and
- Right-of-Way.

Although the standard format was not written specifically for estimating Storm Water BMPs, Sections 3 (Drainage) and 4 (Specialty Items) may be used for this purpose. The concept behind the standard format requires that the cost estimator determine quantities and costs for groups of related work as previously discussed in Sections F.1 through F.5 of this Project Planning and Design Guide (PPDG). Identification of contract items is not necessary (but would be beneficial) to obtain a realistic cost estimate for each viable project alternative. Calculation sheets, maps and sketches used to determine costs and quantities for the cost estimate should be retained in the project files until the project has been completed and finalized.

F.7.1 Drainage

Large drainage facilities (i.e., reinforced concrete boxes, etc.) should be estimated separately and the *Standard Plans* should be consulted for quantities. Drainage items for widening and

rehabilitation projects can be estimated by determining extensions to existing culverts and the number of other features, such as inlets, and overside drains, that will be affected. Be aware of any additional right-of-way that may be needed for drainage easements. Bid sheets from adjacent or similar type projects can be evaluated for estimating unit costs. Cost estimates for drainage on new alignment projects can be quantified by comparisons with similar types of projects.

F.7.2 Specialty Items

Items such as erosion control or slope protection (both during construction and permanent) can be estimated by using slope information obtained from the field review. Items such as hazardous wastes and environmental mitigation require consultation with other functional units in the District, the Engineering Service Center, and Headquarters. It is important to deal with hazardous waste and environmental issues immediately and design the project avoid them if possible, since they often adversely affect project cost estimates.

F.7.3 Right-of-Way Items

The right-of-way portion of the cost estimate should be obtained from the District Right-of-Way Branch. The Right-of-Way Branch prepares its cost estimate based on current procedures and guidelines contained in the *Right-of-Way Manual*. Costs for the listed right-of-way items are to be obtained from the Right-of-Way Data Sheet (see Appendix JJ of the PDPM). The Right-of-Way Data Sheet should be referred to in the project cost estimate as backup information.

"Construction Contract Work" (contractual obligations made by the Right-of-Way Branch with the property owner, such as the costs to relocate fencing, reconstruct gates, reconstruction of road approaches) should be described briefly and the estimated cost to perform this work given. The estimated cost should only be shown in this portion of the PPCE, not included. Construction contractual obligations are to be included in the project cost estimate as construction items of work.

F.7. 4 Cost Estimate

The following pages contain excerpts from Appendix AA of the PDPM. These sheets may be used to track estimates relating to costs for incorporating stormwater BMPs. The reader should refer to the PDPM for more specific guidance on using these forms.

(Enter Type of Project Planning Cost Estimate as Title)

Caltrans Metric

District-County-Route_____

KP (PM) _____

EA _____

Program Code _____

PROJECT DESCRIPTION:

Limits _____

_____

Proposed Improvement (Scope) _____

_____

Alternate _____

SUMMARY OF PROJECT COST ESTIMATE

TOTAL ROADWAY ITEMS	$_____
TOTAL STRUCTURE ITEMS	$_____
SUBTOTAL CONSTRUCTION COSTS	$_____
TOTAL RIGHT OF WAY ITEMS	$_____
TOTAL PROJECT CAPITAL OUTLAY COSTS	$_____

Reviewed by District Program Manager _____
(Signature)

Approved by Project Manager _____ Date _____
(Signature)

Phone No. _____ Page No. ____ of ____

District-County-Route _____
KP (PM) _____
EA _____

Section 3 Drainage	Quantity	Unit	Unit Price	Item Cost
Large Drainage Facilities	_____	____	$_____	$_____
Storm Drains	_____	____	$_____	$_____
Pumping Plants	_____	____	$_____	$_____
Project Drainage (X-Drains, overside, etc.)	_____	____	$_____	$_____
_____	_____	____	$_____	$_____
_____	_____	____	$_____	$_____
_____	_____	____	$_____	$_____
_____	_____	____	$_____	$_____

Subtotal Drainage $_____

*Reference sketch showing typical pavement structural section elements of the roadway. Include (if available) T.I., R-Value and date when tests were performed.

NOTE: Extra lines are provided for items not listed, use additional lines as appropriate.

Page No. ___ of ___

District-County-Route _____
KP (PM) _____
EA _____

Section 4 Specialty Items	**Quantity**	**Unit**	**Unit Price**	**Item Cost**
Retaining Walls	_____	____	$_____	$_____
Noise Barriers	_____	____	$_____	$_____
Barriers and Guardrails	_____	____	$_____	$_____
Equipment/Animal Passes	_____	____	$_____	$_____
Highway Planting	_____	____	$_____	$_____
Replacement Planting	_____	____	$_____	$_____
Irrigation Modification	_____	____	$_____	$_____
Relocate Private Irrigation Facilities	_____	____	$_____	$_____
Erosion Control	_____	____	$_____	$_____
Slope Protection	_____	____	$_____	$_____
Water Pollution Control	_____	____	$_____	$_____
Hazardous Waste Mitigation Work	_____	____	$_____	$_____
Environmental Mitigation	_____	____	$_____	$_____
Resident Engineer Office Space	_____	____	$_____	$_____
_____	_____	____	$_____	$_____
_____	_____	____	$_____	$_____

Subtotal Specialty Items $_____

NOTE: Extra lines are provided for items not listed, use additional lines as appropriate.

District-County-Route _____

KP (PM) _____
EA _____

III. RIGHT OF WAY ITEMS ESCALATED VALUE

A. Acquisition, including excess lands, damages to remainder(s) and Goodwill $_____

B. Utility Relocation (State share) $_____

C. Relocation Assistance $_____

D. Clearance/Demolition $_____

E. Title and Escrow Fees $_____

TOTAL RIGHT OF WAY ITEMS $_____
(Escalated Value)

Anticipated Date of Right of Way Certification $_____
(Date to which Values are Escalated)

F. Construction Contract Work

Brief Description of Work:

_____

_____

_____

Right of Way Branch Cost Estimate for Work * $_____

* This dollar amount is to be included in the Roadway and/or Structures Items of Work, as appropriate. Do not include in Right of Way Items.

COMMENTS:

Estimate Prepared By _____ Phone# _____

Date _____ _____
(Print Name)

NOTE: If appropriate, attach additional pages and backup.

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Appendix G

Abbreviations, Acronyms and Definition of Terms

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G.1 ABBREVIATIONS

a-f	acre-feet
cm	centimeter
cm/hr	centimeters per hour
cfs	cubic feet per second
fps	feet per second
’ or ft	feet
ft^2	square feet
ft^3	cubic feet
g	gram
ha	hectares
” or in	inches
”/hr or in/hr	inches per hour
hr(s)	hour(s)
kg	kilogram
kg/ha	kilograms per hectare
kg/m^2	kilograms per square meter
km	kilometer
l	liter
m	meter
mg	milligram
meq	milliequivalents
min	minute
mm	millimeter
m/s	meters per second
m^3	cubic meters
m^3/yr	cubic meters/year
v:h	vertical : horizontal
yd^3	cubic yard
yr	year
^oC	degrees Celsius
>	greater than
$\geq$	greater than or equal to
<	less than
$\leq$	less than or equal to

G.2 ACRONYMS

ADL	Aerially Deposited Lead
ADT	Annual Average Daily Traffic
APS	Advanced Planning Study
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
BAT	Best Available Technology
BCT	Best Conventional Technology
BCDC	Bay Conservation and Development Commission
BEES	Basic Engineering Estimating System
BFM	Bonded Fiber Matrix
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
BOD_5	5-Day BOD
Caltrans	California Department of Transportation
CDERP	Consideration of Downstream Effects Related to Potentially Increased Flow
CE	Categorical Exemption/Exclusion
CEC	Cation Exchange Capacity
CEQA	California Environmental Quality Act
CFR	Code of Federal Regulations
CO_2	Carbon Dioxide
C-SWAT	Construction Storm Water Advisory Team
CSWPPP	Conceptual Storm Water Pollution Prevention Plan
CTC	California Transportation Commission
CWA	Clean Water Act
DED	Draft Environmental Document
DHS	California Department of Health Services
DPR	Draft Project Report
DTSC	Department of Toxic Substances Control
DSA	Disturbed Soil Area
DWR	California Department of Water Resources
DWP	District Work Plan
EA	Expenditure Authorization
ED	Environmental Document
EPA	U.S. Environmental Protection Agency
ESA	Environmentally Sensitive Area
FED	Final Environmental Document
FES	Flared End Section
FHWA	Federal Highway Administration
GIS	Geographic Information System
GSRD	Gross Solids Removal Device
GW	Groundwater
HDM	Highway Design Manual
HOV	High Occupancy Vehicle
HRT	Hydraulic Residence Time
HSG	Hydrologic Soil Group

HQ	Headquarters
ISA	Initial Site Assessment
KP	Kilometer Post
MCL	Maximum Contaminant Level
MCTT	Multi-Chamber Treatment Train
MEP	Maximum Extent Practicable
MS4	Municipal Separate Storm Sewer System
M-SWAT	Maintenance Storm Water Advisory Team
N	Nitrogen (elemental)
N_2	Nitrogen (molecular) or Nitrogen gas
NEPA	National Environmental Policy Act
NH_3	Ammonia
NH_4^+	Ammonium ion
NO_3^-	Nitrate ion
NOCC	Notice of Completion of Construction
NOC	Notification of Construction
NPDES	National Pollutant Discharge Elimination System
NPRPD	National Pollutant Removal Performance Database
NRCS	Natural Resources Conservation Service
NSBMDB	National Storm Water Best Management Database
OC	Organic Content
OE	Office Engineer
O&G	Oil and Grease
O&M	Operation and Maintenance
PA/ED	Project Approval/Environmental Document
PCC	Portland Cement Concrete
PDCE	Project Design Cost Estimate
PDPM	Project Development Procedures Manual
PD-SWAT	Project Design Storm Water Advisory Team
PDT	Project Development Team
PE	Project Engineer
PEAR	Preliminary Environmental Assessment Report
PEE	Preliminary Environmental Evaluation
PGR	Preliminary Geotechnical Report
PID	Project Initiation Document
PM	Project Manager
POTW	Publicly Owned Treatment Works
PPCE	Preliminary Project Cost Estimate
PPDG	Project Planning and Design Guide (Storm Water Quality Handbooks)
PR	Project Report
PS&E	Plans, Specifications and Estimates
PSR	Project Study Report
RE	Resident Engineer
RECP	Rolled Erosion Control Products
RO	Runoff
RRR	Resurfacing, Restoration & Rehabilitation projects
RSP	Rock Slope Protection

RWQCB	Regional Water Quality Control Board
SAP	Sampling Analysis Plan
SSP	Standard Special Provisions
SUSMP	Standard Urban Storm Water Mitigation Plan
SW	Storm Water
SWAT	Storm Water Advisory Team
SWDR	Storm Water Data Report
SWMP	Storm Water Management Plan
SWPPP	Storm Water Pollution Prevention Plan
SWRCB	California State Water Resources Control Board
TDC	Targeted Design Constituent
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
Total Ortho-P	Total Ortho Phosphate
TP	Total Phosphorous
TRPA	Tahoe Regional Planning Agency
TSS	Total Suspended Solids
UNK	Unknown
USA	Underground Service Alert
USDA	United States Department of Agriculture
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UV	Ultraviolet
WBS	Work Breakdown Structure
WDR	Waste Discharge Requirement
WEF	Water Environment Federation
WLA	Waste Load Allocations
WPCP	Water Pollution Control Program
WQ	Water Quality
WQAG	Water Quality Assessment Guidelines
WQF	Water Quality Flow
WQR	Water Quality Assessment Technical Report
WQ-SWAT	Water Quality Storm Water Advisory Team
WQV	Water Quality Volume

G.3 DEFINITION OF TERMS

Bolded items in the following text signify that their definition can be found in this Appendix.

5-Day Biochemical Oxygen Demand (BOD) Test:

BOD refers to the oxygen used in meeting the metabolic needs of aerobic microorganisms in water containing organic matter. The higher the level of organic matter, the higher the BOD. For example, water polluted with sewage would have a high BOD.

The 5-day BOD test (BOD_5) measures the rate of oxygen required by microorganisms (i.e., a laboratory inoculation) to oxidize the biodegradable matter in a sample under controlled

laboratory test conditions. High BOD results (usually the result of organic contamination) suggest that the dissolved oxygen levels in **receiving water** may be depleted.

303(d) List:

The 303(d) list is a list of **water bodies** that have one or more **beneficial uses** that are impaired by one or more pollutants. The 303(d) list is required by Section 303(d) of the federal **CWA**. Water bodies included on this list are referred to as "impaired waters." The State must take appropriate action to improve impaired water bodies, such as development of a **TMDL.**

Aerially Deposited Lead (ADL):

ADL is the lead that is frequently found in urbanized highway corridors due to historic emissions from automobile exhaust. These emissions are the result of past use of leaded gasoline. Soil impacted by ADL must be handled appropriately to prevent it from impacting the quality of stormwater runoff from Caltrans projects. Caltrans has applied for and received variances from the **DTSC** for the reuse of soils containing hazardous concentrations of lead. However, as per provision H(8) of the **Caltrans Permit**, the **RWQCB** must be notified at least 30 days prior to advertisement for bids to allow a determination by the RWQCB of the need for the development of **WDRs.**

Basin Plan:

A Basin Plan is a water quality control plan developed by each **RWQCB** to identify designated **beneficial uses** and water quality objectives for the **water bodies** and watershed areas within that specific region.

Beneficial Uses:

Streams, lakes, rivers, and other water bodies, have uses to humans and other life; these uses are referred to as the Beneficial Uses of a water body. The beneficial uses of waters in California are described in the Basin Plans adopted by the nine California RWQCBs. Section 13240 of the California Water Code requires adoption of water quality control plans, called Basin Plans, for the protection of water quality within the State's watersheds. **Discharges** from stormwater drainage systems may convey **pollutants** to waters of the State, and therefore may have an adverse impact on the beneficial uses of that water resource. Beneficial uses fall into one or more of the following categories:

- Agricultural Supply (AGR) – water used for irrigation, leaching of salts, stock watering, etc.;
- Industrial Service Supply (IND) – use of water for industrial activities that do not depend primarily on water quality;
- Industrial Process Supply (PRO) – uses of water that depend primarily on water quality;
- Groundwater Recharge (GWR) – replenishment of **groundwater** by percolation from surface waters;
- Municipal and Domestic Supply (MUN) – water supply systems including drinking water supply;
- Freshwater Replenishment (FRSH) – maintenance of surface water quality or quantity;

- Cold Freshwater Habitat (COLD) – maintenance of cold water ecosystems;
- Warm Freshwater Habitat (WARM) – maintenance of warm water ecosystems;
- Estuarine Habitat (EST)) – habitat resulting from commingling of freshwater and saltwater;
- Wildlife Habitat – (WILD) water used to support terrestrial or aquatic ecosystems;
- Preservation of Biological Habitats of Special Significance (BIOL) – water used to support designated areas such as refuges, parks or sanctuaries;
- Spawning, Reproduction, and/or Early Development (SPWN) - water used to support aquatic habitats suitable for reproduction and early development of fish;
- Migration of Aquatic Organisms (MIGR) – water used to support migration or other temporary aquatic organism uses;
- Rare, Threatened, or Endangered Species (RARE) – water used to support aquatic habitats necessary for the survival and maintenance of rare, threatened or endangered species;
- Aquaculture (AQUA) – using water for the propagation, cultivation, maintenance, or harvesting of aquatic plants or animals;
- Shellfish Harvesting (SHELL) – water used to support habitats for the maintenance of filter feeding shellfish;
- Commercial and Sport Fishing (COMM) – collecting fish for commercial or recreational purposes;
- Hydropower Generation (POW) – water used to produce electricity;
- Navigation (NAV) – the use of water for shipping or travel;
- Water Contact Recreation (REC-1) – recreational activities involving body contact with water; and
- Non-Contact Water Recreation (REC-2) – recreational activities involving proximity to water, but generally no body contact or ingestion of water.

Best Available Technology (BAT):

BAT is a term derived from Section 301(b) of the **CWA** and refers to **BMPs** to reduce toxic and non-conventional **pollutants** in **discharges** from **construction sites**. Toxic pollutants are those defined in Section 307 (a)(1) of the **CWA** and include heavy metals and man-made organics. Non-conventional pollutants are those not covered by conventional and toxic pollutants, such as ammonia, chloride, toxicity and nitrogen.

Best Conventional Technology (BCT):

BCT is a term derived from Section 301(b) of the federal **CWA** and refers to **BMPs** to reduce conventional **pollutants** in **discharges** from **construction sites**. Conventional pollutants include **TSS**, oil and grease, fecal coliforms, pH and other pollutants.

Best Management Practice (BMP):

A BMP is a measure that is implemented to protect water quality and reduce potential for pollution associated with stormwater **runoff**. Any program, technology, process, siting criteria, operating method, or device that controls, prevents, removes, or reduces pollution. There are four categories of BMPs: Maintenance, Design Pollution Prevention, Construction Site, and Treatment:

Maintenance:

Maintenance BMPs are water quality controls used to reduce pollutant discharges during highway maintenance activities and activities conducted at maintenance facilities. These BMPs are technology-based controls that attain MEP pollutant control. This category of BMPs includes litter pickup, toxics control, street sweeping, etc.

Design Pollution Prevention:

Design Pollution Prevention BMPs are permanent water quality controls used to reduce pollutant discharges by preventing **erosion**. These BMPs are standard technology-based, non-treatment controls selected to reduce pollutant discharges to the **MEP** requirements. They are applicable to all projects. This category of BMPs includes preservation of existing vegetation; concentrated flow conveyance systems, such as ditches, berms, dikes, swales, overside drains, outlet protection/velocity dissipation devices; and slope/surface protection systems such as vegetated surfaces and hard surfaces.

Construction Site:

Construction site BMPs are temporary controls used to reduce pollutant discharges during construction. These controls are best conventional technology/best available technology **BCT/BAT** based BMPs that may include **soil stabilization**, sediment control, wind **erosion** control, tracking control, non-stormwater management and waste management.

Treatment:

Treatment BMPs are permanent water quality controls used to remove pollutants from stormwater **runoff** prior to being discharged from Caltrans right-of-way. These controls are used to meet **MEP** requirements and are considered for projects discharging directly or indirectly to **receiving waters**. This category of BMPs includes: Traction Sand Traps, Infiltration Devices, Detention Devices, Biofiltration Systems, Dry Weather Flow Diversion, Media Filters, Multi-Chamber Treatment Trains, Wet Basins and **GSRDs**.

California Department of Health Services (DHS):

The California DHS (http://www.dhs.ca.gov/) is a State Government department created to protect and improve the health of Californians. DHS is concerned about the potential of any **BMP** device creating a public hazard by increasing habitat availability for aquatic stages of mosquitoes, and by creating harborage, food, and moisture for other reservoirs and nuisance species.

California Environmental Quality Act (CEQA):

The CEQA of 1970 requires public agencies to prevent significant, avoidable damage to the environment by regulating activities that may affect the quality of the environment. Public agencies accomplish this by requiring projects to consider the use of alternatives or mitigation measures. Regulations for the implementation of CEQA are found in the CEQA

Guidelines and are available online by the California Resources Agency at http://ceres.ca.gov/ceqa.

Caltrans Permit:

Caltrans Permit refers to the **NPDES** Statewide Storm Water Permit issued to Caltrans in 1999 (Order No. 99-06-DWQ) (CAS000003), to regulate stormwater discharges from Caltrans facilities. Caltrans is currently negotiating an updated permit with the **State Water Resources Control Board** (SWRCB).

Categorical Exemption (CE):

A CE is a list of classes of projects that have been determined not to have a significant effect on the environment and which shall, therefore, be exempt from the provisions of **CEQA**. For a list of classes of projects and further information see the web site:
http://ceres.ca.gov/topic/env_law/ceqa/guidelines/art19.html.

Clean Water Act (CWA):

The CWA, originally enacted by Congress in 1972, is a federal law that requires states to protect, restore, and maintain the quality of the waters of the United States, including lakes, rivers, aquifers and coastal areas. The CWA, as amended in 1987, is the enabling legislation for the **NPDES** permitting process.

Code of Federal Regulations (CFR):

The CFR is a document that codifies all rules of the executive departments and agencies of the federal government. It is divided into 50 volumes, known as titles. Title 40 of the CFR (referenced as 40 CFR) contains all environmental regulations. 40 CFR is available from bookstores operated by the Government Printing Office and online at: http://www.epa.gov/epahome/cfr40.htm.

Common Plan of Development:

Although not clearly defined by statute, a Common Plan of Development is generally a contiguous area where multiple, distinct construction activities may be taking place at different times under one plan. A plan is broadly defined as any piece of documentation or physical demarcation that indicates that construction activities may occur on a common plot. For Caltrans, such documentation could consist of the ED, the PSR, condemnation plans or contract documents. Any of these documents could delineate the boundaries of a common plan area.

Construction General Permit (General Permit):

The General Permit is a Statewide General Permit for construction activities (Order No. 99-08-DWQ) (CAS000002) that applies to all stormwater discharges from activities that result in a **DSA** of at least one acre or more. Construction activity that results in a DSA of less than one acre is subject to this General Permit if the construction activity is part of a larger **Common Plan of Development** that encompasses one or more acres of DSA or if there is the potential for significant water quality impairment resulting from the activity as determined by the **RWQCB**.

Construction Site:

The term "construction site" should apply to all areas both within the construction limits on state right-of-way and areas that are directly related to the construction activity, including but

not limited to staging areas, storage yards, material borrow areas and storage areas, access roads, barges or platforms, etc., whether or not they reside within the Caltrans right-of-way.

Construction Site Best Management Practices Manual:

The Construction Site Best Management Practices Manual provides instructions for the selection and implementation of Construction Site **BMPs**. Caltrans requires contractors to identify and utilize these BMPs in preparation of their **SWPPP** or **WPCP**.

Department of Toxic Substances Control (DTSC):

The DTSC (http://www.dtsc.ca.gov/) is the department within the California EPA that has responsibility for regulating the generation, management and disposal of hazardous wastes. Caltrans has applied for and received variances from the DTSC for the reuse of some soils that can contain lead. Caltrans will provide written notification to the **RWQCB** at least 30 days prior to advertisement for bids for projects that involve soils subject to this variance.

Department of Water Resources (DWR):

The California DWR (http://wwwdwr.water.ca.gov/) is a State Government department created to manage the water resources of California in cooperation with other agencies in such a way as to benefit the State's people, and to protect, restore, and enhance the natural and human environments. The DWR is a source for hydrology data, **groundwater** information, water maps, etc.

District Work Plan (DWP):

DWPs (formerly Regional Work Plans) are annual detailed plans subject to the approval of the RWQCB that describes when and how the various programs and BMPs contained in the SWMP will be implemented by each District in each RWQCB jurisdictional area.

Discharge:

The term “discharge” refers to the amount of water flowing out of a drainage structure or facility. It is measured in cubic meters/second. It is any release, spill, leak, pump, flow, escape, dumping, or disposal of any liquid, semi-solid or solid substance.

Disturbed Soil Area (DSA):

DSAs are areas of exposed, erodible soil, including stockpiles, that are within the construction limits and that result from construction activities.

Erosion:

Erosion is the wearing away of earth surfaces by the action of external forces. In the case of drainage terminology, this term generally refers to the wearing away of the earth’s surface by flowing water.

Existing Vegetation:

Existing vegetation is any plant material within the project limits that is present prior to the beginning of construction.

Geographic Information System (GIS):

GIS is a system of hardware and software used for storage, retrieval, mapping, and spatial analysis of geographic data.

Groundwater (GW):

GW is defined as the water that is naturally occurring under the earth's surface. It is situated below the surface of the land, irrespective of its source and transient status. Subterranean streams are flows of GW parallel to and adjoining stream waters, and usually determined to be integral parts of the visible streams. GW is considered a jurisdictional water of the State under the Porter-Cologne Water Quality Act (California Water Code, Division 7).

High Risk Areas:

High Risk Areas are defined as municipal or domestic water supply reservoirs or **groundwater** percolation facilities discharging to aquifers designated as water supply sources.

Highway Design Manual (HDM):

The HDM is a Caltrans document that establishes uniform policies and procedures to carry out the highway design functions of Caltrans.

Litter:

Litter in stormwater is defined by Caltrans as manufactured objects made from paper, plastic, cardboard, glass, metal, etc. This definition does not include materials of natural origin such as gravel or vegetation. Litter in surface waters can inhibit the growth of aquatic vegetation, harm aquatic organisms by ingestion or entanglement, convey other **pollutants** and cause aesthetic problems on shorelines.

Maximum Contaminant Level (MCL):

The MCL is the highest level of a contaminant that is allowed in drinking water.

Maximum Extent Practicable (MEP) Analysis:

The MEP analysis is the process of evaluating the selected **BMPs** based on legal and institutional constraints, technical feasibility, relative effectiveness, and cost/benefit ratio.

Metals (Total and Dissolved):

Metals, both total and dissolved, are commonly monitored constituents and, next to **TSS** and **nutrients**, are the most common constituents cited in the literature as being present in stormwater **runoff.**

Trace quantities of many metals are necessary for biological growth and may naturally occur in runoff. Most metals, however, have numeric water quality standards because of their toxicity to aquatic organisms at high concentrations.

The toxicity of some metals is inversely related to water hardness. The numeric water quality standards for cadmium, chromium, copper, lead, nickel, silver and zinc are hardness-dependent. Copper, lead and zinc are the metals most commonly found in highway runoff.

Municipal Separate Storm Sewer System (MS4):

MS4s are storm drain systems regulated by the federal Phase I and Phase II stormwater regulations. Municipal combined sewer systems are regulated separately. MS4s are defined in the federal regulations at 40 **CFR** 122.26(b)(8). Caltrans is designated as an MS4 permittee.

National Environmental Policy Act (NEPA):

The NEPA of 1969 establishes policies and procedures to bring environmental considerations into the planning process for federal projects. NEPA requires all federal agencies to identify and assess reasonable alternatives to proposed actions that will restore and enhance the quality of the human environment and avoid or minimize adverse environmental impacts. The NEPA process is an overall framework for the environmental evaluation of federal actions.

National Pollutant Discharge Elimination System (NPDES) Permit:

The NPDES Permit is **EPA's** program to control the **discharge** of **pollutants** to waters of the United States. NPDES is a part of the federal **CWA**, which requires point and non-point source dischargers to obtain permits. These permits are referred to as NPDES permits.

Natural Resources Conservation Service (NRCS):

As part of the USDA, the NRCS provides leadership in a partnership effort to help people conserve, maintain, and improve natural resources and the environment. Soil types and local soil survey data can be obtained from the NRCS soil maps. The soil type and soil survey data are used during the desktop screening of potential Infiltration Device sites.

New Construction/Major Reconstruction:

New construction and major reconstruction includes new routes, route alignments, route upgrades (i.e., from two-lane conventional highway to four-lane expressway or freeway), and right-of-way acquisitions for whole parcels or wide swaths. New construction activity does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of the facility, nor does it include emergency construction activities required to protect public health and safety.

Notice of Completion of Construction (NOCC):

The NOCC is a formal notification submitted by Caltrans to the appropriate **RWQCB** upon completion of the construction activities and stabilization of a site for which an **NOC** was previously submitted.

Notification of Construction (NOC):

The NOC is a formal notification submitted by Caltrans to the appropriate **RWQCB** at least 30 days prior to the start of a construction project that will result in the disturbance of one or more acres of soil. Information on the tentative start date, tentative duration, location of construction, description of project, estimated number of affected acres and the address and phone number of the construction field office is provided.

Nutrients:

Nutrients are nutritive substances such as phosphorous and nitrogen whose excessive input into **receiving waters** can over-stimulate the growth of aquatic plants.

Algae and vascular plants can cause numerous deleterious effects. Algae and vascular aquatic plants produce oxygen during the day via photosynthesis and consume oxygen during the night via respiration. The pH of the water is linked to this phenomenon through the carbonate cycle: the pH rises during the day when carbon dioxide (CO_2) is consumed for the photosynthetic production of plant tissue and falls at night when CO_2 is released by respiration. Algal blooms due to inputs of nitrogen or phosphorus can cause wide fluctuations in this dissolved oxygen and pH cycle during a 24-hour period, which

can cause fish kills and mass mortality of benthic organisms. In addition, excessive algal and vascular plant growth can accelerate eutrophication, interfere with navigation, and cause unsightly conditions with reduced water clarity, odors, and diminished habitat for fish and shellfish.

Other trace nutrients, such as iron, are also needed for plant growth. In general, however, phosphorus and nitrogen are the nutrients of importance in aquatic environments.

Phosphorus. Phosphorus is taken up by algae and vascular aquatic plants and, when available in excess of the plant's immediate needs for metabolism and reproduction, can be stored in the cells. With bacterial decomposition of plant materials, relatively labile pools of phosphorus are later released and recycled within the biotic community. The refractory portion (i.e., compounds relatively resistant to biodegradation) tends to sink to the bottom, where it degrades slowly over time.

Analytical tests for the minimum constituent list include TP, which is the sum of the dissolved and particulate orthophosphate, polyphosphate and organic phosphorus; and Total Ortho-P, which is the sum of the dissolved and particulate orthophosphate.

Nitrogen. Transformation of nitrogen compounds can occur through several key mechanisms: fixation, ammonification, synthesis, nitrification, and denitrification. Nitrogen fixation is the conversion of nitrogen gas into nitrogen compounds that can be assimilated by plants; biological fixation is the most common, but fixation can also occur by lightning and through industrial processes. Ammonification is the biochemical degradation of organic-N into NH_3 or NH_4^+ by heterotrophic bacteria under aerobic or anaerobic conditions. Synthesis is the biochemical mechanism in which NH_4^+-N or NO_3^--N is converted into plant protein (Organic-N); nitrogen fixation is also a unique form of synthesis that can be performed only by nitrogen-fixing bacteria. Nitrification is the biological oxidation of NH_4^+ to NO_3^- through a two-step autotrophic process by the bacteria *Nitrosomonas* and *Nitrobacter*; the two-step reactions are usually very rapid, and hence it is rare to find nitrite levels higher than 1.0 mg/l in water. The nitrate formed by nitrification is, in the nitrogen cycle, used by plants as a nitrogen source (synthesis) or reduced to N_2 gas through the process of denitrification; NO_3^- can be reduced, under anoxic conditions, to N_2 gas through heterotrophic biological denitrification.

Analytical tests for the minimum constituent list include NH_3/NH_4^+-N, NO_3^--N, and Total TKN. TKN is a measure of NH_3/NH_4^+-N plus organic-N; the concentration of organic-N is thus obtained by subtracting the concentration of NH_3/NH_4^+-N found in the sample from that of the TKN value.

Pathogens:

Pathogens include viruses, bacteria, protozoa, and possibly helminth worms and are a concern in stormwater **runoff**. The direct measurement of specific pathogens in water is extremely difficult. The coliform group of organisms is commonly used as an indicator of the potential presence of pathogens of fecal origin.

Sources of total and fecal coliforms in stormwater runoff are ubiquitous (e.g., soil particles, droppings of wild and domestic animals, etc.). Human sources could include illicit sewer connections and seepage from septic tanks.

Pesticides:

A pesticide is a chemical agent designed to control pest organisms. The most common forms of pesticides are organic chemicals designed to target insects (insecticides) and vascular plants (herbicides).

Chlorpyrifos and Diazinon. Chlorpyrifos and Diazinon are organophosphate pesticides that have been detected in stormwater **runoff**. Organophosphates exhibit a high pesticidal activity and relatively low persistence in the environment. They also exhibit acute toxicity effects to humans and animals by inhibiting the acetylcholinesterase enzyme activity at nerve endings, which affects the proper functioning of the nervous system. Absorption through the skin is a major route of exposure for all organisms.

Pollutant:

Any constituent present in sufficient quantity to impair the **beneficial uses** of a **receiving water body.**

Primary Pollutant of Concern:

A "Primary Pollutant of Concern" is a constituent that has been identified as a **Targeted Design Constituent** by the Department and for which a water body of interest is listed on the 303(d) list.

Project Development Procedures Manual (PDPM):

The PDPM describes the policies and procedures to be followed by Caltrans for State highway project development.

Project Development Team (PDT):

The PDT guides and develops specific projects. The PDT is typically managed by a District PM and is supported by Functional Managers and units.

Receiving Water:

A river, lake, ocean, stream or other watercourse into which wastewater or treated effluent is discharged as provided in the "Terms of Environment" (U.S. EPA Office of Communications, Education, and Public Affairs; December 1997).

Resident Engineer (RE):

The RE administers the construction contract, makes decisions regarding acceptability of material furnished and work performed, and exercises contractual authority to direct the contractor. The RE may impose sanctions if the contractor fails to follow the appropriate actions specified in the contract to correct deficiencies.

Regional Water Quality Control Board (RWQCB):

The RWQCB means any California RWQCB for a region as specified in Section 13200 of the California Water Code. There are nine RWQCBs that serve under the **SWRCB.** These nine RWQCBs are located in California and are responsible for enforcing water quality standards within their boundaries. A map of these boundaries is located in Section 2, Figure 2-1.

Runoff (RO):

RO is comprised of surface waters that exceed the soil's infiltration rate and depression storage. It includes that portion of precipitation that appears as flow in streams, and also includes drainage or flood discharges that leave an area as surface flow or as pipeline flow, having reached a channel or pipeline by either surface or subsurface routes.

Slope/Soil Stabilization:

Soil stabilization is described as vegetation, such as grasses and wildflowers, and other materials, such as straw, fiber, stabilizing emulsion, protective blankets, etc. Soil stabilization is placed to stabilize areas disturbed by grading operations, to reduce loss of soil due to the action of water or wind, and to prevent water pollution.

Source Controls:

Source controls are control measures used on disturbed areas to reduce the introduction of sediment or other **pollutants** into stormwater **runoff**. Source controls prevent or limit the exposure of materials to stormwater at the source of those materials.

Standard Urban Storm Water Mitigation Plan (SUSMP):

SUSMPs are special local requirements that designate **BMPs** that must be used for specific categories of development projects. Designers should contact the District/Regional **NPDES** Storm Water Coordinator to see if an SUSMP is applicable for projects in urban areas.

State Water Resources Control Board (SWRCB):

As delegated by the **EPA**, the SWRCB is a California agency that implements and enforces the **CWA** Section 401 (p) **NPDES** permit requirements, and is the issuer and administrator of the **Caltrans Permit**. The SWRCB's mission is to preserve, enhance and restore the quality of California's water resources, and ensure their proper allocation and efficient use for the benefit of present and future generations.

Storm Water Advisory Teams (SWAT):

Caltrans has established four Department-wide SWATs to evaluate new or modified **BMPs** and to develop procedures and guidance for implementing the SWMP:

- The Maintenance SWAT (M-SWAT) is composed of District Maintenance Storm Water Coordinators and representatives from each of the affected Headquarters Divisions. The M-SWAT provides any necessary review and/or evaluation of proposed and existing BMPs used by the Division of Maintenance. In addition, the M-SWAT reviews and assists in the development of training classes and guidance documents for implementing stormwater activities described in the **SWMP** for maintaining highways, bridges, facilities, and other appurtenances related to transport.

- The Project Design SWAT (PD-SWAT) is composed of District/Regional Design Storm Water Coordinators and related functional units and representatives from each of the affected Headquarters Divisions. The PD-SWAT provides review of proposed and existing BMPs utilized in the planning and design of projects. BMPs include construction BMPs, design pollution prevention BMPs, and Treatment BMPs. In addition, the PD-SWAT reviews and assists in the development of training classes

and guidance documents for implementing stormwater activities relevant to project design.

- The Construction SWAT (C-SWAT) is composed of District Construction Storm Water Coordinators and representatives from each of the affected Headquarters Divisions. The C-SWAT provides review of proposed and existing construction BMPs and measures used for stabilization of soils. In addition, the C-SWAT reviews and assists in the development of training classes and guidance documents for implementing stormwater activities relevant to construction activities.

- The Encroachment Permits SWAT (EP-SWAT) is composed of District Permit Coordinators and representatives from each of the affected Headquarters Divisions. The EP-SWAT reviews existing procedures to ensure that they integrate the appropriate stormwater BMPs into the requirements of encroachment permits. The EP-SWAT reviews and assists in the development of training classes and guidance documents for implementing stormwater activities for issuing and administering encroachment permits.

- The Water Quality SWAT (WQ-SWAT) is composed of the District NPDES Storm Water Coordinators and representatives from each of the affected Headquarters Divisions. The WQ-SWAT provides review of proposed and existing treatment BMPs, and prioritizes research or studies of Treatment BMPs. The WQ-SWAT is a forum for discussing stormwater coordination activities underway or planned with other municipalities, reviewing and recommending public education efforts, sharing technical information, providing advice on compliance issues, and resolving issues of dispute on stormwater. Many of these activities result in recommendations for changes to the SWMP or policies and other documents on stormwater. The WQ-SWAT discusses stormwater budget allocations for the Districts and HQ Divisions. The WQ-SWAT reviews data and findings from compliance-monitoring and evaluation activities, and recommends changes in practices to improve compliance efforts.

Storm Water Data Report (SWDR):

The SWDR is a document prepared by the PE that summarizes stormwater information. It is used to document decisions and to provide key project information to the Environmental Unit. The Environmental Unit uses the SWDR to assess the potential water quality impacts that may result from the proposed project, and will also use the project information to prepare the **WQR**, if one is required. This report is to be included in the final PS&E package.

Storm Water Management Plan (SWMP):

The SWMP is the Caltrans policy document that describes how Caltrans conducts its stormwater management activities (i.e., procedures and practices). The SWMP provides descriptions of each of the major management program elements, discusses the processes used to evaluate and select appropriate **BMPs**, and presents key implementation responsibilities and schedules.

Storm Water Pollution Prevention Plan (SWPPP):

The **General Permit** requires all construction projects that result in a **DSA** of at least one acre to develop and implement an effective SWPPP. The SWPPP is a plan that includes site map(s), an identification of construction/contractor activities that could cause pollutants in stormwater, and a description of measures or practices to control these **pollutants**. A **RWQCB** may require a SWPPP for projects which do not meet the DSA acreage requirements based upon water quality concerns, or if it is determined that a project is part of a larger **Common Plan of Development.**

Targeted Design Constituent (TDC)

A TDC is a pollutant that has been identified during Departmental runoff characterization studies to be discharging with a load or concentration that commonly exceeds allowable standards and which is considered treatable by currently available Department-approved Treatment BMPs.

Total Dissolved Solids (TDS):

TDS refers to the sum of all cations or anions (sometimes measured in parts per million as calcium carbonate). TDS comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water.

In fresh water the total dissolved solids concentration typically ranges from 20 to 1,000 mg/l; in seawater it ranges from 30,000 to 35,000 mg/l. High levels of dissolved solids concentrations can adversely affect drinking water quality.

Total Maximum Daily Load (TMDL):

TMDLs are pollutant load allocations for all point sources and nonpoint sources, and are intended to achieve a pollutant reduction goal along with a safety factor. TMDLs are developed in response to identification of **pollutants** as impairing a specific body of water identified in the 303(d) list.

Total Suspended Solids (TSS):

TSS is the weight of particles that are suspended in water. Suspended solids in water reduce light penetration in the water column, can clog the gills of fish and invertebrates, and are often associated with toxic contaminants because organics and metals tend to bind to particles.

United States Environmental Protection Agency (EPA):

The EPA (http://www.epa.gov/) provides leadership in the nation's environmental science, research, education and assessment efforts. The EPA works closely with other federal agencies, state and local governments, and Indian tribes to develop and enforce regulations under existing environmental laws. The EPA is responsible for researching and setting national standards for a variety of environmental programs and delegates to states and tribes responsible for issuing permits, and monitoring and enforcing compliance. The EPA issued regulations to control pollutants in stormwater **runoff discharges**, such as the **CWA**. (The CWA and **NPDES** permit requirement.)

Waste Discharge Requirement (WDR):

A WDR is a set of conditions issued by a **RWQCB** for a specific activity. The conditions may include numeric effluent criteria, monitoring requirements, reporting requirements, and other narrative criteria for discharge. WDRs may be required for any non-exempt non-stormwater **discharge.**

Waste Load Allocations (WLA):

A WLA represents the maximum load of **pollutants** each discharger of waste is allowed to release into a particular waterway for which a **TMDL** has been established. **Discharge** limits are usually required for each specific water quality criterion being, or expected to be, violated for that particular **water body.**

Water Body:

Water bodies refer to the waters of the United States. These include (a) All waters, which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide; (b) All interstate waters, including interstate wetlands; (c) All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters: (1) which are or could be used by interstate or foreign travelers for recreational or other purposes; (2) from which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or (3) which are used or could be used for industrial purposes by industries in interstate commerce; (d) All impoundments of waters identified in paragraphs (a) through (d) of this definition; (f) The territorial sea; and (g) Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a) through (f) of this definition.

Water Pollution Control Program (WPCP):

A WPCP is a plan to identify water quality management practices to be implemented that must be prepared for all construction projects that do not require preparation of a **SWPPP.** For Caltrans projects disturbing more than one acre, a SWPPP satisfies the requirement for a WPCP.

Water Quality Assessment Guidelines (WQAG):

The Water Quality Assessment Guidelines (WQAG) provide direction on format, content, and methods for preparing detailed Water Quality Assessment Technical Reports (WQRs) and more summary Water Quality Assessment Technical Memoranda (WQMs).

Water Quality Assessment Technical Report (WQR):

When it is concluded that there are water quality issues raised by a proposed project (and its alternatives) and that a potential for one or more substantive water quality impacts exists, then a comprehensive Water Quality Assessment Technical Report (WQR) is prepared during the PA/ED phase of a project. The need for a WQR is determined by the Water Quality Impact Questionnaire completed as part of the PEAR.

Water Quality Flow (WQF):

The WQF is a design criterion used for various types of filtration treatment control devices currently under development. Caltrans has cooperatively developed rainfall intensity values with the **SWRCB** that can be used in the Rational Formula to calculate the WQF.

Water Quality Impact Questionnaire:

The Water Quality Impact Questionnaire, which identifies potential water quality impacts, is incorporated into the PEAR. The Water Quality Impact Questionnaire was developed to assist in early identification and consideration of the broadest range of potential water quality effects, determine whether a detailed WQR technical report is appropriate, and to scope the PEAR analysis with respect to water quality issues. The Questionnaire asks a series of questions about the project description and alternatives, the project setting, and potential project impacts on water quality.

Water Quality Volume (WQV):

The WQV is the volume of flows associated with the frequent storm events that must be treated. The WQV of treatment **BMPs** is based upon, where established, the sizing criteria from the **RWQCB** or local agency (whichever is more stringent). If no sizing criterion has been established, Caltrans will do one of the following: maximize detention volume determined by the 85th percentile **runoff** capture ratio or; use volume of annual runoff based on unit basin storage WQV to achieve 80 percent or more volume of treatment. For further detail, refer to Section 2.4.2.2.

Work Breakdown Structure (WBS):

The WBS is a product-oriented grouping of project elements that organizes and defines the total scope of the project. Each descending level represents an increasingly detailed definition of a project component. Project components may be products or services. The WBS defines the work elements, not the staff or resources that will perform the work.

GREEN TECHNOLOGY:
THE DELAWARE URBAN RUNOFF MANAGEMENT APPROACH

A TECHNICAL MANUAL FOR DESIGNING NONSTRUCTURAL BMPs TO MINIMIZE STORMWATER IMPACTS FROM LAND DEVELOPMENT

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Prepared For

Delaware Department Of Natural Resources
And Environmental Control
Division Of Soil And Water Conservation

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CHAPTER 1 GREEN TECHNOLOGY OVERVIEW

1.1 BACKGROUND

By early 1970, the deleterious effects of urban runoff on stream water quality had become apparent (Coughlin and Hammer, 1973, and sources cited therein). At the time though, relatively few studies had focused on the nature, extent, and effects of urban runoff. Following passage of the Clean Water Act in 1972, Section 208 Reports from the states began to accumulate a considerable body of information. By the late 1970s, these reports had indicated that urban runoff is a significant source of Nonpoint Source (NPS) Pollution. However, it was difficult to determine the particular effects of urban runoff on water quality due to interferences from other pollutant sources (USEPA, 1984). To address the issue more thoroughly, the Nationwide Urban Runoff Program (NURP) in the early 1980s monitored urban runoff from 28 sites with a wide variety of land uses (USEPA, 1984).

Urban runoff has been known as a source of pollution of water bodies (Hartigan and others, 1979; USEPA, 1984). Urban and suburban regions contribute higher (NPP) loadings on a per acre basis than rural watersheds (CPB 1990). While urban runoff itself may have significant levels of pollutants, the way it travels to receiving waters from developed areas may have even greater implications. After traveling over impervious surfaces coated with fine sediments and their associated nutrients, metals and hydrocarbons, most runoff enters streams directly through piped conveyance systems. These connected impervious areas are referred to as Effective Impervious Areas (EIA). Pollutant loads from EIA surfaces are much higher than those from isolated impervious areas filtered by overland flow at a much slower rate. Instead of percolating into the soil, precipitation from EIA surfaces is diverted to runoff that quickly flows into the aquatic ecosystem (WDE, 1992).

Urban runoff impairs stream systems through two major processes: changes in the water chemistry and changes in stream hydrology. Studies show that urban stream pollution may substantially impair the viability of benthic macroinvertebrates. Urban runoff also fundamentally affects hydrology by increasing storm runoff while reducing recharge, and thus lowering base flow. As a result, stream banks erode on a regular basis, filling the streams with sediment and smothering organisms. The organisms remaining are further stressed by runoff pollutants, as well as by the low flows and elevated temperatures resulting from reduced recharge. Under these circumstances, runoff pollutant concentrations and available dissolved oxygen often approach toxic levels. As a result of these processes, streams in urbanized watersheds have been greatly impaired due to runoff from upland impervious areas. Changes in hydrology seem to be the more pernicious, and harder to rectify.

The issue of stream bank erosion is particularly important. A growing body of research indicates that increased frequency of bankfull flooding due to development is the dominant process that impairs urban streams. In areas where streambanks comprise erosive alluvial soils typical of floodplains, the increase in the frequency and duration of bankfull flow from urban runoff rapidly degrades stream banks. Instream bank erosion may be a dominant source of total suspended solids (TSS) in urban streams.

The threshold at which streams begin to show signs of impairment is surprisingly low, beginning at roughly 5% EIA, typical of low-density residential development. In areas of higher density development, streams may be heavily impaired, with the native community almost entirely replaced by more opportunistic species. The fish community thus shifts from game fish to rough fish. In heavily urbanized streams, worms may be the only organisms surviving.

The lakes and inland bays into which streams and rivers discharge are also adversely affected by urban runoff. In these slow moving or still waters exposed to full sun, excess nutrients cause algae to proliferate inordinately, resulting in eutrophication. In freshwater streams, ponds, and upper tidal rivers, excess phosphorus is the most damaging nutrient. In the lower tidal rivers and inland bays, excess nitrogen is the most damaging nutrient.

Recent research indicates that the current paradigm in stormwater management regulations requiring structural Best Management Practices (BMPs) such as wet ponds does not do enough to alleviate this impairment and, in certain cases, may actually exacerbate aspects of urban runoff. In response, the Green Technology approach has been formulated to mitigate the effects of development on stream ecosystems through the use of innovative nonstructural BMPs. The goal is not only to maintain the health of existing streams, but also to build a foundation for efforts to restore impaired streams.

This Technical Manual reviews current understanding of the impacts of urban runoff upon stream ecosystems and their associated riparian zones. This manual then presents how Green Technology BMPs can effectively address these impacts, and then how to properly design the most appropriate BMP. The technical approach set forth in this Manual is supported by a spreadsheet model and Users Manual in Appendix A to assist in the design of Green Technology BMPs. BMP Design standards, specifications and details are presented in Appendix B.

1.2 THE GREEN TECHNOLOGY BMP APPROACH

In the Green Technology approach, centralized treatment and/or storage facilities located at the “end of pipe” discharge from developed sites are classified as structural BMPs. While structural BMPs such as stormwater ponds and wetlands can be effective in controlling peak flows from the site, current regulatory requirements for these structures do not address the frequent storms that erode stream banks, and do little or nothing to promote recharge. Furthermore, structural BMPs can contribute to downstream flooding when discharges from separate on-site structural BMPs overlap. Structural BMPs can be effective in pollutant removal; but since they generally omit recharge, consume space, and require extensive maintenance, they are less appropriate for the task. There is an emerging recognition that wet detention structural BMPs contribute to elevated stream temperatures, and discharge algae laden effluent, which can substantially degrade the benthic community in the receiving stream.

As a result, many progressive agencies are promoting the Green Technology approach, which is designed to intercept runoff from rooftops, parking lots and roads as close as possible to its source, and direct it into vegetative recharge/filtration facilities incorporated into the overall site design and runoff conveyance system. Green Technology BMPs defined in this Manual include conservation site design, impervious area disconnection, conveyance of runoff through swales and biofiltration swales, filtration through filter strips, terraces, bioretention facilities, and

recharge through infiltration facilities. These BMPs form the basis of Green Technology at the site engineering level.

As vegetated structures that do not rely on detention, these BMPs are "Green". However, while Green Technology BMPs may seem less complex than structural detention BMPs, procedures for their proper design require the same hydrologic and hydraulic methods used in designing structural BMPs. The Green Technology approach also includes a quantitative approach for estimating pollutant loads, and projecting how well a particular design will remove such pollutants. Hence it is a "Technology", capable of providing realistic estimates of pollutant loading and removal, while also addressing hydrologic and hydraulic parameters involved in urban site design. The detailed design principles set forth in this Manual are incorporated into a spreadsheet program, the "Delaware Urban Runoff Management Model", or DURMM.

1.3 GREEN TECHNOLOGY BMPs

The BMPs addressed in Green Technology and pertinent aspects of their design and performance are briefly summarized below:

Conservation Site Design - Site design standards to reduce the extent of impervious surfaces and increase the extent of wooded areas are a key element of this approach, as expressed in the "Conservation Design Manual for Stormwater Management" by DNREC and the Brandywine Conservancy (1997). This Conservation Design Manual addresses many of the background issues in urban runoff and discusses conservation design methods in detail. The reader is referred to it for greater details in Conservation Design principles. Green Technology provides a quantitative approach to define the benefits of Conservation Design.

Source Area Disconnection – Disconnection is the process of directing runoff from impervious surfaces over adjacent vegetated surfaces, providing infiltration and pollutant removal. Green Technology quantifies the runoff reductions by disconnecting flow from impervious surfaces as it discharges onto adjacent pervious areas.

Filter Strips – Filter strips spread runoff uniformly over a filtering surface of vegetation, providing infiltration and pollutant removal. Filter strips can provide substantial treatment if not overloaded by sediment and runoff. Green Technology quantifies the runoff reductions and pollutant removal of filter strips.

Biofiltration Swales/Grassed Swales - Biofiltration swales convey runoff at shallow flow depths through wide swales. They can be very effective in removing Total Suspended Solids (TSS) and adsorbed metals, although less effective in terms of nutrients. While swales are not thought to be capable of quantity management, designs incorporating check dams can provide substantial attenuation of peak flows. Green Technology quantifies the runoff reductions and pollutant removal of overland conveyance through properly designed swales.

Terraces - Terraces are swales extending across gentle slopes designed to intercept runoff and increase the potential for infiltration. In terms of pollutant removal, terraces operate as filter strips, as runoff flows into them from upslope. They are similar to swales in terms of runoff response. Green Technology quantifies the runoff reductions and pollutant removal of overland conveyance through properly designed terraces.

Bioretention Structures - These are landscaped pocket depressions designed to infiltrate runoff through an engineered soil media. Incorporated into the urban landscape, they can provide substantial filtering and nutrient transformations before runoff is discharged into the conveyance system. Ongoing research suggests that this BMP can be designed to provide substantial soluble phosphorus removal capabilities, unlike most other BMPs. Green Technology quantifies the runoff reductions and pollutant removal of overland conveyance through properly designed bioretention structures.

Infiltration Practices - Most Green Technology BMPs incorporate infiltration as part of the treatment process. Specific infiltration facilities include infiltration trenches. Infiltration trenches located in swales provide additional wetted surface area and storage volume, and often they can be designed to penetrate shallow impermeable soil profiles to recharge deeper soil horizons. Green Technology quantifies the runoff reductions of infiltration trenches.

Complementing these engineered BMPs, Riparian Buffer Systems (RBS) and Stream Bank Restoration (SBR) BMPs are other important Green Technology systems that can enhance receiving waters. These BMPs provide substantial improvements in stream habitat and stability, as well as reducing pollutants from urban runoff. RBSs provide considerable benefits to streams through shading, bank stabilization and litterfall. RBSs can also provide substantial runoff filtering and pollutant removal when conditions are favorable. Since RBSs are sensitive to concentrated flows, design procedures to ensure sheet flow through level spreaders, filter strips and parallel swales can be incorporated into the design of this BMP. A companion document specifically focused on RBS design is being prepared by DNREC.

Stream Bank Restoration differs from other BMPs in that it provides no direct hydrological controls, nor does it remove pollutants from upland runoff. However, by stabilizing eroding stream banks, it may be the most effective mitigation measure for unstable streams stressed by urban runoff. Technical approaches for design of SBR BMPs are not included in this Manual. Designers should review the available literature about SBR design.

1.4 MANUAL SUMMARY

Unfortunately, while there is great interest in using Green Technology BMPs, there are remarkably few rigorous procedures available for the engineering and regulatory community to utilize in designing them and evaluating their effectiveness. Many regulatory programs use a straightforward runoff volume approach, in which the increase in small storm runoff volume due to land development is to be treated and/or retained on site. However, this approach typically assumes a constant runoff volume in proportion to rainfall amount, and does not route runoff

through nonstructural BMPs. Instead, simplified volume/outflow equations are extracted from the literature, without addressing the processes involved during storm events. Where this approach leads to over-design, it may be beneficial if the original reduction targets are inadequate, otherwise it causes unnecessary expense. Where it leads to under-design, the hydrological impacts are not adequately mitigated.

DNREC has created DURMM to provide a more rigorous hydrological design tool for Green Technology BMPs. A spreadsheet program is provided that incorporates modified TR-20 storm hydrology to project the hydrological response from contributing source areas. It segregates directly connected runoff from that which flows overland. It provides routines that account for the reductions in peak flow due to overland conveyance. It also includes simplified estimates of the storage volume required for detention in different nonstructural BMPs.

The process of BMP design involves a spreadsheet file for each source subarea and its array of BMPs. Discrete combinations of hydrological soil group and land cover are averaged to generate composite Curve Numbers (*CN*) for the pervious and impervious portions of each source area. Natural areas are treated separately. Impervious areas are also calculated separately, and routed according to the extent of their linkage with adjacent pervious surfaces. The resulting runoff parameters from the source area worksheet are imported into the BMP hydraulic design worksheet. The worksheet routes the source area runoff volumes and peak flows through the BMP based upon the input parameters.

Pollutant loading is calculated by applying typical event mean concentrations (EMCs) to the runoff volume allocated to each type of pervious and impervious surface. By segregating subarea loads according to the type and extent of land cover, the discrete source area approach used in the hydrologic calculations refines accuracy in estimating total pollutant loads. Pollutant removal by the BMP is based upon physical parameters such as slope, pretreatment volume, hydraulic residence time, surface/volume ratio, filter media type, and underlying infiltration characteristics. Given these factors, pollutant load reduction is calculated by algorithms relating input concentrations and decay transformations to estimate mass removal for each pollutant of concern.

The reported pollutant removal effectiveness of BMPs can be highly variable. However, by incorporating hydrologic and hydraulic parameters in runoff routing, and addressing the various removal processes as discrete algorithms within a BMP, better estimates of removal rates are possible. Some variability in projected removal rates is acceptable in any event, since hydrological changes are recognized as perhaps the primary impact of runoff. Furthermore, polluted runoff from the most frequent storms that causes the greatest stress can often be eliminated by the infiltration components of nonstructural BMPs.

DURMM not only provides the tools necessary for designing Green Technology BMPs, typical details of these BMPs in AutoCAD™ format are provided for use by the engineering community. Procedures for site analysis are provided, particularly as they relate to disconnection of impervious runoff. Given a thorough site analysis, locations where BMPs are most needed become apparent. As a Windows™ interface, data from AutoCAD™ or similar design programs can easily be imported into DURMM during project design. The particulars involved in the design of each type of BMP are readily accessible during this process so that

calculation of source area impacts and BMP performance becomes an integrated procedure, and the BMP is designed as a fundamental part of the entire project design process.

To properly address the issue of urban runoff and best mitigate its impacts through Green Technology BMPs, it is first necessary to thoroughly examine the underlying issues. Chapter 2 summarizes the literature on urban runoff impacts, Chapter 3 summarizes the literature on pollutant loads, and Chapter 4 addresses urban runoff criteria. Details of the hydrology of urban runoff are set forth in Chapter 5, and runoff hydraulics and DURMM routing are discussed in Chapter 6. Chapter 7 summarizes pollutant removal processes, while the Green Technology BMPs are described in Chapters 8 though 11.

CHAPTER 2 URBAN RUNOFF IMPACTS

2.1 INTRODUCTION

There are considerable numbers of studies that relate the presence of uncontrolled urban runoff to impairment of streams throughout the US. Studies have demonstrated impacts upon the habitat and native stream ecosystems in the Puget Sound area (WDE, 1992; Horner and others, 1996; Booth and Jackson, 1997), the Midwest (Richards and Host, 1994; Dreher, 1997), and the mid-Atlantic (Coughlin and Hammer, 1973; Schueler and Claytor, 1996; Kennen, 1999; Maxted and Shaver, 1997, Jones and others, 1996).

Urban runoff can affect streams through two processes: its pollutants either stress or totally alter the native benthic community, thus eliminating game fish; and its modification of stream hydrology can result in substantial loss of habitat. Urban runoff can also affect lakes and estuaries by increasing nutrient loads, leading to eutrophication. Consequences include red tides, loss of fisheries, and waters too foul for recreation. USEPA (1999) provides an excellent review of the impacts of urban runoff on receiving streams. The following sections address these processes in detail to better define the problem, its causes, and how nonstructural BMPs can be better designed to mitigate impacts of urban runoff.

2.2 IMPACTS OF URBAN RUNOFF TOXICITY ON BENTHIC COMMUNITIES

Toxic compounds in urban runoff can substantially impair the viability of benthic macroinvertebrates. While these bottom-dwelling insects, worms, and crustaceans may not be directly important to human uses (except fly fishermen), they are a robust indicator of overall stream health. Where a healthy benthic community has shifted to a few pollution-tolerant taxa, a diverse fish assemblage including game fish disappears, to be replaced by a few species of rough fish, if any. Therefore, the Index of Biotic Integrity (IBI) used to evaluate fish assemblages are very closely related to indices of benthic community health. As it is much easier to obtain quantitative information on benthic communities, methods to determine benthic indices such as the USEPA Rapid Bioassessment Protocol (RBP) are almost universally used by the states to evaluate the extent of stream impairment in their 305 (b) Reports to Congress.

Since water chemistry is inextricably linked with the hydrology of urban runoff, it is difficult to segregate the relative influence of hydrological and chemical impacts. However, several studies have explored the impacts of exposure to urban runoff using methods that minimize hydrologic variables. While no study has conclusively demonstrated the toxicity of urban runoff to sensitive benthic taxa, several studies examine the effects of urban runoff toxicity upon test organisms, using the Whole Effluent Toxicity (WET) protocols requiring a 48 hour exposure for acute tests, and a longer exposure for chronic tests.

Urban runoff contains a wide variety of toxic compounds and metals. From a commercial site in the Lincoln Creek watershed, a heavily urbanized stream in Wisconsin, lead EMCs exceeded USEPA's acute toxicity standard in 90% of runoff events (WDNR, 1989, as cited in Bannerman, 2000). In the Dallas area, zinc was found in 100% of all sites, with median

concentration in residential sites of 65 µg/l, and 130 µg/l in commercial sites. The acute water quality criterion of 112 µg/l was exceeded in 36% of the samples (Waller and others, 1997).

In California, concentrations of copper, lead, cadmium and zinc in urban runoff sediments are from 10 to 50 times the background levels found in sediments originating from open areas. Copper exceeded the acute objectives in 70% of observations, and zinc 61% of the time. However, soluble copper, which is considered the toxic species, exceeded the chronic objective only 5% of the time (Cooke and others, 1997). Chronic exposures to runoff from a heavy industrial site in California were lethal to *C. dubia* in 100% of observations, while runoff from residential and commercial sites was lethal 50% of the time, and moderately to highly toxic for the balance. Toxicity in the receiving Coyote Creek varied from event to event, ranging from no observed effect in most cases, to high levels of mortality (Cooke and others, 1997).

Accumulation of metals in the sediments has been recognized as potentially hazardous (Hartigan and others, 1979), and repeated resuspension of contaminated sediments during frequent storms may pose the greatest long term toxic impacts to fisheries (USEPA, 1984, Myers and others, 1985; WDE, 1992). For this reason, Livingston and others (1995) consider sediment sampling a better measure of potential urban runoff toxicity than water chemistry. Resuspension of copper from sediments during stormflow below an abandoned factory has been implicated as a cause of significant mortality to benthic organisms (Diamond, 1996). Locally, the Red Clay Creek in the Piedmont is a good example of the adverse effects of industrial discharges upon stream sediments.

Insecticides are another major toxic contaminant in urban runoff. Used extensively in residential settings, excess diazinon in effluent from many STPs in the southern USA has been implicated in their failure to meet discharge limitations. In Wisconsin, diazinon was reported in 20% to 49% of all samples, with a mean EMC of 0.11 µg/l (Bannerman and others, 1996). In the Dallas area, Waller and others (1995) report that diazinon was found in 100% of commercial and residential sites, and 83% of industrial sites. Median concentration in residential sites was 0.55 µg/l, with 20 of 31 observations in excess of 0.35 µg/l. For the water flea *C. dubia*, this is one value reported for the concentration at which 50% die (LC50). The LC50 of diazinon for *C. dubia* has been reported as high as 0.9 µg/l (Fernandez-Casalderry and others, 1994), so fewer events would exceed this LC50. Thus it is not surprising that acute WET tests of urban runoff from these sites showed minimal toxicity to *C. dubia*, even though most exceeded the acute criteria for zinc as well (Waller and others, 1995). In December, 2000, the USEPA passed rules to phase out the use of diazinon, so this insecticide should become less of a problem as its use declines.

The time scale of exposure is a particularly important issue. Herricks and others (1995) note that the exposure period for acute and chronic exposure in WET tests does not account for the time scale involved in streams, where chronic exposure lasts for the lifetime of the organisms. Herricks and Milne (1996) also noted that mortality from an acute exposure was not manifest until a chronic time period had elapsed. Nonetheless, Herricks and others (1997) reported mortality of *C. dubia* from exposure to the first flush of runoff from Lincoln Creek in WET tests. However, field tests of caged rotifers (*H. azteca*) and native isopods (*Asellus* sp.) showed no event-related effects on mortality.

To isolate flow effects, Crunkilton and others (1997) used mesocosms (essentially aquariums) of test organisms filled with circulating stream water. They reported that 93% of the tests showed significant mortality in *C. dubia* after a 14 day exposure to runoff in Lincoln Creek, and 100% of the tests showed significant mortality in the minnow *P. promelas* after a 61 day exposure. Growth rates of *P. promelas* during long exposures were also reduced relative to controls. Much less effect was seen in shorter duration exposures, supporting the results of Herricks and others (1997). They also note that more sensitive criteria such as biomass accumulation may be better suited to examine the effects of runoff toxicity.

Even more noteworthy, there was little difference in mortality between runoff and baseflow inputs to the mesocosms. This suggests that sediments may accumulate toxic pollutants from runoff events, and supposedly "clean" baseflow becomes toxic as it upwells through bottom sediments and absorbs pollutants.

Bioassay exposure to polyaromatic hydrocarbons (PAH) extracted from stormflow runoff from Lincoln Creek also had substantial effects. However, there was a lesser effect from base flow (Villeneuve, 1997, as cited in Bannerman, 2000), suggesting that some PAHs are more mobile and less likely to be sequestered in the sediments. Recent research indicates that the more soluble PAHs such as benzene and naphthalene are generally more toxic, while larger species bound to sediments exert their effects through bioaccumulation in sediment burrowing organisms (Standley, pers. comm.).

These studies show that urban runoff is toxic when levels of pollutants exceed the threshold particular to a test procedure. Some consider *C. dubia* a most sensitive indicator of toxicity (Waller and others, 1995), so WET sensitivity of *C. dubia* may overstate life cycle sensitivity of other benthic organisms. Sensitivity to long term exposure generally occurs at orders of magnitude below lethality at acute exposure. By inhibiting growth, reproduction, and resistance to stress, sublethal levels of toxic pollutants will have substantial effects on benthic communities and will select for pollutant tolerant taxa.

Undoubtedly, these studies strongly implicate urban runoff toxicity as a factor in the impairment of benthic community structure. Since most of the toxic pollutants such as metals are associated with sediments, measures that reduce TSS are the primary mechanism for reducing toxic runoff pollutants. This can be accomplished by either filtration, infiltration or settling BMPs. The design criterion requires that the storage volume be adequate to treat the vast majority of runoff. It must be stressed that infiltration is not the recommended BMP approach where toxic pollutants are mobile and could contaminate groundwater, as in the case of the soluble forms of zinc, copper, soluble PAHs, and many insecticides.

2.3 IMPACTS OF URBAN RUNOFF NUTRIENTS ON LAKES AND INLAND BAYS

Since free flowing shaded streams obtain their energy inputs from the surrounding riparian forest, benthic macroinvertebrate communities in such streams are generally unaffected by elevated levels of the nutrients phosphorus and nitrogen. However, in still water and slower moving reaches exposed to full sun, stream ecosystems are driven by photosynthesis to metabolize nutrients in the water column. In these conditions, typical of tidal streams and inland bays, nutrient loading from urban runoff can be most damaging. Excess nutrients encourage

unrestricted growth of algae, leading to eutrophication. As the algae decompose, they consume available oxygen, resulting in nearly complete anoxia at the bottom in many cases. In marshes and lakes, phosphorus is relatively scarce under natural conditions, so excess phosphorus is the most damaging nutrient. In inland bays where nitrogen is limited, excess nitrogen is generally the most damaging nutrient, although bays can be occasionally phosphorus limited.

Although agriculture is widely documented as the most pervasive source of NPS pollution, urban runoff is also implicated in the pollution of water bodies (Hartigan and others, 1979). While the total area may be less than that of rural regions, urban and suburban regions are thought to contribute higher NPS loadings on a per acre basis than rural watersheds (CPB, 1990). This has been attributed to atmospheric deposition of pollutants and nitrate onto impervious surfaces and fertilization of turf (MDE, 1986), as well as the prevalence of onsite septic systems. Nitrate and phosphate concentrations have been found in runoff from shopping centers at levels similar to those from row crops. Originating from pets, fecal coliform counts can be very high in urban runoff (USEPA, 1984).

Septic systems are responsible for well over half the total suburban nitrate loading, and over one third of the suburban phosphorus loading into the inland bays (Ritter, 1986, as cited in Martin 1998). Largely as a result of widespread use of septic systems, suburban residential uses thus account for the second largest source of excess nitrogen to the bays. In the mid-Atlantic Coastal Plain, groundwater levels of inorganic nitrogen (mostly nitrate) in areas developed with septic systems were found to be identical to those under agricultural fields (Reay and others, 1996). However, even in the relatively developed Indian River Bay, it is recognized that agricultural sources of nitrogen are over three times those from urban land uses (Horsley and Witten, 1998).

These effects of excess nutrient loading obviously impair the entire ecosystems in lakes and inland bays. When hypertrophic conditions occur due to excess nutrients, inland bays become subject to increased frequency of Pfisteria outbreaks, resulting in widespread fish kills and health impacts upon people in contact with infested waters. Beyond their effect upon ecosystems health, these effects have considerable economic implications to fisheries and tourism.

Delaware's inland bays are considered to be the most highly eutrophic estuaries in the Chesapeake Bay region. Previous oyster, soft clam and bay scallop fisheries are now essentially extinct due to habitat loss and poor water quality (CCMP, 1995). Water quality indices and benthic community structure reflect significant impairment, especially in those areas with the least amount of tidal flushing. Dead-end canals constructed for urban areas are particularly impaired, with nearly complete loss of the natural ecosystem. Chemical pollutants in these canals exceed published guidelines in 91% of the sampled areas, and dissolved oxygen levels were below the 5 ppm threshold for aquatic life in 57% of the sampled area (Chaillou and others, 1996).

Urban land uses in the Indian River and Rehoboth bays has doubled from 1986 to 1992. Most of these new urban areas represent conversion of previously forested lands, while the extent of agricultural land uses has remained largely unchanged (Martin and others, 1998). Although agricultural land uses are the primary source of excess nutrient deliveries to the bays,

this pattern of land use change suggests that nutrient loading will increase due to development, instead of replacing one source of nutrients with another. Therefore, measures to reduce the amount of nutrients in urban runoff are necessary to avoid further deterioration of Delaware's lakes and inland bays as forested lands are developed.

Since much of the phosphorus in urban runoff is associated with suspended sediments, measures to reduce TSS are the primary mechanism for removal of sediments and particulate phosphorus, using filtration, infiltration, or settling BMPs. On the other hand, much of the total nitrogen (TN) occurs in soluble forms. Likewise, most of the bioavailable phosphate occurs in form of soluble orthophosphate. Therefore, nonstructural BMPS using sedimentation and overland filtration processes do not reduce nitrate or orthophosphate levels substantially. Infiltration BMPs transfer nitrate into groundwater, where it is then eventually discharged as base flow into streams. To varying degrees, wetland, riparian forest buffer and denitrifiyng bioretention BMPs provide mechanisms for removal of nitrate from urban runoff.

2.4 IMPACTS OF URBAN RUNOFF HYDROLOGY ON STREAMBANK STABILITY

Although the toxicity data is suggestive, there do not seem to be any studies that isolate specific toxic effects of urban runoff upon benthic macroinvertebrates from its hydrologic impacts (eg., see Diamond, 1996). While there is ample data from Red Clay Creek implicating PCBs from an industrial discharger, or copper from an abandoned factory in Virginia (Diamond, 1996), these situations are not typical for urban runoff. In the mid-Atlantic region, benthic communities in urbanized watersheds were substantially impaired where no changes in water chemistry were noted, in comparison to those in forested watersheds (Jones and others, 1997). In Ohio, biological impairment was noted in 50% of the stream segments, even though no water quality criteria exceedances were observed (Zucker and White, 1996). Though there may be little doubt about the toxicity of urban runoff to test organisms, Horner and others, (1996) note that changes in stream hydrology and geomorphology resulting from urban runoff are even more pernicious for streams and their benthic communities than runoff toxicity and nutrient loading.

Changes in the character of urban streams in response to urban runoff have been observed for some time. In a landmark study, Hammer (1973) noted that channel cross-sectional areas of urban streams in southeastern Pennsylvania were enlarged by a factor of 10 to 20 times that of rural streams with similar drainage areas. Klein (1979) noted that degradation of Piedmont stream channels in Maryland was correlated with the extent of watershed imperviousness. Krug and Goddard (1986) noted a substantial increase in channel size and sediment delivery in a Midwestern watershed undergoing urbanization. Whipple and others (1991) noted that the extent of erosion of urban streams in Maryland was correlated with the extent of Total Impervious Area (TIA) in the watershed.

Under natural conditions, the flow event that moves the most sediment (known as the maximum of the effective work curve) occurs at an interval from one to two years (Leopold and others, 1964). This recurrence interval corresponds to the natural channel forming event frequency (Wolman and Miller, 1960). The primary impact of urban runoff hydrology is the frequency of bankfull flooding increasing from once every two years or so under natural conditions (Wolman and Miller, 1960) to many times per year after urbanization (Arnold and others, 1980; Booth and Jackson, 1997; Moscrip and Montgomery, 1997).

In Washington, DC, dense urbanization has caused bankfull flooding to occur 10 to 20 times more often than the pre-development frequency (Dunne and Leopold, 1978). Conversion of a watershed in western Washington from forested to medium density residential use (EIA at 29%) is projected to increase the frequency of the 5 year bankfull flood to nearly six times per year (Booth, 1990), nearly a thirty-fold increase in the frequency. This is far greater than the two to six-fold increases reported in earlier studies (Coughlin and Hammer, 1973; Schueler, 1987).

This increase in frequent floods shifts the maximum of the effective work curve to mid-bankfull flow events occurring at least several times per year (MacRae and Rowney, 1992). The increase in frequency of flows above the midbank not only causes erosion of bed material, resulting in channel incision (Harvey and Watson, 1986; Shields and others, 1994); it also over-steepens the banks, so bankfull flooding causes stream banks to erode into the incised channel (Arnold and others, 1980; MacRae, 1991). With roots exposed by bank erosion, remaining riparian trees are more subject to windthrow, further widening the banks (Schueler, 1987). Debris dams are left suspended above the channel, reducing roughness so that even greater downcutting occurs (Booth, 1990). This process is aggravated by the increased magnitude and duration of flows that exceed the critical threshold of non-cohesive materials at the toe of the streambank (MacRae, 1991). As urbanization proceeds, the frequency of these sub-bankfull events exceeding this threshold increases by a factor of roughly three (MacRae and Rowney, 1992), or up to ten (MacRae, 1996). For additional discussion of processes involved in stream channel enlargement due to urban runoff, see USEPA (1997) and CWP (2000).

Another contributing factor is the relatively low suspended sediment load in urban runoff. During centuries of intensive agriculture, sediment delivery rates were very high in the eastern U.S. This caused substantial aggradation as the sediments were deposited in floodplains. Following adoption of conservation practices and conversion of upland areas to fallow or urban land uses in the last half century, upland sediment losses have been substantially reduced (Ferguson, 1996; Ruhlman and Nutter, 1999). As a result, the excess kinetic energy formerly used to transport the sediment is presently available to entrain previously deposited bank and bed sediments. This phenomenon of “hungry” streams amplifies the process of stream incision and bank erosion (Heede, 1986). Gravel bars and riffle areas are buried under the sediments as banks erode (WDE, 1992). It is thought that one half of all suspended sediment in urban stream flow is thus generated by these processes of bank erosion (Yu and Wolman, 1986, as cited in MacRae, 1991). In the easily eroded soils of the San Diego Creek watershed, California, bank erosion has been identified as the source of nearly all the suspended sediments found in the streams (Geosyntec, 2002).

There are other adverse hydrological impacts of urbanization due to increased runoff. In Maryland watersheds, Klein (1979) noted that baseflow decreases as extent of urbanization increases. Ferguson and Suckling (1990) noted a similar relation in a Georgia Piedmont stream. On Long Island, Spinello and Simmons (1992, as cited in CWP, 1995a) noted substantial decreases in base flow in intensely urbanized watersheds. Other reviewers suggest that impervious surfaces may have less impact upon baseflow (WEF and ASCE, 1996). This may be due to the fact that although there may be less recharge, there is also is less evapotranspiration from urban sites, so the net effect is not as large as would be expected.

Klein (1979) also noted that summertime water temperatures increased in urban streams. He attributed this to the absence of shade since channels were wider and shallower, and to the reduction in relatively cool baseflow inputs. Urban runoff from paved surfaces and rooftops can be very warm, eliminating cold-water species that are intolerant of warm temperatures (Galli, 1990). Elevated temperatures during summer low flow conditions in urban streams can drive down the concentration of dissolved oxygen to very low levels, resulting in displacement of intolerant species by rough fish that can endure the conditions. In extreme cases during summertime droughts, dissolved oxygen levels can fall so low as to not even support aquatic life, resulting in fish kills. Warmer temperatures also accelerate the release of soluble fractions of zinc, copper, and PAHs into the water column from the sediment pool, further stressing benthic communities and fish.

2.5 IMPACTS OF URBAN RUNOFF HYDROLOGY ON BENTHIC COMMUNITIES

There is a considerable literature documenting the impacts of these changes due to urban land uses upon the resulting benthic macroinvertebrate communities and fisheries. Sedimentation impacts on fisheries can be severe, as the natural sequences of riffles and pools are lost, eliminating spawning areas (WDE, 1992), and reducing salmonid populations (Moscrip and Montgomery, 1999). Siltation in streams is now implicated as the leading cause of impairment to streams (USEPA, 1998).

In Washington, Booth and Jackson (1997) noted substantial declines in fish habitat as effective impervious area (EIA, the impervious areas piped directly to streams) exceeded 8% to 10%. Sediments have been shown to reduce the growth and fecundity of benthic macroinvertebrates, with complete mortality when deposits exceed 10 mm (Sweeney, 1993). Increasing the velocity of flow above 50 cm/sec also eliminates crayfish, resulting in the proliferation of mat-forming algae (Hart, personal comm.), greatly reducing the diatom supply for the remaining invertebrates. As a result, with the adapted food supply and spawning areas greatly reduced or eliminated, desirable native species die off or move away, to be replaced by undesirable opportunistic exotic species (USEPA, 1984; WDE, 1992: and sources cited in Schueler, 1987).

Klein (1979) noted that the species diversity index in streams declined in proportion to the extent of impervious area in the watershed. He attributed the decline to channel enlargement, lowered base flow between storms, and increased temperatures. He also noted the influence of migration barriers and the potential effects of toxic pollutants. He concluded that these effects may be avoided if TIA remains below 15%, or 10% for sensitive stream ecosystems that sustain trout. Numerous other studies have observed this threshold phenomenon of benthic impacts increasing in relation to the extent of watershed imperviousness (eg., Maxted and Shaver, 1997).

In Washington, channel incision and bedload resuspension due to urban runoff has been implicated as the major factor in the destruction of aquatic habitats (WDE, 1992). In the Piedmont area of Pennsylvania, sediments are the foremost pollution problem in aquatic systems (Sweeney, 1993). This can have far reaching consequences, leading to the impairment of economically important fisheries (CPB, 1992). Pederson and Perkins (1986) noted a decline in diversity due to urbanization as benthic taxa shifted from runoff intolerant shredders to runoff tolerant worms. They attributed this shift to the dominance of a silty erosional/depositional

substrate in the urban streams, as well as to the absence of leaves, which were rapidly swept away by the increased flooding in the urban flow regime. Horner and others, (1996) noted a considerable reduction in benthic diversity as TIA approached 10%. In Mississippi, Shields and others (1994) noted a similar decline in habitat due to incision.

In Delaware, Maxted (1996) noted that the benthic community index declined substantially once 10% to 15% of a watershed was urbanized. The extent of this impairment was closely correlated with habitat index based upon observations of bank stability, width/depth ratios, point bars, and other evidence of erosion processes (Maxted and Shaver, 1997, 1999).

2.6 MITIGATION OF RUNOFF IMPACTS BY NONSTRUCTURAL BMPs

The preceding discussion emphasizes the urgent need to reduce the impacts of urban runoff. For too long, the toxic and hydrological consequences of urban runoff have been ignored, with unconscionable impacts upon the receiving waters. Even when water quality structural BMPs were finally mandated in 1991, they did not seem to mitigate the decline in benthic macroinvertebrate communities in the receiving waters (Maxted and Shaver, 1997, 1999). Few studies have investigated the impact of the BMPs on receiving waters, but it is thought that warm, algae laden effluent from wet ponds alters the composition of the benthic community in the receiving stream (Jones and others, 1997, and sources cited therein). Furthermore, thermal effects on streams receiving effluent from unshaded wet ponds can be substantial (Van Buren and others, 2000). A recent review by Horner and others (2000) also suggests that structural BMPs are not as effective as a continuous riparian buffer of native vegetation. This is supported by the findings of Zucker and White (1996), where instream biological metrics were correlated with extent of forested buffers.

However, structural pond BMPs do seem to provide habitat protection benefits, (Maxted and Shaver, 1999), so they are definitely an improvement over no BMP at all. In recognition of the need for further improvement, DNREC has formulated the Green Technology methodology to provide a comprehensive approach to the problem.

By using nonstructural BMPs that filter and settle out pollutants in linear landscaped features that provide for tree cover, algal and thermal impacts can be minimized in comparison to large ponds. Furthermore, by integrating these nonstructural BMPs into the landscape, it is possible to provide for more infiltration than is possible for a pond placed at the lowest point in a site. This can have substantial benefits in terms of reducing base flow temperatures, as discussed above. A final benefit is the potential for a nonstructural BMP to be a landscaped amenity, instead of a large isolated structure requiring substantial area for ancillary access, buffering, screening and maintenance facilities.

By defining the problem of urban runoff impacts in such detail, the way to mitigate these impacts becomes more focused. However, to properly address pollutant load impacts, it is necessary to have a realistic idea of the extent of pollutant loads that can be anticipated from the various urban land cover categories. Chapter 3 examines the literature on pollutant loads from such land covers so as to project the most likely loads of pollutants in urban runoff.

CHAPTER 3 URBAN RUNOFF LOADING

3.1 RUNOFF POLLUTANT LOADING OVERVIEW AND MODEL APPROACH

Urban runoff pollutants comprise many different types of chemical compounds, as discussed in Chapter 2. Runoff from parking lots and streets has been shown to have a greater correlation with impacts on urban streams than that from roofs (Coughlin and Hammer, 1973). Toxic metals such as lead, copper, and zinc associated with vehicular uses have been found in 96% of the samples in the metropolitan Washington area (MDE, 1986). Although newer urban areas are typically minor sediment generators, decaying pavement contaminated with particles from tire wear can be the dominant component in runoff in older urban sites (Myers and others, 1985; Harper, 2002).

The pollutants in urban runoff of most concern are total suspended sediments (TSS), total phosphorus (TP), and total nitrogen (TN). Copper and zinc seem to be the most prevalent metals found at toxic levels (Cooke and others, 1994). Most metals and the particulate fractions of nutrients have a high affinity with suspended sediment, so methods to reduce TSS loadings will also tend to reduce loadings of these compounds. For this reason, nitrogen and phosphorus have been segregated into soluble and particulate fractions.

Settling in bioretention facilities, and filtration in filter strips and biofiltration swales are effective methods for treating particulate pollutants. However, for soluble toxic metals such as soluble fractions of zinc and copper, settling is not effective. Zinc can be quite soluble at the pH of urban runoff, as are dissolved copper, volatile organic compounds (VOCs), and many PAHs. These pollutants from “hot spots” such as automotive service centers, certain industrial sites, and high intensity commercial sites such as convenience stores are not removed by settling processes. For these soluble toxic pollutants, bioretention facilities, and/or a treatment train approach is necessary.

Depending upon the land cover in the source area, different amounts of various pollutants will be washed off during runoff events. Using values for average annual mass loads by land cover category alone can introduce substantial error for pervious surfaces, since the volume of runoff varies greatly in response to soil type. This variation is quite substantial at the low rainfall volumes generated by the quality storm discussed in Chapter 4.

To better estimate pollutant loading by different land covers according to their respective areas, it is thus more accurate to delineate expected pollutant loading from each category of urban land cover in terms of its area weighted event mean concentrations (EMCs). The weighted EMC values can then be multiplied by the runoff volume from each category of urban land cover polygons. This product represents the mass load for each individual combination of land cover/soil type during a runoff event. This method accounts for the variation in runoff volumes generated from the extensive combinations of land covers and soil types discussed in Chapter 5.

However, EMCs from differing land cover categories vary widely from event to event, from region to region, and from study to study. When pollutants have accumulated after periods of dry weather, the earliest runoff often has elevated pollutant levels, while EMCs from runoff

later in the event or from subsequent events are much lower (Novotny and others, 1994; Soeur and others, 1994). Although less prevalent in events from large basins, (Characklis and Weisner, 1997), this "first flush" phenomenon is often found at the site scale addressed by this Manual. Examination of the literature also indicates that concentrations are generally higher in the smaller events, or events that occur during drier years. EMC values thus can vary over several orders of magnitude between the highest and lowest values observed (see data presented Waschbush and others, 2000). Therefore, continuous simulation models such as SLAMM and PCSWMM use Monte Carlo methods based upon a random number generator to generate a range of loading values that changes from event to event, and take into account pollutant accumulation and washoff functions based upon interevent intervals.

Since DURMM is based upon a single event approach, the option to use a range of values is not available. If the intent is to replicate a "typical" event, it is essential to derive the proper value for the EMC. The arithmetic mean of observations is often reported in many studies. More recent studies report the geometric mean as well, since it weights extreme values less, and thus reveals the central tendency better than the arithmetic mean. However, for the purposes of a single event model, the best approach is to add up the total loads generated over a year, and divided by the annual runoff volume. This "flow-weighted" mean thus reflects the "average" event. By using an annual flow-weighted mean, the inherent variability between events is balanced out over the course of a year.

The runoff volume approach discussed in Chapter 5 can be used to determine runoff volumes of individual land uses to obtain the flow-weighted mean. Where annual loads and runoff volumes are supplied in several studies, flow-weighted means were able to be determined, as indicated in Tables 3-1 through 3-4. Tables 3-1 through 3-4 include these flow-weighted means along with the arithmetic and geometric means reported in the literature. This approach not only provides another reasonable estimate for the typical EMC, it further reinforces the central tendencies. The arithmetic, geometric and flow-weighted means reported in the studies were then used as the basis for establishing the values used in DURMM. Values were adjusted in relation to the geometric mean as discussed below if warranted by further examination.

Total impervious loads are determined by summing up the product of event runoff, times the EMC from each category of impervious area, times area of each category. A similar approach is taken for pervious loads. Total pollutant load is then the sum of impervious and pervious loads. Mass loading thus estimated from the pervious and impervious surfaces is added together to determine total mass loading, which is then divided by total runoff volume to provide the EMC from the site. To the extent that impervious disconnection (discussed in Chapter 5) reduces total runoff, the total loads are then reduced proportionately. EMCs into the BMP are then determined by total load divided by total runoff.

3.2 RUNOFF POLLUTANT TRANSPORT PROCESSES

Note that the EMC values addressed in this Manual are exclusively allocated for surface runoff concentrations. In impervious areas, overland flow dominates the runoff response. However, in largely pervious areas, up to 80% of all annual runoff can occur through subsurface flow pathways, ending up as recharge to base flow (Correll and others, 1997). This situation is typical of watersheds throughout the East, where most streamflow comprises groundwater that

has infiltrated previously. Therefore, subsurface pollutant loads can be an important contribution to total annual loads, particularly in agricultural settings.

One of the most effective BMPs is impervious area disconnection, where flow from impervious areas is directed over lawns and other pervious surfaces. For most pollutants, EMCs from impervious surfaces will be substantially reduced where infiltrated through a vegetated root zone overlying an intact soil profile. Vegetative uptake and microbial immobilization transform and sequester nutrients, toxic metals and PAHs. However, once past the root zone, highly soluble pollutants that are not adsorbed by soils can pass into groundwater relatively unaltered.

Parmer and others (1995) reviewed the literature in terms of the potential impacts of urban runoff constituents to groundwater. Nitrate is the most soluble nutrient, while dissolved zinc is the most soluble metal. Depending upon half-life and adsorption coefficients, many pesticides can also infiltrate into groundwater. Organophosphate pesticides are less persistent, but less likely to be adsorbed than organochlorine pesticides. Road salts are very soluble, and minimal reductions in runoff EMCs are observed in BMPs.

Therefore, if heavily polluted runoff is treated by underground infiltration facilities without extensive pretreatment, there is a real concern for groundwater pollution. This is an important consideration for soluble metals and PAHs (Pitt and others, (1996). Nitrate is also very soluble and has minimal uptake by mineral soils. Phosphorus is generally readily bound within the soil profile, even under the very high loads of septic systems (see sources cited in Gold and Sims, 2000). The extent of phosphorus and metals adsorption is quite dependent upon soil properties, as discussed in more detail for bioretention facilities in Chapter 11.

Where infiltration dominates the runoff response, nitrate leaching losses can comprise the majority of total nutrient loading from urban runoff. At present, there are relatively few studies of nitrate leaching losses in urban settings. Most of the literature on urban runoff EMCs focuses on overland flow collected by weirs and other types of collectors. However, there are several that examine leaching losses of nutrients from turf.

Unlike agricultural crops, which are plowed up annually, the well-established root systems of lawns are effectively permanent, so nutrients remain bound up in the shallow soil profile. As a result of nitrate being taken up and/or immobilized in the root zone of the grasses, these studies report minimal leaching losses under normal fertilization and irrigation practices. Average annual flow-weighted loss for typical turf has been reported as low as 0.21 mg/l (Gold and others, 1990) to 1.06 mg/l (Geron and others, 1993). An EPIC simulation of soils thoroughly irrigated with well water at 6.3 mg/l projected a flow-weighted mean of 0.48 mg/l for heavily fertilized fairways (King and Balogh, 1999). Concentrations from over-fertilized sandy soils under excessive irrigation can be as high as 45 mg/l (Watts and others, 1993), but this is not representative of the typical situation.

It is important to note that the volume of rainfall infiltrated into urban lawns typically exceeds the volume that runs off by a factor of at least two (King and Balogh, 1999) or over ten (Kussow, 2002). Several studies show very little runoff from turf, unless frozen (Kussow, 2002) or previously saturated, under high rainfall depths or intensities (Gross and others, 1990; Cole and others, 1997). Depending upon the soil type and climate, leaching loads vary from one-third

the runoff losses (King and Balogh, 1999) to over four times the runoff losses (Linde and Watschke, 1997).

Given this variability, and the difficulty in establishing an approach to replicate such interactions, consideration of subsurface losses is beyond the scope of the surface runoff processes addressed in this Manual. DURMM takes the oversimplified approach of omitting groundwater loading in its entirety. However, since such subsurface losses can be substantial, they should be recognized in selecting the appropriate BMP.

For these reasons, the approach in this Manual is to provide a quantitative estimate of total pollutant loads in surface runoff according to their EMCs, so as to identify the location and degree of potential impacts, and provide direction as to the most appropriate approach to mitigate these impacts. By comparing loading EMCs, receiving water criteria, and site constraints, the proper choice of BMPs becomes evident. For instance, infiltration trenches would be discouraged where EMCs of nitrate or soluble metals are high, while bioretention facilities would be recommended. DURMM thus provides for designers to focus on the optimal BMPs by taking into account implications of individual land cover categories and their runoff response. This approach advances BMP design beyond that offered by a generalized land use approach and simplified runoff volume estimates.

3.3 URBAN RUNOFF POLLUTANT LOADING ESTIMATES

Given that this approach is to segregate and estimate runoff EMCs by category of pervious and impervious urban land covers, the literature has been reviewed to determine the most appropriate value to allocate for each type of land cover. However, the literature on EMCs by land cover type is quite thin. There have been numerous studies of different land covers aggregated into certain land uses, but most do not provide information on which land cover (roofs, parking, loading, streets, sidewalks, lawns, landscaping, etc.) is responsible for which proportion of the total load.

Tables 3-1 through 3-5 summarize much of the literature published on urban runoff pollutant loading by land cover. Tables 3-1 and 3-2 summarize TSS loading and phosphorus species loading, and Tables 3-3 and 3-4 summarize nitrogen species loading. Table 3-5 summarizes Copper and Zinc loads, along with information on the location and method of the sources, and where flow weighted data has been included. Agricultural land cover categories are included in these tables since they represent pre-development conditions.

Note that the TSS value allocated for lawns is a relatively high value of 125 mg/l. While TSS EMCs reported from vegetative filters and biofiltration swales can be as low as 4 mg/l, the higher value represents a “typical” urban lawn that may have some bare patches. A lower value could be justified for fairways or well maintained lawns. Likewise, there is a considerable variation in TSS values from streets. The value in Table 3-1 is close to the observed geometric mean, but much lower than the 340 mg/l needed to calibrate the SLAMM model (Waschbusch and others, 2000). Surprisingly, low volume streets seem to have the higher TSS EMCs, and driveways have the highest EMCs of all impervious surfaces. Since the flow weighted TSS varied from 54 mg/l for low tree canopy streets to 211 mg/l for high tree canopy streets, this trend may reflect TSS contributions by adjacent street trees.

Phosphorus loadings in Tables 3-1 and 3-2 are segregated into soluble and insoluble forms so as to segregate the fractions of total phosphorus loads that settle out from that which remains dissolved. Note that most observations provided only total and dissolved values, so EMCs of the particulate fraction has been calculated by subtraction.

Surprisingly high values are reported for phosphorus losses from woods, even though the undisturbed environment of a well-established litter layer would suggest that little phosphorus would be lost in runoff. (Note that the volume of annual runoff from woods is usually so low that annual loads remain very low.) However, Garn (2002) noted that high levels were found in runoff from wooded sites next to lawns. Waschbusch and others (2000) also note a strong correlation between phosphorus EMCs on streets and the extent of tree cover along streets. In urban streets, decomposition pathways that normally recycle nutrients do not occur. Instead, after leaves fall on impervious surfaces, they are broken down by largely mechanical processes and pass into urban runoff relatively unaltered. Table 3-2 also shows that EMCs of dissolved phosphorus from lawns in a basin with extensive tree cover was almost twice that of the lower canopy basin.

For this reason, soluble phosphorus loading from landscaping is allocated value of 1.10 mg/l, twice the 0.55 mg/l assigned to lawns. Likewise, particulate phosphorus from landscaping is allocated at 2.50 mg/l, over three times that from lawns. Using such a high value provides a mechanism, although over-simplified, to account for the effect of phosphorus loads from landscaping upon adjacent categories without having to adjust their EMCs directly. Instead, the designer can allocate the area of landscaping as a separate category from the underlying lawns.

Total nitrogen loads are partitioned into nitrate, ammonium and organic nitrogen loads. TKN is not addressed, as it is the sum of ammonium and organic loads. TN and TKN loads are not addressed individually. Note that many observations only provide partial measurements, so EMCs of the remaining species have been calculated by subtraction.

Since vegetation is absent in impervious surfaces, most of the nitrogen species in runoff from impervious surfaces would seem to be generated from atmospheric deposition. Averaged over a 17 year period at Wye, MD, Correll and others (1994) noted atmospheric inputs of 5.56 kg/ha/yr of nitrate-N, 3.18 kg/ha/yr of ammonium-N and 3.62 kg/ha/yr of organic nitrogen-N. Note that organic N load was 41% of the nitrate and ammonium loads. Given average annual rainfall of 1.08 meters, these values represent 0.51, 0.29 and 0.34 mg/l, respectively.

Table 3-1: Mean TSS and Total Phosphorus EMCs in Urban and Agricultural Runoff (mg/l)

	TOTAL SUSPENDED SOLIDS												TOTAL PHOSPHORUS											
SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE
Owens et al, 1983												160												
Polls and Lanyon, 1976				266				34																
Peterjohn and Correll, 1984									6480												5.03			
Laflen and Tabatabai, 1984									18940	9710	4940													
Langdale et al, 1985									2310	970											0.08	0.17		
Correl et al, 1984																				0.81	0.16			0.56
Gilliam et al, 1993a									4111												1.70			
Gilliam et al, 1993b									4103												2.14			
Correl et al 1994																				0.35		2.32		0.81
Mendez et al, 1999									7890															
Linde and Watschke, 1997						15																		
Gross et al, 1991						231																		
Gross et al, 1990						25																		
Gross et al, 1990						8																		
Horner et al, 1994			45					1							0.08					0.10				
Garn, 2002																		2.06	3.52					
Schueler & Shepp 1993			11	3											0.50	0.06								
Pitt et al 1996a				450	310	118										0.30	0.63	0.29						
Pitt et al 1996b		0		136	687	807								0.04		0.49	0.62	0.20						
Pitt, et al, 1996	3	27	16	15			38																	
DSWF, 1996	9	19	27	172	173	602	37						0.20	0.09	0.45	0.63	1.16	1.67						
Wisconsin, 1992	19	36	474	241	193	457							0.24	0.19	0.48	0.53	1.50	3.47						
Bannerman et al, 1993	15	27	58	326	173	397							0.20	0.15	0.19	1.07	1.16	2.67						
Steuer et al, 1997	24	36	138	305	157	262							0.09	0.06	0.20	0.23	0.35	2.33						
Waschbusch et al, 1999a	18	16	51	69	34	91							0.07	0.11	0.05	0.32	0.18	1.20						
Waschbusch et al, 1999b		20		211	68	128								0.16		0.76	0.24	1.54						
Waschbusch et al, 1999c	21	18	75	94	266	77							0.13	0.07	0.11	0.38	0.50	1.05						
Waschbusch et al, 1999d	21	20	75	94	255	88							0.13	0.12	0.11	0.38	0.47	1.13						
Arithmetic Mean	16	22	97	183	232	236	37	18	7306	5340	4940	160	0.15	0.11	0.24	0.47	0.68	1.60	3.52	0.42	1.82	1.24		0.68
Geometric Mean	14	14	54	111	177	121	37	6	5791	3069	4940	160	0.14	0.10	0.18	0.38	0.55	1.23	3.52	0.30	0.74	0.63		0.67
MODEL VALUE	15	20	60	110	180	125	50	30	6000	3000	1000	160	0.15	0.11	0.25	0.38	0.49	1.30	3.60	0.30	2.30	1.70	1.10	1.30

Table 3-2: Mean Particulate and Soluble Phosphorus EMCs in Urban and Agricultural Runoff (mg/l)

	PARTICULATE PHOSPHORUS												SOLUBLE PHOSPHORUS											
SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE
Peterjohn and Correll, 1984									4.82												0.21			
Polls and Lanyon, 1976																0.07				0.04				
Laflen and Tabatabai, 1984																					0.08	0.17	0.60	
Langdale et al, 1985									1.82	0.85											0.13	0.23		
Gilliam et al, 1993a									1.16												0.29			
Gilliam et al, 1993b									1.70												0.44			
Correl et al 1994								0.29		2.27		0.76								0.06		0.05		0.05
Cole et al, 1997																		5.21						
Linde and Watschke, 1997																		3.19						
Gross et al, 1991																		0.06						
Gross et al, 1990																		0.03						
Kussow, 2002																		0.12						
Garn, 2002						1.58	2.48											0.48	1.04					
Schueler & Shepp 1993			0.34	0.05											0.16	0.01								
Pitt et al 1996a				0.24	0.25	0.09										0.06	0.38	0.20						
Pitt et al 1996b		0.02		0.46	0.60									0.02		0.03	0.02	0.66						
Wisconsin, 1992	0.13	0.11	0.41	0.39	0.63	1.07							0.11	0.08	0.07	0.14	0.87	2.40						
Bannerman et al, 1993	0.12	0.09	0.14	0.76	0.67	1.22							0.08	0.06	0.05	0.31	0.49	1.45						
Steuer et al, 1997	0.06	0.04	0.18	0.22	0.31	2.24							0.03	0.02	0.02	0.01	0.04	0.09						
Waschbusch et al, 1999a	0.11	0.06	0.08	0.20	0.11	0.63							0.02	0.05	0.02	0.12	0.07	0.57						
Waschbusch et al, 1999b		0.09		0.42	0.12	0.71								0.09		0.34	0.12	0.85						
Waschbusch et al, 1999c	0.09	0.04	0.09	0.20	0.36	0.56							0.02	0.03	0.03	0.19	0.14	0.49						
Waschbusch et al, 1999d	0.09	0.06	0.09	0.20	0.34	0.58							0.02	0.07	0.03	0.18	0.14	0.55						
Arithmetic Mean	0.10	0.06	0.19	0.31	0.38	0.96	2.48	0.29	2.37	1.56		0.76	0.05	0.05	0.06	0.13	0.25	1.09	1.04	0.05	0.23	0.15		
Geometric Mean	0.10	0.06	0.16	0.25	0.31	0.73	2.48	0.29	2.04	1.39		0.76	0.04	0.04	0.04	0.08	0.14	0.47	1.04	0.05	0.19	0.12		
MODEL VALUE	0.10	0.06	0.20	0.30	0.35	0.75	2.50	0.25	2.10	1.40	0.70	0.75	0.05	0.05	0.05	0.08	0.14	0.55	1.10	0.05	0.20	0.30	0.40	0.55

Table 3-3: Mean Total and Nitrate Nitrogen EMCs in Urban and Agricultural Runoff (mg/l)

	TOTAL NITROGEN												NITRATE NITROGEN											
SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE
Peterjohn and Correll, 1984									4.45												4.45			
Laflen and Tabatabai, 1984																					0.18	0.21	1.59	
Correl et al, 1984								0.36	5.26			0.27								0.36	5.26			0.27
Langdale et al, 1985									5.04												5.04			
Gilliam et al, 1993a									0.90												0.90			
Gilliam et al, 1993b									0.83												0.83			
Owens et al, 1983																								1.95
Owens et al, 1989																								0.80
Correl et al 1994								0.14				0.40								0.14		1.61		0.40
Mendez et al, 1999									27.89															
Cole et al, 1997																		2.09						
Linde and Watschke, 1997																		0.42						
King and Balogh, 1997																		2.71						
Gross et al, 1990																		0.27						
Gross et al, 1990																		0.04						
Horner et al, 1994			0.32				0.03								0.32				0.03					
Kussow, 2002																		0.12						
Garn, 2002																		0.12						
Schueler & Shepp 1993			0.01	0.92											0.01	0.92								
Pitt et al 1996a																								
Pitt et al 1996b																								
Steuer et al, 1997	0.49	0.46	0.34	0.32	0.30	0.40							0.49	0.46	0.34	0.32	0.30	0.40						
Arithmetic Mean	0.49	0.46	0.22	0.62	0.30	0.40	0.03	0.25	7.40			0.34	0.49	0.46	0.22	0.62	0.30	0.77	0.03	0.25	2.78	0.91	1.59	0.86
Geometric Mean	0.49	0.46	0.10	0.54	0.30	0.40	0.03	0.23	3.68			0.33	0.49	0.46	0.10	0.54	0.30	0.33	0.03	0.23	1.59	0.58	1.59	0.64
MODEL VALUE	0.50	0.45	0.30	0.55	0.30	0.35	0.25	0.25	1.60	1.80	2.00	0.60	0.50	0.45	0.30	0.55	0.30	0.35	0.25	0.25	1.60	1.80	2.00	0.60

Table 3-4: Mean Ammonia and Organic Nitrogen EMCs in Urban and Agricultural Runoff (mg/l)

	AMMONIA NITROGEN												ORGANIC NITROGEN											
SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE
Peterjohn and Correll, 1984									1.89															
Laflen and Tabatabai, 1984									0.19	0.58	1.23													
Correl et al, 1984								0.98	1.88			0.32								2.17	1.65			1.82
Langdale et al, 1985																								
Gilliam et al, 1993a									0.02												3.43			
Gilliam et al, 1993b									0.34												4.27			
Owens et al, 1983												6.00												3.55
Owens et al, 1989												1.60												2.70
Correl et al 1994								0.12		0.18		0.15								1.39		2.97		3.16
Mendez et al, 1999									4.30												23.59			
Cole et al, 1997						3.65																		
Linde and Watschke, 1997						*0.32*												*1.13*						
Gross et al, 1990						0.21																		
Gross et al, 1990						0.07																		
Horner et al, 1994			0.22												0.35				0.16					
Garn, 2002						0.96																		
Schueler & Shepp 1993			1.58	0.19											3.36	0.65								
Pitt et al 1996a				0.05	0.10	0.40										1.75	2.50	0.80						
Pitt et al 1996b		0.10		0.05	0.30	0.50								0.70		1.55	0.80	0.80						
Steuer et al, 1997	0.67	0.44	0.22	0.35	0.12	0.26							0.93	0.56	1.38	0.95	1.68	9.04						
Arithmetic Mean	0.67	0.27	0.67	0.16	0.17	0.80		0.55	1.44	0.38	1.23	2.02	0.93	0.63	1.70	1.23	1.66	2.94	0.16	1.78	8.23			2.81
Geometric Mean	0.67	0.21	0.42	0.11	0.15	0.41		0.35	0.52	0.32	1.23	0.82	0.93	0.63	1.18	1.14	1.50	1.60	0.16	1.73	4.89			2.72
MODEL VALUE	0.65	0.25	0.45	0.15	0.15	0.50	0.45	0.40	0.60	1.00	1.70	0.70	0.95	0.65	1.20	1.15	1.50	1.80	1.75	1.75	4.90	5.40	6.00	2.75

Table 3-5: Mean Copper and Zinc EMCs in Urban Runoff (mg/l), Sources

TOTAL COPPER (ug/l)

SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE
CH2MHill, 2000				22.1		5.7		5.3	5.4			5.4
Omni source						9.8			11.3			
Horner et al, 1994			4.5									
Tiefefthaler et al, 2001			28.0									
Cook et al, 1996						10.0						
Pitt, et al, 1996	5.0	46.0	285.0	10.0								
DSWF, 1996	7.0	20.0	51.0	24.0	17.0	17.0						
Wisconsin, 1992	10.0	5.0	21.0	25.0	20.0	13.0						
Bannerman et al, 1993	9.0	15.0	15.0	56.0	17.0							
Steuer et al, 1997	20.0	7.0	22.0	30.0	34.0							
Arithmetic Mean	10.2	18.6	60.9	27.9	22.0	11.1		5.3	8.4			5.4
Geometric Mean	9.1	13.7	27.8	24.6	21.1	10.4		5.3	7.8			5.4
MODEL VALUE	10	15	30	25	25	15	5	5	10	10	10	5

TOTAL ZINC (ug/l)

SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO- TILL	PAS-TURE
CH2MHill, 2000				214.6		25.4		24.8	23.5			23.5
Omni source						75.8			64.0			
Horner et al, 1994			90.0									
Tiefefthaler et al, 2001			293.0									
Cook et al, 1996						200.0						
Pitt, et al, 1996	181.0	476.0	64.0	38.0								
DSWF, 1996	256.0	312.0	139.0	173.0	107.0	50.0						
Wisconsin, 1992	363.0	153.0	249.0	245.0	113.0	60.0						
Bannerman et al, 1993	330.0	149.0	178.0	339.0	107.0							
Steuer et al, 1997	348.0	201.0	178.0	166.0	148.0							
Arithmetic Mean	295.6	258.2	170.1	195.9	118.8	82.2		24.8	43.8			23.5
Geometric Mean	286.5	232.6	151.7	164.0	117.6	64.9		24.8	38.8			23.5
MODEL VALUE	290	240	170	160	120	90	25	25	40	50	60	25

SOURCE	LOCATION, METHOD, COMMENTS
Peterjohn and Correll, 1984	MD- arithmetic means, natural events
Laflen and Tabatabai, 1984	IA- arithmetic mean, simulated events
Correl et al, 1984	MD- arithmetic mean, natural events
Langdale et al, 1985	GA- arithmetic means, natural events
Gilliam et al, 1993a	NC- geometric means, natural events
Gilliam et al, 1993b	NC- flowweighted means, natural events
Correl et al 1994	MD- arithmetic means, buffered stormflow
Mendez et al, 1999	VA- arithmetic means, simulated events
Cook et al, 1996	CA- arithmetic means,, streamflow measurments
Cole et al, 1997	Oklahoma, flow weighted mean, intense simulated
Linde and Watschke, 1997	Oklahoma-flow weighted mean, natural and simulated
Gross et al, 1991	Maryland- flow weighted mean, simulated rainfall
Gross et al, 1990	Maryland- flow weighted mean, dry year events
Gross et al, 1990	Maryland- flow weighted mean, average year events
Horner et al, 1994	Nationwide summary
Kussow, 2002	Wisconsin- flow weighted mean, natural events
Garn, 2002	Wisconsin- average of geometric mean, several events
Schueler & Shepp 1993	Maryland -arithmetic mean, natural events
Pitt et al 1996a	Toronto-arithmetic mean, winter events
Pitt et al 1996b	Toronto -arithmetic mean, warm season events
Pitt, et al, 1996	Alabama- arithmetic mean, natural events
DSWF, 1996	Wisc. & Ala.- arithmetic mean, natural events
Wisconsin, 1992	Wisconsin- geometric mean, several events
Bannerman et al, 1993	Wisconsin- geometric mean, several events
Steuer et al, 1997	Michigan- geometric mean, several events
Waschbusch et al, 1999a	Wisconsin-average geometric mean, many events in two basins
Waschbusch et al, 1999b	Wisconsin- flow weighted mean, many events, wooded basin
Waschbusch et al, 1999c	Wisconsin- flow weighted mean, many events, open basin
Waschbusch et al, 1999d	Wisconsin- flow weighted mean, many events, both basins
CH2MHill, 2000	Recommended EMCs for NC based upon measurments
Tiefefthaler et al, 2001	California, mean of many rainfall simulator events

The Model of the Chesapeake Airshed calls for atmospheric deposition rates of 3.22 and 1.94 kg/ha/yr of nitrate-N and ammonia-N, respectively in Wye, MD (Linker and others, 2000). Based upon the results of Scudlark and Church (1993, as cited in Horsley and Witten 1998) for Lewes, DE, average EMCs for nitrate are 0.28 mg/l and 0.17 mg/l for ammonium. Using a 41% value for organic N, this suggests a value of 0.20 mg/l for the particulate organic component. Compared to the EMCs reported in Steuer and others (1997) and Pitt and others (1996), the inorganic forms of nitrogen predicted from deposition are slightly less than observed EMCs. However, levels of organic N in urban runoff from impervious surfaces seem to exceed atmospheric deposition by a factor of at least three. This suggests that there must be additional sources local to the urban environment. Given a TKN level as high as 9.30 mg/l from lawns (Steuer and others, 1997), lawns (and/or trees) would seem to be the primary source of organic N deposition on adjacent impervious surfaces.

For organic N, the geometric mean of the study residual values is applied to impervious surfaces. For lawns, the residual value of 9.04 from Steuer and others (1997) may represent an extreme when compared to the 0.80 reported by Pitt and others (1996), so a design value of 3.45 is used, based on the geometric mean of the studies. This value is similar to the 3.16 mg/l reported for pastures by Correll and others (1994). Given their turf cover and nutrient inputs, pastures could be considered similar to lawns in this analysis.

In the Rhode River watershed near Wye, MD, organic N from crops was 77% of total N in surface runoff, with 92% in the particulate form. In contrast, groundwater levels of organic-N were only 2.4% of total subsurface N loads (Peterjohn and Correll, 1984). Dillaha and others (1989) noted that 95% to 97% of organic N in runoff from plowed fields was in the particulate form. Organic N comprises 80% of the total nitrogen in stormflow from pastures, and over 50% of the load from crops and woods, while base flow ratios varied from 48% to 26% (Correll and others, 1995). These studies suggest that surface runoff pathways dominate stormflow losses of organic N. This was confirmed in subsequent study in the Maryland Piedmont by the same authors, although they reported that 70-80% of organic N was in a dissolved form (Jordan and others, 1997).

If organic N were particulate, most of the organic N in urban runoff would be in a form amenable to settling and filtration. However, organic N EMC reductions by vegetative filtration BMPs are variable, ranging from 30% to 80% (See Chapter 9). This implies that some of the organic N loads must be either soluble, or adsorbed into fractions too fine to settle with these BMPs. Parsons and others (1993) reported average organic N EMC reductions from 31% to 52% from filter strips below cropped areas. Since this study had events similar to conditions encountered in urban BMPs, the lower range seems more appropriate. It seems that organic nitrogen is present in a fraction too fine to filter thoroughly, but with a low ability to percolate into groundwater.

While the main thrust of DURMM is to address sediment and nutrient loads, there is a potential for toxicity from elevated levels of metals, PAHs, organic compounds, and petroleum hydrocarbons in runoff originating from many development sites. Petroleum hydrocarbons from “hot spots” such as intense industrial and commercial land uses can be quite elevated in

comparison to residential streets (Shepp, 1996). A similar relationship was noted for copper and zinc (Schueler and Shepp, 1995). While there is little data on PAH loading by land cover, Steuer and others (1997) noted that total PAHs from parking lots was 90 µg/l, while other impervious surfaces were in the range of 1 to 5 µg/l. No PAHs were noted in runoff from lawns.

Since the literature is just now emerging, the approach taken in DURMM is to wait until better data is available for estimating PAH and organic compound loading from hot spots. Note that the soluble forms of metals are more toxic, but there are no nationwide standards for these species. Table 3-5 summarizes metals loading by land cover.

By defining the extent of urban runoff loads in this method, the requirements needed to mitigate these loads become more focused. However, to more fully address urban runoff impacts, it is also necessary to have a realistic idea of the hydrological impacts of urban runoff. Chapter 4 examines the criteria needed for pollutant removal, and relates these criteria to the Delaware's climate characteristics.

CHAPTER 4 URBAN RUNOFF CRITERIA

4.1 CRITERIA FOR URBAN RUNOFF POLLUTANT TREATMENT

The primary factor in developing treatment criteria for the control of pollutants in urban runoff is to define the runoff volume captured by a water quality BMP. For a treatment process to reduce pollutants to acceptable levels, a BMP must intercept enough of the annual loading of runoff. If the treatment volume is inadequate, it will not provide the necessary benefits that may be otherwise attainable.

The State of Maryland has established goals to reduce TSS loading from urban runoff by 80%, and reduce total phosphorus (TP) loading by 40% (MDE, 1999). It is thought that TSS removal will address most toxic pollutants such as metals, since they are generally associated with sediments. The 80% removal value for TSS implies that the great majority of the annual runoff volume must be captured by a BMP to attain the target level of treatment. In Maryland, roughly 70% of total rainfall occurs in events up to an inch, but an inch of treatment for the larger storms boosts the effective capture volume into the range of 80 to 85% (Prince Georges Co., 2000). Many authorities thus establish a treatment volume at one inch of rainfall as being adequate to attain the desired goals, while still being cost effective (Claytor and Schueler 1996; Prince Georges Co., 2000; MDE, 1999).

The Coastal Zone Management Program recommends treatment of the 2 year, 24 hour storm of over 3 inches (USEPA, 1991). Continuous modeling indicates that nearly as effective treatment could be provided more cost effectively by using a smaller design event, so Wisconsin recommends a design event in the range of 1.25 to 1.5 inches (WDNR, 1995). However, rules proposed to be adopted by the USEPA for marinas and agricultural areas require treatment of 80% of the annual runoff, not annual rainfall. Since pervious areas generate much less runoff than impervious areas at low rainfall amounts, the required rainfall volume to capture 80% of runoff will be greater in sites with more pervious area.

Table 4-1 displays the percentage of annual rainfall volume during events of the indicated size increment at Porter Reservoir in New Castle Co., Dover in Kent Co., and Georgetown in Sussex Co. (Leathers, 2000). Precipitation increment is the product of the average rainfall in each increment and its percent of total rainfall. Note that the final rainfall increment for extreme events is larger, since these events provide 0.3% to 0.6% of total annual rainfall. At rainfall increments greater than the recommended capture depth of 2.0 inches, captured precipitation is the product of capture depth times the incremental percentage of annual rainfall. The amount of annual rainfall captured by a specific volume is then determined by summing across the rows. Depending upon location, a treatment volume of 2.0 inches intercepts 95% to 97% of annual rainfall.

Table 4-1: Annual Precipitation Distribution and Runoff Capture Volumes of the 2.0 Inch Event, New Castle, Kent And Sussex Counties, Delaware

LOWER INCREMENT	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	TOTAL
UPPER INCREMENT	0.24	0.49	0.74	0.99	1.24	1.49	1.74	1.99	2.24	2.49	2.74	2.99	6.00	
PORTER RESERVOIR, NEW CASTLE COUNTY														
UNADJUSTED %	58.0%	17.0%	10.0%	6.0%	4.0%	2.0%	1.0%	0.7%	0.6%	0.5%	0.3%	0.1%	0.3%	100.5%
ADJUSTED %	57.7%	16.9%	10.0%	6.0%	4.0%	2.0%	1.0%	0.7%	0.6%	0.5%	0.3%	0.1%	0.3%	100%
INCRMNT. PRECIP.	6.93	6.26	6.17	5.19	4.46	2.73	1.61	1.30	1.27	1.18	0.78	0.29	1.34	39.5
PRECIP. CAPTURE	6.93	6.26	6.17	5.19	4.46	2.73	1.61	1.30	1.19	1.00	0.60	0.20	0.60	38.2
IMPERV. EVENT	0.04	0.19	0.37	0.59	0.82	1.05	1.30	1.54	1.79	2.04	2.29	2.54	4.17	
IMPERV. ANNUAL	2.48	3.13	3.71	3.50	3.25	2.10	1.29	1.07	1.07	1.01	0.68	0.25	1.24	24.8
IMPERV. CAPTURE	2.48	3.13	3.71	3.50	3.25	2.10	1.29	1.07	0.86	0.73	0.45	0.15	0.37	23.1
PERV. EVENT	0.00	0.00	0.00	0.02	0.04	0.08	0.12	0.17	0.23	0.29	0.36	0.44	1.09	
PERV. ANNUAL	0.00	0.00	0.02	0.11	0.17	0.15	0.12	0.12	0.13	0.12	0.08	0.03	0.15	1.2
PERV. CAPTURE	0.00	0.00	0.02	0.11	0.17	0.15	0.12	0.12	0.10	0.09	0.05	0.02	0.04	1.0
50% PERV. ANNUAL	1.24	1.57	1.86	1.81	1.71	1.13	0.70	0.60	0.60	0.57	0.38	0.14	0.69	13.0
50% PERV. CAPTURE	1.24	1.57	1.86	1.81	1.71	1.13	0.70	0.60	0.48	0.41	0.25	0.09	0.21	12.0
CAPTURE PERCENT	PRECIPITATION			96.8%	IMPERVIOUS		93.2%	PERVIOUS		83.2%	50% COMBINED			92.7%
DOVER, KENT COUNTY														
UNADJUSTED %	53.0%	18.0%	11.0%	6.0%	4.0%	3.0%	1.0%	0.9%	0.8%	0.6%	0.2%	0.2%	0.5%	99.2%
ADJUSTED %	53.4%	18.1%	11.1%	6.0%	4.0%	3.0%	1.0%	0.9%	0.8%	0.6%	0.2%	0.2%	0.5%	100%
INCRMNT. PRECIP.	6.41	6.71	6.88	5.26	4.52	4.14	1.63	1.70	1.71	1.43	0.53	0.58	2.27	43.8
PRECIP. CAPTURE	6.41	6.71	6.88	5.26	4.52	4.14	1.63	1.70	1.61	1.21	0.40	0.40	1.01	41.9
IMPERV. EVENT	0.04	0.19	0.37	0.59	0.82	1.05	1.30	1.54	1.79	2.04	2.29	2.54	4.17	
IMPERV. ANNUAL	2.30	3.36	4.13	3.55	3.29	3.19	1.31	1.40	1.44	1.23	0.46	0.51	2.10	28.3
IMPERV. CAPTURE	2.30	3.36	4.13	3.55	3.29	3.19	1.31	1.40	1.16	0.89	0.30	0.31	0.63	25.8
PERV. EVENT	0.00	0.00	0.00	0.02	0.04	0.08	0.12	0.17	0.23	0.29	0.36	0.44	1.09	
PERV. ANNUAL	0.00	0.00	0.02	0.11	0.18	0.23	0.12	0.15	0.18	0.18	0.07	0.09	0.55	1.9
PERV. CAPTURE	0.00	0.00	0.02	0.11	0.18	0.23	0.12	0.15	0.15	0.13	0.05	0.05	0.17	1.4
50% PERV. ANNUAL	1.15	1.68	2.08	1.83	1.73	1.71	0.71	0.78	0.81	0.70	0.27	0.30	1.33	15.1
50% PERV. CAPTURE	1.15	1.68	2.08	1.83	1.73	1.71	0.71	0.78	0.65	0.51	0.18	0.18	0.40	13.6
CAPTURE PERCENT	PRECIPITATION			95.7%	IMPERVIOUS		91.3%	PERVIOUS		71.8%	50% COMBINED			90.1%
GEORGE TOWN, SUSSEX COUNTY														
UNADJUSTED %	56.0%	17.0%	10.0%	6.0%	4.0%	2.0%	1.0%	0.7%	0.5%	0.4%	0.2%	0.2%	0.6%	98.6%
ADJUSTED %	56.8%	17.2%	10.1%	6.1%	4.1%	2.0%	1.0%	0.7%	0.5%	0.4%	0.2%	0.2%	0.6%	100%
INCRMNT. PRECIP.	6.82	6.38	6.29	5.29	4.54	2.78	1.64	1.33	1.08	0.96	0.53	0.58	2.74	41.0
PRECIP. CAPTURE	6.82	6.38	6.29	5.29	4.54	2.78	1.64	1.33	1.01	0.81	0.41	0.41	1.22	38.9
IMPERV. EVENT	0.04	0.19	0.37	0.59	0.82	1.05	1.30	1.54	1.79	2.04	2.29	2.54	4.17	
IMPERV. ANNUAL	2.44	3.19	3.78	3.57	3.31	2.14	1.32	1.10	0.91	0.83	0.46	0.51	2.54	26.1
IMPERV. CAPTURE	2.44	3.19	3.78	3.57	3.31	2.14	1.32	1.10	0.73	0.60	0.30	0.31	0.76	23.5
PERV. EVENT	0.00	0.00	0.00	0.02	0.04	0.08	0.12	0.17	0.23	0.29	0.36	0.44	1.09	
PERV. ANNUAL	0.00	0.00	0.02	0.11	0.18	0.16	0.12	0.12	0.11	0.12	0.07	0.09	0.67	1.8
PERV. CAPTURE	0.00	0.00	0.02	0.11	0.18	0.16	0.12	0.12	0.09	0.09	0.05	0.05	0.20	1.2
50% PERV. ANNUAL	1.22	1.60	1.90	1.84	1.74	1.15	0.72	0.61	0.51	0.47	0.27	0.30	1.60	13.9
50% PERV. CAPTURE	1.22	1.60	1.90	1.84	1.74	1.15	0.72	0.61	0.41	0.34	0.18	0.18	0.48	12.4
CAPTURE PERCENT	PRECIPITATION			95.0%	IMPERVIOUS		90.2%	PERVIOUS		67.0%	50% COMBINED			88.8%

Table 4-1 also displays capture volumes in terms of percentages of annual runoff, instead of annual rainfall. Event runoff is calculated according to the methods described in Chapter 5, using the average rainfall depth for each increment. Runoff volumes are presented for impervious surfaces with a curve number of 98, pervious surfaces at a curve number of 61, and a combined area that is 50% pervious. Annual depth is incremental rainfall multiplied by the proportion of runoff to rainfall at each increment. At rainfall increments greater than the capture depth of 2.0 inches, captured runoff is the product of annual depth times the ratio of capture depth to upper increment of annual rainfall, less 10% to account for the fact that runoff is less than rainfall. (Actual values of this relationship vary from 5% to 16%, depending upon depth.)

Depending upon the rainfall distribution, 2.0 inches of rainfall capture captures 90% to 93% of the annual runoff from impervious surfaces, but only 67% to 83% from the pervious surfaces. However, when impervious areas are 50% of the total, the total runoff capture percentage ranges from 89% to 93%. This is due to the fact that runoff from impervious areas is much greater than that from pervious areas, exceeding pervious runoff volumes by over a factor of 10. For this reason, changes in pervious curve numbers do not affect the total percentages materially. A capture depth of 2.0 inches thus ensures treatment of at least 80% of annual runoff for the typical development site in which impervious surfaces comprise at least 35%. If the capture threshold were a smaller rainfall event, such as 1.0 inch, the annual capture volume from low-density sites would be less than 80 percent.

Given that BMPs are not 100% effective (typically 80-95% for TSS, 40-60% for total phosphorus, and 0-30% for total nitrogen), this implies that a higher percentage of annual rainfall volume should be captured by a BMP to attain target levels of treatment. If the intent is to provide an 80% reduction in annual loads, the capture percentage has to be multiplied by treatment efficiency. At an efficiency of 90%, reductions in TSS loads would be 83%, 80% and 81% for 50 percent impervious sites in New Castle, Sussex, and Kent Counties, respectively. Since these values correspond to an 80% target, this analysis suggests that a treatment volume of at least 1.5 inches is necessary. This corresponds to the findings established in Wisconsin (WDNR, 1995).

BMPs will provide for more treatment and last longer when the treatment volume is thus increased by 100% over the one inch typically used. Furthermore, BMPs properly designed for a volume of 2.0 inches can often route larger flood flows effectively with a relatively small increase in total storage volume. Such BMPs also provide for extensive contact filtering and the opportunity for infiltration of runoff. Therefore, Green Technology recommends that runoff quality BMPs should be designed to capture and treat runoff volumes for storm events up to 2.0 inches of rainfall.

To promote recharge, designers are encouraged to install BMPs that recharge the losses in recharge volumes due to development. Since this can be difficult in certain sites, recharge is not a requirement of this Manual. Wherever recharge is not a viable option due to site conditions, extended detention of the 2.0 inch volume is recommended, as discussed in more detail in Section 4.2.

4.2 CRITERIA FOR STREAM BANK PROTECTION HYDROLOGY

The need to mitigate the changes in hydrology from urbanization is thus particularly important. Regardless of whether pollutants are present, healthy benthic communities cannot exist in unstable streams. Therefore, measures to alter urban hydrologic responses to that which the receiving stream can tolerate are vitally important to the health of streams. The following discussion sets forth the background and rationale for criteria to protect instream habitat.

In typical soils, infiltration of the entire increase in runoff volume is rarely feasible in developments where imperviousness exceeds 20% or so. Therefore, extended detention of the frequent runoff events is the best option available to minimize downstream bank erosion. As a result, Ontario regulations have required Overcontrol (OC) of the one inch storm by retaining this volume over a 24 hour period. However, too much OC by itself can cause aggradation, which also destabilizes streambanks. Instead, MacRae (1991) recommends the Distributed Runoff Control (DRC) approach, in which the retention structure is designed to increase OC volumes to reduce post-development flows by at least 50% below pre-development flows, at stages below midbank flows. The outflow increases to equal pre-development peak flows of the two-year storm at the bankfull flows. This provides a substantial reduction in the erosional potential of sub-bankfull flows, while allowing the flows at the higher stages to flush out accumulated sediments.

Since midbank flows are the dominant flows causing bank erosion, the midbank flow rate is used as the pre-development target criterion for the 50% over-control release rate. Assuming that the two-year recurrence interval event represents bankfull discharge, and that mid to upper bank flows approach 50% of this flow, design flow would occur at precipitation events in the range of 1.4 to 1.7 inches, representing a recurrence frequency of several times per year. Since these values are close to the 2.0 inches required for quality treatment, Green Technology recommends a reduction in the peak rates from pre-development flows from the storm of 2.0 inches of rainfall, and no increase in the 2 year peak runoff rate.

However, the appropriate DRC reductions from pre-developed flows and the criteria for pre-development conditions are more difficult to establish. Booth and Jackson (1997) note that the threshold for impacts from urbanization occurs at a 10% effective impervious area (EIA), or 20% total impervious area (TIA) typical of medium density single family homes. Using the HSPF model, Booth and Jackson also noted that this threshold was equivalent to a Q_{2post} (post-development peak flow rate from the two-year storm) being equal to or less than Q_{10pre} for forested areas. This tolerance value implies that forested streams could convey up to a 60% increase in flows (the difference between Q_2 and Q_{10}) before destabilization occurs. The 10% EIA threshold seems to correlate well with the 10% to 15% TIA threshold for habitat impacts noted for streams in Delaware by Maxted (1997). Ongoing work in Vermont suggests that an EIA of up to 10% is tolerated by cohesive stream banks, but the most sensitive streams could only handle up to 3% EIA before degradation was noted (MacRae, personal comm.). Note that the threshold concept is not entirely accurate since the decline in benthic indices in proportion to urbanization occurs along a continuum; however, it provides a basis for the criteria discussed above (Maxted and Shaver, 1999).

As discussed above, the extent of DRC reduction depends upon the cohesion of the stream bank toe stratigraphic unit. The Plasticity Index (PI) of the streambank toe seems to correlate highly with cohesion, so it is possible that bank toe information can be estimated from NRCS Soils Mapping. However, this provides a very rough estimate at best, and field measurements are needed to verify the degree of bank stability of the receiving stream. Depending upon the relative stability of the toe unit, MacRae (1991) recommends DRC targets up to 90%. Note that each stream is different, and a DRC percentage beyond the optimal is projected to actually increase bank erosion due to aggradation. Therefore, site-specific revisions to these targets may thus be required, as discussed in more detail below. Since the relative bank stability of the streams has not been methodically evaluated in Delaware, the literature supports a conservative approach requiring at least the minimum protection of a 50% DRC.

However, nearly all of the available land in the Piedmont physiographic region in Delaware has been developed already, with severe impacts upon the receiving streams. Therefore, overcontrol of the quality storm from new developments in this area would have minimal benefits on already impacted streams. Only in the few watersheds that remain pristine would such an approach be warranted. The vast majority of development now occurs in the Coastal Plain physiographic region, where stream gradients are low enough that bank erosion from urban runoff is not a problem (Dickey, personal communication).

Therefore, Green Technology recommends that the criteria for stream bank protection in the Coastal Plain require that post-development peak flows of 2.0 inches of rainfall match pre-development peak flows. Likewise, there shall be no increase in the peak rate of the two-year runoff event. Stricter criteria using forest cover with 10% EIA for pre-development conditions and a 50% reduction in the peak flows for the 2.0 inch event may be applicable to pristine Piedmont watersheds. Modeling BMPs for selected sites designed for these storm events using continuous simulation models such as PCSWMM may refine this runoff criterion.

4.3 OFFSITE FACTORS IN STREAM BANK PROTECTION

A key factor in selecting required levels of peak flow control is an examination of the status of bank stability in the area affected by development. In alluvial streams where the floodplains have been subject to aggradation and subsequent incision, nickpoints caused by increased flows occur at locations of bed instability. (Nickpoints are the drop in bed elevations where a normal channel falls into an incised channel.) This channel incision alters equilibrium conditions upstream by increasing the local gradient. This results in a large increase in stream energy, causing channel incision to progressively migrate all the way up through the watershed until equilibrium is reestablished (Booth, 1990). Thus, degradation of the “local base level" by channel incision has a most important and far reaching impact (Heede, 1986).

Harvey and Watson (1986) note that there are several stages of stability in this type of alluvial stream. Stage I corresponds to a relatively stable stream section in the headwaters above a nickpoint. Stage II corresponds to the deeply incised channel downstream of the nickpoint. Stage III comprises stream reaches undergoing peak rates of bank erosion due to incision, where the channel rapidly widens. Stage IV occurs where the channel has begun to stabilize, and new floodplains have become established within the limits of the widened channel. Stage V

represents a stream reach that has regained dynamic equilibrium, where the original floodplain is now a relict terrace above the new floodplain.

This sequence in the geomorphology of incised channels suggests that stream bank protection measures would be most successful in Stages IV and V (Harvey and Watson, 1986), while nickpoints should be stabilized to preserve Stage I reaches (Harvey and Watson, 1986; Heede, 1986; Booth, 1990). After farming declined in the earlier part of the 20th century in the Delaware Piedmont, most of the streams had attained Stages IV and V by the 1950s. However, due to a new episode of downcutting and bank erosion from urban development over the last few decades, many of these streams are now in Stages II and III. In many of these cases, even the highest level of onsite runoff control will not be adequate, particularly where runoff hydrology has been irretrievably altered by existing development. In the Coastal Plain, bank erosion impacts due to urbanization have been generally less extreme (Dickey, personal comm.). This is due to the lower gradient, as well as the fact that less aggradation has occurred in the first place, and much of the coastal plain remains in agricultural uses.

A further consideration is the role of streamside vegetation. Where streamside vegetation had been removed, highly elevated temperatures and lowered DO levels were observed in Delaware Coastal Plain streams (Maxted and others, 1995). Whipple and others (1981) noted that riparian vegetation increased bank stability in urbanizing creeks. Shields and others (1995) were able to successfully stabilize noncohesive alluvial stream banks by establishing native vegetation. Vegetation decreased bank erosion by up to 80% along a creek in British Columbia (Beeson and Doyle, 1995). Horner and others (1997) noted relatively healthy metrics of benthic diversity in watersheds up to 30% TIA where streams were well buffered with riparian vegetation. Zucker and White (1996) also noted a high correlation between indices of biological integrity and the extent of riparian buffers. Yoder and Miltner (2000) report that habitat and IBI indices are increased in urban areas with intact riparian zones. Horner and others (2000) recommend a continuous riparian buffer of native vegetation as one the best BMPs for streams impacted by urban runoff.

These findings underlie the current thrust in stream restoration efforts with soil bioengineering (Kondolf and Micheli, 1995). Vegetative stabilization is the basis for the potential of RBS and SBR BMPs to provide protection of eroding stream banks. In coordination with onsite controls, RBS and SBR BMPs can provide substantial protection of stream banks and improve streams when compared to existing conditions.

In watersheds where streams are heavily impaired by widespread development, onsite hydrological controls that assume a relatively pristine original condition would be ineffective for new development, and thus represent a wasted expense. In these circumstances, RBS and SBR efforts and structural BMPs, such as regional stormwater facilities and retrofits of existing facilities, would be the most effective approach for restoration. This underlies the need to formulate River Corridor Management Plans (RCMPs) that take into account the status of existing and anticipated watershed development, the destabilization stage of each reach, the susceptibility of streambanks to erosion, and the extent of intact riparian buffers. The cumulative implications of these factors would be used in the RCMP to formulate the appropriate priority for various BMPs, and their target criteria.

In an extremely impaired watershed, a RCMP may permit onsite peak flow controls to use existing average watershed land cover in establishing pre-development conditions, with cost savings to be applied toward offsite BMPs. On the other hand, development in pristine streams with little or no degradation should be subject to the most stringent onsite control requirements, which could likely exceed the 50% DRC reduction, and require a lower EIA in establishing existing conditions. Moderately impaired watersheds could vary between these extremes, depending on the potential for regional facilities and stream bank stability. Where regional offsite facilities are available or projected, onsite control criteria for bank erosion may be relaxed in exchange for pro-rated contributions toward the regional facilities. Where unavailable, the onsite controls would be applied. Absent modifications explicitly incorporated into a RCMP, the minimum required controls would apply to all projects.

4.4 CRITERIA FOR FLOODING EVENTS

Additional criteria include the 10-year storm for conveyance design, and the 100-year storm for flood control. Excluding discharge to tidal waters or situations where regional BMPs are proposed, existing site conditions (without impervious surfaces) represent the targets for the runoff controls.

As 10-year events are generally cyclonic or frontal storms with long interevent intervals, a longer drawdown time of 48 hours is appropriate for storage routing, while avoiding interference from subsequent events. This is important in reducing the flooding potential of synchronized flow peaks from sites with typical 10-year controls. Given that the midbank flood control structure is designed to release its storage volume over 24 hours, the higher control structure would be designed to release its storage volume over the preceding 24-hour period. It is quite possible that the same orifice design for the 2-year peak flow reductions discussed in Section 4.6 would address this requirement in most cases.

Therefore, Green Technology recommends that the design criteria for the 10-year event require that the peak rate be no greater than the pre-development rates under existing conditions (including existing impervious surfaces), and that this volume be released over as long a period as possible. The design criteria recommended for the 100-year event also requires that the peak rate be no greater than the pre-development rates under existing conditions.

CHAPTER 5 URBAN RUNOFF HYDROLOGY

5.1 URBAN RUNOFF MODELS

The hydrological analysis required for urban runoff BMP design must identify the runoff contributions from the various land cover components of a project, as affected by soil characteristics and land cover type. It must also address how such runoff changes in response to rainfall events of differing intensities and precipitation amounts. The hydraulic design elements must be able to realistically calculate the flow path components of runoff, and route runoff through storage structures. It should also be capable of partitioning overland discharge from subsurface infiltration components.

Continuous simulation models such as PCSWMM and HSPF are acknowledged as the most accurate tools for this purpose. Even though these models are now accessible to the desktop, considerable training is required to use them properly, and their extensive data collection, calibration and verification requirements preclude practicality for design of BMPs at the site level. SLAMM (Pitt, 1987) is a simpler continuous model that provides excellent hydrological results in urban watersheds of interest. However, it aggregates many important input parameters for pervious and impervious areas, and has no routing components.

Now that powerful computers are widely available, event-based models have been deemed outdated, inadequate, and even unethical (James, 1994). Simple design storm models are thus considered inappropriate to address receiving water quality issues (Pitt, 2000). However, event based modeling can provide appropriate results when the parameters are properly calibrated by comparison to continuous modeling (Strecker and Reinaga, 2000). These authors noted that the curve number (*CN*) method overestimates runoff peaks in large storms when antecedent moisture conditions were classified as saturated. Using event-based models based upon Hortonian type infiltration equations with decay coefficients, Guo and Adams (1998) and Nnadi and others (1999) report good results compared to continuous simulation modeling. These authors also noted that the *CN* method tended to overestimate runoff in the latter study, apparently due to the influence of antecedent moisture.

The *CN* method has been well documented as an excellent watershed loss model for flooding events (Woodward and others, 2002a). On the other hand, the *CN* method substantially underestimates runoff from small urban watersheds in the small storm events that comprise the great majority of total annual runoff (Pitt, 1987, 2000). Errors in peak flow measurement in these events can range up to 1350 percent (Fennessey and Hawkins, 2002). Indeed, even the authors of the *CN* method have recognized that the curve number for small events (less than 2 inches) must be much higher than the stabilized curve number in order to obtain the observed results (Van Mullem and others, 2002; Hjelmfelt and others, 2002).

Conversely, the *CN* method substantially overestimates runoff peaks (by up to 1000 per cent) from forested watersheds in small storms, since runoff follows shallow subsurface flow pathways with little overland response (Fennessey and others, 2001; Fennessey and Miller, 2002). Since these errors compound each other, using the *CN* method to design BMPs for small

storm events where the undeveloped condition is a wooded watershed would result in detention designs that are quite deficient for the events of interest in Green Technology BMP design. Furthermore, even within the same soil *CN* polygon, there can be substantial variations in *CN* depending upon landscape position, with upland *CN*s being less than half the *CN* in concavities where a saturated zone occurs during storm events (Fennessey and Miller, 2002, Fennessey and Hawkins, 2002).

Notwithstanding these limitations, the *CN* method used in TR-20 still remains the method of choice in the design and regulatory community for designing stormwater management facilities. By disaggregating different combinations of land cover and soil type, TR-20 performs well in the larger flooding events of interest in stormwater quantity management, and addresses many of the factors involved in continuous simulation models. TR-55 was subsequently formulated to simplify TR-20 for smaller watersheds. While reasonably close to TR-20 results (within 5% to 10 %), TR-55 is simpler, and used as a basic hydrology program for relatively small, less complex watersheds.

The Delaware Urban Runoff Management Model, or DURMM, has adapted the *CN* method to address the need for a relatively simple, but more accurate, hydrologic modeling approach for small storm events. DURMM hydrology is based upon the Hortonian infiltration equation, as incorporated into the SLAMM model. Along with the pollutant loading elements discussed in Chapter 3, and the pollutant removal routines discussed in Chapters 7 through 11, DURMM is an integrated model for predicting urban runoff volumes, their pollutant loads and their removal by BMPs.

Since TR-20 is already required in Delaware for the design of structural BMPs, DURMM uses the same allocation of discrete polygons defined by land cover and soil group as is used in the *CN* method. Likewise, the determination of the segmental flow pathways used to determine time of concentration (*Tc*) is similar to that used in TR-20. However, DURMM runoff volume computations follow the SLAMM hydrologic equations for small storm event runoff volumes, and they employ a flow-based approach to routing the segmental flow pathways. In this manner, the precision of TR-20 input procedures is complemented by the greater accuracy of the SLAMM computational algorithms and flow-responsive *Tc* computations.

5.2 DURMM MODEL

TR-20 calculates runoff according to the following equation from NRCS (1985):

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \tag{1}$$

where Q is runoff volume, P is precipitation, S is storage (a term roughly equivalent to accumulated infiltration losses) and Ia is initial abstraction, the initial losses due to interception, depression storage, and evaporation. All units are in terms of depth of runoff and precipitation.

In english units, storage (inches) is related to Curve Number (*CN*) according to the following equation:

$$S = \frac{1000}{CN} - 10 \quad (2)$$

In TR-20, *Ia* is fixed at 0.2*S*, so runoff relates to precipitation and storage as follows:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (3)$$

At a given *P*, as *CN* decreases, *S* increases, so *Q* decreases. The more "pervious" the soil cover complex, the greater the storage, which is rarely exceeded in the most pervious areas. As *P* declines toward 0.2*S*, *Q* approaches 0, so no runoff occurs from pervious areas in small rainfall events.

Note also that, while *Ia* is a function of *S*, its effect is to eliminate initial precipitation, even before any *S* is absorbed. The value of *S* is thus independent of *P*, and assumes that no further storage will occur once *P* exceeds *S*. In essence, the soil group/land cover complex is treated as a sponge with a fixed capacity that begins to fill up once *P* exceeds *I*a.

This approach is not at all the behavior of a field scale infiltration model, where infiltration rates will increase with increasing precipitation intensity (Pitt, 1987; Woodward and others, 2002a). Instead, the *CN* method integrates many components of the entire watershed response, including the partial contributing area (PCA) concept (Van Mullem and others, 2002). PCAs are relatively small saturated areas in downslope concavities adjacent to streams, which can be responsible for much of the runoff generation (Kirkby, 1988; Pionke and others, 1988; Gburek, 1900). PCAs are linked to upslope contributory areas by largely subsurface flow pathways during the rainfall event (Pionke and others, 1988). These subsurface flow pathways also directly contribute to the runoff response (NRCS 1985, Hjelmfelt and others, 2002).

As such, the *CN* method was intended to model the entire watershed response, not that of saturation excess flows (which occur very rarely) from each individual contributory land cover complex polygon in upland areas (Van Mullem and others, 2002). Therefore, its use at the small site scale must be viewed cautiously, as noted by Fennessey and associates (Fennessey and Miller, 2002; Fennessey and Hawkins, 2002). Nonetheless, its rainfall/runoff response is considerably more realistic than the Rational Method, and it is already very familiar to the engineering and regulatory community. As such, the *CN* method provides the best available starting point for developing an approach to designing urban runoff BMPs. By providing the modifications discussed below, DURMM attempts to rectify many of the shortcomings of the *CN* approach.

In the agricultural watersheds and larger storm events for which TR-20 was formulated, the value of *Ia* does not substantially affect results, since *P* is usually much greater than 0.20*S*. This value was chosen to best fit the observed data from many watersheds (NRCS, 1985) as a mean between 0.00 and 0.30 (Ponce and Hawkins, 1996). However, for predicting the hydrology of small urban watersheds under smaller storm events, this fixed value for *Ia* in TR-20 has serious shortcomings, and thus TR-20 tends to grossly under predict the hydrological contribution during smaller rainfall events from the lawns and landscaping that comprise urban

pervious areas (Pitt, 1987, 2000). This is part of the reason why the curve number in smaller events must be increased to match observed responses (Van Mullem and others, 2002). Indeed, a recent paper by the NRCS researchers suggests that the initial abstraction should closer to 0.05*S*, not to the 0.20*S* originally selected in TR-20 (Woodward and others, 2002b).

For these reasons, equation (3) is only used for runoff events of large magnitude over 5.0 inches (125mm) in DURMM. For the smaller events used in the design of Green Technology BMPs, a different relationship is required to obtain more accurate results.

From extensive comparison of the *CN* method against direct observations of urban runoff events, Pitt (1987, page 199) suggests the following relationship for runoff as a function of *P* (in mm) and *g*, a coefficient based upon *CN*:

$$Q = P - S'(1 - e^{-gP}) \tag{4}$$

where *S'* is accumulated losses (in mm) after initial abstraction, or *S* - *Ia*. Note that (4) is very similar to the original equation developed by Victor Mockus in formulating the *CN* method (see Mishra and Singh, 1999).

Pitt (1987) provides a table of *g* coefficients regressed to *CN*. The following equation and coefficients were developed to match the values in Pitt's table as a function of *CN*:

$$g = Ae^{B(CN)} + \frac{Ce^{D(CN-B)}}{10{,}000{,}000} \tag{5}$$

A	B	C	D	E
0.00065	0.0364	155	0.49	80

The first term in (5) is formulated to address the lower *CN*s of pervious areas, while the second term addresses the more direct runoff response of impervious *CN*s. Using these coefficients, equation (5) reproduces the regressed values for coefficient *g* tabulated by Pitt (1987) within 11%.

To get the best fit between (4) and Pitt's (1987) observations for pervious areas, *S'* is set at -0.075, While this negative *Ia* is counterintuitive, it provides the best match to the observations shown in Figure 5-1. Many think *Ia* should be closer to 0.05 for urban areas; for instance see Woodward and others (2002b) who suggest that this value is more appropriate for even rural areas. However, while an *Ia* of 0.05*S* gives a better fit to the observations than 0.20*S*, it is not as good a fit as the negative value used. See also the results presented in Mishra and Singh (1999), in which their model with an *Ia* 0 gave the best fit to observed data for a wide variety of watersheds.

Therefore, there is precedent for the assumption that *S'* would approach *S* for the urban sites of interest in DURMM. When the *CN* is adjusted to correspond to TR-20 values at 125 mm rainfall depths, the value of *S'* used matches observations of runoff from pervious surfaces, as shown in Figure 5-1. The *CN*s allocated for the pervious areas are quite close to the *CN*s used in

TR-20 for lawns in good condition. The curves thus match the observations of the data set as closely as possible, and blend into the TR-20 curves at rainfall depths of 125mm (5 inches).

As shown in Figure 5-1, this curve fit method projects runoff volumes as a function of *CN* that are quite close to runoff observed by Pitt (2000). Note how the runoff volumes at low rainfall depths are much greater than those projected by the *CN* method, while runoff volumes at higher rainfall depths are less than the *CN* method.

This trend in rainfall/runoff relationships follows the observations of rainfall/runoff relationships and declining *CN* values as rainfall amounts increase reported by Pitt (1987), Fennessey and Hawkins (2002), Van Mullem and others (2002), and Mishra and Singh (1999).

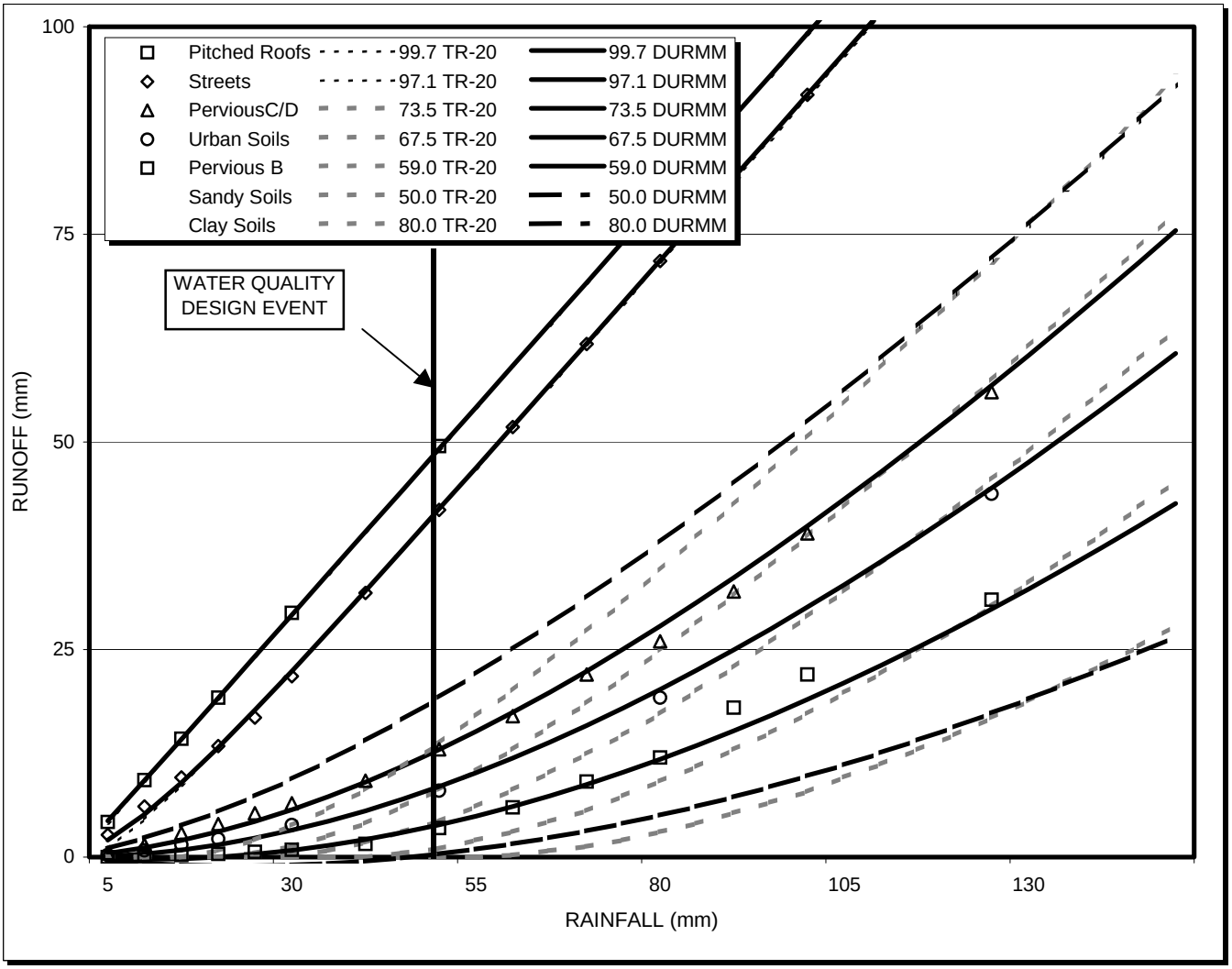

Figure 5-1: TR-20 Runoff, DURMM Runoff, and Observations from Pitt (1987)

5.3 RUNOFF VOLUMES- STORM EVENTS

The runoff predicted from small storms on urban sites using (4) is thus better related to *CN* and *P* than in TR-20. Accuracy in this relationship is essential to realistically model the response of urbanizing area to small precipitation events. At rainfall depths below 60 mm, note how TR-20 runoff volumes (in dotted lines) are much less, or nonexistent, when compared to the curves generated by DURMM routines. Instead, the DURMM curves pass close to the values observed by Pitt at rainfall depths between 25 and 80 mm, the design rainfall amounts for quality and streambank protection routing. To verify that DURMM curves extend over the applicable range of *CN*s for pervious areas, curves are included for sandy soils and clay soils with *CN* values of 50 and 80, respectively. This trend in rainfall/runoff responses follows that generated by reducing *Ia* from 0.20*S* to 0.05*S* as reported by Woodward and others (2002b).

Note the form of equation used in DURMM has the natural log relation used in Hortonian infiltration, and it does not limit infiltration losses as TR-20 does (where *S* is a fixed value). This results in DURMM curves falling below the TR-20 values at higher rainfall depths, as noted by Pitt (1987), Mishra and Singh (1999), and Woodward and others (2002b). This suggests that infiltration rates may increase (and therefore *S* is not a constant value) during more intense rainfall events, as noted by Pitt (1987, 2000).

Taking a conservative approach, DURMM uses the *CN* method equations for the conveyance and flooding events at rainfall depths over 125 mm (5 inches), where the curves between the two methods were selected to meet. Although the crossover threshold in a very pervious watershed occurred at a higher value of 300 mm (Mishra and Singh, 1999), the response of this arid watershed is not applicable to watersheds in the humid east. The effective difference between DURMM and TR-20 is minor at high values of *P*, especially considering that BMP designs evaluate the difference between predevelopment and postdevelopment conditions.

Another very important point raised by Pitt (1987) is that impervious runoff *CN*s are by no means exactly 98, as assumed in TR-20. Impervious surfaces have a certain amount of infiltration and depression storage, depending upon surface roughness and slope, particularly in the case of roofs. Pitched roofs or extensive paving such as parking lots (which permit little infiltration at the edges) have a high *CN* of 99.7, while flat roofs have a *CN* of 98.1, and narrower streets with average roughness have a *CN* of 97.1. Smooth streets have a higher *CN*, and old rough streets have a lower *CN*. When calculating the relative contributions of runoff from these differing types of impervious surfaces, the fine differences between these values are important at low rainfall depths, as shown in Figure 5-1. By eliminating the rounding error introduced in typical TR-20 software packages, DURMM is able to account for these differences. Pitt's values for the differing *CN*s of impervious surfaces are used in the model.

The proper allocation of *CNs* for pervious urban areas is still a matter of some uncertainty. Pitt (1987, 2000) notes that infiltration rates decline over event duration, but increase with rainfall intensity. Compaction has the greatest effect in sandy soils, which would have high rates under natural conditions (Pitt, 2000; Pitt and others, 1999). Clay soils were equally affected by compaction and antecedent moisture. High traffic areas such as playing fields were observed to have infiltration rates even lower than impervious surfaces (Pitt, 1987; 2000; Pitt and others, 1999). A study of lawns on compacted sandy soils in the New Jersey Coastal Plain showed infiltration rates were greatly reduced once bulk density exceeded 1.5

mg/cm^3 (OCSCD, 2001). Originally classified as Hydrologic Soil Group (HSG) A in the uncompacted state, HSGs of the same soils were effectively reduced to C or even D as a result of excessive compaction. The cover condition of these soils would be rated as poor, since plants could not establish an adequate root system.

In contrast to these compaction results, Barros and others (1999) reported that, after a period of adaptation, compacted soils had runoff rates similar to that found under natural conditions. A study of lawn runoff in Wisconsin by Legg and others (1996) noted that there was no runoff from rainfall amounts less than 1 cm, and that rainfall intensity had little effect on infiltration rates. There was substantial variation in runoff rates within individual lawns, and from lawn to lawn. The age of establishment was observed to be a significant variable in determining runoff volumes, with the oldest lawns having the least runoff volumes. Such variations in pervious runoff coefficients were also observed in a study of lawns in Pennsylvania, where infiltration rates were lowest in lawns recently established on compacted areas. Infiltration rates increased as a function of increasing lawn age and soil profile condition, structure and decreasing compaction history (Hamilton and Waddington, 1999).

Well-developed soils with macropores established over time would have better infiltration rates than newly graded sites. This is supported by the findings of Barros and others (1999) that compacted soils returned to a native condition after a period of adaptation over the 9 month time frame of the experimental design. At the end of this period, soils compacted to 90% proctor (nearly suitable for roads), were found to have well developed macropores due to infiltration of applied rainfall. In studies of turfgrass in Wisconsin, Kussow (1994, 1995) reported that runoff volumes from lawns constructed under compaction conditions typically generated by new construction was very low. Appreciable runoff was observed only during the winter when the lawns were frozen.

Recent efforts have examined amending compacted soils by incorporating compost. Pitt and others (1999) note that incorporating compost into the top 10 inches of compacted soils greatly increased infiltration rates, particularly in newer lawns. Runoff responses were commensurate with the increase in infiltration rate. Efforts to improve detention basin performance in New Jersey Coastal Plain using compost have shown substantial increases in infiltration rates (C. Smith, pers. comm.).

Since the underlying design assumptions are directed toward established conditions, the infiltration rates suggested by the older established lawns would be applied in DURMM. Therefore, DURMM presumes that the *CN* values used in TR-20 are applicable to lawns, and that the cover condition is classified as good for typical suburban lawns. For playing fields and urban areas with a high degree of permanent ongoing compaction, the cover condition should be reduced from good to fair to account for compaction that persists over time. In cases of extreme compaction, the cover condition should be classified as poor.

5.4 RUNOFF VOLUMES- ANNUAL DISTRIBUTION

Another approach to evaluate the differing relationships between rainfall and runoff for small events is to compare results from DURMM against that predicted from the *CN* method over the course of a year. Using the annual rainfall distribution set forth in Table 4-1, one can calculate the runoff volume from a given soil cover complex for each quarter inch increment. Multiplied by the percent that each increment comprises of the total rainfall, annual runoff is then derived as the sum of the incremental runoff volumes.

This approach was applied at the landscape scale to the Noxontown Pond watershed in the Delaware Coastal Plain. With an upland area of 5,689 acres, this watershed is largely agricultural, with 62 percent crops, 20 percent forest, 14 percent grass, and an impervious cover of 2.4 percent. Given this setting, pervious runoff, largely from crops, dominates the hydrologic response from the uplands. Noxontown Pond comprises nearly 4 percent of the watershed area, so there is also a substantial volume of direct runoff from the surface of this impoundment.

Upland land cover complex curve numbers were applied from *CN* method, using the values set forth in Table 5-1.

Table 5-1: Land Cover/Soil Group Classifications in Noxontown Pond

NEWTYPE	COVER_	CONDITION_	CURVE NO_A	CURVE NO_B	CURVE NO_C	CURVE NO_D
Agriculture: Cropland	Row Crops, Residue	good	64	75	82	85
Forest: Brush/Shrub	Woods-grass	good	30	58	72	79
Forest: Deciduous	Woods	good	30	55	70	77
Forest: Nursery	Woods-grass	fair	43	65	76	82
Grass: Mixed	Open	fair	49	69	79	84
Grass: Suburban	Open	good	39	61	74	80
Grass: Urban	Open	poor	68	79	86	89
Pastures: Feedlots	Pasture	poor	68	79	86	89
Pastures: Mixed	Pasture	fair	49	69	79	84
Pastures: Open	Pasture	good	39	61	74	80

A GIS was used to determine the total areas of each combination of soil group and land cover, so as to develop the weighted curve number for each land cover type. Note that the cover and condition classification of the crops is rated as good, since the farmers in this area use no-till and cover crops extensively (NCCWRA, 1986). Note also that the grass cover conditions are allocated according to their estimated compaction.

The proportion of rainfall for each quarter inch increment was then applied to the weighted *CN* of each cover type to develop the runoff depth for each rainfall increment. This runoff depth was then multiplied by the percent of rainfall in the increment. Increments were then summed by type to obtain annual runoff depths. Annual runoff depth for each cover type was then multiplied by its surface area to obtain annual runoff volume for each type. Volumes from all types were then summed to obtain the total upland runoff, which was divided by upland area to obtain annual runoff depth.

Using TR-20 routines, the calculated annual runoff depth was only 70 mm (2.77 inches), a value only 7 percent of the annual rainfall of 1,046 mm (41.2 inches). Even applying the worst possible classification to crops (straight row, no residue, poor condition), the runoff depth increased to only 105 mm (4.13 inches). On the other hand, annual runoff using DURMM routines was nearly three times that of the *CN* method, with an annual depth of 189 mm (7.45 inches). Adding the area-normalized runoff depth of 38 mm (1.52 inches) from the pond, the total annual runoff using DURMM routines was computed at 228 mm (8.97 inches).

The USGS has maintained a gauging station for several years on this watershed, so it is possible to obtain a site-specific verification of annual runoff volume. The baseflow component of the runoff hydrographs was determined with the 5 day smoothed minima technique. This is considered the most appropriate method to segregate base flow from runoff (Jordan and others, 1997), particularly in this case, where an impoundment extends stormflow responses. Separation of four years of runoff data resulted in an average annual stormflow volume of 217 mm (8.55 inches). Even though this period is fairly short and rainfall distribution was quite variable, the average rainfall of 1,046 mm is very close to the long-term average of 1,019 mm. This suggests that the value derived from this hydrograph separation is representative of long-term average runoff.

After subtracting direct runoff from the pond, upland runoff by hydrograph separation is computed to be 179 mm (7.05 inches). This value is within 6 percent of that computed by DURMM routines. On the other hand, the *CN* method underestimates this value by over 60 percent. This analysis provides robust support that the routines used in DURMM better replicate actual conditions than the *CN* method for small rainfall events that dominate the annual response.

5.5 IMPERVIOUS DISCONNECTION

Another important factor in determining urban site runoff volumes is the large difference in runoff volumes between pervious and impervious surfaces at a given rainfall depth, as noted in Figure 5-1. Many design manuals and proprietary TR-20 software packages permit averaging the *CN* over both the pervious and impervious surfaces, unless routed as separate subareas during design. However, this approach can lead to substantial errors in runoff volumes, especially during small rainfall events (Panuska and Schilling, 1993; Tsihrintzis and Hamid 1997; Grove and others, 1998).

This simplification has further exacerbated the shortcomings of TR-20 for small storm hydrology. In contrast, DURMM not only has better algorithms for calculating pervious and impervious runoff as a function of rainfall, it calculates runoff volumes from pervious and impervious surfaces as discrete subareas.

It has been recognized for some time that there is a substantial difference in the volume of runoff from impervious source areas that depends upon whether it is conveyed by impervious flow paths (curb and gutters, pipes) versus pervious flow paths (grassed swales). Source areas from which runoff is conveyed by impervious flow paths are defined as connected impervious

areas (CIA), as opposed to total impervious area (TIA). Impervious source areas from which runoff is conveyed by pervious flow paths are called disconnected impervious areas (DIA).

A recent detailed study of urban runoff source areas by Lee and Heaney (2003) documented that CIA runoff comprised 72 percent of total annual runoff, even though it was only 36 percent of TIA, and 13 percent of the watershed. The remaining 87 percent of the watershed contributed runoff only when event rainfall exceeded 20 mm. Indeed, the authors of this study noted that the Rational Method was a reliable indicator of runoff volumes in small events only when restricted to the CIA. These authors thus recommended that CIA runoff be explicitly recognized in computing runoff from urban areas.

In contrast to CIA, substantial reductions in runoff volume from DIA source areas have been noted in many studies of the efficiency of filter strips and swales, where pollutant removal efficiencies have been directly correlated with the reductions in runoff volumes (Wanielesta and Yousef, 1993, and many others). This effect of impervious area disconnection has been noted as an important component of Low Impact Development, and has been incorporated into several BMP Manuals, such as the recent Manuals by New Jersey (NJDEP, 2003) and Maryland (MDE, 2000).

By explicitly segregating impervious from pervious areas, DURMM is capable of quantifying the effects of disconnection. To compute the effects of impervious area disconnection, runoff from disconnected impervious areas is allocated as excess precipitation onto the receiving pervious surfaces (Wanielesta and others, 1997, NJDEP, 2003). By entering the area and *CN* of impervious surfaces, and entering the wetted area and *CN* of receiving pervious surfaces, DURMM then calculates the excess precipitation onto, and the resultant runoff volumes from, the receiving wetted pervious surfaces. While runoff from these pervious surfaces will be higher than that from rainfall alone, it can be substantially less than the sum of runoff from the pervious and impervious areas without disconnection.

To account for these effects, DURMM segregates a site into pervious and impervious subareas. The pervious subarea is further subdivided into a natural pervious area, and a graded pervious subarea. The natural area is considered completely undisturbed, so its soil profile and structure must remain intact. As an incentive to leave as much undisturbed area on a site as possible, runoff from natural areas under post-development conditions is computed by TR-20 routines, thus reducing its runoff compared to DURMM routines for small events. While this may not be technically correct for agricultural areas (see Section 5.4 above), it more closely corresponds to the runoff generated from woodlands and abandoned fields (see Fennessey and Miller, 2002). The graded pervious areas use DURMM routines to compute runoff.

Impervious areas are also further segregated into a disconnected impervious subarea, which discharges into the graded pervious area, and a connected impervious subarea that discharges directly into the BMPs via pipes or curb flow. Within the graded pervious subarea, DURMM computes the reduction in runoff volumes from disconnection routines. In this area, the wetted areas would include some of the lawns below downspouts, filter strips below parking lots and the wetted perimeter of swales. Disconnection routines are also applied to the wetted areas of the BMP(s), further reducing the total runoff during the quality event.

DURMM thus explicitly accounts for the reductions in runoff volumes provided by these wetted pervious surfaces. Designs that promote disconnection can reduce runoff volumes for even highly impervious sites by over 50% in the quality event. If the receiving pervious surfaces are very permeable, disconnection can reduce runoff during the quality event by even more. This feature provides a quantitative process-based approach to project the effects of disconnection, which had hitherto been lacking in the literature, let alone in any quantitative design approach.

As the design basis for the impervious area disconnection BMP, disconnection provides the designer with a powerful tool to quantify the benefits of integrating site planning with drainage design. Measures to decrease *CN* by minimizing impervious areas, maximizing natural pervious areas, and increasing afforestation further reduce runoff volumes. In this manner, DURMM provides a powerful tool to quantify the benefits of conservation design, the most fundamental nonstructural BMP.

By using overland conveyance of runoff wherever possible, not only does overland flow reduce volumes (and peak flow rates, as discussed below), it also permits explicit methods for designing BMPs by disconnecting impervious areas and promoting infiltration as an integral part of the design process. Furthermore, there is substantial potential for removal of pollutants when runoff is conveyed through properly designed swales and filter strips. A critical issue is to properly ensure that the receiving pervious surfaces are truly wetted by locating them below flow spreading structures. Otherwise, the wetted area must be constrained to the channel bottom where flows are concentrated.

After accounting for disconnection, the resulting runoff volume is used for generating event hydrographs using TR-55 routines, as discussed below. Once runoff volumes have been calculated for the different source area categories, DURMM computes pollutant mass loads according to the area weighted Event Mean Concentrations (EMCs) of the contributing source areas, as discussed in the DURMM User's Manual.

5.6 TIME OF CONCENTRATION

Time of concentration (*Tc*) determines the peak flow rate for a given runoff volume. *Tc* is usually determined by the segmental method, in which runoff is first conveyed by sheet flow, then by shallow concentrated overland flow, then by channel flow in pipes or streams. In typical usage on small urban sites, these flow paths times decrease according in that order, with sheet flow being the dominant time element, and channel flow usually being very short.

Even though the watershed response normally comprises subsurface flow and runoff from partial contributing areas that are not subject to segmental flow paths (NRCS, 1985), the segmental method is widely utilized. For small urban sites, it seems to be most appropriate, since the other components of runoff are less applicable. On the other hand, under forested pre-development conditions, subsurface flow paths and PCAs often dominate to the runoff response, so the lag method in NRCS (1985) is considered more appropriate (Fennessey and others, 2001).

However, an investigation of the lag equation applied to 1100 events by Folmar and Miller (2000) indicated that the lag equation under-predicts lag in small watersheds, and over-predicts lag in large watersheds, suggesting that lag time varies less as a function of size. Better results could be obtained adjusting the coefficients, and by accounting for the relief and drainage pattern of the watershed. A comparison of the lag method to observed watershed responses for over 50,000 events by Simas and Hawkins (2002) also suggests that the lag equation in NRCS (1985) should be substantially revised. Even so, when revised to better fit the data, the scatter in the watershed responses was extensive.

For these reasons, the approach in DURMM is to use the segmental approach. However, while *Tc* determines the peak rate, the conveyance velocities that determine *Tc* are themselves determined by peak runoff rate. More complex interactions between flow depth, channel shape and vegetative retardance further affect flow velocities, as will be discussed in detail below. However, the TR-55 equation requires a default coefficient to compute shallow concentrated flow conveyance velocities, in which slope is the only variable.

However, comparison of the segmental method to observations by Folmar and Miller (2000) showed that the segmental approach using the TR-55 coefficient for unpaved shallow concentrated flow grossly underestimates the actual lag time (or *Tc*). This is not surprising, since the default *Kv* coefficient of 16.1 used to compute unpaved flow velocities in TR-20 is 80 percent of that applied to paved surfaces. This results in computed flow velocities that are much faster than actually occur in unpaved areas. Since the flow velocities in shallow vegetated swales are typically much less, this would substantially increase travel times closer to that observed.

Sheet flow is defined as unconcentrated flow occurring for the first 100 to 150 feet of the flow path. Topographic features that would concentrate flows define the end of sheet flow. Sheet flow is calculated according to the equation from TR-20 as follows:

$$Tc = \frac{0.007(nL)^{0.8}}{P^{0.5}s^{0.4}} \tag{6}$$

where *n* is Manning's Roughness coefficient, *L* is flow length (feet), and *s* is slope. Note that *P* (inches) in (6) is not restricted to the two-year event, as is used in TR-20. Instead, sheet flow *Tc* decreases as *P* increases. Analysis of the kinematic wave equation that is the basis for (6) shows that as *P* increases, flow velocity increases, and so *Tc* decreases.

DURMM provides for two consecutive segments of sheet flow to model complex flow paths. When flow velocity from this equation is calculated with the Manning's *n* value of 0.24 allocated by TR-20 for dense grass, the resulting velocity is greater than that calculated for swale flows under similar slopes and volumes, as discussed in Chapter 10. This analysis thus suggests that the proper value for turf would be around 0.45, as recommended by Engman (1986) from experimental observations of sheet flow. This value is close to the 0.41 used in TR-20 for BermudaGrass, which has a similar blade density to dense turf of suburban lawns. While this issue deserves further investigation, a Manning's *n* value of 0.24 is allocated to dense turf in the model so as to correspond with the value presently required in Delaware.

At a 2-year rainfall of 3.2 inches, a lawn with a slope of 2 percent for 150 feet would have sheet flow time of nearly 20 minutes. However, in urban sites, the volume of runoff from impervious surfaces in small events is much greater than that from the pervious surfaces. As such, it is thus inappropriate to use pervious sheet flow paths to determine the *Tc*, and an impervious flow path (typically down the most distant driveway) is more realistic. This greatly reduces sheet flow time.

For shallow concentrated flow (or swale flow), DURMM simultaneously solves for peak flows as a function of *Tc*, while solving for *Tc* as a function of peak flows, as affected by the conveyance parameters. TR-55 is used to estimate peak flows, based upon *Tc* and runoff volumes. The equation used in TR-55 for peak flow is:

$$Q_P = q_u A Q / 640 \tag{7}$$

where Q_P is peak discharge (cfs) , Q is the runoff depth (inches), A is area (acres), and q_u is the unit peak discharge (cfs/mi.^{2}). q_u is defined as follows:

$$\log(q_u) = C_0 + C_1 \log(T_c) + C_2 \log(T_c^2) \tag{8}$$

with coefficients C_0, C_1, and C_2 defined as a function of Ia/P according to the table for Exhibit 4 in Appendix F of TR-55 (NRCS, 1986). Given S from the runoff volumes, DURMM calculates Ia/P to the nearest hundredth for linear interpolation between the tabular values to obtain the values of coefficients C_0, C_1, and C_2. Substituted into (8), this gives the peak flow for a given *Tc*.

As discussed in Chapter 6, DURMM provides routines that calculate the velocity of swale flow as a function of conveyance channel geometry, vegetative type and flow depth. Using iterative runs at differing flow depths, swale conveyance design is analyzed to develop total discharge and velocity, which provides the total *Tc* when added to sheet flow *Tc*. Flow depths are adjusted until the flow velocity used to generate swale discharge and *Tc* matches the discharge rate computed by TR-55 using the *Tc* derived from the swale flow calculations.

As in the case of sheet flow, this approach results in decreasing *Tc* as *P* increases. Although this relationship was not observed by Simas and Hawkins (2002) in their analysis of many events in large watersheds, there are many components to the runoff response that are not modeled by segmental flow paths, as discussed above. Such components are largely absent in the small urban sites, where well-documented hydraulic principles of channel flow would determine travel time.

As a result of the swale routines in DURMM, the relative contribution of swale flow to total *Tc* becomes greater than that of sheet flow. This approach reduces the typical dominance of *Tc* by often over-estimated, thus unreliable, and generally inapplicable, sheet flow computations. The swale design parameters can also address channel flow as a narrow, deep swale with a smooth surface cover. By generating a different *Tc* for each storm event, as suggested by Guo and Adams (1999b), DURMM thus generates the *Tc* needed for hydrograph generation of peak flows for the bank protection, conveyance and flooding events.

CHAPTER 6 URBAN RUNOFF HYDRAULICS

6.1 OVERLAND FLOW CONVEYANCE

The preceding discussion emphasizes the importance of swale flow parameters in determining *Tc*, and the resulting peak flow rates. Therefore, a key element in the design of nonstructural BMPs is the design of overland conveyance to retard runoff velocities wherever possible. Not only can overland conveyance slow down flow velocities and thus increase *Tc*, it also disconnects impervious areas and provides for infiltration as an integral part of the design process. Furthermore, the literature indicates the potential for substantial removal of TSS when runoff is conveyed through properly designed swales (Horner, 1988; SWPCD, 1992; Wanielesta and Yousef, 1993).

To address this issue, the methods used in DURMM incorporate detailed swale design features as a fundamental part of the model. The methods set forth in "Biofiltration Systems for Storm Runoff Quality Control" by Horner (1988) are complemented by the work of Barfield and associates (Kao and Barfield, 1978) to form the basis of the following discussion. Modifications are proposed that assist in simplifying the design procedure. By using DURMM routines to relate the variables involved, the accuracy of the design process is also refined. The following discussion reviews the hydraulic elements involved in overland flow through swales, which are defined as wide shallow channels where flows are often submerged below the vegetation height.

6.2 SWALE CROSS-SECTION AREA

Under field conditions, a trapezoidal swale cross-section set forth in the plans evolves over time into a parabolic section at the lower depths involved in biofiltration. For depths below 0.5’ (generally well above the maximum depth for filtering), DURMM incorporates a function relating top width *w* to depth *d* for a parabolic swale section. Establishing cross-section shape as a function of depth, it is possible to determine cross-sectional area as a function of depth, and substitute this function for the area term in Manning's equation when determining velocity and flow.

The following expression establishes the half-section profile of the swale at depth *d* as a power function of width *w*:

$$d = A(w/2)^B \tag{9}$$

Rearranging to solve for coefficient A at $d = 0.5$ feet,

$$A = 0.5/(w/2)^B \tag{10}$$

Differentiating (9) (where *d* equals *y*, and *w*/2 equals *x*),

$$dy/dx = AB(w/2)^{B-1} \tag{11}$$

Substituting (10) into (11) and rearranging to solve for *B*,

$$B = dy/dx(w) \tag{12}$$

Since slope at a depth of 0.5 feet is the design side slope *ss* (hor./ver.) of the trapezoidal section, it follows that $dy/dx = 1/ss$, and $w = w_{bottom} + (1.0 \times ss)$, where w_{bottom} is the trapezoidal swale bottom width. Given *B*, *A* is then solved from (10).

Integrating (9) gives the area under the half section as follows:

$$A_{under1/2} = \int A(w/2)^B = A(w/2)^{B+1} / (B+1) \tag{13}$$

To obtain swale area, this must be subtracted from the total half area:

$$A_{total1/2} = w/2 \times d = A(w/2)^{B+1} \tag{14}$$

Subtracting (13) from (14), the area of the swale half section is:

$$A_{swale1/2} = A(w/2)^{B+1} \times [1 - 1/(B+1)] = A(w/2)^{B+1} B/(B+1) \tag{15}$$

Multiplying (9) by *w*/2,

$$A(w/2)^{B+1} = wd/2 \tag{16}$$

Substituting (16) into (15), and multiplying by two for the total swale area,

$$A_{swale} = wdB/(B+1) \tag{17}$$

Rearranging (10),

$$w = 2(d/A)^{1/B} \tag{18}$$

Substituting (18) for *w* in (17) gives the cross-section area of the swale section:

$$A_{swale} = 2B/(B+1) \times A^{-1/B} \times d^{(1+1/B)} \tag{19}$$

With coefficients *A* and *B* solved for the design section, it is possible to solve for area as a function of the one variable *d*.

Figure 6-1 shows how the design swale section compares to the typical parabolic swale and trapezoidal swale sections, based upon a 12 foot bottom width and 4:1 side slopes. Note how the swale section remains close to the trapezoidal section at depths up to 1.0 feet, typically the maximum depth under flooding conditions. The trapezoidal section parameters are used to set the construction layout of the swale, which ends up being very close to the design section in the field.

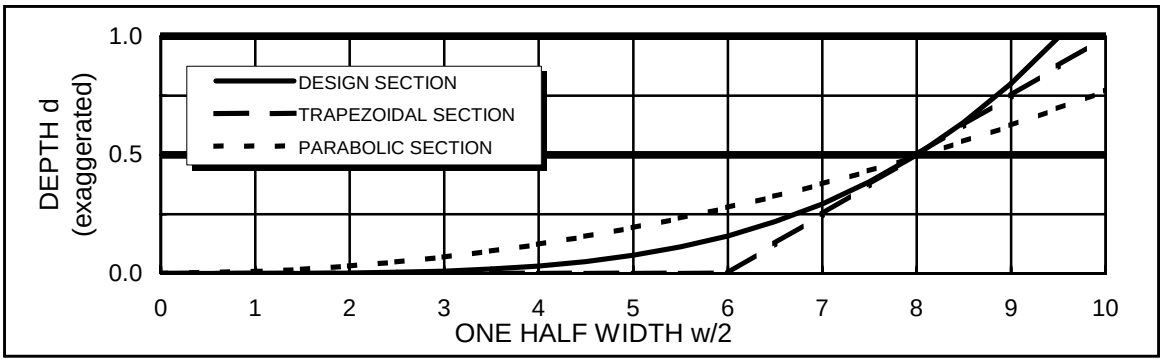

Figure 6-1: Sections for Design, Parabolic and Trapezoidal Cross-Sections

6.3 SWALE HYDRAULIC RADIUS

The wetted perimeter of the swale design function is very close to the width *w* at depths typical for biofiltration. In a trapezoidal section with w_{bottom} of 8 feet and *ss* of 5:1, the difference is less than 1% for depths below 9 inches. This difference would be even less for the design section. Since the term to calculate swale perimeter is somewhat complex, and the area term is much more important in terms of capacity and flow, the approach in this model is to simplify wetted perimeter as being equivalent to top width *w*.

As the exponent for *R* is less than 1.0, the impact of any difference is relatively small. At depths below a foot where biofiltration occurs, this slightly overstates *R*. Therefore, the $R^{0.67}$ term in Manning's equation will increase, overstating velocity and flow. Given that pollutant removal estimates are correlated with increased residence time (at reduced velocities), this introduces a conservative bias to the results. Since the area term is typically at well over one foot, and flow is a function of area squared, precision in the area term is much more important in terms of the overall accuracy of the computations.

Therefore, hydraulic radius *R* is assumed to be equal to A/*w*. Given (17), and wetted perimeter $P = w$, hydraulic radius is as follows:

$$R = dB/(B+1) \tag{20}$$

As in the case of cross-section area, it is thus possible to solve for hydraulic radius as a function of the one variable *d*.

6.4 SWALE ROUGHNESS

A key element involved in the design and function of biofiltration swales is the change in Manning's *n* as a function of *VR*, the product of velocity and hydraulic radius. Ree and Palmer (1949, as cited in NRCS, 1992) were the first to investigate this phenomenon empirically, and their work underlies the design basis of grass swales in the Engineering Field Manual (NRCS, 1992) as well as the design of biofiltration swales by Horner (1988). Ree and Palmer found that at a given *VR*, roughness increases as a function of vegetation density and height. Manning's *n* was highest at the lowest values of *VR*, decreasing as *VR* increased. Since Manning's *n*

decreases as velocity increases, an increase in flow rate affects flow velocity more than flow depth. Laboratory studies (Kao and Barfield; 1978; Kouwen and Li; 1980, Wu and others, 1999) support the general relationships proposed by Ree and Palmer for emerged flow, when vegetation is overtopped and bent down by the flow.

However, when flow depths are submerged below vegetation height, these researchers noted substantial differences in the relationship between Manning's *n* and *VR*. Under these conditions, Manning's *n* increases in proportion to both slope and square of velocity toward a maximum at the transition to overtopping flow depths (Kuo and Barfield, 1978). Measurements of swale flow in Washington showed that the value of Manning's *n* increased 61 percent from 0.123 at 0.336 fps to 0.198 at 0.472 fps (SWPCD, 1992). When flow is thus submerged, an increase in flow rate affects flow depth more than flow velocity. This counterintuitive relationship was confirmed in measurements of swale flow in Washington, where an increase in flow rate of 55 percent increased velocity by 40 percent, while depth increased by 72 percent (SWPCD, 1992).

In the Horner (1988) method of swale design, Manning's *n* is manually derived by an iterative method comparing an estimated value of *n* and interpolated *VR* from the Ree and Palmer retardance curves, and recalculating *VR* with a different value of *n* if the selected value diverges by more than 5%. This requires several iterations, and it does not address values of Manning's *n* for submerged flow, which is not presented in the NRCS (1992) retardance curves of Ree and Palmer for the vegetation types used in biofiltration swales. As a result, a fixed value of 0.20 was recommended for Manning's *n* under submerged flow conditions (SWPCD). However, this approach results in a larger velocity response to differing flow rates, instead of the relatively small changes in velocity observed.

As an alternative to this method, it is desirable to generate a function relating Manning's *n* to *VR* for both flow regimes. Since a correct roughness value is critical in the design of biofiltration and conveyance swales (SWPCD, 1992), DURMM incorporates this function as part of the design worksheet. This relationship is expressed as a family of coefficients for retardance equations relating Manning's *n* as a power function of *VR*, using separate curves for submerged and emerged flow:

$$\text{for emerged flow, } n = C \times VR^{D}, \quad \text{for submerged flow, } n = E \times VR^{F} \tag{21}$$

Both equations are solved simultaneously in DURMM, with the lower value of *n* used in subsequent computations. Table 6-1 below shows how these coefficients vary by surface cover:

Table 6-1: Surface Code/Retardance Coefficients

SURFACE TYPE		PAVEMENT	STONE	SHORT GRASS	DENSE GRASS	THICK BRUSH
SURFACE CODE	RETAR-DANCE	1 N/A	2 N/A	3 ("E")	4 ("D")	5 ("C")
C		0.0110	0.0240	0.0355	0.0600	0.0750
D		-0.080	-0.090	-0.360	-0.495	-0.570
E		N/A	N/A	0.800	1.150	1.900
F		N/A	N/A	0.500	0.540	0.600

Accuracy is improved by fitting this function to the range of *VR* below 1.0 involved in bioswale design. It is thus possible to closely approximate retardance curves (well within scaling accuracy) by choosing the appropriate values of *C*, *D*, *E* and *F*. Figure 6-2 presents a family of curves based upon these coefficients, such that each curve corresponds to a certain range of *VR* for a specific retardance.

Retardance values are scaled from the curves of Ree and Palmer as published in the Engineering Field Manual, and in Kao and Barfield (1978). Data points from flows in grass filter strips from observations by Abu-Zreig (2001) are included for comparison of these submerged flow values. It should be noted that the curves of Kao and Barfield (1978) do not show such a sharp transition from submerged to emerged flow, and slope also has a substantial effect on Manning's *n* that is not addressed in (21). (Curves for a 2% slope were used in Figure 6-2, since they corresponded most closely to the retardance curves at emerged flow, and bioswales should be designed at the lowest possible grade for best performance.)

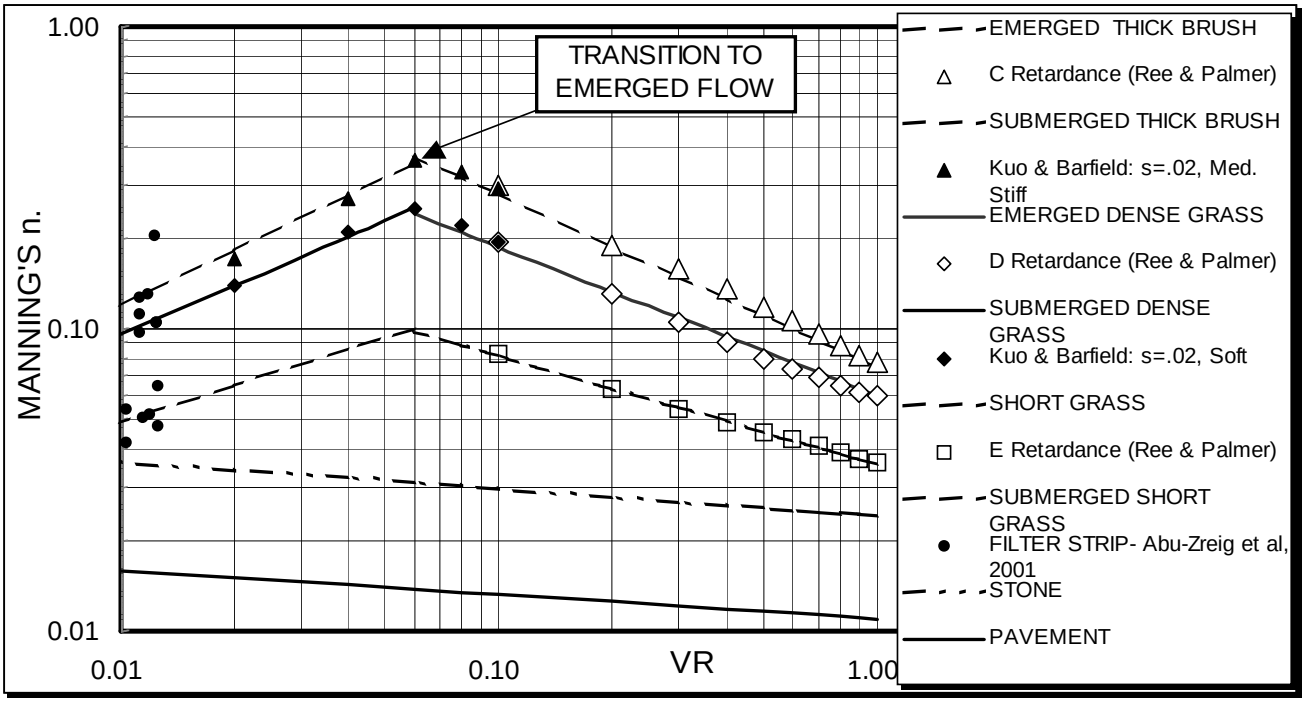

Figure 6-2: Relationship of Manning's *n* to *VR*
Sources: Ree & Palmer (1949), Kao & Barfield (1978) and Abu-Zreig (2001)

Nonetheless, this relationship provides flow velocities for submerged flow that fall within 10% of the flow velocity observations observed by the SWPCD (1992, Table 5-6). This relationship implies that, as flows increase under submerged conditions, flow velocities show minor increases while depth increases. Under emerged conditions, the opposite occurs, as flow depths show minor increases while velocities increase.

The dense grass curve corresponds to Surface Code 4 (or retardance "D") in the range of *VR* values between 0.02 and 1.0 (the Biofiltration Function in Horner's (1988) method). The short grass curve corresponds to Surface Code 3 (or Retardance "E") in values of *VR* between

0.02 and 1.0, representing retardance before grass is well established (the Stability Function). To account for higher retardance due to poor maintenance, the thick brush curve of Surface Code 5 is fitted to values of *VR* between 0.02 and 1.0 for retardance "C" (the Capacity Function). Note that the divergence from the retardance curves is well within 5% at *VR* values below 1.0 typical to biofiltration. Additional curves have been inserted for use on impervious surfaces, using roughness values of 0.11 and 0.24 at *VR* = 1.0 for pavement and stone, respectively. DURMM incorporates these differing surface types in determining flow conditions. Note that Manning's *n* can now be derived as a function of a single variable, depth *d*.

6.5 SWALE FLOW VELOCITY AND DISCHARGE

Given that area, hydraulic radius, and Manning's *n* are all expressed in terms of depth *d*, it is possible to solve for velocity in Manning's equation as a function of depth *d*. Manning's equation for open channel flow is expressed as follows:

$$V = \frac{1.486}{n} \times R^{0.67} \times s^{0.5} \tag{22}$$

where *s* is channel slope. Replacing the terms for *n* and *R* in (20) and (2i) respectively,

$$V = \frac{1.486}{C[VdB/(B+1)]^{D}} \times [dB/(B+1)]^{0.67} \times s^{0.5} \tag{23}$$

Rearranging terms,

$$V = V^{-D} \times \frac{1.486}{C} \times [(B/(B+1)]^{(0.67-D)} \times s^{0.5} \times d^{(0.67-D)} \tag{24}$$

Solving for *V*,

$$V = \left[\frac{1.486}{C} \times [(B/(B+1)]^{(0.67-D)} \times s^{0.5} \times d^{(0.67-D)} \right]^{(1/1+D)} \tag{25}$$

This equation is incorporated into DURMM for swale flow to determine flow velocity as a function of swale shape, surface type and depth of flow, *d*. Swale discharge is then the product of (19) and (25).

When swales are designed for shallow flow depths, the effective roughness values can exceed 0.200, resulting in flow velocities well below one foot per second. This can be particularly important when designing overland flow conveyance BMPs that depend upon residence time to function properly, and it minimizes resuspension of particles in larger events. It is also very important in increasing *Tc* when the dominant flow path is from impervious areas with a rapid sheet flow. Since these swale flow velocities are generally much lower than that allocated by TR-20 in shallow concentrated flow routines, swale flow becomes the controlling factor in determining *Tc*.

The assumptions inherent to equations (19), (20) and (21) introduce minor errors at flow depths above 0.5 feet. With an 0.8 foot depth in an 8 foot wide swale with 5:1 side slopes and a slope of 2%, the area term (19) is reduced by 1%, while hydraulic radius term (20) increases

3.2% and Manning's *n* term (21) decreases by 4.4%. This results in flows decreasing by 5.9%. However, using an example with a given flow of 28.7 cfs, depth decreases only 1.6% and velocity decreases 2.8%. Given that there is interpolation error and the method is quite precise below depths of 0.5 feet, these minor errors are considered acceptable for conveyance design for wide swales with shallow side slopes. However, it is not recommended for triangular channel sections at deep flow depths, where the errors in (21) can become unacceptably large.

Even when there is no defined channel, shallow concentrated flow is replicated as a swale with a wide bottom and very flat side slopes, as determined from the site plan. As *Tc* is recalculated for each runoff event, this results in decreasing *Tc* as *P* increases. By addressing the implications of swale design in such depth, DURMM provides for overland conveyance computations that are much more representative of actual conditions. Furthermore, these routines permit the designer to explicitly optimize swale design to retard flows and extend *Tc*.

Since pipe flow in the small areas involved in nonstructural BMP design is generally fairly short, and its average velocities are relatively high, the travel time involved is typically negligible. Therefore, DURMM usually omits pipe flow considerations in determining *Tc*. If necessary, long runs of pipe flow can be modeled as swale flow with steep side slopes and a paved surface. The velocities resulting from this approximation are quite close to that computed for pipe flow, so the travel time for a given length is quite similar.

The conveyance module of DURMM described in Appendix A provides estimates for swale response as a function of loading rate, length, width, side slopes, longitudinal slope, and surface cover. Consecutive segments of swale flow are provided to model more complex flow paths. Since the average swale flow is less than peak flow from the outlet, DURMM routines allow for direct input of the proportion of total flow that is conveyed by each swale segment. Design standards, construction specifications and details of biofiltration swales are set forth the Green Technology Standards, Specifications and Details, Appendix B.

6.6 SWALE STORAGE AND DISCHARGE THROUGH CHECK DAMS

Placed at regular intervals, check dams in bioswales can be used to create a series of cascading pools that will provide substantial detention. To estimate the storage volume required to meet predevelopment discharge rates, the following equation from TR-55 (Figure 6-1) provides a useful approximation:

$$V_s / V_r = 0.682 - 1.43_1(q_o / qi) + 1.64(q_o / qi)^2 - 0.804(q_o / qi)^3, \quad (26)$$

where V_s/V_r is the ratio of storage volume to runoff volume, and q_o / qi is the ratio of peak outflow to peak inflow. The coefficients are applicable to Type II and Type III precipitation. Given pre- and post-development flow rates and runoff volumes derived from the methods discussed above, DURMM computes the estimated storage needed in each event to meet predevelopment flow rates. Note that these are estimated storage volumes, and a comprehensive storage-indication routing method is necessary to confirm the storage volume required according to the outflow routing dynamics.

Since the storage depths in the pools are quite low, it is necessary to obtain stage-area and stage-discharge relationship information at quite small intervals. However, it is difficult to precisely obtain accurate stage/area relationships from construction plans without substantial interpolation errors. When the bioswale with check dam option is used, DURMM precisely calculates the stage-area and stage-discharge relationships for the swale/check dam system.

Given design parameters of longitudinal slope (*s*), bottom width (*w*) and side slopes (*ss*, hor./vert.), the expression for pool surface area at depth *h* where the pond created by a check dam does not extend up to the next upstream check dam is as follows:

$$A = \frac{h}{s} \times \left[w + (ss \times h) \right] \tag{27}$$

At higher ponding depths, check dam spacing is less than the calculated pool length, so the length term *h/s* is replaced by the length between the pools, or total bioswale length *L* divided by number of pools *n*. The average width term is also adjusted to account for the depth at the upstream dam location, as determined by slope *s* and spacing *L/n*, as below:

$$A = \frac{L}{n} \times \left[w + ss \times (2h - \frac{Ls}{n}) \right] \tag{28}$$

Using this relationship, DURMM computes the stage-area relationships at intervals of one half the check dam height for entry into the stage-area input fields of a separate hydraulic routing software package. By entering various bioswale lengths, slopes and number of dams, this procedure makes it possible to calculate the increase in volume provided by closer spacing and/or higher check dams.

Equations (27) and (28) are also applicable for calculating storage within terraces with differing side slopes, using the average of the two differing side slopes and a bottom width *w* of 0 feet. Where terraces are designed to provide biofiltration, they should have a bottom width required for biofiltration. This will normally require excavation into the native soils, resulting in the more uniform side slopes typical to bioswale.

Given stage-area relationships, it is then necessary to route flows through and over the check dams. Complex (and expensive) prefabricated structures are not the optimal arrangement to control flows through check dams, particularly where a very small orifice needed for quality control would be prone to clogging. As a cost-effective alternative, stone-filled gabions can be designed to provide both the required check dam geometry, as well as a mechanism for conveying low flows through the dams. Smaller flow events are routed through the stone, while an orifice and/or weir in the center of the dam is designed to route the larger events. Actual check dam routing is accomplished by entering the dynamics of the check dam design in a separate hydraulic routing software package.

DURMM provides a method to calculate flows through the stone used to construct check dams. Flow through the stone is calculated as a function of stone size, flow depth, width of flow and flow path length. These relationships were initially investigated by McIntyre (1990), who examined gabion weirs as a measure to control flows released from detention basins. McIntyre

found that unit width flows could be calculated between these variables according to the following relationship:

$$q = A \times (h^B / L^C), \quad (29)$$

where q is the flow per unit width, h is the ponding depth, and *L* is the length of flow (up to two feet). A, B and C are coefficients based upon stone size (small, medium and large). Over flow lengths of 1 to 2 feet, (29) provided a very good relation (r^2 = 0.992 to 0.998) for the media evaluated, given the proper values for coefficients A, B and C.

However, the variation in these coefficients does not follow a straightforward relationship to stone size, so (29) cannot be applied for stone media falling outside of the range of stone sizes evaluated. Also, measurements of the flow profile as it passed through the stone by McIntire et al (1991) indicated that entrance losses were significant, so a different form of the denominator of equation (29) was required. Equation (29) was thus modified to address entrance losses, longer flow lengths and different size stone sizes according to the following relationship (McIntyre et al, 1991):

$$q = \frac{h^{1.5}}{(L/D + 2.5 + L^2)^{0.5}}, \quad (30)$$

where *D* is the average stone diameter in feet. The stone gradation is intended to be relatively uniform in size. Designed for flow paths of up to 6 feet, (30) addresses the range of flow lengths involved in check dam flows. Note that, where the length *L* is short (less than several feet), changes in stone diameter have a relatively greater effect than where flow paths are longer. Flow path length becomes the dominant factor once it exceeds several feet

The typical gabion width is three feet, so this would be the maximum flow length in most designs. However, where the discharge requirements require a stone size in the range of 1 to 2 inches, such stone will not remain inside a gabion with a mesh of 3 inches. To resolve this, the exposed portion of the gabion can be filled with 4-inch rock, while the smaller stone is placed inside. This reduces the effective flow length to 2.3 feet or so, depending upon the average diameter of the larger rock. Even with the smaller flow length, the smaller stone will result in lower discharge rates. If river rock is used for the exterior stone, this type of gabion dam can be quite attractive.

At low flows, the average flow width through the check dam is less than that at high flows, where weir flow dominates the total flow response in most designs. The geometry of the swale width and side slopes thus becomes the dominant determinants of flow routing at a given stone size. The effective flow width *W* is calculated as being the bottom width *w* of the swale, to which is added ponding depth *h* times swale side slopes *ss*:

$$W = (ss \times h) + w, \quad (31)$$

DURMM also permits manual entry of a flow path width if a design section narrower than the full width of the swale is needed to control quality events. Since this can be more difficult to construct, this approach is not recommended unless strict release rate criteria are required.

Given the stage-area and stage discharge relationships, it is thus possible to route flows through the bioswale/check dam system. Usually, the combined volume from all ponds can be routed as if they were one pond, discharging through the outflow design for the lowest pond. In check dams where the final outlet is a structure such as a catch basin, it is best to model that pool as a separate pond, since its outflow dynamics can differ substantially from that found in the check dams.

Tailwater will play an important part in routing flows through the check dams, as tailwater retained in the downstream pools will attenuate the flows through the check dams, particularly during conveyance and flooding events. Assuming that the pools tend to fill and discharge together (see below for more discussion), once the flow depth in the downstream pool has backed up onto the stone, increases in flow depth will not increase the head through the stone. For this reason, DURMM provides stage-discharge data through the stone only up to the pool depth, since it will be essentially constant from then on. This data is entered as a special outlet into a separate hydraulic routing package.

For controlling the larger flows, routing software should be used to determine the dynamics of other weirs and orifices. A simple control structure is to install one or several PVC pipes above the quality storm event elevation, sloped so they discharge at grade on the downstream side. Modeled as culverts with entrance losses, this arrangement is not only inexpensive, it also reduces potential scour at the pipe discharge.

During a runoff event, the upper pool fills up first, increasing its effective discharge relative to the lower pools. Since the peak discharge volume will be more than the individual pool can attenuate by itself, it often will overtop the entire dam by several inches. Therefore, the check dam should be depressed by at least 6 inches in the center to ensure flows do not erode the side slopes of the swale. This peak elevation often occurs after peak discharge, since the lower pool is subsequently filled up, thus creating more tailwater and reducing structure efficiency. As the discharge peak passes through the pools, the upper pools also drain more rapidly than the lower pools, reducing their effective head. This relationship tends to distribute the storage volume more rapidly at the beginning, and delay its release at the end of the event.

Tailwater thus varies throughout the event, and until recently, modeling it accurately in a series pool configuration is beyond the capability of most hydraulic routing software packages available. Where precise routing is required, each pool should be modeled individually using software capable of dynamic routing. If routed as individual ponds, these trends result in slightly poorer peak rate reductions of the swale/check dam system when compared to being routed as one larger pond. However, the peak discharge is delayed for longer period, which can be beneficial by desynchronizing peaks from other subareas.

CHAPTER 7 BMP POLLUTANT REMOVAL PROCESSES

7.1 POLLUTANT REDUCTION PROCESSES

Overland flow BMPs remove pollutants from urban runoff through six major pathways: infiltration, filtration, adsorption, immobilization, settlement and transformation. Some, or even all, of these processes can occur simultaneously, depending upon the pollutant involved and the type of BMP. However, there are very few BMP design tools that explicitly account for how these processes function in overland flow BMPs, let alone project the performance to be expected from a particular design.

In wet retention ponds, settling equations have been applied to TSS and particulate nutrient removal (Ferrara and Hildick-Smith, 1982). In wetlands, first order equations are used to project removal of nitrogen (Kadlec and Knight, 1996), and more complex equations have been proposed for removal of phosphorus (Dortch and Gerald, 1995). The complex processes involved in metals removal by wetlands have been investigated in detail by Kallin (1999). Intricate models that simulate these processes have been formulated by several researchers (Kallin, 1999; and sources cited therein).

In the case of vegetated filter strip BMPs, the VFS-MOD model by Munoz-Carpena and others (1992) is an effective tool to predict suspended sediment removal efficiency. A windows-based program, VFS-MOD is an excellent tool to estimate filter strip performance for TSS removal. Recently, Rudra and others (2002a 2002b) have added a phosphorus component, but it is not available yet. While VFS-MOD is quite easy to use, it requires more data entry than typically applied at the typical site development level, and it does not address other pollutants.

The common thread to all process-based models is that the dynamics of pollutant removal reflect the interactions between pollutant loads, hydrologic factors and BMP design parameters. However, such process-based models are too complex for widespread use at the site level. As a result, the approach generally taken by the regulatory community is to assume that a particular BMP imparts specific pollutant reduction efficiencies, assuming certain minimum dimensional and/or loading criteria are provided.

Unlike retention basins however, there is very little data on filtering BMPs (USEPA, 1999). By assuming that the performance from such a limited dataset should be globally allocated to a particular BMP for every case, there is a high likelihood that the “design” pollutant reduction efficiency to be applied will be incorrect. This is analogous to using a broken clock, which can still tell time accurately twice a day. The designer can only hope that the “time” setting is close to what is realistic. Furthermore, this approach provides neither method nor incentive to optimize BMP design for the particular circumstances of each site. Thus, besides being probably inaccurate, this approach thus neither rewards a good design, nor penalizes a bad design.

On the other hand, it is readily apparent that, the better the design is, the better the removal rate will be, and vice versa. To advance the process of BMP design for the regulatory community, the intent in DURMM is to provide a simplified approach that generates results close

to that anticipated from process-based models, while requiring much less intensive input data. While DURMM does not attempt to replicate the actual processes involved, it does take into account how the design parameters of overland filtering BMPs respond to their influent pollutant and hydraulic loads.

This approach is far preferable to assuming an invariant pollutant removal efficiency for each BMP. To carry out this approach, the literature on BMP performance has been examined to derive trends that can be represented by relatively simple equations based upon design parameters. Essentially, the concept is to "observe and regress". In this manner, the design of overland filtering BMPs can be better tailored to address the particular situation. Although DURMM is an event-based model, if the relationships derived from this process reflect annual loads and annual flow-weighted concentrations, the results are more likely to better reflect BMP performance through the year.

Unfortunately, there is very little data that actually provides the basis for such relationships. Even though there have been many studies of pollutant removal efficiencies, these studies sample different pollutants, use different sampling methods, have very different input loadings, have many different design parameters, and they present their results as the "average" of the differing pollutant reductions observed in many events. Rare are the studies that investigate annual loads to develop flow-weighted average concentrations, as discussed in Chapter 3.

Depending upon the pollutant measured and the BMP, reported reduction percentages can range over an order of magnitude, and negative reduction percentages are often reported. The issue is further confounded by the predilection for total nitrogen and total phosphorus to be reported as if they were single pollutants, when in fact they each comprise several compounds with very different characteristics affecting their removal by BMPs. This latter aspect is particularly important in overland filtering BMPs. As a result of these confounding factors, published summaries of BMP performance report a considerable variation in the efficiency of BMPs to remove pollutants (CWP, 1997; ASCE, 1999; USEPA, 1999).

The following analysis of BMP performance examines the percentage reduction in effluent EMCs by BMPs, known as the efficiency ratio. Efficiency ratio is <u>not</u> equivalent to the removal percentage expressed as a reduction in pollutant mass loads, as is reported in most studies. This is due to the fact that mass loads represent the product of effluent EMCs and effluent volumes. Since effluent volume losses are considerable, and they are accounted for in the hydrology/hydraulics analysis, it is the EMCs of pollutants remaining in the surface runoff conveyed from the BMPs that become the parameter of interest. Multiplied by the computed runoff volumes leaving the BMP, DURMM then develops the reductions in mass loads during the quality runoff event.

The resultant approach thus follows the sum of loads method presented by Strecker and Quigley (1999). This method is more appropriate for the overland BMPs discussed in this Manual, since infiltration losses can be significant, and efficiency ratios by themselves would understate BMP performance. Given dilution by the receiving stream in any event, total loads are also more accurate in estimating runoff contributions to instream pollutant loads as part of

TMDL requirements. It follows that if reduction targets are met in the 2.0 inch quality event, they will be met in all runoff events that are smaller in volume.

To resolve the factors involved in the reported inconsistency in BMP efficiencies, DURMM examines three factors that control much of the variability in BMP performance. These factors are: 1) input EMC, 2) minimum irreducible EMC, and 3) potential maximum efficiency ratio. Note that input concentrations are independent of BMP design, and minimum irreducible EMC and potential maximum efficiency ratio are generic to the type of BMP. Thus the final value for efficiency ratio is related to effectiveness in the design of the BMP itself. To refine estimates of efficiency ratios, total nitrogen and phosphorus are also segregated into the various species that affect their removal by BMPs.

7.2 IRREDUCIBLE CONCENTRATIONS

It has been recognized for some time that BMPs and wastewater treatment wetlands cannot reduce pollutants below certain thresholds. When an input EMC is very low, such facilities may actually release sequestered nutrients and sediments, resulting in negative efficiency ratios (Strecker and Quigley, 1999). Claytor and Schueler (1996) examined this concept of irreducible (or background) concentrations, and reviewed the existing wastewater wetland and urban runoff BMP literature to obtain the minimum concentrations listed below in Table 7-1:

Table 7-1: Irreducible Concentrations (mg/l) in Urban BMPs

PARAMETER	TSS	TN	TKN	NO3	TP
Urban Runoff BMPs (Schueler, 1996)	20-40	1.9	1.2	0.7	0.15-0.20
Wastewater Wetlands (Kadlec and Knight, 1996)	2-15	1.0-2.5	1.0-2.5	0.05	0.02-0.07

These concentrations will be evaluated in depth for each BMP in the following sections. Irreducible concentrations are obtained from the literature by searching for the lowest repeated outlet EMC reported for a given type of BMP. Given that DURMM provides input values of the EMCs as discussed in Chapter 3, two of the three variables that control performance are thus readily available before even beginning design of a BMP. The remaining element is to determine the potential maximum efficiency.

7.3 MAXIMUM EFFICIENCY RATIOS

Bell and others (1995) measured efficiency ratios as a function of input concentration. As displayed in Figure 7-1, total phosphorus efficiency ratios from a sand filter in Alexandria, VA, showed an increasing trend with input concentration, with the highest efficiency ratio at 87%. It is possible to replicate this relationship by using an asymptotic function in the following form, where efficiency ratio *R%* is related to the design maximum efficiency ratio R_{max}%, and the input EMC multiple *M* of the irreducible concentration:

$$R\% = R_{\max}\%(1 - e^{-K(M-1)}) \qquad (32)$$

The lowest effluent concentration reported was 0.065 mg/l, given 35 percent removal at 0.01 mg/l. This suggests that irreducible concentration would be in the range of 0.050 mg/l, shown as the minimum on the upper axis. Using this value for the irreducible concentration, a value of 0.25 for K, and a design maximum efficiency ratio of 90%, the efficiency ratio curve at the higher multiples is within 4 percent of the values reported by Bell and others (1995). The upper x axis displays the input EMC, while the lower x axis displays the multiple *M*. The ordinate displays efficiency ratios, with an asymptote at the maximum of 90%.

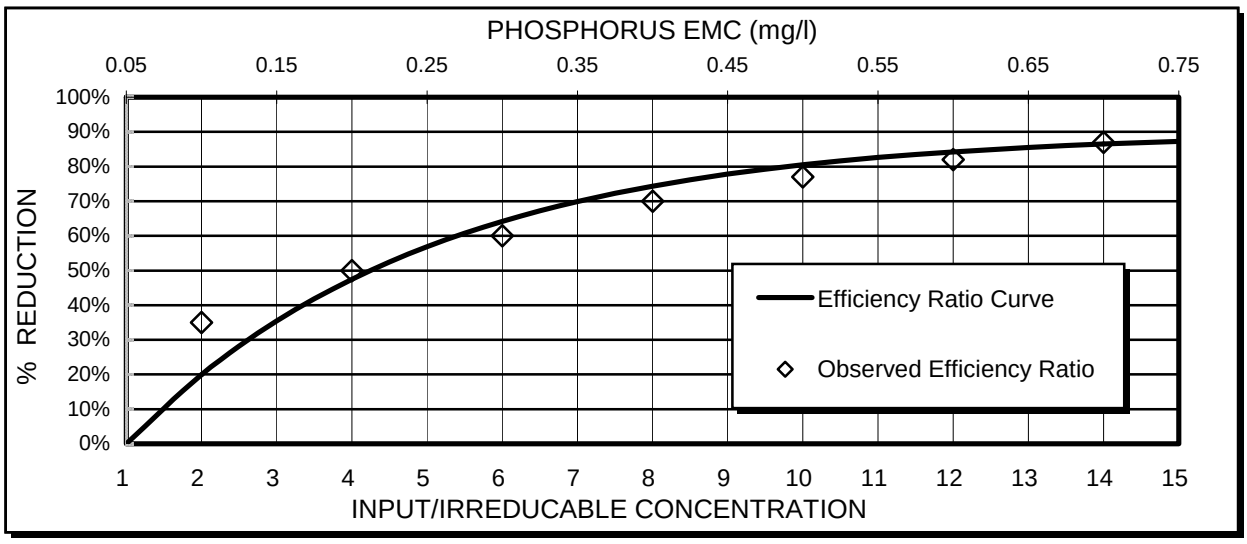

Figure 7-1: Sand Filter Efficiency Ratios as A Function of a Maximum Efficiency Ratios and Input EMC Multiple of the Irreducible Concentration. Source: Bell and others (1995)

Note that this estimated value of the irreducible concentration for TP falls well below the range reported by Claytor and Schueler (1996) for runoff BMPs. In fact, this value is at the low end for wastewater treatment literature. Since (32) underestimates efficiency ratios at multiples below 4, this trend suggests that the minimum may be even lower (which would give higher multiples at these input EMCs). Even though (32) understates the efficiency ratio at low multiples, it is the higher range of multiples that is most relevant to BMP design, so this underestimation has minor effects on the utility of DURMM approach.

Equation (32) thus presents the relationship for projecting likely efficiency ratios as both a function of the irreducible concentration and input EMC. This relationship underlies all further projections of the efficiency ratios as a function of $R_{max}\%$. Note that *(32)* is identical to the standard diffusion equation used in modeling wetland nitrogen removal, when the K value is adjusted to reflect the concentration involved:

$$R\% = (1 - e^{-K(EMC - C\min)}) \qquad (33)$$

Unlike the study displayed in Figure 7-1, most of the literature on BMP performance omits the individual event data needed to plot efficiency ratios as a function of input EMC. Therefore, it is difficult to derive the appropriate value for the coefficient K for other BMPs. In the best possible case, a multiple of at least 9 would be required to obtain a maximum removal efficiency of 90%. Using the K value of 0.25 shown in Figure 7-1, it is seen that maximum removal percentage occurs at a multiplier of at least 14. This suggests that appropriate K values

can be related to maximum removal efficiencies by assuming that the maximum efficiency ratio occurs at an EMC of roughly 15 times the irreducible concentration. In this case, the value of 0.25, as used in Figure 7-1, is applied as the default value for all BMPs. This value should be refined as more data for individual BMPs becomes available.

Too often, total N or total P efficiency ratios are the only criteria reported, with maximum rates typically below 50%. However, in many overland BMPs, efficiency ratios for soluble fractions will be minimal, while efficiency ratios for the particulate fraction are typically much higher. In contrast to the considerable cycling between these forms that occurs in wet basins and wetlands where the retention time is quite long, there is less cycling between these forms in overland filtering BMPs with relatively short retention times. This is the reason that nutrient loading in Chapter 3 is partitioned into nitrate, ammonia, organic nitrogen, soluble phosphorus, and particulate phosphorus fractions. By segregating nutrients into these fractions, it is possible to differentiate potential reduction of each fraction according to the simplified processes involved in each BMP. Each nutrient fraction will have different irreducible EMCs, with resulting efficiency ratios that vary from minimal to high.

For instance, vegetative filters are relatively ineffective in reducing concentrations of soluble phosphorus, while particulate phosphorus can be effectively filtered. If the relative contributions of the soluble and particulate fractions are available from the loading EMCs, it is possible to obtain better results of the total nutrient reductions. The literature for each BMP is analyzed in the following sections to determine the values for minimum concentrations and maximum efficiency ratios. Note that these values should reflect results supported by other values in the same range. Extreme values that are isolated are not a reliable basis to determine these values.

Maximum efficiency ratio is thus dependent on the pollutant involved, the type of BMP, and how well it is designed to address its loading rates. The reduction processes and the particulars involved in optimizing BMP design are addressed for each type of BMP in the following sections. Relevant relationships of factors such as hydraulic residence time, hydraulic loading ratios, surface/volume ratios, length/width ratios, depth of flow and other parameters are examined for each BMP to develop a quantitative approach to project efficiency ratios for each fraction as set forth in Chapters 9, 10, and 11.

CHAPTER 8 INFILTRATION BMPs

8.1 INFILTRATION BMP POLLUTANT REMOVAL MECHANISMS

The issue of potential leaching of toxic pollutants and nutrients from infiltration BMPs into groundwater has been raised in Chapter 3. While there may be less opportunity for transformation and microbial immobilization processes than in a vegetated surface BMP, filtration processes will reduce pathogens and particulate pollutants, and adsorption processes can sequester soluble pollutants. In essence, the subsoil under the infiltration BMP can function as a sand filter in retaining pollutants in the soil profile. However, since the subsoil profile varies greatly in terms of porosity and cation exchange capacity (CEC, a measure of adsorption potential), the potential for infiltration BMPs to avoid contamination of groundwater is also highly variable.

In sandy soils with a low CEC, the potential for adsorption can be quite low, while infiltration rates would be high. On the other hand, finer soils with a high content of clays will provide excellent filtration and adsorption, but infiltration rates will be lower. Since infiltration BMPs are generally designed for higher rates, it follows that the potential for filtration and adsorption will be relatively low in most infiltration BMPs. For this reason, infiltration BMPs are not recommended for urban "Hot Spots", unless runoff is already well filtered by other BMPs (Parmer and others, 1995). In general, if they are located in mineral soil a sufficient distance from groundwater (at least 20 feet) there appears to be minimal concern for groundwater contamination, even with highly polluted runoff (Livingston, pers. comm.). However, in sandy soils and/or where depth to groundwater is shallow, runoff must be pretreated to ensure that dissolved toxins do not migrate directly into the groundwater.

In terms of nitrogen species, ammonia in urban runoff is either adsorbed to the soil particles, or immediately nitrified into nitrate in the oxic zone under the BMP (Gold and Sims, 2000). Much of the adsorbed ammonia will eventually be nitrified. The extent that biogeochemical processes then sequester nitrate in subsoil is much less than found at the surface, where biomass accumulation can be substantial in the root zone. This results in the soluble species of nitrogen leaving the BMP as nitrate. Since nitrate passes through infiltration BMPs into groundwater without transformation, adsorption or uptake, loading of nitrates generally increases in proportion to the reduction in loading of ammonia.

Where ammonia in the receiving waters is more of a problem than nitrate enrichment, as is occasionally the case for upland streams, this is an effective approach to minimize ammonia loading. However, since nitrates will eventually reach the estuaries and inland bays, this approach can have adverse consequences in the long run. Since urban runoff pollutant loads are segregated into both of the soluble forms, as well as the particulate, DURMM could be used to project event subsurface loading of nitrate and ammonia by assuming that most of the ammonia load is transformed into nitrate. Organic N does not seem to leach into groundwater, so leaching losses of organic N should be minimal. Since these processes are either all or none, there are no process-based approaches to determine the extent of load reductions into groundwater.

Even under very high loads from septic systems, nearly all of the soluble orthophosphate is adsorbed within the soil profile (Gold and Sims, 2000), unless the soils are very sandy. Phosphorus losses would be even less for the particulate forms. However, as they accrue over the long term, some of the particulate fractions will be transformed into soluble forms. Leaching of phosphorus in the groundwater has recently been recognized as a contributor to nutrient loads (Sims and others 1998). However, since these issues are so site specific, subsurface losses cannot be reliably estimated by an event-based approach, so they are not addressed in DURMM.

Therefore, even though infiltration BMPs can substantially reduce surface loading of nutrients and other pollutants through volume reduction, this does not necessarily represent a corresponding reduction in the total nutrient load to streams. This is particularly applicable to nitrate, since there are generally minimal transformations once nitrate passes below the root zone. Even though dissolved nutrients may be out of sight, they may not be out of the regional groundwater system, and thus they represent potential loading from site development.

As a result, groundwater loading from infiltration BMPs could result in significantly less reduction of the amount of soluble nutrients than that reported in the literature, where subsurface losses are rarely addressed. In the absence of a rigorous basis to estimate nutrient and pollutant transformations and adsorption processes in the subsoil, the current approach in DURMM is to ignore these losses.

8.2 SUBSURFACE INFILTRATION BMPs

Infiltration trenches are the preferred subsurface nonstructural infiltration BMP. Dry wells connected to roof downspouts are another common infiltration BMP, but they suffer from an absence of pretreatment. Infiltration basins are structural BMPs that require considerable area and maintenance, and they often fail after several years of operation. DURMM thus focuses on infiltration trenches as the main nonstructural BMPs for site design.

For proper operation, infiltration trenches must be designed to ensure that they do not clog over time. This requires that filtering BMPs are used to provide adequate pretreatment, designed according to the principles set forth in the following chapters. Where the dissolved forms of nutrients, metals and PAHs are a concern due to elevated levels in runoff, pretreatment by these BMPs is essential in any event. As shown in Chapter 3, runoff from roofs can have substantial amounts of TSS, zinc and nutrients; if connected directly to a dry well, the facility is likely to clog, and groundwater loading of nutrients and zinc will occur. While an in-line catch basin can reduce TSS loads, it has minimal effect on nutrients, and it is likely to be poorly maintained, leading to eventual failure. For these reasons, direct connection of downspouts to dry wells is not recommended unless measures can be established that ensure adequate maintenance.

Infiltration trenches thus are the preferred nonstructural subsurface infiltration BMP. Note that volume to surface area relationships and the interaction between width and depth to SHWT favor trenches that are long and narrow over shorter, wide trenches (Guo, 1998). This is another reason to avoid dry wells and other rectangular/circular subsurface infiltration structures. However, note that the preferred geometry can be easily incorporated into linear BMPs such as

biofiltration swales and bioretention facilities, which also serve to provide the required pretreatment. This is discussed in more detail in Chapters 10 and 11.

As to the appropriate trench material, crushed stone segregated into one size provides the highest void ratio and least potential for clogging, although a finer material can be used. Coarse filter fabric to prevent the entry of soil fines into the trench should surround the rock at the sides. Recent studies suggest that drainage fabric is not necessary at the top if a smaller stone is used, covered with a sandy loam (Covington, pers. comm.). It is important that the effective pore space of the fabric be quite large, as specified for drainage fabric. Coarse sand should be placed at the bottom to prevent subsidence of the rock into the soil. While clean washed stone is always specified, the reality is that it is rarely provided, so there is a real potential for rock dust to clog the interstitial pores in the adjacent soil matrix and filter fabric. Design standards, construction specifications and details for infiltration trenches are provided in Green Technology Standards, Specifications and Details, Appendix B.

In the case of subsurface infiltration BMPs, there is no reduction in EMCs in runoff that is not infiltrated. Surface runoff loads are only reduced in proportion to the amount of runoff infiltrated during the quality storm event. The inflowing EMC is multiplied by remaining surface runoff volume to determine mass loads leaving the site in surface runoff. The BMP design module of DURMM described in Appendix A provides estimates for infiltration structure performance as a function of loading rate, pollutant levels, length, width, depth, and infiltration rate.

8.3 SURFACE INFILTRATION BMPs

Infiltration has a substantial effect on surface runoff and its pollutant loads by reducing runoff volumes from filter strip, bioswale and bioretention BMPs. As runoff flows from impervious surfaces over the pervious surfaces of these BMPs, its volume can be substantially reduced during the quality storm event. This mechanism is implicitly incorporated into the mass load reduction calculations for filter strip, bioswale and bioretention BMPs as a function of the reductions in runoff volumes due to disconnection. Infiltration also is incorporated into internal site design in terms of impervious area disconnection, as discussed in Chapter 5.

Subsurface leaching losses of nutrients and toxic pollutants are negligible with impervious area disconnection and filtration BMPs, since an intact root zone and soil profile is present to intercept and sequester nutrient and pollutant loads. (See Chapter 3.) Therefore, these infiltration practices are not only very effective; they also have the least potential for groundwater nutrient losses and contamination. Furthermore, they require minimal cost to construct, and the required footprint of surface infiltration BMPs can be incorporated into the overall site layout. Since open areas suitable for surface filtering BMPs are typically provided between buildings and within parking lots in any case, these BMPs do not require excessive loss of potentially useable ground.

For this reason, DURMM goes to some length to determine the extent of runoff reduction in these BMPs, and that resulting from source area disconnection. The input data fields segregate impervious source areas into connected and disconnected categories, as well as receiving pervious areas. Runoff volumes are obtained from both types of impervious areas, to which is

applied the impervious disconnection subroutine onto the receiving pervious areas, be they formal BMPs for connected areas or internal landscaping for disconnected areas.

After reducing EMCs in impervious runoff according to equations developed for overland filtering BMPs in the following sections, and multiplying the resulting EMCs by the reduced runoff volumes, mass loads can be substantially reduced. This approach is used for both disconnected internal flow paths and impervious surface runoff directly connected to BMP. The procedures involved in routing these flow paths are described more fully in the DURMM Users Manual, Appendix A.

CHAPTER 9 FILTER STRIP BMPs

9.1 SHEET FLOW FILTRATION RESULTS

Filter Strips represent a class of BMPs in which runoff passes as sheet flow through vegetation. Filtration BMPs provide reductions of pollutant loads through filtration by vegetation and infiltration. While it would seem that the best filter media is turfgrass, recent reports suggest that a dense native meadow stand can be similarly effective. Turf is the obvious choice for many filter strips, since they can be incorporated as lawn areas that happen to be specifically designed to intercept runoff from buildings and parking areas.

However, native warm season grasses have much deeper rooting systems than turf-type cool-season grasses. This greatly promotes infiltration and recharge of runoff into groundwater. There are also several native grasses that form a dense stand at maturity. Studies of a native grasses filter strip by Schultz and others (1993, as referenced by Prairiesource, 1999) show that native grass filter strips have much higher infiltration rates and vegetative uptake than turf grass. Meyer and others, (1995) demonstrated how a hedge of switchgrass as short as only one foot was able to trap nearly 80% of the total sediment load. Sediments settled out in the water ponded over a foot deep behind the grasses, and trap efficiency was higher for the coarse fractions. Since infiltration and runoff volume reduction is a fundamental BMP (see Chapter 5), native warm season grasses are thus preferable for filter strips. However, it is important that the plantings be as dense as possible for the initial 15 feet, where filtering is most important.

Since filter strips are long and narrow, note that the discussion in this Chapter defines width as the dimension direction parallel to the flow, and length as the direction perpendicular to flow. It would seem that flow velocities through filter strips would be slower than flow through swales; however, the discussion on swale roughness in Chapters 6 and 10 suggests that flow velocities are similar in sheet flow and in swales at very low flow depths. Assuming that retention time is thus not the controlling factor, this suggests that grass filter strips provide a greater reduction in particulate fractions than swales since flow is restricted to the densest thatch and blades.

Unfortunately, most of the filter strip literature examines agricultural runoff conditions, where sediment loading rates are typically at least an order of magnitude greater than found in urban runoff. Using rainfall simulators at very high precipitation rates of 200 mm over a day, Dillaha and others (1989) reported TSS EMC reductions from 49% to 93%. Table 9-1 displays results from this site in the Virginia Piedmont for filter strips 4.5 and 9.1 meters wide over slopes of 11%, 16%, and 5% with a cross slope of 4%.

TABLE 9-1: Virginia Piedmont Filter Strip Load and EMC Reductions
Source: Dillaha and others, 1989

SOURCE AREA	WIDTH (m.)		18.3		LENGTH (m.)		5.5	
SLOPE (%)	11		16		5+4		ALL METHODS	
PRECIP. (mm)	200		200		200		200	
LOAD (cu.ft./ft.))	13.95		10.99		11.78		8.25	
RUNOFF (mm.)	70.8		55.8		59.8		186	
RUNOFF (l.)	7126		5616		6019		18761	
INPUT LOADS (kg/ha)								
TSS	3920		8940		2110		14970	
NH4	1.53		4.28		0.76		6.57	
NO3	1.65		1.98		1.22		4.85	
ON	11.73		26.57		6.92		45.22	
TP	4.34		8.41		2.27		15.02	
SP	0.19		0.17		0.10		0.46	
PP	4.15		8.24		2.17		14.56	
OUTPUT LOADS (kg/ha)								
WIDTH (m.)	4.55	9.1	4.55	9.1	4.55	9.2	4.55	9.2
RUNOFF (mm.)	66.1	17.9	55.8	53.2	16	16.6	137.9	87.7
RUNOFF (l.)	8307	2698	7013	8017	2011	2502	17331	13216
TSS	560	100	4,220	2,720	360	150	5,140	2,970
NH4	0.65	0.17	3.56	2.48	0.19	0.11	4.40	2.76
NO3	1.62	0.36	1.85	1.55	0.34	0.34	3.81	2.25
ON	2.91	0.78	12.76	10.11	1.04	1.34	16.71	12.23
TP	1.18	0.32	4.32	2.95	0.35	0.31	5.85	3.58
SP	0.27	0.08	0.17	0.25	0.04	0.04	0.48	0.37
PP	0.91	0.23	4.15	2.70	0.31	0.27	5.37	3.20
INPUT CONCENTRATION (mg/l)								
TSS	5537		16022		3528		8031	
NH4	2.16		7.67		1.27		3.52	
NO3	2.33		3.55		2.04		2.60	
ON	16.57		47.62		11.57		24.26	
TP	6.13		15.07		3.80		8.06	
SP	0.27		0.30		0.17		0.25	
PP	5.86		14.77		3.63		7.81	
OUTPUT CONCENTRATION (mg/l)								
TSS	679	373	6057	3415	1802	604	2985	2262
NH4	0.79	0.63	5.11	3.11	0.95	0.44	2.56	2.10
NO3	1.96	1.34	2.66	1.95	1.70	1.37	2.21	1.71
ON	3.53	2.91	18.31	12.69	5.21	5.39	9.70	9.31
TP	1.43	1.19	6.20	3.70	1.75	1.25	3.40	2.73
SP	0.33	0.30	0.24	0.31	0.20	0.16	0.28	0.28
PP	1.10	0.86	5.96	3.39	1.55	1.09	3.12	2.44
EMC REDUCTION								
TSS %	88%	*93%*	62%	79%	49%	83%	63%	72%
NH4 %	64%	*71%*	33%	59%	25%	65%	28%	40%
NO3 %	16%	*42%*	25%	45%	17%	33%	15%	34%
ON%	79%	*82%*	62%	73%	55%	53%	60%	62%
SP %	-22%	-11%	*20%*	-3%	-20%	4%	-13%	-14%
PP %	81%	*85%*	60%	77%	57%	70%	60%	69%

The extent of reduction was dependent upon filter strip width and slope; the longer and flatter, the better. Runoff decreased substantially in the flatter filter strips as it passed through them, so total load reductions were even greater. Note that the effluent TSS EMCs were still in the range of higher values reported for urban runoff EMCs, since input load EMCs were so high.

Hydraulic loading rate is defined as the runoff volume divided by the length of the filter strip in terms of cubic feet of runoff divided by linear feet of filter strip length normal to the flow. Hydraulic loading rates ranged from 11 to 14 cubic feet of runoff distributed over each foot of filter strip length. These values are at the upper end for typical BMPs, where the loading rate from a 1.5 inch storm over a 60 foot wide contributing impervious area amounts to 7.5 cubic feet per foot. As such, the reported rates represent up to 3 inches of runoff, which is greater than that required for quality storm design.

Similar reductions were noted in the organic N EMCs, while ammonia reductions ranged from 25% to 71%, and nitrate reductions were 16% to 45%. It was thought that nitrate reductions reflect dilution of runoff by rainfall on the filter strip. The authors noted that N transformations in vegetated filters can release sequestered organic N as nitrate, ammonia and, to a lesser extent, dissolved organic N, which was 5% of the total organic N. Ammonia reductions were greater than nitrate, since ammonia is adsorbed onto clay particles, while nitrate is very soluble. Soluble P reductions were minimal or negative, while particulate P reductions ranged from 57% to 85%.

These results support the partitioning of urban runoff into particulate and soluble fractions. Particulate fractions consistently showed high reductions in EMCs, while the soluble fractions -excluding adsorbed ammonia- showed minimal losses, or even increases. Note that good results were obtained with the shorter filter strip of 15 feet. This was confirmed by field observations showing that most of the sediment deposition occurred within the first meter or so. Even though the remaining length of the filter strip had much less accumulation, better results for the 30 foot filter suggest that runoff is further polished as it passes through the strip.

Using a similar experimental design with rainfall events, Parsons and others (1993) conducted a series of observations in the North Carolina Piedmont with filter strips of 5.2% and 6.3% slopes. Table 9-2 displays a summary of some of the storms monitored in this study. Excluding the storm of day 228 (a two year event), hydraulic loading rates are similar to an urban BMP.

As in the case of the results of Dillaha and others (1989), input EMCs of TSS were very high, as were the output EMCs. Although the loading rates were often in the range of urban runoff BMPs, TSS reductions were less. If data from the heavy storm of day 228 are removed from the totals, average reductions of TSS are in the ranges reported by Dillaha and others (1989). However, losses of ammonia and soluble P were much greater, with negative efficiency ratios for these nutrients. (Cells are left blank where a constituent EMC was greater than its combined species, eg., where TKN was less than ammonia.)

TABLE 9-2: North Carolina Piedmont Filter Strip Load and EMC Reductions.
Source: Parsons and others, 1993

SOURCE AREA	WIDTH(m.)	36.6	LENGTH (m.)	4.57			
JULIAN DAY	day 228, 1990	day 333, 1990	day 88, 1991	day 170, 1991	day 226, 1991	day 262, 1991	TOTALS (without day 228, 1990)
SLOPE (%)	6.3	6.3	6.3	5.2	5.2	6.3	
PRECIP. (mm)	71.6	25.4	0.76?	72.4	41.9	39.4	
LOAD (cu.ft./ft.))	12.93	5.99	3.42	5.21	6.73	5.01	
RUNOFF (mm.)	32.8	15.2	8.7	13.2	17.1	12.7	66.9
RUNOFF (l.)	5488	2543	1450	2210	2858	2128	11189
INPUT LOADS (g)							
TSS	45492	8057	5604	25209	3835	3199	45904
NH4	1.2	1.9	1.9	0.0	0.0	0.0	3.8
NO3	20.3	1.2	0.4	2.3	2.5	2.9	9.3
ON	71.0	9.4	3.1	27.1	4.4	3.8	47.8
SP	3.7	1.2	0.6	0.2	0.6	2.3	4.9
PP	23.70	2.30	1.50	12.70	1.70	0.80	19.00

OUTPUT LOADS (g)														
WIIDTH(m.)	4.2	8.4	4.2	8.4	4.2	8.4	4.2	8.4	4.2	8.4	4.2	8.4	4.2	8.4
RUNOFF (mm.)	31.2	31.9	16.1	13.9	10.8	6.5	5.0	8.1	7.5	1.1	6.0	1.8	45.4	31.5
RUNOFF (l.)	5822	6558	3008	2860	2009	1328	930	1673	1392	236	1123	375	8462	6472
TSS	25,490	18,905	2,908	4,616	1,066	2,550	1,137	1,307	170	0	536	336	5,817	8,809
NH4	0.39	0.09	1.90	1.80	4.30	2.00	0.01	0.01	0.01	0.01	0.01	1.80	6.23	3.82
NO3	11.60	10.40	1.60	1.30	2.20	0.60	3.00	3.10	1.40	0.01	5.20	0.01	13.40	5.02
ON	43.21	34.61	10.30	8.30	8.40	0.70	4.09	2.69	1.59	-	2.99	-1.79	27.37	11.69
SP	2.80	2.70	1.80	2.10	2.60	1.40	1.00	2.20	0.90	0.01	3.60	1.10	9.90	5.71
PP	21.20	17.90	2.30	1.20	1.60	-	1.90	0.60	0.30	-	0.40	-0.30	6.50	1.80

INPUT CONCENTRATION (mg/l)							
TSS	8289	3168	3865	11407	1342	1503	4103
NH4	0.22	0.75	1.31	0.00	0.00	0.01	0.34
NO3	3.70	0.47	0.28	1.04	0.87	1.36	0.83
ON	12.94	3.70	2.14	12.26	1.54	1.78	4.27
SP	0.67	0.47	0.41	0.09	0.21	1.08	0.44
PP	4.32	0.90	1.03	5.75	0.59	0.38	1.70

OUTPUT CONCENTRATION (mg/l)														
TSS	4378	2883	967	1614	531	1920	1223	781	122	0	477	896	687	1361
NH4	0.07	*0.01*	0.63	0.63	2.14	1.51	0.01	0.01	0.01	0.04	0.01		0.74	.59
NO3	1.99	1.59	0.53	0.45	1.10	0.45	3.23	1.85	1.01	*0.04*	4.63		1.58	0.78
ON	7.42	5.28	3.42	2.90	4.18	*0.53*	4.40	1.61	1.14	0.00	2.66		3.23	1.81
SP	0.48	0.41	0.60	0.73	1.29	1.05	1.08	1.32	0.65	*0.04*	3.21		1.17	0.88
PP	3.64	2.73	0.76	0.42	0.80	0.00	2.04	0.36	*0.22*	0.00	0.36		0.77	0.28

PERCENT REMOVAL														
TSS	47%	65%	69%	49%	86%	50%	89%	*93%*	91%	100%	68%	40%	60%	61%
NH4	69%	*94%*	15%	16%	-63%	-15%	-138%	-32%	-105%		5%		-53%	-45%
NO3	46%	*57%*	-13%	4%	-297%	-64%	-210%	-78%	-15%	95%	-240%		1%	33%
ON	43%	59%	7%	21%	-96%	75%	64%	*87%*	26%		-50%		31%	52%
SP	29%	*39%*	-27%	-56%	-213%	-155%	-1088	-1353	-208%		-197%		-72%	-42%
PP	16%	37%	15%	54%	23%	*100%*	64%	94%	64%		5%		24%	42%

In the case of ammonia, this can be attributed to the low average input concentration of 0.34 mg/l, as well as the nutrient transformations in the filter strip as discussed above. The losses of soluble P suggest a similar mechanism. These authors also observed the accumulation of sediment in the first meter of the filter strip. However, note that there were minimal, or even negative, reductions of TSS by the longer filter strip, as runoff loads and EMCs from several storms actually seemed to increase from the longer strip. This result of several events suggests that the filter strip cover may have been less than optimal. It should be noted that the total loads decreased due to reductions in runoff volumes.

Recently, Barett and others (1997) reported results from a study of runoff filtration by median strips in Texas. In this study of two medians, roadway loads were measured from road inlets or bridge scuppers adjacent to the median, and median strip EMCs were measured from storm drains that drained the medians. Respective means of TSS, nitrate, TKN, total P and zinc EMCs from the roadways were 157, 0.91, 2.17, 0.55, and 0.347 mg/l for the U.S. 183 site, and 190, 1.27, 2.61, 0.24, and 0.129 mg/l at the Walnut Creek site. Respective means of TSS, nitrate, TKN, total P and zinc EMCs from the median strips were 21, 0.46, 1.46, 0.31, and 0.032 mg/l for the U.S. 183 site, and 29, 0.97, 1.45, 0.16, and 0.032 mg/l at the Walnut Creek site.

The authors noted that flow concentrations did not decrease substantially as flow traveled down the median to the drain, indicating that nearly all of the reduction occurred in the side slopes. The side slopes ranged from 7.5 to 8.2 meters wide, with slopes from 7.2% to 9.4%. According to their estimate of annual loads using the "Simple Method" to estimate runoff volumes, minimal infiltration occurred in the C and D soils in the medians. As a result, filtration was the main process involved in reducing the loads. The authors also observed the accumulation of sediments in the first several feet next to the roadway, with accumulated sediment developing a lip at the edge of the pavement.

While these reductions were substantial, inspection of the experimental design as described in Walsh and others (1997) reveals that these EMCs represent the average (central tendency) of 34 storm events, and a paired analysis was not used. (Several storms monitored for roadway runoff were not monitored for median runoff, and vice versa.) Therefore, these results do not represent a stringent input/output relationship. Furthermore, median flows included flows from other larger pervious areas on the Walnut Creek site, and only half the median of the U.S. 183 site intercepted roadway runoff. At best, the monitored median flow thus includes at least a 50% contribution by overland flow that is not affected by roadway runoff. This predominance by pervious surfaces may explain the increase in fecal coliform observed in the swale runoff.

Even though similar results were obtained for median strip EMCs, it is difficult to ascertain what the EMCs would be at the toe of the median strip itself from this design. Using the median grab samples in the U.S. 183 site as a guide, comparison with the reported EMCs suggests that toeslope TSS EMCs would be roughly twice that reported. To resolve the input/output issue, results from certain storm events are summarized in Table 9-3. To obtain average EMC over the events, EMCs were multiplied by the event runoff volumes, summed and then divided by the sum of event volumes. Table 9-3 provides a better illustration of filter strip efficiencies because it represents the flow-weighted averages from cumulative mass loads.

Using this flow-weighted approach, respective means of TSS, nitrate, TKN, total P and zinc EMCs from the roadways were 335, 1.35, 1.70, 0.35, and 0.268 mg/l for the U.S. 183 site, and 185, 1.27, 1.72, 0.22, and 0.121 mg/l at the Walnut Creek site. Respective means of TSS, nitrate, TKN, total P, and zinc EMCs from the median strips were 13.7, 0.70, 1.04, 0.288, and 0.031 mg/l for the U.S. 183 site, and 17.8, 0.74, 1.04, 0.155, and 0.037 mg/l at the Walnut Creek site. Respective reduction of TSS, nitrate, TKN, total P, and zinc EMCs from the roadways were 96%, 48%, 39%, 17%, and 88% for the U.S. 183 site, and 90%, 42%, 40%, 29%, and 69% at the Walnut Creek site. However, it should be emphasized that these figures represent the upper end of efficiency ratios due to the masking effect of unloaded pervious runoff. Using 5 lanes (60 feet) of roadway, the hydraulic loading rate for a 1.5 inch event would be 7.5 cu. ft. per linear foot of filter length.

Efficiency ratios have also been reported for a filter strip system installed for a ten acre shopping center in Virginia (Yu and others, as cited in CWP, 1994). In this system, 0.4 watershed inches of runoff were diverted to 600 foot long level spreader discharging into a 150 foot wide filter strip with a 6% slope. Efficiency ratios in the upper 75 feet were relatively poor, since vegetative cover was sparse, and gullies had formed. Efficiency ratios at the bottom were similar to that reported by Barrett and others (1998). It is instructive to note that hydraulic loading rates for this filter strip are 24.2 cu. ft. per linear foot of filter length. This loading rate is over 3 times that of the typical median strip situation, and nearly twice of the highest reported by Dillaha and others (1989), so the poor results in the first 75 feet may not be unexpected.

Woodard and Rock (1995) reported the extent of filter strip reduction in TSS and Total P EMCs from homesite construction site runoff in Maine. This study reported substantial reductions of these pollutants over forested filter strip widths of 15 meters, while shorter strips were less effective. The longer filter width needed was attributed to the fairly sparse surface cover of the filter. Slope effects were manifest more in terms of increased loading EMCs than by decreased efficiency ratios. Post-construction loadings were much lower, and the filter strip reductions were proportionately less. Total phosphorus EMCs leaving the filter were fairly high, reflecting the background phosphorus contributions from the forest canopy.

Table 9-3: Input and Output Volumes and EMCs from Highway Median Strips
Source, Barrett and others, 1997

AREA	1200	%IMP.	IMP AREA (sq.m.)	1200	IMP. LENGTH (m)	37.3	WALNUT CREEK SITE						
RV	0.95	100%	PER. AREA	0	IMP WIDTH (m.)	32.2							
STORM	6	15	16	19	20	26	27	28	30	32	31	34	ALL EVENTS
EMCS FROM ROAD													WEIGHTED AVERAGE
TSS	257	104	93	26	23	54	98	227	147	256	526	113	185.44
NO3	0.67	4.74	4.12	1.16	0.45	0.95	1.01	1.21	1.14	1.00		3.37	1.27
TKN	1.22	3.20	2.14	1.59	3.04	0.81	2.05	1.79	1.73	1.95	1.85	3.00	1.72
TP	0.33	0.23	0.28	0.48	0.21	0.07	0.16		0.15	0.35	0.39	0.25	0.219
ZN	0.178	0.110	0.076	0.036	0.024	0.007	0.280	0.085	0.093	0.131	0.280	0.226	0.121
SWALE OUTPUT													
AREA	104600	%IMP.	IMP AREA (sq.m.)	39352	IMP WIDTH (m)	37	SWALE WIDTH	18	%SWALE				
RV	0.23	38%	PER. AREA	65249	IMP LENGTH (m.)	1055	SWALE AREA	18990	0.29	ALL EVENTS			
EMCS FROM SWALE													WEIGHTED AVERAGE & % REDUCED
TSS	51	24	41	6	4	17	16	8	14	5	60	13	17.8	90%
NO3	1.07	3.69	2.53	3.49	*0.36*	0.50	1.03	0.51	1.45	0.83	0.01	1.22	0.74	42%
TKN	0.90	2.74	2.11	2.11	0.92	0.69	0.97	0.90	0.98	1.01	1.42	1.30	1.04	40%
TP	0.04	0.18	0.22	0.21	0.19	0.19	0.13		*0.11*	0.16	0.15	0.16	0.155	29%
ZN	0.023	0.003	*0.002*	0.002	0.003	0.003	0.018	0.003	0.044	0.122	0.067	0.147	0.037	69%

AREA (sq.m.)	850	%IMP.	IMP AREA (sq.m.)	850	IMP. WIDTH (m)	19	183 SITE				
RV	0.95	100%	PER. AREA	0	IMP LENGTH (m.)	44.7					
STORM NO.	15	16	19	20	22	25	28	32	33	36	ALL EVENTS
RUNOFF	6800	18480	5940	15260	32320	30600	55180	20490	12360	87389	284819
EMCS FROM ROAD											WEIGHTED AVERAGE
TSS	247	117	31	17	135	81	98	3328	522	48	332.9
NO3	3.29	5.66	2.66	0.8	2.25	0.53	0.55	0.43	1.63	0.94	1.35
TKN	5.92	1.87	2.99	1.20	2.21	0.62	0.89	2.06	0.31	2.18	1.70
TP	0.60	0.35	0.51	0.20	0.39	0.16		0.58	0.69	0.30	0.35
ZN	0.459	0.285	0.279	0.030	0.123	0.126	0.093	0.440	0.690	0.410	0.268
SWALE											
AREA (sq.m.)	13000	%IMP.	IMP AREA	6764	IMP. WIDTH (m)	19	SWALE WIDTH	17.5	%		
RV	0.37	52%	PERV. AREA	6236	IMP LENGTH (m.)	356.0	SWALE AREA	6230	100%		
EMCS FROM SWALE											WEIGHTED AVERAGE
TSS	38	50	3	5	7	14	7	6	6	19	13.7
NO3	2.71	3.71	0.31	0.20	1.32	*0.20*	0.25	0.41	0.68	0.48	0.70
TKN	1.97	1.73	1.83	1.18	0.90	0.78	0.63	1.33	1.07	1.12	1.04
TP	0.46	0.24	0.35	0.21	0.32	0.43			0.28	0.19	0.29
ZN	0.002	0.003	0.002	0.002	0.002	0.025	0.022	0.070	0.050	0.070	0.031
PER CENT CONCENTRATION REDUCTIONS											
TSS	85%	57%	90%	71%	95%	83%	93%	100%	99%	60%	96%
NO3	18%	34%	88%	75%	41%	62%	55%	5%	58%	49%	48%
TKN	67%	7%	39%	2%	59%	-26%	29%	35%	-246%	48%	39%
TP	23%	31%	31%	-5%	18%	-169%			59%	37%	17%
ZN	100%	99%	99%	93%	98%	80%	76%	84%	93%	83%	88%

9.2 VFS-MOD MODEL

A decade ago, Munoz-Carpena, Parsons and Gilliam (1992) developed the VFS-MOD filter strip model. This model uses the *CN* method to predict runoff, and the Modified Universal Soil Loss Equation (MUSLE) to predict sediment loads from the source areas. Filter strip runoff volume reductions are computed by the Green-Ampt equation, while flow through the strip is based upon a kinematic wave approximation. Sediment reductions are computed according to the procedures developed in the 1970's at the University of Kentucky by the team of Tollner, Barfield and Hayes (See Munoz-Carpena and others (1992) for references). This model explicitly computes the runoff volume and sediment losses as it passes through the strip. It also accounts for the development of the initial wedge of sediment that occurs in the first few feet of the strip discussed above.

The VFS-MOD model was subsequently validated in studies of 27 rainfall events in the North Carolina Piedmont (Munoz-Carpena and others, 1999). These investigators reported that the hydrologic responses, sediment loads and subsequent reductions predicted by VFS-MOD were very close to observations, so long as no channelization occurred. Table 9-4 shows how the filter strip performance closely matched predicted observations, with an average error below 6 percent. Note that most of the load reductions were close to the concentration reductions, suggesting that decreases in runoff volume were not substantial.

Note that the 8.4 meter wide strip was much more effective than the 4.2 meter strip at loads above 7,900 mg/l. However, such loads are extremely high for urban situations. At loads below 2,500 mg/l more typical of urban runoff, removal efficiencies in the 4.2 meter wide strips were quite good. This is in accordance with the results of Barrett and others (1997) displayed in Table 9-3. This further confirms that even narrow filter strips can provide good removal rates for urban runoff.

Table 9-4: Input/Output Loads and EMCs from Filter Strips
Source, Munoz-Carpena and others (1999)

Strip Event	112-92 g4	112-92 r1	151b-92 g4	331a-92 g4	331a-92 g8	024-93 g4
Strip Width (m)	4.2	4.2	4.2	4.2	8.4	4.2
INPUT						
Concentration (mg/l)	1080	750	2440	7930	7930	11470
Sediment Load (g)	287.0	188.9	968.3	5788.0	5788.0	6187.8
OUTPUT						
Runoff Volume (m3)	0.1873	0.1129	0.1905	0.6411	0.5240	0.3687
% Model Error	-10.6%	23.5%	-1.6%	-1.1%	5.3%	12.1%
Sediment Load (g)	30.5	17.9	20.1	2488.0	345.0	639.0
% Model Error	1.3%	9.2%	0.7%	0.4%	19.5%	-3.5%
Concentration (mg/l)	162.8	158.5	105.5	3880.8	658.4	1733.1
Conc. Reduction	84.9%	78.9%	95.7%	51.1%	91.7%	84.9%
Load Reduction	89.4%	90.5%	97.9%	57.0%	94.0%	89.7%

In Canada, Abu-Zreig and others (2001), recently confirmed the validity of the VFS-MOD model, once concentrated flows across the filter strip were explicitly modeled as discrete segments. Coefficients of determination (R^2) for infiltration volume and trap efficiency were 0.95 and 0.90, respectively, and the results were highly significant ($p<0.01$). These results confirm that the VFS-MOD model is an effective method to predict filter strip removal kinetics.

9.3 FILTER STRIP REMOVAL KINETICS

The preceding discussion highlights three factors that affect the performance of filter strip BMPs: filter strip width, slope, and hydraulic loading rate, assuming a uniform turf cover condition. There is an abundant literature demonstrating that filter strip trap efficiency increases as filter strip width increases (Dillaha and others, 1989; and many others), although there are occasional circumstances where sediment concentrations increase as filter strip widths increase (Parsons and others, 1993). The authors attributed this latter finding to the relatively poor cover in the filter strip. It should be noted that most TSS deposition occurs within the first few feet, and trapping efficiencies are statistically identical from 15 to 30 feet (Mendez and others, 1989).

To develop a relationship between filter strip width and trap efficiency, Abu-Zreig (2001) ran VFS-MOD on filter strips of varying widths and slopes. Figure 9-1 displays how predicted trap efficiencies approached the maximum reported removal of 93 percent in filter strip widths of 40 to 50 feet. The hydraulic loading rate was 10.8 cubic feet per foot, a value typical for urban runoff loading rates. However, the input concentration was a fairly high 4,000 mg/l, a value roughly 20 times that expected in urban runoff. Note how the VFS-MOD results generally correspond to the observations of Dillaha and others (1989). A relationship following the asymptotic form of equation (32) is applicable to these results. Excluding hydraulic loading rate adjustments, the form of equation used in DURMM is shown in thicker lines in Figure 9-1.

Abu-Zreig (2001) also presented the trap efficiency for the clay fraction, which has much lower efficiencies than suspended sediment as a whole. This is not surprising, since clays have a much slower settling kinetics for a given filter surface area or detention time. Unlike the exponential decay seen in coarser sediments, the trapping efficiency of clay shows nearly linear removal kinetics. Since adsorbed phosphorus is preferentially bound to the clay fraction, this has implications for particulate phosphorus removal.

A counterintuitive finding of this study is that the effect of slope is much less pronounced, and it is absent if the strip is wide enough. In essence, the effect of increasing slope is to shift the x-intercept to the right, so its effect is more pronounced at lesser widths. This relationship is partially due to the fact that increasing slope increases Manning's roughness value under submerged flow conditions (Kao and Barfield, 1978; Kouwen and Lee, 1980). This finding was confirmed by the observations of Abu-Zreig and others (2001). Since both the numerator and denominator of Manning's equation thus increase simultaneously, flow velocity and filter strip retention time is comparatively unaffected. As a result, it is not surprising that the 18% increase in trap efficiency between 11% and 16% slopes shown in Table 9-1 is much less than the 45% reduction in slope. Therefore, slope effects in filter strip efficiency seem to be fairly minor, and have minimal effect on maximum efficiency ratios.

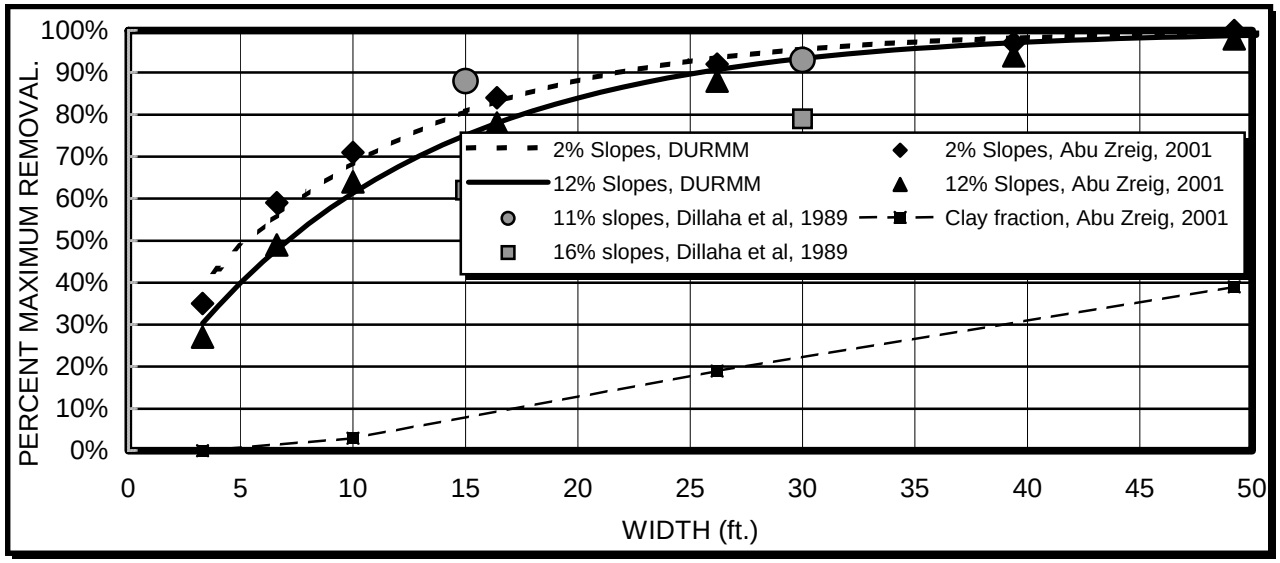

Figure 9-1: Percent Of Maximum Trap Efficiency as a Function of Filter Strip Width and Slope
Sources: Dillaha and others, 1989; Abu-Zreig, 2001

Given the validity of the VFS-MOD model, the following discussion presents model results for a turf grass filter at varying slopes and hydraulic loads. Input parameters were a silty-clay filter strip soil at a moisture deficit of 17.5 percent, suspended sediment with a fine particle distribution (d_{50} = 23 microns), an input concentration of 300 mg/l, and a hydraulic load of 10.5 cubic feet per foot. Results for varying slopes and widths are displayed in Figure 9-2.

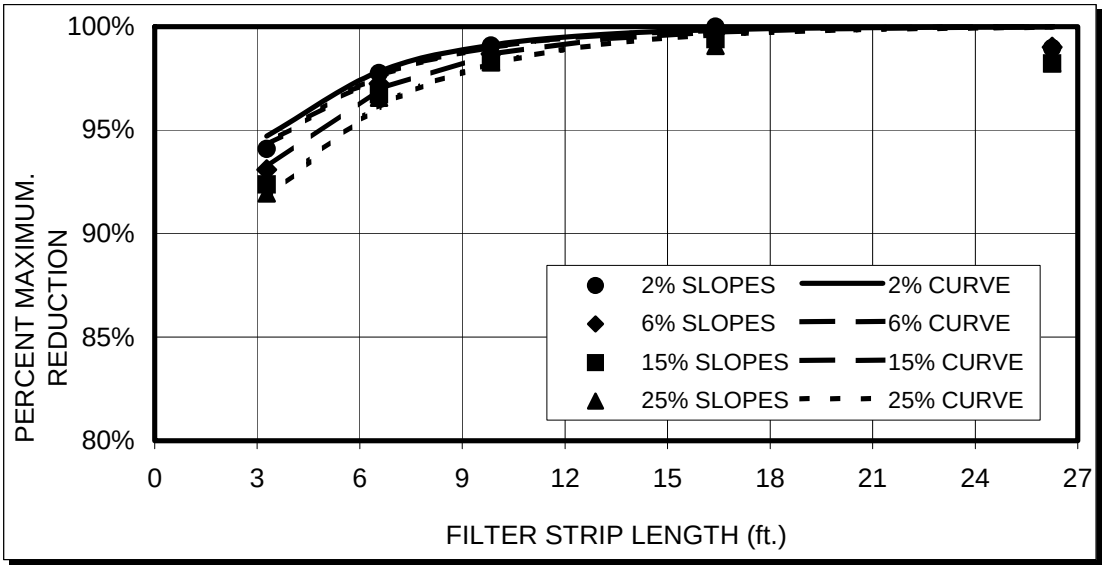

Figure 9-2: Percent Of Maximum Reduction Efficiency as a Function of Filter Strip Width and Slope

Even under these less than optimal conditions, with silty-clay sediment and tight, moist soils, the computed maximum reduction efficiency was 96.9 percent, a value similar to that reported by Barrett and others (1997). There was very little change in this value (±0.3 percent) for loading rates of 200 and 100 mg/l on a 5 meter strip, so results for these lower loading rates were not computed further.

These model runs further demonstrate the relative lack of sensitivity to slope, even for slopes as high as 25 percent. Note that the scale has been exaggerated to highlight the small differences in removal efficiencies. When removal efficiency is this high, a small difference in removal efficiency represents a large difference in the final output concentration. Therefore, the computation of such subtle differences is important in predicting output loads from filter strips. Note also that the best performance of the filter strip occurs at a width of 16.5 feet (5 meters), and reduction efficiency decreases somewhat at higher widths. This is due to the model computing volumes that decrease more than the loads at the higher width, resulting in higher concentrations.

This effect of differing hydraulic load has not been explicitly reported in the literature, so additional runs of VFS-MOD were preformed to investigate this aspect of filter strip performance. Using the same input parameters as in Figure 9-2 for a 2 percent slope filter strip, Figure 9-3 presents the effects of increasing the hydraulic loads to 21.0 and 31.5 cubic feet per foot of filter strip length:

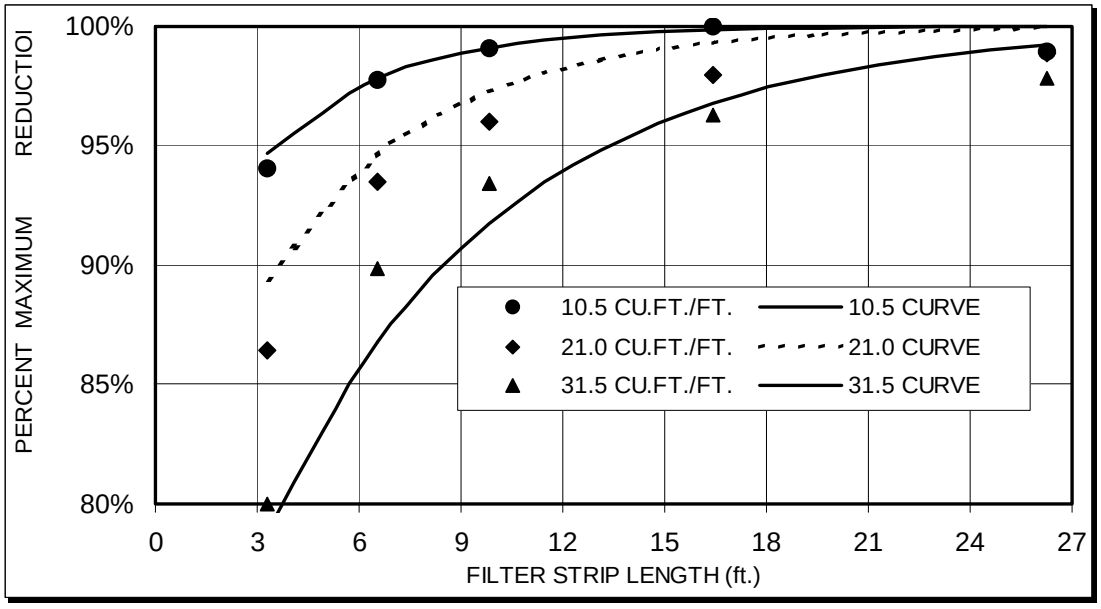

Figure 9-3: Percent Of Maximum Reduction Efficiency as a Function of Filter Strip Width and Hydraulic Load

Over the range of expected loading rates, variations in hydraulic load are seen to have a much greater effect than is projected for slopes. As in the case of slopes, these effects become less prominent as the filter strip gets wider.

Another important variable is the stem density. The results presented above assume that the filter strip cover is in good condition. Obviously, such results would not be expected for filter strips in poor conditions or in winter, when the effective stem density will be less. Since this is

the season when most runoff occurs, results for poorer conditions and grasses other than turf need to be examined. In VFS-MOD, bluegrass turf is allocated as having a stem distance (density) of 1.65 cm between stems, while mixed grasses are allocated as having a density of 2.15 cm. (Grasses with higher densities are not recommended in the documentation.) Under the same input parameters as Figure 9-1, the results for the mixed grass stem density are shown below in Figure 9-4. Surprisingly, increasing the stem density by a factor of nearly three to 6.0 did not seem to materially affect performance.

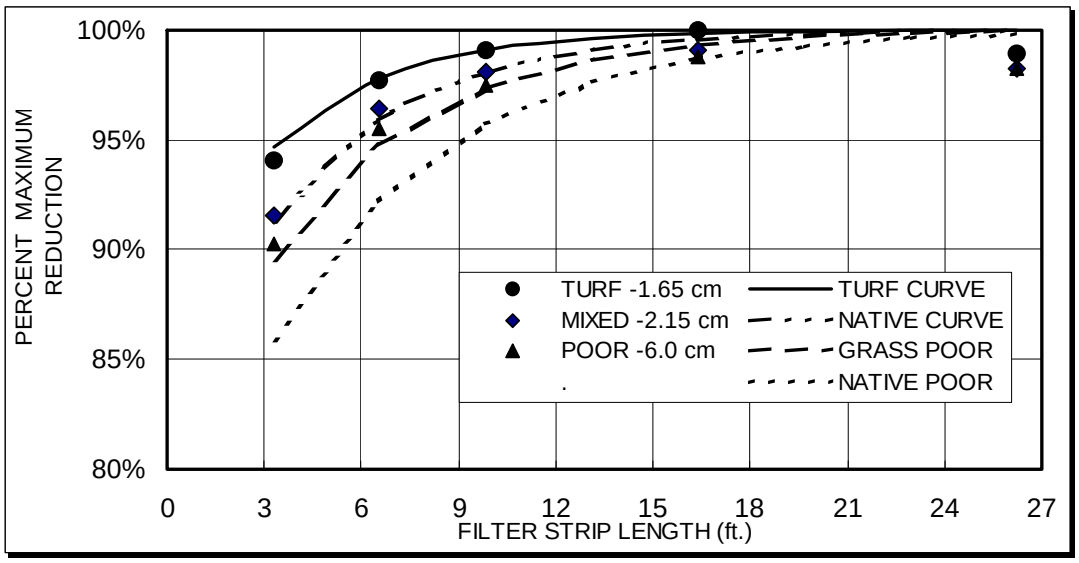

Figure 9-4: Percent Of Maximum Reduction Efficiency as a Function of Filter Strip Width and Stem Density

To replicate these trends with a minimum of computational overhead, DURMM uses the following expression and coefficient values to relate maximum design efficiency ratio, $R_{max}\%$, to maximum possible efficiency ratio *Max%*, coefficient *K*, width *w*, hydraulic loading rate *r*, slope *s*, and stem density factor *d*:

$$R\%_{\max} = Max\% \times \left\{1 - e^{f(K,w,r,s,d)}\right\} \tag{34}$$

where

$$f(K,w,r,s,d) = K \times (A - w) \times (1 - r/B) \times (1 - C/s) \times 1/d \tag{35}$$

Coefficients for (35) are listed below:

K	A	B	C
0.340	-2.30	55	0.65

Stem density factors are listed below:

TURF GOOD	MIXED GOOD	TURF POOR	NATIVE POOR
1.00	1.20	1.30	1.50

The curves derived from equations (34) and (35) are shown in Figures 9-2 through 9-4. While the correspondence to VFS-MOD results is not perfectly matched by these curves, the general trends and range of values are quite satisfactory. In this manner, DURMM provides the capability to rapidly determine the most important elements of filter strip performance in relation to specific site design parameters. It is recommended that poor conditions be applied to the design to account for variability in seasonal growth and potentially poor maintenance. To account for the worst circumstances, an estimated curve for native grasses in poor condition is shown in Figure 9-4.

9.4 MAXIMUM EFFICIENCY RATIOS AND IRREDUCIBLE CONCENTRATIONS

Table 9-5 summarizes data in Tables 9-1, 9-2, and 9-3 relating to the maximum likely efficiency ratios and minimum effluent EMCs for which grass filter strips are capable. The lowest values and highest removal rates are outlined in italics in Tables 9-1 through 9-3. Since the literature is so sparse to refine some of these values, reference is also made to the literature values for biofiltration swales discussed in the next Chapter. Note that the minimum values and maximum removal are intended to be representative values, not the most extreme value observed, which may reflect sampling error.

Based upon the data, particulate and adsorbable soluble species such as TSS, organic N, PP, ammonia and zinc show high potential maximum efficiency ratios in the range of 60% to 97%. Ammonia is subject to both processes of transformation, adsorption and dilution, with projected reductions based upon the Texas results. Although total P showed lower efficiency ratios in Barrett and others (1997), this may be due to the relatively low inflow concentrations. There were high efficiency ratios for particulate P in Dillaha and others (1989) and Parsons and others (1993), where concentrations were much higher. However, recent papers by Rudra and others (2001a, 2001b) suggest that particulate phosphorus removal is likely to be substantially less than TSS removal, since phosphorus is preferentially adsorbed to the finer particles, which have much lower filtration efficiency. Since this depends on both the characteristics of incoming runoff and different filter strip length relationships, no attempt has been made in this version to precisely address the differing reduction kinetics. However, note that the maximum removal percentage for particulate phosphorus is allocated at a conservative 60 percent.

Even though the reduction in nitrate EMCs seems to mostly reflect dilution effects, this is modeled as a reduction in EMCs since DURMM accounts for overall event hydrologic processes, and infiltrated nitrate is largely sequestered in the root zone. However, atmospheric deposition requires that the minimum concentration for nitrate be in the range of 0.15 mg/l, even though reported effluent values are as low as 0.04 mg/l. Since there are many cases where efficiency ratios are negative, the maximum efficiency is projected at 40 percent. The maximum soluble P efficiency ratio is even lower, since biological transformations in the filter strip often exceed input loads due to release of previously sequestered soluble P. Since there is no data on copper

removal in the filter strip literature, results from the bioswale analysis in Chapter 10 are projected to apply to filter strips.

To obtain the efficiency ratio for Filter Strip BMPs, maximum reduction percentage *Max%* from Table 9-5 is entered as the first term of the filter strip design equation (34). The rest of the terms in equation (35) are set by the actual design parameters to obtain design efficiency ratio $R_{max}\%$, expressed as a percent of the potential maximum ratio for each pollutant of interest. The minimum EMC values entered as part of the general efficiency equation (32). Actual efficiency ratio *R%* is then depends upon the input concentration entered into (32).

Table 9-5: Maximum Efficiency Ratios and Minimum EMCs for Filter Strips

POLLUTANT	TSS	PP	SP	ON	NH_4	NO_3	Cu	Zn
MAXIMUM REDUCTION %	97%	60%	15%	90%	70%	40%	85%	97%
MINIMUM EMC (mg/l)	5	0.10	0.05	0.40	0.15	0.15	0.002	0.006

The BMP design module of DURMM described in Appendix A provides estimates for filter strip performance as a function of loading rate, pollutant levels, width, slope, and stem density. Design standards, construction specifications and details of the filter strips and level spreader design are set forth the Green Technology Standards, Specifications and Details, Appendix B.

9.5 FILTER STRIP BMPs AND INTEGRATION WITH TERRACE BMPs

An imperative feature in the design in all sheet flow filtration BMPs is the provision of sheet flow conditions. Filter strips are thus best suited for situations where runoff has not been concentrated, as is found from parking lots, driveways, sidewalks, and uncurbed streets. When used as median strips or adjacent to parking lots, the paving itself is an effective level spreading device. However, if filter strips are used after flow has become channelized, their efficiency ratios are not nearly as effective (Dillaha and others, 1989, and many others).

Therefore, an engineered level spreader is necessary to restore sheet flow discharge to the filter strip. Absolutely level surfaces are necessary, and the appropriate structure must be provided. Where runoff from rooftops and curbed roadways is conveyed through pipes, a level spreader is necessary in order to reestablish sheet flow conditions needed for filter strips. See the level spreader details set forth in the Standards, Specifications and Details in Appendix B. Since biofiltration swales are as effective as filter strips in these circumstances, it is questionable whether the potentially less reliable performance of level spreaders is worthwhile, unless there are special circumstances, such as concentrated discharge directly onto a hill slope where a biofiltration swale would require excessive grading.

Filter strips are an integral part of terrace BMPs. In this case, the side slope entering the terrace operates as a filter strip, functioning in a manner analogous to the median filter strips reported in Texas (Barrett and others, 1998). Filtration reductions in the conveyance channel are assumed to be minimal, as flow depths are relatively deep, and runoff is already filtered. Since the side slope provides such substantial filtering, further reductions along the channel would provide minimal additional removal. DURMM thus allocates terrace side slope filtering according to the design parameters in equations (34) and (35).

CHAPTER 10 BIOFILTRATION BMPs

10.1 BIOFILTRATION SWALE RESULTS

Biofiltration swales represent a class of BMPs in which filtering occurs as flow travels along a defined channel. The filter media is usually grass, although ground cover vines, sedges and rushes can also be used. Channel flow velocities along biofiltration swales would seem to be faster than sheet flow through filter strips, since flow depths are greater. However, this may not be the case, as discussed in Section 5.6. Typical flow depths are deeper than sheet flow BMPs, although they should be well below the top of vegetation in properly designed swales. As discussed in Chapter 6, it is very important that vegetation not be submerged, since this causes the vegetation to bend over with the flow, which reduces roughness. Resulting flow velocities will be much greater, and the opportunity for contact filtering is less.

Biofiltration swales are well suited for concentrated flow situations, where runoff has already been collected by piped conveyance systems. However, they are also very effective as a conveyance system in themselves, they can also be designed to provide detention to meet the discharge criteria set forth in Chapter 4. Using detention routing in a similar manner, terraces represent a swale that is surcharged laterally, instead of from a point discharge. As such, terrace BMP removal processes could be considered analogous to that involved in the median filter strips discussed in the previous Chapter.

The literature on biofiltration swale EMC reductions is rather sparse. While there is some data from Florida (Yousef and others, as cited in CWP, 1995), the data is expressed in terms of mass reduction where considerable infiltration had occurred, so removals due to EMC reductions are elusive. The only data set from a swale where infiltration was minimal is presented in a report by the SWPCD (1992). This report measured the responses to 12 storms of a 187 foot long bioswale 5 feet wide with 3:1 side slopes in Seattle, Washington. The authors attempted to ascertain the reduction in swale efficiency if swale retention time was halved by doubling the input flows. However, as discussed in Chapter 6, submerged flow velocities in this swale were essentially constant, regardless of flow rates. As table 5-6 in SWPCD (1992) shows, the cross-sectional areas for the “shorter” runs were identical to the cross-sectional area used in longer runs at similar flow rates, thus the presumed reductions in retention time were based upon a “shorter” effective width. This width was assumed to be half the measured width of 187 feet, since halving the flow was supposed to halve the area. However, the latter is true only in terms of cross-sectional area, not overall wetted area. Table 10-1 presents results from the SWPCD (1992) study.

Flow weighted averages are determined as the sum of products of each event EMC times its flow, divided by cumulative flow of the events measured. Note that Table 10-1 has partitioned total P and the metals into soluble and particulate fractions. Values shown in italics are either below detection limits, flagged as unreliable, or a constituent EMC that had a higher EMC than the total EMC (eg, where dissolved copper EMC was greater than the total copper EMC). These values are excluded from the flow-weighted averages.

Table 10-1: Performance of Biofiltration Swale in Washington State Source: SWPCD, 1992

PARA-METER	INDIVIDUAL STORM EVENT DATA												FLOW WEIGHTED AVERAGES		
DATE	6/20/91	7/15/91	7/24/91	8/9/91	10/24/91	10/31/91	11/17/91	1/16/92	1/23/92	3/27/92	4/17/92	4/29/92	6/20/91 to 1/23/92	3/27/92 to 4/29/92	ALL STORMS
Qavg.(cfs)	0.16	0.02	0.40	0.31	0.21	0.10	0.07	0.03	0.05	0.21	0.25	0.11			
Qpeak(cfs)	0.29	0.12	**0.78**	**1.35**	**0.61**	0.18	0.29	0.09	0.18	**0.49**	**0.65**	**0.56**			
DEPTH(ft.)	0.09	0.01	0.20	0.16	0.11	0.06	0.04	0.02	0.03	0.11	0.13	0.06			
FLOW(cu.ft.)	3168	180	4320	4464	5481	2700	2898	378	1260	2268	3600	2376	2761	916	2758
INPUT CONCENTRATION (mg/l)															
TSS	18	51	180	32	190	19	57	91	51	150	190	150	108	167	113
NO3	0.210	0.640	0.470	0.310	0.230	0.250	0.06	0.590	0.230	0.420	0.031	0.230	0.314	0.195	0.255
SP	0.017	0.043	0.031	0.042	0.088	0.036	0.005	0.005	0.005	0.007	0.022	0.005	0.045	0.013	0.033
PP	0.075	0.287	0.309	0.053	0.142	0.074	0.024	0.115	0.020	0.008	0.138	0.235	0.137	0.130	0.122
Zn-D	0.048	0.150	0.110	0.023	0.021	0.015	0.003	0.003	0.002	*0.042*	0.034	0.019	0.043	0.028	0.035
Zn-P	0.020	0.100	0.100	0.048	0.029	0.023	0.013	0.107	0.094	*0.005*	0.096	0.121	0.053	0.106	0.058
Cu-D	0.002	0.021	0.010	*0.007*	*0.002*	*0.004*	*0.021*	0.002	0.001	0.001	0.002	0.002	0.009	0.002	0.004
Cu-P	0.000	0.010	0.003					0.006	0.005	0.006	0.010	0.012	0.004	0.009	0.006
OUTPUT CONCENTRATION (mg/l)															
TSS	2	12	14	**34**	6	4	4	7	9	**140**	**50**	**150**	13	104	35
NO3	0.210	2.100	1.200	0.570	0.310	0.210	0.060	0.740	0.240	0.490	0.059	0.250	0.544	0.233	0.414
SP	0.014	0.043	0.027	0.088	0.051	0.016	0.005	0.005	0.005	0.005	0.013	0.034	0.042	0.017	0.032
PP	0.056	0.207	0.213	0.022	0.045	0.036	0.010	0.026	0.010	0.000	0.117	0.146	0.075	0.093	0.072
Zn-D	0.010	*0.072*	0.055	*0.058*	0.007	0.002	0.014	0.002	0.001	*0.024*	0.031	0.023	0.021	0.028	0.020
Zn-P	0.022		0.018		0.011	0.004	0.008	0.047	0.012	*0.054*	0.051	0.087	0.016	0.065	0.025
Cu-D	*0.001*	0.012	*0.013*	0.001	*0.004*	*0.005*	*0.006*	0.001	0.001	0.001	0.002	0.002	0.001	0.002	0.002
Cu-P		0.000		0.001				0.002	0.001	0.014	0.007	0.016	0.001	0.012	0.007
EMC REDUCTION															
TSS	89%	76%	92%	-6%	97%	79%	93%	92%	82%	7%	74%	0%	88%	38%	69%
NO3	0%	-228%	-155%	-84%	-35%	16%	0%	-25%	-4%	-17%	-90%	-9%	-73%	-19%	-63%
SP	18%	0%	13%	-110%	42%	56%	0%	0%	0%	29%	41%	-580%	8%	-30%	4%
PP	25%	28%	31%	58%	68%	51%	58%	77%	50%	100%	15%	38%	45%	28%	41%
Zn-D	79%	52%	50%	-152%	67%	87%	-367%	33%	50%	*43%*	9%	-21%	51%	1%	44%
Zn-P	-10%	100%	82%	100%	62%	83%	38%	56%	87%	*-980%*	47%	28%	69%	38%	56%
Cu-D	*50%*	43%	*-30%*	*86%*	*-100%*	*-25%*	*71%*	50%	0%	0%	0%	0%	85%	0%	61%
Cu-P		100%						67%	80%	-133%	30%	-33%	67%	-22%	-21%

Note how the bioswale generally performed well in terms of TSS reductions until the last three storm events. Comparison of the weighted averages displays very different responses from the other storm events in terms of EMC efficiency ratios, some of which can be attributed to reductions in input concentrations. However, even though input TSS EMCs were generally similar, the poor performance of the 3/27/92 and 4/29/92 storms is difficult to explain. The authors noted that the storms in April conveyed substantial silt into the swale, which may have been resuspended during subsequent runoff events.

However, note that poorer results occurred with storms at the higher flow rates, 8/9/91 and 3/27/92. These storms were the worst performing in terms of TSS reduction, suggesting that hydraulic loading rate (or flow depth) has an effect. However, the storms of 7/24/91 and

10/24/91 were among those with the deepest flow depths, yet they obtained excellent reductions. It is possible that these contrary results indicate resuspension of previously deposited fine sediments. It is also important to note that the peak and average flows were quite low in general, especially considering a 14.7 acre watershed with 44% impervious cover. Average flow depths in these storms were quite low, suggesting that performance will be compromised if flow depths get at all close to emergence.

The preceding discussion, however, does not provide any information as to the pertinent details needed to optimize the design of bioswales. The effect of relevant parameters such as hydraulic loading rate (or flow depth) and retention time cannot be determined from the SWPCD (1992) study. However, in a companion study to the median strip results discussed above, Walsh and others (1997) measured EMCs in an artificial flume 30 inches wide and 40 meters long at a slope of 0.44%. It was planted in buffalo grass over a 6 inch topsoil and 3 inch gravel matrix with an underdrain to catch leachate. A "cocktail" of synthetic urban runoff was delivered to the flume, with measurements of EMCs at 0, 10, 20 30, and 40 meters along the flume. Flows were set at depths of 3, 4, 7.5 and 10 cm. Since the latter depth is well above the proper depth for biofiltration, its results have not been displayed in the following discussion.

Figures 10-1 and 10-2 display the reductions in EMCs and efficiency ratios for TSS and Zinc in this experiment. Reductions ranged from 22% to 66% for total P, from 14% to 47% for TKN and minimal or negative for nitrate, as can be expected from previous analysis of filtering literature. There was little correlation with distance or depth of flow for these constituents. While zinc reduction percentages were greater than observed in Seattle, the minimum EMC was in the range of 0.05 mg/l.

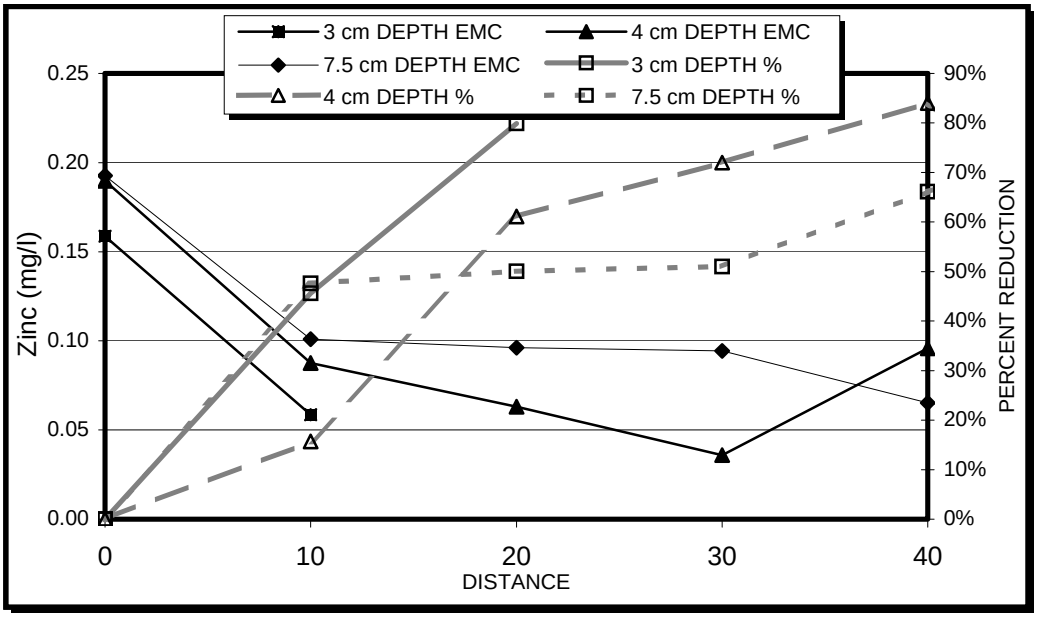

Figure 10-1: Percent Reduction of Zinc as a Function of Distance and Depth
Source: Walsh and others (1997)

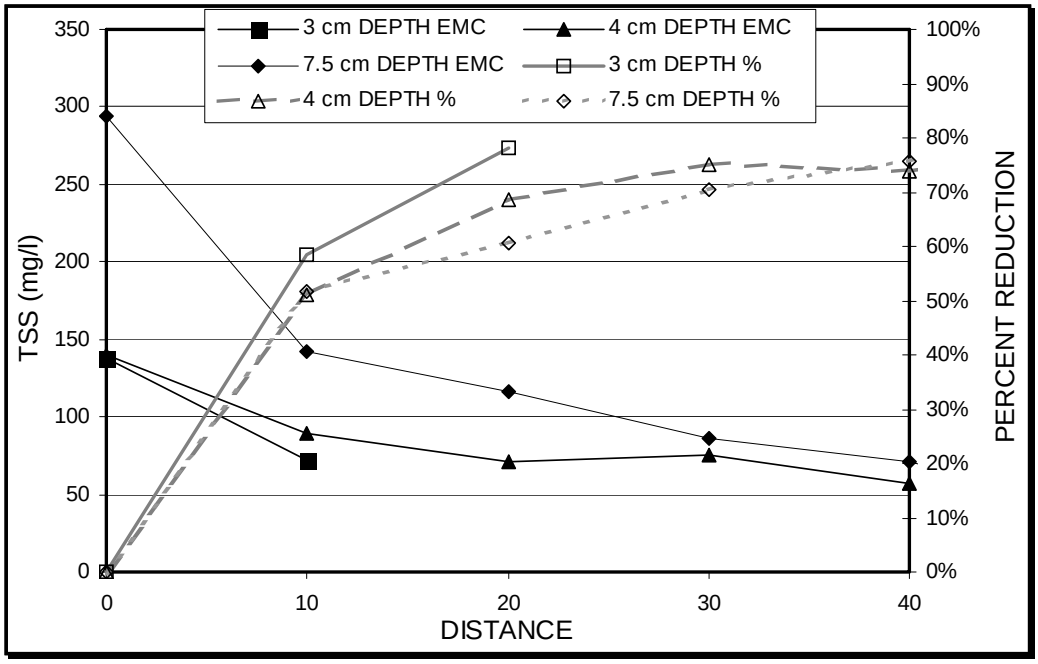

Figure 10-2: Percent Reduction of TSS as a Function of Distance and Depth
Source: Walsh and others (1997)

Note that TSS and Zinc EMCs show a substantial decreasing trend with length. Reductions peaked at around 80% for both these constituents, similar to that observed by the SWPCD (1992) for TSS. Most of the reductions occurred within the first 20 meters, and further losses were relatively minor after 20 meters. Although not shown, the maximum reduction at the 10 cm depth was only 50%, which was reached at 20 meters. Sediment coating on the grass was obvious within the first 3 meters, and still could be observed at 10 meters, but was absent at 20 meters and beyond.

These results suggest that, at the experimental slope of 0.44%, the minimum length for effective TSS and zinc reduction should be at least 20 meters, and preferably 30 meters. Using the geometry of the swale, average flow velocities are calculated between 0.16 and 0.18 ft/sec for the range of flow depths involved. At 30 meters, this suggests a retention time of 9.9 minutes for best results. This value agrees remarkably well with the conclusions of the SWPCD (1992) swale study.

However, note that the final TSS EMC was in the range of 50 to 70 mg/l, roughly ten times the minimum EMC from the Seattle swale. To account for this result, note that the minimum TSS EMC in the leachate was 36 mg/l, with an average of 39 mg/l in the 7.5 cm tests, and 57 mg/l in the 4 cm tests. Given a profile of 6 inches of soil on top of only 3 inches of gravel, a substantial fraction of TSS is lost from the soil profile in every test, so it is not filtered at any length. As such, this fraction seems to be an artifact of the design that may not be applicable to typical biofiltration swale designs for urban runoff.

If the average leachate TSS concentrations are then subtracted from the input and effluent TSS concentrations for the results of the 4 and 7.5 cm tests, the resulting concentrations and efficiency ratios are remarkably similar to that observed in filter strips and in the SWPCD swale.

Figure 10-3 plots the resulting EMCs and reductions as a function of length and retention time. Note that maximum efficiency ratios exceed 90%, and minimum EMCs are 18 and 33 mg/l for the 4 and 7.5 cm tests, respectively. These values are more in line with the results in the SWPCD (1992) swale.

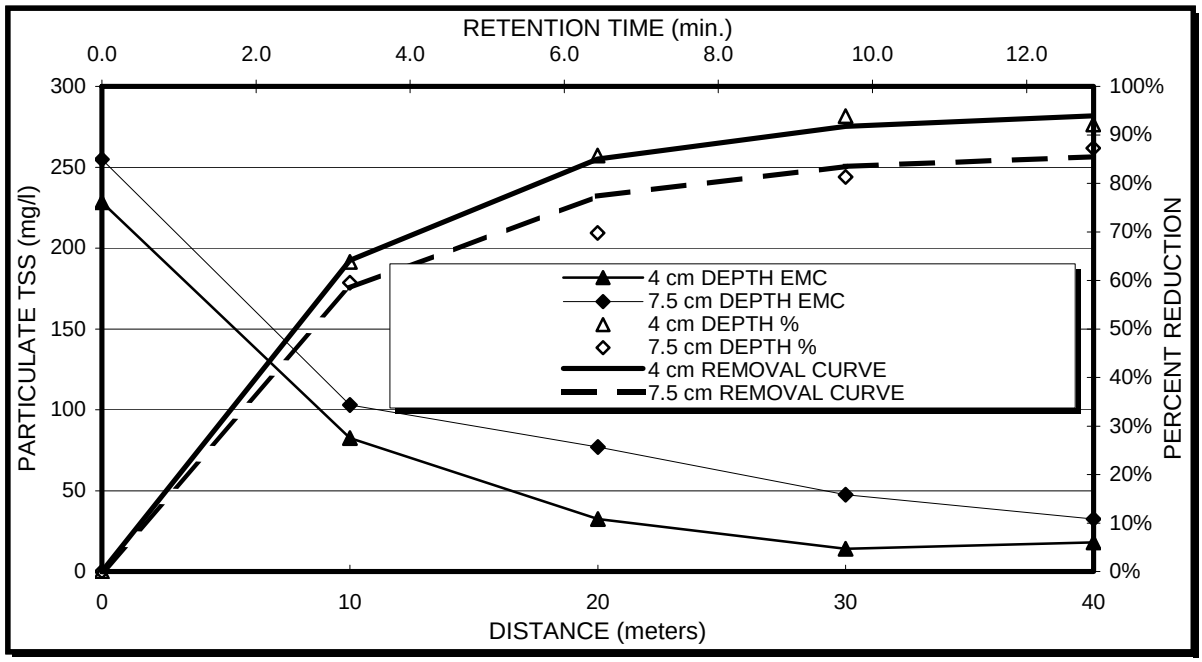

Figure 10-3: TSS EMCs and Reductions as a Function of Distance, Retention Time, and Flow Depth. Data adjusted from Walsh and others (1997)

10.2 BIOFILTRATION SWALE KINETICS

These results show a clear trend for a reduction in efficiency and increase in the minimum concentration with increasing depth of flow, although the minimum EMCs begin to converge by 40 meters. At depths up to 7.5 cm, Equation (36) reproduces these results for efficiency ratio $R_{max}\%$ as a function of retention time T and depth d (in feet):

$$R_{\max}\% = MAX\% \times (1 - e^{-KT}) \times (A/d)^{B} \qquad (36)$$

MAX%	K	A	B
95%	-0.350	0.131	0.15

Using the results of the SWPCD study and this study, Table 10-2 displays the anticipated maximum efficiency ratios and minimum EMCs for bioswales. Again, since the data is rather sparse, reference is made to the filter strip data to project minimum EMCs for certain pollutants, As a result the values are nearly identical to that projected for filter strips, which is to be expected, since similar removal processes by exposure to vegetation are involved.

Table 10-2: Maximum Efficiency ratios and Minimum EMCs

POLLUTANT	TSS	PP	SP	ON	NH4	NO3	CU	ZN
MAXIMUM REDUCTION	95%	95%	45%	90%	70%	45%	85%	85%
MINIMUM EMC (mg/l)	4	0.010	0.005	0.40	0.15	0.15	0.002	0.006

Note that relatively poor reduction (50% compared to 75%) was noted at flow depths of 10 cm (0.33 feet), while good results occur at depths up to 7.5 cm (0.25 feet). For these reasons, biofiltration swales should be designed so that the maximum flow depth does not exceed 0.25 feet during the design flow event, unless a dense uncut stand of native grasses is provided. If swales operate at even lower depths, the performance will be even better.

Since bioswale flow depths need to be totally submerged for decent results, their filtering mechanisms would seem to correspond to that of filter strips. In this light, it is instructive to calculate the retention time in a filter strip, using the sheet flow equation (6), and allocating hydraulic loading as excess precipitation, as is used for impervious disconnection. At a hydraulic loading rate of 12 cu.ft./ft. into a 30 foot filter strip, the resulting excess precipitation would be 0.4 feet. Added to 1.5 inches of rainfall depth, this is a rainfall depth of 7.2 inches. Using equation (6) for a 5% slope at roughness value of 0.45, the travel time through the strip is roughly 4.2 minutes, and 3.1 minutes for a 10% slope. Since these times are at the low end for effective biofiltration, this suggests that either filter strip filtration is more effective for a given time interval (perhaps due to stem density in thatch layer), and/or equation (6), with its parameter values, overstates flow velocities.

10.3 BIOFILTRATION SWALE BMPs

It is essential that the swale soil profile promote vegetative growth, and infiltration, if located above the water table. Therefore, bioswales should be constructed into uncompacted soils where possible. However, construction inevitably involves mass grading, reconfiguration of underlying drainage patterns, and substantial compaction, often deep into native soils. Therefore, prior to topsoil return, the compacted subgrade at the bottom of the swale should be overlaid with a coarse sand mix, which is then subsoiled for several feet, to promote infiltration and biological growth. The facility should then be disked after construction before final grading the topsoil.

The BMP design module of DURMM described in Appendix A provides estimates for biofiltration swale performance as a function of loading rate, pollutant levels, length, width, side slopes, longitudinal slope, and surface cover. Design standards, construction specifications and details of biofiltration swales are set forth the Green Technology Standards, Specifications and Details, Appendix B.

Another important benefit of biofiltration swales is their ability to provide detention storage for events larger than the quality event. By installing stone check dams at regular intervals, a bioswale several feet deep can provide enough storage for reducing the peak flow of even the 100 year event. Check dams constructed with a turf reinforcement matting apron on the downstream side to provide a stable substrate to absorb the energy concentrated in the fall over the dam. Check dams thus absorb the energy of high flows, reducing the potential for

resuspension of previously deposited sediments in larger storms. Since the flow from the hydraulic jump on the apron immediately enters the pool created by the next check dam, flow velocities remain quite low throughout, even in extreme events.

Using check dams, many of the benefits of an off-line layout can be provided without the need for flow-splitting devices and the loss of space required for an off-line facility. The BMP design module of DURMM described in Appendix A provides estimates for storage as the check dams fill up. A detail of the typical check dam elevation and profile, including grade drop structures, is displayed in Appendix B.

10.4 INFILTRATING BIOFILTRATION SWALE BMPs

A further important benefit inherent to bioswales is their ability to incorporate an infiltration trench along the center. Since filtration occurs down the sides and along the check dam, by the time runoff flows over the check dam into the stone apron it is already well filtered, so contamination of groundwater by metals is less likely. (However, nitrate loads could still be a problem.) Designing the stone apron as an extension of the infiltration trench, filtered runoff from the upslope section will preferentially fill up the infiltration trench before flowing along the swale. Unfiltered runoff into the next section of the swale has to pass all the way down to the next check dam before it is infiltrated at the next apron.

Infiltration performance is addressed by the infiltration trench routine discussed in Chapter 8. The BMP design module of DURMM described Exhibit A presents the calculations of storage and infiltration as the trench fills up and discharges from storm to storm. Details of the typical bioswale incorporating an infiltration trench are displayed in Appendix B. Design standards, construction specifications and details of the infiltration trench design are set forth the Green Technology Standards, Specifications and Details, Appendix B.

In this manner, a bioswale incorporating a series of cascading dams and infiltration trenches can accomplish remarkable results in terms of filtration, infiltration, streambank protection, and peak flow controls, all in one BMP. As a linear feature roughly 18 feet wide, the multipurpose bioswale is not that much wider than the landscaped islands already required for parking lots. Landscaped with trees along the side slopes, bioswales can be easily integrated into the overall site design without excessive loss of usable ground. It is important though, that enough light remains to permit a dense grass cover. At maturity, the trees will provide enough shade to reduce elevated temperatures in swale runoff. Combined with the savings of land as well as expense from not having to construct a structural BMP, this integrated approach is actually more cost effective, not to mention far healthier to the environment.

CHAPTER 11 BIORETENTION BMPs

11.1 BIORETENTION BMP BACKGROUND

The preceding vegetative filtering BMPs are the first line of defense in the nonstructural BMP approach. If thoughtfully incorporated into the site design, biofiltration BMPs can reduce pollutants to acceptable levels by themselves. However, in more intense urban development, where space may be at a premium and/or the runoff EMCs are elevated, additional nonstructural BMPs are necessary.

Bioretention BMPs are a very effective recent development in BMP design. These "living filters" comprise an organic sandy loam at least two feet deep, covered with a layer of mulch and vegetation. Generally located off-line in small depressions designed to intercept the quality storm volume, filtering occurs as runoff percolates through the mulch and soil matrix into an underdrain. Where infiltration rates are high, exfiltration from the facility can replace the need for underdrains. Bioretention BMPs are particularly effective for removing metals and TSS, and phosphorus to a lesser extent. Nitrogen reduction is more variable and less effective (Coffman and Winogradoff, 1998).

Since much of the captured runoff is released by evapotranspiration, bioretention facilities provide mass reductions even greater than that removed by their reduction in EMCs. Underdrain effluent from bioretention facilities can be up to 12° C cooler than the temperature of incoming runoff (Davis and others, 2000b), providing excellent thermal protection to the receiving waters. These aspects of bioretention facilities make them particularly attractive as a nonstructural BMP, particularly for intensively used paved areas.

Depending upon the infiltration rates of the soil matrix, bioretention facilities are typically sized to handle a hydraulic loading rate of 1.5 inches per hour. Since hydraulic loading rates control facility sizing, it is important that the facility be located to capture the most polluted runoff from impervious areas, with as few contributions from pervious areas as is possible. Depending upon the *CN* of the contributing watershed, these factors suggest that bioretention facilities be sized at roughly 5% of the drainage area.

If the landscaping is not flood tolerant, surface ponding should be restricted to less than a foot at most, and surface drainage should occur within hours after the rainfall ends (Coffman and Winogradoff, 1998). This is necessary to ensure that such landscaping will bear the occasional immersion. Therefore, bioretention BMPs should be located off-line so extended detention surcharge from larger storms is not a potential problem. However, if facultative wetland species are used, a greater range of flooding regimes is acceptable. Not only can such plants tolerate greater depths for longer times, they can also function in hydrologic conditions that approach constant saturation. For these reasons, DURMM recommends facultative plants for bioretention facilities. As discussed below, denitrifying bioretention facilities require facultative landscaping.

Filtration and adsorption are the two mechanisms of pollutant reduction in bioretention. Adsorption is particularly effective in removing the soluble metals that are not susceptible to filtration. As such, the proper composition of the soil matrix of the facility is very important. Sometimes, additional fines such as sand are needed to ensure adequate percolation rates, but sand has a very low CEC, so soil adsorption potential is low. If there is too much sand, efficiency is reduced (Davis and others 2000b), because either adsorption is too low or infiltration rates are too high. Therefore, the proportion of sand should be only what is needed to provide adequate infiltration, with the balance in an organic soil/compost mix.

11.2 BIORETENTION BMP RESULTS

If the infiltration rates are adequate, laboratory experiments suggest that topsoil is an excellent medium, as organic soils have 15 times the CEC of mineral soils on a weight basis (Brady, 1990). Column tests indicate that dissolved copper, zinc, and lead all have similar adsorption rates within a topsoil matrix. The mulch layer is also particularly important, providing adsorption coefficients three times that of the soil matrix (Davies and others, 2000a). To ensure adequate infiltration rates, the organic soils should be augmented with fines so the final mix is less than 15% clay. For best results, the pH should be close to neutral so zinc adsorption is maximized.

Recently, Davis and others (2000a, 2000b) published two studies of bioretention performance. The first report was a laboratory study of two pilot bioretention boxes comprising a sandy loam topsoil with 0.6% organic matter and a CEC of 29 meq/kg, relatively low values for optimal adsorption. A surface layer of shredded hardwood mulch was interspersed with several junipers to replicate field conditions as accurately as possible. Depths of the two boxes were 2.5 and 3.5 feet, with sample ports at intermediate depths to extract effluent as it passes through the soil matrix (Davis and others, 2000a).

A synthetic urban runoff “cocktail” was used to ensure uniform input concentrations. Applied at 4.1 cm/hr for 6 hours, this application rate was designed to represent runoff from a rainfall event of 1.5 cm over a drainage area with a runoff coefficient of 0.8 and 20 times the surface area of the facility. While this application volume is only 30% of the quality storm depth of 5.0 cm recommended in Chapter 4, it is applied over 6 hours instead of the 24-hour distribution of the quality event. If the first 10 hours of the latter event are essentially dry, this represents an average rainfall rate of 0.36 cm/hr over 14 hours, similar to the 0.25 cm/hr rate used in the experiment.

Nonetheless, surface ponding up to 7 inches deep was observed once the facilities had become saturated. While the shallower box percolated at 1 to 2 cm/hr, infiltration rates in the deeper box were as low as 0.3 to 0.4 cm/hr, and ponding remained for roughly two days after application. However, drainage from the boxes was restricted to the small diameter observation port, instead of being allowed to freely drain downward into an underlying soil or underdrain, as would be the case in the field, so these slow rates may be an artifact of the experimental design. As both boxes were comprised of identical soils, this also highlights the inherent variability of soils, suggesting that the proper composition of, and low compaction, of a thoroughly mixed soil matrix is essential.

Results from the effluent sampling in the pilot study are displayed in Table 11-1. Output concentrations are calculated as the average reduction percentage times input concentration. Except in the case of phosphorus, ammonia, and nitrate, reductions were high in all sampling ports. Applied as soluble P, the phosphorus reductions were not nearly as high in the upper ports as that seen in the output effluent. Phosphorus reductions were primarily due to adsorption. This is the primary relationship involved in determining the required depth of the facility, as depths of less than 2 feet provided substantially less reduction in phosphorus levels.

In this analysis, organic N is allocated as the residual of TKN less ammonia. Organic N reductions varied from 84% to –64%, suggesting minimal reductions on average. Whether dissolved or particulate, the widely varying reductions of organic N concentrations do not seem to follow the trends discussed in Chapter 3, where concentrations of organic N are relatively low in base flow, even where they are high in surface runoff. As a substantial component of urban runoff, organic N responses to bioretention are a need for future research. Nitrate reduction was actually negative in the upper ports, with minor efficiency ratios overall. Negligible reductions in ammonia levels were also observed in the upper ports, but since ammonia is adsorbed onto soils, reductions had increased substantially by the bottom. These results suggest that organic N and ammonia captured in the upper layers are transformed into nitrate between tests (Davies and others, 2000a), a conclusion others have reached for the filtration results discussed above.

Analysis of the filter matrix indicated that the mulch retained very high concentrations of metals compared to the soils. However, since mulch is a much smaller proportion than soils by weight, it retained only 20% of the applied metals, with the balance remaining in the soils. This suggests that regular replacement of the mulch layer would improve performance and useful life. Accumulation rates in the soils indicated a useful life of nearly 60 years before the soils matrix becomes saturated, or longer if the mulch is replaced regularly.

Table 11-1: Input and Output EMCs and Efficiency Ratios in Pilot Bioretention Tests

PARAMETER	NO3	NH4	TKN	ON	SP	Zn	Pb	Cu
AVERAGE INPUT CONCENTRATION (mg/l)								
SMALL		1.20	3.50	2.30	0.44	0.600	0.061	0.140
LARGE	0.34	2.40	2.80	0.40	0.52	0.590	0.054	0.064
AVERAGE OUTPUT CONCENTRATION (mg/l)								
SMALL		0.48	0.88	0.40	0.13	<0.025	<0.002	<0.002
LARGE	0.26	0.50	0.90	0.39	0.10	<0.025	<0.002	0.005
EMC REDUCTION								
SMALL		60%	75%	83%	71%	>97%	>98%	98%
LARGE	24%	79%	68%	2%	81%	>98%	>98%	92%

Following the pilot study, the same research team studied field performance of two bioretention facilities in Maryland. The Greenbelt facility constructed in 1992 incorporated well-established grass and shrubs on a mostly soil matrix. The Landover facility constructed in 1998 had less landscaping on a filter media of 50% sand, 20-30% topsoil, and 20-30% leaf mulch. Both facilities were tested with the same synthetic runoff at the same application rate as the pilot

tests. Antecedent moisture conditions were favorable for infiltration (Davies and others, 2000b). Results are displayed in table 11-2.

Note that the Greenbelt facility performed as well as the pilot studies, all of which used soils as the media. However, the Landover facility had poorer performance in terms of metals reduction. The authors note that even though the Landover facility had a good mulch layer, which should have effectively removed metals, observed reductions were less than optimal. The possibility of preferential flow through the porous media was discounted since nutrient reductions were similar in each test. However, they also noted that the Greenbelt facility had a higher soil to fines ratio, increasing the potential for adsorption. Since all of the better performing facilities had a topsoil media, this suggests that the mixture used in the Landover facility could be improved. This is an important issue for future research.

Table 11-2: Input and Output EMCs and Efficiency Ratios in Field Bioretention Tests

PARAMETER	NO3	NH4	TKN	ON	SP	Zn	Pb	Cu
INPUT CONCENTRATION (mg/l)								
GREENBELT	0.33	2.60	3.5	0.90	0.52	0.53	0.042	0.066
LANDOVER	1.30		6.9		0.83	1.10	0.054	0.120
OUTPUT CONCENTRATION (mg/l)								
GREENBELT	0.28	0.22	1.65	1.47	0.19	<0.025	<0.002	<0.002
LANDOVER	1.10		2.3		0.11	0.39	0.016	0.069
EMC REDUCTION								
GREENBELT	16%	92%	52%	-64%	65%	>95%	>95%	97%
LANDOVER	15%		67%		87%	64%	70%	43%

Hsieh and Davis (2202) recently reported results for a subsequent study of bioretention in columns. In this study, columns were filled with a variety of different media and the resulting reduction efficiencies measured. Removal of oil and grease was excellent (greater than 99 percent) as was the removal of lead, which was adsorbed onto TSS, that was also removed at high rates. Nitrate removal was quite low (1 percent to 43 percent). Sand performed very poorly for nitrate, while mulch performed the best.

Phosphorus removal was variable, ranging from 5 percent to over 80 percent. It was noted that mulch dominated columns had poor removal rates and slow infiltration rates, while sand had 80 percent removal and high infiltration rates. For this reason, mulch is not considered a good medium for phosphorus removal. Since it also decomposes rapidly, mulch is not recommended as part of the bioretention media, unless nitrate removal is identified as a problem, and mulch can be reliably added on a regular basis to replace that lost by decomposition.

This relationship results in a counterintuitive trend where the better the infiltration rate was, the better the removal rates were. Even though sand removed phosphorus at high rates in this study, it seems unlikely that it would continue to perform at such high rates once its CEC sites become saturated. Dissolved orthophosphate would then pass through unimpeded. For this reason, proportions of sand over 90 percent are not recommended.

11.3 BIORETENTION BMP KINETICS

The preceding discussion demonstrates the excellent potential of bioretention facilities for removing metals, soluble P, and ammonia from urban runoff. Combining the better results from Tables 11-1 and 11-2, Table 11-3 sets forth the irreducible concentrations and maximum reduction percentage possible from bioretention facilities. Since DURMM does not account for N transformations, the maximum nitrate efficiency ratio is 20%, and organic N reductions are estimated at 25%. Although there were no measurements of TSS and particulate P reductions, the metals reduction percentage suggest similar reductions for TSS. Since some of the particulate P will undergo transformations to soluble forms, its net reductions would be less than TSS but more than soluble P. It is thus estimated at 85% in this analysis.

At a given depth, there does not seem to be any design factors that provide incremental changes in efficiency ratios. Instead, two thresholds should be met in all designs: a minimum soil media depth of 2.5 feet (76 cm) for optimal phosphorus reduction; and a maximum loading rate of 1.5 inches/hour over a 12 hour period for a one inch event. Additional research may provide data to ascertain if flushing effects occur at higher rates. Even though one pilot facility had ponding problems with a 6-hour period, this is likely to be due to drainage from the facility being restricted to the small diameter observation port. Since there were no problems with ponding on the field studies, the design loading rate and 12 hour application period seems reasonable. As discussed above, the proper composition of the filter media is essential.

As Table 11-3 indicates, bioretention facilities can provide excellent reductions in metals, phosphorus and TSS. However, since nitrate can comprise much of the total N in urban runoff, the typical aerobic bioretention facility could still release unacceptably high levels of nitrate where the receiving waters are nitrate limited.

Table 11-3: Maximum Efficiency Ratios and Minimum EMCs for Bioretention Facilities

POLLUTANT	TSS	PP	SP	ON	NH4	NO3	CU	ZN
MAXIMUM REDUCTION	97%	95%	85%	85%	90%	24%	99%	99%
MINIMUM EMC (mg/l)	3	0.02	0.10	0.35	0.20	0.25	0.002	0.002

The BMP design module of DURMM described in Appendix A provides estimates on bioretention facility performance as a function of loading rate, pollutant levels, length, width, and side area. Infiltration performance is addressed by the infiltration trench routine discussed in Chapter 8. The BMP design module of DURMM described Exhibit A presents the calculations of storage and infiltration as the facility fills up and discharges from storm to storm. Details of the typical infiltration trench are displayed in Appendix B. Design standards, construction specifications and details of the bioretention facility design are set forth the Green Technology Standards, Specifications and Details, Appendix B.

11.4 DENITRIFYING BIORETENTION

To address the issue of nitrate loads, members of Davis team reported results from column tests designed to provide nitrate removal by denitrification (Kim and others, 2000). Experiments were designed to screen out the best carbon/electron source from among the candidates alfalfa, newspaper, leaf mulch, sawdust, wood chips, and wheat straw. An inorganic electron donor, sulfur was also evaluated in terms of two different particle sizes, 0.6 to 1.18 mm and 2 to 2.36 mm. Limestone was added to buffer the acid production from sulfur oxidation. 40 cm high by 6.4 cm diameter columns with these media were inoculated with secondary effluent from an activated sludge plant for 2 days. Anoxic synthetic runoff was then introduced at 4 cm/hr. Removals were then measured after 35 to 40 days of retention.

Over this period, newspaper and wood chips were the best organic electron sources, providing nearly complete denitrification without other adverse effects. Leaf mulch was less effective at 60% reduction, while alfalfa released odors, turbidity, and 2-3 mg/l TKN. Wheat straw also had high levels of turbidity and TKN, while wood chips and sawdust had low turbidity. However, sawdust had lower reductions in nitrate levels than the wood chips and newspaper, which approached 100% reduction in nitrate levels.

Of the sulfur experiments, the smallest particle size performed best, with nitrate reductions close to 92%, while the larger particles reduction was 33%. The better results with the smaller particle sizes were attributed to their more than doubled surface to volume ratio. However, there is some concern that some of the nitrate is leaving the system as nitrite. Longer retention times were thought to lower the nitrite levels.

The TKN release from alfalfa and wheat straw was attributed to the relatively low C:N ratio in these materials, which tends to promote conversion of organic N to ammonia (ammonification or mineralization). The authors also noted that sulfate-reducing bacteria could reduce nitrate to ammonia under anaerobic conditions when there is a high carbon to nitrate ratio, which would conserve total N. It was thought that this effect would decline over time.

The hydraulic loading rate and time span of the experiment need to be evaluated in terms of their applicability to urban runoff events. The ratio of event volume to interevent interval controls average runoff loading rates during field conditions. However, the 35 to 40 day time span of the experiment exceeds typical intervals between runoff events by a factor of 10. No data is presented for reductions in nitrate levels at the shorter intervals of interest in BMP design (typically 2-4 days between events). Rate kinetics may be inferred from the sulfur experiments where the extent of denitrification seems proportional to surface area. The decline in reduction with larger size particles suggests that they should be more effective if given a longer retention time; conversely, the smallest particles would be less effective at a shorter time frame. If this were the case, sulfur at any size would seem to be ineffective at the shorter time periods of interest.

Assuming 40% in pore space, 16 cm of runoff would fill the columns in roughly 4 hours. Containing some 500 cc of runoff at a nitrate concentration of 2.0 mg/l, the total load of nitrate N would be 1.0 mg. Normalized by the column area of 0.0032 m^2, this represents a load of 3.1

kg/ha. Given a 16:1 ratio of runoff to rainfall similar to that used in the previous pilot and field experiments, this implies a total rainfall volume of 1 cm, well below the 5.0 cm recommended in Chapter 4. At an annual precipitation capture of 35 cm, total annual denitrification would be roughly 35 times 3.1 kg/ha, or 109 kg/ha/yr.

The likely effects of higher loading rates, N transformations, and shorter retention time can be clarified by analysis of the literature on N processes in the landscape. The required annual denitrification of 109 kg/ha/yr is similar to the average annual denitrification rates in forest soils amended with nitrate (Groffman and Tiedje, 1989). Ammonia in streamflow from agricultural areas is less than 2% of total N (Correll and others, 1994), thus the sulfate reduction pathway does not seem to occur in the field. In agricultural fields where roughly 2% of the organic N pool is mineralized per year, high C:N ratios in cover residues substantially reduce nitrate losses (Baker and Senft, 1992). These and other field studies confirm that high C:N ratios determine the potential for denitrification (Drury and others, 1991, and many others). A similar relationship is likely to exist for the column experiments.

As to the retention time necessary for complete denitrification, denitrification rates in pasture soil cores under conditions optimal for denitrification have been measured as high as 5 kg/ha/day (Colburn, 1993). Normalized over column area, this rate corresponds to 67 µg/hr. However, nitrate concentrations in the soil cores were as high as 24 mg/l, 12 times the 2 mg/l used in the columns. Colburn (1993) proposed the following equation for estimating denitrification rate D as a function of nitrate concentration N, temperature T and soil moisture content W:

$$D = Ne^{(0.1W+0.1T-8.3)} \tag{37}$$

Assuming that the values of T and W in the soil cores represent field conditions typical for bioretention facilities, denitrification rates are then directly proportional to nitrate concentrations. This implies that the rates in the columns would be 1/12 of that observed in the field cores, or around 6 µg/hr. Over a 72 hour interevent interval, the amount of nitrate N reduced at this rate would be 0.43 mg, or 43% of the applied N.

Given that nitrate concentrations in urban runoff are typically lower than 2 mg/l, the removal rate in soils under field conditions would be even lower. However, nitrate reduction in soils is localized to microsites within the soil profile (Parkin, 1987), whose activities dominate the denitrification response of soil cores (Christensen and others, 1990). Since the column media is optimized for nitrate reduction throughout, its removal rate per unit area should be considerably higher than soils. Therefore, the potential for reducing nitrate in bioretention facilities using a sawdust media appears to be quite promising, although complete denitrification may not occur between closely spaced large events. As indicated in the pilot and field studies, there does appear to be some nitrate reduction occurring in the topsoil bioretention media.

Kim and others (2000) propose a denitrifying cell below a 2' bioretention layer, with denitrified effluent discharged from the bottom as it is surcharged from above. However, given a permanently saturated zone at the bottom surface of the bioretention media, capillary suction would induce moisture into the bioretention layer above. This would induce anaerobic

conditions to persist for several days after a storm event, or even weeks during winter. Under such circumstances, nitrification of ammonia would be inhibited, reducing potential reduction in total N by the denitrification layer.

To avoid capillary suction, a capillary fringe barrier in the form of several inches of coarse sand would be required between the bioretention and denitrification layers. The required volume of the denitrifying layer should be equal to the design event runoff volume, less soil storage capacity in the bioretention layer. This permits time for denitrification of this volume to occur during the average interevent interval of around three days. Given an average of 20% of the media volume in macropores, a bioretention layer 60 cm deep would provide for 12 cm of storage. At a 40% void ratio, 40 cm of runoff (assuming the same ratio of impervious area to biofiltration area as used above; equal to 16 times the 2.5 cm design event), less 12 cm, would require a denitrification layer 70 cm deep. Design depths would be adjusted in relation to the volume of runoff divided by surface area.

The preceding discussion on denitrification in agricultural soils raises an interesting possibility for the design of bioretention facilities. Since soils denitrify at high rates when saturated, the bioretention layer could incorporate fine sulfur and sawdust as the fines fraction with a topsoil adsorption fraction, overlaid upon a denitrifying layer of saturated sawdust. During saturated conditions, the bioretention soil layer would also denitrify nitrate from incoming runoff and that which has been nitrified from organic N. This would improve interevent efficiency ratios, and perhaps reduce the required volume of the denitrifying layer. Facultative plant species would be required since the root zone would cycle between aerobic and anaerobic conditions, which would stress exclusively upland plant species.

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New York State

Stormwater Management Design Manual

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Forward

On November 16, 1990, the initial federal NPDES stormwater regulations were established. These required certain industrial activities to obtain permit authorization in order to discharge site runoff. DEC, as the NPDES permit issuing authority in this State, promulgated two SPDES general permits for stormwater runoff in 1993, GP-93-05 for the more traditional industrial sites and GP-93-06 for construction sites.

GP-93-06 requires that an operator who is covered under the permit implement a stormwater pollution prevention plan (SWPPP) that has been developed for the particular site. The minimum components of the SWPPP include a variety of requirements, including both structural and non-structural practices, inspections, contractor certifications, compliance with narrative water quality standards and other conditions. The attention, concern and efforts being directed at stormwater management practices at construction sites are constantly growing as new technologies emerge and experiences with older ones is gained. Additionally, construction site runoff is gaining wider attention as the federal NPDES stormwater program progresses. There is an ever-growing need to disseminate information concerning practices that are acceptable in New York.

The scope of attention is broadening on a national scale to smaller construction sites as evidenced by the APhase 2" stormwater regulations. Phase 2 lowers the threshold to one or more acres of disturbance, the runoff from which requires NPDES authorization for discharges to surface waters. Permitting will be required beginning on March 10, 2003. Its becoming more evident as time passes that there is a greater need for stormwater management practices that are technically effective and viable in New York State. "Spreading the word" to engineers, municipal officials, and the general public is crucial to the success of DECs efforts in implementing the federal NPDES stormwater regulations and reducing incidences of water quality impairments.

Accordingly, permits that are issued in the future for construction site runoff will rely heavily on this new manual and the practices that are described therein. When properly designed and maintained, the implementation of these practices will become an important component of New Yorks overall stormwater management program. Adherence to the criteria and practices described will better ensure a successful implementation of stormwater controls and compliance with the SPDES general permit(s) issued for construction site runoff and maintaining water quality.

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Preface

The New York State Stormwater Design Manual is prepared to provide standards for the design of the Stormwater Management Practices (SMPs) to protect the waters of the State of New York from the adverse impacts of urban stormwater runoff. This manual is intended to establish specifications and uniform criteria for the practices that are part of a Stormwater Pollution Prevention Plan (SWPPP).

This manual is intended primarily for engineers and other professionals who are engaged in the design of stormwater treatment facilities for new developments. Users are assumed to have a background in hydrology, hydraulics, and runoff and pollutant load computation. It is not intended to be a primer on any of these subjects. The manual may also be used by reviewing authorities to assess the adequacy of SWPPPs.

The manual is limited to the design of structures. It does not address the temporary control of sedimentation and erosion from construction activities, nor the development of Stormwater Pollution Prevention Plans. The reader is referred to the documents *"Reducing the Impacts of Runoff from New Development"* and *"New York State Guidelines for Urban Erosion and Sediment Control"* for guidance with these subjects.

Recommended Standards, consisting of proven technology, are intended to serve as a guide in the design and preparation of plans and specifications for Stormwater Management Practices, to suggest limiting values for items upon which an evaluation of such plans and specifications may be made by the reviewing authority, and to establish, as far as practicable, uniformity of practice. As statutory requirements and legal authority pertaining to stormwater management are not uniform across the State, and since conditions and administrative procedures and policies also differ, the use of these Standards must be adjusted to these variations.

The terms "shall" and "must" are used where the practice is sufficiently standardized to permit specific delineation of requirements or where safeguarding of the public health justifies such definite action. Other terms, such as "should," "recommend," and "preferred," indicate desirable procedures or methods, with deviations subject to individual consideration.

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Chapter 1

Introduction

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Chapter 1: Introduction to the Manual

Section 1.1 Purpose of the Manual

The purpose of this manual is threefold:

1. To protect the waters of the State of New York from the adverse impacts of urban stormwater runoff
2. To provide design guidance on the most effective stormwater management practices (SMPs) for new development sites
3. To improve the quality of SMPs constructed in the State, specifically in regard to their performance, longevity, safety, ease of maintenance, community acceptance and environmental benefit

Section 1.2 How to Use the Manual

The *New York State Stormwater Management Design Manual* provides designers a general overview on how to size, design, select and locate SMPs at a development site to comply with State stormwater performance standards. The manual also contains appendices with more detailed information on landscaping, SMP construction specifications, step–by- step SMP design examples and other assorted design tools. The manual is organized as follows:

Chapter 2. Impacts of Stormwater Runoff

This chapter examines the physical, chemical, and biological effects of unmanaged stormwater runoff on the water quality of local streams and waterbodies. This brief overview provides the background for why the stormwater management manual is needed and how the new criteria will help local communities meet water quality standards.

Chapter 3. Permit Requirements

This chapter explains the permitting process for stormwater management facilities, and what permits may be necessary to construct these facilities.

Chapter 4. Sizing Criteria

This chapter explains sizing criteria for water quality, channel protection, overbank flood control, and extreme flood management in the State of New York. The chapter also outlines the basis for design calculations.

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Chapter 5. List of Practices

This chapter briefly outlines the five groups of acceptable structural SMPs that can be used to meet water quality sizing criteria. The following are acceptable SMP groups:

- Stormwater Ponds
- Stormwater Wetlands
- Infiltration Practices
- Filtering Systems
- Open-Channel Practices

The chapter also explains the criteria for addition of a new practice to the list of acceptable SMPs, and provides fact sheets for some practices that are not on the list of practices, but can be used to provide supplemental treatment.

Chapter 6. Performance Criteria

This chapter presents specific performance criteria and guidelines for the design of the five groups of structural SMPs. The performance criteria for each group of SMPs are based on six factors:

- Feasibility
- Conveyance
- Pretreatment
- Treatment
- Landscaping
- Maintenance

In addition, the chapter provides guidance on design adjustments that may be required to ensure proper functioning in cold climates.

Chapter 7. Guide to SMP Selection and Location

This chapter presents guidance on how to select the best SMP or group of practices at a development site, as well as environmental and other factors to consider when actually locating each SMP. The chapter contains five comparative matrices that evaluate SMPs based on the following factors:

- Land Use
- Physical Feasibility
- Watershed /Regional Factors
- Stormwater Management Capability
- Community and Environmental Factors

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Chapter 7 is designed so that the reader can use the matrices in a step-wise fashion to identify the most appropriate SMP or group of practices to use at a site.

Chapter 8. Design Examples

Design examples are provided to help designers and plan reviewers better understand the new criteria in this manual. The step-by-step design examples demonstrate how the new stormwater sizing criteria are applied, and some of the design procedures and performance criteria that should be considered when planning a new stormwater management practice.

Stormwater Design Appendices

The appendices contain the technical information needed to actually design, landscape and construct an SMP. There are a total of thirteen appendices:

Appendix A. The Simple Method to Calculate Urban Stormwater Loads

This appendix describes a fast and effective way to calculate stormwater runoff pollutant loads. Using impervious cover estimates based on land use, the Simple Method calculates annual runoff volume as a product of annual rainfall, and a runoff coefficient (Rv). Annual runoff can then be combined with readily available stormwater pollutant concentrations to provide a quick estimate of annual pollutant loads. The appendix also discusses the limitations of the Simple Method.

Appendix B. Design Tools

The accurate calculation of stormwater flows may require modifications to some methods to account for small storm hydrology. This appendix provides methodologies to calculate the storage requirements for the channel protection flow event, and a methodology to calculate the peak flow from the small water quality storm.

Appendix C. SMP Construction Specifications

Good designs only work if careful attention is paid to proper construction techniques and materials. Appendix C contains detailed specifications for constructing ponds, infiltration practices, filters, bioretention areas and open channels.

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Appendix D. Infiltration Testing

This appendix describes methodologies to test soil infiltration rates, in order to determine if infiltration is an acceptable option on site.

Appendices E-G. Checklists

These three appendices provide example checklists that can be used to assist in the plan review, construction, and operation and maintenance of an SMP.

Appendix H. Landscaping Guidance

Good landscaping can often be an important factor in the performance and community acceptance of stormwater SMPs. Appendix H also includes tips on how to establish more functional landscapes within stormwater SMPs, and contains an extensive list of trees, shrubs, ground covers, and wetland plants that can be used to develop an effective and diverse planting plan.

Appendix I. Cold Climate Sizing Example

This appendix supplies guidance on sizing SMPs to account for cold climate conditions that might hamper performance. Example sizing designs that illustrate how to incorporate cold climate criteria into SMP design are also included.

Appendix J. Geomorphic Assessment

This appendix provides a description of the Distributed Runoff Control (DRC) methodology to size stormwater practices based on downstream geomorphic characteristics.

Appendix K. Miscellaneous Details

The designs of various structures previously discussed in the manual are presented in Appendix K. These structures help enhance the performance of stormwater management practices, especially in cold climates. Schematics of structures such as weirs, trash racks, and observation wells are included.

Appendix L. Critical Erosive Velocities

This appendix provides data on critical erosive velocities for soil and grasses.

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Section 1.3 Symbols and Acronyms

As an aid to the reader, Table 1.1 outlines the symbols and acronyms that are used throughout the text. In addition, a glossary is provided at the end of this volume that defines the terminology used in the text.

Table 1.1 Key Symbols and Acronyms Cited in Manual

Symbol	Definition	Symbol	Definition
A	drainage area	Qf	extreme flood storage volume
A_f	filter bed area	Qi	peak inflow discharge
A_s	surface area, sedimentation basin	Qo	peak outflow discharge
cfs	cubic feet per second	Qp	overbank flood control storage volume
Cp_v	channel protection storage volume	q_p	water quality peak discharge
CMP	corrugated metal pipe	qu	unit peak discharge
CN	curve number	SMP	stormwater management practice
Cp_v-ED	extended detention of the 1 year post-development runoff	R_v	volumetric runoff coefficient
d_f	depth of filter bed	R/W	right of way
du	dwelling units	SD	separation distance
DOT	Department of Transportation	SPDES	State Pollutant Discharge Elimination System
DPW	Department of Public Works	t_c	time of concentration
ED	extended detention	t_t	time to drain filter bed
f_c	soil infiltration rate	TR-20	Technical Release No. 20 Project Formulation-Hydrology, computer program
fps	feet per second	TR-55	Technical Release No. 55 Urban Unit Hydrology for Small Watersheds
h_f	head above filter bed	TSS	total suspended solids
HSG	hydrologic soil group	Vr	volume of runoff
Ia	initial abstraction	Vs	volume of storage
I	percent impervious cover	Vt	total volume
K	coefficient of permeability	Vv	volume of voids
NYSDEC	New York State Department of Environmental Conservation	WQ_v	water quality storage volume
NRCS	Natural Resources Conservation Service	WQ_v-ED	12 or 24 hour extended detention of the water quality volume
P	precipitation depth	WSEL	water surface elevation

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Chapter 2

Impacts of New Development

New York State Stormwater Management Design Manual

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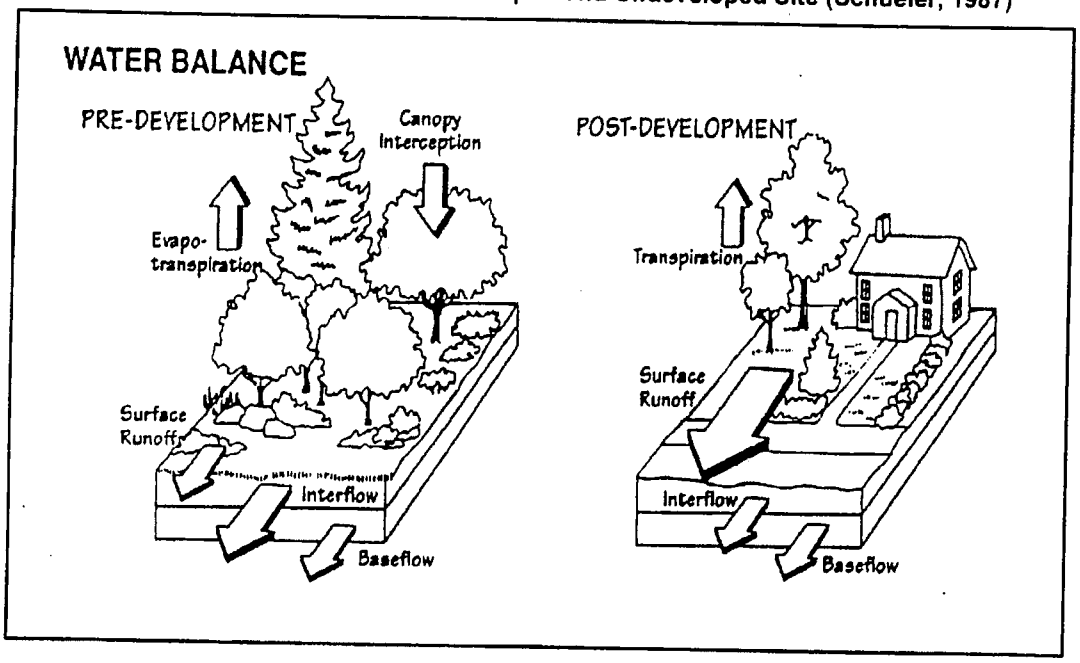
Urban development has a profound influence on the quality of New York's waters. To start, development dramatically alters the local hydrologic cycle (see Figure 2.1). The hydrology of a site changes during the initial clearing and grading that occur during construction. Trees that had intercepted rainfall are removed, and natural depressions that had temporarily ponded water are graded to a uniform slope. The spongy humus layer of the forest floor that had absorbed rainfall is scraped off, eroded or severely compacted. Having lost its natural storage capacity, a cleared and graded site can no longer prevent rainfall from being rapidly converted into stormwater runoff.

Figure 2.1 Water Balance at a Developed and Undeveloped Site (Schueler, 1987)



The situation worsens after construction. Rooftops, roads, parking lots, driveways and other impervious surfaces no longer allow rainfall to soak into the ground. Consequently, most rainfall is directly converted into stormwater runoff. This phenomenon is illustrated in Figure 2.2, which shows the increase in the volumetric runoff coefficient (R_v) as a function of site imperviousness. The runoff coefficient expresses the fraction of rainfall volume that is converted into stormwater runoff. As can be seen, the volume of stormwater runoff increases sharply with impervious cover. For example, a one-acre parking lot can produce 16 times more stormwater runoff than a one-acre meadow each year (Schueler, 1994).

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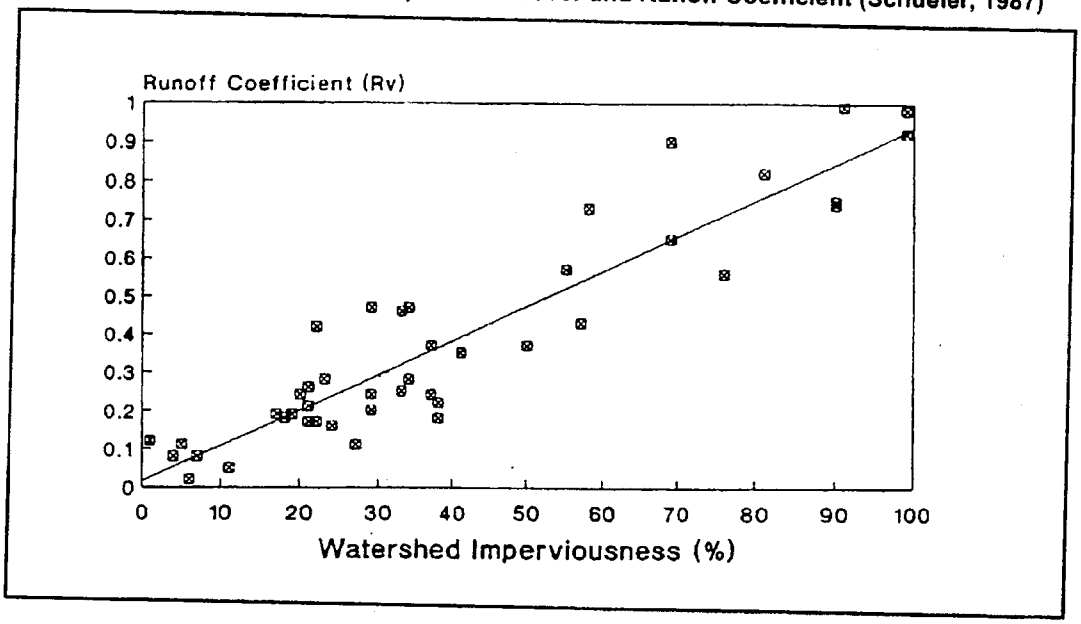
The increase in stormwater runoff can be too much for the existing drainage system to handle. As a result, the drainage system is often "improved" to rapidly collect runoff and quickly convey it away (using curb and gutter, enclosed storm sewers, and lined channels). The stormwater runoff is subsequently discharged to downstream waters, such as streams, reservoirs, lakes or estuaries.

Figure 2.2 Relationship Between Impervious Cover and Runoff Coefficient (Schueler, 1987)



Section 2.1 Declining Water Quality

Impervious surfaces accumulate pollutants deposited from the atmosphere, leaked from vehicles, or windblown in from adjacent areas. During storm events, these pollutants quickly wash off, and are rapidly delivered to downstream waters. Some common pollutants found in urban stormwater runoff are profiled in Table 2.1.

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Table 2.1 National Median Concentrations for Chemical Constituents in Stormwater

Constituent	Units	Concentration
Total Suspended Solids[1]	mg/l	54.5
Total Phosphorus[1]	mg/l	0.26
Soluble Phosphorus[1]	mg/l	0.10
Total Nitrogen[1]	mg/l	2.00
Total Kjeldhal Nitrogen[1]	mg/l	1.47
Nitrite and Nitrate[1]	mg/l	0.53
Copper[1]	ug/l	11.1
Lead[1]	ug/l	50.7
Zinc[1]	ug/l	129
BOD[1]	mg/l	11.5
COD[1]	mg/l	44.7
Organic Carbon[2]	mg/l	11.9
PAH[3]	mg/l	3.5*
Oil and Grease[4]	mg/l	3.0*
Fecal Coliform[5]	col/100 ml	15,000*
Fecal Strep[5]	col/ 100 ml	35,400*
Chloride (snowmelt)[6]	mg/l	116

* Represents a Mean Value

Source:

1: Pooled NURP/USGS (Smullen and Cave, 1998)
2: Derived from the National Pollutant Removal Database (Winer, 2000)
3: Rabanal and Grizzard 1995
4: Crunkilton *et al.* (1996)
5: Schueler (1999)
6: Oberts 1994

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Sediment (Suspended Solids)

Sources of sediment include washoff of particles that are deposited on impervious surfaces and erosion from streambanks and construction sites. Streambank erosion is a particularly important source of sediment, and some studies suggest that streambank erosion accounts for up to 70% of the sediment load in urban watersheds (Trimble, 1997).

Both suspended and deposited sediments can have adverse effects on aquatic life in streams, lakes and estuaries. Turbidity resulting from sediment can reduce light penetration for submerged aquatic vegetation critical to estuary health. In addition, the reflected energy from light reflecting off of suspended sediment can increase water temperatures (Kundell and Rasmussen, 1995). Sediment can physically alter habitat by destroying the riffle-pool structure in stream systems, and smothering benthic organisms such as clams and mussels. Finally, sediment transports many other pollutants to the water resource.

Nutrients

Runoff from developed land has elevated concentrations of both phosphorus and nitrogen, which can enrich streams, lakes, reservoirs and estuaries. This process is known as eutrophication. Significant sources of nitrogen and phosphorus include fertilizer, atmospheric deposition, animal waste, organic matter, and stream bank erosion. Another nitrogen source is fossil fuel combustion from automobiles, power plants and industry. Data from the upper Midwest suggest that lawns are a significant contributor, with concentrations as much as four times higher than other land uses, such as streets, rooftops, or driveways (Steuer *et al.*, 1997; Waschbusch *et al.*, 2000; Bannerman *et al.*, 1993).

Nutrients are of particular concern in lakes and estuaries, and are a source of degradation in many of New York's waters. Nitrogen has contributed to hypoxia in the Long Island Sound, and is a key pollutant of concern in the New York Harbor and the Peconic Estuary. Phosphorus in runoff has impacted the quality of a number of New York natural lakes, including the Finger Lakes and Lake Champlain, which are susceptible to eutrophication from phosphorus loading. Phosphorus has been identified as a key parameter in the New York City Reservoir system. The New York City DEP recently developed water quality guidance values for phosphorus for City drinking water reservoirs (NYC DEP, 1999); a source-water phosphorus guidance value of 15 µg/l has been proposed for seven reservoirs (Kensico, Rondout, Ashokan, West Branch, New Croton, Croton Falls, and Cross River) in order to protect them from use-impairment due to eutrophication, with other reservoirs using the State recommended guidance value of 20 µg/l.

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Organic Carbon

Organic matter, washed from impervious surfaces during storms, can present a problem in slower moving downstream waters. Some sources include organic material blown onto the street surface, and attached to sediment from stream banks, or from bare soil. In addition, organic carbon is formed indirectly from algal growth within systems with high nutrient loads.

As organic matter decomposes, it can deplete dissolved oxygen in lakes and tidal waters. Declining levels of oxygen in the water can have an adverse impact on aquatic life. An additional concern is the formation of trihalomethane (THM), a carcinogenic disinfection by-product, due to the mixing of chlorine with water high in organic carbon. This is of particular importance in unfiltered water supplies, such as the New York City Reservoir System.

Bacteria

Bacteria levels in stormwater runoff routinely exceed public health standards for water contact recreation. Some stormwater sources include pet waste and urban wildlife. Other sources in developed land include sanitary and combined sewer overflows, wastewater, and illicit connections to the storm drain system. Bacteria is a leading contaminant in many of New York's waters, and has lead to shellfish bed closures in the New York Bight Area, on Long Island, and in the Hudson-Raritan Estuary. In addition, Suffolk, Nassau, and Erie Counties issue periodic bathing-beach advisories each time a significant rainfall event occurs (NRDC, 2000).

Hydrocarbons

Vehicles leak oil and grease that contain a wide array of hydrocarbon compounds, some of which can be toxic to aquatic life at low concentrations. Sources are automotive, and some areas that produce runoff with high runoff concentrations include gas stations, commuter parking lots, convenience stores, residential parking areas, and streets (Schueler, 1994).

Trace Metals

Cadmium, copper, lead and zinc are routinely found in stormwater runoff. Many of the sources are automotive. For example, one study suggests that 50% of the copper in Santa Clara, CA comes from brake pads (Woodward-Clyde, 1992). Other sources of metals include paints, road salts, and galvanized pipes.

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These metals can be toxic to aquatic life at certain concentrations, and can also accumulate in the bottom sediments of lakes and estuaries. Specific concerns in aquatic systems include bioaccumulations in fish and macro-invertebrates, and the impact of toxic bottom sediments on bottom-dwelling species.

Pesticides

A modest number of currently used and recently banned insecticides and herbicides have been detected in urban and suburban streamflow at concentrations that approach or exceed toxicity thresholds for aquatic life. Key sources of pesticides include application to urban lawns and highway median and shoulder areas.

Chlorides

Salts that are applied to roads and parking lots in the winter months appear in stormwater runoff and meltwater at much higher concentrations than many freshwater organisms can tolerate. One study of four Adirondack streams found severe impacts to macroinvertebrate species attributed to chlorides (Demers and Sage, 1990). In addition to the direct toxic effects, chlorides can impact lake systems by altering their mixing cycle. In 1986, incomplete mixing in the Irondequoit Bay was attributed to high salt use in the region (MCEMC, 1987). A primary source of chlorides in New York State, particularly in the State's northern regions, is salt applied to road surfaces as a deicer.

Thermal Impacts.

Runoff from impervious surfaces may increase temperature in receiving waters, adversely impacting aquatic organisms that require cold and cool water conditions (e.g., trout). Data suggest that increasing development can increase stream temperatures by between five and twelve degrees Fahrenheit, and that the increase is related to the level of impervious cover in the drainage area (Galli, 1991). Thermal impacts are a serious concern in trout waters, where cold temperatures are critical to species survival.

Trash and Debris

Considerable quantities of trash and debris are washed through the storm drain networks. The trash and debris accumulate in streams and lakes and detract from their natural beauty. Depending on the type of trash, this material may also lead to increased organic matter or toxic contaminants in water bodies.

Snowmelt Concentrations

The snow pack can store hydrocarbons, oil and grease, chlorides, sediment, and nutrients. In cold regions, the pollutant load during snowmelt can be significant, and chemical traits of snowmelt change over the

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course of the melt event. Oberts (1994) studied this phenomenon, and describes four types of snowmelt runoff (Table 2.2). Oberts and others have reported that 90% of the hydrocarbon load from snowmelt occurs during the last 10% of the event. From a practical standpoint, the high hydrocarbon loads experienced toward the end of the season suggest that stormwater management practices should be designed to capture as much of the snowmelt event as possible.

Table 2.2 Runoff and Pollutant Characteristics of Snowmelt Stages (Oberts, 1994)

Snowmelt Stage	Duration/ Frequency	Runoff Volume	Pollutant Characteristics
Pavement Melt	Short, but many times in winter	Low	Acidic, high concentrations of soluble pollutants, Cl, nitrate, lead. Total load is minimal.
Roadside Melt	Moderate	Moderate	Moderate concentrations of both soluble and particulate pollutants.
Pervious Area Melt	Gradual, often most at end of season	High	Dilute concentrations of soluble pollutants, moderate to high concentrations of particulate pollutants, depending on flow.
Rain-on-Snow Melt	Short	Extreme	High concentrations of particulate pollutants, moderate to high concentrations of soluble pollutants. High total load.

Section 2.2 Diminishing Groundwater Recharge and Quality

The slow infiltration of rainfall through the soil layer is essential for replenishing groundwater. Groundwater is a critical water resource across the State. Not only do many residents depend on groundwater for their drinking water, but the health of many aquatic systems is also dependent on its steady discharge. For example, during periods of dry weather, groundwater sustains flows in streams and helps to maintain the hydrology of non-tidal wetlands.

Because development creates impervious surfaces that prevent natural recharge, a net decrease in groundwater recharge rates can be expected in urban watersheds. Thus, during prolonged periods of dry weather, streamflow sharply diminishes. Another source of diminishing baseflow is well drawdowns as populations increase in the watershed. In smaller headwater streams, the decline in stream flow can cause a perennial stream to become seasonally dry. One study in Long Island suggests that the supply of

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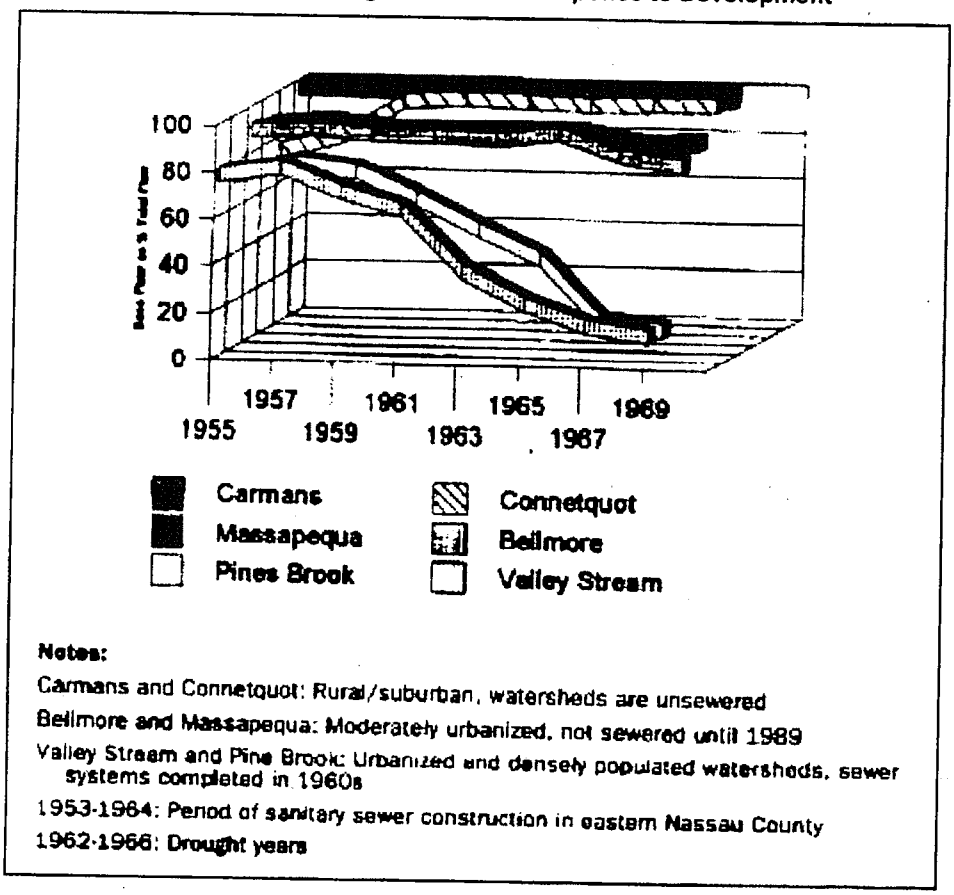
baseflow decreased in some developing watersheds, particularly where the water supply was sewered (Spinello and Simmons, 1992; Figure 2.3).

Urban land uses and activities can also degrade *groundwater quality,* if stormwater runoff is infiltrated without adequate treatment. Certain land uses and activities are known to produce higher loads of metals and toxic chemicals and are designated as *stormwater hotspots*. Soluble pollutants, such as chloride, nitrate, copper, dissolved solids and some polycyclic aromatic hydrocarbons (PAH's) can migrate into groundwater and potentially contaminate wells. Stormwater runoff from designated hotspots should never be infiltrated, unless the runoff receives full pretreatment with another practice.

Figure 2.3 Declining Baseflow in Response to Development



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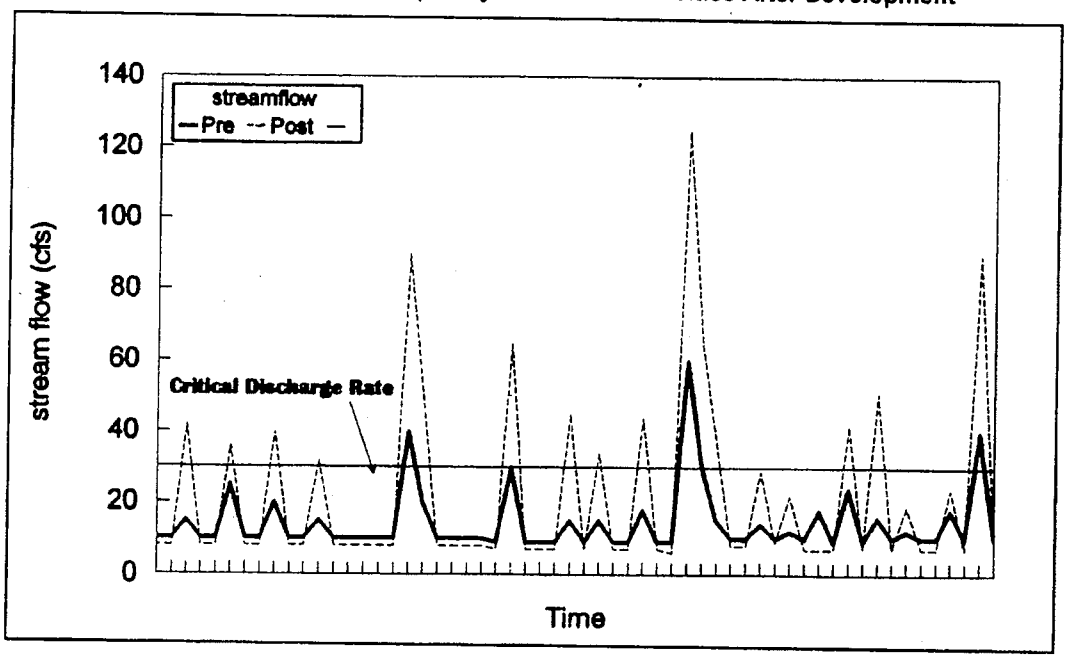
Section 2.3 Impacts to the Stream Channel

As pervious meadows and forests are converted into less pervious urban soils, or pavement, both the frequency and magnitude of storm flows increase dramatically. As a result, the bankfull event occurs two to seven times more frequently after development occurs (Leopold, 1994). In addition, the discharge associated with the original bankfull storm event can increase by up to five times (Hollis, 1975). As Figure 2.4 demonstrates, the total flow beyond the "critical erosive velocity" increases substantially after development occurs. The increased energy resulting from these more frequent bankfull flow events results in erosion and enlargement of the stream channel, and consequent habitat degradation.

Figure 2.4 Increased Frequency of Erosive Velocities After Development



Channel enlargement in response to watershed development has been observed for decades, with research indicating that the stream channel area expands to between two and five times its original size in response to upland development (Hammer, 1972; Morisawa and LaFlure, 1979; Allen and Narramore, 1985; Booth, 1990). One researcher developed a direct relationship between the level of impervious cover and the "ultimate" channel enlargement, the area a stream will eventually reach over time (MacRae, 1996; Figure 2.5).

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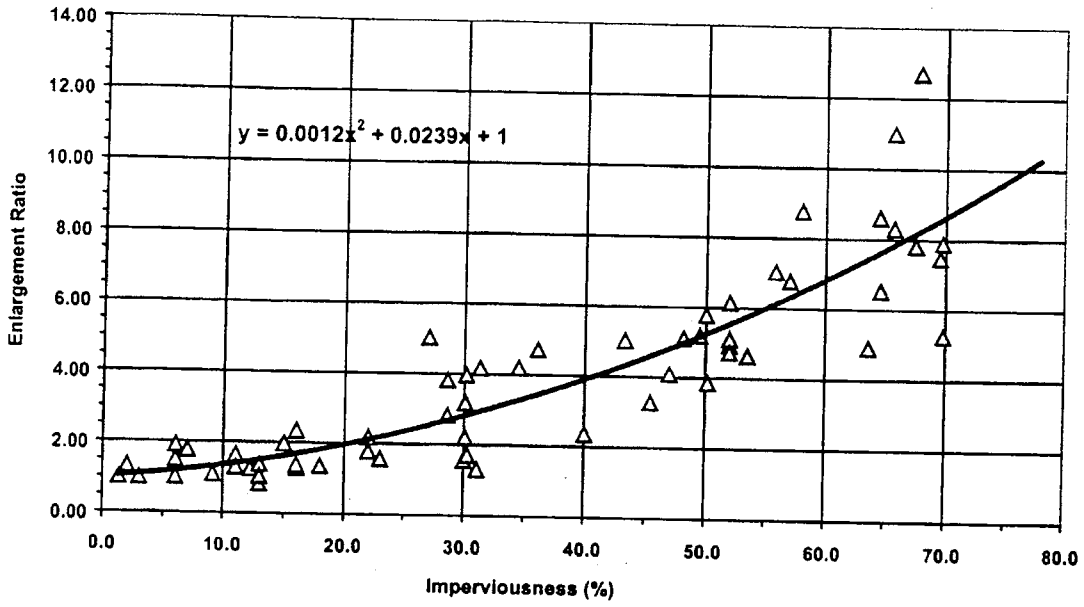
Figure 2.5 Relationship Between Impervious Cover and Channel Enlargement



Historically, New York has used two-year control (i.e., reduction of the peak flow from the two-year storm to predeveloped levels) to prevent channel erosion, as required in the 1993 SPDES General Permit (GP-93-06). Research suggests that this measure does not adequately protect stream channels (McCuen and Moglen, 1988, MacRae, 1996). Although the peak flow is lower, it is also extended over a longer period of time, thus increasing the duration of erosive flows. In addition, the bankfull flow event actually becomes more frequent after development occurs. Consequently, capturing the two-year event may not address the channel-forming event.

This stream channel erosion and expansion, combined with direct impacts to the stream system, act to decrease the habitat quality of the stream. The stream will thus experience the following impacts to habitat (Table 2.3):

- Decline in stream substrate quality (through sediment deposition and embedding of the substrate)
- Loss of pool/riffle structure in the stream channel
- Degradation of stream habitat structure
- Creation of fish barriers by culverts and other stream crossings
- Loss of "large woody debris," which is critical to fish habitat

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Table 2.3 Impacts to Stream Habitat			
Stream Channel Impact	**Key Finding**	**Reference**	**Year**
Habitat Characteristics			
Embeddedness	Interstitial spaces between substrate fill with increasing watershed imperviousness	Horner *et al.*	1996
Large Woody Debris (LWD)	Important for habitat diversity and anadramous fish.	Spence *et al.*	1996
	Decreased LWD with increases in imperviousness	Booth *et al.*	1996
Changes in Stream Features	Altered pool/riffle sequence with urbanization	Richey	1982
	Loss of habitat diversity	Scott *et al.*	1986
Direct Channel Impacts			
Reduction in 1st Order Streams	Replaced by storm drains and pipes increases erosion rate downstream	Dunne and Leopold	1972
Channelization and hardening of stream channels	Increase instream velocities often leading to increased erosion rates downstream	Sauer *et al.*	1983
Fish Blockages	Fish blockages caused by bridges and culverts	MWCOG	1989

Section 2.4 Increased Overbank Flooding

Flow events that exceed the capacity of the stream channel spill out into the adjacent floodplain. These are termed "overbank" floods, and can damage property and downstream structures. While some overbank flooding is inevitable and sometimes desirable, the historical goal of drainage design in New York has been to maintain pre-development peak discharge rates for both the two- and ten-year frequency storm after development, thus keeping the level of overbank flooding the same over time. This management technique prevents costly damage or maintenance for culverts, drainage structures, and swales.

Overbank floods are ranked in terms of their statistical return frequency. For example, a flood that has a 50% chance of occurring in any given year is termed a "two-year" flood. The two-year event is also known as the "bankfull flood," as researchers have demonstrated that most natural stream channels in the State have just enough capacity to handle the two-year flood before spilling out into the floodplain. Although many factors, such as soil moisture, topography, and snowmelt, can influence the magnitude of a particular flood event, designers typically design for the "two-year" storm event. In New York State,

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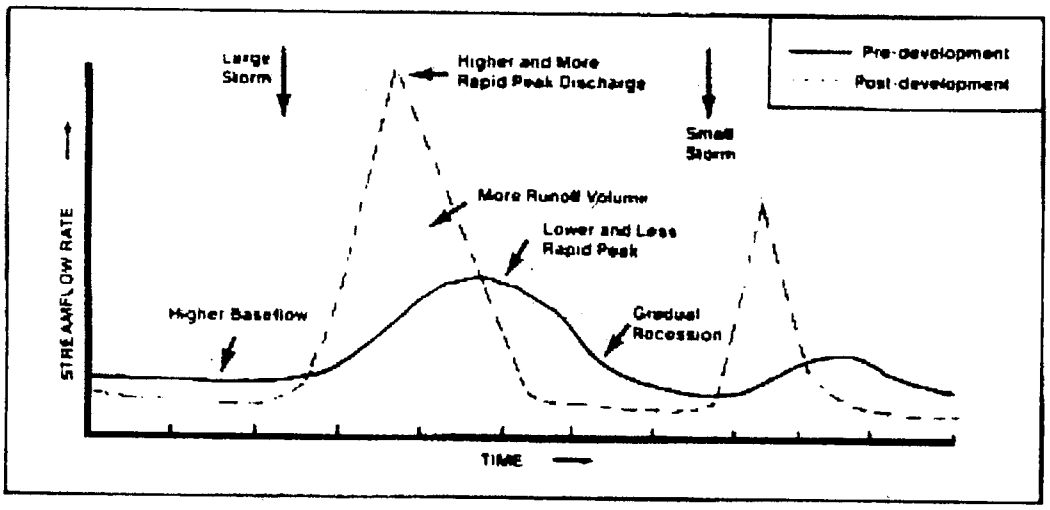
the two-year design storm ranges between about 2.0 to 4.0 inches of rain in a 24-hour period. Similarly, a flood that has a 10% chance of occurring in any given year is termed a "ten-year flood." A ten-year flood occurs when a storm event produces between 3.2 and 6.0 inches of rain in a 24-hour period. Under traditional engineering practice, most channels and storm drains in New York are designed with enough capacity to safely pass the peak discharge from the ten-year design storm.

Urban development increases the peak discharge rate associated with a given design storm, because impervious surfaces generate greater runoff volumes and drainage systems deliver it more rapidly to a stream. The change in post-development peak discharge rates that accompany development is profiled in Figure 2.6. Note that this change in hydrology increases not only the magnitude of the peak event, but the total volume of runoff produced.

Figure 2.6 Hydrographs Before and After Development



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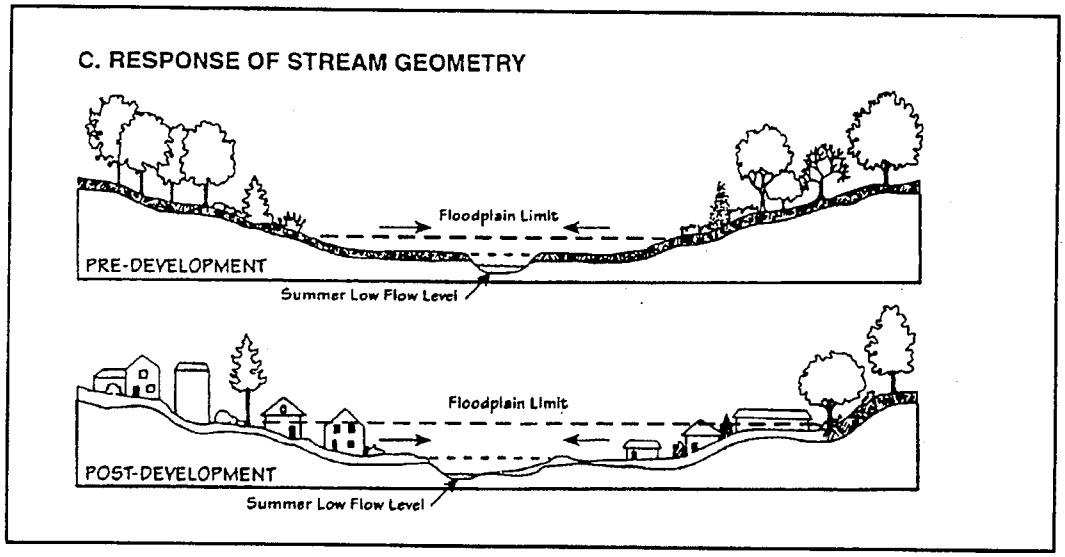
Section 2.5 Floodplain Expansion

The level areas bordering streams and rivers are known as floodplains. Operationally, the floodplain is usually defined as the land area within the limits of the 100-year storm flow water elevation. The 100-year storm has a 1% chance of occurring in any given year. In New York, a 100-year flood occurs after between five and eight inches of rainfall in a 24-hour period (i.e., the 100-year storm). These floods can be very destructive, and can pose a threat to property and human life.

As with overbank floods, development sharply increases the peak discharge rate associated with the 100-year design storm. As a consequence, the elevation of a stream's 100-year floodplain becomes higher and the boundaries of its floodplain expand (see Figure 2.7). In some instances, property and structures that had not previously been subject to flooding are now at risk. Additionally, such a shift in a floodplain's hydrology can degrade wetland and forest habitats.

Figure 2.7 Floodplain Expansion with New Development



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Section 2.6 Impacts to Aquatic Organisms

The decline in the physical habitat of the stream, coupled with lower base flows and higher stormwater pollutant loads, has a severe impact on the aquatic community. Research suggests that new development impacts aquatic insects, fish, and amphibians at fairly low levels of imperviousness, usually around 10% impervious cover (Table 2.4). New development appears to cause declining **richness** (the number of different species in an area or community), **diversity** (number and relative frequency of different species in an area or community), and **abundance** (number of individuals in a species).

Table 2.4 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms

Watershed Indicator	Key Finding	Reference	Year	Location
Aquatic insects and fish	A comparison of three stream types found urban streams had lowest diversity and richness. Urban streams had substantially lower EPT scores (22% vs 5% as number of all taxa, 65% vs 10% as percent abundance) and IBI scores in the poor range.	Crawford & Lenat	1989	North Carolina
Insects, fish, habitat water quality,	Steepest decline of biological functioning after 6% imperviousness. There was a steady decline, with approx 50% of initial biotic integrity at 45% I.	Horner *et al.*	1996	Puget Sound Washington
Fish, Aquatic insects	A study of five urban streams found that as land use shifted from rural to urban, fish and macroinvertebrate diversity decreased.	Masterson & Bannerman	1994	Wisconsin
Insects, fish, habitat, water quality, riparian zone	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as the percentage of total impervious area exceeded the 5-10% range.	May *et al.*	1997	Washington
Aquatic insects and fish	There was significant decline in the diversity of aquatic insects and fish at 10% impervious cover.	MWCOG	1992	Washington, DC
Aquatic insects and fish	Evaluation of the effects of runoff in urban and non-urban areas found that native fish and insect species dominated the non-urban portion of the watershed, but native fish accounted for only 7% of the number of species found in urban areas.	Pitt	1995	California
Wetland plants, amphibians	Mean annual water fluctuation inversely correlated to plant & amphibian density in urban wetlands. Declines noted beyond 10% impervious area.	Taylor	1993	Seattle

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Table 2.4 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms

Watershed Indicator	Key Finding	Reference	Year	Location
Aquatic insects & fish	Residential urban land use in Cuyahoga watersheds created a significant drop in IBI scores at around 8%, primarily due to certain stressors that functioned to lower the non-attainment threshold When watersheds smaller than 100mi^2 were analyzed separately, the level of urban land use for a significant drop in IBI scores occurred at around 15%.	Yoder *et. al.*	1999	Ohio
Aquatic insects & fish	All 40 urban sites sampled had fair to very poor index of biotic integrity (IBI) scores, compared to undeveloped reference sites.	Yoder	1991	Ohio

IBI: Index of Biotic Integrity: A measure of species diversity for fish and macroinvertebrates
EPT: A measure of the richnies of three sensitive macro-invertebrates (may flies, caddis flies, and stone flies), used to indicate the ability of a waterbody to support sensitive organisms.

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Chapter 3

Stormwater Permit Requirements

New York State Stormwater Management Design Manual

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Chapter 3: Department of Environmental Conservation Permits

This chapter provides a summary of the applications that may need to be filed with the Department of Environmental Conservation (DEC) for new development projects. This section identifies general policies and timelines for filing a State Pollutant Discharge Elimination System ("SPDES") General Permit for stormwater discharges from construction activities as well as environmental permits under the Uniform Procedures Act (UPA). More detailed information on the permits and up-to-date regional contact information are available from the DEC web site at the following URLs:

www.dec.state.ny.us/website/dcs/permits_level2.html

www.dec.state.ny.us/website/dcs/upa/upa_permits.html

Section 3.1 Filing for a Stormwater Permit

40 CFR Part 122 prohibits point source discharges of stormwater to waters of the United States without a permit issued under the National Pollutant Discharge Elimination System ("NPDES"). New York State is approved by the EPA to administer its SPDES program in lieu of EPA's NPDES program. The operator of a storm water discharge, which qualifies for coverage under the SPDES General Permit for stormwater, must submit a Notice of Intent (NOI) form to obtain permit coverage. Consult the general permit for any possible restrictions on eligibility of coverage. The permit includes a complete set of instructions for filing an NOI and for filing a Notice of Termination (NOT).

3.1.1 Where to File the NOI Form

Completed NOIs should be sent to:

NYS DEC – Notice of Intent
Bureau of Water Permits
625 Broadway
Albany, NY 12233-3505

3.1.2 Stormwater Pollution Prevention Plan

The applicant must check whether the project will be a small or large one and whether the plan conforms to either NYSDEC or local Municipal Separate Storm Sewer System (MS4) requirements. The flow chart in Figure 3.1 identifies what components of the Stormwater Pollution Prevention Plan need to be prepared depending on the size and complexity of the site.

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If one wishes to seek some variance from either local or NYSDEC requirements, then the information in Section V of the NOI must be filled out. The purpose of this section is to give NYSDEC some preliminary information. Based on the information provided, DEC will determine if other information is required. Only operators who state that their plan will NOT conform to either NYSDEC or local MS4 requirements need to fill out this section.

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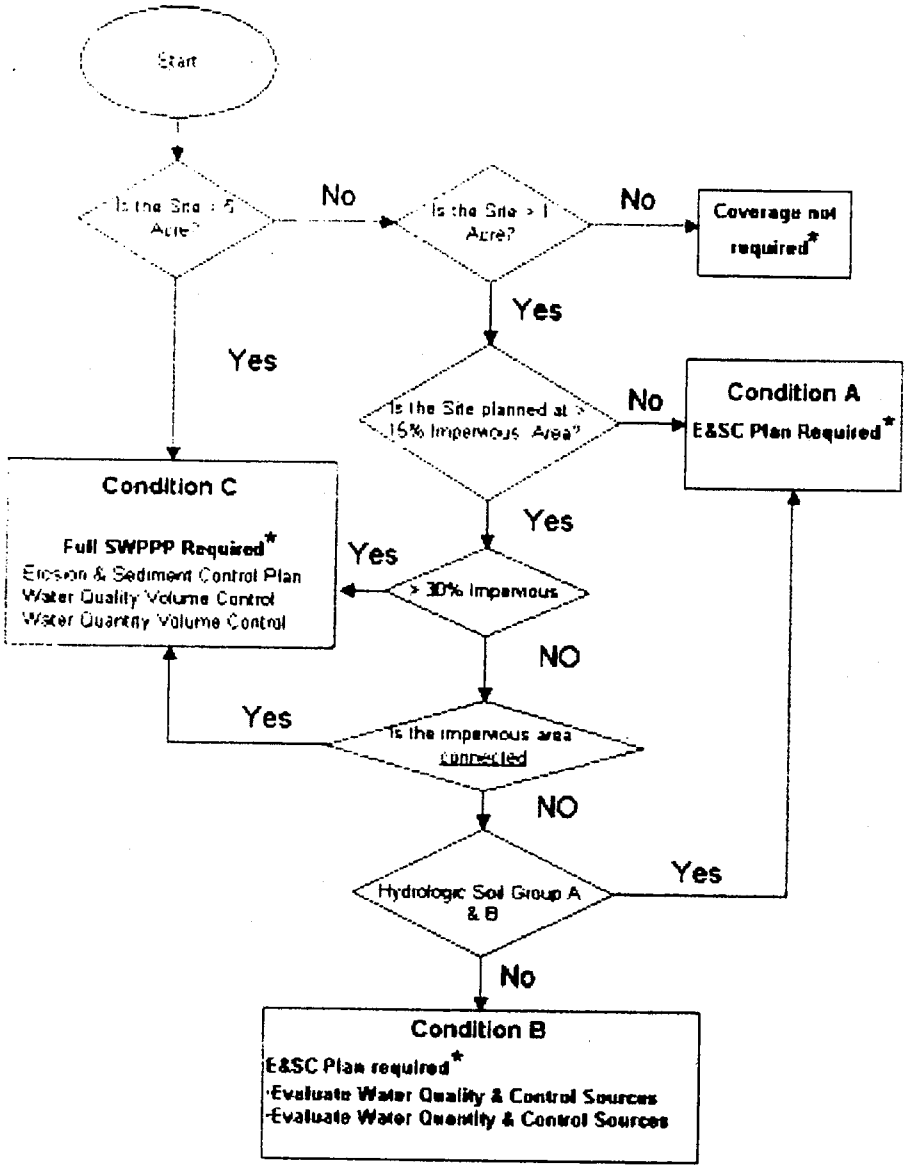
Figure 3.1 Stormwater Pollution Prevention Plan Component Requirements



* Under any of the above conditions other permits may be required

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3.1.3 Review and Approval

Once the Notice of Intent (NOI) has been reviewed by DEC, an acknowledgement letter will be returned to the sender. Filing of an NOI does not supercede or negate the necessity to comply with other local laws and other state or federal requirements, which affect stormwater management. It is the responsibility of the operator to comply with any and all such regulations. Operators are encouraged to have their Stormwater Pollution Prevention Plan reviewed by the local Soil and Water Conservation District.

New York City has enacted various land use controls that affect certain construction projects in areas tributary to their drinking water reservoirs. Similarly, the Lake George Park Commission and the Adirondack Park Agency (APA) have enacted regulations which impact construction activity. The APA has jurisdiction over private lands within the Adirondack Park and requires environmental review for most land development projects. It also administers the State's Wild and Scenic Rivers and Freshwater Wetlands programs on these lands. Development within the APA's jurisdiction is not subject to SEQR. For more information, please contact the APA at 518-891-4050.

Other municipalities and agencies of New York State may have adopted similar legislation. It is the responsibility of the operator to comply with any and all such regulations. Table 3.1 provides a summary table describing the permits issued by DEC that may apply to the new development.

Section 3.2 Filing Other Permit Applications

Most other environmental permits are administered under the UPA, which establishes uniform review procedures for the DEC's major regulatory programs and provides time periods for DEC action on applications for environmental protection permits. Generally permits identified under the UPA need to be filed through the DEC Regional Office. (See Figure 3.2 for regional contact information). If more than one permit is required, the applicant should submit all applications at one time. In addition, the applicant must list permits of other agencies that he or she knows to be applicable, together with a statement of the status of approval of the review under the State Environmental Quality Review (SEQR).

3.2.1 What Other Permits Do I Need to File?

Several permits under the UPA may be applicable to a particular development project. Table 3.1 lists many of permits required under the UPA that may apply to new residential, commercial, and industrial development in New York State, and provides a brief description of each. Please note that the table includes only the permits that are directly applicable to the stormwater and site plan development. Thus

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several UPA permits may be required that are not included on this table, including Long Island Wells, Water Supply, 401 Water Quality Certification, Air Pollution Control, Mined Land Reclamation, Hazardous Waste Management Facilities, and Waste Transporter.

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Table 3.1 Summary of Environmental Permits Issued by DEC That May Apply to New Development			
3.1 Permit Title	**3.2 Implementation Authority**	**3.2.1 Applicability**	**3.2.2 Regulated Activities**
State Pollutant Discharge Elimination System	ECL Article 17 Division of Water	• Construction sites disturbing one acre or more.	*Regulated:* Stormwater discharge associated with industrial activity, including new construction; point source discharges and disposal systems *Exempted:* Agricultural discharge[1], discharge of sewage effluent to groundwater less than 1,000 gallons a day.
Dam Safety	ECL Article 15-0503 see *Guidelines for Design of Dams*	• Applies to on-stream and off-stream structures having height > 6' and storage capacity > 3MG, or height ≥ 15' and storage capacity ≥ 1 MG.	*Regulated:* Construction, reconstruction, repair or removal of dams or impoundment. *Exempted:* Structures for treatment or storage of wastewater, or materials other than water.
Freshwater Wetlands	ECL Article 24 Division of Fish, Wildlife and Marine Resources	• Freshwater wetlands appearing on New York State freshwater wetland maps • Generally limited to 12.4 acres or greater, but stricter requirements in the Adirondack Park	*Regulated:* Construction of buildings, roadways, septic systems, dams, docks; filling, draining, or excavating; vegetation removal *Exempted:* Ordinary maintenance and repair of existing structures; recreational activities
Tidal Wetlands	ECL Article 25 NY DEC, Tidal Wetlands Regulatory Program	• Official DEC tidal wetlands maps. • Anywhere tidal inundation occurs on a daily, monthly, or intermittent basis, including but not exclusively within the salt wedge (salt marshes, vegetated flats, and shorelines)[2] • Adjacent areas extend up to 300 ft. inland from wetland boundary (NYC 150 ft)	*Regulated:* Residences and condos; accessory structures; commercial and industrial buildings; roadways and parking lots; boat ramps; septic systems; drainage structures; erosion control structures (groins, sea walls); docks, piers, etc. Clearing/clear cutting; beach nourishment; dredging, excavation, and grading.
Protection of Waters	Title 5, ECL Article 15 Division of Fish, Wildlife and Marine Resources	Bed or banks of protected streams	*Regulated:* Modification or disturbance of the bed or banks of protected streams, including removal of sand or gravel; filling dredging in navigable waters; construction/modification/ repair of

[1]- Eligible for coverage under Concentrated Animal Feeding Operation (CAFO)

[2] Applicable to Rockland and Westchester Counties, NYC and Long Island.

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Table 3.1 Summary of Environmental Permits Issued by DEC That May Apply to New Development			
			certain dams, docks, and mooring areas. *Exempted:* Ordinary maintenance
Coastal Erosion Hazard Areas	ECL Article 34 Division of Water	• Lands adjacent to Lakes Erie and Ontario; the St. Lawrence, Niagara, Harlem, East, and Hudson Rivers; Kill van Kull; Arthur Kill; Atlantic Ocean; and connective water-bodies. • Natural Protective Features (NPF) nearshore areas; and landward Structural Hazard Areas (SHA)	*Regulated*: Construction/ modification/ restoration of structures, e.g. buildings, docks, piers, walkways; Filling, draining or excavating; Construction/modification/restoration of erosion control structures *Exempted:* Ordinary maintenance and repair of existing structures
Wild, Scenic, & Recreational Rivers	Title 27, ECL Article 15 Division of Fish, Wildlife and Marine Resources	All or portions of DEC-designated waterways: Three levels of classification include recreational rivers, scenic rivers, wild rivers	*Regulated*: Specifics depend on classification, but includes construction of residential, non-residential, accessory structures, and roads; Water quality, wastewater treatment, disposal; Vegetative cutting and agriculture; Recreational uses and development; Commercial and industrial uses. *Exempted*: Continuation of existing land uses; Maintenance and repair--without changes
* UPA permits not included in this table are Long Island Wells, Water Supply, 401 Water Quality Certification, Air Pollution Control; Mined Land Reclamation, Hazardous Waste Management Facilities, Waste Transporter Source URL:(http://www.dec.state.ny.us/website/dcs/upa/upa_permits.html)			

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3.2.2 Schedule for DEC Review

The time for permit approval depends on whether a project is determined to be UPA major or UPA minor. Each of the permits included in the UPA process has specific definitions of what constitutes UPA major and UPA minor projects. DEC first determines if an application is complete, and then begins the review process. For most projects, DEC must determine completeness within 15 days and for federally delegated permits within 60 days. For UPA minor projects, DEC must make a decision on the permit within 45 days of determining the application complete.

For UPA major projects, the length of time for review depends on whether a public hearing is required. If no hearing is required, DEC must make a decision within 90 days of determining the project complete. If a hearing is required, DEC notifies the applicant and the public of a hearing within 60 days of the completeness determination. The hearing must commence within 90 days of the completeness determination. Once the hearing ends, DEC must issue a final decision on the application within 60 days after receiving the final hearing record.

- **Dam Safety**

Constructing, reconstructing, repairing, or modifying dams and water impounding structures that permanently or temporarily impound water as a result of a structure placed across a watercourse or overland drainage way or which receive water from an external source such as drainage diversion or pumping of groundwater require a dam safety permit. Some examples of activities requiring this permit are: siting and constructing a new dam or water impounding structure, reconstruction, modification or maintenance which may affect the structural integrity or functional capability of a dam or impounding structure.

- **Freshwater Wetlands/Tidal Wetlands**

A freshwater or tidal wetlands permit may be required for work in or adjacent to wetlands designated by the State. Official tidal wetlands maps showing the locations of New York's regulated tidal wetlands are on file at DEC regional offices in Regions 1, 2, and 3, and in the County Clerks' Offices of Nassau, Suffolk, Bronx, Kings, New York, Queens, Richmond, Rockland, and Westchester Counties. They are also available at local assessing agencies in these areas. Official freshwater wetlands maps showing the locations of New York's wetlands are on file at DEC regional offices, the Adirondack Park Agency, and local government offices.

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Wetlands permit applications require analysis of alternatives. Even when a development is adjacent to a regulated wetland, the site plan and stormwater management plan need to be modified to adequately protect these resources.

- **Protection of Waters**

This permit applies to the dredging and filling in navigable waters and dams and work on the banks of protected streams. The permit also regulates the construction of dams in both waterways and overland drainage ways. When a site plan includes dam construction as a part of a quantity or quality control requirement, a permit will be required unless the following conditions are met:

- Maximum height is six feet or less (maximum height is measured as the height from the downstream (outside) toe of the dam at its lowest point to the highest point at the top of the dam).
- Maximum impounding capacity is one million gallons or less (maximum impounding capacity is measured as the volume of water impounded when the water level is at the top of the dam).
- Maximum height is between six feet and 15 feet and the maximum impounding capacity is less than three million gallons.

- **Coastal Erosion Hazard Areas**

This permit is required where coastal erosion is a concern, and applies to Natural Protective Features (NPFs), such as sand dunes, and a Shoreline Hazard Area (SHA) defined based on the annual recession rate of the coast. The permit is required for construction of any structures within the SHA, and the permitee must demonstrate that the proposed project does not contribute to coastal erosion.

- **Wild, Scenic, & Recreational Rivers**

This regulation applies strict regulations, which restrict certain uses for development bordering wild, scenic, or recreational rivers in New York State. Furthermore, the applicant must demonstrate that no reasonable alternative exists, and that the proposed activity will not have an undue adverse environmental impact. Listed waterways include:

<u>Scenic Rivers</u>

Carmans River
Peconic River
East Canada Creek
Grasse River
Oswegatchie River
GenesseeRiver

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Recreational Rivers

Carmans River
Connetquot River
Nissequogue River
Peconic River
Ramapo River
Shawangunk Kill
Ausable River
Fall Creek

- **State Environmental Quality Review Act (SEQR)**

Many projects are subject to SEQR. It is important that operators inform local governments about their projects and obtain necessary local approvals before starting work. Projects, for which only a general permit is needed, are not subject to SEQR. If any other permits are required, the applicant must submit applications, which are reviewed in accordance with SEQR.

All agencies involved (state and local), must consider the environmental impacts of construction projects before approving, funding, or directly undertaking an action. Development projects subject to SEQR will require an Environmental Assessment Form. If a project may have a significant environmental impact, an Environmental Impact Statement (EIS) will be required. Projects will require public involvement as a part of this process.

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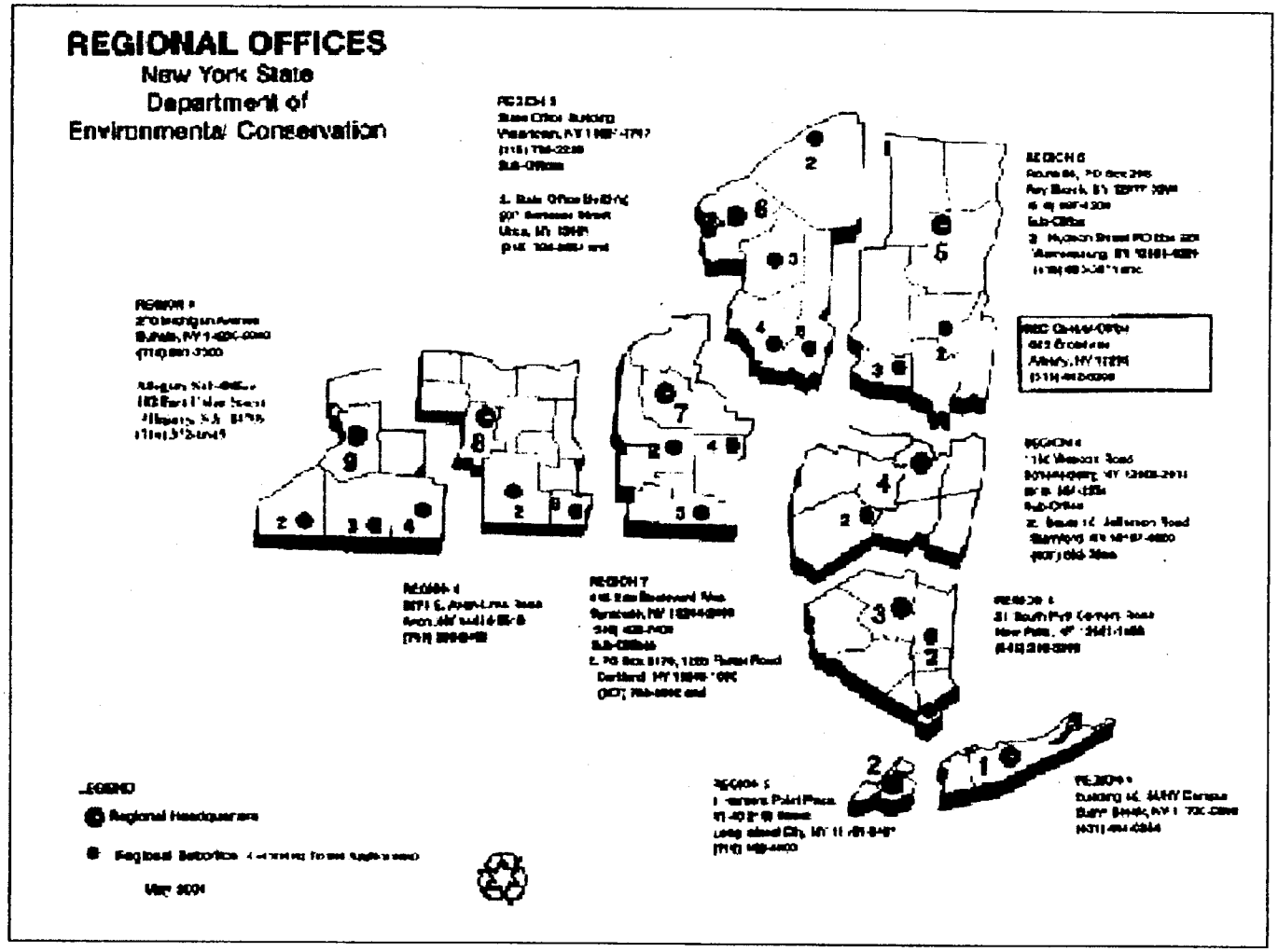
Figure 3.2 New York State Regional Contact Information



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Chapter 4

Unified Stormwater Sizing Criteria

New York State Stormwater Management Design Manual

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Chapter 4: Unified Stormwater Sizing Criteria

Section 4.1 Introduction

This chapter presents a unified approach for sizing SMPs in the State of New York to meet pollutant removal goals, reduce channel erosion, prevent overbank flooding, and help control extreme floods. For a summary, please consult Table 4.1 below. The remaining sections describe the four sizing criteria in detail and present guidance on how to properly compute and apply the required storage volumes.

Table 4.1 New York Stormwater Sizing Criteria

Water Quality (WQ_v)	**90% Rule:** $WQ_v = [(P)(R_v)(A)] /12$ $Rv = 0.05+0.009(I)$ I = Impervious Cover (Percent) Minimum Rv = 0.2 P = 90% Rainfall Event Number (See Figure 4.1) A = site area in acres
Channel Protection (Cp_v)	**Default Criterion:** Cp_v = 24 hour extended detention of post-developed 1-year, 24-hour storm event. **Option for Sites Larger than 50 Acres:** Distributed Runoff Control - geomorphic assessment to determine the bankfull channel characteristics and thresholds for channel stability and bedload movement.
Overbank Flood (Q_p)	Control the peak discharge from the 10-year storm to 10-year predevelopment rates.
Extreme Storm (Q_f)	Control the peak discharge from the 100-year storm to 100-year predevelopment rates. Safely pass the 100-year storm event.
Note: The local review authority may waive channel protection, overbank flood, and extreme storm requirements in some instances. Guidance is provided in this chapter.	

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Section 4.2 Water Quality Volume (WQ_v)

The Water Quality Volume (denoted as the WQ_v) is designed to improve water quality sizing to capture and treat 90% of the average annual stormwater runoff volume. The WQ_v is directly related to the amount of impervious cover created at a site. Contour lines of the 90% rainfall event are presented in Figure 4.1.

The following equation can be used to determine the water quality storage volume WQ_v (in acre-feet of storage):

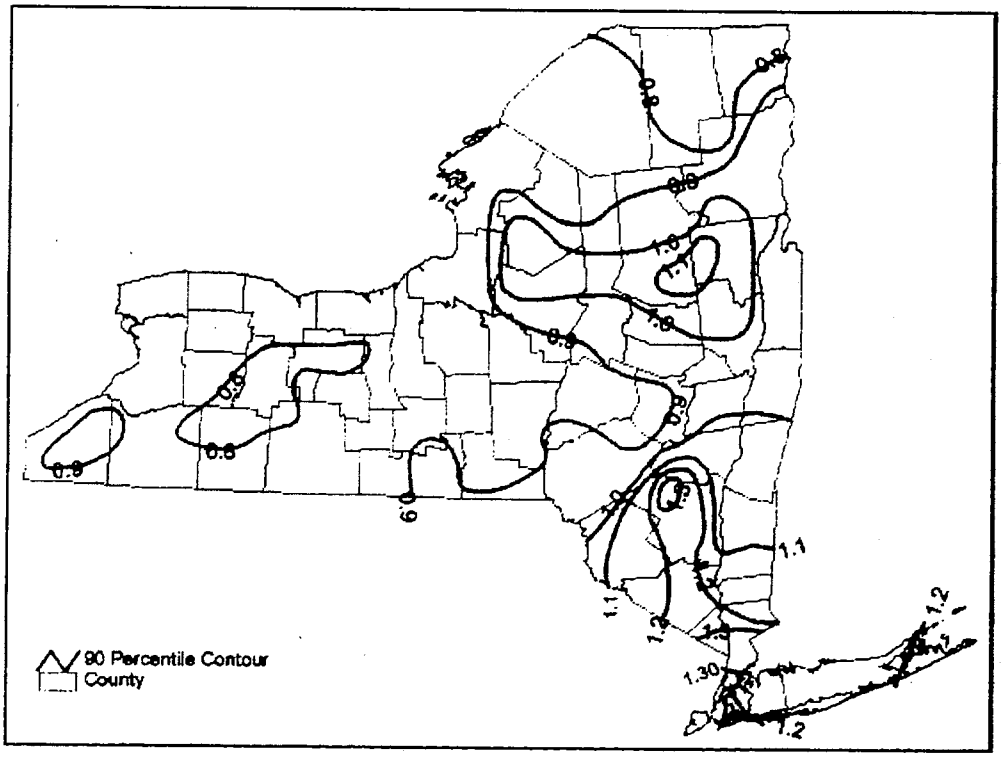
$$WQ_v = \frac{(P)(R_v)(A)}{12}$$

where:

WQ_v = water quality volume (in acre-feet)
P = 90% Rainfall Event Number (see Figure 4.1)
R_v = 0.05 + 0.009(I), where I is percent impervious cover
A = site area in acres

A minimum WQ_v of 0.2 inches per acre shall be met at residential sites that have less than 17% impervious cover.

Figure 4.1 90% Rainfall in New York State



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It is assumed that by meeting the WQ_v requirements through employment of the practices presented in Table 5.1 a project will, by default, meet water quality objectives. In some jurisdictions, on-site load calculations are required to demonstrate removal of specific pollutants. As an aid to communities, Appendix A of this manual includes a discussion of a method for calculating pollutant export loads from development sites. This method, known as the "Simple Method," provides estimates for stormwater runoff pollutant loads for urban areas using a modest amount of information, including the subwatershed drainage area and impervious cover, stormwater runoff pollutant concentrations, and annual precipitation. Please consult Appendix A for a more detailed discussion of the Simple Method and its applications for water quality determinations. Please note that the Simple Method is intended as an analysis tool, and should not be used to guide the design of SMPs.

Basis Of Design for Water Quality

As a basis for design, the following assumptions may be made:

- *Measuring Impervious Cover*: the measured area of a site plan that does not have permanent vegetative or permeable cover shall be considered total impervious cover. Impervious cover is defined as all impermeable surfaces and includes: paved and gravel road surfaces, paved and gravel parking lots, paved driveways, building structures, paved sidewalks, and miscellaneous impermeable structures such as patios, pools, and sheds. Porous or modular block pavement may be considered 50% impervious. Where site size makes direct measurement of impervious cover impractical, the land use/impervious cover relationships presented in Table 4.2 can be used to initially estimate impervious cover.

Table 4.2 Land Use and Impervious Cover (Source: Cappiella and Brown, 2001)

Land Use Category	Mean Impervious Cover
Agriculture	**2**
Open Urban Land*	**9**
2 Acre Lot Residential	**11**
1 Acre Lot Residential	**14**
1/2 Acre Lot Residential	**21**

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Table 4.2 Land Use and Impervious Cover (Source: Cappiella and Brown, 2001)	
Land Use Category	**Mean Impervious Cover**
1/4Acre Lot Residential	**28**
1/8 Acre Lot Residential	**33**
Townhome Residential	**41**
Multifamily Residential	**44**
Institutional**	**28-41%**
Light Industrial	**48-59%**
Commercial	**68-76%**
* Open urban land includes developed park land, recreation areas, golf courses, and cemeteries. ** Institutional is defined as places of worship, schools, hospitals, government offices, and police and fire stations	

- *Aquatic Resources*: More stringent local regulations may be in place or may be required to protect drinking water reservoirs, lakes, or other sensitive aquatic resources. Consult the local authority to determine the full requirements for these resources.

- *SMP Treatment*: The final WQ_v shall be treated by an acceptable practice from the list presented in this manual. Please consult Chapter 5 for a list of acceptable practices.

- *Determining Peak Discharge for WQ_v Storm*: When designing flow splitters for off-line practices, consult the small storm hydrology method provided in Appendix B.

- *Extended Detention for Water Quality Volume*: The water quality requirement can be met by providing 24 hours of the WQ_v (provided a micropool is specified) extended detention. A local jurisdiction may reduce this requirement to as little as 12 hours in trout waters to prevent stream warming.

- *Off-site Areas:* Provide treatment for off-site areas in their current condition. If water quality treatment is provided off-line, the practice must only treat on-site runoff.

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Section 4.3 Stream Channel Protection Volume Requirements (Cp_v)

Stream Channel Protection Volume Requirements (Cp_v) are designed to protect stream channels from erosion. In New York State this goal is accomplished by providing 24-hour extended detention of the one-year, 24-hour storm event. Trout waters may be exempted from the 24-hour ED requirement, with only 12 hours of extended detention required to meet this criterion.

For developments greater than 50 acres, with impervious cover greater than 25%, it is recommended that a detailed geomorphic assessment be performed to determine the appropriate level of control. Appendix J provides guidance on how to conduct this assessment.

The Cp_v requirement does not apply in certain conditions, including the following:

- Recharge of the entire Cp_v volume is achieved at a site.
- The site discharges directly tidal waters or fourth order (fourth downstream) or larger streams. Within New York State, streams are classified using the following:
  New York State Codes Rules and Regulations (NYCRR)
  Volumes B-F, Parts 800-941
  West Publishing, Eagan, MN
- A downstream analysis reveals that channel protection is not required (see section 4.7).

Detention ponds or underground vaults are methods to meet the Cp_v requirement (and subsequent Q_{p10} and Q_f criteria). Schematics of typical designs are shown in Figures 4.2. and 4.3. Note that, although these practices meet water quantity goals, they are unacceptable for water quality because of poor pollutant removal, and need to be coupled with a practice listed in Table 5.1. The Cp_v requirement may also be provided above the water quality (WQ_v) storage in a wet pond or stormwater wetland.

Basis for Determining Channel Protection Storage Volume

The following represent the minimum basis for design:

- TR-55 and TR-20 (or approved equivalent) shall be used to determine peak discharge rates.
- Rainfall depths for the one-year, 24 hour storm event are provided in Figure 4.4.
- Off-site areas should be modeled as "present condition" for the one-year, 24 hour storm event.
- The length of overland flow used in time of concentration (t_c) calculations is limited to no more than 100 feet for post development conditions.
- Cp_v is not required at sites where the resulting diameter of the ED orifice is too small to prevent clogging. (A minimum 3" orifice with a trash rack or 1" if the orifice is protected by a standpipe

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having slots with an area less than the internal orifice are recommended to prevent clogging. See Figure 3 in Appendix K for design details).

- Extended detention storage provided for the channel protection (Cp_v-ED) does not meet the WQ_v requirement. Both water quality and channel protection storage may be provided in the same SMP, however.
- The CP_v detention time for the one-year storm is defined as the time difference between the center of mass of the inflow hydrograph (entering the SMP) and the center of mass of the outflow hydrograph (leaving the SMP). See Appendix B for a methodology for detaining this storm event.

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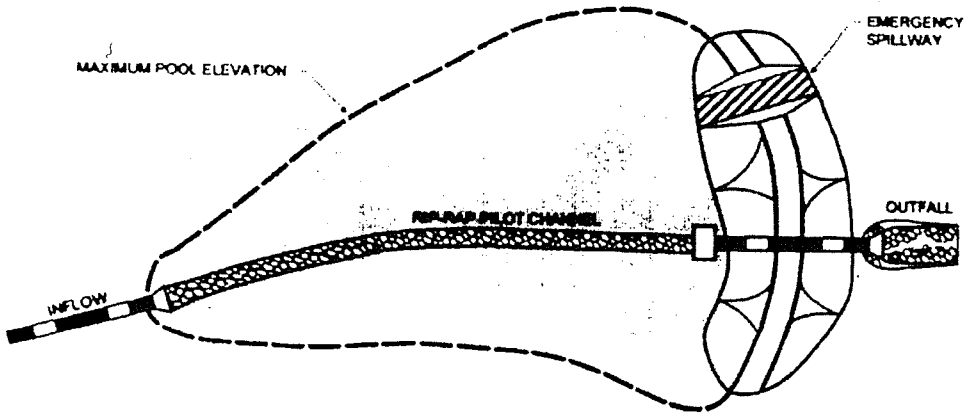
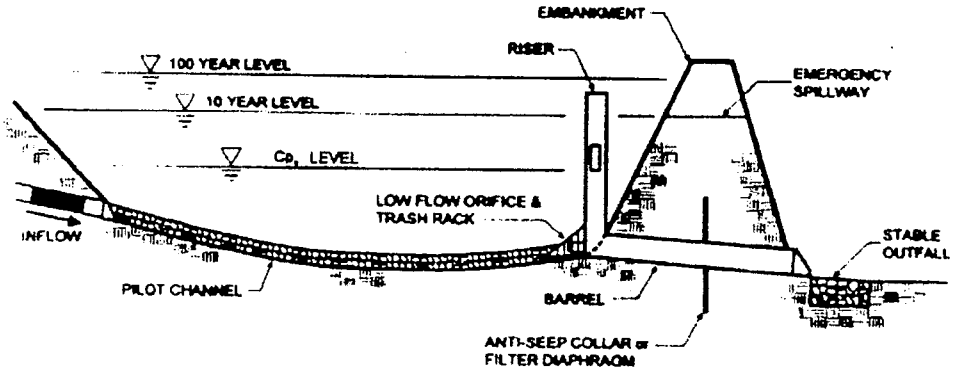
Figure 4.2 Example of a Conventional Stormwater Detention Pond



PLAN VIEW



PROFILE

A typical detention facility provides channel protection control (Cp_v) and overbank control (Q_p) but no water quality control (WQ_v). If this practice is used, WQv must be provided in a separate facility listed in Table 5.1.

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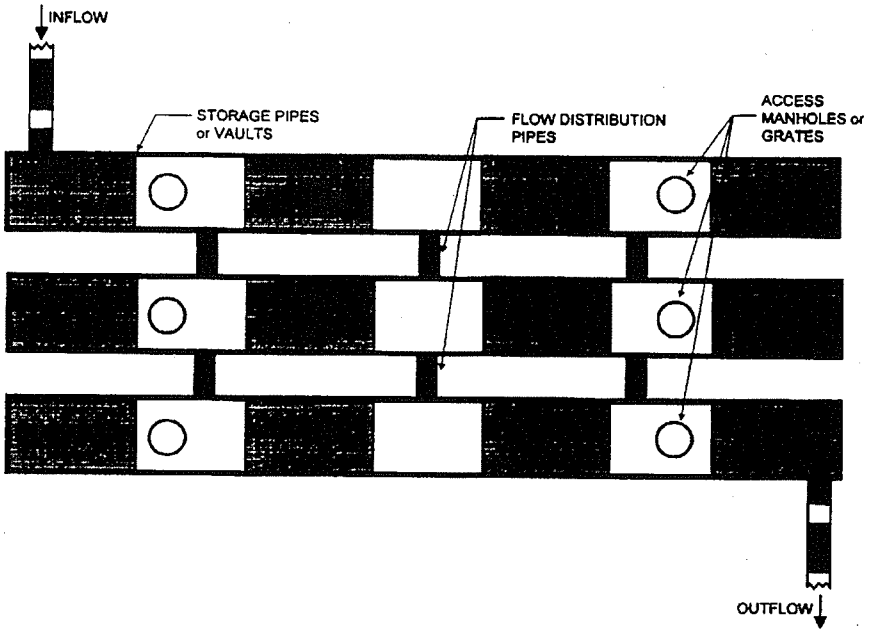
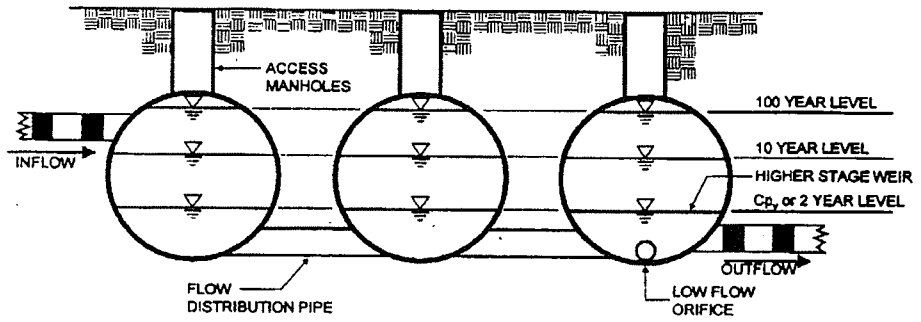
Figure 4.3 Example of Stormwater Detention Provided by an Underground Pipe System



PLAN VIEW



TYPICAL SECTION

An underground pipe system or vaults may be used to provide Cp_v, Q_p and Q_f controls but not WQ_v.

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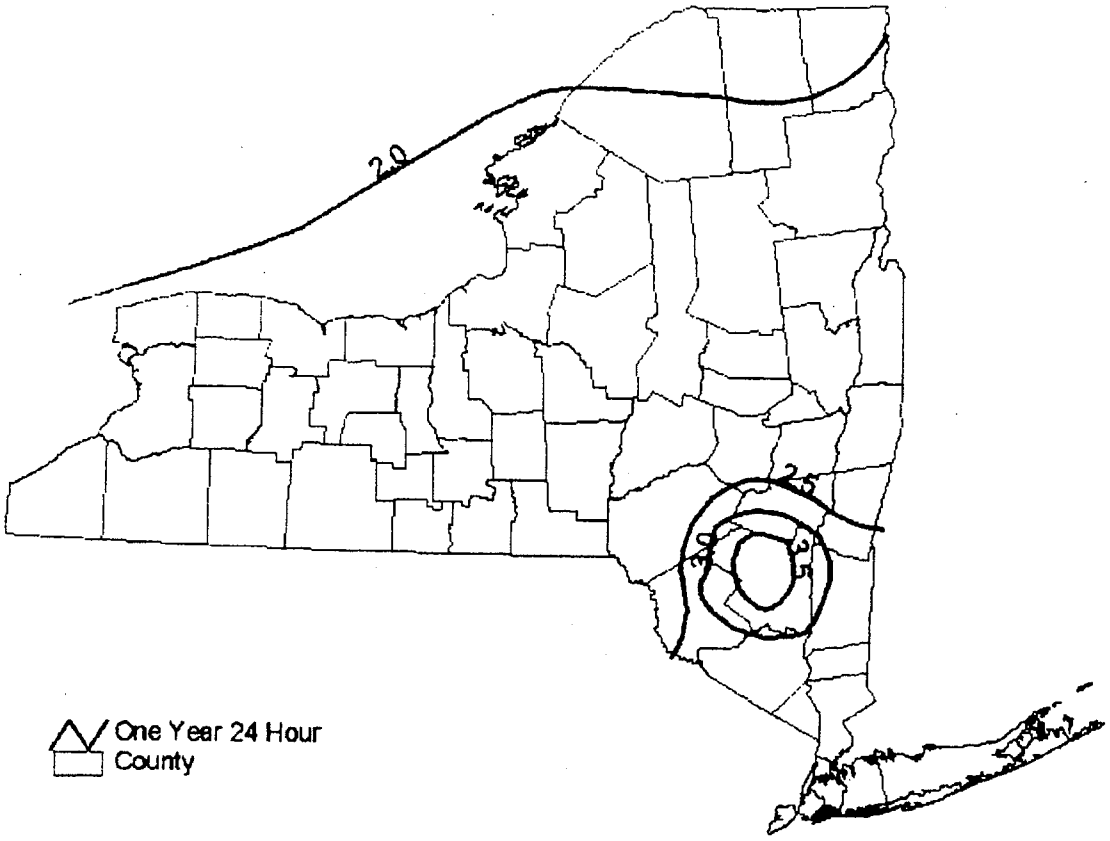
Figure 4.4 One-Year Design Storm



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Section 4.4 Overbank Flood Control Criteria (Q_p)

The primary purpose of the overbank flood control sizing criterion is to prevent an increase in the frequency and magnitude of out-of-bank flooding generated by urban development (i.e., flow events that exceed the bankfull capacity of the channel, and therefore must spill over into the floodplain).

Overbank control requires storage to attenuate the post development 10-year, 24-hour peak discharge rate (Q_p) to predevelopment rates.

The overbank flood control requirement (Q_p) does not apply in certain conditions, including:

- The site discharges directly tidal waters or fourth order (fourth downstream) or larger streams. Within New York State, streams are classified using the following:
  New York State Codes Rules and Regulations (NYCRR)
  Volumes B-F, Parts 800-941
  West Publishing, Eagan, MN
- A downstream analysis reveals that overbank control is not needed (see section 4.7).

Basis for Design of Overbank Flood Control

When addressing the overbank flooding design criteria, the following represent the minimum basis for design:

- TR-55 and TR-20 (or approved equivalent) will be used to determine peak discharge rates.
- When the predevelopment land use is agriculture, the curve number for the pre-developed condition shall be derived from the recommended five-year crop rotation for a region, from the local Soil Conservation Service, or from the historical five-year crop rotation for the site, whichever results in a lower curve number value.
- Off-site areas should be modeled as "present condition" for the 10-year storm event.
- Figure 4.5 indicates the depth of rainfall (24 hour) associated with the 10-year storm event throughout the State of New York.
- The length of overland flow used in t_c calculations is limited to no more than 150 feet for predevelopment conditions and 100 feet for post development conditions. On areas of extremely flat terrain (<1% average slope), this maximum distance is extended to 250 feet for predevelopment conditions and 150 feet for postdevelopment conditions.

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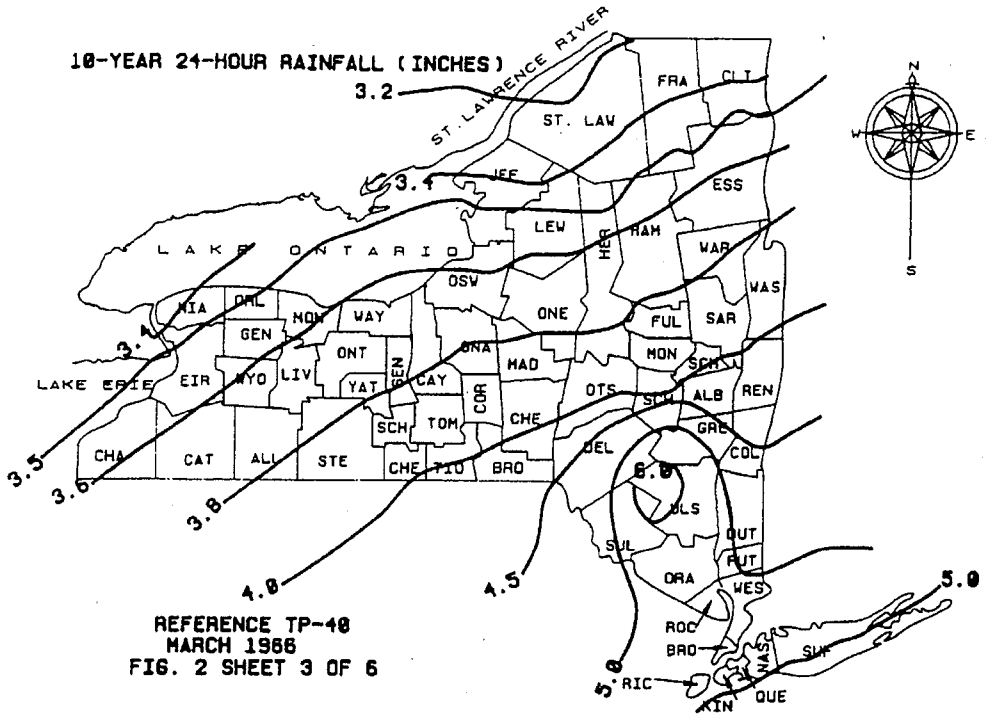
Figure 4.5 10-Year Design Storm



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Section 4.5 Extreme Flood Control Criteria (Q_f)

The intent of the extreme flood criteria is to (a) prevent the increased risk of flood damage from large storm events, (b) maintain the boundaries of the predevelopment 100-year floodplain, and (c) protect the physical integrity of stormwater management practices

100 Year Control requires storage to attenuate the post development 100-year, 24-hour peak discharge rate (Q_f) to predevelopment rates.

The 100-year storm control requirement can be waived if:

- The site discharges directly tidal waters or fourth order (fourth downstream) or larger streams. Within New York State, streams are classified using the following:
  New York State Codes Rules and Regulations (NYCRR)
  Volumes B-F, Parts 800-941
  West Publishing, Eagan, MN
- Development is prohibited within the ultimate 100-year floodplain
- A downstream analysis reveals that 100-year control is not needed (see section 4.7)

Detention structures must provide safe overflow of the 100-year flood, as discussed in the New York State Department of Environmental Conservation publication: "Guidelines for the Design of Dams," available from the Bureau of Flood Protection at 518-402-8151.

Basis for Design for Extreme Flood Criteria

- Consult with the appropriate review authority *including the local municipality's flood protection permit administrator,* to determine the analysis required for the Q_f storm.
- The same hydrologic and hydraulic methods used for overbank flood control shall be used to analyze Q_f.
- Figure 4.6 indicates the depth of rainfall (24 hour) associated with the 100-year storm event throughout New York State.
- When determining the storage required to reduce 100-year flood peaks, model off-site areas under current conditions.
- When determining storage required to safely pass the 100-year flood, model off-site areas under ultimate conditions.

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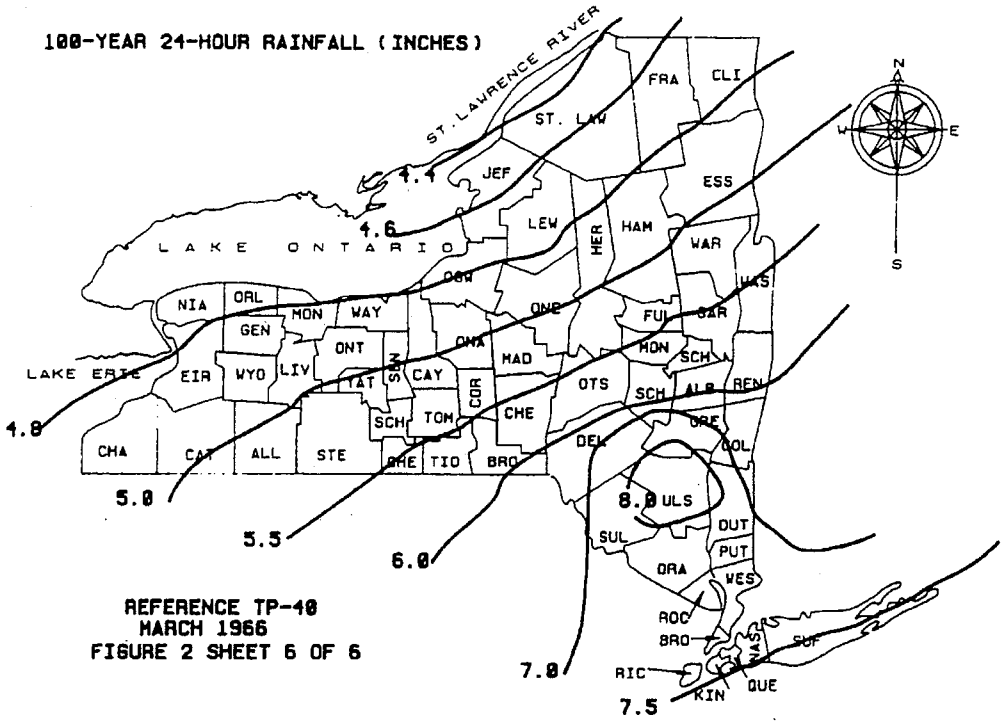
Figure 4.6 100-Year Design Storm



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Section 4.6 Conveyance Criteria

In addition to the stormwater treatment volumes described above, the manual also provides guidance on safe and non-erosive conveyance to, from, and through SMPs. Typically, the targeted storm frequencies for conveyance are the two-year and ten-year events. The two-year event is used to ensure non-erosive flows through roadside swales, overflow channels, pond pilot channels, and over berms within practices. Figure 4.7 presents rainfall depths for the two-year, 24-hour storm event throughout New York State. The 10-year storm is typically used as a target sizing for outfalls, and as a safe conveyance criterion for open channel practices and overflow channels. Note that some agencies or municipalities may use a different design storm for this purpose.

Section 4.7 Downstream Analysis

A community may waive the channel protection, overbank, and extreme flood requirements based on the results of a downstream analysis. In addition, such an analysis is recommended for larger sites (i.e., greater than 50 acres) to size facilities in the context of a larger watershed. The analysis will help ensure that storage provided at a site is appropriate to when combined with upstream and downstream flows. For example, detention at a site may in some instances exacerbate flooding problems within a watershed. This section provides brief guidance for conducting this analysis, including the area of stream to be evaluated and minimum elements to be included in the analysis.

Downstream analysis can be conducted using the 10% rule. That is, the analysis should extend downstream to the point where the site represents 10% of the total drainage area. For example, the analysis point for a 10-acre site would be analyzed to the nearest downstream point with a drainage area of 100 acres.

The analysis should include the following:

- Computation of flows and velocities for channel protection, overbank, and flood control storms at 200-foot intervals, at the point where the 10% rule is met, and at all confluences along the downstream channel with first order or higher streams.
- Hydrologic and hydraulic effects of all culverts and/or obstructions within the downstream channel.
- An assessment of water surface elevations to determine if an increase in water surface elevations will impact existing buildings and other structures.

The design, or waiver, at a site level can be approved if the following criteria are met:

- Flow rates and velocities increase by less than 5% of the pre-developed condition for all flow conditions analyzed.
- No downstream structures or buildings are impacted.
- The site as designed is not expected to exacerbate downstream channel erosion.

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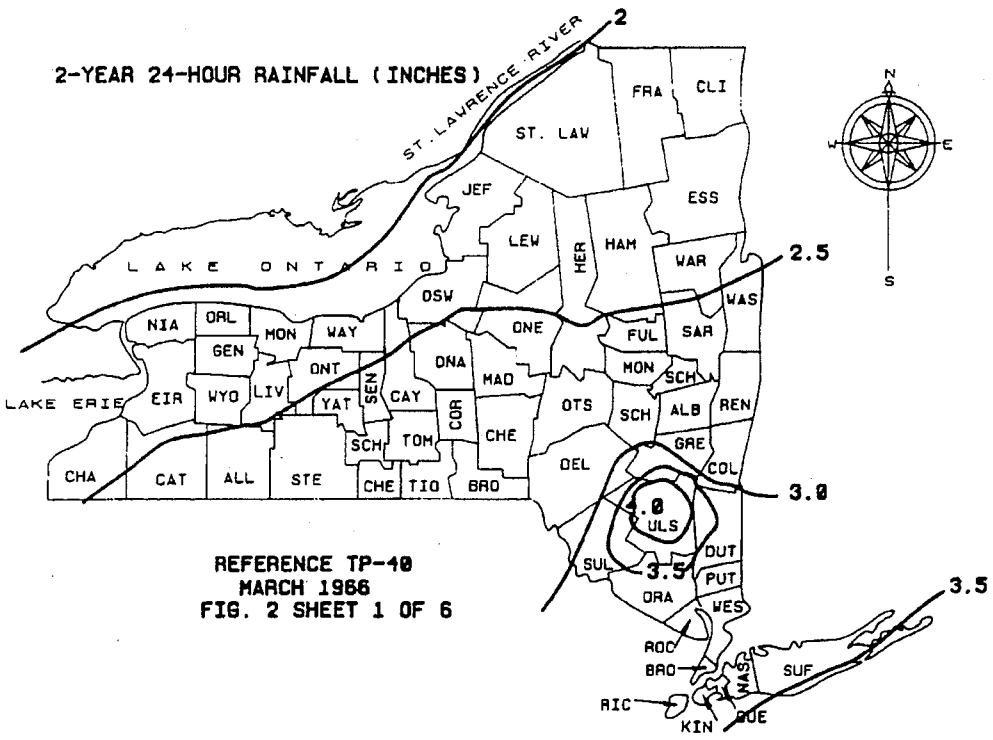
Figure 4.7. Two-Year Design Storm



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Section 4.8 Stormwater Hotspots

A stormwater hotspot is defined as a land use or activity that generates higher concentrations of hydrocarbons, trace metals or toxicants than are found in typical stormwater runoff, based on monitoring studies. If a site is designated as a hotspot, it has important implications for how stormwater is managed. First and foremost, stormwater runoff from hotspots cannot be allowed to infiltrate into groundwater, where it may contaminate water supplies. Second, a greater level of stormwater treatment is needed at hotspot sites to prevent pollutant washoff after construction. This treatment plan typically involves preparing and implementing *a stormwater pollution prevention plan* that involves a series of operational practices at the site that reduce the generation of pollutants from a site or prevent contact of rainfall with the pollutants. Table 4.3 provides a list of designated hotspots for the State of New York

Under EPA's stormwater NPDES program, some industrial sites are required to prepare and implement a stormwater pollution prevention plan. A list of industrial categories that are subject to the pollution prevention requirement can be found in the State of New York SPDES. In addition, New York's requirements for preparing and implementing a stormwater pollution prevention plan are described in the SPDES general discharge permit. The stormwater pollution prevention plan requirement applies to both existing and new industrial sites.

Table 4.3 Classification of Stormwater Hotspots

The following land uses and activities are deemed *stormwater hotspots:*

- Vehicle salvage yards and recycling facilities #
- Vehicle fueling stations
- Vehicle service and maintenance facilities
- Vehicle and equipment cleaning facilities #
- Fleet storage areas (bus, truck, etc.) #
- Industrial sites (based on SIC codes outlined in the SPDES)
- Marinas (service and maintenance) #
- Outdoor liquid container storage
- Outdoor loading/unloading facilities
- Public works storage areas
- Facilities that generate or store hazardous materials #
- Commercial container nursery
- Other land uses and activities as designated by an appropriate review authority

 # indicates that the land use or activity is required to prepare a stormwater pollution prevention plan under the SPDES stormwater program.

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The following land uses and activities are not normally considered hotspots:

- Residential streets and rural highways
- Residential development
- Institutional development
- Office developments
- Non-industrial rooftops
- Pervious areas, except golf courses and nurseries (which may need an Integrated Pest Management (IPM) Plan).

While large highways (average daily traffic volume (ADT) greater than 30,000) are not designated as a stormwater hotspot, it is important to ensure that highway stormwater management plans adequately protect groundwater.

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Chapter 5

List of Acceptable Stormwater Management Practices

New York State Stormwater Management Design Manual

Chapter 5: Acceptable Stormwater Management Practices (SMPs)

This section presents a list of practices that are acceptable for water quality treatment. The practices on this list are selected based on the following criteria:

1. Can capture and treat the full water quality volume (WQ_v)
2. Are capable of 80% TSS removal and 40% TP removal.
3. Have acceptable longevity in the field.
4. Have a pretreatment mechanism.

It also provides data justifying the use of these practices, and minimum criteria for the addition of new practices to the list.

Section 5.1 Practice List

Practices on the following list will be presumed to meet water quality requirements set forth in this manual if designed in accordance with the sizing criteria presented in Chapter 4 and constructed in accordance with the performance criteria in Chapter 6. The practices must also be maintained properly in accordance with the prescribed maintenance criteria also presented in Chapter 6. Acceptable practices are divided into five broad groups, including:

I. **Stormwater Ponds**	Practices that have either a permanent pool of water or a combination of permanent pool and extended detention capable of treating the WQ_v
II. **Stormwater Wetlands**	Practices that include significant shallow marsh areas, and may also incorporate small permanent pools and extended detention storage to achieve the full WQ_v
III. **Infiltration Practices**	Practices that capture and temporarily store the WQ_v before allowing it to infiltrate into the soil.
IV. **Filtering Practices**	Practices that capture and temporarily store the WQ_v and pass it through a filter bed of sand, organic matter, soil, or other acceptable treatment media.
V. **Open Channel Practices**	Practices explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means.

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Within each of these broad categories, select practices are presumed to meet the established water quality goals (see Table 5.1). It is important to note that several practices that are not on the list may be of value as pretreatment, or to meet water quantity requirements (see Section 5.2). Guidance on the performance criteria for each practice type and matrices for selecting practices are provided in Chapters 6 and 7.

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Table 5.1 Stormwater Management Practices Acceptable for Water Quality		
Group	**Practice**	**Description**
Pond	Micropool Extended Detention Pond (P-1)	Pond that treats the majority of the water quality volume through extended detention, and incorporates a micropool at the outlet of the pond to prevent sediment resuspension.
	Wet Pond (P-2)	Pond that provides storage for the entire water quality volume in the permanent pool.
	Wet Extended Detention Pond (P-3)	Pond that treats a portion of the water quality volume by detaining storm flows above a permanent pool for a specified minimum detention time.
	Multiple Pond System (P-4)	A group of ponds that collectively treat the water quality volume.
	Pocket Pond (P-5)	A stormwater wetland design adapted for the treatment of runoff from small drainage areas that has little or no baseflow available to maintain water elevations and relies on ground water to maintain a permanent pool.
Wetland	Shallow Wetland (W-1)	A wetland that provides water quality treatment entirely in a wet shallow marsh.
	Extended Detention Wetland (W-2)	A wetland system that provides some fraction of the water quality volume by detaining storm flows above the marsh surface.
	Pond/ Wetland System (W-3)	A wetland system that provides a portion of the water quality volume in the permanent pool of a wet pond that precedes the marsh for a specified minimum detention time.
	Pocket Wetland (W-4)	A shallow wetland design adapted for the treatment of runoff from small drainage areas that has variable water levels and relies on groundwater for its permanent pool.
Infiltration	Infiltration Trench (I-1)	An infiltration practice that stores the water quality volume in the void spaces of a gravel trench before it is infiltrated into the ground.
	Infiltration Basin (I-2)	An infiltration practice that stores the water quality volume in a shallow depression, before it is infiltrated it into the ground.
	Dry Well (I-3)	An infiltration practice similar in design to the infiltration trench, and best suited for treatment of rooftop runoff.
Filtering Practices	Surface Sand Filter (F-1)	A filtering practice that treats stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a sand matrix.
	Underground Sand Filter (F-2)	A filtering practice that treats stormwater as it flows through underground settling and filtering chambers.
	Perimeter Sand Filter (F-3)	A filter that incorporates a sediment chamber and filer bed as parallel vaults adjacent to a parking lot.
	Organic Filter (F-4)	A filtering practice that uses an organic medium such as compost in the filter, in the place of sand.
	Bioretention (F-5)	A shallow depression that treats stormwater as it flows through a soil matrix, and is returned to the storm drain system.
Open Channels	Dry Swale (O-1)	An open drainage channel or depression explicitly designed to detain and promote the filtration of stormwater runoff into the soil media.
	Wet Swale (O-2)	An open drainage channel or depression designed to retain water or intercept groundwater for water quality treatment.

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Section 5.2 Structural Practices Suitable for Pretreatment or as Supplemental Practices Only

Several practices that are not capable of providing water quality treatment can nonetheless function in a pretreatment role or as a supplemental practice to the recommended practices in Table 5.1. These practices can often be incorporated into SMP design as pretreatment devices, to treat a small portion of a site, or in retrofit or redevelopment applications. Some of these practices, including dry ponds and underground storage vaults, can be used to meet water quantity goals such as channel protection and flood control requirements. In addition, some of these practices may be helpful to reduce the total volume of runoff from a site or to disconnect impervious surfaces, as indicated on the Fact Sheets presented in this chapter. Some practices not currently deemed effective for stand-alone water quality treatment include:

- Catch basin inserts
- Dry ponds
- Underground vaults (designed for flood control)
- Oil/grit separators and hydrodynamic structures
- Filter strips
- Grass channels (includes ditches designed primarily for conveyance as well as modified practices that can achieve some pollutant removal)
- Deep sump catch basins
- On-line storage in the storm drain network
- Porous pavement

Fact sheets for some of these practices (dry ponds, filter strips, porous pavement, and grass channels) have been provided following section 5.3.

Section 5.3 Criteria for Practice Addition

The stormwater field is always evolving, and new technologies constantly emerge. New practices can be included in future revisions to the stormwater design manual, provided they can prove that they meet the water quality goals established in the manual. These goals include the 80% TSS (defined as suspended organic and inorganic material) and 40% TP removal target and a proven record of longevity in the field. For a practice to receive consideration for addition to the manual, the following monitoring criteria must be met by supporting studies:

- Must be monitored in at least two locations.
- At least five storm events must be sampled at each site.
- Concentrations reported in the studies must be flow-weighted.
- The studies must be independent (i.e., may not be conducted by the vendor or designer).
- The studies must be conducted in the field, as opposed to laboratory testing.

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- The practice must have been in the ground for at least one year at the time of monitoring (to assume the practice will be tested after a minimum amount of "in-service" time).
- At least one storm event in each study must be greater than the 90% storm event for the location.

Additional testing for new technologies based on the performance of practices with a similar design may be required before consideration. For example, if a practice has a very similar design to an oil/grit separator, which has consistently poor removal, then additional studies may be required to justify incorporation of that practice into the manual. The long-term performance of a practice based on field applications in New York or other regions with a similar climate or conditions may also determine if that practice will receive consideration for inclusion in the manual. A poor maintenance record is a valid justification for not including a practice in the manual.

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Dry Ponds



Description: Dry extended detention ponds (a.k.a. dry ponds, extended detention basins, detention ponds, extended detention ponds) are basins designed to temporarily detain runoff for some minimum time. Dry detention ponds are used for water quantity control only, and can also be used to provide flood control by including additional flood detention storage.

REASONS FOR LIMITED USE

- Controls stormwater quantity – not intended to provide water quality treatment

KEY CONSIDERATIONS

- Applicable for drainage areas up to 75 acres
- Typically less costly than stormwater (wet) ponds for equivalent flood storage, as less excavation is required
- May provide recreational and open space opportunities between storm runoff events

STORMWATER MANAGEMENT SUITABILITY

- ☐ **Water Quality**
- ☒ **Channel/Flood Protection**

SPECIAL APPLICATIONS

- ☐ **Pretreatment**
- ☐ **High Density/Ultra-Urban**
- ☐ **Runoff Reduction/Impervious Cover Disconnection**

Residential Subdivision Use: *Yes*

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Filter Strip



Description: Grassed filter strips (a.k.a., vegetated filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces and remove pollutants through filtration and infiltration.

REASONS FOR LIMITED USE

- Cannot alone achieve the 80% TSS removal target

KEY CONSIDERATIONS

- Runoff from an adjacent impervious area must be evenly distributed across the filter strip (i.e., sheet flow)
- Can be used as part of the runoff conveyance system to provide pretreatment
- Can provide groundwater recharge
- Reasonably low construction cost
- Large land requirement
- Requires periodic repair, regrading, and sediment removal to prevent channelization
- To size this practice, design a berm at the base of the filter strip. The volume to be treated should be captured behind the berm.

STORMWATER MANAGEMENT SUITABILITY

- [ ] **Water Quality**
- [ ] **Channel/Flood Protection**

SPECIAL APPLICATIONS

- [X] **Pretreatment**
- [ ] **High Density/Ultra-Urban**
- [X] **Runoff Reduction / Impervious Cover Disconnection**
- [X] **Other:** Use in buffer system; treating runoff from pervious areas

Residential Subdivision Use: *Yes*

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Modular Block Porous Pavement



Description: Modular block porous pavement is a permeable pavement surface with an underlying stone reservoir designed to temporarily store surface runoff before it infiltrates into the subsoil. Porous pavement options are primarily intended for low vehicle traffic areas such as spillover parking or simply the parking aisle portion of a parking lot.

REASONS FOR LIMITED USE

- Maintenance record is unclear, and pretreatment cannot be provided.
- Should not be applied on parking lots that are sanded or salted for snow control.

DESIGN CONSIDERATIONS

- Soil permeability between 0.5 and 3.0 inches per hour
- Do not locate on slopes > 15% or within fill soils
- Site at least 3 feet above the seasonally high groundwater table, and at least 100 feet away from drinking water wells
- Direct runoff from pervious or exposed areas away from pavement
- Size the gravel trench using the same equation provided in Section 6.3 for infiltration trenches.
- Provide conveyance for larger storms with raised inlet or perimeter gravel trench
- Sediment-laden runoff must be directed away from the porous pavement
- Maximum depth should not exceed 4 feet
- Ensure that the upland drainage is fully stabilized after construction;.
- Use permanent sign(s) containing a short list of maintenance requirements
- Do not use excavated stone reservoir as a sediment control device
- Avoid compacting subsoils during construction
- Ensure that paving dewaters between storms
- Periodically inspect the surface for deterioration or spalling

STORMWATER MANAGEMENT SUITABILITY

- [ ] **Water Quality**
- [ ] **Channel/Flood Protection**

SPECIAL APPLICATIONS

- [ ] **Pretreatment**
- [X] **High Density/Ultra-Urban**
- [X] **Runoff Reduction / Impervious Cover Disconnection**
- [X] **Other:** Overflow Parking

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Grass Channel



Description: Vegetated channels designed to filter stormwater runoff and meet velocity targets for the water quality design storm and the two-year storm event.

REASONS FOR LIMITED USE

- Cannot alone achieve the 80% TSS removal target

KEY CONSIDERATIONS

- Can be used as part of the runoff conveyance system to provide pretreatment
- Grass channels can act to partially infiltrate runoff from small storm events if underlying soils are pervious
- Less expensive than curb and gutter systems
- Should not be used on slopes greater than 4%; slopes between 1% and 2% recommended
- Design as a parabola, or as a trapezoid with a bottom width of between 2' and 8', with 3:1 or flatter side slopes.
- Provide sufficient length to retain the treatment volume in the system for 10 minutes, to flow at no greater than 1.0 fps, and at a depth of no greater than 4".
- Design to maintain between 4.0 and 5.0 fps for the 2-year storm, and no greater than 7.0 fps for the 10-year storm event.
- Size the channel to safely convey the 10-year storm event.
- Size using Manning's Equation (US DOT, 1990). Us an "n" value of 0.15 for flow depths of 4" or smaller, and linearly increase to 0.03 for a depth of 12".

STORMWATER MANAGEMENT SUITABILITY

- [ ] **Water Quality**
- [ ] **Channel/Flood Protection**

SPECIAL APPLICATIONS

- [X] **Pretreatment**
- [ ] **High Density/Ultra-Urban**
- [X] **Runoff Reduction / Impervious Cover Disconnection**
- [X] **Other:** Curb and gutter replacement

Residential Subdivision Use: *Yes*

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Chapter 6

Performance Criteria

New York State Stormwater Management Design Manual

Chapter 6: Performance Criteria

This chapter outlines performance criteria for five groups of structural stormwater management practices (SMPs) to meet water quality treatment goals. These include ponds, wetlands, infiltration practices, filtering systems and open channels. Each set of SMP performance criteria, in turn, is based on six performance goals:

Feasibility

Identify site considerations that may restrict the use of a practice.

Conveyance

Convey runoff to the practice in a manner that is safe, minimizes erosion and disruption to natural channels, and promotes filtering and infiltration.

Pretreatment

Trap coarse elements before they enter the facility, thus reducing the maintenance burden and ensuring a long-lived practice.

Treatment Geometry

Provide water quality treatment, through design elements that provide the maximum pollutant removal as water flows through the practice.

Environmental/Landscaping

Reduce secondary environmental impacts of facilities through features that minimize disturbance of natural stream systems and comply with environmental regulations. Provide landscaping that enhances the pollutant removal and aesthetic value of the practice.

Maintenance

Maintain the long-term performance of the practice through regular maintenance activities, and through design elements that ease the maintenance burden.

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Cold climate regions of New York State may present special design considerations. Each section includes a summary of possible design modifications that address the primary concerns associated with the use of that SMP in cold climates. A more detailed discussion of cold climate modifications can be found in the publication *Stormwater BMP Design Supplement for Cold Climates* (Caraco & Claytor, 1997). In addition, Appendix I of this manual provides some sizing examples that incorporate cold climate design.

IMPORTANT NOTES:

ANY PRACTICE THAT CREATES A DAM IS REQUIRED TO FOLLOW THE GUIDANCE PRESENTED IN THE *GUIDELINES FOR DESIGN OF DAMS* AND MAY REQUIRE A PERMIT FROM THE NYSDEC. FOR THE MOST RECENT COPY OF THIS DOCUMENT, CONTACT THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, DAM SAFETY DIVISION, AT: 518-402-8151. AN EVALUATION OF HAZARD CLASSIFICATION MUST BE INCLUDED IN THE DESIGN REPORT FOR STORMWATER PONDS OR WETLANDS CREATED BY A DAM.

THIS CHAPTER FOLLOWING TEXT PRESENTS CRITERIA IN TWO PARTS. DESIGN GUIDELINES ARE FEATURES THAT ENHANCE PRACTICE PERFORMANCE, BUT MAY NOT BE NECESSARY FOR ALL APPLICATIONS. REQUIRED ELEMENTS ARE FEATURES THAT SHOULD BE USED IN ALL APPLICATIONS. A FACT SHEET AT THE BACK OF EACH SECTION HIGHLIGHTS THE REQUIRED ELEMENTS.

APPENDICES F AND G PROVIDE EXAMPLE CHECKLISTS FOR THE CONSTRUCTION AND OPERATION&MAINTENANCE OF EACH OF THE PRACTICE TYPES.

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Section 6.1 Stormwater Ponds

Stormwater ponds are practices that have either a permanent pool of water, or a combination of a permanent pool and extended detention, and some elements of a shallow marsh equivalent to the entire WQ_v. Five design variants include:

- P-1 Micropool Extended Detention Pond (Figure 6.1)
- P-2 Wet Pond (Figure 6.2)
- P-3 Wet Extended Detention Pond (Figure 6.3)
- P-4 Multiple Pond System (Figure 6.4)
- P-5 Pocket Pond (Figure 6.5)

Treatment Suitability:

Dry extended detention ponds without a permanent pool are not considered an acceptable option for meeting water quality treatment goals. Each of the five stormwater pond designs can be used to provide channel protection volume as well as overbank and extreme flood attenuation. The term "pocket" refers to a pond or wetland that has such a small contributing drainage area that little or no baseflow is available to sustain water elevations during dry weather. Instead, water elevations are heavily influenced, and in some cases maintained, by a locally high water table.

IMPORTANT NOTES:

ANY PRACTICE THAT CREATES A DAM IS REQUIRED TO FOLLOW THE GUIDANCE PRESENTED IN THE *GUIDELINES FOR DESIGN OF DAMS* AND MAY REQUIRE A PERMIT FROM THE NYSDEC. FOR THE MOST RECENT COPY OF THIS DOCUMENT, CONTACT THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, DAM SAFETY DIVISION, AT: 518-402-8151. AN EVALUATION OF HAZARD CLASSIFICATION MUST BE INCLUDED IN THE DESIGN REPORT FOR STORMWATER PONDS CREATED BY A DAM.

WHILE THE STORMWATER PONDS DESIGNED ACCORDING TO THIS GUIDANCE MAY ACT AS A COMMUNITY AMMENITY, AND MAY PROVIDE SOME HABITAT VALUE, THEY CANNOT BE ANTICIPATED TO FUNCTION AS NATURAL LAKES OR PONDS.

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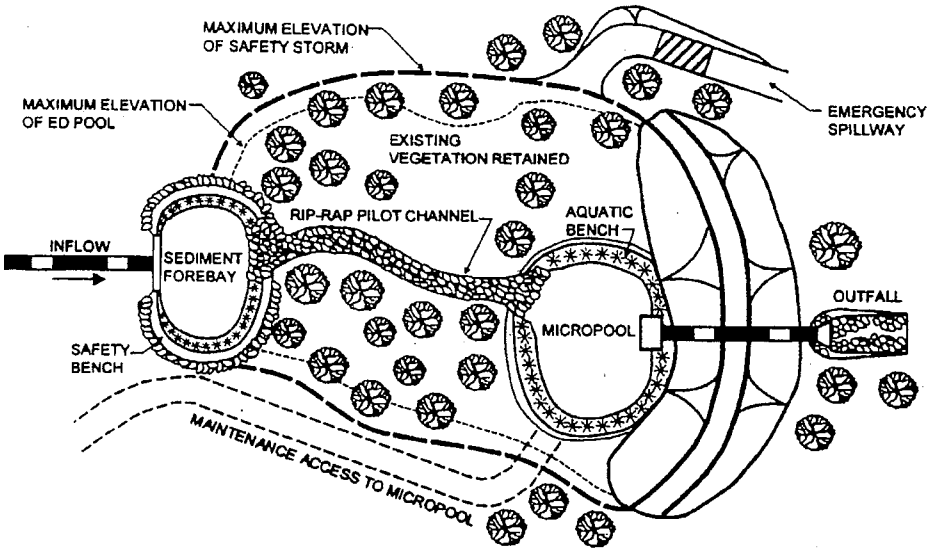
Figure 6.1 Micropool Extended Detention Pond (P-1)



PLAN VIEW

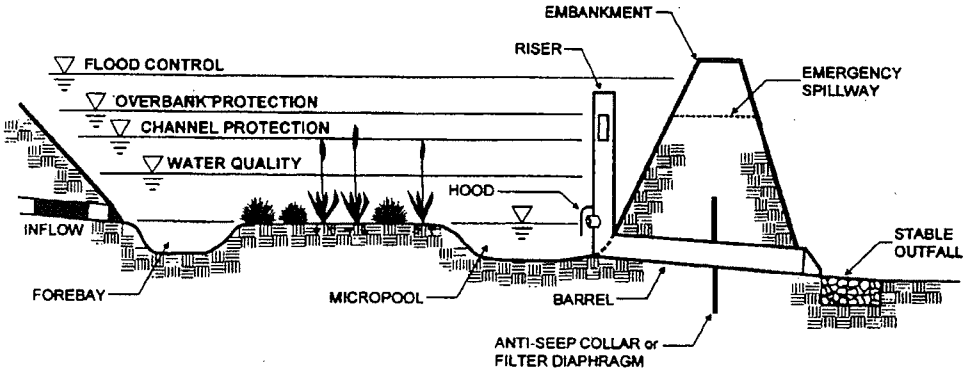


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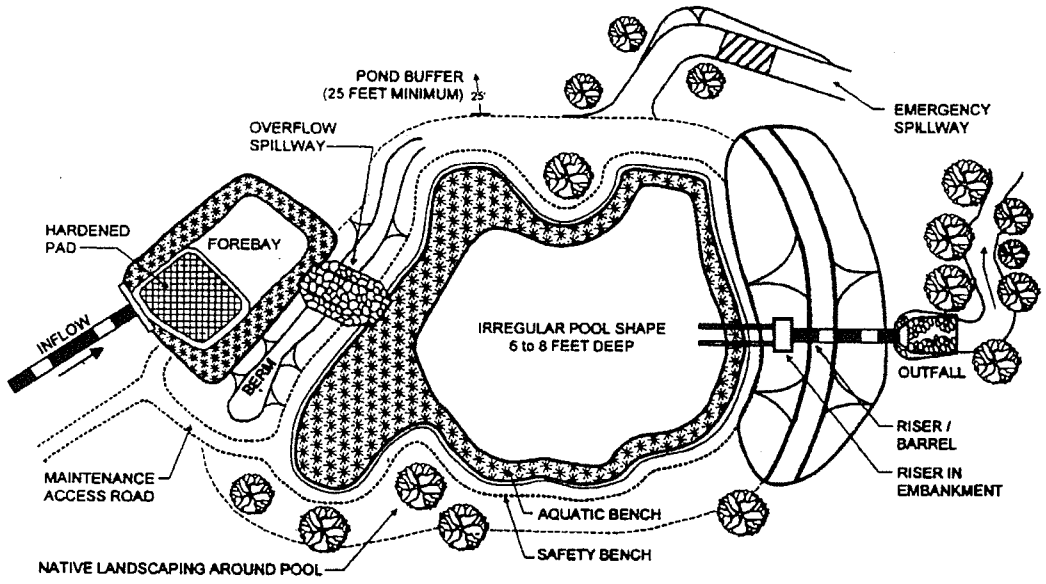
Figure 6.2 Wet Pond (P-2)



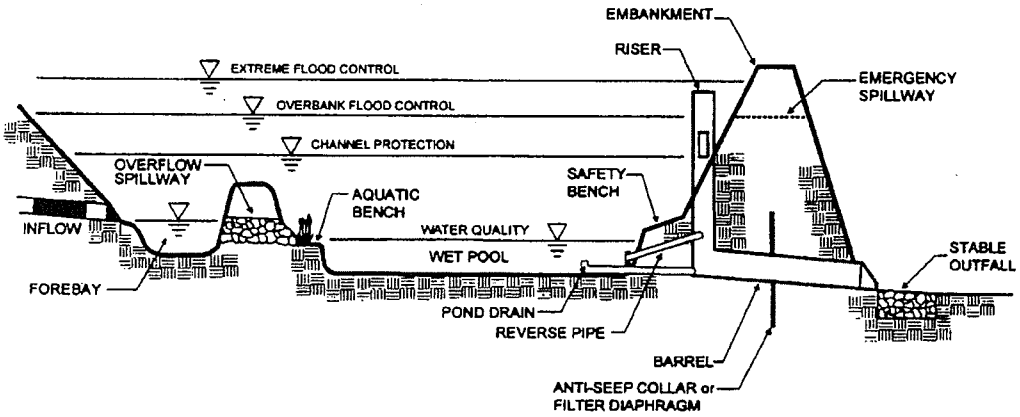


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Figure 6.3 Wet Extended Detention Pond (P-3)

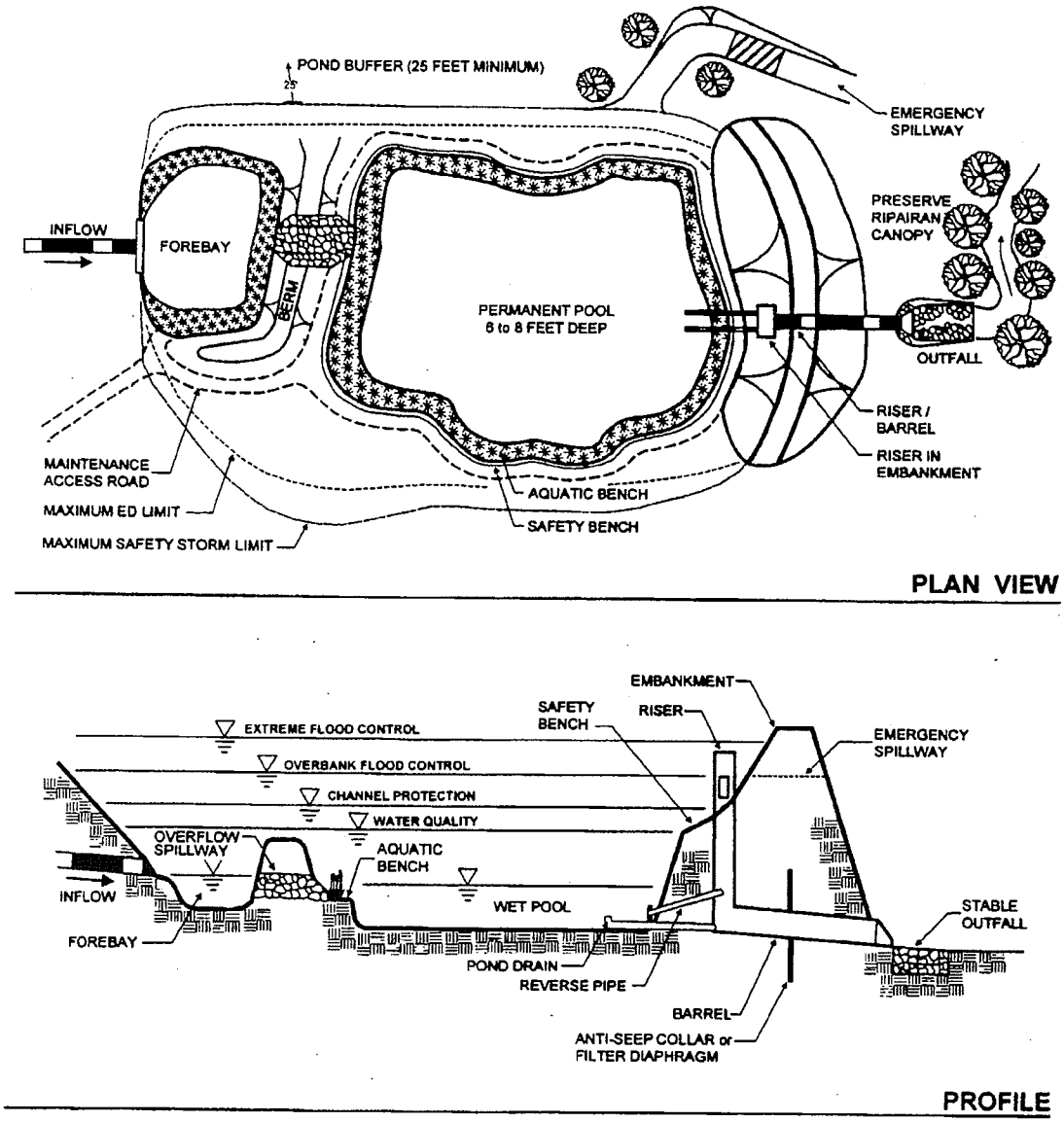

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Figure 6.4 Multiple Pond System (P-4)

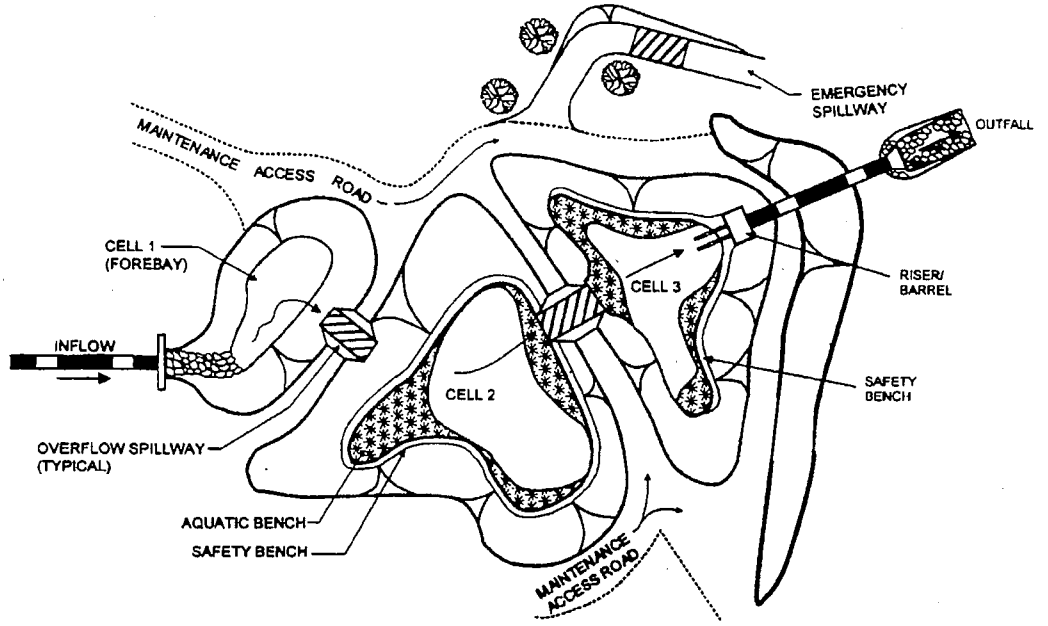

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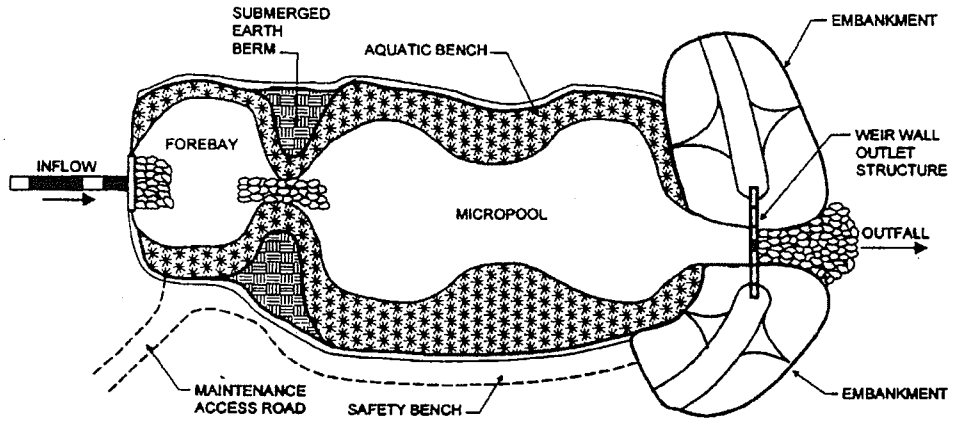
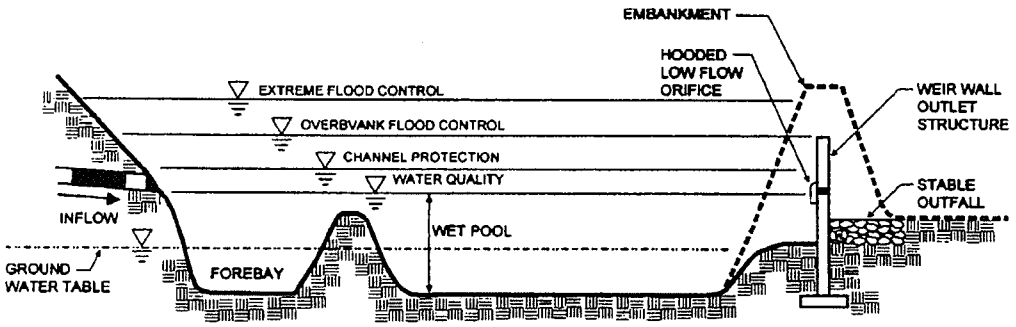
Figure 6.5 Pocket Pond (P-5)



PLAN VIEW



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6.1.1 Feasibility

Required Elements

- Designs P-2, P-3, and P-4 shall have a minimum contributing drainage area of 25 acres. A 10-acre drainage is required for design P-1.
- Stormwater ponds shall not be located within jurisdictional waters, including wetlands.
- Evaluate the site to determine the Hazard Class, and to determine what design elements are required to ensure dam safety (see *Guidelines for Design of Dams)*. For the most recent copy of this document, contact the New York State Department of Environmental Conservation, Dam Safety Division, at: 518-402-8151.
- Avoid direction of hotspot runoff to design P-5.
- Provide a 2' minimum separation between the pond bottom and groundwater in sole source aquifer recharge areas.

Design Guidance

- The use of stormwater ponds (with the exception of design P-1, Micropool Extended Detention Pond) on trout waters is strongly discouraged, as available evidence suggests that these practices can increase stream temperatures.
- Avoid location of pond designs within the stream channel, to prevent habitat degradation caused by these structures.
- A maximum drainage area of five acres is suggested for design P-5.

6.1.2 Conveyance

Inlet Protection

Required Elements

- A forebay shall be provided at each pond inflow point, unless an inflow point provides less than 10% of the total design storm flow to the pond.

Design Guidance

- Inlet areas should be stabilized to ensure that non-erosive conditions exist for at least the 2-year frequency storm event.

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- Except in cold regions of the State, the ideal inlet configuration is a partially submerged (i.e., ½ full) pipe.

Adequate Outfall Protection

Required Elements

- The channel immediately below a pond outfall shall be modified to prevent erosion and conform to natural dimensions in the shortest possible distance, typically by use of appropriately-sized riprap placed over filter cloth. Typical examples include submerged earthen berms, concrete weirs, and gabion baskets.
- A stilling basin or outlet protection shall be used to reduce flow velocities from the principal spillway to non-erosive velocities (3.5 to 5.0 fps). (See Appendix L for a table of erosive velocities for grass and soil).

Design Guidance

- Outfalls should be constructed such that they do not increase erosion or have undue influence on the downstream geomorphology of the stream.
- Flared pipe sections that discharge at or near the stream invert or into a step-pool arrangement should be used at the spillway outlet.
- If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of riprap should be avoided to reduce stream warming.

Pond Liners

Design Guidance

- When a pond is located in gravelly sands or fractured bedrock, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include: (a) six to 12 inches of clay soil (minimum 15% passing the #200 sieve and a minimum permeability of 1 x 10^{-5} cm/sec), (b) a 30 ml poly-liner (c) bentonite, (d) use of chemical additives (*see NRCS Agricultural Handbook No. 386*, dated 1961, or *Engineering Field Manual*) or (e) a design prepared by a Professional Engineer registered in the State of New York.

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6.1.3 Pretreatment

Required Elements

- A sediment forebay is important for maintenance and longevity of a stormwater treatment pond. Each pond shall have a sediment forebay or equivalent upstream pretreatment. The forebay shall consist of a separate cell, formed by an acceptable barrier. Typical examples include earthen berms, concrete weirs, and gabion baskets.
- The forebay shall be sized to contain 10% of the water quality volume (WQ_v), and shall be four to six feet deep. The forebay storage volume counts toward the total WQ_v requirement.
- The forebay shall be designed with non-erosive outlet conditions, given design exit velocities.
- Direct access for appropriate maintenance equipment shall be provided to the forebay.
- In sole source aquifers, 100% of the WQ_v for stormwater runoff from designated hotspots shall be provided in pretreatment.

Design Guidance

- A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time.
- The bottom of the forebay may be hardened to ease sediment removal

6.1.4 Treatment

Minimum Water Quality Volume (WQ_v)

Required Elements

- Provide water quality treatment storage to capture the computed WQ_v from the contributing drainage area through a combination of permanent pool, extended detention (WQ_v-ED) and marsh. The division of storage into permanent pool and extended detention is outlined in Table 6.1.

Table 6.1 Water Quality Volume Distribution in Pond Designs

Design Variation	%WQ_v	
	Permanent Pool	Extended Detention
P-1	20% min.	80% max.
P-2	100%	0%
P-3	50% min.	50% max.
P-4	50% min.	50% max.
P-5	50% min.	50% max.

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- Although both CP_v and WQ_v-ED storage can be provided in the same practice, WQ_v cannot be met by simply providing Cp_v storage for the one-year storm.

Design Guidance

- It is generally desirable to provide water quality treatment off-line when topography, hydraulic head and space permit (i.e., apart from stormwater quantity storage; see Appendix K for a schematic).
- Water quality storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and marsh).

Minimum Pond Geometry

Required Elements

- The minimum length to width ratio for the pond is 1.5:1 (i.e., length relative to width).
- Provide a minimum Surface Area:Drainage Area of 1:100.

Design Guidance

- To the greatest extent possible, maintain a long flow path through the system, and design ponds with irregular shapes.

6.1.5 Landscaping

Pond Benches

Required Elements

- The perimeter of all deep pool areas (four feet or greater in depth) shall be surrounded by two benches:
  - Except when pond side slopes are 4:1 (h:v) or flatter, provide a safety bench that generally extends 15 feet outward (10' to 12' allowable on sites with extreme space limitations) from the normal water edge to the toe of the pond side slope. The maximum slope of the safety bench shall be 6%; *and*

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- Incorporate an aquatic bench that generally extends up to 15 feet inward from the normal shoreline, has an irregular configuration, and a maximum depth of 18 inches below the normal pool water surface elevation.

Landscaping Plan

Required Elements

- A landscaping plan for a stormwater pond and its buffer shall be prepared to indicate how aquatic and terrestrial areas will be vegetatively stabilized and established.

Design Guidance

- Wherever possible, wetland plants should be encouraged in a pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes (ED wetlands) or within shallow areas of the pool itself.
- The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within six inches (plus or minus) of the normal pool.
- The soils of a pond buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration, and therefore, may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites, and backfill these with uncompacted topsoil.
  - As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the rootball (of balled and burlap stock), and five times deeper and wider for container grown stock. This practice should enable the stock to develop unconfined root systems. Avoid species that require full shade, are susceptible to winterkill, or are prone to wind damage. Extra mulching around the base of the tree or shrub is strongly recommended as a means of conserving moisture and suppressing weeds.

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Pond Buffers and Setbacks

Required Elements

- A pond buffer shall be provided that extends 25 feet outward from the maximum water surface elevation of the pond. The pond buffer shall be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers). An additional setback may be provided to permanent structures.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure.

Design Guidance

- Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To help discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers.
- Annual mowing of the pond buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.

6.1.6 Maintenance

Required Elements

- Maintenance responsibility for a pond and its buffer shall be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.
- The principal spillway shall be equipped with a removable trash rack, and generally accessible from dry land.
- Sediment removal in the forebay shall occur every five to six years or after 50% of total forebay capacity has been lost.

Design Guidance

- Sediments excavated from stormwater ponds that do not receive runoff from designated hotspots are generally not considered toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing may be required prior to sediment disposal when a hotspot land use is present (see Section 4.8 for a list of potential hotspots).

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- Sediment removed from stormwater ponds should be disposed of according to an approved comprehensive operation and maintenance plan.

Maintenance Access

Required Elements

- A maintenance right of way or easement shall extend to the pond from a public or private road.

Design Guidance

- Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access should extend to the forebay, safety bench, riser, and outlet and be designed to allow vehicles to turn around.

Non-clogging Low Flow Orifice

Required Elements

- A low flow orifice shall be provided, with the size for the orifice sufficient to ensure that no clogging shall occur. (See Appendix K for details of a low flow orifice and trash rack options).

Design Guidance

- The low flow orifice should be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 3") or by internal orifice protection that may allow for smaller diameters (recommended minimum orifice of 1").
- The preferred method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point one foot below the normal pool elevation.
- Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 12 inches below the normal pool.
- The use of horizontally extended perforated pipe protected by geotextile fabric and gravel is not recommended. Vertical pipes may be used as an alternative if a permanent pool is present.

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Riser in Embankment

Required Elements

- The riser shall be located within the embankment for maintenance access, safety and aesthetics.

Design Guidance

- Access to the riser should be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls. The principal spillway opening should be "fenced" with pipe or rebar at 8-inch intervals (for safety purposes).

Pond Drain

Required Elements

- Except where local slopes prohibit this design, each pond shall have a drain pipe that can completely or partially drain the pond. The drain pipe shall have an elbow or protected intake within the pond to prevent sediment deposition, and a diameter capable of draining the pond within 24 hours.

Design Guidance

- Care should be exercised during pond drawdowns to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The approving jurisdiction should be notified before draining a pond.

Adjustable Gate Valve

Required Elements

- Both the WQ_v-ED pipe and the pond drain shall be equipped with an adjustable gate valve (typically a handwheel activated knife gate valve).
- Valves shall be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner.

Design Guidance

- Both the WQ_v-ED pipe and the pond drain should be sized one pipe size greater than the calculated design diameter.

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- To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step or other fixed object.

Safety Features

Required Elements

- Side slopes to the pond shall not exceed 3:1 (h:v), and shall terminate at a safety bench.
- The principal spillway opening shall not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter shall be fenced to prevent a hazard.

Design Guidance

- Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool.
- Warning signs prohibiting swimming and skating may be posted.
- Pond fencing is generally not encouraged, but may be required by some municipalities. A preferred method is to manage the contours of the pond to eliminate dropoffs or other safety hazards.

6.1.7 Cold Climate Pond Design Considerations

Inlets, outlet structures and outfall protection for pond systems require modifications to function well in cold climates. Among the problems those wishing to use stormwater ponds in cold climates may encounter are:

- Higher runoff volumes and increased pollutant loads during the spring melt
- Pipe freezing and clogging
- Ice formation on the permanent pool
- Road sand build-up

Higher runoff volumes and increased pollutant loads during the spring melt

- Operate the pond based on seasonal inputs by adjusting dual water quality outlets to provide additional storage (see Figure 6.6).
- Adapt sizing based on snowmelt characteristics (see Appendix I).
- Do not drain ponds during the spring season. Due to temperature stratification and high chloride concentrations at the bottom, the water may become highly acidic and anoxic and may cause negative downstream effects.

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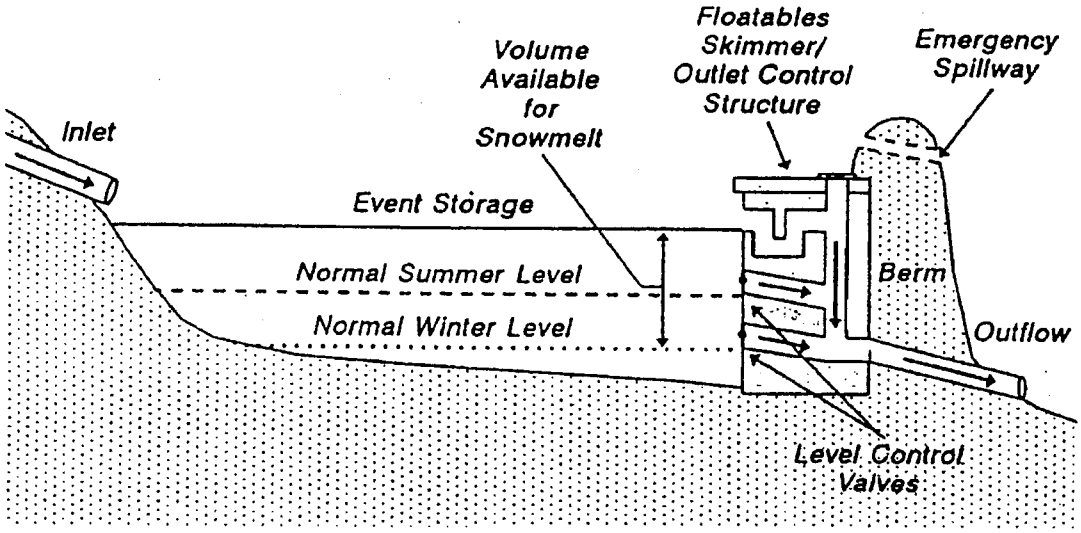
Pipe Freezing and Clogging

- Inlet pipes should not be submerged, since this can result in freezing and upstream damage or flooding.
- Bury all pipes below the frost line to prevent frost heave and pipe freezing. Bury pipes at the point furthest from the pond deeper than the frost line to minimize the length of pipe exposed.
- Increase the slope of inlet pipes to a minimum of 1% to prevent standing water in the pipe, reducing the potential for ice formation. This design may be difficult to achieve at sites with flat local slopes.
- If perforated riser pipes are used, the minimum orifice diameter should be ½". In addition, the pipe should have a minimum 6" diameter.
- When a standard weir is used, the minimum slot width should be 3", especially when the slot is tall.
- Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of baseflow through the system (see Appendix K).
- In cold climates, riser hoods and reverse slope pipes should draw from at least 6" below the typical ice layer. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet.
- Trash racks should be installed at a shallow angle to prevent ice formation (see Appendix K).

Figure 6.6 Seasonal Operation Pond



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Ice Formation on the Permanent Pool

- In cold climates, the treatment volume of a pond system should be adjusted to account for ice build-up on the permanent pool by providing one foot of elevation above the WQ_v. The total depth of the pond, including this additional elevation, should not exceed eight feet.
- Using pumps or bubbling systems can reduce ice build-up and prevent the formation of an anaerobic zone in pond bottoms.
- Provide some storage as extended detention. This recommendation is made for very cold climates to provide detention while the permanent pond is iced over. In effect, it discourages the use of wet ponds (P-2), replacing them with wet extended detention ponds (P-3).
- Multiple pond systems are recommended regardless of climate because they provide redundant treatment options. In cold climates, a berm or simple weir should be used instead of pipes to separate multiple ponds, due to their higher freezing potential.

Road Sand Build-up

- In areas where road sand is used, an inspection of the forebay and pond should be scheduled after the spring melt to determine if dredging is necessary. For forebays, dredging is needed if one half of the capacity of the forebay is full.

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Stormwater Ponds



Description:
Constructed stormwater retention basin that has a permanent pool (or micropool). Runoff from each rain event is detained and treated in the pool through settling and biological uptake mechanisms.

Design Options:
Micropool Extended Detention (P-1), Wet Pond (P-2), Wet Extended Detention (P-3), Multiple Pond (P-4), Pocket Pond (P-5)

KEY CONSIDERATIONS

FEASIBILITY
- Contributing drainage area greater than 10 acres for P-1, 25 acres for P-2 to P-4.
- Follow DEC Guidelines for Design of Dams.
- Provide a minimum 2' separation from the groundwater in sole source aquifers.
- Do not locate ponds in jurisdictional wetlands.
- Avoid directing hotspot runoff to design P-5.

CONVEYANCE
- Forebay at each inlet, unless the inlet contributes less than 10% of the total inflow, 4' to 6' deep.
- Stabilize the channel below the pond to prevent erosion.
- Stilling basin at the outlet to reduce velocities.

PREATREATMENT
- Forebay volume at least 10% of the WQ_v
- Forebay shall be designed with non-erosive outlet conditions.
- Provide direct access to the forebay for maintenance equipment
- In sole source aquifers, provide 100% pretreatment for hotspot runoff.

TREATMENT
- Provide the water quality volume in a combination of permanent pool and extended detention (Table 6.1 in manual provides limitations on storage breakdown)
- Minimum length to width ratio of 1.5:1
- Minimum surface area to drainage area ratio of 1:100

LANDSCAPING
- Provide a minimum 10' and preferably 15' safety bench extending from the high water mark, with a maximum slope of 6%.
- Provide an aquatic bench extending 15 feet outward from the shoreline, and a maximum depth of 18" below normal water elevation.
- Develop a landscaping plan.
- Provide a 25'pond buffer.
- No woody vegetation within 15 feet of the toe of the embankment, or 25 feet from the principal spillway.

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [X] **Channel Protection**
- [X] **Overbank Flood Protection**
- [X] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes*
(2 feet minimum separation distance required to water table)

FEASIBILITY CONSIDERATIONS

- [L] **Cost**
- [L] **Maintenance Burden**

Key: **L**=Low **M**=Moderate **H**=High

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *No*

Soils: *Hydrologic group 'A' soils may require pond liner*

Hydrologic group 'D' soils may have compaction constraints

Other Considerations:
- *Thermal effects*
- *Outlet clogging*
- *Safety bench*

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MAINTENANCE REQUIREMENTS

- Legally binding maintenance agreement
- Sediment removal from forebay every five to six years or when 50% full.
- Provide a maintenance easement and right-of-way.
- Removable trash rack on the principal spillway.
- Non-clogging low flow orifice
- Riser in the embankment.
- Pond drain required, capable of drawing down the pond in 24 hours.
- Notification required for pond drainage.
- Provide an adjustable gate valve on both the WQ_v-ED pipe, and the pond drain.
- Side Slopes less than 3:1, and terminate at a safety bench.
- Principal spillway shall not permit access by small children, and endwalls above pipes greater than 48" in diameter shall be fenced.

POLLUTANT REMOVAL

G	**Phosphorus**
G	**Nitrogen**
G	**Metals** - Cadmium, Copper, Lead, and Zinc removal
G	**Pathogens** Coliform, E.Coli, Streptococci removal

Key: **G**=Good **F**=Fair **P**=Poor

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Section 6.2 Stormwater Wetlands

Stormwater wetlands are practices that create shallow marsh areas to treat urban stormwater and often incorporate small permanent pools and/or extended detention storage to achieve the full WQv. Design variants include:

- W-1 Shallow Wetland (Figure 6.7)
- W-2 ED Shallow Wetland (Figure 6.8)
- W-3 Pond/Wetland System (Figure 6.9)
- W-4 Pocket Wetland (Figure 6.10)

Wetland designs W-1 through W-4 can be used to provide Channel Protection volume as well as Overbank and Extreme Flood attenuation. In these design variations, the permanent pool is stored in a depression excavated into the ground surface. Wetland plants are planted at the wetland bottom, particularly in the shallow regions.

IMPORTANT NOTES

ALL OF THE POND CRITERIA PRESENTED IN PERFORMANCE CRITERIA – PONDS (CHAPTER 6.1) ALSO APPLY TO THE DESIGN OF STORMWATER WETLANDS. ADDITIONAL CRITERIA THAT GOVERN THE GEOMETRY AND ESTABLISHMENT OF CREATED WETLANDS ARE PRESENTED IN THIS SECTION.

ANY PRACTICE THAT CREATES A DAM IS REQUIRED TO FOLLOW THE GUIDANCE PRESENTED IN THE *GUIDELINES FOR DESIGN OF DAMS* AND MAY REQUIRE A PERMIT FROM THE NYSDEC. FOR THE MOST RECENT COPY OF THIS DOCUMENT, CONTACT THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, DAM SAFETY DIVISION, AT: 518-402-8151. AN EVALUATION OF HAZARD CLASSIFICATION MUST BE INCLUDED IN THE DESIGN REPORT FOR STORMWATER WETLANDS CREATED BY A DAM.

WHILE THE STORMWATER WETLANDS DESIGNED ACCORDING TO THIS GUIDANCE MAY ACT AS A COMMUNITY AMMENITY, AND MAY PROVIDE SOME HABITAT VALUE, THEY CANNOT BE ANTICIPATED TO FUNCTION AS NATURAL WETLANDS

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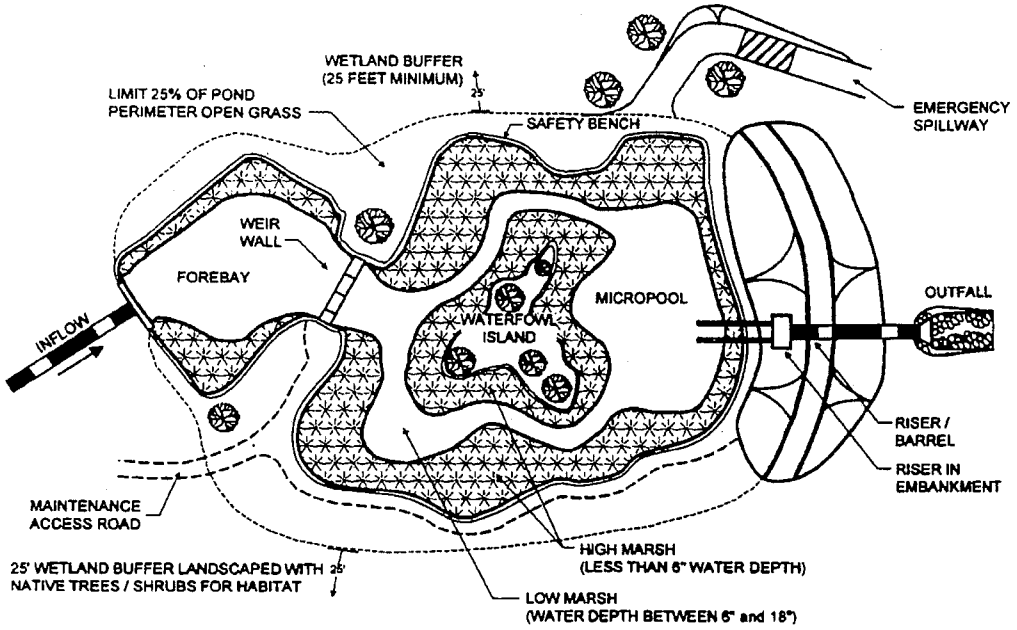
Figure 6.7 Shallow Wetland (W-1)



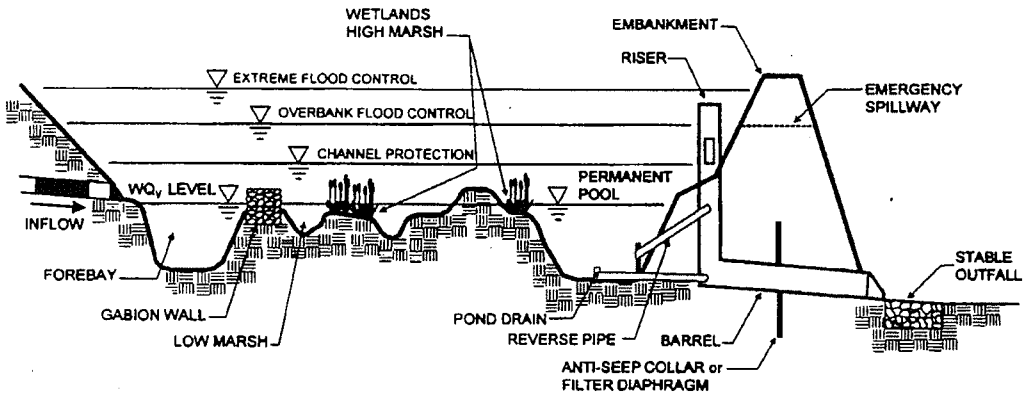


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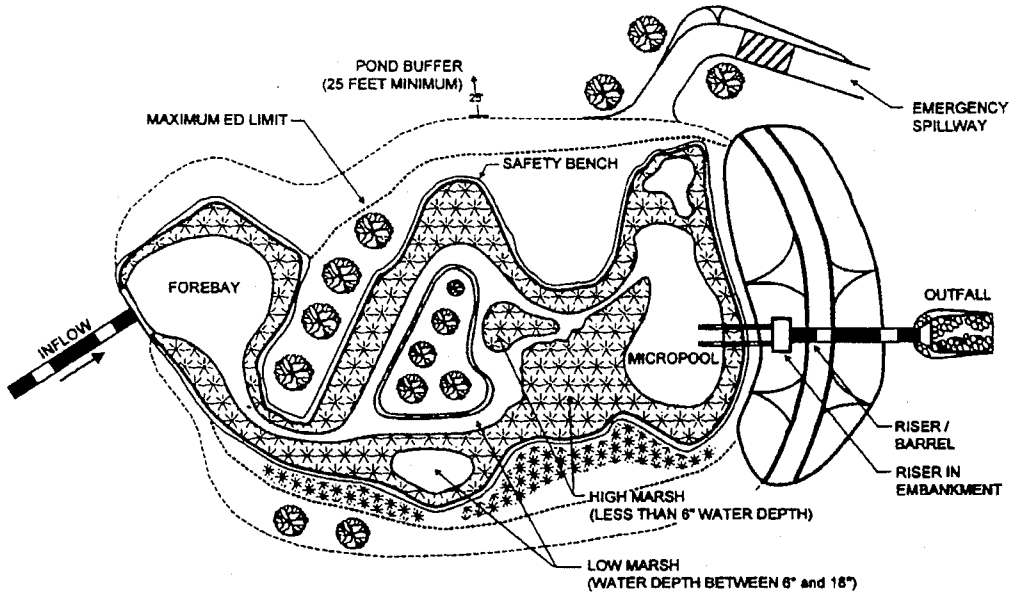
Figure 6.8 Extended Detention Shallow Wetland (W-2)



PLAN VIEW

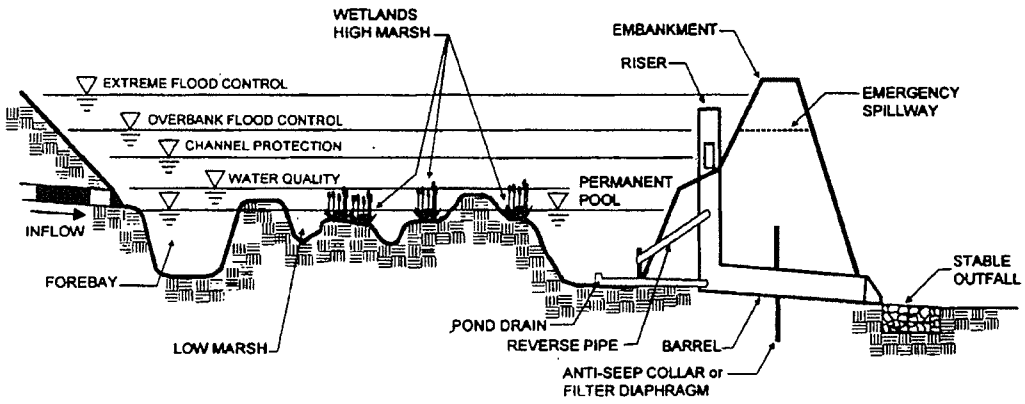


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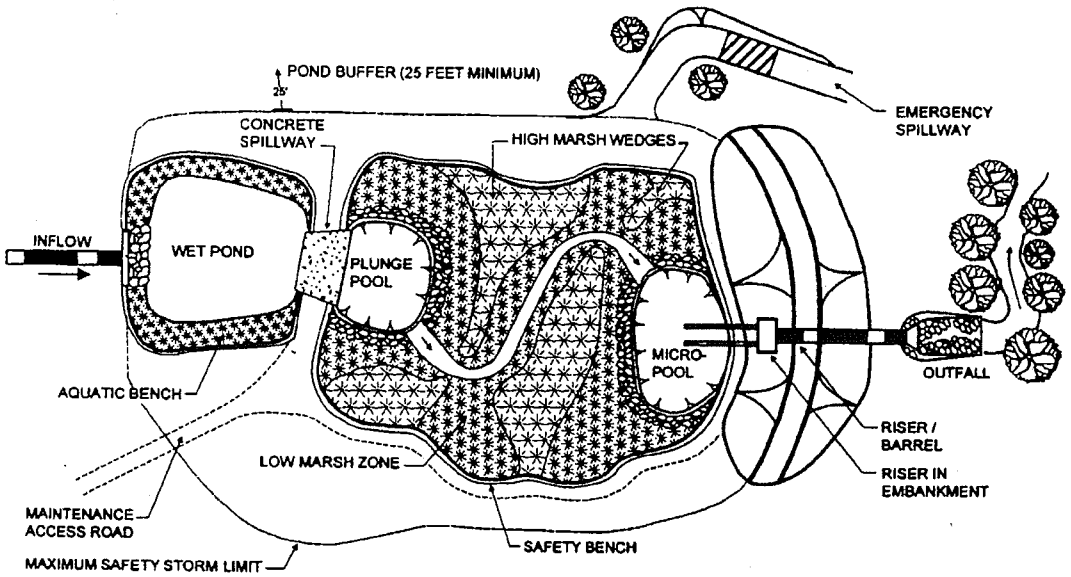
Figure 6.9 Pond/Wetland System (W-3)



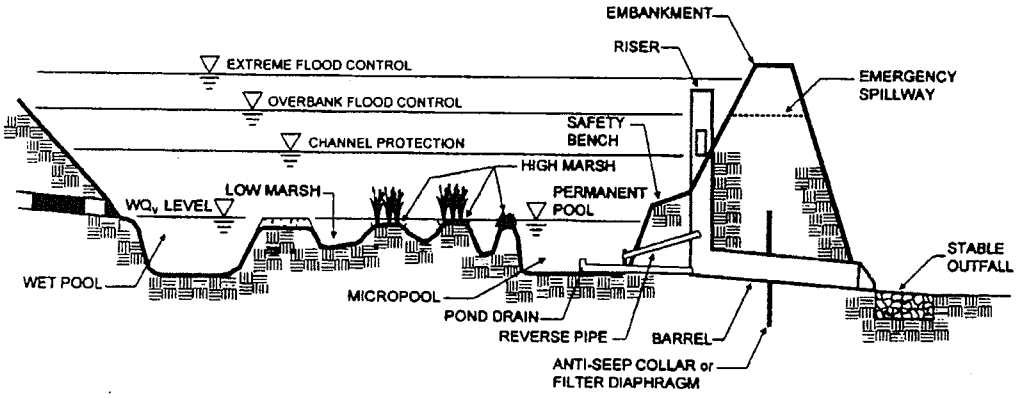


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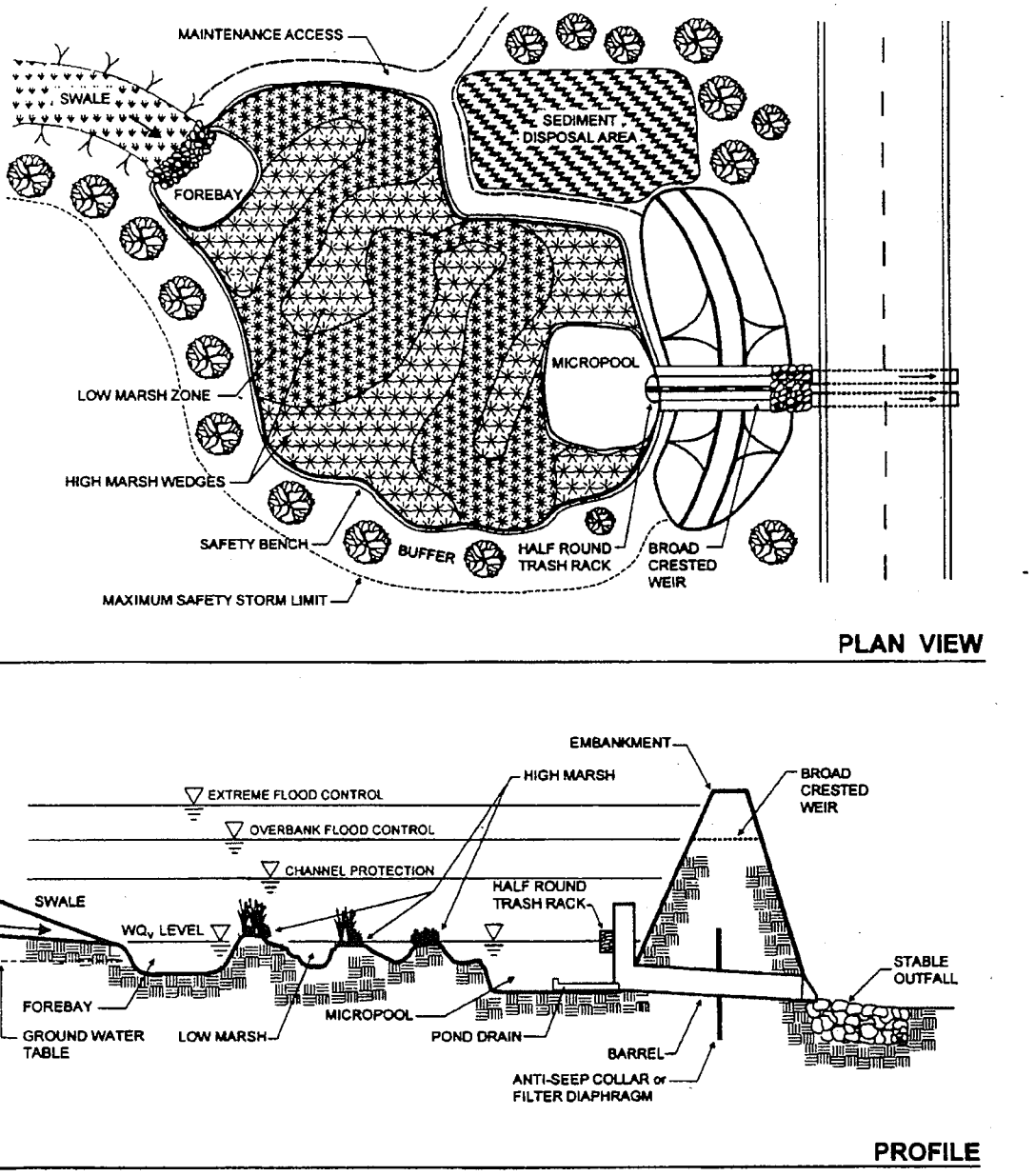
Figure 6.10 Pocket Wetland (W-4)



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6.2.1 *Feasibility*

Design Guidance

- *Stormwater wetlands should not be located within existing jurisdictional wetlands.* In some isolated cases, a permit may be granted to convert an existing degraded wetland in the context of local watershed restoration efforts.
- The use of stormwater wetlands on trout waters is strongly discouraged, as available evidence suggests that these practices can increase stream temperatures.

6.2.2 Conveyance

Required Elements

- Flowpaths from the inflow points to the outflow points of stormwater wetlands shall be maximized.
- A minimum flowpath of 2:1 (length to relative width) shall be provided across the stormwater wetland. This path may be achieved by constructing internal berms (e.g., high marsh wedges or rock filter cells).

Design Guidance

- Microtopography is encouraged to enhance wetland diversity.

6.2.3 Pretreatment

Required Elements

- A forebay shall be located at the inlet, and a four to six foot deep micropool that stores approximately 10% of the WQ_v shall be located at the outlet to protect the low flow pipe from clogging and prevent sediment resuspension.

6.2.4 Treatment

Required Elements

- The surface area of the entire stormwater wetland shall be at least one percent of the contributing drainage area (1.5% for shallow marsh design).
- At least 25% of the WQ_v shall be in deepwater zones with a depth greater than four feet.

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- A minimum of 35% of the total surface of area can have a depth of six inches or less, and at least 65% of the total surface area shall be shallower than 18 inches.
- If extended detention is used in a stormwater wetland, provide a minimum of 50% of the WQ_v in permanent pool; the maximum water surface elevation of WQ_v-ED shall not extend more than three feet above the permanent pool.

Design Guidance

- The bed of stormwater wetlands should be graded to create maximum internal flow path and microtopography.
- To promote greater nitrogen removal, rock beds may be used a medium for growth of wetland plants. The rock should be one to three inches in diameter, placed up to the normal pool elevation, and open to flow-through from either direction.

6.2.5 Landscaping

Required Elements

- A landscaping plan shall be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of pondscaping zones, selection of corresponding plant species, planting plan, sequence for preparing wetland bed (including soil amendments, if needed) and sources of plant material.
- A wetland plant buffer must extend 25 feet outward from the maximum water surface elevation, with an additional 15-foot setback to structures.
- Donor soils for wetland mulch shall not be removed from natural wetlands.

Design Guidance

- Structures such as fascines, coconut rolls, straw bales, or carefully designed stone weirs can be used to create shallow marsh cells in high-energy areas of the stormwater wetland.
- The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers.
- Follow wetland establishment guidelines (see Appendix H).

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6.2.6 Maintenance

Required Elements

- If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, a reinforcement planting is required.

Design Guidance

- Stormwater wetlands that are separated from jurisdictional wetlands and regularly maintained are not typically regulated under State and Federal laws.

6.2.7 Cold Climate Design Considerations

Many of the cold climate concerns for wetlands are very similar to the ones for ponds. Two additional concerns with regards to stormwater wetlands focus on cold climate impacts to wetland plants:

- Short Growing Season
- Chlorides

Short Growing Season

- Planting schedule should reflect the short growing season, perhaps incorporating relatively mature plants, or planting rhizomes during the winter.

Chlorides

- Use in combination with a grassed infiltration area prior to the wetland to provide some infiltration of chlorides to dampen the shock to wetland plants
- Emphasize the pond/wetland design option to dilute chlorides prior to the wetland area. If this option is used, the pond should use the modifications described in Section 6.1.7. The pond system dilutes chlorides before they enter the marsh, protecting wetland plants.
- Consider salt-tolerant plants if wetland treats runoff from roads or parking lots where salt is used as a deicer.

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Stormwater Wetlands



Description: Stormwater wetlands (a.k.a. constructed wetlands) are structural practices that incorporate wetland plants into the design to both store and treat runoff. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake within the practice

Design Options:
Shallow wetland (W-1), Extended Detention Wetland (W-2), Pond/Wetland (W-3), Pocket Wetland (W-4)

KEY CONSIDERATIONS

MUST MEET ALL OF THE REQUIREMENTS OF STORMWATER PONDS.

CONVEYANCE

- Minimum flowpath of 2:1 (length to width)
- Flowpath maximized

PREATREATMENT

- Micropool at outlet, capturing 10% of the WQ_v

TREATMENT

- Minimum drainage area to surface ratio of 1:100
- ED no greater than 50% of entire WQ_v (permanent pool at least 50% of the volume)25% of the WQ_v in deepwater zones.
- 35% of the total surface area in depths six inches or less, and 65% shallower than 18"

LANDSCAPING

- Landscaping plan that indicates methods to establish and maintain wetland coverage. Minimum elements include: delineation of pondscaping zones, selection of species, planting plan, and sequence for bed preparation.
- Wetland buffer 25 feet from maximum surface elevation, with 15 foot additional setback for structures.
- Donor plant material must not be from natural wetlands

MAINTENANCE REQUIREMENTS

- Reinforcement plantings after second season if 50% coverage not achieved

POLLUTANT REMOVAL

G	**Phosphorus**
G	**Nitrogen**
F	**Metals** - Cadmium, Copper, Lead, and Zinc removal
G	**Pathogens** - Coliform, Streptococci, E.Coli removal

Key: G=Good F=Fair P=Poor

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [X] **Channel Protection**
- [X] **Overbank Flood Protection**
- [X] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes*
(2 feet minimum separation distance required to water table)

IMPLEMENTATION CONSIDERATIONS

Capital Cost [M]

Maintenance Burden:

M	Shallow Wetland
M	ED Shallow Wetland
H	Pocket Wetland
M	Pond/Wetland

Residential Subdivision Use: Yes
High-Density/Ultra-Urban: *No*

Soils: *Hydrologic group 'A' and 'B' soils may require liner*

Key : L=Low M=Moderate H=High

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Section 6.3 Stormwater Infiltration

Stormwater infiltration practices capture and temporarily store the WQ_v before allowing it to infiltrate into the soil over a two-day period. Design variants include the following:

- I-1 Infiltration Trench (Figure 6.11)
- I-2 Infiltration Basin (Figure 6.12)
- I-3 Dry Well (Figure 6.13)

Treatment Suitability: Infiltration practices alone typically cannot meet detention (Q_p) and channel protection (Cp_v) requirements, except on sites where the soil infiltration rate is greater than 5.0 in/hr. However, extended detention storage may be provided above an infiltration basin. Extraordinary care should be taken to assure that long-term infiltration rates are achieved through the use of performance bonds, post construction inspection and long-term maintenance.

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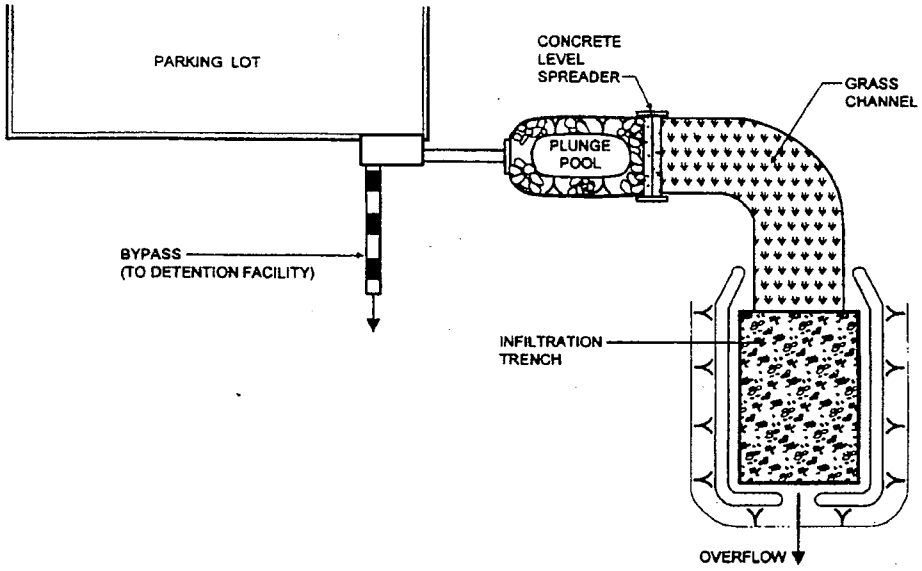
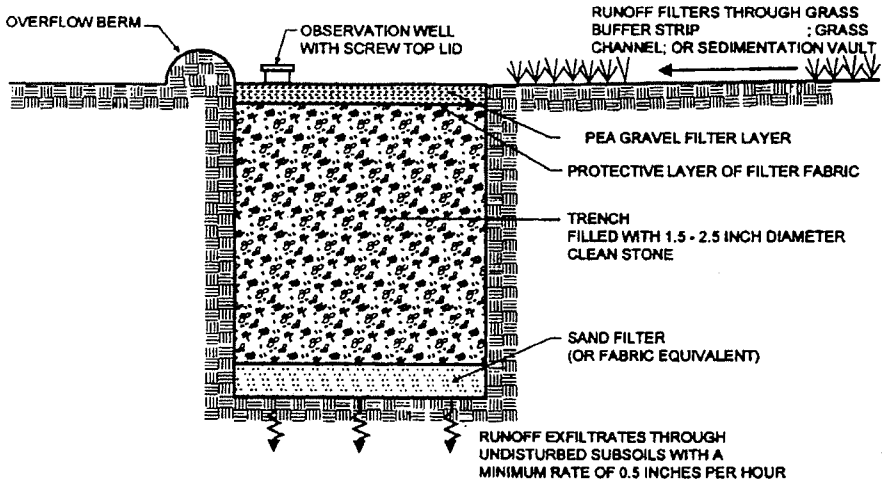
Figure 6.11 Infiltration Trench (I-1)



PLAN VIEW



SECTION

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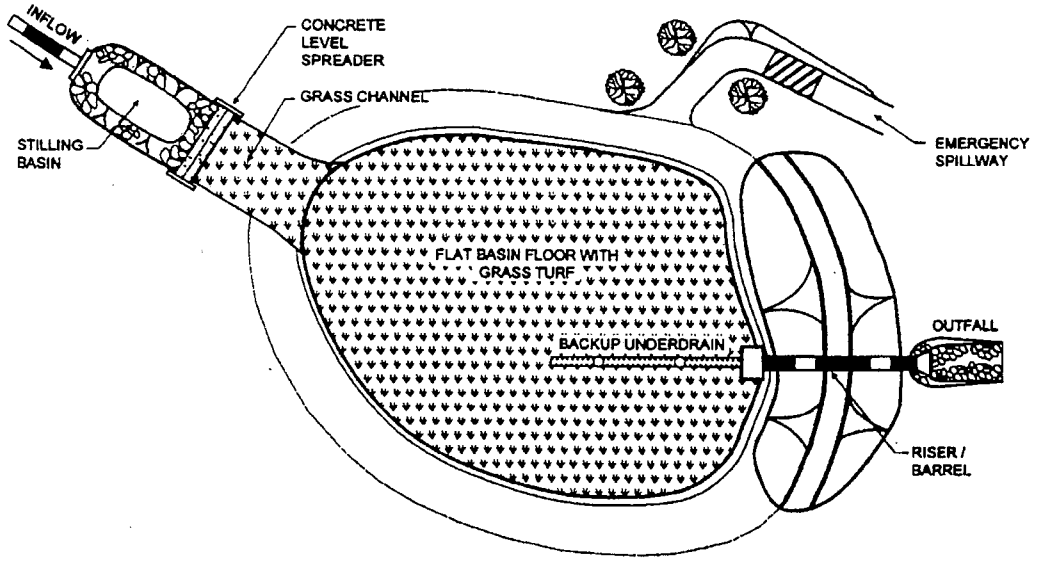
Figure 6.12 Infiltration Basin (I-2)



PLAN VIEW

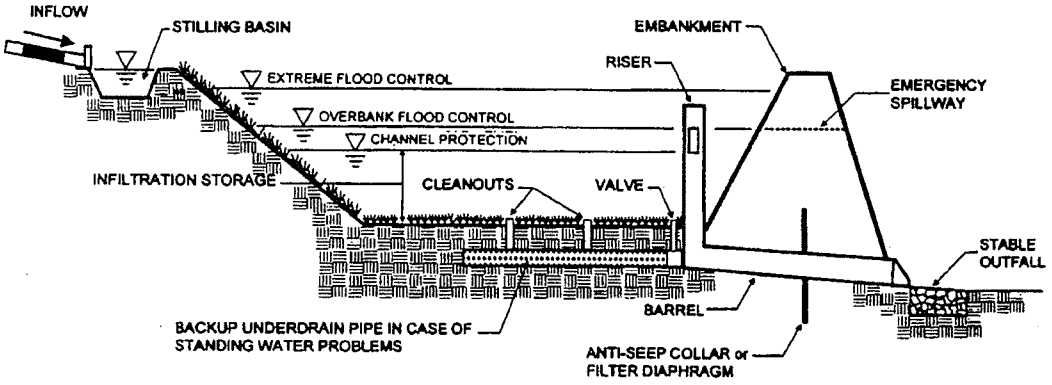


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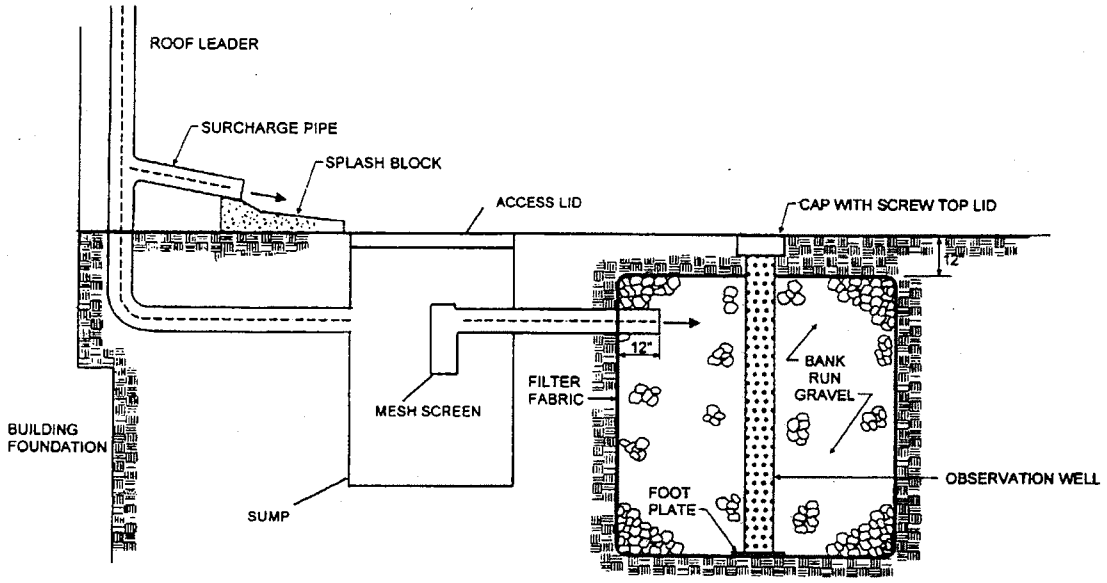
Figure 6.13 Dry Well (I-3)



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6.3.1 Feasibility

Required Elements

- To be suitable for infiltration, underlying soils shall have an infiltration rate (fc) of at least 0.5 inches per hour, as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests (see Appendix D). The minimum geotechnical testing is one test hole per 5000 sf, with a minimum of two borings per facility (taken within the proposed limits of the facility).
- Soils shall also have a clay content of less than 20% and a silt/clay content of less than 40%.
- Infiltration practices cannot be located on areas with natural slopes greater than 15%.
- Infiltration practices cannot be located in fill soils, except the top quarter of an infiltration trench or dry well.
- To protect groundwater from possible contamination, runoff from designated hotspot land uses or activities must not be directed to a formal infiltration facility. In cases where this goal is impossible (e.g., where the storm drain system leads to a large recharge facility designed for flood control), redundant pretreatment must be provided by applying two of the practices listed in Table 5.1 in series, both of which are sized to treat the entire WQ_v.
- The bottom of the infiltration facility shall be separated by at least three feet vertically from the seasonally high water table or bedrock layer, as documented by on-site soil testing. (Four feet in sole source aquifers).
- Infiltration facilities shall be located at least 100 feet horizontally from any water supply well.
- Infiltration practices cannot be placed in locations that cause water problems to downgradient properties. Infiltration trenches and basins shall be setback 25 feet downgradient from structures and septic systems. Dry wells shall be separated a minimum of 10 feet from structures.

Design Guidance

- The maximum contributing area to infiltration basins or trenches should generally be less than five acres. The infiltration basin can theoretically receive runoff from larger areas, provided that the soil is highly permeable (i.e., greater than 5.0 inches per hour). (See Appendix L for erosive velocities of grass and soil).
- The maximum drainage area to dry wells should generally be smaller than one acre, and should include rooftop runoff only.

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6.3.2 Conveyance

Required Elements

- The overland flow path of surface runoff exceeding the capacity of the infiltration system shall be evaluated to preclude erosive concentrated flow during the overbank events. If computed flow velocities exceed erosive velocities (3.5 to 5.0 fps), an overflow channel shall be provided to a stabilized watercourse. (See Appendix L for erosive velocities of grass and soil).
- All infiltration systems shall be designed to fully de-water the entire WQ_v within 48 hours after the storm event.
- If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice must be designed as an off-line practice (see Appendix K for a detail), except when used as a regional flood control practice.

Design Guidance

- For infiltration basins and trenches, adequate stormwater outfalls should be provided for the overflow associated with the 10-year design storm event (non-erosive velocities on the down-slope
- For dry wells, all flows that exceed the capacity of the dry well should be passed through the surcharge pipe.

6.3.3 Pretreatment

Required Elements

- A minimum pretreatment volume of 25% of the WQ_v must be provided prior to entry to an infiltration facility, and can be provided in the form of a sedimentation basin, sump pit, grass channel, plunge pool or other measure.
- If the f_c for the underlying soils is greater than 2.00 inches per hour, a minimum pretreatment volume of 50% of the WQ_v must be provided.
- If the f_c for the underlying soils is greater than 5.00 inches per hour, 100% of the WQ_v shall be pre-treated prior to entry into an infiltration facility.
- Exit velocities from pretreatment chambers shall be non-erosive (3.5 to 5.0 fps) during the two-year design storm). (See Appendix L for erosive velocities of grass and soil).

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Pretreatment Techniques to Prevent Clogging

Infiltration basins or trenches can have redundant methods to ensure the long-term integrity of the infiltration rate. The following techniques are pretreatment options for infiltration practices:

- Grass channel (Maximum velocity of 1 fps for water quality flow. See the Fact Sheet on page 5-10 for more detailed design information.)
- Grass filter strip (minimum 20 feet and only if sheet flow is established and maintained)
- Bottom sand layer (for I-1)
- Upper sand layer (for I-1; 6" minimum with filter fabric at sand/gravel interface)
- Use of washed bank run gravel as aggregate
- Alternatively, a pre-treatment settling chamber may be provided and sized to capture the pretreatment volume. Use the method prescribed in section 6.4.3 (i.e., the Camp-Hazen equation) to size the chamber.
- Plunge Pool
- An underground trap with a permanent pool between the downspout and the dry well (I-3)

Design Guidance

- The sides of infiltration trenches and dry wells should be lined with an acceptable filter fabric that prevents soil piping.
- In infiltration trench designs, incorporate a fine gravel or sand layer above the coarse gravel treatment reservoir to serve as a filter layer.

6.3.4 Treatment

Required Elements

- Infiltration practices shall be designed to exfiltrate the entire WQ_v through the floor of each practice (sides are not considered in sizing).
- The construction sequence and specifications for each infiltration practice shall be precisely followed. Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction
- Calculate the surface area of infiltration trenches as:

$$A_p = V_w / (nd_t)$$

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Where:

A_p = surface area (sf)
V_W = design volume (e.g., WQ_V) (ft^3)
n = porosity (assume 0.4)
d_t = trench depth (maximum of four feet, and separated at least three feet from seasonally high groundwater) (ft)

- Calculate the approximate bottom area of infiltration basins using the following equation:

$$A = V_w/d_b$$

Where:

A = surface area of the basin (ft^2)
d_b = depth of the basin (ft)

Note that in trapezoidal basins, this area should first be used to approximate the area at the bottom of the basin, but can later be modified to account for additional storage provided above side slopes.

Design Guidance

- Infiltration practices are best used in conjunction with other practices, and downstream detention is often needed to meet the Cp_v and Q_p sizing criteria.
- A porosity value (V_v/V_t) of 0.4 can be used to design stone reservoirs for infiltration practices.

The bottom of the stone reservoir should be completely flat so that infiltrated runoff will be able to infiltrate through the entire surface.

6.3.5 Landscaping

Required Elements

- Upstream construction shall be completed and stabilized before connection to a downstream infiltration facility. A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility.
- Infiltration trenches shall not be constructed until all of the contributing drainage area has been completely stabilized.

Design Guidance

- Mow upland and adjacent areas, and seed bare areas.

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6.3.6 Maintenance

Required Elements

- Infiltration practices shall never serve as a sediment control device during site construction phase. In addition, the Erosion and Sediment Control plan for the site shall clearly indicate how sediment will be prevented from entering an infiltration facility. Normally, the use of diversion berms around the perimeter of the infiltration practice, along with immediate vegetative stabilization and/or mulching can achieve this goal.
- An observation well shall be installed in every infiltration trench and dry well, consisting of an anchored six- inch diameter perforated PVC pipe with a lockable cap installed flush with the ground surface.
- Direct access shall be provided to infiltration practices for maintenance and rehabilitation. If a stone reservoir or perforated pipe is used to temporarily store runoff prior to infiltration, the practice shall not be covered by an impermeable surface.

Design Guidance

- OSHA trench safety standards should be consulted if the infiltration trench will be excavated more than five feet.
- Infiltration designs should include dewatering methods in the event of failure. Dewatering can be accomplished with underdrain pipe systems that accommodate drawdown.

6.3.7 Cold Climate Design Considerations

Because of additional challenges in cold climates, infiltration SMPs need design modifications to function properly. These modifications address the following problems:

- Reduced infiltration into frozen soils
- Chlorides

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Reduced Infiltration

- Draining the ground beneath an infiltration system with an underdrain can increase cold weather soil infiltration.
- Another alternative is to divide the treatment volume between an infiltration SMP and another SMP to provide some treatment during the winter months.
- A seasonally operated infiltration/detention facility combines several techniques to improve the performance of infiltration SMPs in cold climates. Two features, the underdrain system and level control valves, are useful in cold climates. The level control and valves are opened at the beginning of the winter season and the soil is allowed to drain. As the snow begins to melt in the spring, the valves are closed, and the snowmelt is infiltrated until the capacity of the soil is reached. After this point, the facility acts as a detention facility, providing storage for particles to settle (Figure 6.14)

Chlorides

- Consider diverting snowmelt runoff past infiltration devices, especially in regions where chloride concentration in groundwater is a concern.
- Incorporate mulch into infiltration basin soil to mitigate problems with soil fertility.
- The selection of upland landscaping materials should include salt-tolerant grasses where appropriate.

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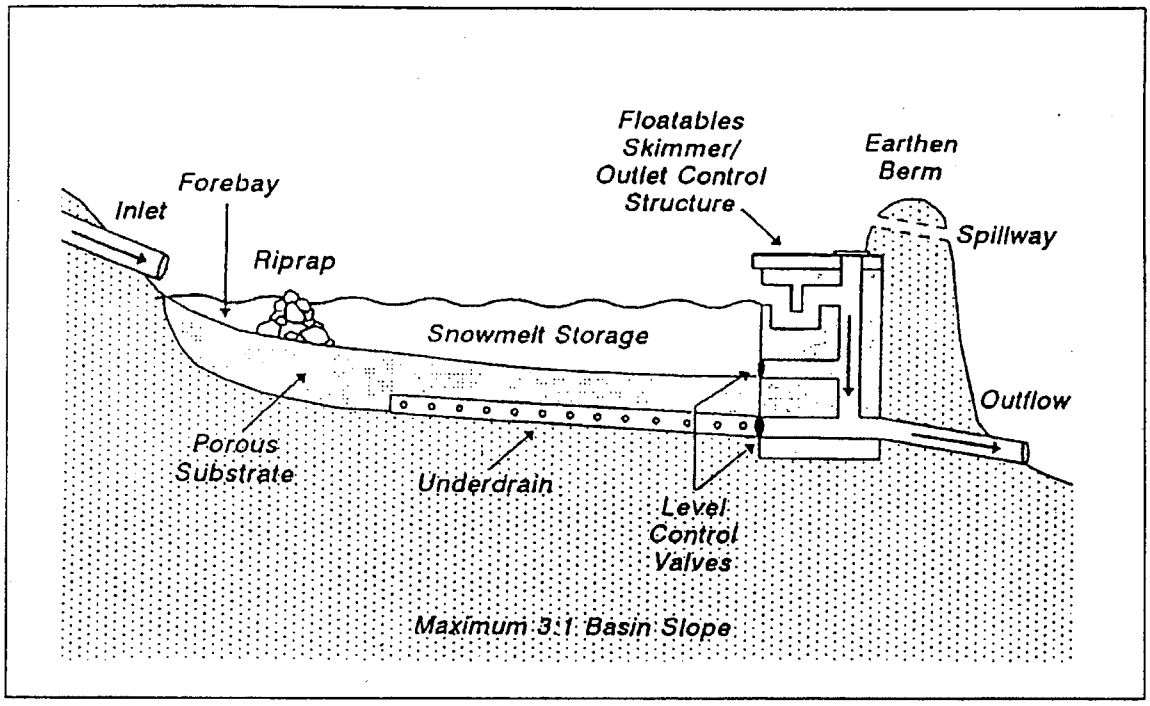
Figure 6.14 Seasonal Operation Infiltration Facility



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Infiltration Practices



Description: Excavated trench or basin used to capture and allow infiltration of stormwater runoff into the surrounding soils from the bottom and sides of the basin or trench.

Design Options:
Infiltration Trench (I-1), Shallow Infiltration Basin (I-2), Dry Well (I-3)

KEY CONSIDERATIONS

FEASIBILITY

- Minimum soil infiltration rate of 0.5 inches per hour
- Soils less than 20% clay, and 40% silt/clay, and no fill soils.
- Natural slope less than 15%
- Cannot accept hotpot runoff, except under the conditions outlined in Section 6.3.1.
- Separation from groundwater table of at least three feet (four feet in sole source aquifers).
- 25' separation from structures for I-1 and I-2; 10' for I-3.

CONVEYANCE

- Flows exiting the practice must be non-erosive (3.5 to 5.0 fps)
- Maximum dewatering time of 48 hours.
- Design off-line if stormwater is conveyed to the practice by a storm drain pipe.

PRETREATMENT

- Pretreatment of 25% of the WQv at all sites.
- 50% pretreatment if fc >2.0 inches/hour.
- 100% pretreatment in areas with fc >5.0 inches/hour.
- Exit velocities from pretreatment must be non-erosive for the 2-year storm.

TREATMENT

- Water quality volume designed to exfiltrate through the floor of the practice.
- Construction sequence to maximize practice life.
- Trench depth shall be less than four feet (I-2 and I-3).
- Follow the methodologies in Chapter 6 to size practices.

LANDSCAPING

- Upstream area shall be completely stabilized before flow is directed to the practice.

MAINTENANCE REQUIREMENTS

- Never serves as a sediment control device
- Observation well shall be installed in every trench, (6" PVC pipe, with a lockable cap)
- Provide direct maintenance access.

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [ ] **Channel Protection**
- [ ] **Overbank Flood Protection**
- [ ] **Extreme Flood Protection**

Accepts Hotspot Runoff: *No*

IMPLEMENTATION CONSIDERATIONS

- [H] **Capital Cost**
- [H] **Maintenance Burden**

Residential Subdivision Use: Yes

High Density/Ultra-Urban: *Yes*

Drainage Area: *10 acres max.*

Soils: *Pervious soils required (0.5 in/hr or greater)*

Other Considerations:

- *Must not be placed under pavement or concrete*

Key: **L**=Low **M**=Moderate **H**=High

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POLLUTANT REMOVAL G **Phosphorus** G **Nitrogen** G **Metals** - Cadmium, Copper, Lead, and Zinc removal G **Pathogens** - Coliform, Streptococci, E.Coli removal **Key: G=Good F=Fair P=Poor**	

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Section 6.4 Stormwater Filtering Systems

Stormwater filtering systems capture and temporarily store the WQ_v and pass it through a filter bed of sand, organic matter, or soil. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially exfiltrate into the soil. Design variants include:

F-1	Surface Sand Filter	(Figure 6.15)
F-2	Underground Sand Filter	(Figure 6.16)
F-3	Perimeter Sand Filter	(Figure 6.17)
F-4	Organic Filter	(Figure 6.18)
F-5	Bioretention	(Figure 6.19)

Treatment Suitability: Filtering systems should not be designed to provide stormwater detention (Q_p) or channel protection (Cp_v) except under extremely unusual conditions. Filtering practices shall generally be combined with a separate facility to provide those controls.

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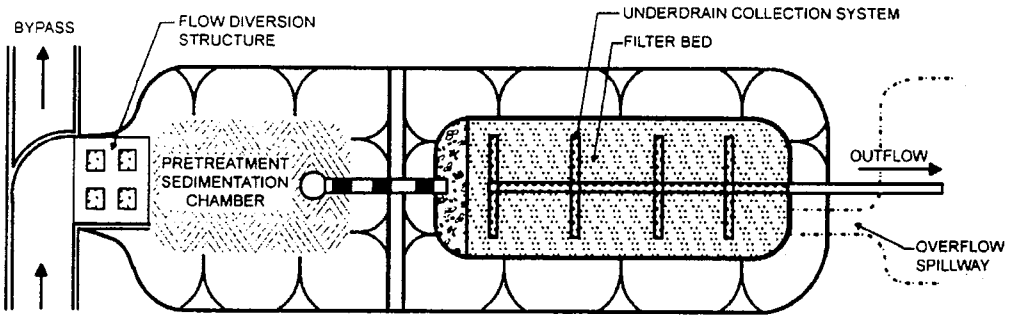
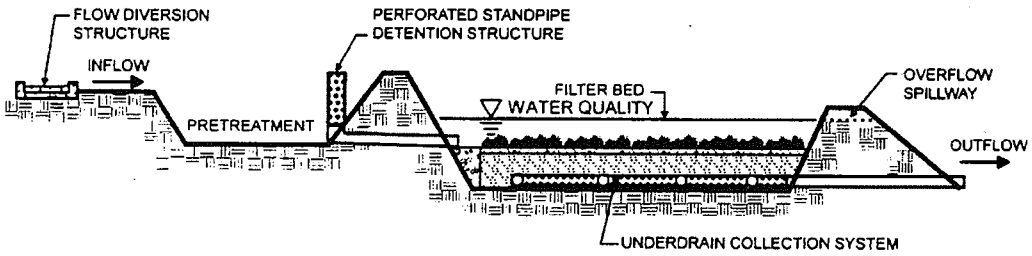
Figure 6.15 Surface Sand Filter (F-1)



PLAN VIEW



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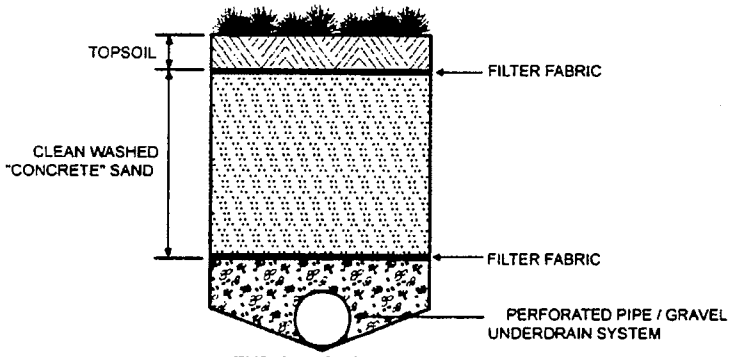

TYPICAL SECTION

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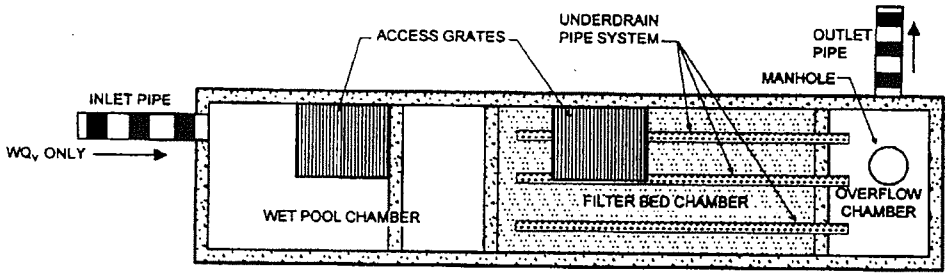
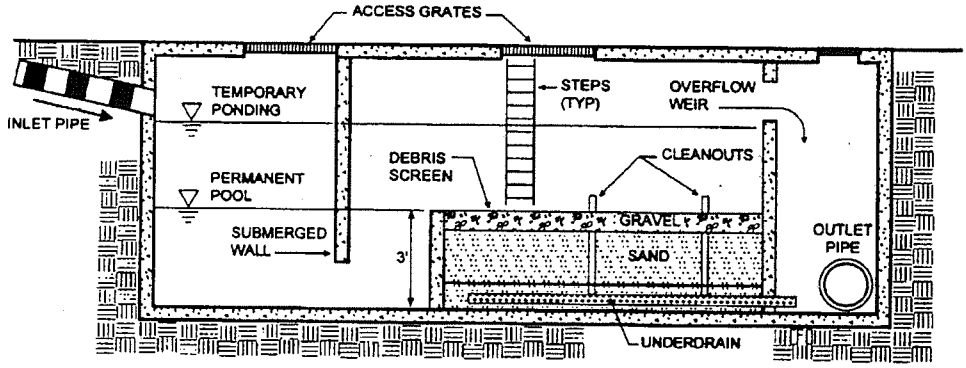
Figure 6.16 Underground Sand Filter (F-2)



PLAN VIEW



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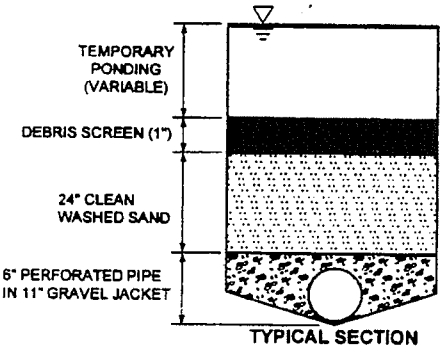

TYPICAL SECTION

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Figure 6.17 Perimeter Sand Filter (F-3)

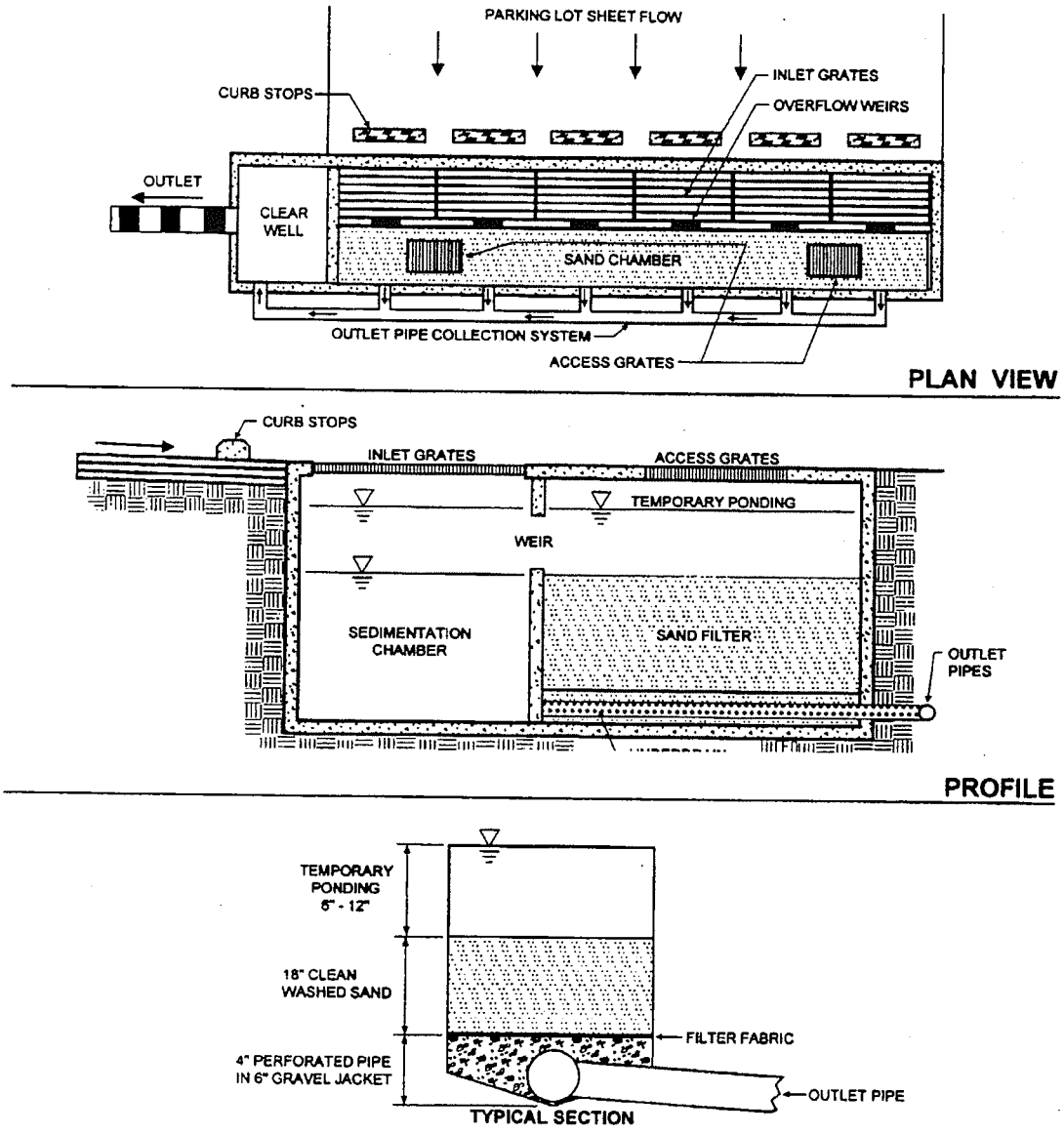

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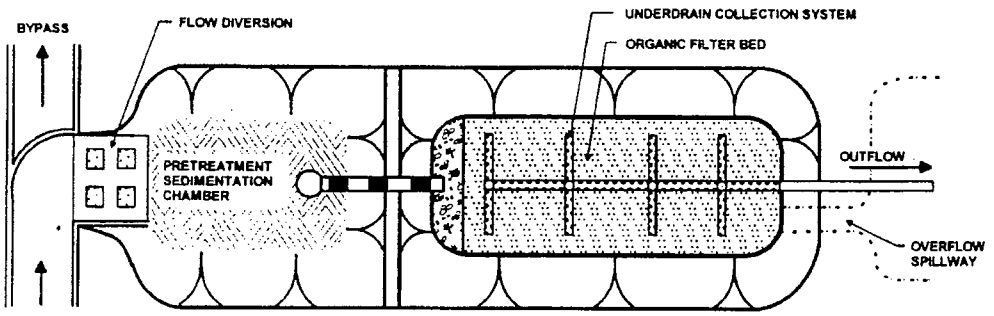
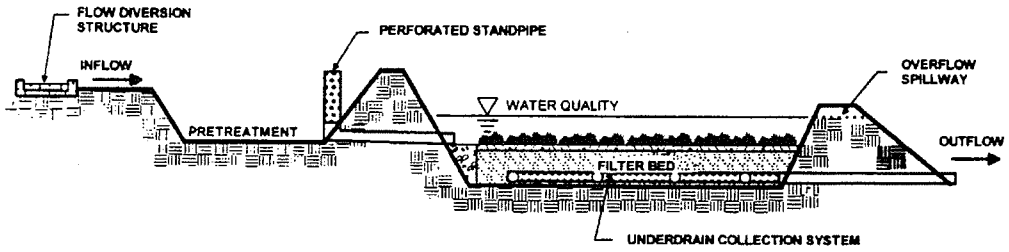
Figure 6.18 Organic Filter (F- 4)



PLAN VIEW



PROFILE

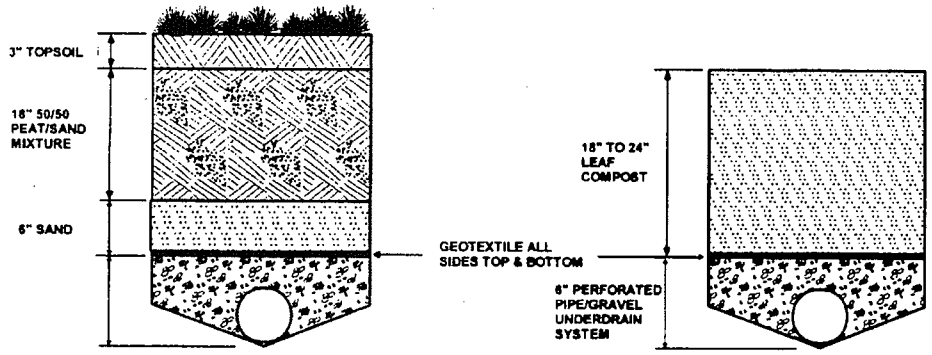


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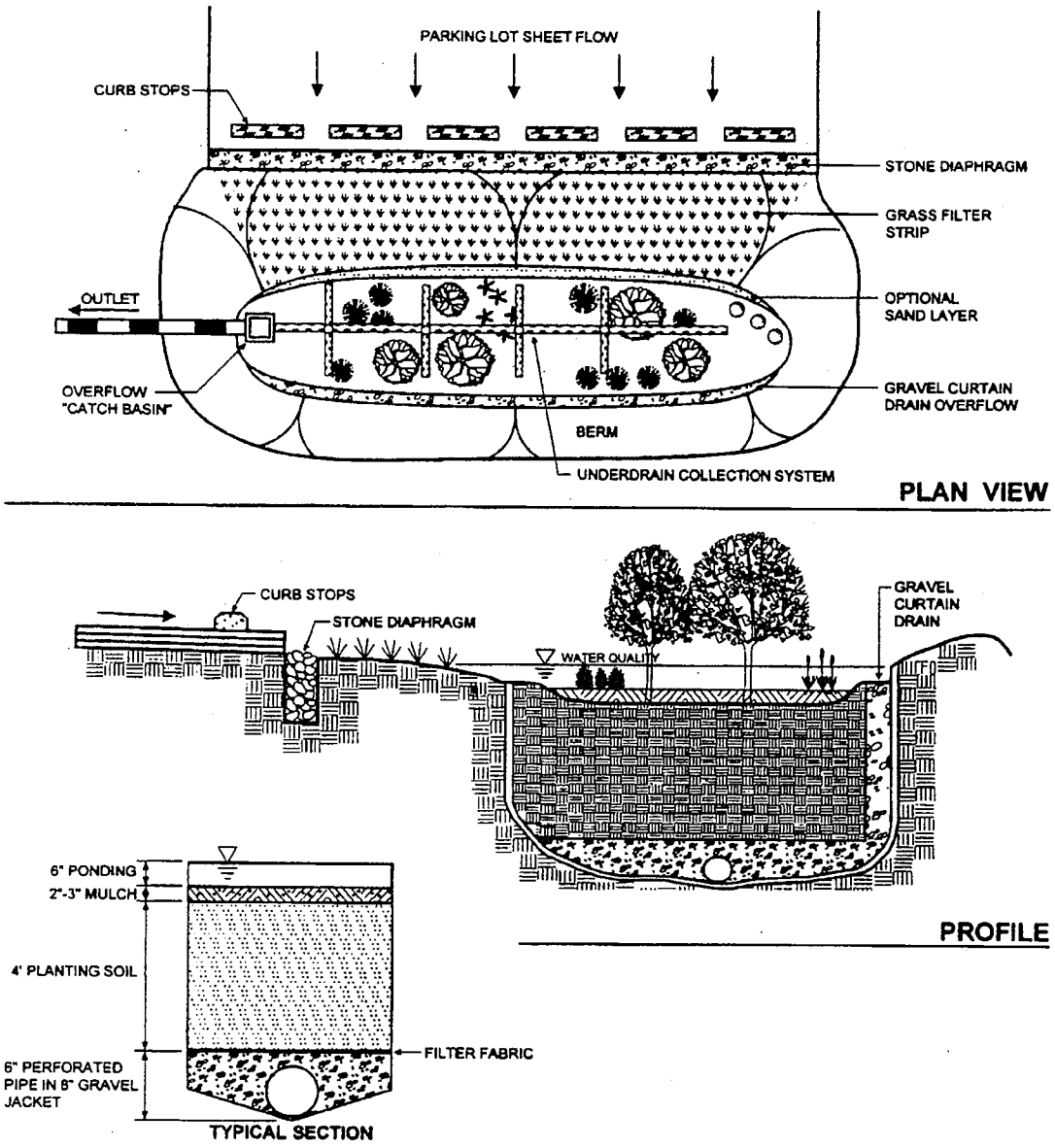
Figure 6.19 Bioretention (F-5)



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6.4.1 Feasibility

Design Guidance

- Most stormwater filters require four to six feet of head, depending on site configuration and land area available. The perimeter sand filter (F-3), however, can be designed to function with as little as 18" to 24" of head.
- The recommended maximum contributing area to an individual stormwater filtering system is usually less than 10 acres. In some situations, larger areas may be acceptable.
- Sand and organic filtering systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with imperviousness less than 75% will require full sedimentation pretreatment techniques.

6.4.2 Conveyance

Required Elements

- If runoff is delivered by a storm drain pipe or is along the main conveyance system, the filtering practice shall be designed off-line (see Appendix K).
- An overflow shall be provided within the practice to pass a percentage of the WQ_v to a stabilized water course. In addition, overflow for the ten-year storm shall be provided to a non-erosive outlet point (i.e., prevent downstream slope erosion).
- A flow regulator (or flow splitter diversion structure) shall be supplied to divert the WQ_v to the filtering practice, and allow larger flows to bypass the practice.
- Stormwater filters shall be equipped with a minimum 4" perforated pipe underdrain (6" is preferred) in a gravel layer. A permeable filter fabric shall be placed between the gravel layer and the filter media.
- Require a minimum 2' separation between the filter bottom and groundwater.

6.4.3 Pretreatment

Required Elements

- Dry or wet pretreatment shall be provided prior to filter media equivalent to at least 25% of the computed WQ_v. The typical method is a sedimentation basin that has a length to width ratio of 1.5:1. The Camp-Hazen equation is used to compute the required surface area for sand and organic filters requiring full sedimentation for pretreatment (WSDE, 1992) as follows:

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- The required sedimentation basin area is computed using the following equation:

$$A_s = -(Qo/W) \cdot Ln\ (1-E)$$

where:

A_s = Sedimentation basin surface area (ft^2)
E = sediment trap efficiency (use 90%)
W = particle settling velocity (ft/sec)
use 0.0004 ft/sec for imperviousness (I) ≤75%
use 0.0033 ft/sec for I > 75%
Qo = Discharge rate from basin = (WQ_v/24 hr)

This equation reduces to:

A_s = (0.066) (WQ_v) ft^2 for I ≤75%
A_s = (0.0081) (WQ_v) ft^2 for I > 75%

Design Guidance

- Adequate pretreatment for bioretention systems should incorporate all of the following: (a) grass filter strip below a level spreader or grass channel, (b) gravel diaphragm and (c) a mulch layer.
- The grass filter strip should be sized using the guidelines in Table 6.2.

Table 6.2 Guidelines for Filter Strip Pretreatment Sizing

Parameter	Impervious Parking Lots				Residential Lawns			
Maximum Inflow Approach Length (ft.)	35		75		75		150	
Filter Strip Slope	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%
Filter Strip Minimum Length	10'	15'	20'	25'	10'	12'	15'	18'

- The grass channel should be sized using the following procedure:
  1- Determine the channel length needed to treat the WQ_v, using sizing techniques described in the Grass Channel Fact Sheet (Chapter 5).
  2- Determine the volume directed to the channel for pretreatment
  3- Determine the channel length by multiplying the length determined in step 1 above by the ratio of the volume in step 2 to the WQ_v.

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6.4.4 Treatment

Required Elements

- The entire treatment system (including pretreatment) shall be sized to temporarily hold at least 75% of the WQ_v prior to filtration.
- The filter media shall consist of a medium sand (meeting ASTM C-33 concrete sand). Media used for organic filters may consist of peat/sand mix or leaf compost. Peat shall be a reed-sedge hemic peat.
- Bioretention systems shall consist of the following treatment components: A four foot deep planting soil bed, a surface mulch layer, and a six inch deep surface ponding area. Soils shall meet the design criteria outlined in Appendix H.

Design Guidance

- The filter bed typically has a minimum depth of 18". The perimeter filter may have a minimum filter bed depth of 12".
- The filter area for sand and organic filters should be sized based on the principles of Darcy's Law. A coefficient of permeability (k) should be used as follows:

Sand:	3.5 ft/day (City of Austin 1988)
Peat:	2.0 ft/day (Galli 1990)
Leaf compost:	8.7 ft/day (Claytor and Schueler, 1996)
Bioretention Soil:	0.5 ft/day (Claytor and Schueler, 1996)

The required filter bed area is computed using the following equation

$$A_f = (WQ_v)\,(d_f) / [\,(k)\,(h_f + d_f)\,(t_f)]$$

Where:

A_f = Surface area of filter bed (ft^2)
d_f = Filter bed depth (ft)
k = Coefficient of permeability of filter media (ft/day)
h_f = Average height of water above filter bed (ft)
t_f = Design filter bed drain time (days)
(1.67 days or 40 hours is recommended maximum t_f for sand filters, two days for bioretention)

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6.4.5 Landscaping

Required Elements

- A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility.
- Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan must be provided for bioretention areas.

Design Guidance

- Surface filters can have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.

- Planting recommendations for bioretention facilities are as follows:
  - Native plant species should be specified over non-native species.
  - Vegetation should be selected based on a specified zone of hydric tolerance.
  - A selection of trees with an understory of shrubs and herbaceous materials should be provided.
  - Woody vegetation should not be specified at inflow locations.
  - Trees should be planted primarily along the perimeter of the facility.
  - A tree density of approximately one tree per 100 square feet (i.e., 10 feet on-center) is recommended. Shrubs and herbaceous vegetation should generally be planted at higher densities (five feet on-center and 2.5 feet on center, respectively).

6.4.6 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the local review authority to ensure the following:

  - Sediment shall be cleaned out of the sedimentation chamber when it accumulates to a depth of more than six inches. Vegetation within the sedimentation chamber shall be limited to a height of 18 inches. The sediment chamber outlet devices shall be cleaned/repaired when drawdown times exceed 36 hours. Trash and debris shall be removed as necessary.

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- Silt/sediment shall be removed from the filter bed when the accumulation exceeds one inch. When the filtering capacity of the filter diminishes substantially (i.e., when water ponds on the surface of the filter bed for more than 48 hours), the top few inches of discolored material shall be removed and shall be replaced with fresh material. The removed sediments shall be disposed in an acceptable manner (i.e., landfill).

- A stone drop of at least six inches shall be provided at the inlet of bioretention facilities (F-6) (pea gravel diaphragm). Areas devoid of mulch shall be re-mulched on an annual basis. Dead or diseased plant material shall be replaced.

Design Guidance

- Organic filters or surface sand filters that have a grass cover should be mowed a minimum of three times per growing season to maintain maximum grass heights less than 12 inches.

6.4.7 Cold Climate Design Considerations

In cold climates, stormwater filtering systems need to be modified to protect the systems from freezing and frost heaving. The primary cold climate concerns to address with regards to filtering systems are:

- Freezing of the filter bed
- Pipe freezing
- Clogging of filter

NOTE

ALTHOUGH FILTERING SYSTEMS ARE NOT AS EFFECTIVE DURING THE WINTER, THEY ARE OFTEN EFFECTIVE AT TREATING STORM EVENTS IN AREAS WHERE OTHER SMPS ARE NOT PRACTICAL, SUCH AS IN HIGHLY URBANIZED REGIONS. THUS, THEY MAY BE A GOOD DESIGN OPTION, EVEN IF WINTER FLOWS CANNOT BE TREATED. IT IS ALSO IMPORTANT TO REMEMBER THAT THESE SMPS ARE DESIGNED FOR HIGHLY IMPERVIOUS AREAS. IF THE SNOW FROM THEIR CONTRIBUTING AREAS IS TRANSPORTED TO ANOTHER AREA, SUCH AS A PERVIOUS INFILTRATION AREA, A PRACTICE'S PERFORMANCE DURING THE WINTER SEASON MAY BE LESS CRITICAL TO OBTAIN WATER QUALITY GOALS.

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Freezing of the Filter Bed

- Place filter beds for underground filter below the frost line to prevent the filtering medium from freezing during the winter.
- Discourage organic filters using peat and compost media, which are ineffective during the winter in cold climates. These organic filters retain water, and consequently can freeze solid and become completely impervious during the winter.
- Combine treatment with another SMP option that can be used as a backup to the filtering system to provide treatment during the winter when the filter is ineffective

Pipe Freezing

- Use a minimum 8" underdrain diameter in a 1' gravel bed. Increasing the diameter of the underdrain makes freezing less likely, and provides a greater capacity to drain standing water from the filter. The porous gravel bed prevents standing water in the system by promoting drainage. Gravel is also less susceptible to frost heaving than finer grained media.
- Replace standpipes with weirs, which can be "frost free." Although weir structures will not always provide detention, they can provide retention storage (i.e., storage with a permanent pool) in the pretreatment chamber.

Clogging of Filter with Excess Sand from Runoff

- If a filter is used to treat runoff from a parking lot or roadway that is frequently sanded during snow events, there is a high potential for clogging from sand in runoff. In these cases, the size of the pretreatment chamber should be increased to 40% of the treatment volume. For bioretention systems, a grass strip, such as a swale, of at least twenty-five feet in length should convey flow to the system.
- Filters should always be inspected for sand build-up in the filter chamber following the spring melt event.

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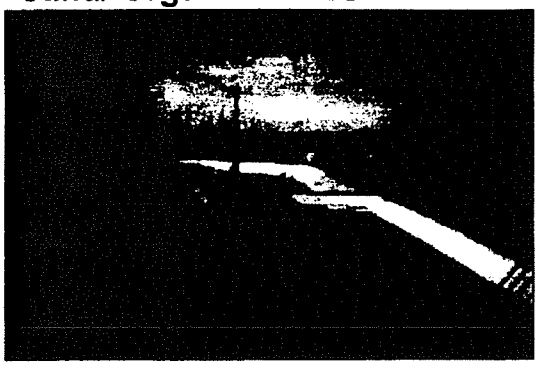
Sand/ Organic Filters



Description: Multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay, a primary filter media and, typically, an underdrain collection system.

Design Variations:
Surface Sand Filter (F-1), Underground Sand Filter (F-2), Perimeter Sand Filter (F-3), Organic Sand Filter (F-4)

KEY CONSIDERATIONS

CONVEYANCE

- If stormwater is delivered by stormdrain, design off-line.
- Overflow shall be provided to pass a fraction of the WQ_v to a stabilized watercourse.
- Overflow for the ten-year storm to a non-erosive point.
- Flow regulator needed to divert WQ_v to the practice, and bypass larger flows.
- Underdrain (4" perforated pipe minimum; 6" preferred)

PRETREATMENT

- Pretreatment volume of 25% of WQ_v.
- Typically a sediment basin with a 1.5:1 L:W ratio, sized with the Camp-Hazen equation (See Section 6.4.3)

TREATMENT

- System must hold 75% of the WQ_v
- Filter media shall be ASTM C-33 sand for sand filters
- Organic filters shall be a peat/sand mix, or leaf compost.
- Peat shall be reed-sedge hemic peat

LANDSCAPING

- Contributing area stabilized before runoff is directed to the facility

MAINTENANCE REQUIREMENTS:

- Legally binding maintenance agreement.
- Sediment cleaned out of sedimentation chamber when it reaches more than 6" in depth.
- Vegetation height limited to 18"
- Sediment chamber cleaned if drawdowns exceed 36 hours.
- Trash and debris removal
- Silt/sediment removed from filter bed after it reaches one inch.
- If water ponds on the filter bed for greater than 48 hours, remove material, and replace.

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [ ] **Channel Protection**
- [ ] **Overbank Flood Protection**
- [ ] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

IMPLEMENTATION CONSIDERATIONS

- [H] **Capital Cost**
- [H] **Maintenance Burden**

Residential Subdivision Use: No

High Density/Ultra-Urban: *Yes*

Drainage Area: *2-10 acres max.*

Soils: *No restrictions*

Other Considerations:

Typically needs to be combined with other controls to provide water quantity control

Key: L=Low M=Moderate H=High

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POLLUTANT REMOVAL	
G **Phosphorus**	
G **Nitrogen**	
G **Metals** - Cadmium, Copper, Lead, and Zinc removal	
F **Pathogens** - Coliform, Streptococci, E.Coli removal	
Key: G=Good **F**=Fair **P**=Poor	

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Bioretention Areas (F-5)



Description: Shallow stormwater basin or landscaped area which utilizes engineered soils and vegetation to capture and treat runoff. The practice is often located in parking lot islands, and can also be used to treat residential areas.

KEY CONSIDERATIONS

CONVEYANCE

- Provide overflow for the 10-year storm to the conveyance system.
- Conveyance to the system is typically overland flow delivered to the surface of the system, typically through curb cuts or over a concrete lip.

PRETREATMENT

- Pretreatment consists of a grass channel or grass filter strip, a gravel diaphragm, and a mulch layer, sized based on the methodologies described in Section 6.4.2.

TREATMENT

- Treatment area should have a four foot deep planting soil bed, a surface mulch layer, and a 6" ponding layer.
- Size the treatment area using equations provided in Chapter 6.

LANDSCAPING

- Detailed landscaping plan required.

MAINTENANCE

- Inspect and repair/replace treatment area components
- Stone drop (at least 6") provided at the inlet
- Remulch annually

POLLUTANT REMOVAL

G	**Phosphorus**
G	**Nitrogen**
G	**Metals** - Cadmium, Copper, Lead, and Zinc removal
F	**Pathogens** – Coliform, Streptococci, E.Coli removal

Key: **G**=Good **F**=Fair **P**=Poor

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [ ] **Channel Protection**
- [ ] **Overbank Flood Protection**
- [ ] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

IMPLEMENTATION CONSIDERATIONS

M	**Capital Cost**
M	**Maintenance Burden**

Residential Subdivision Use: Yes

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max.*

Soils: *Planting soils must meet specified criteria; No restrictions on surrounding soils*

Other Considerations:

- *Use of native plants is recommended*

Key: L=Low **M**=Medium **H**=High

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Section 6.5 Open Channel Systems

Open channel systems are vegetated open channels that are explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means. Design variants include:

- O-1 Dry Swale (Figure 6.20)
- O-2 Wet Swale (Figure 6.21)

Treatment Suitability: Open Channel Systems can meet water quality treatment goals only, and are not appropriate for Cp_v or Q_p.

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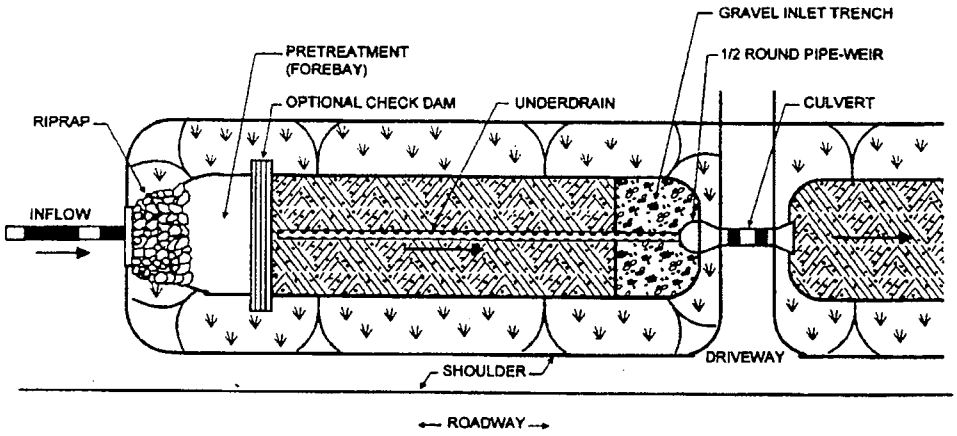
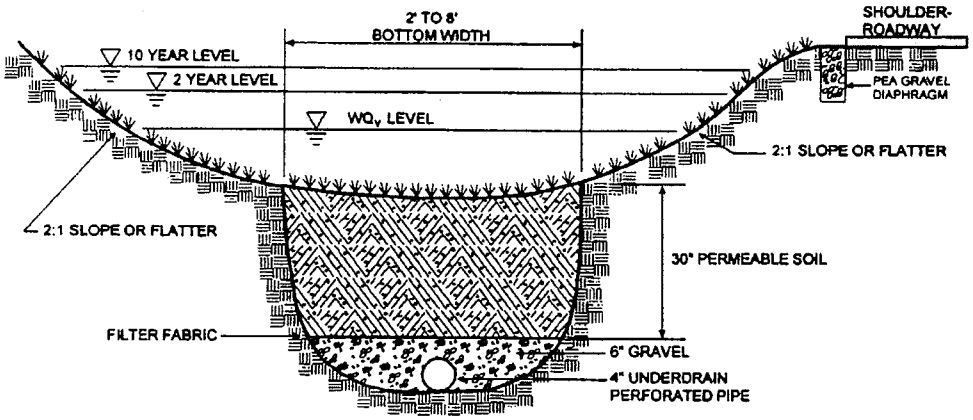
Figure 6.20 Dry Swale (O-1)



PLAN VIEW



SECTION

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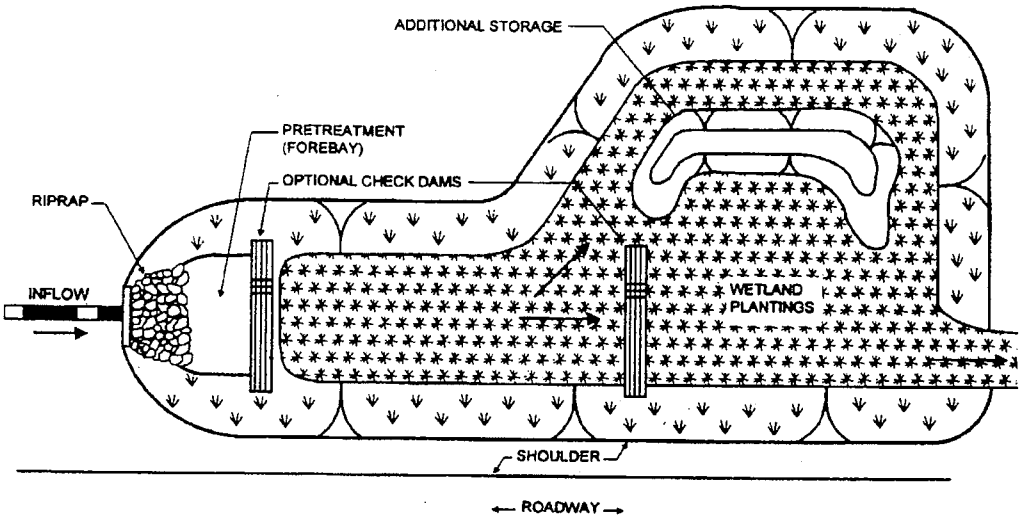
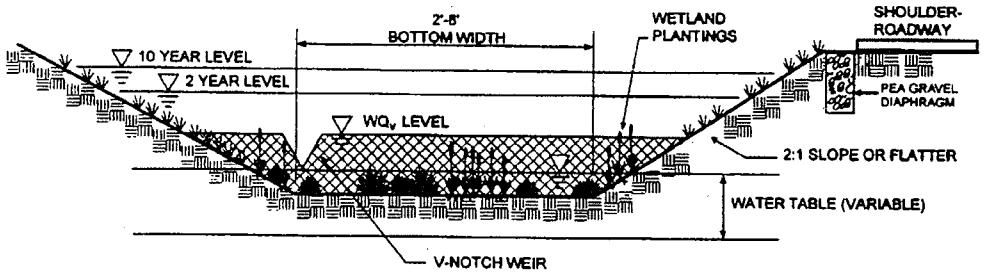
Figure 6.21 Wet Swale (O-2)



PLAN VIEW



PROFILE

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6.5.1 Feasibility

Required Elements

- The system shall have a maximum longitudinal slope of 4.0%

Design Guidance

- Dry Swales (O-1) are primarily applicable for land uses such as roads, highways, residential development, and pervious areas.
- Wet Swales (O-2) should be restricted in residential areas because of the potential for stagnant water and other nuisance ponding.
- Provide a 2' separation distance from groundwater for O-2.

6.5.2 Conveyance

Required Elements

- The peak velocity for the two-year storm must be non-erosive (i.e., 3.5-5.0 fps). (See Appendix L for a table of erosive velocities for grass and soil).
- Open channels shall be designed to safely convey the ten-year storm with a minimum of 6 inches of freeboard. Note that some agencies or local municipalities may design channel to convey a different design storm.
- The maximum allowable temporary ponding time within a channel shall be less than 48 hours. An underdrain system shall be used in the dry swale to ensure this ponding time.
- Channels shall be designed with moderate side slopes (flatter than 3:1) for most conditions. 2:1 is the absolute maximum side slope.

Design Guidance

- Open channel systems which directly receive runoff from impervious surfaces may have a 6 inch (maximum) drop onto a protected shelf (pea gravel diaphragm) to minimize the clogging potential of the inlet.
- The underdrain system should be composed of a 6" gravel bed with a 4" PVC pipe.
- If the site slope is greater than 2%, check dams may be needed to retain the water quality volume within the swale system.

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6.5.3 Pretreatment

Required Elements

- Provide 10% of the WQ_v in pretreatment. This storage is usually obtained by providing checkdams at pipe inlets and/or driveway crossings.

Design Guidance

- Utilize a pea gravel diaphragm and gentle side slopes along the top of channels to provide pretreatment for lateral sheet flows.

6.5.4 Treatment

Required Elements

- Temporarily store the WQ_v within the facility to be released over a minimum 30 minute duration.
- Design with a bottom width no greater than eight feet to avoid potential gullying and channel braiding, but no less than two feet.
- Soil media for the dry swale shall meet the specifications outlined in Appendix H.

Design Guidance

- Open channels should maintain a maximum ponding depth of one foot at the mid-point of the channel, and a maximum depth of 18" at the end point of the channel (for storage of the WQ_v).

6.5.5 Landscaping

Design Guidance

- Landscape design should specify proper grass species and wetland plants based on specific site, soils and hydric conditions present along the channel (see Appendix H for landscaping guidance for New York).

6.5.6 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the local review authority to ensure the following:

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- Sediment build-up within the bottom of the channel or filter strip is removed when 25% of the original WQ_v volume has been exceeded.
- Vegetation in dry swales is mowed as required during the growing season to maintain grass heights in the 4 to 6 inch range.

6.5.7 Cold Climate Design Considerations

For open channel systems, the primary cold climate design challenges that need to be addressed are:

- Snowmelt infiltration on frozen ground
- Culvert freezing
- The impacts of deicers on channel vegetation.

Snowmelt Infiltration on Frozen Ground

- In order to ensure that the filter bed remains dry between storm events, increase the size of the underdrain pipe to a minimum diameter of 6" with a minimum 1' filter bed.
- The soil bed permeability of the dry swale should be NRCS class SM (NRCS, 1984), which is slightly higher than in the base criteria. This increased permeability will encourage snowmelt infiltration.

Culvert Freezing

- Use culvert pipes with a minimum diameter of 18".
- Design culverts with a minimum 1% slope where possible.

The Impacts of De-icers on Channel Vegetation

- Inspect open channel systems after the spring melt. At this time, residual sand should be removed and any damaged vegetation should be replaced.
- If roadside or parking lot runoff is directed to the practice, mulching may be required in the spring to restore soil structure and moisture capacity to reduce the impacts of deicing agents.
- Use salt-tolerant plant species in vegetated swales.

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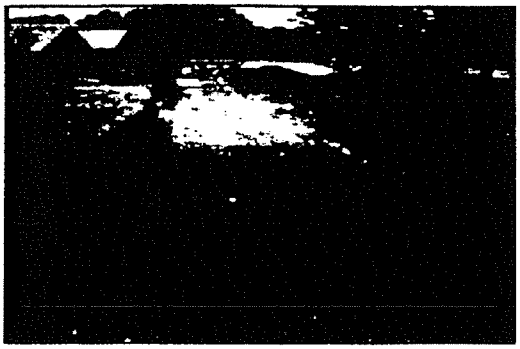
Open Channels



Description: Vegetated channels that are explicitly designed and constructed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other means.

Design Options:
Dry Swale (O-1), Wet Swale (O-2)

KEY CONSIDERATIONS

FEASIBILITY

- Maximum longitudinal slope of 4%

CONVEYANCE

- Non-erosive (3.5 to 5.0 fps) peak velocity for the 2-year storm
- Safe conveyance of the ten-year storm with a minimum of 6 inches of freeboard.
- Side slopes gentler than 2:1 (3:1 preferred).
- The maximum allowable temporary ponding time of 48 hours

PRETREATMENT

- 10% of the WQ_v in pretreatment, usually provided using check dams at culverts or driveway crossings.

TREATMENT

- Temporary storage the WQ_v within the facility to be released over a minimum 30 minute duration.
- Bottom width no greater than 8 feet, but no less than two feet.
- Soil media as detailed in Appendix H.

MAINTENANCE

- Removal of sediment build-up within the bottom of the channel or filter strip when 25% of the original WQ_v volume has been exceeded.
- Maintain a grass height of 4" to 6" in dry swales.

MANAGEMENT CAPABILITY

G	**Phosphorus**
F	**Nitrogen**
G	**Metals** - Cadmium, Copper, Lead, and Zinc removal
P	**Pathogens** - Coliform, Streptococci, E.Coli removal

Key: G=Good F=Fair P=Poor

STORMWATER MANAGEMENT SUITABILITY

- [X] **Water Quality**
- [ ] **Channel Protection**
- [ ] **Overbank Flood Protection**
- [ ] **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

IMPLEMENTATION CONSIDERATIONS

L	**Capital Cost**
L	**Maintenance Burden**

Residential Subdivision Use: Yes

High Density/Ultra-Urban: *No*

Drainage Area: *5 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Permeable soil layer (dry swale)*
- *Wetland plants (wet swale)*

Key: H=High M=Medium L=Low

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Chapter 7

SMP Selection Matrices

New York State Stormwater Management Design Manual

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Chapter 7: SMP Selection

This chapter presents a series of matrices that can be used as a screening process to select the best SMP or group of SMPs for a development site. It also provides guidance for best locating practices on the site. The matrices presented can be used to screen practices in a step-wise fashion. The screening factors include:

1. Land Use
2. Physical Feasibility
3. Watershed/ Regional Factors
4. Stormwater Management Capability
5. Community and Environmental Factors

The five matrices presented here are not exhaustive. Specific additional criteria may be incorporated depending on local design knowledge and resource protection goals. Furthermore, many communities may wish to eliminate some of the selection factors presented in this section. Caveats for the application of each matrix are included in the detailed description of each.

More detail on the proposed step-wise screening process is provided below:

Step 1 Land Use

Which practices are best suited for the proposed land use at this site? In this step, the designer makes an initial screen to select practices that are best suited to a particular land use.

Step 2 Physical Feasibility Factors

Are there any physical constraints at the project site that may restrict or preclude the use of a particular SMP? In this step, the designer screens the SMP list using Matrix No. 2 to determine if the soils, water table, drainage area, slope or head conditions present at a particular development site might limit the use of a SMP.

Step 3 Watershed Factors

What watershed protection goals need to be met in the resource my site drains to? Matrix No.3 outlines SMP goals and restrictions based on the resource being protected.

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Step 4 Stormwater Management Capability

Can one SMP meet all design criteria, or is a combination of practices needed? In this step, designers can screen the SMP list using Matrix No. 4 to determine if a particular SMP can meet water quality, channel protection, and flood control storage requirements. At the end of this step, the designer can screen the SMP options down to a manageable number and determine if a single SMP or a group of SMPs is needed to meet stormwater sizing criteria at the site.

Step 5 Community and Environmental Factors

Do the remaining SMPs have any important community or environmental benefits or drawbacks that might influence the selection process? In this step, a matrix is used to compare the SMP options with regard to cold climate restrictions, maintenance, habitat, community acceptance, cost and other environmental factors.

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Section 7.1 Land Use

This matrix allows the designer to make an initial screen of practices most appropriate for a given land use (Table 7.1).

Rural. This column identifies SMPs that are best suited to treat runoff in rural or very low density areas (e.g., typically at a density of less than ½ dwelling unit per acre).

Residential. This column identifies the best treatment options in medium to high density residential developments.

Roads and Highways. This column identifies the best practices to treat runoff from major roadways and highway systems.

Commercial Development. This column identifies practices that are suitable for new commercial development

Hotspot Land Uses. This last column examines the capability of an SMP to treat runoff from designated hotspots (see Appendix A). An SMP that receives hotspot runoff may have design restrictions, as noted.

Ultra-Urban Sites. This column identifies SMPs that work well in the ultra-urban environment, where space is limited and original soils have been disturbed. These SMPs are frequently used at redevelopment sites.

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Table 7.1 Land Use Selection Matrix

SMP Group	SMP Design	Rural	Residential	Roads and Highways	Commercial/ High Density	Hotspots	Ultra Urban
Pond	Micropool ED	○	○	○	◗	①	●
	Wet Pond	○	○	○	◗	①	●
	Wet ED Pond	○	○	○	◗	①	●
	Multiple Pond	○	○	◗	◗	①	●
	Pocket Pond	○	◗	○	◗	●	●
Wetland	Shallow Wetland	○	○	◗	◗	①	●
	ED Wetland	○	○	◗	◗	①	●
	Pond/Wetland	○	○	●	◗	①	●
	Pocket Wetland	○	◗	○	◗	●	●
Infiltration	Infiltration Trench	◗	◗	○	○	●	◗
	Shallow I-Basin	◗	◗	◗	◗	●	◗
	Dry Well[1]	◗	○	●	◗	●	◗
Filters	Surface Sand Filter	●	◗	○	○	②	○
	Underground SF	●	●	◗	○	○	○
	Perimeter SF	●	●	◗	○	○	○
	Organic SF	●	◗	○	○	②	○
	Bioretention	◗	◗	○	○	②	○
Open Channels	Dry Swale	○	◗	○	◗	②	◗
	Wet Swale	○	●	○	●	●	●

○: Yes. Good option in most cases.
◗: Depends. Suitable under certain conditions, or may be used to treat a portion of the site.
●: No. Seldom or never suitable.
①: Acceptable option, but may require a pond liner to reduce risk of groundwater contamination.
②: Acceptable option, if not designed as an exfilter.
1: The dry well can only be used to treat rooftop runoff

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Section 7.2 Physical Feasibility Factors

This matrix allows the designer to evaluate possible options based on physical conditions at the site (Table 7.2). More detailed testing protocols are often needed to confirm physical conditions at the site. Five primary factors are:

Soils. The key evaluation factors are based on an initial investigation of the NRCS hydrologic soils groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors. Appendix H describes geotechnical testing requirements for New York State.

Water Table. This column indicates the minimum depth to the seasonally high water table from the bottom elevation, or floor, of an SMP.

Drainage Area. This column indicates the minimum or maximum drainage area that is considered optimal for a practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is warranted where a practice meets other management objectives. Likewise, the minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (baseflow or groundwater), mechanisms employed to prevent clogging, or the ability to assume an increased maintenance burden.

Slope. This column evaluates the effect of slope on the practice. Specifically, the slope guidance refers to how flat the area where the practice is installed must be and/or how steep the contributing drainage area or flow length can be.

Head. This column provides an estimate of the elevation difference needed for a practice (from the inflow to the outflow) to allow for gravity operation.

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Table 7.2 Physical Feasibility Matrix

SMP Group	SMP Design	Soils	Water Table	Drainage Area (acres)	Site Slope	Head (ft)
Pond	Micropool ED	HSG A soils may require pond liner.	2 foot separation if hotspot or aquifer	10 min[1]	No more than 15%	6 to 8 ft
	Wet Pond			25 min[1]		
	Wet ED Pond					
	Multiple Pond					
	Pocket Pond	OK	below WT	5 max[2]		4 ft
Wetland	Shallow Wetland	HSG A soils may require liner	2 foot separation if hotspot or aquifer	25 min	No more than 8%	3 to 5 ft
	ED Wetland					
	Pond/Wetland					
	Pocket Wetland	OK	below WT	5 max		2 to 3 ft
Infiltration	Infiltration Trench	f_c > 0.5 inch/hr; additional pretreatment required over 2.0 in/hr (See Section 6.3.3)	3 feet, 4 feet if sole source aquifer.	5 max	No more than 15%	1 ft[6]
	Shallow I-Basin			10 max[3]		3 ft
	Dry Well			1 max[4]		1 ft
Filters	Surface SF	OK	2 feet[5]	10 max[2]	No more than 6%	5 ft
	Underground SF			2 max[2]		5 to 7ft
	Perimeter SF			2 max[2]		2 to 3 ft
	Organic SF			5 max[2]		2 to 4 ft
	Bioretention			5 max[2]		5 ft
	Dry Swale	Made Soil				3 to 5 ft
Open Channels	Wet Swale	Made Soil	2 feet	5 max	No more than 4%	1 ft
	Wet Swale	OK	below WT	5 max		1 ft

Notes:
1: Unless adequate water balance and anti-clogging device installed
2: Drainage area can be larger in some instances
3: May be larger in areas where the soil percolation rate is greater than 5.0 in/hr
4: Designed to treat rooftop runoff only
5: If designed with a permeable bottom, must meet the depth requirements for infiltration practices.
6: Required ponding depth above geotextile layer.

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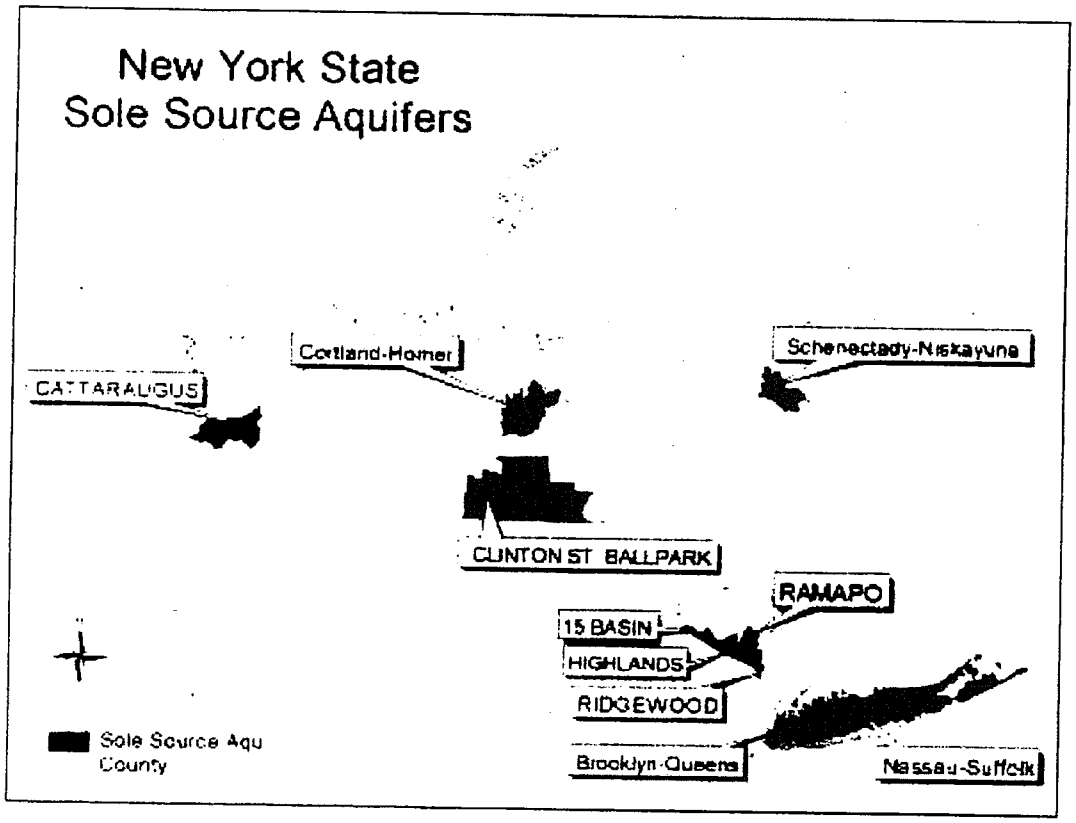
Section 7.3 Watershed/Regional Factors

The choices made by the designer should be influenced to some extent by the resource being protected, and the region of New York State where the site is located. The following matrices (Tables 7.3a and 7.3b) present some design considerations for six watershed or regional factors in New York:

Sensitive Streams. The guidance presented here should apply to all trout waters and Class N waters, and any streams that support high biodiversity and water quality, and have a low density of development.

Aquifers. In sole source aquifers, special care should be taken to select practices and incorporate design considerations that protect the groundwater quality. Figure 7.1 depicts sole source aquifers in the State of New York.

Figure 7.1 Sole Source Aquifers in New York State



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Lakes. Lakes are of particular concern in New York, which has many natural lake systems and borders on two Great Lakes. The information in this matrix focuses on phosphorous removal, which is an important concern in most lake systems. It is important to note, however, that many lakes in New York State have other important issues to address. Some lakes, such as Lake Onondoga, have other specific concerns, such as toxics and metals. Each community should also take these goals into consideration when reviewing site plans.

Table 7.3a Watershed/ Regional Selection Matrix-1

SMP Group	Sensitive Stream	Aquifer	Lakes
Ponds	Emphasize channel protection. Restrict in-stream practices. In trout waters, minimize permanent pool area, and encourage shading.	May require liner if HSG A soils are present. Pretreat 100% of WQ_v from hotspots. Provide a 2' separation distance to water table.	Encourage the use of a large permanent pool to improve phosphorus removal.
Wetlands	Require channel protection. Restrict in-stream practices. Restrict use in trout waters.		
Infiltration	Strongly encourage use for groundwater recharge. Combine with a detention facility to provide channel protection.	Provide 100' horizontal separation distance from wells and 4' vertical distance from the water table.	OK. Provides high phosphorus removal.
Filtering Systems	Combine with a detention facility to provide channel protection.	Excellent pretreatment for infiltration or open channel practices.	OK, but designs with a submerged filter may result in phosphorus release.
Open Channels	Combine with a detention facility to provide channel protection.	OK, but hotspot runoff must be adequately pretreated	OK. Moderate P removal.

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Reservoirs. For drinking water reservoirs, and in particular for unfiltered water supplies such as the New York City Reservoir system, turbidity, phosphorous removal, and bacteria are of particular concern. A particular reservoir may have other specific concerns, which should be identified as part of a Source Water Assessment.

Estuary/Coastal. In New York State, coastal or estuary areas include the South Shore Estuary Reserve, Peconic Estuary, NY/NJ Harbor, and Hudson River Estuary. In these areas, nitrogen is typically a concern due to potential eutrophication. In addition, bacteria control is important to protect shellfish beds.

Cold Climates. Many portions of New York State experience cold or very snowy winters. This matrix summarizes some of the design considerations in these cold climate areas. For more detailed information, consult Chapter 6, which provides cold climate design guidance for each group of SMPs.

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Table 7.3b Watershed/Regional Selection Matrix-2			
SMP Group	**Reservoir**	**Estuary/Coastal**	**Cold Climates**
Ponds	Encourage the use of a large permanent pool to improve sediment and phosphorous removal. Promote long detention times to encourage bacteria removal.	Encourage long detention times to promote bacteria removal. Provides high nitrogen removal. In flat coastal areas, a pond drain may not be feasible.	Incorporate design features to improve winter performance.
Wetlands			Encourage the use of salt-tolerant vegetation.
Infiltration	Provide a separation distance from bedrock and water table Pretreat runoff prior to infiltration practices.	OK, but provide a separation distance to seasonally high groundwater. In the sandy soils typical of coastal areas, additional pretreatment may be required (See Section 6.3.3)	Incorporate features to minimize the risk of frost heave. Discourage infiltration of chlorides.
Filtering Systems	Excellent pretreatment for infiltration or open channel practices. Moderate to high coliform removal	Moderate to high coliform removal Designs with a submerged filter bed appear to have very high nitrogen removal	Incorporate design features to improve winter performance.
Open Channels	Poor coliform removal for wet swales.	Poor coliform removal for grass wet swales.	Encourage the use of salt-tolerant vegetation.

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Section 7.4 Stormwater Management Capability

This matrix examines the capability of each SMP option to meet stormwater management criteria (Table 7.4). It shows whether an SMP can meet requirements for:

Water Quality. The matrix summarizes the relative pollutant removal of each practice for nitrogen, metals, and bacteria. All of the practices approved for water quality achieve at least 80% TSS and 40% TP removal. For more detailed information, consult Appendix A, which describes the application of the Simple Method in New York State. Pollutant removals are based a comprehensive pollutant removal database produced by the Center for Watershed Protection (Winer, 2000).

Channel Protection. The matrix indicates whether the SMP can typically provide channel protection storage. The finding that a particular SMP cannot meet the channel protection requirement does not necessarily imply that the SMP should be eliminated from consideration, but is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream ED pond).

Flood Control The matrix shows whether an SMP can typically meet the overbank flooding criteria for the site. Again, the finding that a particular SMP cannot meet the requirement does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream stormwater detention pond).

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Table 7.4 Stormwater Management Capability Matrix

SMP Group	SMP Design	Water Quality			Channel Protection	Flood Control
		Nitrogen	Metals	Bacteria		
Pond	Micropool ED	○	○	○	○	○
	Wet Pond				○	○
	Wet ED Pond				○	○
	Multiple Pond				○	○
	Pocket Pond				○	○
Wetland	Shallow Wetland	○	◗	○	○	○
	ED Wetland				○	○
	Pond/Wetland				○	○
	Pocket Wetland				○	❶
Infiltration	Infiltration Trench	○	○	○	●	●
	Shallow I-Basin				❷	❷
	Dry Well				●	●
Filters	Surface Sand Filter	○	○	◗	❶	●
	Underground SF				●	●
	Perimeter SF				●	●
	Organic SF				●	●
	Bioretention				❶	●
	Dry Swale				●	●
Open Channels	Wet Swale	◗	○	●	●	●
	Wet Swale				●	●

○: Good option for meeting management goal
Good pollutant removal (>30% TN, >60% Metals, >70% Bacteria)
◗: Fair pollutant removal (15-30% TN, 30-60% Metals, 35-70% Bacteria)
●: Cannot meet management goal.
Poor pollutant removal (<15% TN, <30 Metals, <35% Bacteria)
❶: In most cases, cannot meet this goal, but the design may be adapted to add storage.
❷: Generally cannot meet this goal, except in areas with soil percolation rates greater than 5.0 in/hr

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Section 7.5 Community and Environmental Factors

The last step assesses community and environmental factors involved in SMP selection. This matrix employs a comparative index approach (Table 7.5.). An open circle indicates that the SMP has a high benefit and a dark circle indicates that the particular SMP has a low benefit.

Ease of Maintenance. This column assesses the relative maintenance effort needed for an SMP, in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging) and reported failure rates. It should be noted that **all SMPs** require routine inspection and maintenance.

Community Acceptance. This column assesses community acceptance, as measured by three factors: market and preference surveys, reported nuisance problems, and visual orientation (i.e., is it prominently located or is it in a discrete underground location). It should be noted that a low rank can often be improved by a better landscaping plan.

Affordability. The SMPs are ranked according to their relative construction cost per impervious acre treated.

Safety. A comparative index that expresses the relative safety of an SMP. An open circle indicates a safe SMP, while a darkened circle indicates deep pools may create potential safety risks. The safety factor is included at this stage of the screening process because liability and safety are of paramount concern in many residential settings.

Habitat. SMPs are evaluated on their ability to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, wetland features and vegetative cover of the SMP and its buffer.

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Table 7.5 Community and Environmental Factors Matrix

SMP Group	SMP List	Ease of Maintenance	Community Acceptance	Affordability	Safety	Habitat
Ponds	Micropool ED	◗	◗	○	○	◗
	Wet Pond	○	○	○	●	○
	Wet ED Pond	○	○	○	●	○
	Multiple Pond	○	○	◗	●	○
	Pocket Pond	●	◗	○	◗	●
Wetlands	Shallow Wetland	◗	○	◗	○	○
	ED Wetland	◗	◗	◗	◗	○
	Pond/Wetland	○	○	◗	●	○
	Pocket Wetland	●	●	○	○	◗
Infiltration	Infiltration Trench	●	○	◗	○	●
	Shallow I-Basin	●	●	◗	○	●
	Dry Well	●	◗	◗	○	●
Filters	Surface SF	◗	◗	●	○	●
	Underground SF	●	○	●	◗	●
	Perimeter SF	●	○	●	○	●
	Organic SF	◗	○	●	○	●
	Bioretention	◗	◗	◗	○	◗
Open Channels	Dry Swale	○	○	◗	○	●
	Wet Swale	○	◗	○	○	◗

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Chapter 8

Stormwater Management Design Examples

New York State Stormwater Management Design Manual

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Chapter 8: Stormwater Management Design Examples

This chapter presents design examples for two hypothetical development sites in the State of New York. The first site, "Stone Hill Estates," is a residential development near Ithaca. The second is a commercial site in Albany. The chapter is divided into five sections, each of which focuses on a particular element of stormwater management design.

- Section 8.1 provides an example of detailed hydrology calculations at the residential site.
- Section 8.2 presents a pond design example based on the hydrology calculated in Section 8.1. This design example demonstrates the hydrologic and hydraulic computations to achieve water quality and water quantity control for stormwater management. Other specific dam design criteria such as soil compaction, structural appurtenances, embankment drainage, outlet design, gates, reservoir drawdown requirements, etc. are stated in Guidelines For Design of Dams.
- This design example in Section 8.2 requires an Article 15 Permit from NYS-DEC since the dam is 15 feet high measured from the top of dam to the low elevation at the downstream outlet, and the storage measured behind the structure to the top of the dam is 2.2 MG.
- Sections 8.3 through 8.5 present design examples for three practices on the commercial site: a sand filter, infiltration trench, and bioretention practice.

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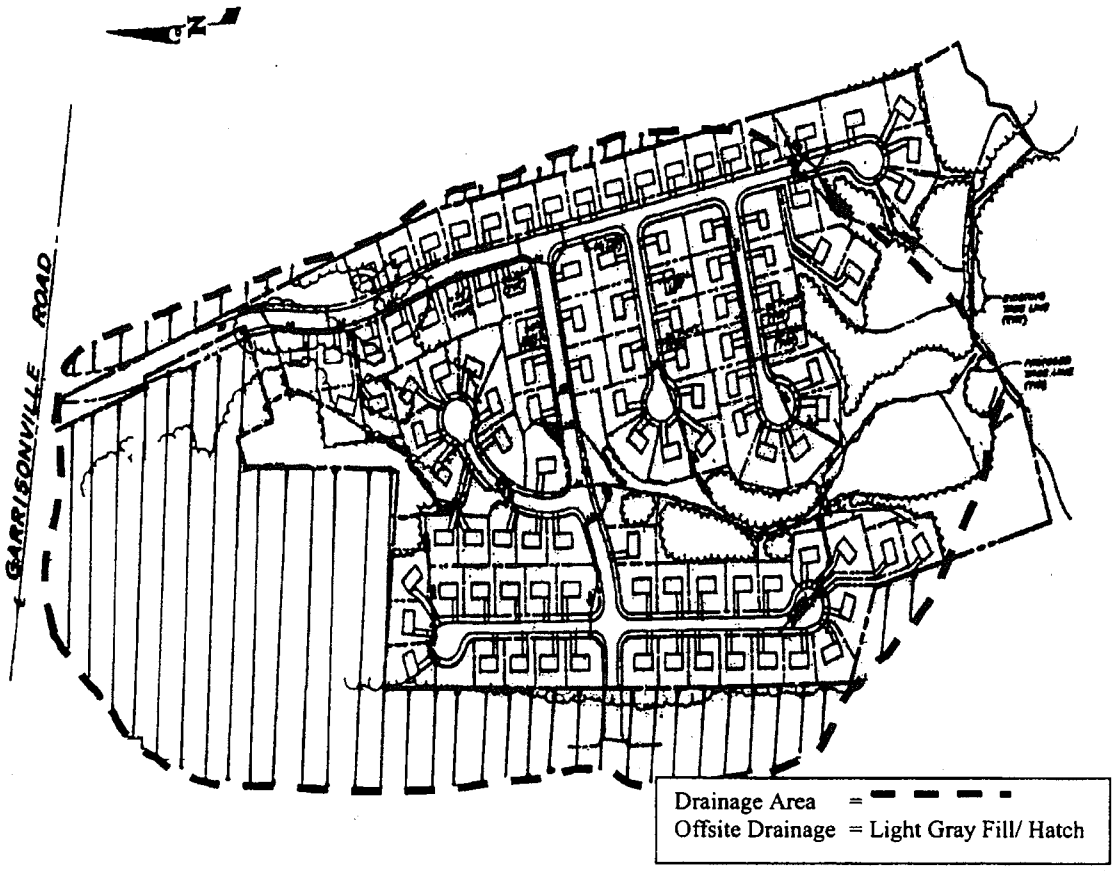
Section 8.1 Sizing Example - Stone Hill Estates

Following is a sizing example for the hypothetical "Stone Hill Estates," a 45-acre residential development in Ithaca, New York (Figure 8.1). The site also drains approximately 20 acres of off-site drainage, which is currently in a meadow condition. The site is on mostly C soils with some D soils.

Figure 8.1 Stone Hill Site Plan



Base Data
Location: Ithaca, NY
Site Area = 45.1 ac; Offsite Area = 20.0 ac (meadow)
Total Drainage Area (A) = 65.1
Measured Impervious Area=12.0 ac;
Site Soils Types: 78% "C", 22% "D"
Offsite Soil Type: 100% "C"
Zoning: Residential (½ acre lots)

Hydrologic Data

	Pre	Post	Ult.
CN	72	78	82
t_c (hr)	.46	.35	.35

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Computation of Preliminary Stormwater Storage Volumes and Peak Discharges

The layout of the Stone Hill subdivision is shown on the previous page.

Water Quality Volume, WQ_v

- Compute Impervious Cover

  Use both on-site and off-site drainage:

  $I = 12.0 \text{ acres}/65.1 \text{ acres}$

  $= 18.4\%$

- Compute Runoff Coefficient, R_v

$$R_v = 0.05 + (I)(0.009)$$
$$= 0.05 + (18.4)(0.009) = 0.22$$

- Compute WQ_v (Includes both on-site and off-site drainage)

Use the 90% capture rule with 0.9" of rainfall. (From Figure 4.1)

$$WQ_v = (0.9")(R_v)(A)$$
$$= (0.9")(0.22)(65.1 \text{ ac})(1\text{ft}/12\text{in})$$
$$= 1.07 \text{ ac-ft}$$

Establish Hydrologic Input Parameters and Develop Site Hydrology (see Figures 8.2, 8.3, and 8.4)

Condition	Area	CN	Tc
	Ac		*hrs*
Pre-developed	65.1	72	0.46
Post-developed	65.1	78	0.35
Ultimate buildout*	65.1	82	0.35

*Zoned land use in the drainage area.

Hydrologic Calculations

Condition	$Q_{1\text{-yr}}$	$Q_{1\text{-yr}}$	$Q_{10\text{-yr}}$	$Q_{100\text{-yr}}$
Runoff	*inches*	*cfs*	*cfs*	*cfs*
Pre-developed	0.4	19	72	141
Post-developed	0.7	38	112	202
Ultimate buildout	NA	NA	NA	227

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PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	PRE DEVELOPMENT			21-Jan-97
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D?	Curve	AREA (In acres)
MEADOW		C	71	20.25 Ac.
MEADOW		D	78	7.95 Ac.
WOOD		C	70	15.09 Ac.
WOOD		D	77	1.81 Ac.
OFF-SITE MEADOW		C	71	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	150 Ft.	3.80% 0.28 Hrs
Shallow Flow	UNPAVED		1300 Ft. 2.65 F.P.S.	2.70% 0.14 Hrs.
Channel Flow Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 17.5 Ft.	1100 Ft. 7.14 F.P.S.	2.70% 0.04 Hrs.

Total Area in Acres =	65.10 Ac.	Total Sheet Flow=	Total Shallow Flow=	Total Channel Flow =
Weighted CN =	72			
Time Of Concentration =	0.46 Hrs.	0.28 Hrs.	0.14 Hrs.	0.04 Hrs.
Pond Factor =	1	RAINFALL TYPE II		

STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.4 In.	18.6 CFS	101,195 Cu. Ft.
2 Year	2.7 In.	0.6 In.	30.2 CFS	150,257 Cu. Ft.
10 Year	3.9 In.	1.4 In.	72 CFS	328,570 Cu. Ft.
100 Year	5.5 In.	2.6 In.	141 CFS	611,958 Cu. Ft.

Figure 8.2 Stone Hill Pre-Development Conditions

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PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	POST DEVELOPMENT			21-Jan-97
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D?	Curve	AREA (In acres)
MEADOW		C	71	0.16 Ac.
MEADOW		D	78	0.14 Ac.
WOOD		C	70	3.09 Ac.
WOOD		D	77	1.81 Ac.
IMPERVIOUS			98	12.00 Ac.
GRASS		C	74	20.09 Ac.
GRASS		D	80	7.81 Ac.
OFFSITE MEADOW		C	71	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	100 Ft.	3.80% 0.20 Hrs
Shallow Flow (a)	UNPAVED		100 Ft. 1.98 F.P.S.	1.50% 0.01 Hrs.
(b)	PAVED		400 Ft. 2.03 F.P.S.	1.00% 0.05 Hrs.
Channel Flow (a) Hydraulic Radius =0.50	1.6 SqFt	'n'=0.013 3.2 Ft.	1550 Ft. 7.22 F.P.S.	1.00% 0.06 Hrs.
(b) Hydraulic Radius =1.42	12.0 SqFt	'n'=0.030 8.5 Ft.	350 Ft. 13.01 F.P.S.	4.30% 0.01 Hrs.
(c) Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 8.5 Ft.	300 Ft. 7.89 F.P.S.	3.30% 0.01 Hrs.
Total Area in Acres =	65.10 Ac.	Total Sheet Flow=	Total Shallow Flow=	Total Channel Flow =
Weighted CN =	78	0.20 Hrs.	0.07 Hrs.	0.08 Hrs.
Time Of Concentration =	0.35 Hrs.			
Pond Factor =	1	RAINFALL TYPE II		

STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.7 In.	37.6 CFS	156,283 Cu. Ft.
2 Year	2.7 In.	0.9 In.	54.0 CFS	217,511 Cu. Ft.
10 Year	3.9 In.	1.8 In.	112 CFS	427,155 Cu. Ft.
100 Year	5.5 In.	3.1 In.	202 CFS	742,265 Cu. Ft.

Figure 8.3 Stone Hill Post-Development Conditions

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PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			EWB
DRAINAGE AREA NAME:	ULTIMATE BUILDOUT			21-Jan-97
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D?	Curve	AREA (In acres)
MEADOW		C	71	0.16 Ac.
MEADOW		D	78	0.14 Ac.
WOOD		C	70	3.09 Ac.
WOOD		D	77	1.81 Ac.
IMPERVIOUS			98	12.00 Ac.
GRASS		C	74	20.09 Ac.
GRASS		D	80	7.81 Ac.
OFFSITE ULTIMATE				
SF RES (0.25 AC LOTS)		C	83	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 2.7 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	100 Ft.	3.80% 0.20 Hrs
Shallow Flow (a)	UNPAVED		100 Ft. 1.98 F.P.S.	1.50% 0.01 Hrs.
(b)	PAVED		400 Ft. 2.03 F.P.S.	1.00% 0.05 Hrs.
Channel Flow (a) Hydraulic Radius =0.50	1.6 SqFt	'n'=0.013 3.2 Ft.	1550 Ft. 7.22 F.P.S.	1.00% 0.06 Hrs.
(b) Hydraulic Radius =1.42	12.0 SqFt	'n'=0.030 8.5 Ft.	350 Ft. 13.01 F.P.S.	4.30% 0.01 Hrs.
(c) Hydraulic Radius =1.26	22.0 SqFt	'n'=0.040 8.5 Ft.	300 Ft. 7.89 F.P.S.	3.30% 0.01 Hrs.
Total Area in Acres =	65.10 Ac.	Total Sheet	Total Shallow	Total Channel
Weighted CN =	82	Flow=	Flow=	Flow =
Time Of Concentration =	0.35 Hrs.	0.20 Hrs.	0.07 Hrs.	0.08 Hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.3 In.	0.9 In.	50.9 CFS	201,772 Cu. Ft.
2 Year	2.7 In.	1.1 In.	70.0 CFS	271,097 Cu. Ft.
10 Year	3.9 In.	2.1 In.	135 CFS	500,458 Cu. Ft.
100 Year	5.5 In.	3.5 In.	227 CFS	834,167 Cu. Ft.

Figure 8.4 Stone Hill Ultimate Buildout Conditions

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Compute Stream Channel Protection Volume, (Cp_v) (see Section 4.3 and Appendix B)

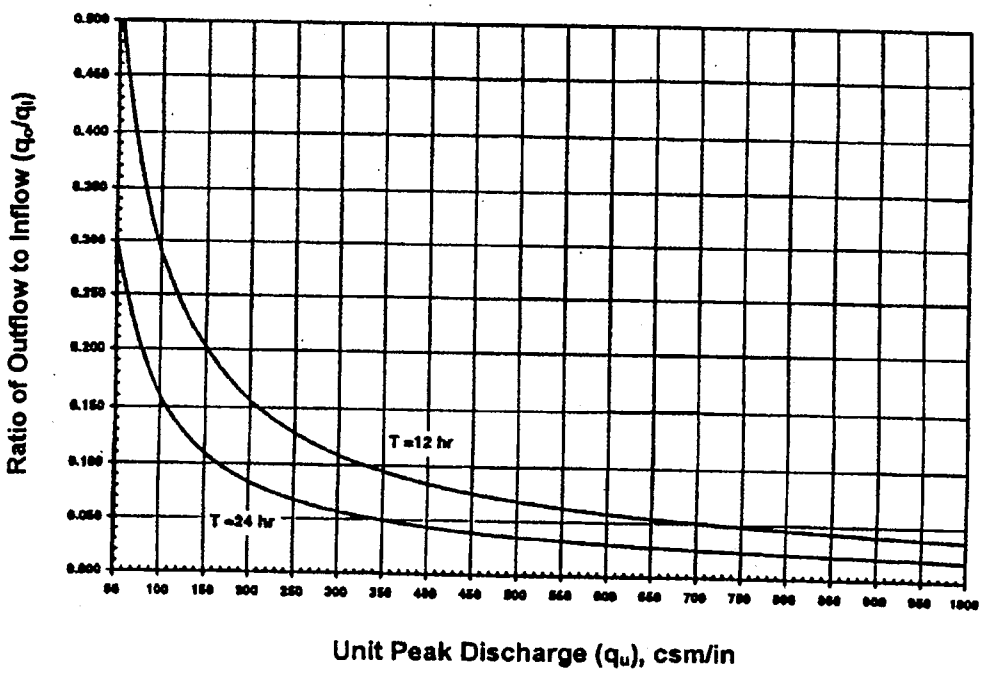
For stream channel protection, provide 24 hours of extended detention (T) for the one-year event.

Compute Channel Protection Storage Volume

First, determine the value of the unit peak discharge (q_u) using TR-55 and Type II Rainfall Distribution

- Initial abstraction (Ia) for CN of 78 is 0.564: [Ia = (200/CN - 2)]
- Ia/P = (0.564)/ 2.3 inches = 0.245
- T_c = 0.35 hours
- Using the above data, q_u = 570 csm/in (cubic feet per second per square mile per year)

Figure 8.5 Detention Time vs. Discharge Ratios (Source: MDE, 2000)



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- Knowing q_u and T = 24 hours, find q_o/q_i using Figure 8.5 (also see methodology in Appendix B)
- Peak outflow discharge/peak inflow discharge $(q_o/q_i) = 0.035$
- $Vs/Vr = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$ (from Appendix B)
  Where Vs equals channel protection storage (Cp_v) and Vr equals the volume of runoff in inches.
- Vs/Vr = 0.63 and, from figure 8.3, Q = 0.7"
- Solving for V_s

  $Vs = Cp_v = 0.63(0.7")(1/12)(65.1\ ac) = 2.4$ ac-ft (104,214 cubic feet)

Define the Average Release Rate

- The above volume, 2.4 ac-ft, is to be released over 24 hours
- $(2.4\ ac\text{-}ft \times 43{,}560\ ft^2/ac) / (24\ hrs \times 3{,}600\ sec/hr) = 1.2$ cfs

Compute Overbank Flood Protection Volume, (Qp_{10}) (see Section 4.4)

For both the overbank flood protection volume and the extreme flood protection volume, size is determined using the TR-55 "Short-Cut Method," which relates the storage volume to the required reduction in peak flow and storm inflow volume (Figure 8.6).

- For a q_i of of 112 cfs (post-developed), and an allowable q_o of 72 cfs (pre-developed), the value of $(q_o)/(q_i)$ is 0.64
- Using figure 8.6, and a post-developed curve number of 78, Vs/Vr = 0.23
- Using a total storm runoff volume of 427,155 cubic feet (9.8 acre-feet), the required storage (Vs) is:

  $V_s = Qp_v = 0.23(427{,}155)/43{,}560 = 2.26$ acre-feet

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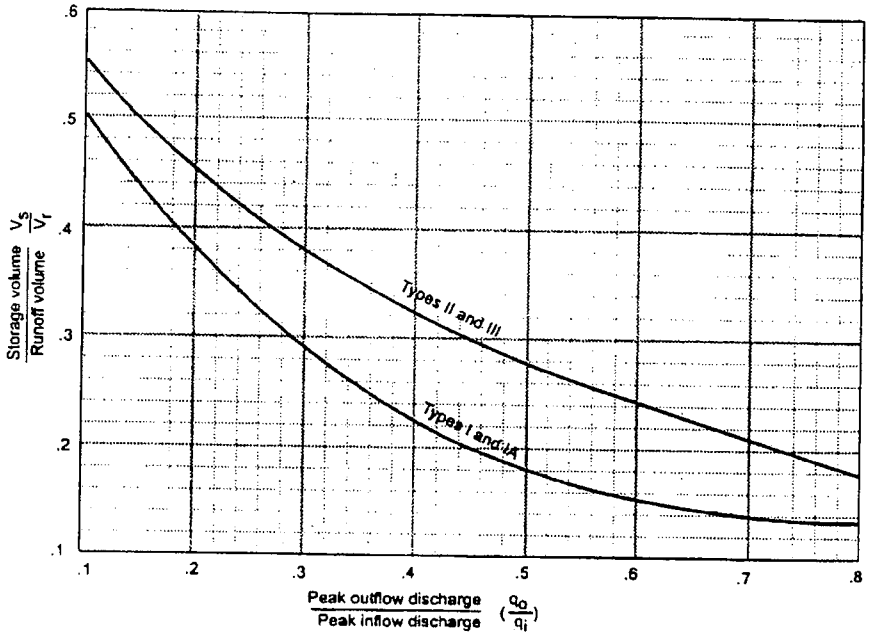
Figure 8.6 Approximate Detention Basin Routing for Rainfall Types I, IA, II, and III
Source: TR-55, 1986



While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided inclusive with the 10-year storm. So, for preliminary sizing purposes, add 15% to the required volume for the 10-year storm. $Q_{p\text{-}10} = 2.23 \times 1.15 = 2.59$ ac-ft.

Compute Extreme Flood Protection Volume, (Q_f)

Extreme flood protection is calculated using the same methodology as overbank protection.

- For a Q_{in} of, and an allowable Q_{out} of, and a runoff volume of the Vs necessary for 100-year control is, under a developed CN of 78. Note that 5.5 inches of rain fall during this event, with approximately 3.1 inches of runoff.
- While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided inclusive with the 100-year storm. So, for preliminary sizing purposes add 15% to the required volume for the 100-year storm. $Q_{f\text{-}100} = 3.53 \times 1.15 = 4.06$ ac-ft.

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Analyze Safe Passage of 100-Year Design Storm (Qf)

If peak discharge control of the 100-year storm is not required, it is still necessary to provide safe passage for the 100-year event under ultimate buildout conditions (Q_{ult} = 227 cfs).

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Section 8.2 Pond Design Example

Following is a step-by-step design example for an extended detention pond (P-3) applied to Stone Hill Estates, which is described in detail in Section 8.1 along with design treatment volumes. This example continues with the design to develop actual design parameters for the constructed facility.

Step 1. Compute preliminary runoff control volumes.

The volume requirements were determined in Section 8.1. Table 8.1 provides a summary of the storage requirements.

Table 8.1. Summary of General Storage Requirements for Stone Hill Estates

Symbol	*Category*	Volume Required (ac- ft)	*Notes*
WQ_v	Water Quality Volume	1.07	
Cp_v	Stream Protection	2.4	Average ED release rate is 1.2 cfs over 24 hours
Q_p	Peak Control	2.6	10-year, in this case
Q_f	Flood Control	4.1	

Step 2. Determine if the development site and conditions are appropriate for the use of a stormwater pond.

The drainage area to the pond is 65.1 acres. Existing ground at the proposed pond outlet is 619 MSL. Soil boring observations reveal that the seasonally high water table is at elevation 618. The underlying soils are SC (sandy clay) and are suitable for earthen embankments and to support a wet pond without a liner. The stream invert at the adjacent stream is at elevation 616.

Step 3. Confirm local design criteria and applicability.

There are no additional requirements for this site.

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Step 4. Determine pretreatment volume.

Size wet forebay to treat 10% of the WQ_v. (10%)(1.07 ac-ft) = **0.1 ac-ft**
(forebay volume is included in WQ_v as part of permanent pool volume)

Step 5. Determine permanent pool volume and ED volume.

Size permanent pool volume to contain 50% of WQ_v:
0.5 × (1.07 ac-ft) = **0.54 ac-ft.** (includes 0.1 ac-ft of forebay volume)

Size ED volume to contain 50% of WQ_v: 0.5 × (1.07 ac-ft) = **0.54 ac-ft**

NOTE

THIS DESIGN APPROACH ASSUMES THAT ALL OF THE ED VOLUME WILL BE IN THE POND AT ONCE. WHILE THIS WILL NOT BE THE CASE, SINCE THERE IS A DISCHARGE DURING THE EARLY STAGES OF STORMS, THIS CONSERVATIVE APPROACH ALLOWS FOR ED CONTROL OVER A WIDER RANGE OF STORMS, NOT JUST THE TARGET RAINFALL.

Step 6. Determine pond location and preliminary geometry. Conduct pond grading and determine storage available for WQv permanent pool and WQv-ED if applicable.

This step involves initially grading the pond (establishing contours) and determining the elevation-storage relationship for the pond. Storage must be provided for the permanent pool (including sediment forebay), extended detention (WQ_v-ED), Cp_v-ED, 10-year storm, 100-year storm, plus sufficient additional storage to pass the ultimate condition 100-year storm with required freeboard. An elevation-storage table and curve is prepared using the average area method for computing volumes. See Figure 8.7 for pond location on site, Figure 8.8 for grading and Figure 8.9 for Elevation-Storage Data.

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Figure 8.7 Pond Location on Site

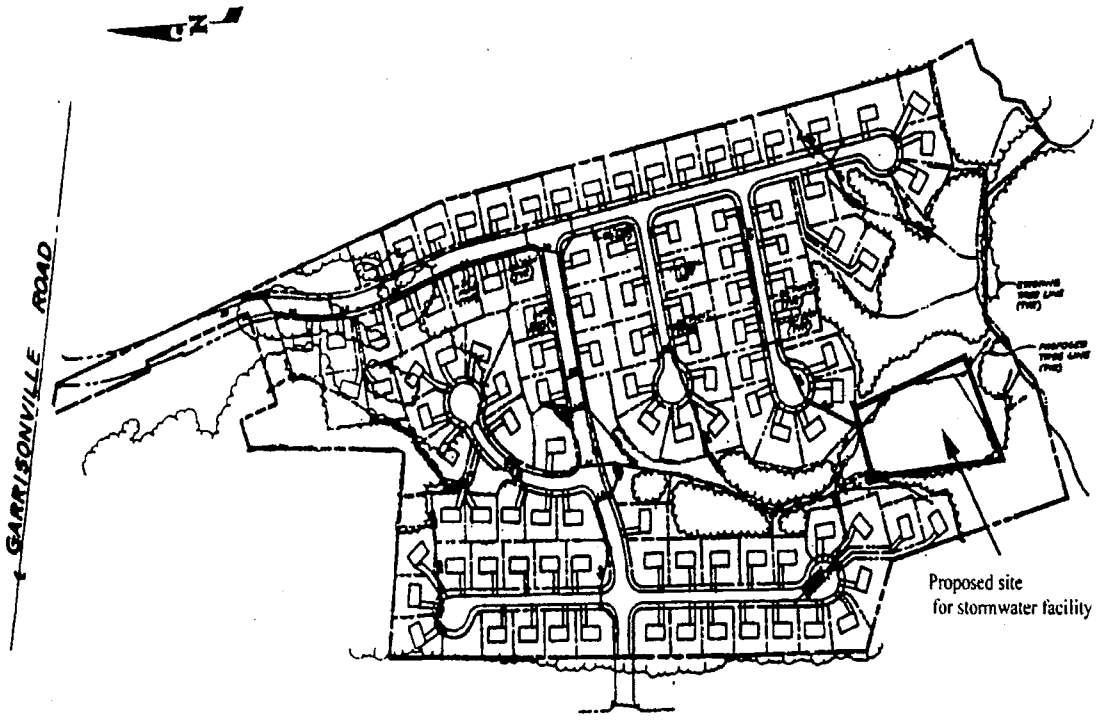

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Figure 8.8 Plan View of Pond Grading (Not to Scale)

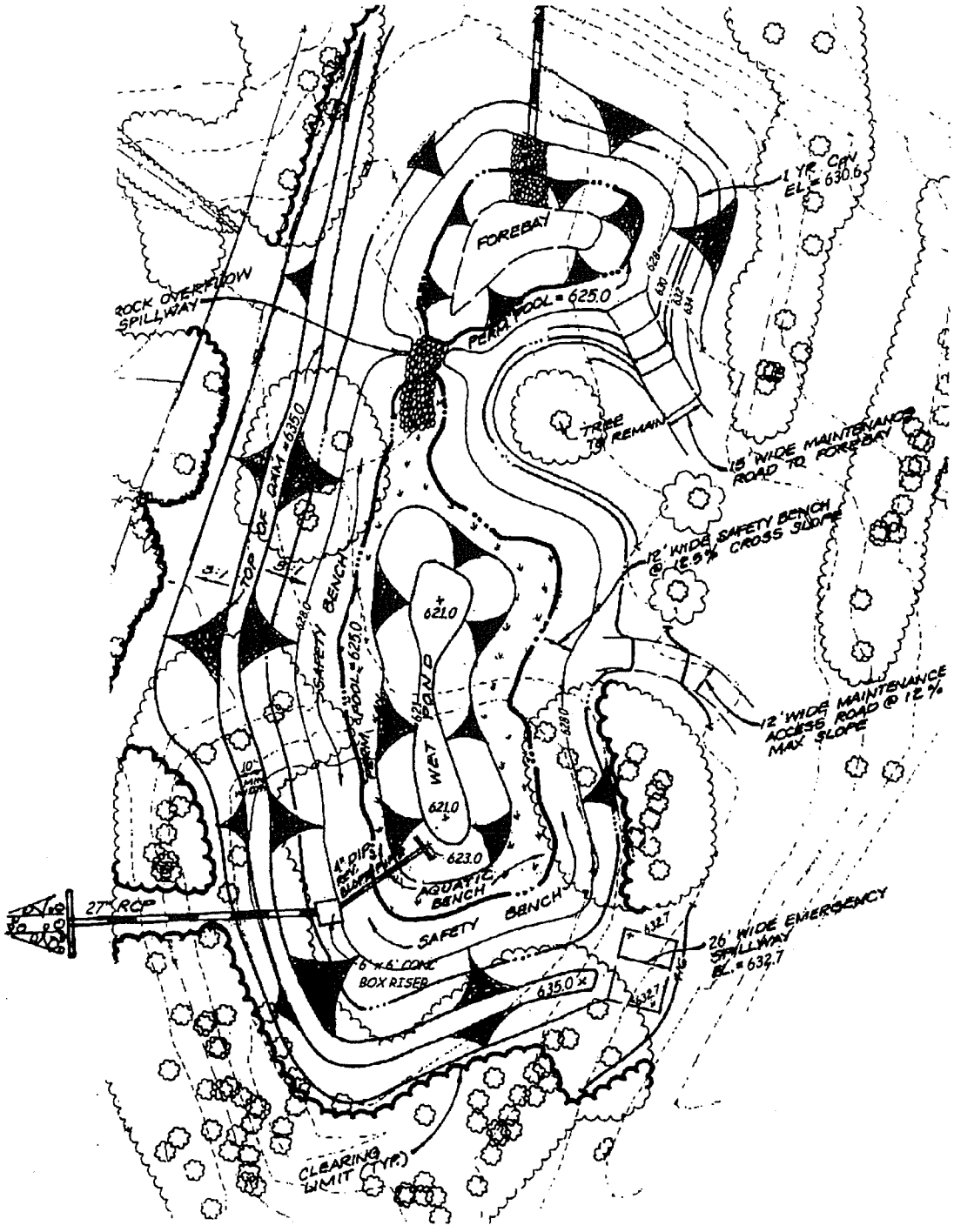

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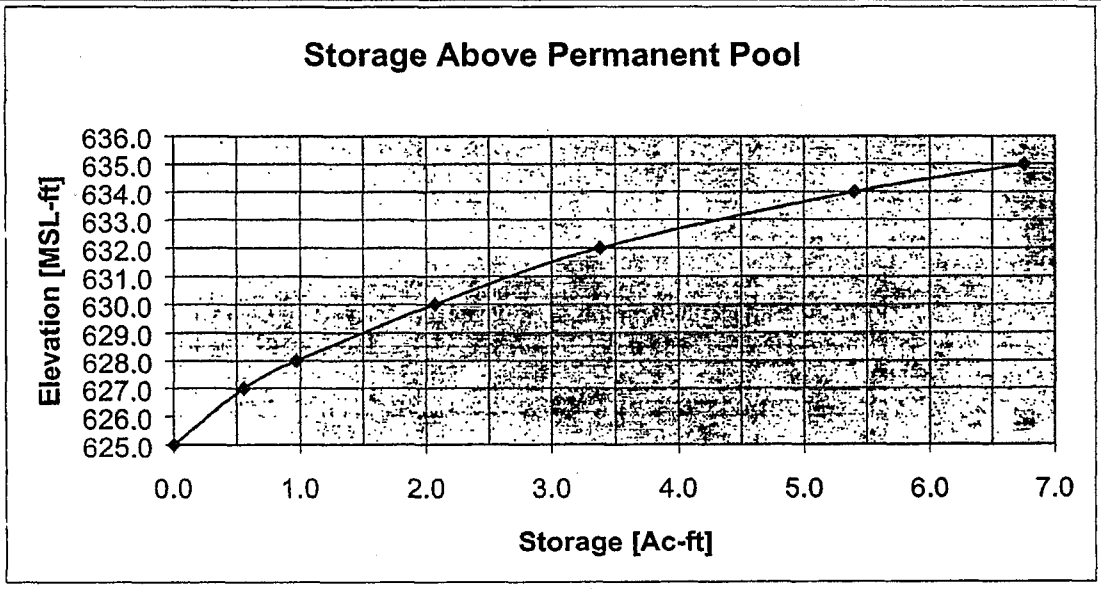
Figure 8.9 Storage-Elevation Table/Curve

Elevation MSL	Area ft^2	Average Area ft^2	Depth ft	Volume ft^3	Cumulative Volume ft^3	Cumulative Volume ac-ft	Volume Above Permanent Pool ac-ft
621.0	3150						
624.0	8325	5738	3	17213	17213	0.40	
625.0	10400	9363	1	9363	26575	0.61	0
627.0	13850	12125	2	24250	50825	1.17	0.56
628.0	21850	17850	1	17850	68675	1.58	0.97
630.0	26350	24100	2	48200	116875	2.68	2.07
632.0	30475	28413	2	56825	173700	3.99	3.38
634.0	57685	44080	2	88160	261860	6.01	5.40
635.0	60125	58905	1	58905	320765	7.36	6.75



Set basic elevations for pond structures

- The pond bottom is set at elevation 621.0
- Provide gravity flow to allow for pond drain, set riser invert at 620.5
- Set barrel outlet elevation at 620.0

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Set water surface and other elevations

- Required permanent pool volume = 50% of WQv = 0.54 ac-ft. From the elevation-storage table, read elevation 625.0 (0.61 ac-ft > 0.54 ac-ft) site can accommodate it and it allows a small safety factor for fine sediment accumulation – OK

Set permanent pool wsel = 625.0

- Forebay volume provided in single pool with volume = 0.1 ac-ft - OK
- Required extended detention volume (WQ_v-ED)= 0.54 ac-ft. From the elevation-storage table (volume above permanent pool), read elevation 627.0 (0.56 ac-ft > 0.54 ac-ft) OK. Set ED wsel = 627.0

Note: Total storage at elevation 627.0 = 1.17 ac-ft (greater than required WQ_v of 1.07 ac-ft)

Compute the required WQ_v-ED orifice diameter to release 0.54 ac-ft over 24 hours

- Avg. ED release rate = (0.54 ac-ft)(43,560 ft^2/ac)/(24 hr)(3600 sec/hr) = 0.27 cfs
- Invert of orifice set at wsel = 625.0
- Average head = (627.0 - 625.0)/ 2 = 1.0'
- Use orifice equation to compute cross-sectional area and diameter

  $Q = CA(2gh)^{0.5}$, for Q=0.27 cfs h = 1.0 ft; C = 0.6 = discharge coefficient. Solve for A

  $A = 0.27 \text{ cfs} / [(0.6)((2)32.2 \text{ ft/s}^2)(1.0 \text{ ft}))^{0.5}]$ $A = 0.057 \text{ ft}^2$, $A = \pi d^2 / 4$;

  dia. = 0.26 ft = 3.2", say 3.0 inches

  Use 4" pipe with 4" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 3.0" dia. WQv orifice

- $Q_{WQv\text{-}ED} = CA(2gh)^{0.5} = (0.6)\ (0.052 \text{ ft}^2)\ [((2)(32.2 \text{ ft/s}^2))^{0.5}]\ (h^{0.5})$,
- $Q_{WQv\text{-}ED} = (0.25)\ h^{0.5}$, where: h = wsel - 625.125

  (Note: Account for one half of orifice diameter when calculating head)

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Step 7. Compute ED orifice size, and compute release rate for Cpv-ED control and establish Cpv elevation.

Set the Cp_v pool elevation

- Required Cp_v storage = 2.4 ac-ft (see Table 1).
- From the elevation-storage table, read elevation 630.6 (this includes the WQ_v).
- Set Cp_v wsel = 630.6

Size Cp_v orifice

- Size to release average of 1.2 cfs.
- Set invert of orifice at wsel = 627.0
- Average WQ_v-ED orifice release rate is 0.41 cfs, based on average head of 2.74' ((630.6 – 625.125)/2)
- Cp_v-ED orifice release = 1.2 -0.41 = 0.79 cfs
- Head = (630.6 - 627.0)/2 = 1.8'

Use orifice equation to compute cross-sectional area and diameter

- $Q = CA(2gh)^{0.5}$, for h = 1.8'
  - $A = 0.79 \text{ cfs} / [(0.6)((2)(32.2'/s^2)(1.8'))^{0.5}]$
  - $A = 0.12 \text{ ft}^2$, $A = \pi d^2 / 4$;
  - dia. = 0.39 ft = 4.7"
  - Use 6" pipe with 6" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 4.7" dia. Cp_v orifice

- $Q_{Cpv\text{-}ED} = CA(2gh)^{0.5} = (0.6)\ (0.12 \text{ ft}^2)\ [((2)\ (32.2'/s^2))^{0.5}]\ (h^{0.5})$,
- $Q_{Cpv\text{-}ED} = (0.58)\ (h^{0.5})$, where: h = wsel – 627.2

(Note: Account for one half of orifice diameter when calculating head)

Step 8. Calculate Qp_{10} (10 year storm) release rate and water surface elevation.

In order to calculate the 10 year release rate and water surface elevation, the designer must set up a stage-storage-discharge relationship for the control structure for each of the low flow release pipes (WQ_v-ED and Cp_v-ED) plus the 10 year storm.

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Develop basic data and information

- The 10 year pre-developed peak discharge = 72 cfs,
- The post developed inflow = 112 cfs, from Table 1,
- From previous estimate Q_{p-10} = 2.26 ac-ft. Adding 15% to account for ED storage yields a preliminary volume of 2.56 ac-ft.
- From elevation-storage table (Figure 8.9), read elevation 631.0.
- Size 10 year slot to release 72 cfs at elevation 631.0.

@ wsel 631.0:

- WQ_v-ED orifice releases 0.61 cfs,
- Cp_v-ED orifice releases 1.13 cfs, therefore;
- Allowable Q_{p-10} = 72 cfs - (.61 + 1.13) = 70.26 cfs, say 70.3 cfs.
- Set weir crest elevation at wsel = 630.6
- Max head = (631.0 – 630.6) = 0.4'

Use weir equation to compute slot length

- $Q = CLh^{3/2}$
- $L = 70.3 \text{ cfs} / (3.1)(0.4^{3/2}) = 89.6$ ft
- This weir length is impractical, so adjust max head (and therefore slot height) to 1.5' and recalculate weir length.
- $L = 70.3 \text{ cfs} / (3.1)(1.5^{3/2}) = 12.3$ ft
- Use three 5ft x 1.5 ft slots for 10-year release (opening should be slightly larger than needed so as to have the barrel control before slot goes from weir flow to orifice flow).
- Maximum $Q = (3.1)(15)(1.5)^{3/2} = 85.4$ cfs

Check orifice equation using cross-sectional area of opening

- $Q = CA(2gh)^{0.5}$, for h = 0.75' (For orifice equation, h is from midpoint of slot)
- $A = 3\ (5.0')\ (1.5') = 22.5 ft^2$
- $Q = 0.6\ (22.5ft^2)\ [(64.4)(0.75)]^{0.5} = 93.8$ cfs > 85.4 cfs, so use weir equation

$$Q_{10} = (3.1)\ (15')\ h^{3/2}\ ,\ Q_{10} = (46.5)\ h^{3/2}, \text{ where } h = wsel - 630.6$$

- Size barrel to release approximately 70.3 cfs at elevation 632.1 (630.6 + 1.5)
- Check inlet condition: (use FHWA culvert charts)

H_w = 632.1-620.5 = 11.6 ft

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- Try 27" diameter RCP, Using FHWA Chart ("Headwater Depth for Concrete Pipe Culverts with Inlet Control") with entrance condition 1
- $H_w / D = 11.6/2.25 = 5.15$, Discharge = 69 cfs
- Check outlet condition (use NRCS pipe flow equation from NEH Section 5 ES-42):
- $Q = a [(2gh)/(1+k_m+k_pL)]^{0.5}$

where:
- Q = discharge in cfs
- a = pipe cross sectional area in ft^2
- g = acceleration of gravity in ft/sec^2
- h = head differential (wsel - downstream centerline of pipe or tailwater elev.)
- k_m = coefficient of minor losses (use 1.0)
- k_p = pipe friction loss coef. (= $5087n^2/d^{4/3}$, d in inches, n is Manning's n)
- L = pipe length in ft

$h = 632.1 - (620.0 + 1.125) = 10.98'$

for 27" RCP, approximately 70 feet long:

$Q = 4.0 [(64.4) (10.98) / (1+1+(0.0106) (70))]^{0.5} = 64.2$ cfs

64.2 cfs < 69 cfs, so barrel is outlet controlled and use outlet equation

$Q = 19.4 (h)^{0.5}$, where h = wsel – 621.125

Note: pipe will control flow before high stage inlet reaches max head.

Complete stage-storage-discharge summary (Figure 8.10) up to preliminary 10-year wsel (632.1) and route 10 year post-developed condition inflow using computer software (e.g., TR-20). Pond routing computes 10-year wsel at 632.5 with discharge = 65.4 cfs < 72 cfs, OK (see Figure 8.11).

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Figure 8.10 Stage-Storage-Discharge Summary

Elevation MSL	Storage ac-ft	Low Flow WQv-ED 3.0" eq dia		Riser						27" Barrel				Emergency Spillway 26' earthen 3:1		Total Discharge
				Cpv-ED 4.7" eq. dia		High Stage Slot				Inlet		Pipe				
						Orifice		Weir								
		H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	Q cfs
625.0	0.00	0	0													0.00
625.5	0.14	0.4	0.15													0.15
626.0	0.28	0.9	0.23													0.23
626.5	0.42	1.4	0.29													0.29
627.0	0.56	1.9	0.34	0.0	0.00											0.34
627.5	0.77	2.4	0.39	0.3	0.32											0.70
628.0	0.97	2.9	0.42	0.8	0.52											0.94
629.0	1.52	3.9	0.49	1.8	0.78											1.27
629.5	1.80	4.4	0.52	2.3	0.88											1.40
630.0	2.07	4.9	0.55	2.8	0.97											1.52
630.6	2.40	5.5	0.58	3.4	1.07	-	-	0.0	0.0							1.65
631.0	2.73	5.9	0.61	3.8	1.13	-	-	0.4	11.8							13.5
632.1	3.45	7.0	0.66	4.9	1.28	0.75	94	1.5	85.4	11.6	69.0	11.0	64.2			64.2
632.5	3.80	7.4	0.68	5.3	1.34	0.95	106	-	-	12.0	70.0	11.4	65.4			65.4
632.7	4.10	7.6	0.69	5.5	1.36	1.05	111	-	-	12.2	71.0	11.6	66.0	0.0	0.0	66.0
633.3	4.70	-	-	-	-	-	-	-	-	12.8	72.0	12.2	67.6	0.6	26.0	93.6
634.0	5.40	-	-	-	-	-	-	-	-	13.5	73.0	12.9	69.6	1.3	95.0	164.6
635.0	6.75	-	-	-	-	-	-	-	-	14.5	86.0	13.9	72.2	2.3	251.0	323.2

Note: Adequate outfall protection must be provided in the form of a riprap channel, plunge pool, or combination to ensure non-erosive velocities.

Step 9. Calculate Qp_{100} (100-year storm) release rate and water surface elevation, size emergency spillway, calculate 100-year water surface elevation.

In order to calculate the 100-year release rate and water surface elevation, the designer must continue with the stage-storage-discharge relationship (Figure 8.10) for the control riser and emergency spillway.

Develop basic data and information

- The 100 year pre-developed peak discharge = 141 cfs,
- The post developed inflow = 202 cfs, from Table 1,
- From previous estimate $Q_{p\text{-}100}$ = 3.53 ac-ft. Adding 15% to account for ED storage yields a preliminary volume of 4.06 ac-ft.
- From elevation-storage table (Figure 8.10), read elevation 632.8, say 633.0.

The 10-year wsel is at 632.5. Set the emergency spillway at elevation at 632.7 (this allows for some additional storage above the 10-yr wsel) and use design information and criteria for Earth Spillways (not included in this manual).

- Size 100 year spillway to release 141 cfs at elevation 633.0.
- @ wsel 633.0:

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- Outflow from riser structure is controlled by barrel (under outlet control), from Figure 8.11, read Q = 67.6 cfs at wsel = 633.3. Assume Q = 67 cfs at wsel = 633.0.
- Set spillway invert at wsel = 632.7
- Try 26' wide vegetated emergency spillway with 3:1 side slopes.
- Finalize stage-storage-discharge relationships and perform pond routing

Pond routing (TR-20) computes 100-year wsel at 633.76 with discharge = 140.95 cfs < 141 cfs, OK (see Figure 8.11).

Note: this process of sizing the emergency spillway and storage volume determination is usually iterative. This example reflects previous iterations at arriving at an acceptable design solution.

Step 10. Check for safe passage of Qp_{100} under ultimate buildout conditions and set top of embankment elevation.

The safety design of the pond embankment requires that the 100-year discharge, based on ultimate buildout conditions be able to pass safely through the emergency spillway with sufficient freeboard (one foot). This criteria does not mean that the ultimate buildout peak discharge be attenuated to pre-development rates.

From previous hydrologic modeling we know that:

- The 100 year ultimate buildout peak discharge = 227 cfs,
- The ultimate buildout composite curve number is 82.

Using TR-20 or equivalent routing model, determine peak wsel. Pond routing computes 100-year wsel at 634.0 with discharge = 192 cfs (Figure 8.12).

Therefore, with one foot of freeboard, the minimum embankment elevation is 635.0. Table 8.2 provides a summary of the storage, stage, and discharge relationships determined for this design example. See Figure 8.13 for a schematic of the riser.

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Table 8.2 Summary of Controls Provided					
Control Element	**Type/Size of Control**	**Storage Provided**	**Elevation**	**Discharge**	**Remarks**
Units		Acre-feet	MSL	cfs	
Permanent Pool		0.61	625.0	0	part of WQ_v
Forebay	submerged berm	0.1	625.0	0	included in permanent pool vol.
Extended Detention (WQ_v-ED)	4" pipe, sized to 3.0" equivalent diameter	0.56	627.0	0.25	part of WQ_v, vol. above perm. pool, discharge is average release rate over 24 hours
Channel Protection (Cp_v-ED)	6" pipe sized to 4.7" equivalent diameter	2.4	630.6	1.2	volume above perm. pool, discharge is average release rate over 24 hours
Overbank Protection ($Q_{p\text{-}10}$)	Three 5' x 1.5' slots on a 6' x 6' riser, 30"barrel.	2.5	632.5	65.4	volume above perm. pool
Extreme Storm ($Q_{f\text{-}100}$)	26' wide earth spillway	4.0	633.8	140.9	volume above perm. pool
Extreme Storm Ultimate Buildout	26' wide earth spillway	NA	634	192.0	Set minimum embankment height at 635.0

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Figure 8.11 TR-20 Model Input and Output

```
******************80-80 LIST OF INPUT DATA FOR TR-20 HYDROLOGY******************

JOB TR-20                        FULLPRINT                        NOPLOTS
TITLE      New York Manual Wet ED Example 1/01          EWB
TITLE      Post Developed Conditions Routing for 1, 10, and 100
 3 STRUCT       1
 8                       625.0       0.0         0.0
 8                       625.5       0.15        0.14
 8                       626.0       0.23        0.28
 8                       626.5       0.29        0.42
 8                       627.0       0.34        0.56
 8                       627.5       0.70        0.77
 8                       628.0       0.94        0.97
 8                       629.0       1.27        1.52
 8                       629.5       1.40        1.80
 8                       630.0       1.52        2.07
 8                       630.6       1.65        2.40
 8                       631.0       13.50       2.73
 8                       632.1       64.20       3.45
 8                       632.7       66.00       4.10
 8                       633.3       93.60       4.70
 8                       634.0       165.0       5.40
 8                       635.0       35230       6.75
 9 ENDTBL
 6 RUNOFF 1     1     2 0.102       78.0        0.35        1 1   0 0 1
 6 RESVOR 2     1 2   3 625.0                                1 1       1
   ENDATA
 7 INCREM 6             0.1
 7 COMPUT 7     1     1 0.0         2.3         1.0         2 2   1  01
   ENDCMP 1
 7 COMPUT 7     1     1 0.0         3.9         1.0         2 2   1  10
   ENDCMP 1
 7 COMPUT 7     1     1 0.0         5.5         1.0         2 2   1  99
   ENDCMP 1
   ENDJOB 2

*******************************END OF 80-80 LIST*********************************
```


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TR20 XEQ 1/22/** New York Manual Wet ED Example 1/01 EWB JOB 1 SUMMARY
REV 09/01/83 Post Developed Conditions Routing for 1, 10, and 100 PAGE 8

SUMMARY TABLE 1 - SELECTED RESULTS OF STANDARD AND EXECUTIVE CONTROL INSTRUCTIONS IN THE ORDER PERFORMED
A STAR(*) AFTER THE PEAK DISCHARGE TIME AND RATE (CFS) VALUES INDICATES A FLAT TOP HYDROGRAPH
A QUESTION MARK(?) INDICATES A HYDROGRAPH WITH PEAK AS LAST POINT.)

SECTION/ STRUCTURE ID	STANDARD CONTROL OPERATION	DRAINAGE AREA (SQ MI)	RAIN TABLE #	ANTEC MOIST COND	MAIN TIME INCREM (HR)	PRECIPITATION BEGIN (HR)	PRECIPITATION AMOUNT (IN)	PRECIPITATION DURATION (HR)	RUNOFF AMOUNT (IN)	PEAK DISCHARGE ELEVATION (FT)	PEAK DISCHARGE TIME (HR)	PEAK DISCHARGE RATE (CFS)	PEAK DISCHARGE RATE CSM)
ALTERNATE 1 STORM 1													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	2.30	24.00	.66	---	12.13	40.62	398.2
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	2.30	24.00	.40	630.31	18.00?	1.59?	15.6
ALTERNATE 1 STORM 10													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	3.90	24.00	1.81	---	12.11	118.47	161.5
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	3.90	24.00	1.49	632.51	12.34	65.43	41.5
ALTERNATE 1 STORM 99													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	5.50	24.00	3.14	---	12.11	206.59	025.4
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	5.50	24.00	2.80	633.76	12.29	140.95	381.9

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Figure 8.12 TR-20 Model Input and Output for Ultimate Buildout Conditions

```
TR20 XEQ  1/22/**          New York Manual Wet ED Example 1/01          EWB          JOB  1   SUMMARY
     REV 09/01/83          Ultimate Buildout Conditions for 100-yr                        PAGE  4

SUMMARY TABLE 1 - SELECTED RESULTS OF STANDARD AND EXECUTIVE CONTROL INSTRUCTIONS IN THE ORDER PERFORMED
                  (A STAR(*) AFTER THE PEAK DISCHARGE TIME AND RATE (CFS) VALUES INDICATES A FLAT TOP HYDROGRAPH
                   A QUESTION MARK(?) INDICATES A HYDROGRAPH WITH PEAK AS LAST POINT.)
```

SECTION/ STRUCTURE ID	STANDARD CONTROL OPERATION	DRAINAGE AREA (SQ MI)	RAIN TABLE #	ANTEC MOIST COND	MAIN TIME INCREM (HR)	PRECIPITATION BEGIN (HR)	PRECIPITATION AMOUNT (IN)	PRECIPITATION DURATION (HR)	RUNOFF AMOUNT (IN)	PEAK DISCHARGE ELEVATION (FT)	PEAK DISCHARGE TIME (HR)	PEAK DISCHARGE RATE (CFS)	PEAK DISCHARGE RATE (CSM)
ALTERNATE 1 STORM 99													
STRUCTURE 1	RUNOFF	.10	2	2	.10	.0	5.50	24.00	3.53	---	12.10	230.71	2261.9
STRUCTURE 1	RESVOR	.10	2	2	.10	.0	5.50	24.00	3.19	634.00	12.22	191.83	1880.7

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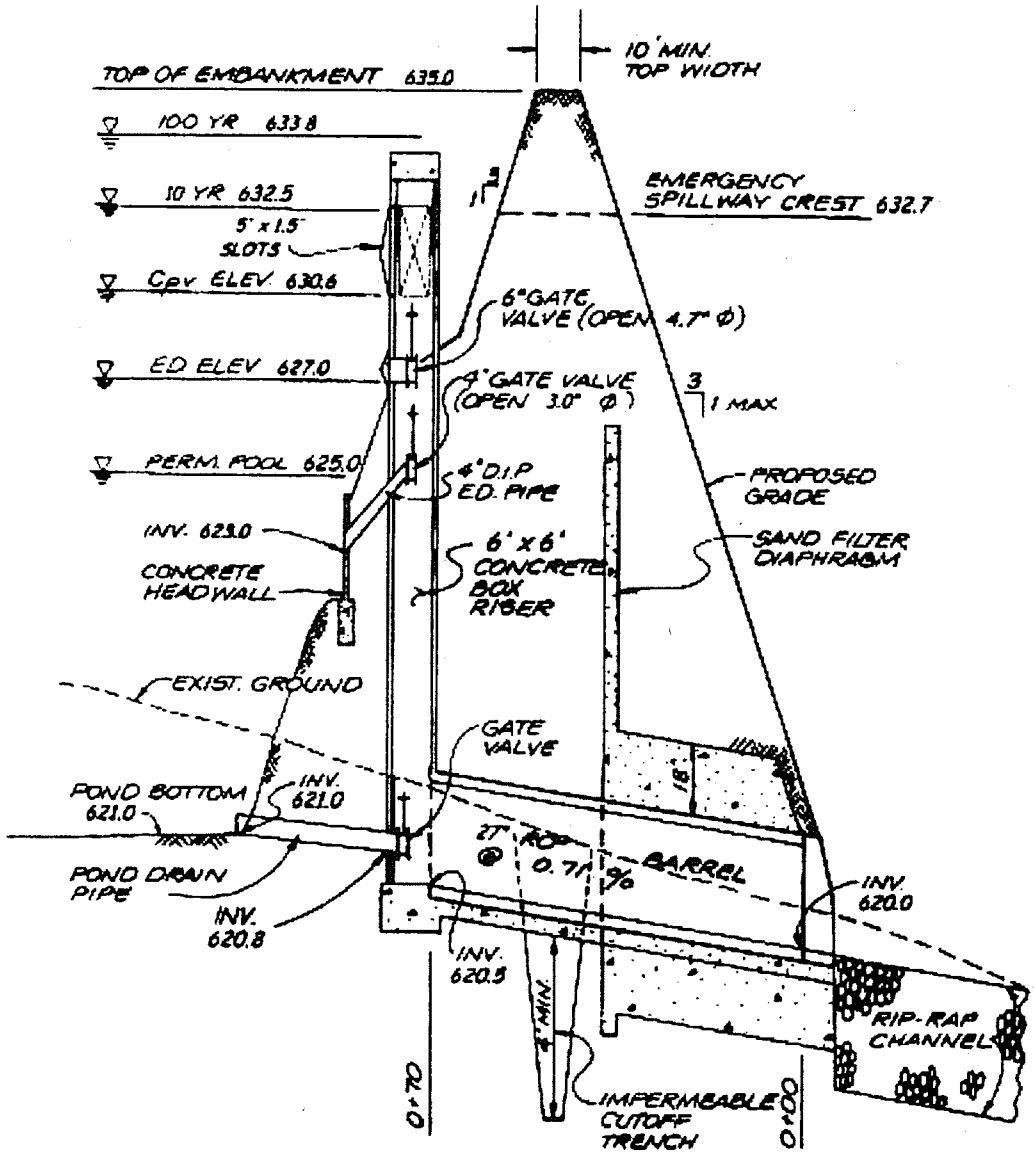
Figure 8.13 Profile of Principle Spillway



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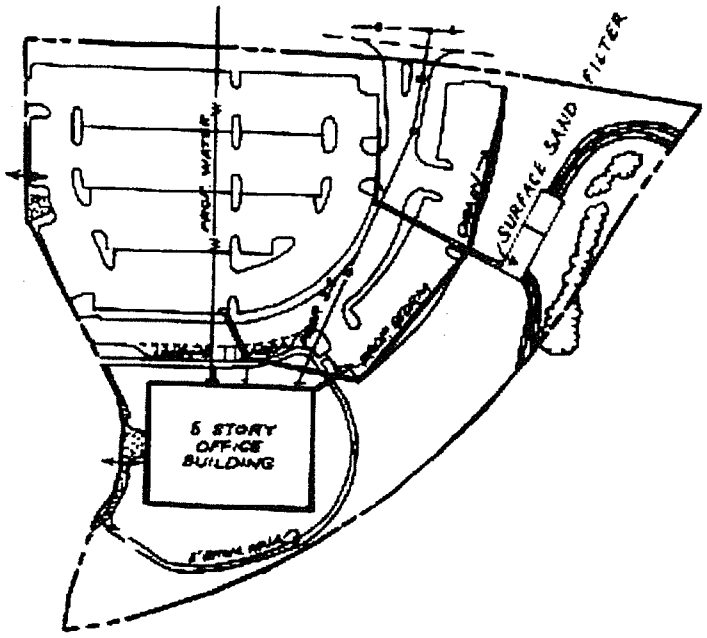
Section 8.3 Sand Filter Design Example

This design example focuses on the design of a sand filter for a 4.5-acre catchment of Lake Center, a hypothetical commercial site located in Albany, NY. A five-story office building and associated parking are proposed within the catchment. The layout is shown in Figure 8.14. The catchment has 3.05 acres of impervious cover, resulting in 68% impervious cover. The pre-developed site is a mixture of forest and meadow. On-site soils are predominantly HSG "B" soils.

Figure 8.14 Lake Center Site Plan



Base Data
Location: Albany, NY
Site Area = Total Drainage Area (A) = 4.50 ac
Impervious Area = 3.05 ac; or I =3.05/4.50 = 68%
Soils Type "B"

Hydrologic Data

	Pre	Post
CN	58	83
t_c (hr)	.44	.10

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This step-by-step example will focus on meeting the water quality requirements. Channel protection control, overbank flood control, and extreme flood control are not addressed in this example. Therefore, a detailed hydrologic analysis is not presented. For an example of detailed sizing calculations, consult section 8.1. In general, the primary function of sand filters is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. For this example, the post-development 10-yr peak discharge is provided to appropriately size the necessary by-pass flow splitter. Where quantity control is required, bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults).

Step 1. Compute design volumes using the Unified Stormwater Sizing Criteria.

Water Quality Volume, WQ_v

Select the Design Storm

Consulting Figure 4.1 of this document, use 1.0" as the 90% rainfall event for Albany.

Compute Runoff Coefficient, R_v

$R_v = 0.05 + (68)\ (0.009) = 0.66$

Compute WQ_v

$WQ_v = (1.0")\ (R_v)\ (A) / 12$

$= (1.0")\ (0.66)\ (4.5\ ac)\ (43{,}560 ft^2/ac)\ (1ft/12in)$

$= \underline{10{,}781}\ ft^3 = \underline{0.25\ ac\text{-}ft}$

Develop Site Hydrologic Input Parameters and Perform Preliminary Hydrologic Calculations (see Table 8.3)

Note: For this design example, the 10-year peak discharge is given and will be used to size the bypass flow splitter. Any hydrologic models using SCS procedures, such as TR-20, HEC-HMS, or HEC-1, can be used to perform preliminary hydrologic calculations.

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Table 8.3 Site Hydrology					
Condition	**CN**	**Q_1**	**Q_2**	**Q_{10}**	**Q_{100}**
		cfs	*cfs*	*cfs*	*cfs*
Pre-developed	58	0.2	0.4	3	9
Post-Developed	83	7	10	19	36

Step 2. Determine if the development site and conditions are appropriate for the use of a surface sand filter.

Site Specific Data:

Existing ground elevation at practice location is 222.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 211.0 feet. Adjacent drainage channel invert is at 213.0 feet.

Step 3. Compute available head, & peak discharge (Q_{wq}).

- Determine available head (See Figure 8.15)

The low point at the parking lot is 223.5. Subtract 2' to pass the Q_{10} discharge (221.5) and a half foot for the inflow channel to the facility (221.0). The low point at the channel invert is 213.0. Set the outfall underdrain pipe 1.0' above the drainage channel invert and add 0.5' to this value for the drain slope (214.5). Add to this value 8" for the gravel blanket over the underdrains, and 18" for the sand bed (216.67). The total available head is 221.0 - 216.67 or 4.33 feet. Therefore, the available average depth (h_f) = 4.33' / 2 = 2.17'.

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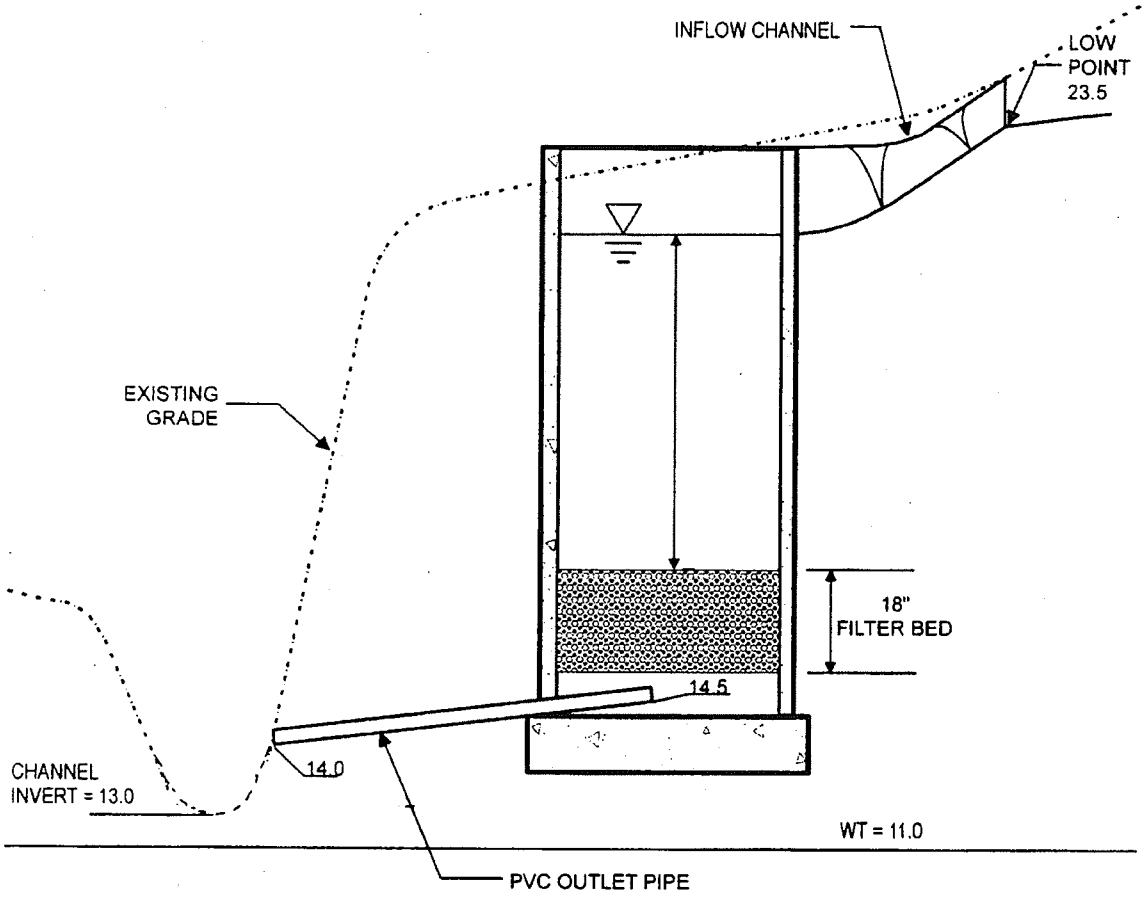
Figure 8.15 Available Head Diagram



- Compute Peak Water Quality Discharge:

The peak rate of discharge for the water quality design storm is needed for the sizing of off-line diversion structures, such as sand filters and grass channels. The Small Storm Hydrology Method presented in Appendix B was followed to calculate a modified curve number and subsequent peak discharge associated with the 1.0-inch rainfall. Calculation steps are provided below.

Compute modified CN for 1.0" rainfall

$P = 1.0"$

$Q_a = WQ_v \div \text{area} = (10{,}781\ ft^3 \div 4.5\ ac \div 43{,}560\ ft^2/ac \times 12\ in/ft) = 0.66"$

$CN = 1000/[10+5P+10Q_a-10(Q_a^2+1.25*Q_a*P)^{½}]$

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$= 1000/[10+5*1.0+10*0.66-10(0.66^2+1.25*0.66*1.0)^{½}]$

$= 96.4$

Use CN = 96

For CN = 96 and the t_c = 0.1 hours, compute the Q_{wq} for a 1.0" storm. With the CN = 96, a 1.0" storm will produce 0.6" of runoff. From TR-55 Chapter 2, Hydrology, I_a = 0.083, therefore:

$I_a/P = 0.083/1.0 = 0.083$.

From TR-55 Chapter 4 q_u = 1000 csm/in, and

Q_{wq} = (1000 csm/in) (4.5 ac/640ac/sq mi.) (0.66") = 4.6 cfs.

Step 4. Size the flow diversion structure.

Assume that flows are diverted to a diversion structure (Figure 8.16). First, size a low-flow orifice to pass the water quality storm (Q_p = 4.6 cfs).

$Q = CA(2gh)^{1/2}$; 4.6 cfs = (0.6) (A) $[(2)\ (32.2\ ft/s^2)\ (1.5')]^{1/2}$

A = 0.77 sq ft = $\pi d^2/4$: d = 0.99' or 12"

Size the 10-year overflow as follows:
The 10-year wsel is initially set at 223.0. Use a concrete weir to pass the 10-year flow (19.0 cfs), minus the flow carried by the low flow orifice, into a grassed overflow channel using the Weir equation. Assume 2' of head to pass this event. Overflow channel should be designed to provide sufficient energy dissipation (e.g., riprap, plunge pool, etc.) so that there will be non-erosive velocities.

Determine the flow from the low-flow orifice (Q_{lf}). Assume 3.5' of head (1.5' plus 2' for the 10-year head):

Q_{lf}=(0.6) (A) $[(2)\ (32.2\ ft/s^2)\ (3.5')]^{1/2}$

$A = \pi(1')^2/4$

$= 0.78$ sf

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So,

Q_{lf} = (0.6) (0.78) [(2) (32.2 ft/s^2) (3.5')]$^{1/2}$

= 7.0 cfs

Thus, determine the flow passed to the through the channel as:

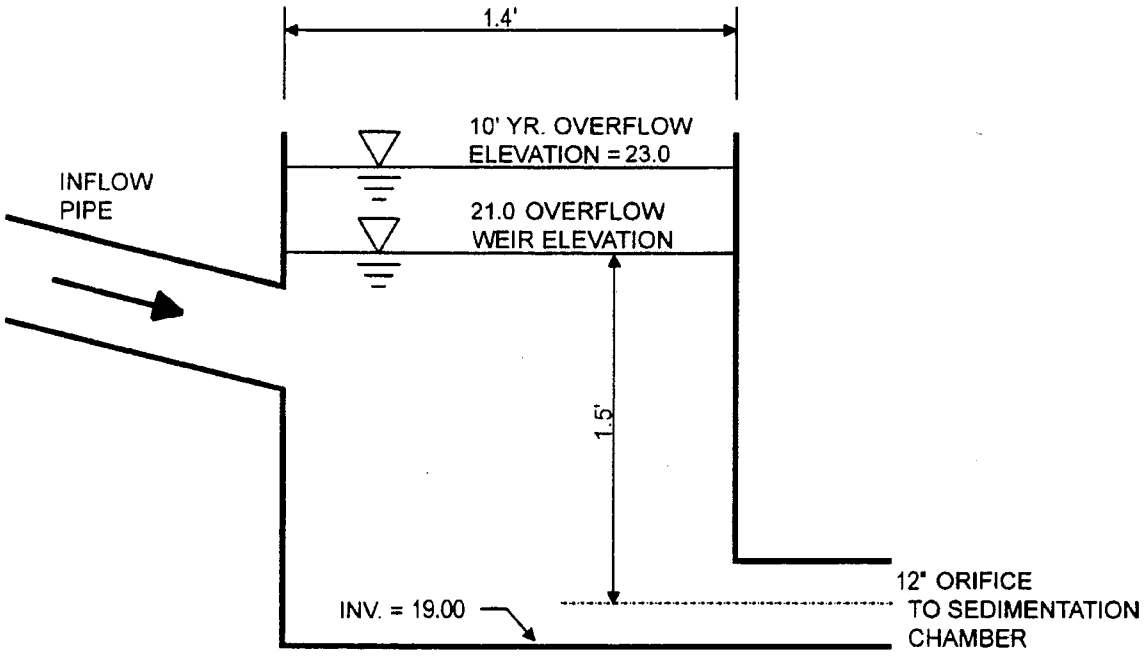
$Q = CLH^{3/2}$

(19-7) = 3.1 (L) (2')$^{1.5}$

L = 1.4' which sets the minimum length of the flow diversion overflow weir.

Weir wall elev. = 21.0. Set low flow invert at 21.0 - [1.5' + (0.5*12"*1ft/12")] = 19.00.

Figure 8.16 Flow Diversion Structure



Step 5. Size filtration bed chamber (see Figure 8.17).

From Darcy's Law: $A_f = WQ_v (d_f) / [k (h_f + d_f) (t_f)]$

where d_f = 18" or 1.5' (Filter thickness)

k = 3.5 ft/day (Flow-through rate)

h_f = 2.17' (Average head on filter)

t_f = 40 hours (Drain time)

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A_f = (10,781 cubic feet) (1.5') / [3.5 (2.17' + 1.5') (40hr/24hr/day)]

A_f = 755 sq ft; filter is 20' by 40' (= 800 sq ft)

Step 6. Size sedimentation chamber.

Size the sedimentation chamber as wet storage with a 2.5' depth. Determine the pretreatment volume as:

P_v = (0.25) (10,781 cf)

= 2,695 cf

Therefore,

A_s = (2,695 cf)/(2.5')

= 1,078 sf (Use 20'X55' or 1,100 sf)

Step 7. Compute V_{min}.

V_{min} = ¾(WQ_v) or 0.75 (10,781 cubic feet) = 8,086 cubic feet

Step 8. Compute volume within practice.

Volume within filter bed (V_f): $V_f = A_f (d_f) (n)$; n = 0.4 for sand

V_f = (800 sq ft) (1.5') (0.4) = 480 cf

temporary storage above filter bed ($V_{f\text{-}temp}$): $V_{f\text{-}temp} = 2h_fA_f$

$V_{f\text{-}temp}$ = 2 (2.17') (800 sq ft) = 3,472 cf

Compute storage in the sedimentation chamber (V_s):

V_s = (2.5')(1,100 sf)+4.33'(1,100 sf) = 7,513 cf

$V_f + V_{f\text{-}temp} + V_s$ = 480 cf + 3,472 cf + 7,513 cf = 11,465 cf

11,465 > 8,086 OK.

Pass flow through to the distribution chamber using a 12" orifice with an inverted elbow (see Figure 8.17).

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Step 9. Compute sedimentation chamber and filter bed overflow weir sizes.

Assume overflow that needs to be handled is equivalent to the 12" orifice discharge under a head of 3.5 ft (i.e., the head in the diversion chamber associated with the 10-year peak discharge).

$Q = CA(2gh)^{1/2}$

$Q = 0.6(0.79\ ft^2)[(2)(32.2\ ft/s^2)(3.5\ ft)]^{1/2}$

$Q = 7.1 cfs$

Size the overflow weir from the sediment chamber and the filtration chamber to pass 7.1 cfs (this assumes no attenuation within the practice).

Weir equation: $Q = CLh^{3/2}$, assume a maximum allowable head of 0.5'

$7.1 = 3.1 * L * (0.5\ ft)^{3/2}$

$\underline{L = 6.5\ ft.}$

Adequate outlet protection and energy dissipation (e.g., riprap, plunge pool, etc.) should be provided for the downstream overflow channel.

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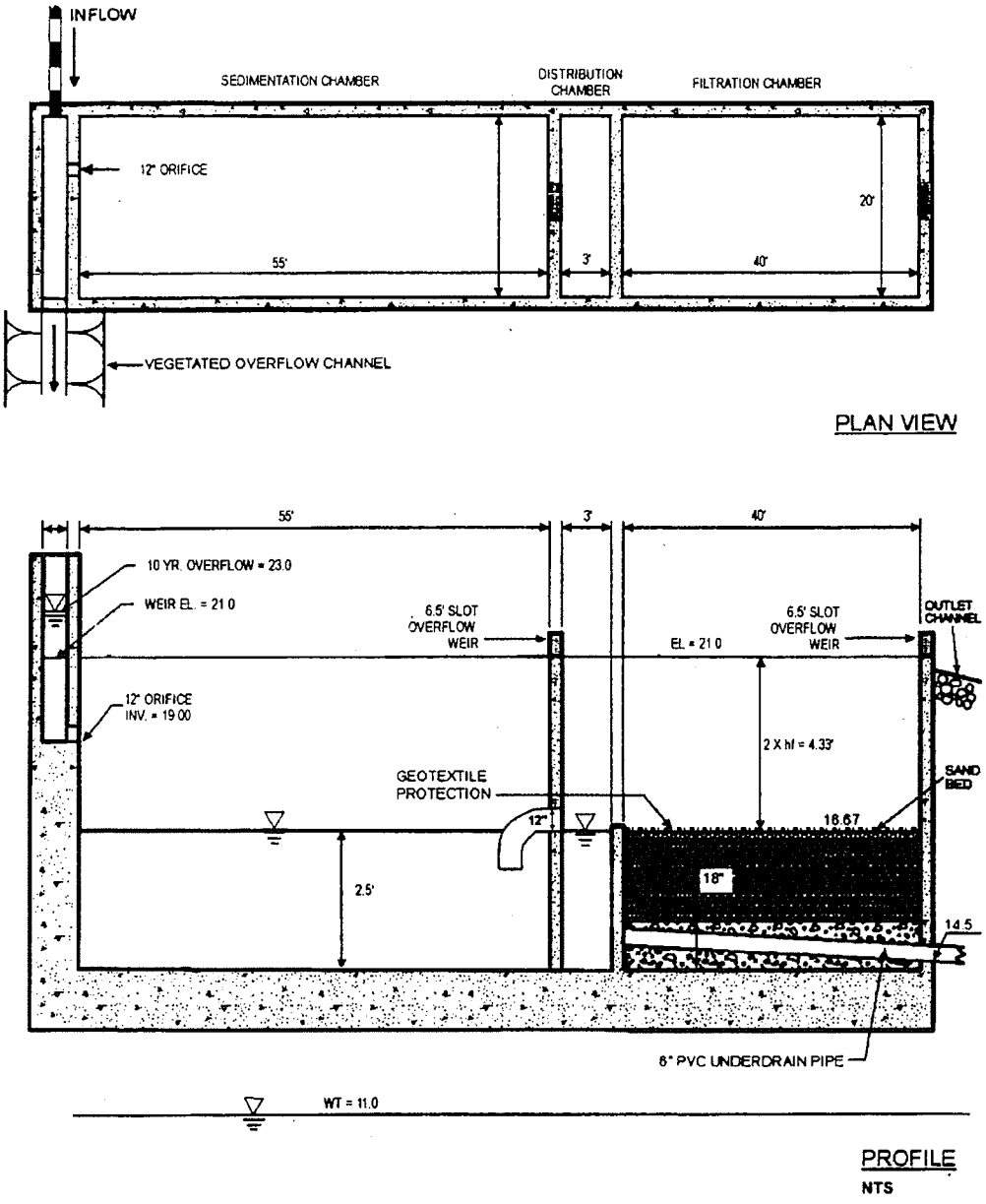
Figure 8.17 Plan and Profile of Surface Sand Filter



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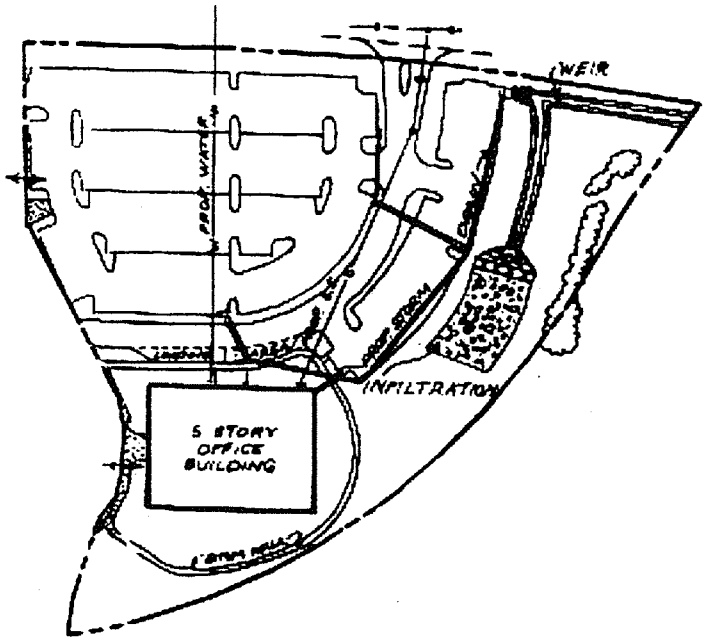
Section 8.4 Infiltration Trench Design Example

This design example focuses on the design of an infiltration trench for a 4.5-acre catchment of the Lake Center, a hypothetical commercial site located in Albany, NY. A five-story office building and associated parking are proposed within this catchment. The layout is shown in Figure 8.18. The catchment has 3.05 acres of impervious cover, resulting in a site impervious cover of 68%. The pre-developed site is a mixture of forest and meadow. On-site soils are predominantly HSG "B" soils.

Figure 8.18 Lake Center Site Plan



Base Data	*Hydrologic Data*		
Location: Albany, NY			
Site Area = Total Drainage Area (A) = 4.5 ac			
Impervious Area = 3.05 ac; or I =3.05/4.50 = 68%		**Pre**	**Post**
Soils Type "B"	CN	58	83
	t_c (hrs)	.44	.10

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This step-by-step example will focus on meeting the water quality requirements. Channel protection control, overbank flood control, and extreme flood control are not addressed in this example. Therefore, a detailed hydrologic analysis is not presented. For an example of detailed sizing calculations, consult section 8.1. In general, the primary function of infiltration practices is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. For this example, the post-development 10-yr peak discharge is provided to appropriately size the necessary by-pass flow splitter. Where quantity control is required, bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults).

Step 1. Compute design volumes and flows using the Unified Stormwater Sizing Criteria.

Design values are presented in Table 8.4 below.

Table 8.4 Site Design Hydrology

Condition	CN	WQ_v	Q_1	Q_2	Q_{10}
		ft³	*cfs*	*cfs*	*cfs*
Pre-Developed	58		0.2	0.4	3
Post-Developed	83	10,781	7	10	19

Step 2. Determine if the development site and conditions are appropriate for the use of an infiltration trench.

Site Specific Data:

Table 8.5 presents site-specific data, such as soil type, percolation rate, and slope, for consideration in the design of the infiltration trench. See Appendix D for infiltration testing requirements and Appendix C for infiltration practice construction specifications.

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Table 8.5 Site Specific Data	
Criteria	**Value**
Soil	Silt Loam
Percolation Rate	0.5"/hour
Ground Elevation at BMP	219'
Seasonally High Water Table	211'
Local Ground Slope	<1%

Step 3. Confirm local design criteria and applicability.

Table 8.6, below, summarizes the requirements that need to be met to successfully implement infiltration practices. On this site, infiltration is feasible, with restrictions on the depth and width of the trench.

Table 8.6 Infiltration Feasibility	
Criteria	**Status**
Infiltration rate (f_c) greater than or equal to 0.5 inches/hour.	• Infiltration rate is 0.5 inches/hour. OK.
Soils have a clay content of less than 20% and a silt/clay content of less than 40%.	• Silt Loam meets both criteria.
Infiltration cannot be located on slopes greater than 6% or in fill soils.	• Slope is <1%; not fill soils. OK.
Hotspot runoff should not be infiltrated.	• Not a hotspot land use. OK.
The bottom of the infiltration facility must be separated by at least two feet vertically from the seasonally high water table.	• Elevation of seasonally high water table: 11' • Elevation of BMP location: 19'. • The difference is 8'. • Thus, the trench can be up to 5' deep. OK.
Infiltration facilities must be located 100 feet horizontally from any water supply well.	• No water supply wells nearby. OK.
Maximum contributing area generally less than 5 acres.	• Area draining to facility is approximately 4.5 acres.
Setback 25 feet down-gradient from structures.	• Trench edge is > 25' from all structures. OK.

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Step 4. Size overflow channel.

Water flows from the edge of the parking lot to a 4' wide, flat bottom channel with 3:1 side slopes and a 2% slope. This channel also provides pretreatment (See Step 6). Use a weir to divert the water quality volume to the infiltration trench, while allowing the 10-year event to an adjacent drainage channel and the water quality storm to flow to the infiltration trench. The peak flow for the water quality storm is 4.6 cfs (see Section 8.3 for an example calculation).

Determine the depth of flow for the water quality storm using Manning's equation. (Several software packages can be used). The following assumptions are made:

Trapezoidal channel with 3:1 side slopes

4' bottom width.

S = 1%

n varies between 0.03 at 1' depth to 0.15 at 4" depth (See Appendix L and Grass Channel Fact Sheet in Chapter 5).

Determine that the water quality storm passes at d = 0.64'.

Size a weir to pass the 10-year peak event, less the water quality peak flow, so that:

Q = 19cfs – 4.6 cfs = 14.4 cfs.

Use a weir length, L, of 4.0'.

By rearranging the weir equation:

$H= (Q/CL)^{2/3} = (14.4/3.1(4))^{2/3} = 1.1'$

Size the channel to pass the 10-year event with 6" of freeboard.

Step 5. Size the infiltration trench.

The area of the trench can be determined by the following equation:

$A = WQv/(nd)$

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Where:

A = Surface Area

WQ_v = Water Quality volume (ft^3)

n = Porosity

d = Trench depth (feet)

Assume that:

n = 0.4

d = 4 feet

Therefore:

A = 10,781 ft^3 / (0.4 × 4)ft

A = 6,738ft^2

The proposed location for the infiltration trench will accommodate a trench width of up to 65 feet. Therefore, the minimum length required would be:

L = 6,738 ft^2 / 65 ft

L = 104 feet, <u>say 105 feet</u>

Step 6. Size pretreatment.

Pass the 10-year flow event through an overflow channel.

Size pretreatment to treat ¼ of the WQ_v. Therefore, treat 10,781 × 0.25 = 2,695 ft^3.

For pretreatment, use a pea gravel filter layer with filter fabric, a plunge pool, and a grass channel.

Pea Gravel Filter

The pea gravel filter layer covers the entire trench with 2" (see Figure 8.19). Assuming a porosity of 0.32, the pretreatment volume (Pv) provided in the pea gravel filter layer is:

Pv_{filter} = (0.32)(2")(1 ft/12 inches)(125')(50') = 333 ft^3

Plunge Pools

Use a 65 'X20' triangular plunge pool with a two foot depth as flow is diverted to the infiltration trench.

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Pv_{pool} = (65 x 20 ft)/2 *(2 ft) = 1,300 ft^3

Grass Channel

Accounting for the pretreatment volumes provided by the pea gravel filter and plunge pool, the grass channel then needs to treat at least (2,695 - 333 – 1,300)ft^3 = 1,062 ft^3

Currently stormwater flows through a 150' long channel, with parameters described under step 4. For this channel, the flow velocity of the peak flow from the water quality storm (4.6 cfs) is approximately 1.2 fps.

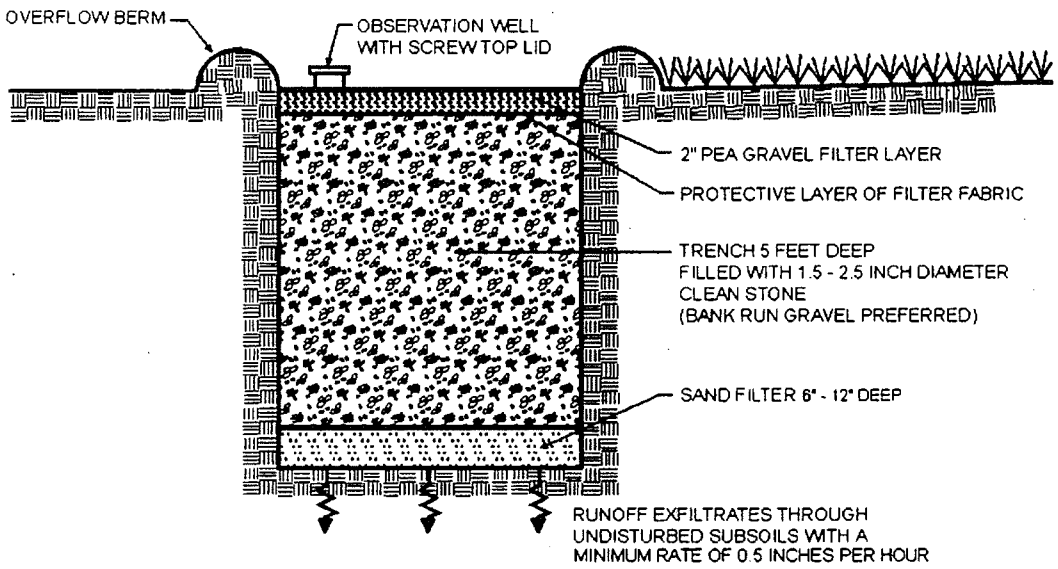
Using a required residence time of 10 minutes (600 seconds), the required length of channel for 100% of the WQ_v (10,781 ft^3) would be 1.2 fps x 600 sec = 720ft.

Adjust the length to account for the volume that must be provided, or:

(720ft) (1,062 ft^3)/(10,781 ft^3) = 71 ft

Therefore, for this example, a grass channel length of at least 71 feet is required. 150' is OK.

Figure 8.19 Schematic Infiltration Trench Cross Section



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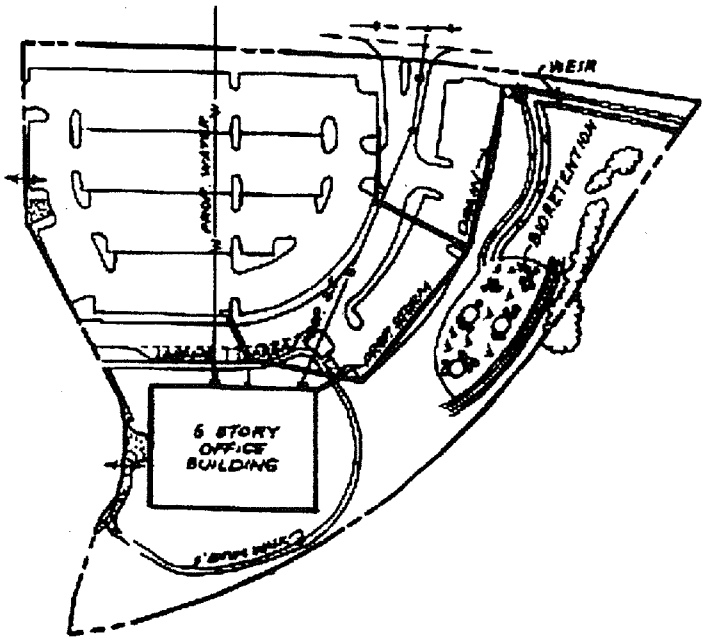
Section 8.5 Bioretention Design Example

This design example focuses on the design of a Bioretention area for a 4.5-acre catchment of Lake Center, a hypothetical commercial site located in Albany, NY. A five-story office building and associated parking are proposed within this catchment. The layout is shown in Figure 8.20. The catchment has 3.05 acres of impervious cover, resulting in 68% impervious cover. The pre-developed site is a mixture of forest and meadow. On-site soils are predominantly HSG "B" soils.

Figure 8.20 Lake Center Site Plan



Base Data
Location: Albany, NY
Site Area = Total Drainage Area (A) = 4.5 ac
Impervious Area = 3.05 ac; or I =3.05/4.50 = 68%
Soils Type "B"

Hydrologic Data

	Pre	Post
CN	58	83
t_c	.44	.10

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This step-by-step example will focus on meeting the water quality requirements. Channel protection control, overbank flood control, and extreme flood control are not addressed in this example. Therefore, a detailed hydrologic analysis is not presented. For an example of detailed sizing calculations, consult section 8.1. In general, the primary function of bioretention is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. For this example, the post-development 2-year and 10-year peaks are used to appropriately size the grass channel leading to the facility.

Step 1. Compute design volumes using the Unified Stormwater Sizing Criteria.

Design volumes are presented in Table 8.7 below.

Table 8.7 Design Hydrology

Condition	CN	WQ_v	Q_1	Q_2	Q_{10}
		ft³	*cfs*	*cfs*	*cfs*
Pre-developed	58		0.3	0.6	4
Post-Developed	83	10,781	9	13	26

Step 2. Determine if the development site and conditions are appropriate for the use of a bioretention area.

Site Specific Data:

Existing ground elevation at practice location is 222.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 211.0 feet and underlying soil is silt loam (ML). Adjacent channel invert is at 213 feet.

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Step 3. Determine size of bioretention filter area.

$A_f = (WQ_v)(d_f) / [(k)(h_f + d_f)(t_f)]$

Where:
- A_f = surface area of filter bed (ft^2)
- d_f = filter bed depth (ft)
- k = coefficient of permeability of filter media (ft/day)
- h_f = average height of water above filter bed (ft)
- t_f = design filter bed drain time (days) (2 days is recommended)

$A_f = (10{,}781\ ft^3)(5') / [(0.5'/day)(0.25' + 5')(2\ days)]$ (With k = 0.5'/day, $h_f = 0.25'$, $t_f = 2$ days)

$A_f =$ 10,267 sq ft

Step 4. Set design elevations and dimensions.

Assume a roughly 2 to 1 rectangular shape. Given a filter area requirement of 10,267 sq ft, say facility is roughly 70' by 150'. Set top of facility at 219.0 feet, with the berm at 220.0 feet. The facility is 5' deep, which will allow 3' of separation distance over the seasonally high water table. See Figure 8.21 for a typical section of the facility.

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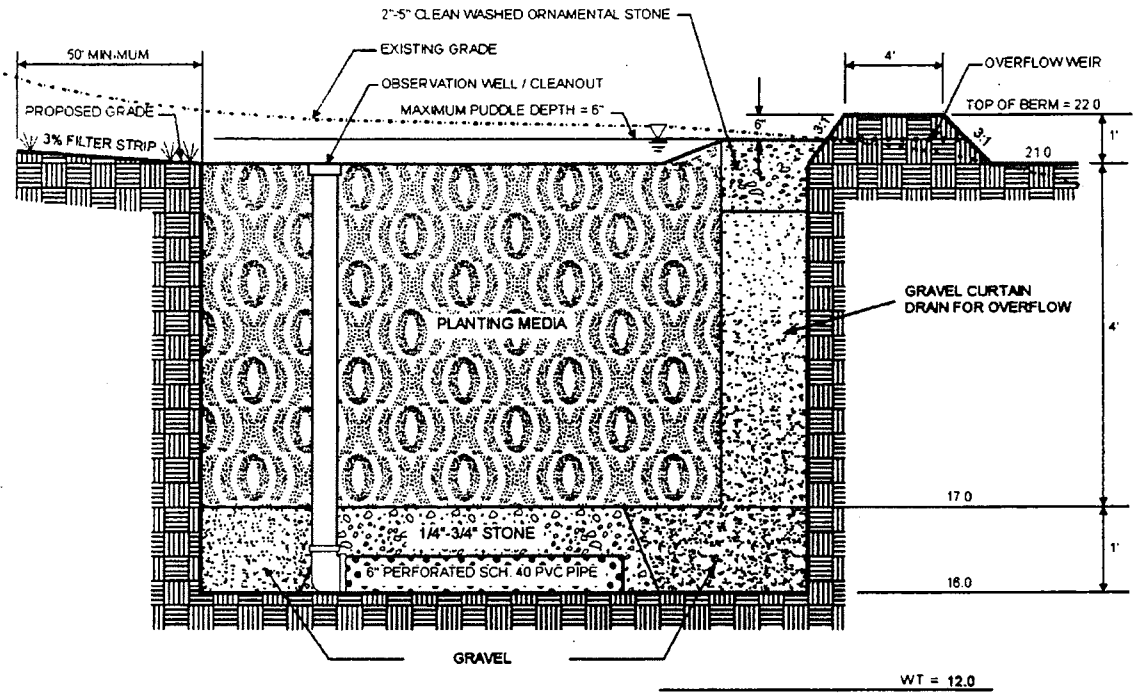
Figure 8.21 Typical Section of Bioretention Facility



Step 5. Size overflow channel.

Assuming the same channel configuration as in Section 8.3, use a 4' weir set 0.63' above the base of the overflow channel. The overflow channel will flow to the adjacent drainage channel, while the water quality storm will be diverted to the bioretention cell.

Step 6. Design Pretreatment

Size pretreatment to treat ¼ of the WQ_v. Therefore, treat $10,781 \times 0.25 = 2,695$ ft^3.

For pretreatment, a grass channel is used. This channel has a 4' width and 3:1 side slopes.

Using the methodologies described in Section 6.3, determine that the length of channel required to treat the entire water quality volume is 720 ft. Adjust the length to correspond to the pretreatment volume, or L = (720 ft)(2,695/10,781) = 180ft.

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Step 7. Size underdrain area.

As a rule of thumb, the length of underdrain should be based on 10% of the A_f or 1,027 sq ft and a three-foot wide zone of influence. Using 8" perforated plastic pipes surrounded by a three-foot wide gravel bed, 10' on center (o.c.), yields the following length of pipe:

(1,027 sq ft)/3' per foot of underdrain = 342' of perforated underdrain

Step 8. Create overdrain design.

To ensure against the planting media clogging, design a small ornamental stone window of 2" to 5" stone connected directly to the gravel curtain drain. This area is based on 5% of the A_f or 514 sq ft. Say 15' by 35' (see Figure 8.23).

Step 9. Choose plants for planting area.

Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Select species locations (i.e., on center planting distances) so species will not "shade out" one another. Do not plant trees and shrubs with extensive root systems (e.g., willows) near pipe work. A potential plant list for this site is presented in Appendix H.

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Glossary

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Glossary

ANTI-SEEP COLLAR - An impermeable diaphragm usually of sheet metal or concrete constructed at intervals within the zone of saturation along the conduit of a principal spillway to increase the seepage length along the conduit and thereby prevent piping or seepage along the conduit.

ANTI-VORTEX DEVICE - A device designed and placed on the top of a riser or at the entrance of a pipe to prevent the formation of a vortex in the water at the entrance.

AQUATIC BENCH - A ten to fifteen foot wide bench which is located around the inside perimeter of a permanent pool and is normally vegetated with aquatic plants; the goal is to provide pollutant removal and enhance safety in areas using stormwater pond SMP's.

AQUIFER - A geological formation which contains and transports groundwater.

"AS-BUILT" - Drawing or certification of conditions as they were actually constructed.

BAFFLES - Guides, grids, grating or similar devices placed in a pond to deflect or regulate flow and create a longer flow path.

BANKFULL FLOW - The condition where streamflow just fills a stream channel up to the top of the bank and at a point where the water begins to overflow onto a floodplain.

BARREL - The closed conduit used to convey water under or through an embankment: part of the principal spillway.

BASE FLOW - The stream discharge from ground water.

BERM - A shelf that breaks the continuity of a slope; a linear embankment or dike.

BIORETENTION - A water quality practice that utilizes landscaping and soils to treat urban stormwater runoff by collecting it in shallow depressions, before filtering through a fabricated planting soil media.

CHANNEL - A natural stream that conveys water; a ditch or channel excavated for the flow of water.

CHANNEL STABILIZATION - Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, structural linings, vegetation and other measures.

CHECK DAM - A small dam constructed in a gully or other small watercourse to decrease the stream flow velocity (by reducing the channel gradient), minimize channel scour, and promote deposition of sediment.

CHUTE - A high velocity, open channel for conveying water to a lower level without erosion.

CLAY (SOILS) - 1. A mineral soil separate consisting of particles less than 0.002 millimeter in equivalent diameter. 2. A soil texture class. 3. (Engineering) A fine grained soil (more than 50 percent passing the No. 200 sieve) that has a high plasticity index in relation to the liquid limit. (Unified Soil Classification System)

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COCONUT ROLLS - Also known as coir rolls, these are rolls of natural coconut fiber designed to be used for streambank stabilization.

COMPACTION (SOILS) - Any process by which the soil grains are rearranged to decrease void space and bring them in closer contact with one another, thereby increasing the weight of solid material per unit of volume, increasing the shear and bearing strength and reducing permeability.

CONDUIT - Any channel intended for the conveyance of water, whether open or closed.

CONTOUR - 1. An imaginary line on the surface of the earth connecting points of the same elevation. 2. A line drawn on a map connecting points of the same elevation.

CORE TRENCH - A trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

CRADLE - A structure usually of concrete shaped to fit around the bottom and sides of a conduit to support the conduit, increase its strength and in dams, to fill all voids between the underside of the conduit and the soil.

CREST - 1. The top of a dam, dike, spillway or weir, frequently restricted to the overflow portion. 2. The summit of a wave or peak of a flood.

CRUSHED STONE - Aggregate consisting of angular particles produced by mechanically crushing rock.

CURVE NUMBER (CN) - A numerical representation of a given area's hydrologic soil group, plant cover, impervious cover, interception and surface storage derived in accordance with Natural Resources Conservation Service methods. This number is used to convert rainfall volume into runoff volume.

CUT - Portion of land surface or area from which earth has been removed or will be removed by excavation; the depth below original ground surface to excavated surface.

CUT-AND-FILL - Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

CUTOFF - A wall or other structure, such as a trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

CZARA - Acronym used for the Coastal Zone Act Reauthorization Amendments of 1990. These amendments sought to address the issue of nonpoint source pollution issue by requiring states to develop Coastal Nonpoint Pollution Control Programs in order to receive federal funds.

DAM - A barrier to confine or raise water for storage or diversion, to create a hydraulic head, to prevent gully erosion, or for retention of soil, sediment or other debris.

DETENTION - The temporary storage of storm runoff in a SMP with the goals of controlling peak discharge rates and providing gravity settling of pollutants.

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DETENTION STRUCTURE - A structure constructed for the purpose of temporary storage of stream flow or surface runoff and gradual release of stored water at controlled rates.

DIKE - An embankment to confine or control water, for example, one built along the banks of a river to prevent overflow or lowlands; a levee.

DISTRIBUTED RUNOFF CONTROL (DRC) - A stream channel protection criteria which utilizes a non-uniform distribution of the storage stage-discharge relationship within a SMP to minimize the change in channel erosion potential from predeveloped to developed conditions.

DISTURBED AREA - An area in which the natural vegetative soil cover has been removed or altered and, therefore, is susceptible to erosion.

DIVERSION - A channel with a supporting ridge on the lower side constructed across the slope to divert water from areas where it is in excess to sites where it can be used or disposed of safely. Diversions differ from terraces in that they are individually designed.

DRAINAGE - 1. The removal of excess surface water or ground water from land by means of surface or subsurface drains. 2. Soils characteristics that affect natural drainage.

DRAINAGE AREA (WATERSHED) - All land and water area from which runoff may run to a common (design) point.

DROP STRUCTURE - A structure for dropping water to a lower level and dissipating surplus energy; a fall. The drop may be vertical or inclined.

DRY SWALE - An open drainage channel explicitly designed to detain and promote the filtration of stormwater runoff through an underlying fabricated soil media.

EMERGENCY SPILLWAY - A dam spillway designed and constructed to discharge flow in excess of the principal spillway design discharge.

ENERGY DISSIPATOR - A designed device such as an apron of rip-rap or a concrete structure placed at the end of a water transmitting apparatus such as pipe, paved ditch or paved chute for the purpose of reducing the velocity, energy and turbulence of the discharged water.

EROSION - 1. The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. 2. Detachment and movement of soil or rock fragments by water, wind, ice or gravity. The following terms are used to describe different types of water erosion:

Accelerated erosion - Erosion much more rapid than normal, natural or geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of other animals or natural catastrophes that expose base surfaces, for example, fires.

Gully erosion - The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 or 2 feet to as much as 75 to 100 feet.

Rill erosion - An erosion process in which numerous small channels only several inches deep are formed. See rill.

Sheet erosion - The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not subsequently be removed by surface runoff.

EROSIVE VELOCITIES - Velocities of water that are high enough to wear away the land surface. Exposed soil will generally erode faster than stabilized soils. Erosive velocities will vary according to the soil type, slope, structural, or vegetative stabilization used to protect the soil.

EXFILTRATION - The downward movement of water through the soil; the downward flow of runoff from the bottom of an infiltration SMP into the soil.

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EXTENDED DETENTION (ED) - A stormwater design feature that provides for the gradual release of a volume of water over a 12 to 48 hour interval in order to increase settling of urban pollutants and protect downstream channels from frequent storm events.

EXTREME FLOOD (Q_f) - The storage volume required to control those infrequent but large storm events in which overbank flows approach the floodplain boundaries of the 100-year flood.

FILTER BED - The section of a constructed filtration device that houses the filter media and the outflow piping.

FILTER FENCE - A geotextile fabric designed to trap sediment and filter runoff.

FILTER MEDIA - The sand, soil, or other organic material in a filtration device used to provide a permeable surface for pollutant and sediment removal.

FILTER STRIP - A strip of permanent vegetation above ponds, diversions and other structures to retard flow of runoff water, causing deposition of transported material, thereby reducing sediment flow.

FINES (SOIL) - Generally refers to the silt and clay size particles in soil.

FLOODPLAIN - Areas adjacent to a stream or river that are subject to flooding or inundation during a storm event that occurs, on average, once every 100 years (or has a likelihood of occurrence of 1/100 in any given year).

FLOW SPLITTER - An engineered, hydraulic structure designed to divert a percentage of storm flow to a SMP located out of the primary channel, or to direct stormwater to a parallel pipe system, or to bypass a portion of baseflow around a SMP.

FOREBAY - Storage space located near a stormwater SMP inlet that serves to trap incoming coarse sediments before they accumulate in the main treatment area.

FREEBOARD (HYDRAULICS) - The distance between the maximum water surface elevation anticipated in design and the top of retaining banks or structures. Freeboard is provided to prevent overtopping due to unforeseen conditions.

FOURTH ORDER STREAM - Designation of stream size where many water quantity requirements may not be needed. A first order stream is identified by "blue lines" on USGS quad sheets. A second order stream is the confluence of two first order streams, and so on.

FRENCH DRAIN - A type of drain consisting of an excavated trench refilled with pervious material, such as coarse sand, gravel or crushed stone, through whose voids water percolates and flows to an outlet.

GABION - A flexible woven-wire basket composed of two to six rectangular cells filled with small stones. Gabions may be assembled into many types of structures such as revetments, retaining walls, channel liners, drop structures and groins.

GABION MATTRESS - A thin gabion, usually six or nine inches thick, used to line channels for erosion control.

GRADE - 1. The slope of a road, channel or natural ground. 2. The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction, like paving or laying a conduit. 3. To finish the surface of a canal bed, roadbed, top of embankment or bottom of excavation.

GRASS CHANNEL - A open vegetated channel used to convey runoff and to provide treatment by filtering out pollutants and sediments.

GRAVEL - 1. Aggregate consisting of mixed sizes of 1/4 inch to 3 inch particles which normally occur in or near old streambeds and have been worn smooth by the action of water. 2. A soil having particle sizes, according to the Unified Soil Classification System, ranging from the No. 4 sieve size angular in shape as produced by mechanical crushing.

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GRAVEL DIAPHRAGM - A stone trench filled with small, river-run gravel used as pretreatment and inflow regulation in stormwater filtering systems.

GRAVEL FILTER - Washed and graded sand and gravel aggregate placed around a drain or well screen to prevent the movement of fine materials from the aquifer into the drain or well.

GRAVEL TRENCH - A shallow excavated channel backfilled with gravel and designed to provide temporary storage and permit percolation of runoff into the soil substrate.

GROUND COVER - Plants which are low-growing and provide a thick growth which protects the soil as well as providing some beautification of the area occupied.

GULLY - A channel or miniature valley cut by concentrated runoff through which water commonly flows only during and immediately after heavy rains or during the melting of snow. The distinction between gully and rill is one of depth. A gully is sufficiently deep that it would not be obliterated by normal tillage operations, whereas a rill is of lessor depth and would be smoothed by ordinary farm tillage.

HEAD (HYDRAULICS) - 1. The height of water above any plane of reference. 2. The energy, either kinetic or potential, possessed by each unit weight of a liquid expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various terms such as pressure head, velocity head, and head loss.

HERBACEOUS PERENNIAL (PLANTS) - A plant whose stems die back to the ground each year.

HI MARSH - A pondscaping zone within a stormwater wetland which exists from the surface of the normal pool to a six inch depth and typically contains the greatest density and diversity of emergent wetland plants.

HI MARSH WEDGES - Slices of shallow wetland (less than or equal to 6 inches) dividing a stormwater wetland.

HOT SPOT - Area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

HYDRAULIC GRADIENT - The slope of the hydraulic grade line. The slope of the free surface of water flowing in an open channel.

HYPOXIA - Lack of oxygen in a waterbody resulting from eutrophication.

HYDROGRAPH - A graph showing variation in stage (depth) or discharge of a stream of water over a period of time.

HYDROLOGIC SOIL GROUP (HSG) - A Natural Resource Conservation Service classification system in which soils are categorized into four runoff potential groups. The groups range from A soils, with high permeability and little runoff production, to D soils, which have low permeability rates and produce much more runoff.

HYDROSEED - Seed or other material applied to areas in order to revegetate after a disturbance.

IMPERVIOUS COVER (I) - Those surfaces in the urban landscape that cannot effectively infiltrate rainfall consisting of building rooftops, pavement, sidewalks, driveways, etc.

INDUSTRIAL STORMWATER PERMIT - An NPDES permit issued to a commercial industry or group of industries which regulates the pollutant levels associated with industrial storm water discharges or specifies on-site pollution control strategies.

INFILTRATION RATE (F_c) - The rate at which stormwater percolates into the subsoil measured in inches per hour.

INFLOW PROTECTION - A water handling device used to protect the transition area between any water conveyance (dike, swale, or swale dike) and a sediment trapping device.

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LEVEL SPREADER - A device for distributing stormwater uniformly over the ground surface as sheet flow to prevent concentrated, erosive flows and promote infiltration.

MANNING'S FORMULA (HYDRAULICS) - A formula used to predict the velocity of water flow in an open channel or pipeline:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where V is the mean velocity of flow in feet per second; R is the hydraulic radius; S is the slope of the energy gradient or for assumed uniform flow the slope of the channel, in feet per foot; and n is the roughness coefficient or retardance factor of the channel lining.

MICROPOOL - A smaller permanent pool which is incorporated into the design of larger stormwater ponds to avoid resuspension or settling of particles and minimize impacts to adjacent natural features.

MICROTOPOGRAPHY - The complex contours along the bottom of a shallow marsh system, providing greater depth variation which increases the wetland plant diversity and increases the surface area to volume ratio of a stormwater wetland.

MULCH - Covering on surface of soil to protect and enhance certain characteristics, such as water retention qualities.

MUNICIPAL STORMWATER PERMIT - A SPDES permit issued to municipalities to regulate discharges from municipal separate storm sewers for compliance with EPA established water quality standards and/or to specify stormwater control strategies.

NPDES - Acronym for the National Pollutant Discharge Elimination System, which regulates point source and non-point source discharge.

NITROGEN-FIXING (BACTERIA) - Bacteria having the ability to fix atmospheric nitrogen, making it available for use by plants. Inoculation of legume seeds is one way to insure a source of these bacteria for specified legumes.

NORMAL DEPTH - Depth of flow in an open conduit during uniform flow for the given conditions.

OUTFALL - The point where water flows from a conduit, stream, or drain.

OFF-LINE - A stormwater management system designed to manage a storm event by diverting a percentage of stormwater events from a stream or storm drainage system.

ON-LINE - A stormwater management system designed to manage stormwater in its original stream or drainage channel.

ONE YEAR STORM ($Q_{P\,1}$) - A stormwater event which occurs on average once every year or statistically has a 100% chance on average of occurring in a given year.

ONE HUNDRED YEAR STORM ($Q_{P\,100}$) A extreme flood event which occurs on average once every 100 years or statistically has a 1% chance on average of occurring in a given year.

OPEN CHANNELS - Also known as swales, grass channels, and biofilters. These systems are used for the conveyance, retention, infiltration and filtration of stormwater runoff.

OUTLET - The point at which water discharges from such things as a stream, river, lake, tidal basin, pipe, channel or drainage area.

OUTLET CHANNEL - A waterway constructed or altered primarily to carry water from man-made structures such as terraces, subsurface drains, diversions and impoundments.

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PEAK DISCHARGE RATE - The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

PERMANENT SEEDING - Results in establishing perennial vegetation which may remain on the area for many years.

PERMEABILITY - The rate of water movement through the soil column under saturated conditions

PERMISSIBLE VELOCITY (HYDRAULICS) - The highest average velocity at which water may be carried safely in a channel or other conduit. The highest velocity that can exist through a substantial length of a conduit and not cause scour of the channel. A safe, non-eroding or allowable velocity

pH - A number denoting the common logarithm of the reciprocal of the hydrogen ion concentration. A pH of 7.0 denotes neutrality, higher values indicate alkalinity, and lower values indicate acidity.

PIPING - Removal of soil material through subsurface flow channels or "pipes" developed by seepage water.

PLUGS - Pieces of turf or sod, usually cut with a round tube, which can be used to propagate the turf or sod by vegetative means.

POCKET POND - A stormwater pond designed for treatment of small drainage area (< 5 acres) runoff and which has little or no baseflow available to maintain water elevations and relies on ground water to maintain a permanent pool.

POCKET WETLAND - A stormwater wetland design adapted for the treatment of runoff from small drainage areas (< 5 acres) and which has little or no baseflow available to maintain water elevations and relies on ground water to maintain a permanent pool.

POND BUFFER - The area immediately surrounding a pond which acts as filter to remove pollutants and provide infiltration of stormwater prior to reaching the pond. Provides a separation barrier to adjacent development.

POND DRAIN - A pipe or other structure used to drain a permanent pool within a specified time period.

PONDSCAPING - Landscaping around stormwater ponds which emphasizes native vegetative species to meet specific design intentions. Species are selected for up to six zones in the pond and its surrounding buffer, based on their ability to tolerate inundation and/ or soil saturation.

POROSITY - Ratio of pore volume to total solids volume.

PRETREATMENT - Techniques employed in stormwater SMPs to provide storage or filtering to help trap coarse materials before they enter the system.

PRINCIPAL SPILLWAY - The primary pipe or weir which carries baseflow and storm flow through the embankment.

REDEVELOPMENT - New development activities on previously developed land.

RETENTION - The amount of precipitation on a drainage area that does not escape as runoff. It is the difference between total precipitation and total runoff.

REVERSE-SLOPE PIPE - A pipe which draws from below a permanent pool extending in a reverse angle up to the riser and which determines the water elevation of the permanent pool.

RIGHT-OF-WAY - Right of passage, as over another's property. A route that is lawful to use. A strip of land acquired for transport or utility construction.

RIP-RAP - Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves); also applies to brush or pole mattresses, or brush and stone, or similar materials used for soil erosion control.

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RISER - A vertical pipe or structure extending from the bottom of a pond SMP and houses the control devices (weirs/orifices) to achieve the discharge rates for specified designs.

ROUGHNESS COEFFICIENT (HYDRAULICS) - A factor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.

RUNOFF (HYDRAULICS) - That portion of the precipitation on a drainage area that is discharged from the area in the stream channels. Types include surface runoff, ground water runoff or seepage.

RUNOFF COEFFICIENT (R_V) - A value derived from a site impervious cover value that is applied to a given rainfall volume to yield a corresponding runoff volume.

SAFETY BENCH - A flat area above the permanent pool and surrounding a stormwater pond designed to provide a separation from the pond pool and adjacent slopes.

SAND - 1. (Agronomy) A soil particle between 0.05 and 2.0 millimeters in diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System, a soil particle larger than the No. 200 sieve (0.074mm) and passing the No. 4 sieve (approximately 1/4 inch).

SEDIMENT - Solid material, both mineral and organic, that is in suspension, being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

SEEPAGE - 1. Water escaping through or emerging from the ground.2. The process by which water percolates through the soil.

SEEPAGE LENGTH - In sediment basins or ponds, the length along the pipe and around the anti-seep collars that is within the seepage zone through an embankment.

SETBACKS - The minimum distance requirements for location of a structural SMP in relation to roads, wells, septic fields, other structures.

SHEET FLOW - Water, usually storm runoff, flowing in a thin layer over the ground surface.

SIDE SLOPES (ENGINEERING) - The slope of the sides of a channel, dam or embankment. It is customary to name the horizontal distance first, as 1.5 to 1, or frequently, 1 ½: 1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

SILT - 1. (Agronomy) A soil separate consisting of particles between 0.05 and 0.002 millimeter in equivalent diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System a fine grained soil (more than 50 percent passing the No. 200 sieve) that has a low plasticity index in relation to the liquid limit.

SOIL TEST - Chemical analysis of soil to determine needs for fertilizers or amendments for species of plant being grown.

SPILLWAY - An open or closed channel, or both, used to convey excess water from a reservoir. It may contain gates, either manually or automatically controlled to regulate the discharge of excess water.

STABILIZATION - Providing adequate measures, vegetative and/or structural that will prevent erosion from occurring.

STAGE (HYDRAULICS) - The variable water surface or the water surface elevation above any chosen datum.

STILLING BASIN - An open structure or excavation at the foot of an outfall, conduit, chute, drop, or spillway to reduce the energy of the descending stream of water.

STORMWATER FILTERING - Stormwater treatment methods which utilize an artificial media to filter out pollutants entrained in urban runoff.

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STORMWATER PONDS - A land depression or impoundment created for the detention or retention of stormwater runoff.

STORMWATER WETLANDS - Shallow, constructed pools that capture stormwater and allow for the growth of characteristic wetland vegetation.

STREAM BUFFERS - Zones of variable width which are located along both sides of a stream and are designed to provided a protective natural area along a stream corridor.

STREAM CHANNEL PROTECTION (Cp_V) - A design criteria which requires 24 hour detention of the one year postdeveloped, 24 hour storm event for the control of stream channel erosion.

STRUCTURAL SMPs - Devices which are constructed to provide temporary storage and treatment of stormwater runoff.

SUBGRADE - The soil prepared and compacted to support a structure or a pavement system.

TAILWATER - Water, in a river or channel, immediately downstream from a structure.

TECHNICAL RELEASE No. 20 (TR-20) - A Soil Conservation Service (now NRCS) watershed hydrology computer model that is used to compute runoff volumes and route storm events through a stream valley and/or ponds.

TECHNICAL RELEASE No. 55 (TR-55) - A watershed hydrology model developed by the Soil Conservation Service (now NRCS) used to calculate runoff volumes and provide a simplified routing for storm events through ponds.

TEMPORARY SEEDING - A seeding which is made to provide temporary cover for the soil while waiting for further construction or other activity to take place.

TEN YEAR STORM ($Q_{P\ 10}$) - The peak discharge rate associated with a 24 hour storm event that occurs on average once every ten years (or has a likelihood of occurrance of 1/10 in a given year).

TIME OF CONCENTRATION - Time required for water to flow from the most remote point of a watershed, in a hydraulic sense, to the outlet.

TOE (OF SLOPE) - Where the slope stops or levels out. Bottom of the slope.

TOE WALL - Downstream wall of a structure, usually to prevent flowing water from eroding under the structure.

TOPSOIL - Fertile or desirable soil material used to top dress roadbanks, subsoils, parent material, etc.

TOTAL SUSPENDED SOLIDS - The total amount of soil particulate matter, including both organic and inorganic material, suspended in the water column.

TRASH RACK - Grill, grate or other device at the intake of a channel, pipe, drain or spillway for the purpose of preventing oversized debris from entering the structure.

TROUT WATERS - Waters classified as (T) or (TS) by the New York State DEC.

TWO YEAR STORM ($Q_{P\ 2}$) - The peak discharge rate associated with a 24 hour storm event that occurs on average once every two years (or has a likelihood of occurrance of 1/2 in a given year).

ULTIMATE CONDITION - Full watershed build-out based on existing zoning.

ULTRA-URBAN - Densely developed urban areas in which little pervious surface exists.

VELOCITY HEAD - Head due to the velocity of a moving fluid, equal to the square of the mean velocity divided by twice the acceleration due to gravity (32.16 feet per second per second).

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VOLUMETRIC RUNOFF COEFFICIENT (R_v) - The value that is applied to a given rainfall volume to yield a corresponding runoff volume based on the percent impervious cover in a drainage basin.

WATER QUALITY VOLUME (WQ_v) - The storage needed to capture and treat 90% of the average annual stormwater runoff volume.

WATER SURFACE PROFILE - The longitudinal profile assumed by the surface of a stream flowing in an open channel; the hydraulic grade line.

WEDGES - Design feature in stormwater wetlands which increases flow path length to provide for extended detention and treatment of runoff.

WET SWALE - An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.

WETTED PERIMETER - The length of the line of intersection of the plane or the hydraulic cross-section with the wetted surface of the channel.

WING WALL - Side wall extensions of a structure used to prevent sloughing of banks or channels and to direct and confine overfall.

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Appendix A: The Simple Method to Calculate Urban Stormwater Loads

This appendix presents data and methodologies for using the Simple Method (Schueler, 1987) to estimate pollutant load from a site or drainage area. This appendix is meant for planning purposes only, and should not be used for SMP design.

The Simple Method estimates stormwater runoff pollutant loads for urban areas. The technique requires a modest amount of information, including the subwatershed drainage area and impervious cover, stormwater runoff pollutant concentrations, and annual precipitation. With the Simple Method, the investigator can either break up land use into specific areas, such as residential, commercial, industrial, and roadway and calculate annual pollutant loads for each type of land, or utilize more generalized pollutant values for urban runoff. It is also important to note that these values may vary depending on other variables such as the age of development.

The Simple Method estimates pollutant loads for chemical constituents as a product of annual runoff volume and pollutant concentration, as:

$$\mathbf{L = 0.226 * R * C * A}$$

Where:	L	=	Annual load (lbs)
	R	=	Annual runoff (inches)
	C	=	Pollutant concentration (mg/l)
	A	=	Area (acres)
	0.226	=	Unit conversion factor

For bacteria, the equation is slightly different, to account for the differences in units. The modified equation for bacteria is:

$$\mathbf{L = 103 * R * C * A}$$

Where:	L	=	Annual load (Billion Colonies)
	R	=	Annual runoff (inches)
	C	=	Bacteria concentration (1,000/ ml)
	A	=	Area (acres)
	103	=	Unit conversion factor

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A.1 Pollutant Concentrations

Stormwater pollutant concentrations can be estimated from local or regional data, or from national data sources. Table A.1 presents typical concentration data for pollutants in urban stormwater.

Table A.1 National Median Concentrations for Chemical Constituents in Stormwater

Constituent	Units	Urban Runoff
TSS	mg/l	54.5[1]
TP	mg/l	0.26[1]
TN	mg/l	2.00[1]
Cu	ug/l	11.1[1]
Pb	ug/l	50.7[1]
Zn	ug/l	129[1]
F Coli	1,000 col/ ml	1.5[2]

Source:

1: Pooled NURP/USGS (Smullen and Cave, 1998)

2: Schueler (1999)

In addition, some source areas appear to be particularly important for some pollutants. Table A.2 summarizes these data for several key source areas. It is important to note that, because the Simple Method computes runoff based on an impervious area fraction, it cannot be easily used to isolate pervious sources, such as lawns. However, a user can evaluate particular hotspots, such as auto recyclers, separately. In addition, a composite runoff concentration can be developed based on the fraction of lawn, driveway, and roof on a residential site, for example.

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Table A.2 Pollutant Concentrations from Source Areas							
Constituent	**TSS[1]**	**TP[2]**	**TN[3]**	**F Coli[1]**	**Cu[1]**	**Pb[1]**	**Zn[1]**
	mg/l	mg/L	mg/l	1,000 col/ ml	ug/l	ug/l	ug/l
Resid Roof	19	0.11	1.5	0.26	20	21	312
Comm Roof	9	0.14	2.1	1.1	7	17	256
Indust Roof	17	-	-	5.8	62	43	1,390
C/R Parking	27	0.15	1.9	1.8	51	28	139
Indust Parking	228	-	-	2.7	34	85	224
Res Street	172	0.55	1.4	37	25	51	173
Comm Street	468	-	-	12	73	170	450
Rural Highway	51	-	22	-	22	80	80
Urban Highway	142	0.32	3.0	-	54	400	329
Lawns	602	2.1	9.1	24	17	17	50
Landscaping	37	-	-	94	94	29	263
Driveway	173	0.56	2.1	17	17	-	107
Gas Station	31	-	-	-	88	80	290
Auto Recycler	335	-	-	-	103	182	520
Heavy Industrial	124	-	-	-	148	290	1600

1: Claytor and Schueler (1996)

2: Average of Steuer et al. (1997),Bannerman (1993) and Waschbusch (2000)

3: Steuer et al. (1997)

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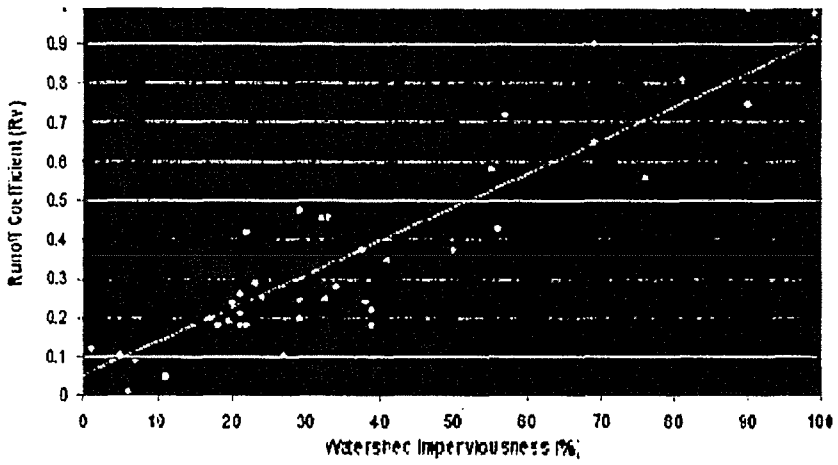
Figure A.1 Relationship Between Watershed Imperviousness and the Stormwater Runoff Coefficient



A.2 Annual Runoff

The Simple Method calculates annual runoff as a product of annual runoff volume, and a runoff coefficient (Rv). Runoff volume is calculated as:

$$R = P * P_j * Rv$$

Where:
- R = Annual runoff (inches)
- P = Annual rainfall (inches)
- P_j = Fraction of annual rainfall events that produce runoff (usually 0.9)
- Rv = Runoff coefficient

In the Simple Method, the runoff coefficient is calculated based on impervious cover in the subwatershed. This relationship is shown in Figure A.1. Although there is some scatter in the data, watershed imperviousness does appear to be a reasonable predictor of Rv.

The following equation represents the best fit line the dataset (N=47, R^2=0.71).

$$Rv=0.05+0.9Ia$$

Where: Ia = Impervious fraction

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A.3 Impervious Cover Data

The Simple Method uses different impervious cover values for separate land uses within a subwatershed. Representative impervious cover data, are presented in Table A.3. These numbers are derived from a recent study conducted by the Center for Watershed Protection under a grant from the U.S. Environmental Protection Agency to update impervious cover estimates for a variety of land uses. (Cappiella and Brown, 2001). In addition, some jurisdictions may have detailed impervious cover information if they maintain a detailed land use/land cover GIS database.

Table A.3 Land Use and Impervious Cover Estimates

Land Use Category	Mean Impervious Cover
Agriculture	**2**
Open Urban Land*	**9**
2 Acre Lot Residential	**11**
1 Acre Lot Residential	**14**
1/2 Acre Lot Residential	**21**
1/4Acre Lot Residential	**28**
1/8 Acre Lot Residential	**33**
Townhome Residential	**41**
Multifamily Residential	**44**
Institutional**	**31-38%**
Light Industrial	**50-56%**
Commercial	**70-74%**

* Open urban land includes developed park land, recreation areas, golf courses, and cemeteries.

** Institutional is defined as places of worship, schools, hospitals, government offices, and police and fire stations

A.4 Limitations of the Simple Method

The Simple Method should provide reasonable estimates of changes in pollutant export resulting from urban development activities. However, several caveats should be kept in mind when applying this method.

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The Simple Method is most appropriate for assessing and comparing the relative stormflow pollutant load changes of different land use and stormwater management scenarios. The Simple Method provides estimates of storm pollutant export that are probably close to the "true" but unknown value for a development site, catchment, or subwatershed. However, it is very important not to over emphasis the precision of the results obtained. For example, it would be inappropriate to use the Simple Method to evaluate relatively similar development scenarios (e.g., 34.3% versus 36.9% Impervious cover). The simple method provides a general planning estimate of likely storm pollutant export from areas at the scale of a development site, catchment or subwatershed. More sophisticated modeling may be needed to analyze larger and more complex drainages.

In addition, the Simple Method only estimates pollutant loads generated during storm events. It does not consider pollutants associated with baseflow volume. Typically, baseflow is negligible or non-existent at the scale of a single development site, and can be safely neglected, unless wastewater sources such as illicit connections and wastewater treatment plans are significant. However, catchments and subwatersheds do generate baseflow volume. Pollutant loads in baseflow are generally low and can seldom be distinguished from natural background levels (NVPDC, 1980). Consequently, baseflow pollutant loads normally constitute only a small fraction of the total pollutant load delivered from an urban area. Nevertheless, it is important to remember that the load estimates refer only to storm event derived loads and should not be confused with the total pollutant load from an area. This is particularly important when the development density of an area is low. For example, in a large low density residential subwatershed (Imp. Cover < 5%), as much as 75% of the annual runoff volume may occur as baseflow. In such a case, the annual baseflow nutrient load may be equivalent to the annual stormflow nutrient load.

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A.5 SMP Pollutant Removal

The removal efficiencies of various SMP practices also help determine final annual pollutant loads. Table A.4 provides estimates of the average pollutant removal efficiency of the five SMP categories.

Table A.4. Suggested Removal Rates for SMPs

	TSS	TP	TN	Metals[1]	Bacteria
Wet Ponds	80	50 (51)	35 (33)	60 (62)	70
Stormwater Wetlands	80[2] (76)	50 (49)	30	40 (42)	80 (78)
Filtering Practices	85 (86)	60 (59)	40 (38)	70 (69)	35 (37)
Infiltration Practices [4]	90[3] (95)	70	50 (51)	90[3] (99)	90[4]
Water Quality Swales	85 (84)	40 (39)	50[5] (84)	70	0 (-25)[6]

1. Average of zinc and copper. Only zinc for infiltration
2. Many wetland practices in the database were poorly designed, and we consequently adjusted sediment removal upward.
3. It is assumed that no practice is greater than 90% efficient.
4. Data inferred from sediment removal.
5. Actual data is based on only two highly performing practices.
6. Assume 0 rather than a negative removal.

Note: Data in parentheses represent median pollutant removal data reported in the *National Pollutant Removal Database - Revised Edition* (Winer, 2000). These data were adjusted for convenience and to reflect biases in the data.

These efficiencies represent ideal pollutant removal rates that cannot be achieved at all sites, or at a watershed level. Typically, they need to be "discounted" to account for site constraints, and other factors that reduce practice efficiency. For example, the removal rate should be adjusted to reflect the fraction of runoff captured by a practice on an annual basis (90% if this guidance is followed). For more detail on how to apply these discounts, consult Caraco (2001)..

One particularly important consideration is how to account for practices applied in series (e.g., two ponds applied in sequence). If the volume within the practices adds up to the total water quality volume, they are assumed to act as a single practice with that volume. Otherwise, total pollutant removal should be determined by the following equation:

$$R = L\,[(E_1)+(1-E_1)E_2+(1-((E_1)+(1-E_1)E_2)E_3+\ldots]$$

Where:

R = Pollutant Removal (lbs)

L = Annual Load from Simple Method (lbs.)

E_i = Efficiency of the ith practice in a series

Another adjustment can be made to these removals to account for loss of effectiveness and "irreducible concentrations." Evidence suggests that, at low concentrations, SMPs can no longer remove pollutants.

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Table A.5 depicts typical outflow concentrations for various SMPs. Another simplified way to account for this phenomenon is to reduce the efficiency of a second or third practice in a series. For example, the removal efficiency could be cut in half to reflect inability to remove fine particles.

Table A.5. Typical SMP Effluent Concentrations

	TSS	TP	TN	Cu	Zn
Wet Ponds	17	0.11	1.3	5.0	30
Wetlands	22	0.20	1.7	7.0	31
Filtering Practices	11	0.10	1.12	10	21
Infiltration Practices	17[2]	0.05[2]	3.8[2]	4.8[2]	39[2]
Open Channel Practices	14	0.19	1.12	10	53

1. Units for Zn and Cu are micrograms per liter
2. Data based on fewer than five data points

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Appendix B

New York State Stormwater Management Design Manual

Appendix B: Hydrologic Analysis Tools

This Appendix presents two hydrologic and hydraulic analysis tools that can be used to size stormwater management practices (SMPs). The first is the TR-55 (NRCS, 1986) "short-cut" sizing technique, used to size practices designed for extended detention, slightly modified to incorporate the small flows necessary to provide channel protection. The second is a method used to determine the peak flow from water quality storm events. (This is often important when the water quality storm is diverted to a water quality practice, with other larger events bypassed).

B.1 Storage Volume Estimation

This section presents a modified version of the TR-55 short cut sizing approach. The method was modified by Harrington (1987), for applications where the peak discharge is very small compared with the uncontrolled discharge. This often occurs in the 1-year, 24-hour detention sizing.

Using TR-55 guidance (NRCS, 1986), the unit peak discharge (qu) can be determined based on the the Curve Number and Time of Concentration. Knowing q_U and T (extended detention time), q_O/q_I (peak outflow discharge/peak inflow discharge) can be estimated from Figure B.1.

Figure B.2 can also be used to estimate V_S/V_r. For a Type II or Type III rainfall distribution, V_S/V_r can also be calculated using the following equation:

$$V_S/V_r = 0.682 - 1.43\,(q_O/q_I) + 1.64\,(q_O/q_I)^2 - 0.804\,(q_O/q_I)^3 \qquad (2.1.16)$$

Where:

V_S = required storage volume (acre-feet)

V_r = runoff volume (acre-feet)

q_O = peak outflow discharge (cfs)

q_I = peak inflow discharge (cfs)

The required storage volume can then be calculated by:

$$V_S = \frac{(V_S/V_r)(Q_d)(A)}{12} \qquad (2.1.17)$$

Where: V_S and V_r are defined above

Q_d = the post-developed runoff for the design storm (inches)

A = total drainage area (acres)

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While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided.

Figure B.1 Detention Time vs. Discharge Ratios (Source: MDE, 2000)

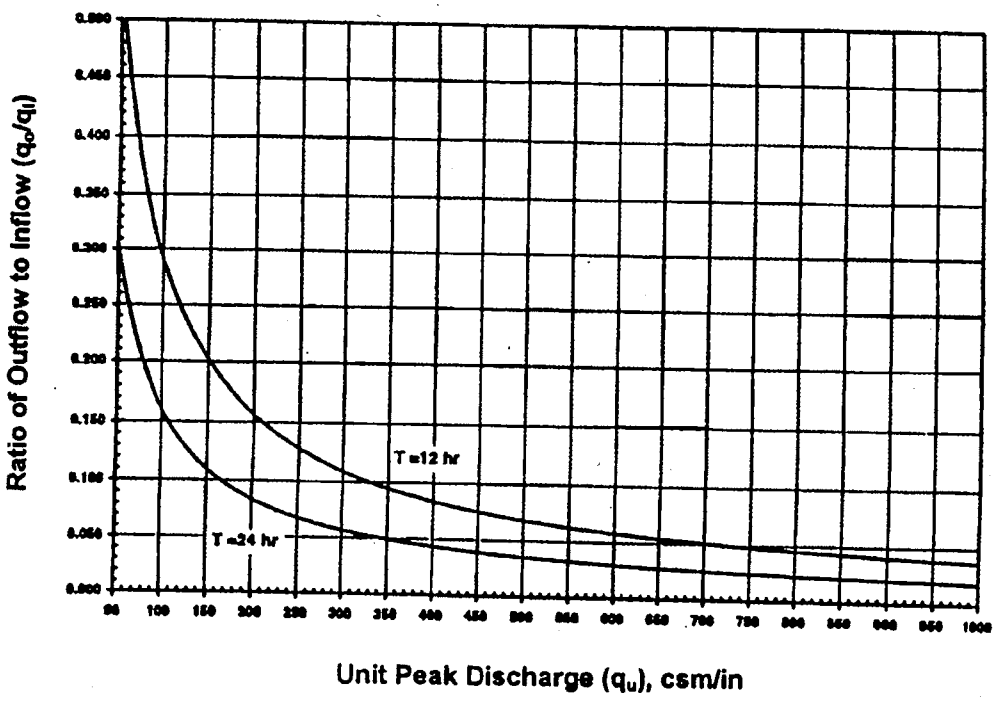
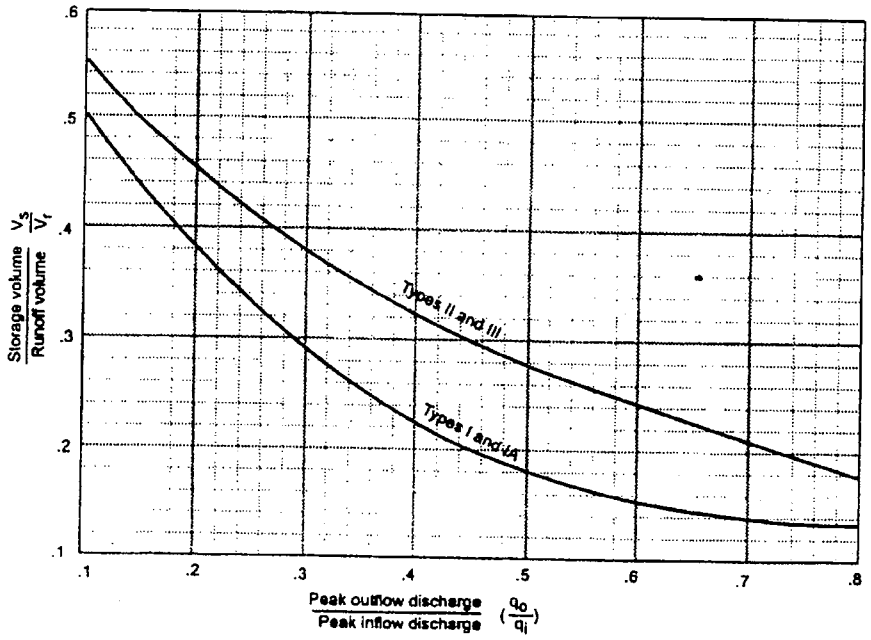


Figure B.2 Approximate Detention Basin Routing For Rainfall Types I, IA, II, and III (Source: NRCS, 1986)



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B.2 Water Quality Peak Flow Calculation

The peak rate of discharge for the water quality design storm is needed for the sizing of diversion structures for off-line practices such as sand filters. An arbitrary storm would need to be chosen using the Rational method, and conventional SCS methods have been found to underestimate the volume and rate of runoff for rainfall events less than 2". This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the filtering treatment practice due to an inadequately sized diversion structure and leads to the design of undersized bypass channels.

The following procedure can be used to estimate peak discharges for small storm events. It relies on the Water Quality Volume and the simplified peak flow estimating method above. A brief description of the calculation procedure is presented below.

Using the water quality volume (WQ_V), a corresponding Curve Number (CN) is computed utilizing the following equation:

$$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25\,QP)^{1/2}]$$

Where

P = rainfall, in inches (use the 90% rainfall event from Figure 4.1 for the Water Quality Storm)

Q = runoff volume, in inches

Once a CN is computed, the time of concentration (t_c) is computed using guidance provided in TR-55.

Using the computed CN, t_c and drainage area (A), in acres; the peak discharge (Q_p) for the water quality storm event is computed (either Type II or Type III in the State of New York).

Read initial abstraction (Ia), compute Ia/P

Read the unit peak discharge (qu) for appropriate t_c

Using the water quality volume (WQ_V), compute the peak discharge (Q_p)

$$Q_p = q_u * A * WQ_V$$

where Q_p = the peak discharge, in cfs

q_u = the unit peak discharge, in cfs/mi²/inch

A = drainage area, in square miles

WQ_V = Water Quality Volume, in watershed inches

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Appendix C

New York State Stormwater Management Design Manual

Appendix C: Construction Standards and Specifications

C.1 Pond Construction Standards/Specifications

These specifications are generally appropriate to all earthen ponds, and are adapted from NRCS Pond Code 378. Practitioners should always consult the New York State Department of Environmental Conservation – Dam Safety Division for the most recent guidance. All references to ASTM and AASHTO specifications apply to the most recent version.

Site Preparation

Areas designated for borrow areas, embankment, and structural works shall be cleared, grubbed and stripped of topsoil. All trees, vegetation, roots and other objectionable material shall be removed. Channel banks and sharp breaks shall be sloped to no steeper than 1:1. All trees shall be cleared and grubbed within 15 feet of the toe of the embankment.

Areas to be covered by the reservoir will be cleared of all trees, brush, logs, fences, rubbish and other objectionable material unless otherwise designated on the plans. Trees, brush, and stumps shall be cut approximately level with the ground surface. For dry stormwater management ponds, a minimum of a 25-foot radius around the outlet structure shall be cleared.

All cleared and grubbed material shall be disposed of outside and below the limits of the dam and reservoir as directed by the owner or his representative. When specified, a sufficient quantity of topsoil will be stockpiled in a suitable location for use on the embankment and other designated areas.

Earth Fill

Material - The fill material shall be taken from approved designated borrow areas. It shall be free of roots, stumps, wood, rubbish, stones greater than 6", frozen or other objectionable materials. Fill material for the center of the embankment, and cut off trench shall conform to Unified Soil Classification GC, SC, CH, or CL and must have at least 30% passing the #200 sieve. Consideration may be given to the use of other materials in the embankment if designed by a geotechnical engineer. Such special designs must have construction supervised by a geotechnical engineer.

Materials used in the outer shell of the embankment must have the capability to support vegetation of the quality required to prevent erosion of the embankment.

Placement - Areas on which fill is to be placed shall be scarified prior to placement of fill. Fill materials shall be placed in maximum 8 inch thick (before compaction) layers which are to be continuous over the entire length of the fill. The most permeable borrow material shall be placed in the downstream portions of the embankment. The principal spillway must be installed concurrently with fill placement and not excavated into the embankment.

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Compaction - The movement of the hauling and spreading equipment over the fill shall be controlled so that the entire surface of each lift shall be traversed by not less than one tread track of heavy equipment or compaction shall be achieved by a minimum of four complete passes of a sheepsfoot, rubber tired or vibratory roller. Fill material shall contain sufficient moisture such that the required degree of compaction will be obtained with the equipment used. The fill material shall contain sufficient moisture so that if formed into a ball it will not crumble, yet not be so wet that water can be squeezed out.

When required by the reviewing agency the minimum required density shall not be less than 95% of maximum dry density with a moisture content within 2% of the optimum. Each layer of fill shall be compacted as necessary to obtain that density, and is to be certified by the Engineer at the time of construction. All compaction is to be determined by AASHTO Method T-99 (Standard Proctor).

Cut Off Trench - The cutoff trench shall be excavated into impervious material along or parallel to the centerline of the embankment as shown on the plans. The bottom width of the trench shall be governed by the equipment used for excavation, with the minimum width being four feet. The depth shall be at least four feet below existing grade or as shown on the plans. The side slopes of the trench shall be 1 to 1 or flatter. The backfill shall be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability.

Embankment Core - The core shall be parallel to the centerline of the embankment as shown on the plans. The top width of the core shall be a minimum of four feet. The height shall extend up to at least the 10 year water elevation or as shown on the plans. The side slopes shall be 1 to 1 or flatter. The core shall be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability. In addition, the core shall be placed concurrently with the outer shell of the embankment.

Structure Backfill

Backfill adjacent to pipes or structures shall be of the type and quality conforming to that specified for the adjoining fill material. The fill shall be placed in horizontal layers not to exceed four inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material needs to fill completely all spaces under and adjacent to the pipe. At no time during the backfilling operation shall driven equipment be allowed to operate closer than four feet, measured horizontally, to any part of a structure. Under no circumstances shall equipment be driven over any part of a concrete structure or pipe, unless there is a compacted fill of 24" or greater over the structure or pipe.

Structure backfill may be flowable fill meeting the requirements of the New York State Department of Transportation. The mixture shall have a 100-200 psi; 28 day unconfined compressive strength. The flowable fill shall have a minimum pH of 4.0 and a minimum resistivity of 2,000 ohm-cm. Material shall be placed such that a minimum of 6" (measured perpendicular to the outside of the pipe) of flowable fill shall be under (bedding), over and, on the sides of the pipe. It only needs to extend up to the spring line for rigid conduits. Average slump of the fill shall be 7" to assure flowability of the material. Adequate measures shall be taken (sand bags, etc.) to prevent floating the pipe. When using flowable fill, all metal pipe shall be bituminous coated. Any adjoining soil fill shall be placed in horizontal layers not to exceed four inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material shall completely fill all voids adjacent to the flowable fill zone. At no time during the backfilling operation shall driven equipment be allowed to operate closer than four feet, measured horizontally, to any part of a structure. Under no circumstances shall equipment be driven over any part of a structure or pipe unless there is a compacted fill of 24" or greater over the structure or pipe. Backfill material outside the structural backfill (flowable fill) zone shall be of the type and quality conforming to that specified for the core of the embankment or other embankment materials.

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Pipe Conduits

All pipes shall be circular in cross section.

Corrugated Metal Pipe - All of the following criteria shall apply for corrugated metal pipe:

Materials - (Polymer Coated steel pipe) - Steel pipes with polymeric coatings shall have a minimum coating thickness of 0.01 inch (10 mil) on both sides of the pipe. This pipe and its appurtenances shall conform to the requirements of AASHTO Specifications M-245 & M-246 with watertight coupling bands or flanges.

Materials - (Aluminum Coated Steel Pipe) - This pipe and its appurtenances shall conform to the requirements of AASHTO Specification M-274 with watertight coupling bands or flanges. Aluminum Coated Steel Pipe, when used with flowable fill or when soil and/or water conditions warrant the need for increased durability, shall be fully bituminous coated per requirements of AASHTO Specification M-190 Type A. Any aluminum coating damaged or otherwise removed shall be replaced with cold applied bituminous coating compound. Aluminum surfaces that are to be in contact with concrete shall be painted with one coat of zinc chromate primer or two coats of asphalt.

Materials - (Aluminum Pipe) - This pipe and its appurtenances shall conform to the requirements of AASHTO Specification M-196 or M-211 with watertight coupling bands or flanges. Aluminum Pipe, when used with flowable fill or when soil and/or water conditions warrant for increased durability, shall be fully bituminous coated per requirements of AASHTO Specification M-190 Type A. Aluminum surfaces that are to be in contact with concrete shall be painted with one coat of zinc chromate primer or two coats of asphalt. Hot dip galvanized bolts may be used for connections. The pH of the surrounding soils shall be between 4 and 9.

Coupling bands, anti-seep collars, end sections, etc., must be composed of the same material and coatings as the pipe. Metals must be insulated from dissimilar materials with use of rubber or plastic insulating materials at least 24 mils in thickness.

Connections - All connections with pipes must be completely watertight. The drain pipe or barrel connection to the riser shall be welded all around when the pipe and riser are metal. Anti-seep collars shall be connected to the pipe in such a manner as to be completely watertight. Dimple bands are not considered to be watertight.All connections shall use a rubber or neoprene gasket when joining pipe sections. The end of each pipe shall be re-rolled an adequate number of corrugations to accommodate the bandwidth. The following type connections are acceptable for pipes less than 24 inches in diameter: flanges on both ends of the pipe with a circular 3/8 inch closed cell neoprene gasket, pre-punched to the flange bolt circle, sandwiched between adjacent flanges; a 12-inch wide standard lap type band with 12-inch wide by 3/8-inch thick closed cell circular neoprene gasket; and a 12-inch wide hugger type band with o-ring gaskets having a minimum diameter of 1/2 inch greater than the corrugation depth. Pipes 24 inches in diameter and larger shall be connected by a 24 inch long annular corrugated band using a minimum of 4 (four) rods and lugs, 2 on each connecting pipe end. A 24-inch wide by 3/8-inch thick closed cell circular neoprene gasket will be installed with 12 inches on the end of each pipe. Flanged joints with 3/8 inch closed cell gaskets the full width of the flange is also acceptable.

Helically corrugated pipe shall have either continuously welded seams or have lock seams with internal caulking or a neoprene bead.

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Bedding - The pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material shall be removed and replaced with suitable earth compacted to provide adequate support.

Backfilling shall conform to Structure Backfill requirements.

Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

Reinforced Concrete Pipe - All of the following criteria shall apply for reinforced concrete pipe:

Materials - Reinforced concrete pipe shall have bell and spigot joints with rubber gaskets and shall equal or exceed ASTM C-361.

Bedding - Reinforced concrete pipe conduits shall be laid in a concrete bedding / cradle for their entire length. This bedding / cradle shall consist of high slump concrete placed under the pipe and up the sides of the pipe at least 50% of its outside diameter with a minimum thickness of 6 inches. Where a concrete cradle is not needed for structural reasons, flowable fill may be used as described in the Structure Backfill section of this standard. Gravel bedding is not permitted.

Laying pipe - Bell and spigot pipe shall be placed with the bell end upstream. Joints shall be made in accordance with recommendations of the manufacturer of the material. After the joints are sealed for the entire line, the bedding shall be placed so that all spaces under the pipe are filled. Care shall be exercised to prevent any deviation from the original line and grade of the pipe. The first joint must be located within 4 feet from the riser.

Backfilling shall conform to **Structure Backfill** requirements.

Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

Plastic Pipe - The following criteria shall apply for plastic pipe:

1. Materials - PVC pipe shall be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241. Corrugated High Density Polyethylene (HDPE) pipe, couplings and fittings shall conform to the following: 4" through 10" pipe shall meet the requirements of AASHTO M252 Type S, and 12" through 24" pipe shall meet the requirements of AASHTO M294 Type S.

2. Joints and connections to anti-seep collars shall be completely watertight.

3. Bedding -The pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material shall be removed and replaced with suitable earth compacted to provide adequate support.

4. Backfilling shall conform to **Structure Backfill** requirements.

5. Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

Drainage Diaphragms - When a drainage diaphragm is used, a registered professional engineer will supervise the design and construction inspection.

Concrete

Concrete shall meet the requirements of the New York State Department of Transportation.

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Rock Riprap

Rock riprap shall meet the requirements of the New York State Department of Transportation.

Geotextile shall be placed under all riprap and shall meet the requirements of the New York State Department of Transportation.

Care of Water During Construction

All work on permanent structures shall be carried out in areas free from water. The Contractor shall construct and maintain all temporary dikes, levees, cofferdams, drainage channels, and stream diversions necessary to protect the areas to be occupied by the permanent works. The contractor shall also furnish, install, operate, and maintain all necessary pumping and other equipment required for removal of water from various parts of the work and for maintaining the excavations, foundation, and other parts of the work free from water as required or directed by the engineer for constructing each part of the work. After having served their purpose, all temporary protective works shall be removed or leveled and graded to the extent required to prevent obstruction in any degree whatsoever of the flow of water to the spillway or outlet works and so as not to interfere in any way with the operation or maintenance of the structure. Stream diversions shall be maintained until the full flow can be passed through the permanent works. The removal of water from the required excavation and the foundation shall be accomplished in a manner and to the extent that will maintain stability of the excavated slopes and bottom required excavations and will allow satisfactory performance of all construction operations. During the placing and compacting of material in required excavations, the water level at the locations being refilled shall be maintained below the bottom of the excavation.

Stabilization

All borrow areas shall be graded to provide proper drainage and left in a sightly condition. All exposed surfaces of the embankment, spillway, spoil and borrow areas, and berms shall be stabilized by seeding, liming, fertilizing and mulching in accordance with local Natural Resources Conservation Service Standards and Specifications.

Erosion and Sediment Control

Construction operations will be carried out in such a manner that erosion will be controlled and water and air pollution minimized. Federal, State and local laws concerning pollution abatement will be followed. Construction plans shall detail erosion and sediment control measures.

Operation and Maintenance

An operation and maintenance plan in accordance with Local or State Regulations will be prepared for all ponds. As a minimum, a dam inspection checklist shall be included as part of the operation and maintenance plan and performed at least annually. Written records of maintenance and major repairs need to be retained in a file.

Supplemental Stormwater Pond and Wetland Specifications

1. It is preferred to use the same material in the embankment as is being installed for the core trench. If this is not possible, a dam core with a shell may be used. The cross-section of the stormwater facility should show the limits of the dam core (up to the 10-year water surface elevation) as well as the acceptable materials for the shell. The shape of the dam core and the material to be used in the shell should be provided by the geotechnical engineer.

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2. If the compaction tests for the remainder of the site improvements is using Modified Proctor (AASHTO T-180), then to maintain consistency on-site, modified proctor may be used in lieu of standard proctor (AASHTO T-99) for checking embankment compaction. The minimum required density using the modified proctor test method shall be at least 92% of maximum dry density with a moisture content of 2% of the optimum.

3. For all stormwater management facilities, a geotechnical engineer must be present to verify compaction in accordance with the selected test method. This information needs to be provided in a report to the design engineer, so that as-built certification of the facility can be made.

4. A 4-inch layer of topsoil shall be placed on all disturbed areas of the dam embankment. Seeding, liming, fertilizing, mulching, etc. shall be in accordance with NRCS Soil Standards and Specifications or New York State Standards and Specifications for Soil Erosion and Sediment Control. The purpose of the topsoil is to establish a good growth of grass which is not always possible with some of the materials that may be placed for the embankment fill.

5. Filter fabric placed beneath the rip-rap shall meet state or local department of transportation requirements for a Class "C" filter fabric. Some acceptable filter fabrics that meet the Class "C" criteria include:

   Mirafi 180-N

   Amoco 4552

   Webtec N07

   Geolon N70

   Carthage FX-70S

   This is only a partial listing of available filter fabrics based on information provided by the manufacturers to the 1997 Specifier's Guide dated December 1996. It is the responsibility of the engineer to verify the adequacy of the material, as there are changes in the manufacturing process and the type of fabric used, which may affect the continued acceptance.

6. The design engineer and geotechnical engineer should make the determination that the settlement of the pond will not cause excessive joint extension. For further information on joint extension analysis, see NRCS Publication TR-18.

7. Fill placement shall not exceed a maximum of 8-inch lift thickness. Each lift shall be continuous for the entire length of the embankment.

8. The embankment fill **shall not** be placed higher than the centerline of the principle spillway until after the principle spillway has been installed.

9. The side slopes of a cut to repair a dam, install a principle spillway for an excavated pond, or other repair work, shall be stepped and on an average slope of 2:1 or flatter.

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C.2 Construction Specifications for Infiltration Practices

Infiltration Trench General Notes and Specifications

The infiltration trench systems may not receive run-off until the entire contributing drainage area to the infiltration system has received final stabilization.

1. Heavy equipment and traffic shall be restricted from traveling over the infiltration trench to minimize compaction of the soil.

2. Excavate the infiltration trench to the design dimensions. Excavated materials shall be placed away from the trench sides to enhance trench wall stability. Large tree roots must be trimmed flush with the trench sides in order to prevent fabric puncturing or tearing of the filter fabric during subsequent installation procedures. The side walls of the trench shall be roughened where sheared and sealed by heavy equipment.

3. A Class "C" geotextile or better shall interface between the trench side walls and between the stone reservoir and gravel filter layers. A partial list of non-woven filter fabrics that meet the Class "C" criteria is contained below. Any alternative filter fabric must be approved by the local municipality prior to installation.

   Mirafi 180-N
   Amoco 4552
   WEBTEC N70
   GEOLON N70
   Carthage FX-80S

   The width of the geotextile must include sufficient material to conform to trench perimeter irregularities and for a 6-inch minimum top overlap. The filter fabric shall be tucked under the sand layer on the bottom of the infiltration trench for a distance of 6 to 12 inches. Stones or other anchoring objects should be placed on the fabric at the edge of the trench to keep the trench open during windy periods. When overlaps are required between rolls, the uphill roll should lap a minimum of 2 feet over the downhill roll in order to provide a shingled effect.

4. A 6 inch sand layer may be placed on the bottom of the infiltration trench in lieu of filter fabric, and shall be compacted using plate compactors. The sand for the infiltration trench shall be washed and meet AASHTO Std. M-43, Size No. 9 or No. 10. Any alternative sand gradation must be approved by the Engineer or the local municipality.

5. The stone aggregate should be placed in lifts and compacted using plate compactors. A maximum loose lift thickness of 12 inches is recommended. Gravel filling (rounded bank run gravel is preferred) for the infiltration trench shall be washed and meet one of the following: AASHTO Std. M-43; Size No. 2 or No. 3.

6. Following the stone aggregate placement, the filter fabric shall be folded over the stone aggregate to form a 6-inch minimum longitudinal lap. The desired fill soil or stone aggregate shall be placed over the lap at sufficient intervals to maintain the lap during subsequent backfilling.

7. Care shall be exercised to prevent natural or fill soils from intermixing with the stone aggregate. All contaminated stone aggregate shall be removed and replaced with uncontaminated stone aggregate.

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8. Voids can be created between the fabric and the excavation sides and shall be avoided. Removing boulders or other obstacles from the trench walls is one source of such voids, therefore, natural soils should be placed in these voids at the most convenient time during construction to ensure fabric conformity to the excavation sides.

9. Vertically excavated walls may be difficult to maintain in areas where soil moisture is high or where soft cohesive or cohesionless soils are predominate. These conditions may require laying back of the side slopes to maintain stability.

10. PVC distribution pipes shall be Schedule 40 and meet ASTM Std. D 1784. All fittings and perforations (1/2 inch in diameter) shall meet ASTM Std. D 2729. A perforated pipe shall be provided only within the infiltration trench and shall terminate 1 foot short of the infiltration trench wall. The end of the PVC pipe shall be capped.

11. Corrugated metal distribution pipes shall conform to AASHTO Std. M-36, and shall be aluminized in accordance with AASHTO Std. M-274. Coat aluminized pipe in contact with concrete with an inert compound capable of effecting isolation of the deleterious effect of the aluminum on the concrete. Perforated distribution pipe shall be provided only within the infiltration trench and shall terminate 1 foot short of the infiltration trench wall. An aluminized metal plate shall be welded to the end of the pipe.

12. The observation well is to consist of 6-inch diameter PVC Schedule 40 pipe (ASTM Std. D 1784) with a cap set 6 inches above ground level and is to be located near the longitudinal center of the infiltration trench. Preferably the observation well will not be located in vehicular traffic areas. The pipe shall have a plastic collar with ribs to prevent rotation when removing cap. The screw top lid shall be a "Panella" type cleanout with a locking mechanism or special bolt to discourage vandalism. A perforated (1/2 inch in diameter) PVC Schedule 40 pipe shall be provided and placed vertically within the gravel portion of the infiltration trench and a cap provided at the bottom of the pipe. The bottom of the cap shall rest on the infiltration trench bottom.

13. If a distribution structure with a wet well is used, a 4-inch PVC drain pipe shall be provided at opposite ends of the infiltration trench distribution structure. Two (2) cubic feet of porous backfill meeting AASHTO Std. M-43 Size No. 57 shall be provided at each drain.

14. If a distribution structure is used, the manhole cover shall be bolted to the frame.

NOTE: PVC pipe with a wall thickness classification of SDR-35 meeting ASTM standard D3034 is an acceptable substitution for PVC Schedule 40 pipe.

Infiltration Basins Notes and Specifications

1. The sequence of various phases of basin construction shall be coordinated with the overall project construction schedule. A program should schedule rough excavation of the basin (to not less than 2' from final grade) with the rough grading phase of the project to permit use of the material as fill in earthwork areas. The partially excavated basin, however, **cannot** serve as a sedimentation basin.

Specifications for basin construction should state: (1) the earliest point in progress when storm drainage may be directed to the basin, and (2) the means by which this delay in use is to be

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accomplished. Due to the wide variety of conditions encountered among projects, each should be separately evaluated in order to postpone use as long as is reasonably possible.

2. Initial basin excavation should be carried to within 2 feet of the final elevation of the basin floor. Final excavation to the finished grade should be deferred until all disturbed areas on the watershed have been stabilized or protected. The final phase excavation should remove all accumulated sediment. Relatively light tracked equipment is recommended for this operation to avoid compaction of the basin floor. After the final grading is completed, the basin should retain a highly porous surface texture.

3. Infiltration basins may be lined with a 6- to 12-inch layer of filter material such as coarse sand (AASHTO Std. M-43, Sizes 9 or 10) to help prevent the buildup of impervious deposits on the soil surface. The filter layer can be replaced or cleaned when it becomes clogged. When a 6-inch layer of coarse organic material is specified for discing (such as hulls, leaves, stems, etc.) or spading into the basin floor to increase the permeability of the soils, the basin floor should be soaked or inundated for a brief period, then allowed to dry subsequent to this operation. This induces the organic material to decay rapidly, loosening the upper soil layer.

4. Establishing dense vegetation on the basin side slopes and floor is recommended. A dense vegetative stand will not only prevent erosion and sloughing, but will also provide a natural means of maintaining relatively high infiltration rates. Erosion protection of inflow points to the basin shall also be provided.

5. Selection of suitable vegetative materials for the side slope and all other areas to be stabilized with vegetation and application of required lime, fertilizer, etc. shall be done in accordance with the NRCS Standards and Specifications or your local Standards and Specifications for Soil Erosion and Sediment Control.

6. Grasses of the fescue family are recommended for seeding primarily due to their adaptability to dry sandy soils, drought resistance, hardiness, and ability to withstand brief inundations. The use of fescues will also permit long intervals between mowings. This is important due to the relatively steep slopes which make mowing difficult. Mowing twice a year, once in June and again in September, is generally satisfactory.

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C.3 Construction Specifications for Bioretention, Sand Filters and Open Channels

Sand Filter Specifications

Material Specifications for Sand Filters

The allowable materials for sand filter construction are detailed in Table 1.

Sand Filter Testing Specifications

Underground sand filters, facilities within sensitive groundwater aquifers, and filters designed to serve urban hot spots are to be tested for water tightness prior to placement of filter layers. Entrances and exits should be plugged and the system completely filled with water to demonstrate water tightness.

All overflow weirs, multiple orifices and flow distribution slots to be field-tested as to verify adequate distribution of flows.

Sand Filter Construction Specifications

Provide sufficient maintenance access; 12-foot-wide road with legally recorded easement. Vegetated access slopes to be a maximum of 10%; gravel slopes to 15%; paved slopes to 25%.

Absolutely no runoff is to enter the filter until all contributing drainage areas have been stabilized.

Surface of filter bed to be *completely level.*

All sand filters should be clearly delineated with signs so that they may be located when maintenance is due.

Surface sand filters shall be planted with appropriate grasses as specified in your local NRCS Standards and Specifications guidance.

Pocket sand filters (and residential bioretention facilities treating areas larger than an acre) shall be sized with an ornamental stone window covering approximately 10% of the filter area. This surface shall be 2" to 5" size stone on top of a pea gravel layer (3/4 inch stone) approximately 4 to 6" of pea gravel.

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Specifications Pertaining to Underground Sand Filters

Provide manhole and/or grates to all underground and below grade structures. Manholes shall be in compliance with standard specifications for each jurisdiction but diameters should be 30" minimum (to comply with OSHA confined space requirements) but not too heavy to lift. Aluminum and steel louvered doors are also acceptable. Ten-inch long (minimum) manhole steps (12" o.c.) shall be cast in place or drilled and mortared into the wall below each manhole. A 5= minimum height clearance (from the top of the sand layer to the bottom of the slab) is required for all permanent underground structures. Lift rings are to be supplied to remove/replace top slabs. Manholes may need to be grated to allow for proper ventilation; if required, place manholes *away* from areas of heavy pedestrian traffic.

Underground sand filters shall be constructed with a dewatering gate valve located just above the top of the filter bed should the bed clog.

Underground sand beds shall be protected from trash accumulation by a wide mesh geotextile screen to be placed on the surface of the sand bed; screen is to be rolled up, removed, cleaned and re-installed during maintenance operations.

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Table C-1 Sand Filter Material Specifications

Parameter	Specification	Size	Notes
Sand	Clean AASHTO M-6 or ASTM C-33 concrete sand	0.02" to 0.04"	Sand substitutions such as Diabase and Graystone #10 are not acceptable. No calcium carbonated or dolomitic sand substitutions are acceptable. "Rock dust" cannot be substituted for sand.
Peat	Ash content: < 15% PH range: 5.2 to 4.9 Loose bulk density 0.12 to 0.15 g/cc	n/a	The material must be Reed-Sedge Hemic Peat, shredded, uncompacted, uniform, and clean.
Underdrain Gravel	AASHTO M-43 No. 67	0.25" to 0.75"	
Geotextile Fabric (if required)	ASTM D-751 (puncture strength - 125 lb.) ASTM D-1117 (Mullen Burst Strength - 400 psi) ASTM D-1682 (Tensile Strength - 300 lb.)	0.08" thick equivalent opening size of #80 sieve	Must maintain 125 gpm per sq. ft. flow rate. Note: a 4" pea gravel layer may be substituted for geotextiles meant to separate sand filter layers.
Impermeable Liner (if required)	ASTM D 751 (thickness) ASTM D 412 (tensile strength 1,100 lb., elongation 200%) ASTM D 624 (Tear resistance - 150 lb./in) ASTM D 471 (water adsorption: +8 to -2% mass)	30mil thickness	Liner to be ultraviolet resistant. A geotextile fabric should be used to protect the liner from puncture.
Underdrain Piping	ASTM D-1785 or AASHTO M-278	6" rigid schedule 40 PVC	3/8" perf. 6" on center, 4 holes per row; minimum of 3" of gravel over pipes; not necessary underneath pipes
Concrete (Cast-in-place)	See local DOT Standards and Specs. f=c = 3500 psi, normal weight, air-entrained; re-inforcing to meet ASTM 615-60	n/a	on-site testing of poured-in-place concrete required: 28 day strength and slump test; all concrete design (cast-in-place or pre-cast) *not using previously approved State or local standards* requires design drawings sealed and approved by a licensed professional structural engineer.
Concrete (pre-cast)	per pre-cast manufacturer	n/a	SEE ABOVE NOTE
Non-rebar steel	ASTM A-36	n/a	structural steel to be hot-dipped galvanized ASTM A123

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Specifications for Bioretention

Material Specifications

The allowable materials to be used in bioretention area are detailed in Table G.2.

Planting Soil

The soil shall be a uniform mix, free of stones, stumps, roots or other similar objects larger than two inches. No other materials or substances shall be mixed or dumped within the bioretention area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The planting soil shall be free of noxious weeds.

The planting soil shall be tested and shall meet the following criteria:

pH range	5.2 - 7.0
organic matter	1.5 - 4%
magnesium	35 lb./ac
phosphorus P_2O_5	75 lb./ac
potassium K_2O	85 lb./ac
soluble salts	not to exceed 500 ppm

All bioretention areas shall have a minimum of one test. Each test shall consist of both the standard soil test for pH, phosphorus, and potassium and additional tests of organic matter, and soluble salts. A textural analysis is required from the site stockpiled topsoil. If topsoil is imported, then a texture analysis shall be performed for each location where the top soil was excavated.

Since different labs calibrate their testing equipment differently, all testing results shall come from the same testing facility.

Should the pH fall out of the acceptable range, it may be modified (higher) with lime or (lower) with iron sulfate plus sulfur.

Compaction

It is very important to minimize compaction of both the base of the bioretention area and the required backfill. When possible, use excavation hoes to remove original soil. If bioretention areas are excavated using a loader, the contractor should use wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high pressure tires will cause excessive compaction resulting in reduced infiltration rates and storage volumes and is not acceptable. Compaction will significantly contribute to design failure.

Compaction can be alleviated at the base of the bioretention facility by using a primary tilling operation such as a chisel plow, ripper, or subsoiler. These tilling operations are to refracture the soil profile through the 12 inch compaction zone. Substitute methods must be approved by the engineer. Rototillers typically do not till deep enough to reduce the effects of compaction from heavy equipment.

Rototill 2 to 3 inches of sand into the base of the bioretention facility before back filling the required sand layer. Pump any ponded water before preparing (rototilling) base.

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When back filling the topsoil over the sand layer, first place 3 to 4 inches of topsoil over the sand, then rototill the sand/topsoil to create a gradation zone. Backfill the remainder of the topsoil to final grade.

When back filling the bioretention facility, place soil in lifts 12" or greater. Do not use heavy equipment within the bioretention basin. Heavy equipment can be used around the perimeter of the basin to supply soils and sand. Grade bioretention materials by hand or with light equipment such as a compact loader or a dozer/loader with marsh tracks.

Plant Installation

Mulch around individual plants only. Shredded hardwood mulch is the only accepted mulch. Pine mulch and wood chips will float and move to the perimeter of the bioretention area during a storm event and are not acceptable. Shredded mulch must be well aged (6 to 12 months) for acceptance.

The plant root ball should be planted so $1/8^{th}$ of the ball is above final grade surface.

Root stock of the plant material shall be kept moist during transport and on-site storage. The diameter of the planting pit shall be at least six inches larger than the diameter of the planting ball. Set and maintain the plant straight during the entire planting process. Thoroughly water ground bed cover after installation.

Trees shall be braced using 2" X 2" stakes only as necessary and for the first growing season only. Stakes are to be equally spaced on the outside of the tree ball.

Grasses and legume seed shall be tilled into the soil to a depth of at least one inch. Grass and legume plugs shall be planted following the non-grass ground cover planting specifications.

The topsoil specifications provide enough organic material to adequately supply nutrients from natural cycling. The primary function of the bioretention structure is to improve water quality. Adding fertilizers defeats, or at a minimum, impedes this goal. Only add fertilizer if wood chips or mulch is used to amend the soil. Rototill urea fertilizer at a rate of 2 pounds per 1000 square feet.

Underdrains

Under drains to be placed on a 3'-0" wide section of filter cloth. Pipe is placed next, followed by the gravel bedding. The ends of under drain pipes not terminating in an observation well shall be capped.

The main collector pipe for underdrain systems shall be constructed at a minimum slope of 0.5%. Observation wells and/or clean-out pipes must be provided (one minimum per every 1000 square feet of surface area).

Miscellaneous

The bioretention facility may not be constructed until all contributing drainage area has been stabilized.

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Table C.2 Materials Specifications for Bioretention

Parameter	Specification	Size	Notes
Plantings	see your local NRCS Standards and Specifications guidance.	n/a	plantings are site-specific
Planting Soil [4= deep]	sand 35 - 60% silt 30 - 55% clay 10 - 25%	n/a	USDA soil types loamy sand, sandy loam or loam
Mulch	shredded hardwood		aged 6 months, minimum
pea gravel diaphragm and curtain drain	pea gravel: ASTM D 448 ornamental stone: washed cobbles	pea gravel: No. 6 stone: 2" to 5"	
Geotextile	Class "C" apparent opening size (ASTM-D-4751) grab tensile strength (ASTM-D-4632) burst strength (ASTM-D-4833)	n/a	for use as necessary beneath underdrains only
underdrain gravel	AASHTO M-43. No. 67.	0.25" to 0.75"	
underdrain piping	ASTM D 1785 or AASHTO M-278	6" rigid schedule 40 PVC	3/8" perf. @ 6" on center, 4 holes per row; minimum of 3" of gravel over pipes; not necessary underneath pipes
poured in place concrete (if required)	See local DOT Standards and Specs.; f=c = 3500 psi. @ 28 days, normal weight, air-entrained; re-inforcing to meet ASTM 615-60	n/a	on-site testing of poured-in-place concrete required: 28 day strength and slump test; all concrete design (cast-in-place or pre-cast) *not using previously approved State or local standards* requires design drawings sealed and approved by a licensed professional structural engineer.
sand [1= deep]	AASHTO M-6 or ASTM C-33	0.02" to 0.04"	Sand substitutions such as Diabase and Graystone #10 are not acceptable. No calcium carbonated or dolomitic sand substitutions are acceptable. No "rock dust" can be used for sand.

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Specifications for Open Channels and Filter Strips

Material Specifications
The recommended construction materials for open channels and filter strips are detailed in Table G.3.

Dry Swales

Roto-till soil/gravel interface approximately 6" to avoid a sharp soil/gravel interface.

Permeable soil mixture (20" to 30" deep) should meet the bioretention planting soil specifications.

Check dams, if required, shall be placed as specified.

System to have 6" of freeboard, minimum.

Side slopes to be 3:1 minimum; (4:1 or greater preferred).

No gravel or perforated pipe is to be placed under driveways.

Bottom of facility to be above the seasonably high water table.

Seed with flood/drought resistant grasses; see your local NRCS Standards and Specifications guidance.

Longitudinal slope to be 1 to 2%, maximum [up to 5% with check dams].

Bottom width to be 8'= maximum to avoid braiding; larger widths may be used if proper berming is supplied. Width to be 2'= minimum.

Wet Swales
Follow above information for dry swales, with the following exceptions: the seasonally high water table may inundate the swale; but not above the design bottom of the channel [NOTE: if the water table is stable within the channel; the WQv storage may start at this point]

Excavate into undisturbed soils; do not use an underdrain system.

Filter Strips

Construct pea gravel diaphragms 12" wide, minimum, and 24" deep minimum.

Pervious berms to be a sand/gravel mix (35-60% sand, 30-55% silt, and 10-25% gravel). Berms to have overflow weirs with 6 inch minimum avilable head.

Slope range to be 2% minimum to 6% maximum.

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Table C.3 Open Vegetated Swale and Filter Strip Materials Specifications

Parameter	Specification	Size	Notes
Dry swale soil	USCS; ML, SM, SC	n/a	soil with a higher percent organic content is preferred
Dry Swale sand	ASTM C-33 fine aggregate concrete sand	0.02" to 0.04"	
Check Dam (pressure treated)	AWPA Standard C6	6" by 6" or 8" by 8"	*do not* coat with creosote; embed at least 3= into side slopes
Check Dam (natural wood)	Black Locust, Red Mulberry, Cedars, Catalpa, White Oak, Chestnut Oak, Black Walnut	6" to 12" diameter; notch as necessary	*do not* use the following, as these species have a predisposition towards rot: Ash, Beech, Birch, Elm, Hackberry, hemlock, Hickories, Maples, Red and Black Oak, Pines, Poplar, Spruce, Sweetgum, Willow
Filter Strip sand/gravel pervious berm	sand: per dry swale sand gravel; AASHTO M-43 No. 57	sand: 0.02" to 0.04" gravel: 2" to 1"	mix with approximately 25% loan soil to support grass cover crop; see Bioretention planting soil notes for more detail.
pea gravel diaphragm and curtain drain	ASTM D 448	varies (No. 6) or (1/8" to 3/8")	use clean bank-run gravel
under drain gravel	AASHTO M-43 No. 67	0.25" to 0.75"	
under drain	ASTM D -1785 or AASHTO M-278	6" rigid Schedule 40 PVC	3/8" perf. @ 6" o.c.; 4 holes per row
Geotextile	See local DOT Standards and Specs	n/a	
rip rap	per local DOT criteria	size per New York State DOT requirements based on 10-year design flows	

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Appendix D

New York State Stormwater Management Design Manual

Appendix D: Infiltration Testing Requirements

General Notes Pertinent to All Testing

1. For infiltration practices, a minimum field infiltration rate (f_c) of 0.5 inches per hour is required; areas yielding a lower rate preclude these practices. If the minimum f_c exceeds two inches per hour, half of the WQ_v must be treated by an upstream SMP that does allow infiltration. For F-1 and F-6 practices, no minimum infiltration rate is required if these facilities are designed with a "day-lighting" underdrain system; otherwise these facilities require a 0.5 inch per hour rate.

2. Number of required borings is based on the size of the proposed facility. Testing is done in two phases, (1) Initial Feasibility, and (2) Concept Design Testing.

3. Testing is to be conducted by a qualified professional. This professional shall either be a registered professional engineer in the State of New York, a soils scientist or geologist also licensed in the State of New York.

Initial Feasibility Testing

Feasibility testing is conducted to determine whether full-scale testing is necessary, and is meant to screen unsuitable sites, and reduce testing costs. A soil boring is not required at this stage. However, a designer or landowner may opt to engage Concept Design Borings per Table H-1 at his or her discretion, without feasibility testing.

Initial testing involves either one field test per facility, regardless of type or size, or previous testing data, such as the following:

* septic percolation testing on-site, within 200 feet of the proposed SMP location, and on the same contour [can establish initial rate, water table and/or depth to bedrock]
* previous written geotechnical reporting on the site location as prepared by a qualified geotechnical consultant
* NRCS County Soil Mapping *showing an unsuitable soil group* such as a hydrologic group "D" soil in a low-lying area, or a Marlboro Clay

If the results of initial feasibility testing as determined by a qualified professional show that an infiltration rate of greater than 0.5 inches per hour is probable, then the number of *concept design test* pits shall be per the following table. An encased soil boring may be substituted for a test pit, if desired.

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Table D-1 Infiltration Testing Summary Table

Type of Facility	Initial Feasibility Testing	Concept Design Testing (initial testing yields a rate greater than 0.5"/hr)	Concept Design Testing (initial testing yields a rate lower than 0.5"/hr)
I-1 (trench)	1 field percolation test, test pit not required	1infiltration test and 1 test pit per 50' of trench	not acceptable practice
I-2 (basin)	1 field percolation test, test pit not required	1 infiltration test* and 1 test pit per 200 sf of basin area	not acceptable practice
F-1(sand filter)	1 field percolation test, test pit not required	1 infiltration test and 1 test pit per 200 sf of filter area (no underdrains required**)	underdrains required
F-6 (bioretention)	1 field percolation test, test pit not required	1 infiltration test and 1 test pit per 200 sf of filter area (no underdrains required**)	underdrains required

*feasibility test information already counts for one test location
** underdrain installation still strongly suggested

Documentation

Infiltration testing data shall be documented, which shall also include a description of the infiltration testing method, if completed. This is to ensure that the tester understands the procedure.

Test Pit/Boring Requirements

a. excavate a test pit or dig a standard soil boring to a minimum depth of 4 feet below the proposed facility bottom elevation

b. determine depth to groundwater table (if within 4 feet of proposed bottom) upon initial digging or drilling, and again 24 hours later

c. conduct Standard Penetration Testing (SPT) every 2' to a depth of 4 feet below the facility bottom

d. determine USDA or Unified Soil Classification System textures at the proposed bottom and 4 feet below the bottom of the SMP

e. determine depth to bedrock (if within 4 feet of proposed bottom)

f. The soil description should include all soil horizons.

g. The location of the test pit or boring shall correspond to the SMP location; test pit/soil boring stakes are to be left in the field for inspection purposes and shall be clearly labeled as such.

Infiltration Testing Requirements

a. Install casing (solid 5 inch diameter, 30" length) to 24" below proposed SMP bottom (see Figure D-1).

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b. Remove any smeared soiled surfaces and provide a natural soil interface into which water may percolate. Remove all loose material from the casing. Upon the tester's discretion, a two (2) inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring and sediment. Fill casing with *clean* water to a depth of 24" and allow to pre-soak for twenty-four hours

c. Twenty-four hours later, refill casing with another 24" of clean water and monitor water level (measured drop from the top of the casing) for 1 hour. Repeat this procedure (filling the casing each time) three additional times, for a total of four observations. Upon the tester's discretion, the final field rate may either be the average of the four observations, or the value of the last observation. The final rate shall be reported in *inches per hour*.

d. May be done though a boring or open excavation.

e. The location of the test shall correspond to the SMP location.

f. Upon completion of the testing, the casings shall be immediately pulled, and the test pit shall be back-filled.

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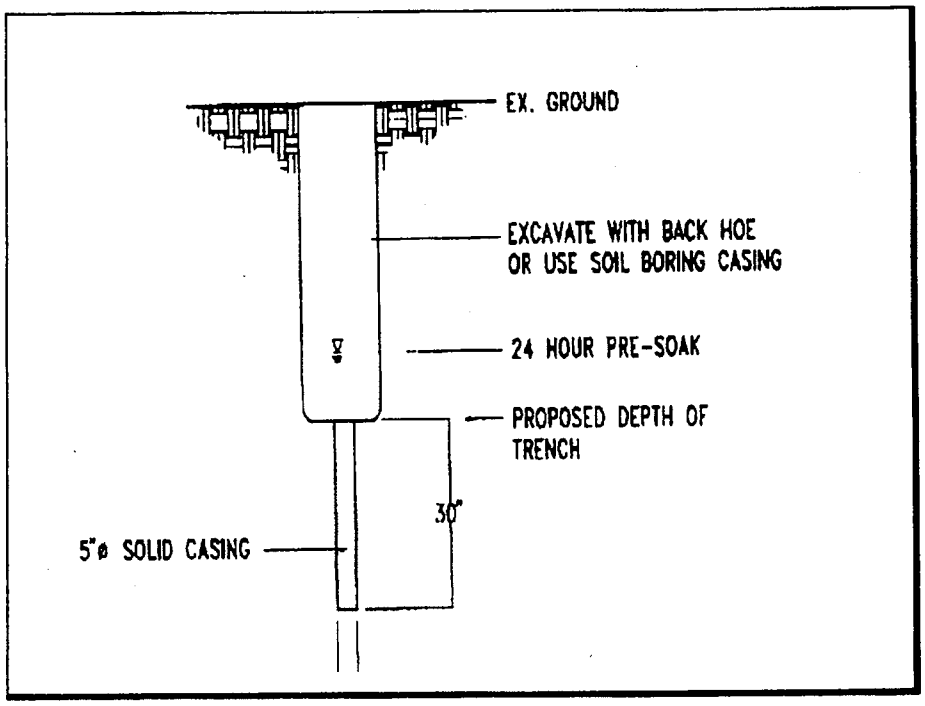
Figure D.1 Infiltration Testing Requirements



Laboratory Testing

a. Grain-size sieve analysis and hydrometer tests where appropriate may be used to determine USDA soils classification and textural analysis. Visual field inspection by a qualified professional may also be used, provided it is documented. *The use of lab testing to establish infiltration rates is prohibited.*

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Bioretention Testing

All areas to be used as bioretention facilities shall be back-filled with a suitable sandy loam planting media. The borrow source of this media, which may be the same or different location from the bioretention area itself, must be tested as follows:

If the borrow area is virgin, undisturbed soil, one test is required per 200 sf of borrow area; the test consists of "grab" samples at one foot depth intervals to the bottom of the borrow area. All samples at the testing location are then mixed, and the resulting sample is then lab-tested to meet the following criteria:

a) USDA minimum textural analysis requirements: A textural analysis is required from the site stockpiled topsoil. If topsoil is imported, then a texture analysis shall be performed for each location where the top soil was excavated.

Minimum requirements:

sand	35 - 60%
silt	30 - 55%
clay	10 - 25%

b) The soil shall be a uniform mix, free of stones, stumps, roots or other similar objects larger than two inches.

c) Consult the bioretention construction specifications (Appendix J) for further guidance on preparing the soil for a bioretention area.

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Appendix E

New York State Stormwater Management Design Manual

Example Checklist for Preliminary/Concept Stormwater Management Plan Preparation and Review

- ☐ Applicant information
- ☐ Name, legal address, and telephone number
- ☐ Common address and legal description of site
- ☐ Vicinity map
- ☐ Existing and proposed mapping and plans (recommended scale of 1" = 50'.) which illustrate at a minimum:
  - ▸ Existing and proposed topography (minimum of 2-foot contours recommended)
  - ▸ Perennial and intermittent streams
  - ▸ Mapping of predominant soils from USDA soil surveys
  - ▸ Boundaries of existing predominant vegetation and proposed limits of clearing
  - ▸ Location and boundaries of resource protection areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks)
  - ▸ Location of existing and proposed roads, buildings, and other structures
  - ▸ Existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
  - ▸ Location of existing and proposed conveyance systems such as grass channels, swales, and storm drains
  - ▸ Flow paths
  - ▸ Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
  - ▸ Preliminary location and dimensions of proposed channel modifications, such as bridge or culvert crossings
  - ▸ Preliminary location, size, and limits of disturbance of proposed stormwater treatment practices
- ☐ Hydrologic and hydraulic analysis including:
  - ▸ Existing condition analysis for runoff rates, volumes, and velocities presented showing methodologies used and supporting calculations
  - ▸ Proposed condition analysis for runoff rates, volumes, and velocities showing the methodologies used and supporting calculations
  - ▸ Preliminary analysis of potential downstream impact/effects of project, where necessary
  - ▸ Preliminary selection and rationale for structural stormwater management practices
  - ▸ Preliminary sizing calculations for stormwater treatment practices including contributing drainage area, storage, and outlet configuration
- ☐ Preliminary landscaping plans for stormwater treatment practices and any site reforestation or revegetation
- ☐ Preliminary erosion and sediment control plan that at a minimum meets the requirements outlined in local Erosion and Sediment Control guidelines
- ☐ Identification of preliminary waiver requests

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Example Checklist for Final Stormwater Management Plan Preparation and Review

- ☐ Applicant information
  Name, legal address, and telephone number
- ☐ Common address and legal description of site
- ☐ Signature and stamp of registered engineer/surveyor and design/owner certification
- ☐ Vicinity map
- ☐ Existing and proposed mapping and plans (recommended scale of 1" = 50' or greater detail) which illustrate at a minimum:
  - ▸ Existing and proposed topography (minimum of 2-foot contours recommended)
  - ▸ Perennial and intermittent streams
  - ▸ Mapping of predominant soils from USDA soil surveys as well as location of any site-specific borehole investigations that may have been performed.
  - ▸ Boundaries of existing predominant vegetation and proposed limits of clearing
  - ▸ Location and boundaries of resource protection areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks)
  - ▸ Location of existing and proposed roads, buildings, and other structures
  - ▸ Location of existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
  - ▸ Location of existing and proposed conveyance systems such as grass channels, swales, and storm drains
  - ▸ Flow paths
  - ▸ Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
  - ▸ Location and dimensions of proposed channel modifications, such as bridge or culvert crossings
  - ▸ Location, size, maintenance access, and limits of disturbance of proposed structural stormwater Management practices
- ☐ Representative cross-section and profile drawings and details of structural stormwater Management practices and conveyances (i.e., storm drains, open channels, swales, etc.) which include:
  - ▸ Existing and proposed structural elevations (e.g., invert of pipes, manholes, etc.)
  - ▸ Design water surface elevations
  - ▸ Structural details of outlet structures, embankments, spillways, stilling basins, grade control structures, conveyance channels, etc.
  - ▸ Logs of borehole investigations that may have been performed along with supporting geotechnical report.

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- ☐ Hydrologic and hydraulic analysis for all structural components of stormwater system (e.g., storm drains, open channels, swales, Management practices, etc.) for applicable design storms including:
  - Existing condition analysis for time of concentrations, runoff rates, volumes, velocities, and water surface elevations showing methodologies used and supporting calculations
  - Proposed condition analysis for time of concentrations, runoff rates, volumes, velocities, water surface elevations, and routing showing the methodologies used and supporting calculations
  - Final sizing calculations for structural stormwater Management practices including, contributing drainage area, storage, and outlet configuration
  - Stage-discharge or outlet rating curves and inflow and outflow hydrographs for storage facilities (e.g., stormwater ponds and wetlands)
  - Final analysis of potential downstream impact/effects of project, where necessary
  - Dam breach analysis, where necessary
- ☐ Final landscaping plans for structural stormwater Management practices and any site reforestation or revegetation
- ☐ Structural calculations, where necessary
- ☐ Applicable construction specifications
- ☐ Erosion and sediment control plan that at a minimum meets the requirements of the local Erosion and Sediment Control Guidelines
- ☐ Sequence of construction
- ☐ Maintenance plan which will include:
  - Name, address, and phone number of responsible parties for maintenance.
  - Description of annual maintenance tasks
  - Description of applicable easements
  - Description of funding source
  - Minimum vegetative cover requirements
  - Access and safety issues
  - Testing and disposal of sediments that will likely be necessary
- ☐ Evidence of acquisition of all applicable local and non-local permits
- ☐ Evidence of acquisition of all necessary legal agreements (e.g., easements, covenants, land trusts)
- ☐ Waiver requests
- ☐ Review agency should have inspector's checklist identifying potential features to be inspected on site visits

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Appendix F

New York State Stormwater Management Design Manual

Stormwater/Wetland Pond Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Pre-Construction/Materials and Equipment		
Pre-construction meeting		
Pipe and appurtenances on-site prior to construction and dimensions checked		
1. Material (including protective coating, if specified)		
2. Diameter		
3. Dimensions of metal riser or pre-cast concrete outlet structure		
4. Required dimensions between water control structures (orifices, weirs, etc.) are in accordance with approved plans		
5. Barrel stub for prefabricated pipe structures at proper angle for design barrel slope		
6. Number and dimensions of prefabricated anti-seep collars		
7. Watertight connectors and gaskets		
8. Outlet drain valve		
Project benchmark near pond site		
Equipment for temporary de-watering		

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CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
2. Subgrade Preparation		
Area beneath embankment stripped of all vegetation, topsoil, and organic matter		
3. Pipe Spillway Installation		
Method of installation detailed on plans		
A. Bed preparation		
Installation trench excavated with specified side slopes		
Stable, uniform, dry subgrade of relatively impervious material (If subgrade is wet, contractor shall have defined steps before proceeding with installation)		
Invert at proper elevation and grade		
B. Pipe placement		
Metal / plastic pipe		
1. Watertight connectors and gaskets properly installed		
2. Anti-seep collars properly spaced and having watertight connections to pipe		
3. Backfill placed and tamped by hand under "haunches" of pipe		
4. Remaining backfill placed in max. 8 inch lifts using small power tamping equipment until 2 feet cover over pipe is reached		

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CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
3. Pipe Spillway Installation		
Concrete pipe		
1. Pipe set on blocks or concrete slab for pouring of low cradle		
2. Pipe installed with rubber gasket joints with no spalling in gasket interface area		
3. Excavation for lower half of anti-seep collar(s) with reinforcing steel set		
4. Entire area where anti-seep collar(s) will come in contact with pipe coated with mastic or other approved waterproof sealant		
5. Low cradle and bottom half of anti-seep collar installed as monolithic pour and of an approved mix		
6. Upper half of anti-seep collar(s) formed with reinforcing steel set		
7. Concrete for collar of an approved mix and vibrated into place (protected from freezing while curing, if necessary)		
8. Forms stripped and collar inspected for honeycomb prior to backfilling. Parge if necessary.		
C. Backfilling		
Fill placed in maximum 8 inch lifts		
Backfill taken minimum 2 feet above top of anti-seep collar elevation before traversing with heavy equipment		

R0080462

SARB_010433

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
4. Riser / Outlet Structure Installation		
Riser located within embankment		
A. Metal riser		
Riser base excavated or formed on stable subgrade to design dimensions		
Set on blocks to design elevations and plumbed		
Reinforcing bars placed at right angles and projecting into sides of riser		
Concrete poured so as to fill inside of riser to invert of barrel		
B. Pre-cast concrete structure		
Dry and stable subgrade		
Riser base set to design elevation		
If more than one section, no spalling in gasket interface area; gasket or approved caulking material placed securely		
Watertight and structurally sound collar or gasket joint where structure connects to pipe spillway		
C. Poured concrete structure		
Footing excavated or formed on stable subgrade, to design dimensions with reinforcing steel set		
Structure formed to design dimensions, with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place (protected from freezing while curing, if necessary)		
Forms stripped & inspected for "honeycomb" prior to backfilling; parge if necessary		

R0080463

SARB_010434

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
5. Embankment Construction		
Fill material		
Compaction		
Embankment		
1. Fill placed in specified lifts and compacted with appropriate equipment		
2. Constructed to design cross-section, side slopes and top width		
3. Constructed to design elevation plus allowance for settlement		
6. Impounded Area Construction		
Excavated / graded to design contours and side slopes		
Inlet pipes have adequate outfall protection		
Forebay(s)		
Pond benches		
7. Earth Emergency Spillway Construction		
Spillway located in cut or structurally stabilized with riprap, gabions, concrete, etc.		
Excavated to proper cross-section, side slopes and bottom width		
Entrance channel, crest, and exit channel constructed to design grades and elevations		

R0080464

SARB_010435

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
8. Outlet Protection		
A. End section		
Securely in place and properly backfilled		
B. Endwall		
Footing excavated or formed on stable subgrade, to design dimensions and reinforcing steel set, if specified		
Endwall formed to design dimensions with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place (protected from freezing, if necessary)		
Forms stripped and structure inspected for "honeycomb" prior to backfilling; parge if necessary		
C. Riprap apron / channel		
Apron / channel excavated to design cross-section with proper transition to existing ground		
Filter fabric in place		
Stone sized as per plan and uniformly place at the thickness specified		
9. Vegetative Stabilization		
Approved seed mixture or sod		
Proper surface preparation and required soil amendments		
Excelsior mat or other stabilization, as per plan		

R0080465

SARB_010436

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
10. Miscellaneous		
Drain for ponds having a permanent pool		
Trash rack / anti-vortex device secured to outlet structure		
Trash protection for low flow pipes, orifices, etc.		
Fencing (when required)		
Access road		
Set aside for clean-out maintenance		
11. Stormwater Wetlands		
Adequate water balance		
Variety of depth zones present		
Approved pondscaping plan in place Reinforcement budget for additional plantings		
Plants and materials ordered 6 months prior to construction		
Construction planned to allow for adequate planting and establishment of plant community (April-June planting window)		
Wetland buffer area preserved to maximum extent possible		

Comments:

R0080466

SARB_010437

Actions to be Taken:

R0080467

SARB_010438

Infiltration Trench Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Soil permeability tested		
Groundwater / bedrock sufficient at depth		
2. Excavation		
Size and location		
Side slopes stable		
Excavation does not compact subsoils		
3. Filter Fabric Placement		
Fabric specifications		
Placed on bottom, sides, and top		

R0080468

SARB_010439

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Aggregate Material		
Size as specified		
Clean / washed material		
Placed properly		
5. Observation Well		
Pipe size		
Removable cap / footplate		
Initial depth =_____feet		
6. Final Inspection		
Pretreatment facility in place		
Contributing watershed stabilized prior to flow diversion		
Outlet		

Comments:

R0080469

SARB_010440

Actions to be Taken:

R0080470

SARB_010441

Infiltration Basin Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
1. Pre-Construction		
Runoff diverted		
Soil permeability tested		
Groundwater / bedrock depth		
2. Excavation		
Size and location		
Side slopes stable		
Excavation does not compact subsoils		
3. Embankment		
Barrel		
Anti-seep collar or Filter diaphragm		
Fill material		

R0080471

SARB_010442

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
4. Final Excavation		
Drainage area stabilized		
Sediment removed from facility		
Basin floor tilled		
Facility stabilized		
5. Final Inspection		
Pretreatment facility in place		
Inlets / outlets		
Contributing watershed stabilized before flow is routed to the factility		

Comments:

Actions to be Taken:

R0080472
SARB_010443

Sand/Organic Filter System Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Pre-construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
Facility location staked out		
2. Excavation		
Size and location		
Side slopes stable		
Foundation cleared of debris		
If designed as exfilter, excavation does not compact subsoils		
Foundation area compacted		
3. Structural Components		
Dimensions and materials		
Forms adequately sized		
Concrete meets standards		
Prefabricated joints sealed		
Underdrains (size, materials)		

R0080473
SARB_010444

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Completed Facility Components		
24 hour water filled test		
Contributing area stabilized		
Filter material per specification		
Underdrains installed to grade		
Flow diversion structure properly installed		
Pretreatment devices properly installed		
Level overflow weirs, multiple orifices, distribution slots		
5. Final Inspection		
Dimensions		
Surface completely level		
Structural components		
Proper outlet		
Ensure that site is properly stabilized before flow is directed to the structure.		

R0080474

SARB_010445

Comments:

Actions to be Taken:

R0080475
SARB_010446

Bioretention Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
If designed as exfilter, soil testing for permeability		
Facility location staked out		
2. Excavation		
Size and location		
Lateral slopes completely level		
If designed as exfilter, ensure that excavation does not compact susoils.		
Longitudinal slopes within design range		

R0080476
SARB_010447

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
3. Structural Components		
Stone diaphragm installed correctly		
Outlets installed correctly		
Underdrain		
Pretreatment devices installed		
Soil bed composition and texture		
4. Vegetation		
Complies with planting specs		
Topsoil adequate in composition and placement		
Adequate erosion control measures in place		
5. Final Inspection		
Dimensions		
Proper stone diaphragm		
Proper outlet		
Soil/ filter bed permeability testing		
Effective stand of vegetation and stabilization		
Construction generated sediments removed		
Contributing watershed stabilized before flow is diverted to the practice		

R0080477

SARB_010448

Comments:

Actions to be Taken:

R0080478

SARB_010449

Open Channel System Construction Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

Construction Sequence	Satisfactory / Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility location staked out		
2. Excavation		
Size and location		
Side slope stable		
Soil permeability		
Groundwater / bedrock		
Lateral slopes completely level		
Longitudinal slopes within design range		
Excavation does not compact subsoils		
3. Check dams		
Dimensions		
Spacing		
Materials		

R0080479
SARB_010450

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Structural Components		
Underdrain installed correctly		
Inflow installed correctly		
Pretreatment devices installed		
5. Vegetation		
Complies with planting specifications		
Topsoil adequate in composition and placement		
Adequate erosion control measures in place		
6. Final inspection		
Dimensions		
Check dams		
Proper outlet		
Effective stand of vegetation and stabilization		
Contributing watershed stabilized before flow is routed to the factility		

Comments:

R0080480
SARB_010451

Actions to be Taken:

R0080481

SARB_010452

Appendix G

R0080482
SARB_010453

Stormwater Pond/Wetland Operation, Maintenance and Management Inspection Checklist

Project _____
Location: _____
Site Status: _____

Date: _____
Time: _____

Inspector: _____

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
1. Embankment and emergency spillway (Annual, After Major Storms)		
1. Vegetation and ground cover adequate		
2. Embankment erosion		
3. Animal burrows		
4. Unauthorized planting		
5. Cracking, bulging, or sliding of dam		
a. Upstream face		
b. Downstream face		
c. At or beyond toe		
downstream		
upstream		
d. Emergency spillway		
6.Pond, toe & chimney drains clear and functioning		
7.Seeps/leaks on downstream face		
8.Slope protection or riprap failure		
9. Vertical/horizontal alignment of top of dam "As-Built"		

R0080483
SARB_010454

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
10. Emergency spillway clear of obstructions and debris		
11. Other (specify)		
2. Riser and principal spillway (Annual)		
Type: Reinforced concrete _____ Corrugated pipe _____ Masonry _____ 1. Low flow orifice obstructed		
2. Low flow trash rack. a. Debris removal necessary		
b. Corrosion control		
3. Weir trash rack maintenance a. Debris removal necessary		
b. corrosion control		
4. Excessive sediment accumulation insider riser		
5. Concrete/masonry condition riser and barrels a. cracks or displacement		
b. Minor spalling (<1")		
c. Major spalling (rebars exposed)		
d. Joint failures		
e. Water tightness		
6. Metal pipe condition		
7. Control valve a. Operational/exercised		
b. Chained and locked		
8. Pond drain valve a. Operational/exercised		
b. Chained and locked		
9. Outfall channels functioning		
10. Other (specify)		

R0080484

SARB_010455

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
3. Permanent Pool (Wet Ponds) (monthly)		
1. Undesirable vegetative growth		
2. Floating or floatable debris removal required		
3. Visible pollution		
4. Shoreline problem		
5. Other (specify)		
4. Sediment Forebays		
1.Sedimentation noted		
2. Sediment cleanout when depth < 50% design depth		
5. Dry Pond Areas		
1. Vegetation adequate		
2. Undesirable vegetative growth		
3. Undesirable woody vegetation		
4. Low flow channels clear of obstructions		
5. Standing water or wet spots		
6. Sediment and / or trash accumulation		
7. Other (specify)		
6. Condition of Outfalls (Annual , After Major Storms)		
1. Riprap failures		
2. Slope erosion		
3. Storm drain pipes		
4.Endwalls / Headwalls		
5. Other (specify)		
7. Other (Monthly)		
1. Encroachment on pond, wetland or easement area		

R0080485

SARB_010456

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
2. Complaints from residents		
3.Aesthetics a. Grass growing required		
b. Graffiti removal needed		
c. Other (specify)		
4. Conditions of maintenance access routes.		
5. Signs of hydrocarbon build-up		
6. Any public hazards (specify)		
8. Wetland Vegetation (Annual)		
1. Vegetation healthy and growing Wetland maintaining 50% surface area coverage of wetland plants after the second growing season. (If unsatisfactory, reinforcement plantings needed)		
2. Dominant wetland plants: Survival of desired wetland plant species Distribution according to landscaping plan?		
3. Evidence of invasive species		
4. Maintenance of adequate water depths for desired wetland plant species		
5. Harvesting of emergent plantings needed		
6. Have sediment accumulations reduced pool volume significantly or are plants "choked" with sediment		
7. Eutrophication level of the wetland.		
8. Other (specify)		

Comments:

R0080486

SARB_010457

Actions to be Taken:

R0080487

SARB_010458

Infiltration Trench Operation, Maintenance, and Management Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Trench surface clear of debris		
Inflow pipes clear of debris		
Overflow spillway clear of debris		
Inlet area clear of debris		
2. Sediment Traps or Forebays (Annual)		
Obviously trapping sediment		
Greater than 50% of storage volume remaining		
3. Dewatering (Monthly)		
Trench dewaters between storms		
4. Sediment Cleanout of Trench (Annual)		
No evidence of sedimentation in trench		
Sediment accumulation doesn't yet require cleanout		
5. Inlets (Annual)		

R0080488

SARB_010459

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
Good condition		
No evidence of erosion		
6. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repair		
No evidence of erosion		
7. Aggregate Repairs (Annual)		
Surface of aggregate clean		
Top layer of stone does not need replacement		
Trench does not need rehabilitation		

Comments:

Actions to be Taken:

R0080489

SARB_010460

Sand/Organic Filter Operation, Maintenance and Management Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Contributing areas clean of debris		
Filtration facility clean of debris		
Inlet and outlets clear of debris		
2. Oil and Grease (Monthly)		
No evidence of filter surface clogging		
Activities in drainage area minimize oil and grease entry		
3. Vegetation (Monthly)		
Contributing drainage area stabilized		
No evidence of erosion		
Area mowed and clipping removed		
4. Water Retention Where Required (Monthly)		
Water holding chambers at normal pool		
No evidence of leakage		
5. Sediment Deposition (Annual)		

R0080490

SARB_010461

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
Filter chamber free of sediments		
Sedimentation chamber not more than half full of sediments		
6. Structural Components (Annual)		
No evidence of structural deterioration		
Any grates are in good condition		
No evidence of spalling or cracking of structural parts		
7. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repairs		
No evidence of erosion (if draining into a natural channel)		
8. Overall Function of Facility (Annual)		
Evidence of flow bypassing facility		
No noticeable odors outside of facility		

Comments:

Actions to be Taken:

R0080491
SARB_010462

Bioretention Operation, Maintenance and Management Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Bioretention and contributing areas clean of debris		
No dumping of yard wastes into practice		
Litter (branches, etc.) have been removed		
2. Vegetation (Monthly)		
Plant height not less than design water depth		
Fertilized per specifications		
Plant composition according to approved plans		
No placement of inappropriate plants		
Grass height not greater than 6 inches		
No evidence of erosion		
3. Check Dams/Energy Dissipaters/Sumps (Annual, After Major Storms)		
No evidence of sediment buildup		

R0080492
SARB_010463

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
Sumps should not be more than 50% full of sediment		
No evidence of erosion at downstream toe of drop structure		
4. Dewatering (Monthly)		
Dewaters between storms		
No evidence of standing water		
5. Sediment Deposition (Annual)		
Swale clean of sediments		
Sediments should not be > 20% of swale design depth		
6. Outlet/Overflow Spillway (Annual, After Major Storms)		
Good condition, no need for repair		
No evidence of erosion		
No evidence of any blockages		
7. Integrity of Filter Bed (Annual)		
Filter bed has not been blocked or filled inappropriately		

R0080493

SARB_010464

Comments:

Actions to be Taken:

R0080494

SARB_010465

Open Channel Operation, Maintenance, and Management Inspection Checklist

Project:
Location:
Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Contributing areas clean of debris		
2. Check Dams or Energy Dissipators (Annual, After Major Storms)		
No evidence of flow going around structures		
No evidence of erosion at downstream toe		
Soil permeability		
Groundwater / bedrock		
3. Vegetation (Monthly)		
Mowing done when needed		
Minimum mowing depth not exceeded		
No evidence of erosion		
Fertilized per specification		
4. Dewatering (Monthly)		
Dewaters between storms		

R0080495

SARB_010466

MAINTENANCE ITEM	SATISFACTORY/ UNSATISFACTORY	COMMENTS
5. Sediment deposition (Annual)		
Clean of sediment		
6. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repairs		
No evidence of erosion		

Comments:

Actions to be Taken:

R0080496
SARB_010467

Appendix H

New York State Stormwater Management Design Manual

R0080497
SARB_010468

Appendix H: Landscaping Guidance/Plant Lists

H.1 Ponds and Wetlands

For areas that are to be planted within a stormwater pond, it is necessary to determine what type of hydrologic zones will be created within the pond. The following six zones describe the different conditions encountered in stormwater management facilities. Every facility does not necessarily reflect all of these zones. The hydrologic zones designate the degree of tolerance the plant exhibits to differing degrees of inundation by water.

Table H.5 at the end of this appendix designates appropriate zones for each plant. There may be other zones listed outside of these brackets. The plant materials may occur within these zones, but are not typically found in them. Plants suited for specific hydrologic conditions may perish when those conditions change, exposing the soil, and therefore, increasing the chance for erosion.

Each zone has its own set of plant selection criteria based on the hydrology of the zone, the stormwater functions required of the plant and the desired landscape effect. The hydrologic zones are as follows:

Table H.1 Hydrologic Zones

Zone #	Zone Description	Hydrologic Conditions
Zone 1	Deep Water Pool	1-6 feet deep Permanent Pool
Zone 2	Shallow Water Bench	6 inches to 1 foot deep
Zone 3	Shoreline Fringe	Regularly inundated
Zone 4	Riparian Fringe	Periodically inundated
Zone 5	Floodplain Terrace	Infrequently inundated
Zone 6	Upland Slopes	Seldom or never inundated

Zone 1: Deep Water Area ***(1- 6 Feet)***

Ponds and wetlands both have deep pool areas that comprise Zone 1. These pools range from one to six feet in depth, and are best colonized by submergent plants, if at all.

This pondscaping zone has not been routinely planted for several reasons. First, the availability of plant materials that can survive and grow in this zone is limited, and it is also feared that plants could clog the stormwater facility outlet structure. In many cases, these plants will gradually become established through natural recolonization (e.g., transport of plant fragments from other ponds via the feet and legs of waterfowl). If submerged plant material becomes more commercially available and clogging concerns are addressed, this area can be planted. The function of the planting is to reduce resedimentation and improve oxidation while creating a greater aquatic habitat.

R0080498
SARB_010469

- Plant material must be able to withstand constant inundation of water of one foot or greater in depth.
- Plants may be submerged partially or entirely.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, desirable insects, and other aquatic life.

Zone 2: Shallow Water Bench ***(Normal Pool To 1 Foot)***

Zone 2 includes all areas that are inundated below the normal pool to a depth of one foot, and is the primary area where emergent plants will grow in a stormwater wetlands. Zone 2 also coincides with the aquatic bench found in stormwater ponds. This zone offers ideal conditions for the growth of many emergent wetland species. These areas may be located at the edge of the pond or on low mounds of earth located below the surface of the water within the pond. When planted, Zone 2 can be an important habitat for many aquatic and nonaquatic animals, creating a diverse food chain. This food chain includes predators, allowing a natural regulation of mosquito populations, thereby reducing the need for insecticidal applications.

- Plant material must be able to withstand constant inundation of water to depths between six inches and one foot deep.
- Plants will be partially submerged.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, desirable insects and other aquatic life.

Plants will stabilize the bottom of the pond, as well as the edge of the pond, absorbing wave impacts and reducing erosion, when water level fluctuates. Plant also slow water velocities and increase sediment deposition rates. Plants can reduce resuspension of sediments caused by the wind. Plants can also soften the engineered contours of the pond, and can conceal drawdowns during dry weather.

Zone 3: Shoreline Fringe ***(Regularly Inundated)***

Zone 3 encompasses the shoreline of a pond or wetland, and extends vertically about one foot in elevation from the normal pool. This zone includes the safety bench of a pond, and may also be periodically inundated if storm events are subject to extended detention. This zone occurs in a wet pond or shallow marsh and can be the most difficult to establish since plants must be able to withstand inundation of water during storms, when wind might blow water into the area, or the occasional drought during the summer. In order to stabilize the soil in this zone, Zone 3 must have a vigorous cover.

- Plants should stabilize the shoreline to minimize erosion caused by wave and wind action or water fluctuation.
- Plant material must be able to withstand occasional inundation of water. Plants will be partially submerged at this time.
- Plant material should, whenever possible, shade the shoreline, especially the southern exposure. This will help to reduce the water temperature.

R0080499

SARB_010470

- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, songbirds, and wildlife. Plants could also be selected and located to control overpopulation of waterfowl.
- Plants should be located to reduce human access, where there are potential hazards, but should not block the maintenance access.
- Plants should have very low maintenance requirements, since they may be difficult or impossible to reach.
- Plants should be resistant to disease and other problems which require chemical applications (since chemical application is not advised in stormwater ponds).

Zone 4: Riparian Fringe ***(Periodically Inundated)***

Zone 4 extends from one to four feet in elevation above the normal pool. Plants in this zone are subject to periodic inundation after storms, and may experience saturated or partly saturated soil conditions. Nearly all of the temporary ED area is included within this zone.

- Plants must be able to withstand periodic inundation of water after storms, as well as occasional drought during the warm summer months.
- Plants should stabilize the ground from erosion caused by run-off.
- Plants should shade the low flow channel to reduce the pool warming whenever possible.
- Plants should be able to enhance pollutant uptake.
- Plant material should have very low maintenance, since they may be difficult or impossible to access.
- Plants may provide food and cover for waterfowl, songbirds and wildlife. Plants may also be selected and located to control overpopulation of waterfowl.
- Plants should be located to reduce pedestrian access to the deeper pools.

Zone 5: Floodplain Terrace ***(Infrequently Inundated)***

Zone 5 is periodically inundated by flood waters that quickly recedes in a day or less. Operationally, Zone 5 extends from the maximum two year or Cpv water surface elevation up to the 10 or 100 year maximum water surface elevation. Key landscaping objectives for Zone 5 are to stabilize the steep slopes characteristic of this zone, and establish a low maintenance, natural vegetation.

- Plant material should be able to withstand occasional but brief inundation during storms, although typical moisture conditions may be moist, slightly wet, or even swing entirely to drought conditions during the dry weather periods.
- Plants should stabilize the basin slopes from erosion.
- Ground cover should be very low maintenance, since they may be difficult to access on steep slopes or if frequency of mowing is limited. A dense tree cover may help reduce maintenance and discourage resident geese.
- Plants may provide food and cover for waterfowl, songbirds, and wildlife.

R0080500
SARB_010471

- Placement of plant material in Zone 5 is often critical, as it often creates a visual focal point and provides structure and shade for a greater variety of plants.

Zone 6: Upland Slopes *(Seldom or Never Inundated)*

The last zone extends above the maximum 100 year water surface elevation, and often includes the outer buffer of a pond or wetland. Unlike other zones, this upland area may have sidewalks, bike paths, retaining walls, and maintenance access roads. Care should be taken to locate plants so they will not overgrow these routes or create hiding places that might make the area unsafe.

- Plant material is capable of surviving the particular conditions of the site. Thus, it is not necessary to select plant material that will tolerate any inundation. Rather, plant selections should be made based on soil condition, light, and function within the landscape.
- Ground covers should emphasize infrequent mowing to reduce the cost of maintaining this landscape.
- Placement of plants in Zone 6 is important since they are often used to create a visual focal point, frame a desirable view, screen undesirable views, serve as a buffer, or provide shade to allow a greater variety of plant materials. Particular attention should be paid to seasonal color and texture of these plantings.

R0080501
SARB_010472

H.2 Bioretention

Planting Soil Bed Characteristics

The characteristics of the soil for the bioretention facility are perhaps as important as the facility location, size, and treatment volume. The soil must be permeable enough to allow runoff to filter through the media, while having characteristics suitable to promote and sustain a robust vegetative cover crop. In addition, much of the nutrient pollutant uptake (nitrogen and phosphorus) is accomplished through adsorption and microbial activity within the soil profile. Therefore, the soils must balance soil chemistry and physical properties to support biotic communities above and below ground.

The planting soil should be a sandy loam, loamy sand, loam (USDA), or a loam/sand mix (should contain a minimum 35 to 60% sand, by volume). The clay content for these soils should by less than 25% by volume. Soils should fall within the SM, or ML classifications of the Unified Soil Classification System (USCS). A permeability of at least 1.0 feet per day (0.5"/hr) is required (a conservative value of 0.5 feet per day is used for design). The soil should be free of stones, stumps, roots, or other woody material over 1" in diameter. Brush or seeds from noxious weeds. Placement of the planting soil should be in lifts of 12 to 18", loosely compacted (tamped lightly with a dozer or backhoe bucket). The specific characteristics are presented in Table H.2.

Table H.2 Planting Soil Characteristics

Parameter	Value
PH range	5.2 to 7.00
Organic matter	1.5 to 4.0%
Magnesium	35 lbs. per acre, minimum
Phosphorus (P_2O_5)	75 lbs. per acre, minimum
Potassium (K_2O)	85 lbs. per acre, minimum
Soluble salts	≤ 500 ppm
Clay	10 to 25%
Silt	30 to 55%
Sand	35 to 60%

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Mulch Layer

The mulch layer plays an important role in the performance of the bioretention system. The mulch layer helps maintain soil moisture and avoid surface sealing which reduces permeability. Mulch helps prevent erosion, and provides a micro-environment suitable for soil biota at the mulch/soil interface. It also serves as a pretreatment layer, trapping the finer sediments which remain suspended after the primary pretreatment.

The mulch layer should be standard landscape style, single or double, shredded hardwood mulch or chips. The mulch layer should be well aged (stockpiled or stored for at least 12 months), uniform in color, and free of other materials, such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of three inches. Grass clippings should not be used as a mulch material.

Planting Plan Guidance

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an ecosystem consisting of an upland-oriented community dominated by trees, but having a distinct community, or sub-canopy, of understory trees, shrubs and herbaceous materials. The intent is to establish a diverse, dense plant cover to treat stormwater runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention facility (Figure H.1). The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports a slightly drier group of plants, but still tolerates fluctuating water levels. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions. When using Table A.5 to identify species, use the following guideline:

Lowest Zone: Zones 2-3

Middle Zone: Zones 3-4

Outer Zone: Zones 5-6

The layout of plant material should be flexible, but should follow the general principals described in Table H.3. The objective is to have a system which resembles a random and natural plant layout, while maintaining optimal conditions for plant establishment and growth.

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Figure H.1 Planting Zones for Bioretention Facilities

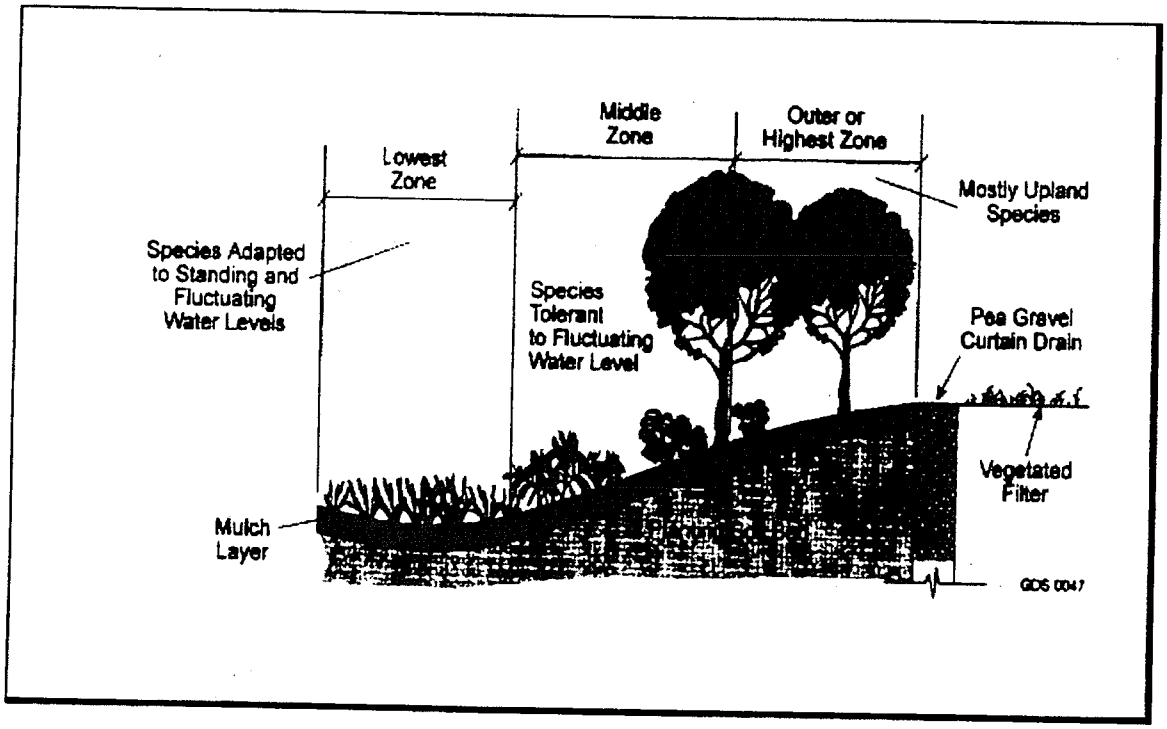

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Table H.3 Planting Plan Design Considerations
Native plant species should be specified over exotic or foreign species.
Appropriate vegetation should be selected based on the zone of hydric tolerance (see Figure H.1).
Species layout should generally be random and natural.
A canopy should be established with an understory of shrubs and herbaceous materials.
Woody vegetation should not be specified in the vicinity of inflow locations.
Trees should be planted primarily along the perimeter of the bioretention area.
Urban stressors (e.g., wind, sun, exposure, insect and disease infestation, drought) should be considered when laying out the planting plan.
Noxious weeds should not be specified.
Aesthetics and visual characteristics should be a prime consideration.
Traffic and safety issues must be considered.
Existing and proposed utilities must be identified and considered.

Plant Material Guidance

Plant materials should conform to the American Standard Nursery Stock, published by the American Association of Nurserymen, and should be selected from certified, reputable nurseries. Planting specifications should be prepared by the designer and should include a sequence of construction, a description of the contractor's responsibilities, a planting schedule and installation specifications, initial maintenance, and a warranty period and expectations of plant survival. Table H.4 presents some typical issues for planting specifications.

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Table H.4 Planting Specification Issues for Bioretention Areas	
Specification Element	**Elements**
Sequence of Construction	Describe site preparation activities, soil amendments, etc.; address erosion and sediment control procedures; specify step-by-step procedure for plant installation through site clean-up.
Contractor's Responsibilities	Specify the contractors responsibilities, such as watering, care of plant material during transport, timeliness of installation, repairs due to vandalism, etc.
Planting Schedule and Specifications	Specify the materials to be installed, the type of materials (e.g., B&B, bare root, containerized); time of year of installations, sequence of installation of types of plants; fertilization, stabilization seeding, if required; watering and general care.
Maintenance	Specify inspection periods; mulching frequency (annual mulching is most common); removal and replacement of dead and diseased vegetation; treatment of diseased trees; watering schedule after initial installation (once per day for 14 days is common); repair and replacement of staking and wires.
Warranty	Specify the warranty period, the required survival rate, and expected condition of plant species at the end of the warranty period.

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)						
Plant Name	**Zone**	**Form**	**Available**	**Inundation Tolerance**	**Wildlife Value**	**Notes**
Trees and Shrubs						
American Elm *(Ulmus americana)*	4,5,6	Dec. Tree	yes	Irregular-seasonal saturation	High. Food (seeds,browsing), cover, nesting for birds & mammals	Susceptible to diesease (short-lived). Sun to full shade, tolerates drought and wind/ice damage.
Arrowwood Viburnium *(Viburrium dentatum)*	3,4	Dec. Shrub	yes	yes	High. Songbirds and mammals	Grows best in sun to partial shade
Bald Cypress *(Taxodium distichum)*	3,4	Dec. Tree	yes	yes	Little food value, but good perching site for waterfowl	Forested Coastal Plain. North of normal range. Tolerates drought.
Bayberry *(Myrica pensylvanica)*	4,5,6	Dec. Shrub	yes	yes	High. Nesting, food, cover. Berries last into winter	Coastal Plain only. Roots fix N_2 Tolerates slightly acidic soils.
Black Ash *(Fraxinus nigra)*	3,4,5	Dec. Tree	yes	Irregular-seasonal saturation	High. Food (seeds, sap), cover, nesting for birds & mammals. Fruit persists in winter	Rapid growth. Requires full sun. Susceptible to wind/ice damage & disease. Tolerates drought and infrequent flooding by salt water.
Black Cherry *(Prunus serotina)*	5,6	Dec. Tree	yes	no	High. Food	Moist soils or wet bottomland areas
Blackgum or Sourgum *(Nyssa sylvatica)*	4,5,6	Dec. Tree	yes	yes	High. Songbirds, egrets, herons, raccoons, owls	Can be difficult to transplant. Prefers sun to partial shade
Black Willow *(Salix nigra)*	3,4,5	Dec. Tree	yes	yes	High. Browsing and cavity nesters.	Rapid growth, stabilizes stream-banks. Full sun
Buttonbush *(Cepahlanthus occidentalis)*	2,3,4,5	Dec. Shrub	yes	yes	High. Ducks and shorebirds. Seeds, nectar and nesting.	Full sun to partial shade. Will grow in dry areas.
Common Spice Bush *(Lindera benzoin)*	3,4,5	Dec. Shrub	yes	yes	Very high. Songbirds	Shade and rich soils. Tolerates acidic soils. Good understory species

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Eastern Cottonwood *(Populus deltoides)*	4,5	Dec. Tree	yes	yes	Moderate. Cover, food.	Shallow rooted, subject to windthrow. Invasive roots. Rapid growth.
Eastern Hemlock *(Tsuga canadensis)*	5,6	Conif Tree	yes	yes	Moderate. Mostly cover and some food	Tolerates all sun/shade conditions. Tolerates acidic soil.
Eastern Red Cedar *(Juniperus virginiana)*	4,5,6	Conif Tree	yes	no	High. Fruit for birds. Some cover.	Full sun to partial shade. Common in wetlands, shrub bogs and edge of stream
Elderberry *(Sambucus canadensis)*	3,4,5,6	Dec. Shrub	yes	yes	Extremely high. Food and cover, birds and mammals.	Full sun to partial shade.
Green Ash, Red Ash *(Fraxinus pennsylvania)*	4,5	Dec. Tree	yes	yes	Moderate. Songbirds.	Rapid growing streambank stabilizer. Full sun to partial shade.
Hackenberry *(Celtis occidentalis)*	5,6	Dec. Tree	yes	some	High. Food and cover	Full sun to partial shade.
Larch, Tamarack *(Larix latricina)*	3,4	Conif Tree	no	yes	Low. Nest tree and seeds.	Rapid initial growth. Full sun, acidic boggy soil.
Pin Oak *(Quercus palustris)*	3,4,5,6	Dec. Tree	yes	yes	High. Tolerates acidic soil	Gypsy moth target. Prefers well drained, sandy soils.
Red Choke Berry *(Pyrus arbutifolia)*	3,4,5	Dec. Shrub	no	yes	Moderate. Songbirds.	Bank stabilizer. Partial sun.
Red Maple *(Acer rubrum)*	3,4,5,6	Dec. Tree	yes	yes	High seeds and browse. Tolerates acidic soil.	Rapid growth.
River Birch *(Betula nigra)*	3,4,5	Dec. Tree	yes	yes	Low. Good for cavity nesters.	Bank erosion control. Full sun.
Shadowbush, Serviceberry *(Amelanchier*	4,5,6	Dec. Shrub	yes	yes	High. Nesting, cover, food. Birds and	Prefers partial shade. Common in forested

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
canadensis)					mammals.	wetlands and upland woods.
Silky Dogwood *(Cornus amomium)*	3,4,5	Dec. Shrub	yes	yes	High. Songbirds, mammals.	Shade and drought tolerant. Good bank stabilizer.
Slippery Elm *(Ulnus rubra)*	3,4,5	Dec. Tree	rare	yes	High. Food (seeds, buds) for birds & mammals (browse). Nesting	Rapid growth, no salinity tolerance. Tolerant to shade and drought.
Smooth Alder *(Alnus serrulata)*	3,4,5	Dec. Tree	no	yes	High. Food, cover.	Rapid growth. Stabilizes streambanks.
Speckled Alder *(Alnus rugosa)*	3,4	Dec. Shrub	yes	yes	High. Cover, browse for deer, seeds for bird.	
Swamp White Oak *(Quercus bicolor)*	3,4,5	Dec. Tree	yes	yes	High. Mast	Full sun to partial shade. Good bottomland tree.
Swamp Rose *(Rosa Palustrus)*	3,4	Dec. Shrub		Irregular, seasonal, or regularly saturated	High. Food (hips) for birds including turkey, ruffed grouse and mammals. Fox cover.	Prefers full sun. Easy to establish. Low salt tolerance.
Sweetgum *(Liquidambar styraciflua)*	4,5,6	Dec. Tree	yes	yes	Moderate. Songbirds	Tolerates acid or clay soils. Sun to partial shade.
Sycamore *(Platanus occidentalis)*	4,5,6,	Dec. Tree	yes	yes	Low. Food, cavities for nesting.	Rapid growth. Common in floodplains and alluvial woodlands.
Tulip Tree *(Liriodendron tulipifera)*	5,6	Dec. Tree	yes	no	Moderate. Seeds and nest sites	Full sun to partial shade. Well drained soils. Rapid growth.
Tupelo *(Nyssa sylvatica vari biflora)*	3,4,5	Dec. Tree	yes	yes	High. Seeds and nest sites	Ornamental

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
White Ash *(Fraxinus americana)*	5,6	Dec. Tree	yes	no	High. Food	All sunlight conditions. Well drained soils.
Winterberry *(Ilex verticillata)*	3,4,5	Dec. Shrub	yes	yes	High. Cover and fruit for birds. Holds berries into winter.	Full sun to partial shade. Seasonally flooded areas.
Witch Hazel *(Hamamelis virginiana)*	4,5	Dec. Shrub	yes	no	Low. Food for squirrels, deer, and ruffed grouse.	Prefers shade. Ornamental.
Herbaceous Plants						
Arrow arum *(Peltandra virginica)*	2,3	Emergent	yes	up to 1 ft.	High. Berries are eaten by wood ducks.	Full sun to partial shade.
Arrowhead, Duck Potato *(Saggitaria latifolia)*	2,3	Emergent	yes	up to 1 ft.	Moderate. Tubers and seeds eaten by ducks.	Aggressive colonizer.
Big Bluestem (*Andropogon gerardi*)	4,5	Perimeter	yes	Irregular or seasonal inundation.	High. Seeds for songbirds. Food for deer	Requires full sun.
Birdfoot deervetch (*Lotus Corniculatus*)	4,5,6	Perimeter	yes	Infrequent inundation	High. Food for birds.	Full sun. Nitrogen fixer.
Blue Flag Iris *(Iris versicolor)*	2,3	Emergent	yes	Regular or permanently, up to ½ ft or saturated	Moderate. Food muskrat and wildfowl. Cover, marshbirds	Slow growth. Full sun to partial shade. Tolerates clay. Fresh to moderately brackish water.
Blue Joint (*Calamagrotis canadensis*)	2,3,4	Emergent	yes	Regular or permanent inundation up to 0.5 ft.	Moderate. Food for game birds and moose.	Tolerates partial shade
Broomsedge *(Andropogon virginicus)*	2,3	Perimeter	yes	up to 3 in.	High. Songbirds and browsers. Winter food and cover.	Tolerant of fluctuation water levels & partial shade.
Bushy Beardgrass *(Andropogon glomeratus)*	2,3	Emergent	yes	up to 1 ft.		Requires full sun.
Cardinal flower (*Lobelia cardinalis*)	4,5,6	Perimeter	yes	Some. Tolerates saturation up to 100% of season.	High. Nectar for hummingbird, oriole, butterflies.	Tolerates partial shade

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Cattail *(Typha sp.)*	2,3	Emergent	yes	up to 1 ft.	Low. Except as cover	Aggressive. May eliminate other species. Volunteer. High pollutant treatment
Coontail *(Ceratophyllum demersum)*	1	Submergent	no	yes	Low food value. Good habitat and shelter for fish and invertebrates.	Free floating SAV. Shade tolerant. Rapid growth.
Common Three-Square *(Scirpus pungens)*	2	Emergent	yes	up to 6 in.	High. Seeds, cover. Waterfowl and fish.	High metal removal.
Duckweed *(Lemma sp.)*	1,2	Submergent/ Emergent	yes	yes	High. Food for waterfowl and fish.	High metal removal.
Fowl mannagrass (*Glyceria striata*)	4,5	Perimeter	yes	Irregular or seasonal inundation	High. Food for waterfowl, muskrat, and deer.	Partial to full shade.
Hardstem Bulrush *(Scirpus acutus)*	2	Emergent	yes	up to 3 ft.	High. Cover, food (achenes, rhizomes) ducks, geese, muskrat, fish. Nesting for bluegill and bass.	Quick to establish, fresh to brackish. Good for sediment stabilization and erosion control.
Giant Burreed *(Sparganium eurycarpum)*	2,3	Emergent	rare	Regular to permanently inundated. up to 1 ft.	High. Food (seeds, plant) waterfowl, beaver & other mammals. Cover for marshbirds, waterfowl.	Rapid spreading . Tolerates partial sun. Good for shoreline stabilization.. Salinity <0.5 ppt
Lizard's Tail *(Saururus cernuus)*	2	Emergent	yes	up to 1 ft.	Low, except wood ducks.	Rapid growth. Shade tolerant
Long-leaved Pond Weed *(Potamogeton nodosus)*	1,2	Rooted submerged aquatic	yes	up to 1-6 ft. depending on turbidity	High. Food (seeds, roots) waterfowl, aquatic fur-bearers, deer, moose. Habitat for fish	Rapid spread. Salinity <0.5 ppt. Flowers float on surface, Aug.-Sept.

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Marsh Hibiscus *(Hibiscus moscheutos)*	2,3	Emergent	yes	up to 3 in.	Low. Nectar.	Full sun. Can tolerate periodic dryness.
Pickerelweed *(Pontederia cordata)*	2,3	Emergent	yes	up to 1 ft.	Moderate. Ducks. Nectar for butterflies.	Full sun to partial shade.
Pond Weed, Sago *(Potamogeton pectinatus*	1	Submergent	yes	yes	Extremely high. Waterfowl, marsh and shorebirds.	Removes heavy metals.
Redtop (*Agrostis alba*)	3,4,5	Perimeter	yes	Up to 25% of season	Moderate. Rabbits and some birds.	Quickly established but not highly competitive.
Rice Cutgrass *(Leersia oryzoides)*	2,3	Emergent	yes	up to 3 in.	High. Food and cover.	Full sun although tolerant of shade. Shoreline stabilization.
Sedges *(Carex spp.)*	2,3	Emergent	yes	up to 3 in.	High waterfowl, songbirds.	Many wetland and upland species.
Tufted Hairgrass (*Deschampsia caespitosa*)	3,4,5	Perimeter	yes	Regular to irregular inundation.	High.	Full sun. May become invasive.
Soft-stem Bulrush *(Scirpus validus)*	2,3	Emergent	yes	up to 1 ft.	Moderate. Good cover and food.	Full sun. Aggressive colonizer. High pollutant removal.
Smartweed *(Polygonum spp.)*	2,3,4	Emergent	yes	up to 1 ft.	High. Waterfowl, songbirds. Seeds and cover.	Fast colonizer. Avoid weedy aliens such as *P. perfoliatum.*
Soft Rush *(Juncus effusus)*	2,3,4	Emergent	yes	up to 3 in.	Moderate.	Tolerates wet or dry conditions.
Spatterdock *(Nuphar luteum)*	2	Emergent	yes	up to 3 ft.	Moderate for food but high for cover.	Fast colonizer. Tolerant of fluctuating water levels.
Switchgrass *(Panicum virgatum)*	2,3,4,5,6	Perimeter	yes	up to 3 in.	High. Seeds, cover for waterfowl, songbirds.	Tolerates wet/dry conditions.

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Table H.5 Native Plant Guide for Stormwater Management Areas (NY)

Plant Name	Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Sweet Flag *(Acorus calamus)*	2,3	Herbaceous	yes	up to 3 in.	Low.	Tolerant of dry periods. Not a rapid colonizer. Tolerates acidic conditions.
Waterweed *(Elodea canadensis)*	1	Submergent	yes	yes	Low.	Good water oxygenator. High nutrient, copper, manganese and chromium removal.
Wild Celery *(Valisneria americana)*	1	Submergent	yes	yes	High. Food for waterfowl. Habitat for fish and invertebrates.	Tolerant of murkey water and high nutrient loads.
Wild Rice *(Zizania aquatica)*	2	Emergent	yes	up to 1 ft.	High. Food for birds.	Prefers full sun
Wool Grass *(Scirpus cyperinus)*	2,3	Emergent	yes	Irregularly to seasonally indundated	Moderate. Cover, Food.	Requires full sun. Can tolerate acidic soils, drought. Colonizes disturbed areas, moderate growth.

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Appendix I

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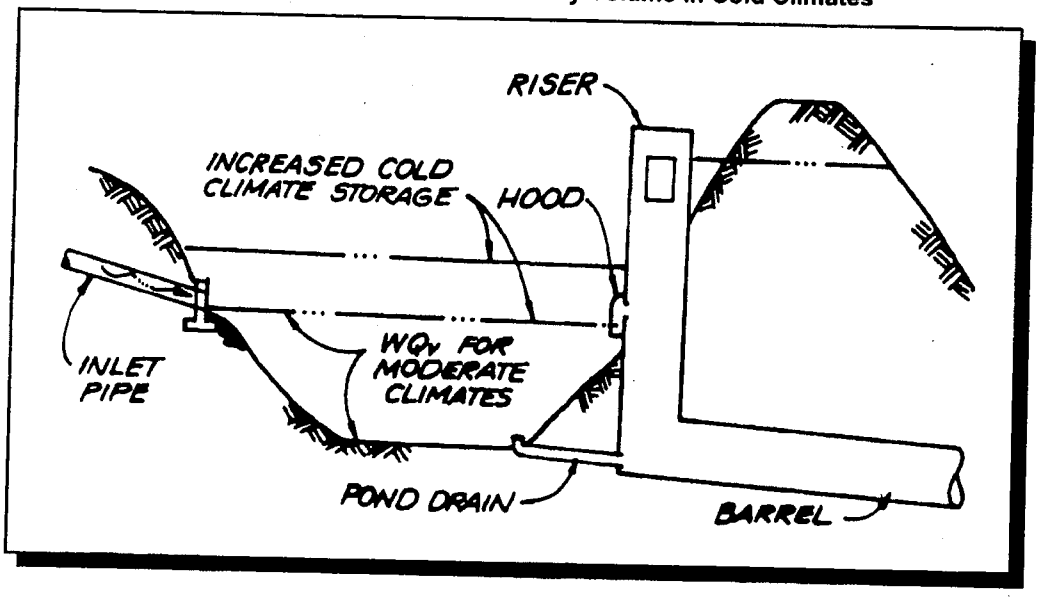
Traditional SMP sizing criteria are based on the hydrology and climatic conditions of moderate climates. These criteria are not always applicable to cold climate regions due to snowmelt, rain-on-snow and frozen soils. This chapter identifies methods to adjust both water quality (Section I.1) and water quantity (Section I.2) sizing criteria for cold climates.

I.1 Water Quality Sizing Criteria

The water quality volume is the portion of the SMP reserved to treat stormwater either through detention, filtration, infiltration or biological activity. Base criteria developed for SMP sizing nationwide are based on rainfall events in moderate climates (e.g., Schueler, 1992). Designers may wish to increase the water quality volume of SMPs to account for the unique conditions in colder climates, particularly when the spring snowfall represents a significant portion of the total rainfall. Spring snowmelt, rain-on-snow and rain-on-frozen ground may warrant higher treatment volumes. It is important to note that **the base criteria required by a region must always be met**, regardless of calculations made for cold climate conditions.

Figure I.1 Increased Water Quality Volume in Cold Climates



The goal of treating 90% of the annual pollutant load (Schueler, 1992), can be applied to snowmelt runoff and rain-on snow events. In the following conditions, cold climate sizing may be greater than base criteria sizing:

- Snowfall represents more than 10% of total annual precipitation. This value is chosen because, at least some portion of the spring snowmelt needs to be treated in order to treat 90% of annual runoff in these conditions. Using the rule of thumb that the moisture content of snowfall has about 10% moisture content, this rule can be simplified as:

  Oversize when average annual snowfall depth is greater than or equal to annual precipitation depth.

- The area is in a coastal or Great Lakes region with more than 3' of snow annually. In these regions, rain-on-snow events occur frequently enough to justify oversizing stormwater SMPs for water quality.

The following caveats apply to the sizing criteria presented in this section:

- These criteria are not appropriate for very deep snowpacks (i.e., greater than 4') because the volume to be treated would be infeasible, and often unnecessary.
- Sizing for snow storage areas is described in Appendix C.
- Snowmelt is a complicated process, with large annual variations. While the criteria presented here address the

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affects of snowmelt and rain-on-snow, several simplifying assumptions are made. Where local data or experience are available, more sophisticated methods should be substituted.

I.1.1 Water Quality Volume for Snowmelt

In order to treat 90% of annual runoff volume, sizing for snowmelt events needs to be completed in the context of the precipitation for the entire year. In relatively dry regions that receive much of their precipitation as snowfall, the sizing is heavily influenced by the snowmelt event. On the other hand, in regions with high annual rainfall, storm events are more likely to carry the majority of pollutants annually. The sizing criteria for this section are based on three assumptions: 1) SMPs should be sized to treat the spring snowmelt event 2)Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture 3) No more than five percent of the annual runoff volume should bypass treatment during the spring snowmelt event and 4) SMPs can treat a snowmelt volume greater than their size.

- *SMPs should be sized to treat the spring snowmelt runoff event*

  Snowmelt occurs throughout the winter in small, low-flow events. These events have high concentrations of soluble pollutants such as chlorides and metals, because of "preferential elution" from the snowpack (Jeffries, 1988). Although these events have significant pollutant loads, the flows are very low intensity, and generally will not affect SMP sizing decisions.

  The spring snowmelt, on the other hand, is higher in suspended solids and hydrophobic elements, such as hydrocarbons, which can remain in the snowpack until the last five to ten percent of water leaves the snowpack (Marsalek, 1991). In addition, a large volume of runoff occurs over a comparatively short period of time (i.e., approximately two weeks). Most SMPs rely on settling to treat pollutants, and the pollutants carried in the spring snowmelt are more easily treated by these mechanisms. In addition, the large flow volume during this event may be the critical water quality design event in many cold regions.

- *Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture*

  Because of small snowmelt events that occur throughout the winter, losses through sublimation, and management practices such as hauling snow to other locations, the snowpack only contains a fraction of the moisture from the winter snowfall. Thus, the remaining moisture in the snowpack can be estimated by:

  $$M=0.1 \cdot S-L_1-L_2-L_3 \qquad \text{Equation I.1}$$

  Where:

  M=Moisture in the Spring Snowpack (inches)
  S=Annual Snowfall (inches)
  L_1, L_2 and L_3 = Losses to Hauling, Sublimation and Winter Melt, respectively.

  The volume of snow hauled off site can be determined based on available information on current plowing practices. In New York, sublimation to the atmosphere is not very important

  The design examples in this section use a simple "rule of thumb" approach, to estimate winter snowmelt for simplicity (Table I.1). The method assumes that winter snowmelt is influenced primarily by temperature, as represented by the average daily temperature for January. One half of the snow (adjusted for plowing and sublimation) is assumed to melt during the winter in very cold regions (Average T_{max} <25°F) and two thirds is assumed to melt during the winter in moderately cold regions (Average T_{max} <35°F). Winter snowmelt can be estimated using several methods, such as the simple degree-day method, or through more complex continuous modeling efforts.

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Table I.1 Winter Snowmelt*

Adjusted Snowfall Moisture Equivalent	Winter Snowmelt (January T_{max}<25°F)	Winter Snowmelt (January T_{max}<35°F)
2"	1.0"	1.3"
4"	2.0"	2.7"
6"	3.0"	4.0"
8"	4.0"	5.3"
10"	5.0"	6.7"
12"	6.0"	8.0"

* Snowmelt occuring before the spring snowmelt event, based on the moisture content in the annual snowfall. The value in the first column is adjusted for losses due to sublimation and plowing off site.

Snowmelt is converted to runoff when the snowmelt rate exceeds the infiltration capacity of the soil. Although the rate of snowmelt is slow compared with rainfall events, snowmelt can cause significant runoff because of frozen soil conditions. The most important factors governing the volume of snowmelt runoff are the water content of the snowpack and the soil moisture content at the time the soil freezes (Granger et al., 1984). If the soil is relatively dry when it freezes, its permeability is retained. If, on the other hand, the soil is moist or saturated, the ice formed within the soil matrix acts as an impermeable layer, reducing infiltration. Section I.1.3 outlines a methodology for computing snowmelt runoff based on this principle.

- *No more than 5% of the **annual runoff volume** should bypass treatment during spring snowmelt* In order to treat 90% of the annual runoff volume, at least some of the spring snowmelt, on average, will go un-treated. In addition, large storm events will bypass treatment during warmer months. Limiting the volume that bypasses treatment during the spring snowmelt to 5% of the annual runoff volume allows for these large storm events to pass through the facility untreated, while retaining the 90% treatment goal.

The resulting equation is:

$T=(R_s-0.05R)A/12$ (Equation I.2)

Where:

T = Volume Treated (acre-feet)

R_s = Snowmelt Runoff [See Section I.1.3]

R = Annual Runoff Volume (inches) [See Section I.1.2]

A = Area (acres)

- *SMPs can treat a volume greater than their normal size.*

Snowmelt occurs over a long period of time, compared to storm events. Thus, the SMP does not have to treat the entire water quality treatment volume computed over twenty four hours, but over a week or more. As a result, the necessary water quality volume in the structure will be lower than the treatment volume. For this manual, we have assumed a volume of ½ of the value of the computed treatment volume (T) calculated in equation I.2.

Thus,

$WQ_s = ½ T$ (Equation I.3)

I.1.2 Base Criteria/ Annual Runoff

The base criterion is the widely-used, traditional water quality sizing rule. This criterion, originally developed for moderate climates, represents the minimum recommended water quality treatment volume. In this manual, the runoff from a one inch rainfall event is used as the base criteria. The basis behind this sizing criteria is that approximately 90% of the storms are treated using this event. This value may vary nationwide, depending on local historical rainfall frequency distribution data. However, the one inch storm is used as a simplifying assumption. The base criteria included in this manual is chosen because it incorporates impervious area in the sizing of urban SMPs, and modifications are used nationwide. The cold climate sizing modifications used in this manual may be applied to any

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base criteria, however.

Runoff for rain events can be determined based on the Simple Method (Schueler, 1987).

$r = p(.05+.9I)$ (Equation I.4)

Where: r = Event Rainfall Runoff (inches)
p = Event Precipitation (inches)
I = Impervious Area Fraction

Thus, the water quality volume for the base criteria can be determined by:

$WQ_v = (0.05+.9I)\ A/12$ (Equation I.5)

Where: WQ_v =Water Quality Volume (acre-feet)
I= Impervious Fraction
A=Area (acres)

The Simple Method can also be used to determine the annual runoff volume. An additional factor, P_j, is added because some storms do not cause runoff. Assume $P_j = 0.9$ (Schueler, 1987). Therefore, annual runoff volume from rain can be determined by:

$R = 0.9\ P\ (0.05+.9I)$ (Equation I.6)

Where: R = Annual Runoff (inches)
P = Annual Rainfall (inches)

I.1.3 Calculating the Snowmelt Runoff

To complete water quality sizing, it is necessary to calculate the snowmelt runoff. Several methods are available, including complex modeling measures. For the water quality volume, however, simpler sizing methods can be used since the total water quality volume, not peak flow, is critical. One method, modified from Granger et al. (1984) is proposed here. Other methods can be used, particularly those adjusted to local conditions.

According to Granger et al. (1984) the infiltration into pervious soils is primarily based on the saturation of the soils prior to freezing. While saturated soils allow relatively little snowmelt to infiltrate, dry soils have a high capacity for infiltration. Thus, infiltration volumes vary between wet, moderate and dry soil conditions (Figure I.2).

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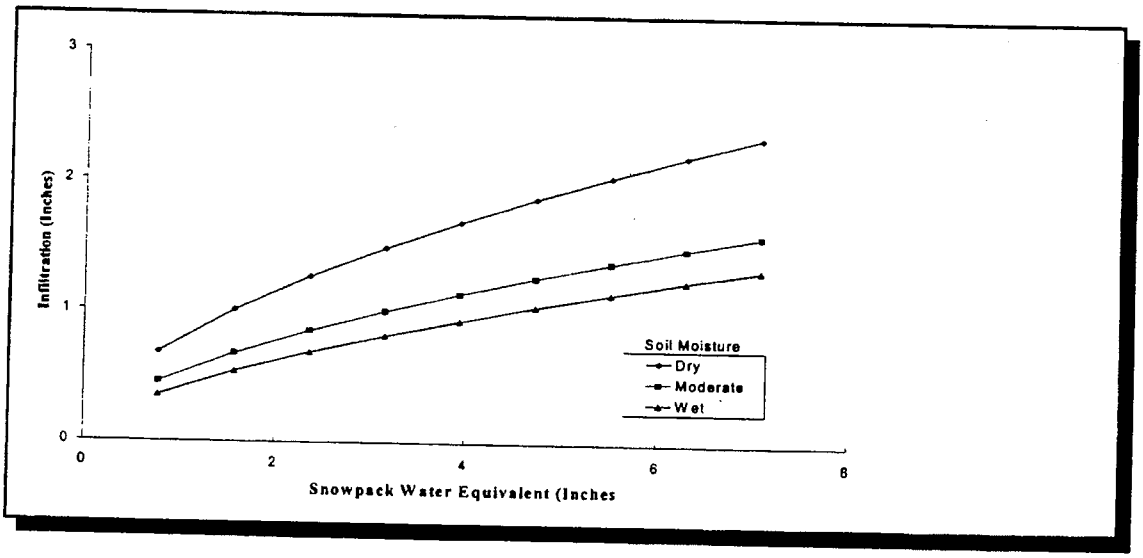
Figure I.2 Snowmelt Infiltration Based on Soil Moisture



Assume also that impervious area produces 100% runoff. The actual percent of snowmelt converted to runoff from impervious areas such as roads and sidewalks may be less than 100% due to snow removal, deposition storage and sublimation. However, stockpiled areas adjacent to paved surfaces often exhibit increased runoff rates because of the high moisture content in the stockpiled snow (Buttle and Xu, 1988). This increased contribution from pervious areas off-sets the reduced runoff rates from cleared roads and sidewalks.

The resulting equation to calculate snowmelt runoff volume based on these assumptions is:

R_S = [runoff generated from the pervious areas] + [runoff from the impervious areas]

R_s = [(1 - I)(M-Inf)] + [(I)(1)(M)] (Equation I.7)

where:

R_S = Snowmelt Runoff
I = Impervious Fraction
M = Snowmelt (inches)
Inf = Infiltration (inches)

Sizing Example 1: Snowpack Treatment

Scenario:
50 Acre Watershed
40% Impervious Area
Average Annual Snowfall= 5'=60"
Average Daily Maximum January Temperature= 20°
Average Annual Precipitation = 30"
20% of snowfall is hauled off site
Sublimation is not significant
Prewinter soil conditions: moderate moisture.

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Sizing Example 1: Snowpack Treatment

Step 1: Determine if oversizing is necessary
Since the average annual precipitaiton is only ½ of average annual snowfall depth, oversizing is needed.

Step 2: Determine the annual losses from sublimation and snow plowing.
Since snow hauled off site is about 20% of annual snowfall, the loss from snow hauling, L_1, can be estimated by:

$L_1 = (0.2)(0.1)S$

Where: L_1 = Water equivalent lost to hauling snow off site (inches)
S = Annual snowfall (inches)
0.1 = Factor to convert snowfall to water equivalent

Therefore, the loss to snow hauling is equal to:
$L_1 = (0.2)(0.1)(60")$
$L_1 = 1.2"$

Since sublimation is negligible, $L_2 = 0$

Step 3: Determine the annual water equivalent loss from winter snowmelt events
Using the information in Step 2, the moisture equivalent in the snowpack remaining after hauling is equal to:

$60" \cdot 0.1 - 1.2" = 4.8"$

Substituting this value into Table I.1, and interpolating, find the volume lost to winter melt, L_3.

$L_3 = 2.4"$

Step 4: Calculate the final snowpack water equivalent, M
$M = 0.1 \cdot S - L_1 - L_2 - L_3$ (Equation I.1)
$S = 60"$
$L_1 = 1.2"$
$L_1 = 0"$
$L_3 = 2.4"$

Therefore, $M = 2.4"$

Step 5: Calculate the snowmelt runoff volume, R_s
$R_s = (1-I)(M-Inf) + I \cdot M$ Equation I.7
$M = 2.4"$
$I = 0.4$
$Inf = 0.8"$ (From figure I.2; assume average moisture)
Therefore, $R_S = 1.9"$

Step 6: Determine the annual runoff volume, R
Use the Simple Method to calculate rainfall runoff:
$R = 0.9(0.05 + 0.9*I)P$ (Equation I.6)
$I = 0.4$
$P = 30"$
Therefore, $R = 11"$

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Sizing Example 1: Snowpack Treatment

Step 7: Determine the runoff to be treated
Treatment, T should equal:
$T = (R_s - 0.05*R)\ A/12$ (Equation I.2)
$R_s = 1.9"$
$R = 11"$
A = 50 Acres
Therefore, T=5.6 acre-feet

Step 8: Size the SMP
The volume treated by the base criteria would be:
$WQ_v = (.05+.9*.4)(1'/12")(50\ acres) = 1.7$ acre-feet (Equation I.5)

For cold climates:
$WQ_v = 1/2(T) = 2.8$ acre-feet (Equation I.3)
The cold climate sizing criteria is larger, and should be used to size the SMP.

I.1.4 Rain-on-Snow Events

For water quality volume, an analysis of rain-on-snow events is important in coastal regions. In non-coastal regions, rain-on-snow events may occur annually but are not statistically of sufficient volume to affect water quality sizing, especially after snowpack size is considered. In coastal regions, on the other hand, flooding and annual snowmelt are often driven by rain-on-snow events (Zuzel et al., 1983). Nearly 100% of the rain from rain-on-snow events and rain immediately following the spring melt is converted to runoff (Bengtsson, 1990). Although the small rainfall events typically used for SMP water quality do not produce a significant amount of snowmelt (ACOE, 1956), runoff produced by these events is high because of frozen and saturated ground under snow cover.

Many water quality volume sizing rules are based on treating a certain frequency rainfall event, such as treating the 1-year, 24-hour rainfall event. The rationale for treating 90% of the pollutant load (Schueler, 1992) can also be applied to rain-on-snow events, as shown in the following example.

Sizing Example 2: Rain-on-Snow

Step 1: Develop a rain-on-snow data set.
Find all the rainfall events that occur during snowy months. Rainfall from December through April were included. Please note that precipitation data includes both rainfall and snowfall, and only data from days without snowfall should be included. Exclude non-runoff-producing events (less than 0.1"). Some of these events may not actually occur while snow is on the ground, but they represent a fairly accurate estimate of these events.

Step 2: Calculate a runoff distribution for rain-on-snow events
Since rain-on-snow events contribute directly to runoff, the runoff distribution is the same as the precipitation distribution in Figure I.3.

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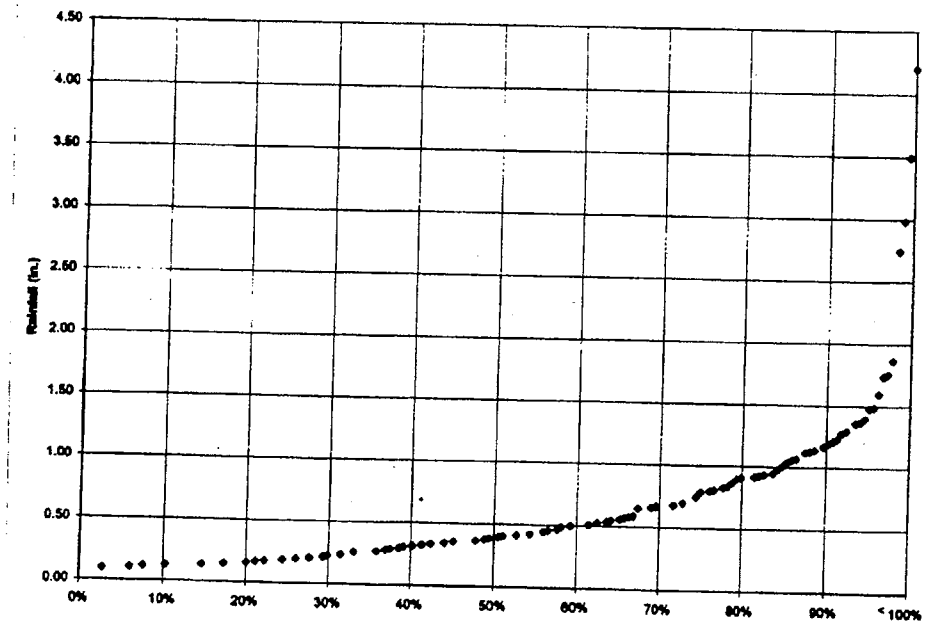
Sizing Example 2: Rain-on-Snow

Figure I.3 Rainfall Distribution for Snowy Months



Step 3: Calculate a rainfall distribution for non-snow months.
Develop a distribution of rainfall for months where snow is not normally on the ground. The rainfall distribution for May through November is included in Figure I.4.

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Sizing Example 2: Rain-on-Snow

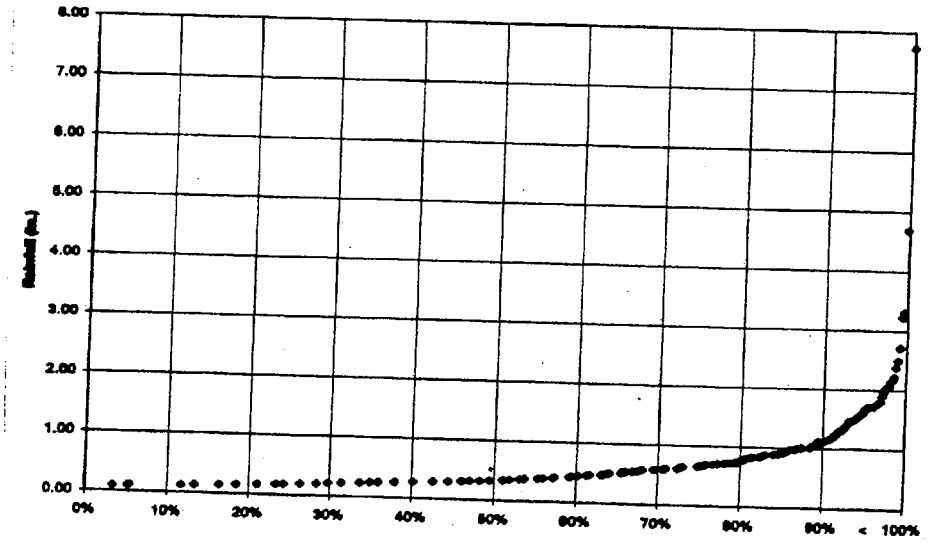

Figure I.4

Rainfall Distribution for Non-Snowy Months

Step 4: Calculate the runoff distribution for non-snow months.
Use a standard method to convert rainfall to runoff, particularly methods that are calibrated to local conditions. For this example, use the Simple Method. Runoff is calculated as:

$$r=(0.05+0.9\ I)p \quad \text{(Equation I.4)}$$

For this example, I=0.3 (30% impervious area), so:

$$r=0.32\ p$$

The runoff distribution for non-snow months is calculated by multiplying the rainfall in Figure I.4 by 0.32.

Step 5: Combine the runoff distributions calculated in Steps 2 and 4 to produce an annual runoff distribution. The resulting runoff distribution (Figure I.5) will be used to calculate the water quality volume.

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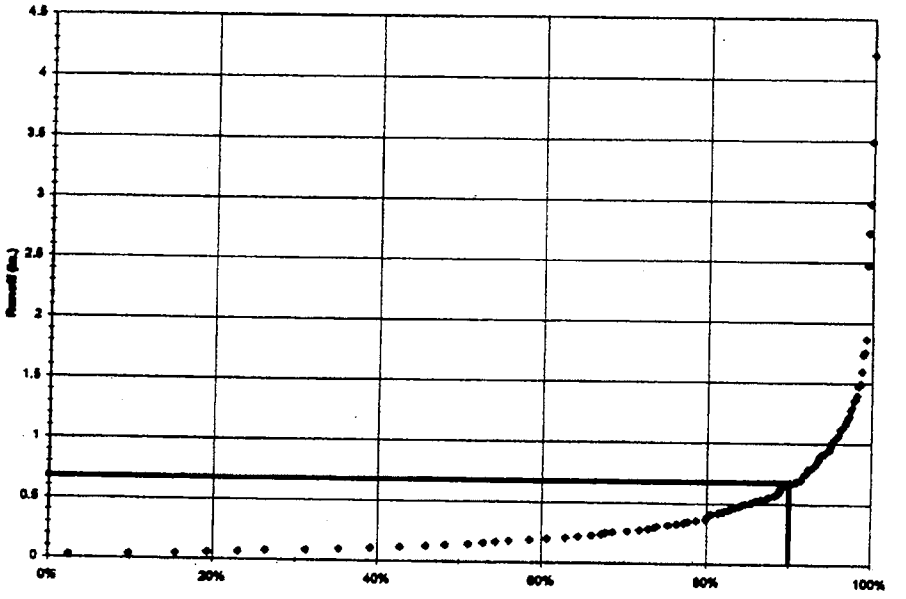
Sizing Example 2; Rain-on-Snow

Figure I.5 Annual Runoff Distribution



Step 6: Size the SMP.

In this case, use the 90% frequency runoff event (Figure I.4), or 0.65 watershed inches. This value is greater than the base criteria of 0.32 watershed inches (1" storm runoff). Therefore, the greater value is used.

WQ_v=(0.65 inches) (1 foot/12 inches) (50 acres) = 2.7 acre-feet

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Appendix J

New York State Stormwater Management Design Manual

Appendix J: Geomorphic Assessment

Distributed Runoff Control Methodology
Pond Outlet Structure Design Example

The following design example illustrates a step-by-step methodology for the design of a weir for the control of instream erosion potential using a Stormwater Management (SWM) wet pond design based on the Distributed Runoff Control (DRC) approach. The DRC approach incorporates boundary material composition and its sensitivity to erosion (entrainment and transport) into the design protocol. The boundary materials are characterized at the point of maximum boundary shear stress on the bed and the point of secondary maximum boundary shear stress on the bank. By examining the channel at selected sites downstream of the SWM facility the DRC protocol provides a pseudo 3-dimensional assessment of the impact of development and the SWM facility on the receiving channel.

This design example involves 5 Steps as listed in Table J.1.

Table J.1 Overview of Key Steps in the DRC Design Approach

1) Determine the "stability" and "mode-of-adjustment" of the receiving channel
2) Complete a Diagnostic Geomorphic Survey of the receiving channel
3) Determine channel sensitivity to an alteration in the sediment-flow regime
4) Approximate the elevation-discharge curve for the pond.
5) Size the DRC weir

Step 1. Determine Channel "Stability" and "Mode-of-Adjustment"

Channel stability is determined using a Rapid Geomorphic Assessment (RGA) of the channel downstream of the outlet of the proposed Stormwater Management (SWM) pond. The RGA protocol involves the identification of the presence of in-stream features resulting from a variety of geomorphic processes to provide a semi-quantitative assessment of a stream's stability and mode-of-adjustment. The processes are represented by four Factors: aggradation (AF), widening (WF), downcutting (DF), and planimetric form adjustment (PF)). Each Factor is composed of 7 to 10 indices for which a "present" or "absent" response is required. The total number of "present" or "yes" responses is summed and divided by the total number of responses (both "yes" and "no") to derive a value for each Factor. An index that is not relevant is not assigned a response. An example of an RGA Form is provided in Table J.2.

A Stability Index (SI) value is determined from the Factor values using the following equation:

$$SI = \frac{\{AF + DF + WF + PF\}}{m} \quad \text{.....[J.1]}$$

where 'm' is the number of Factors (typically 4 for alluvial streams).

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Table J.2 Rapid Geomorphic Assessment Form					
FORM/ PROCESS	GEOMORPHIC INDICATOR		PRESENT		FACTOR VALUE
	No.	Description	No	Yes	
Evidence of Aggradation (AI)	1	Lobate bar	1		1/7=0.143
	2	Coarse material in riffles embedded		1	
	3	Siltation in pools	1		
	4	Medial bars	1		
	5	Accretion on point bars	1		
	6	Poor longitudinal sorting of bed materials	1		
	7	Deposition in the overbank zone	1		
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	-	-	2/6=0.333
	2	Exposed sanitary/storm sewer/pipeline/etc.	-	-	
	3	Elevated stormsewer outfall(s)	-	-	
	4	Undermined gabion baskets/concrete aprons/etc.	-	-	
	5	Scour pools d/s of culverts/stormsewer outlets	1		
	6	Cut face on bar forms	1		
	7	Head cutting due to knick point migration	1		
	8	Terrace cut through older bar material		1	
	9	Suspended armor layer visible in bank		1	
	10	Channel worn into undisturbed overburden/bedrock	1		
Evidence of Widening (WI)	1	Fallen/leaning trees/fence posts/etc.		1	3/10=0.30
	2	Occurrence of Large Organic Debris		1	
	3	Exposed tree roots		1	
	4	Basal scour on inside meander bends	1		
	5	Basal scour on both sides of channel through riffle	1		
	6	Gabion baskets/concrete walls/armor stone/etc. out flanked	1		
	7	Length of basal scour >50% through subject reach	1		
	8	Exposed length of previously buried pipe/cable/etc.	1		
	9	Fracture lines along top of bank	1		
	10	Exposed building foundation	1		
Evidence of Planimetric Form Adjustment (PI)	1	Formation of cute(s)	1		0/7=0
	2	Evolution of single thread channel to multiple channel	1		
	3	Evolution of pool-riffle form to low bed relief form	1		
	4	Cutoff channel(s)	1		
	5	Formation of island(s)	1		
	6	Thalweg alignment out of phase with meander geometry	1		
	7	Bar forms poorly formed/reworked/removed	1		
STABILITY INDEX (SI) = (AI+DI+WI+PI)/m				SI= 0.19	

The Stability Index (SI) provides an indication of the stability of the creek channel at a given time based on the guidelines provided in Table J.3. The SI Value, however, does not differentiate between current and past disturbances.

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Table J.3 Interpretation of the RGA Stability Index Value		
Stability Index Value	**Stability Class**	**Description**
0.0<SI<0.25	Stable	Metrics describing channel form are within the expected range of variance (typically accepted as one standard deviation from the mean) for stable channels of similar type
0.25<SI<0.4	Transitional	Metrics are within the expected range of variance as defined above but with evidence of stress
0.4<SI<1.0	In Adjustment	Metrics are outside of the expected range of variance for channels of similar type.

The guidelines presented in Table J.3 for the interpretation of the SI Value will vary with the field experience and the bias of the observer. The SI Values however, have been shown to be consistent between observers indicating that the protocol, once calibrated to the observer provides a reliable means of screening the channel for stability and mode-of-adjustment.

The RGA protocol is applied to channel segments of two meanders in length or the equivalent of 20 bankfull channel widths (the width of the channel at the geomorphically dominant discharge, recurrence interval of between 1 and 2 years or 1.5 years on average).

The segment chosen for application of the RGA assessment is selected to be representative of the morphology of the channel for some distance up and downstream of the surveyed segment. That is, the parameters defining channel cross-section and plan form (e.g. width, depth, meander wavelength, etc.) are within a consensual level of variance for this reach of channel. An acceptable level of variance is typically defined as within one standard deviation of the mean. These reaches are referred to as being of "like" morphology. Since the morphology of the channel will vary in the longitudinal direction with changes in flow, slope, physiography, etc., it will be necessary to re-apply the RGA protocol where the parameters characterizing the morphology of the channel have changed beyond the consensual level of variance from the previous survey reach. In this manner the channel is divided into a series of reaches of "like" morphology.

Having determined the length of the survey reach, the longitudinal profile can be plotted from topographic mapping as illustrated in Figure J.1 (Topo). Examination of Figure J.1 (topographic map data) suggests that the channel can be differentiated into three distinct reaches. In the first reach (length L=146 ft, the channel has an average slope of S=0.00385 ft/ft and a meander-pool-riffle morphology. In the middle reach (L≈356 ft; S≈0.0142 ft/ft) the channel has cascade morphology. The third reach (L≈258 ft; S≈0.00794 ft/ft) returns to the meander-pool-riffle form.

Land use through the study reach is homogeneous (forest) and there are no other features (e.g. bridges, dams, weirs, instream works, etc.) that would affect the hydraulic characteristics of the active channel. Consequently, a preliminary definition of "like" reaches includes the three morphologies described above.

A synoptic geomorphic survey was conducted through the subject reach with an RGA assessment completed for each of the three reaches of "like" morphology. The results of the RGA assessment for the first reach (Reach 1) are reported in Tables J.2 and J.4. Referring to Table J.2, the Stability Index (SI) value was found to be SI=0.19, which is less than 0.25, therefore the channel is considered to be "stable" (Table J.3).

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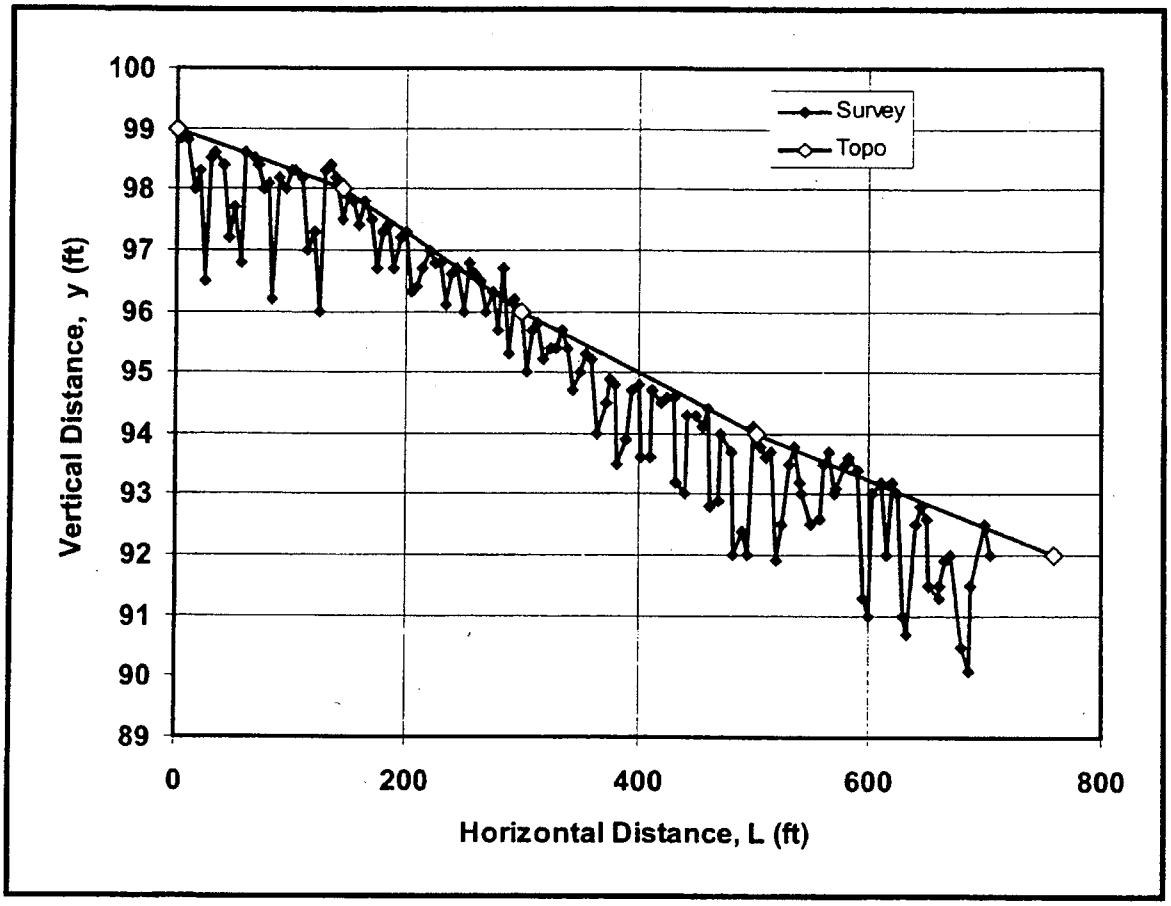

Figure J.1 Longitudinal Profile from Topographic Mapping and Field Survey of Channel Thalweg

Table J.4 Summary of Average Longitudinal Slope and Pool-Riffle Dimensions			
Parameter	**Reach 1**	**Reach 2**	**Reach 3**
Longitudinal Gradient, S (ft/ft)	0.00385	0.0142	0.00794
Riffle Length, LRIF (ft)	16	34	27
Pool Length, LPOL (ft)	37	10	18
Total Pool-Riffle Length, LTOT (ft)	53	44	45

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Step 2. Diagnostic Geomorphic Survey

Following completion of the identification of reaches of "like" morphology and the synoptic survey to finalize the delineation of the "like" reaches, a diagnostic geomorphic survey is undertaken to characterize the morphological attributes of the channel. This information has two primary functions.

1. The optimization of the erosion control benefit of the pond; and,
2. The provision for establishing a baseline condition from which it is possible to assess the performance of the SWM measures.

A detailed diagnostic survey includes a collection of a comprehensive set of parameters to assess and evaluate stream geomorphic conditions. A complete survey is typically required when:

a) A post-construction monitoring program is mandated; and,
b) Data are required for the design and construction of instream works.

Only a partial diagnostic survey is needed where the above issues are not relevant to the project. The following lists those parameters required for the partial diagnostic survey:

1. In the absence of flow measurements, a field estimate of Manning's 'n' value is obtained for comparison with sediment computed estimates.
2. Detailed survey of the channel cross-section, including the floodplain, to determine hydraulic geometry metrics at a so called "Master cross-section" and the relative location of bank material strata.
3. The longitudinal profile of the bed along the channel thalweg and the water surface at the time of survey over a distance of one meander wavelength or 10 bankfull widths. These data are used to determine the longitudinal gradient of the channel from riffle crest to riffle crest and to determine the dimensions of the pool-riffle complex.
4. At least one estimate of bankfull depth (the depth of flow at the dominate discharge) at the Master cross-section and all ancillary cross-sections (3 alternative methods are described in this example for illustrative purposes).
5. Bed material characteristics based on pebble counts of the bed material at a riffle crossover. These data are collected to help assess roughness coefficients, bed material resistance, and provide an alternate method for the estimation of bankfull depth.
6. Soil pits in the banks to map bank stratigraphy and to determine bank material composition using soil consistency tests (stickiness, plasticity and firmness) or particle size analysis (percent silt clay) with Atterberg Limits (Plasticity Index) for each stratigraphic unit. These data are required to help assess historic degradation or aggradation patterns and determine bank material resistance.
7. Map riparian vegetation and root zone characteristics in the soil pits for assessment of the affect of root binding on bank material resistance.

The cross-section data and bank material characterization is completed at a Master cross-section within the representative segment of each "like" reach. The Master cross-section is typically located at a riffle crossover on a straight reach between meander bends. Ancillary cross-sections are located in the lower one third of the meander bends and riffle crossover points up and downstream of the Master cross-section. Data collected at the ancillary cross-sections includes a cross-section profile (typically 7 to 9 ordinates) and estimates of bankfull stage. The longitudinal profile is collected throughout the survey segment along with characterization of plan form geometry.

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Design Case: Diagnostic Geomorphic Survey

The longitudinal survey of the channel along the thalweg is presented in Figure J.1 ("Survey" data points). This profile more clearly demonstrates the differences between the three reaches as represented by slope and pool-riffle dimensions (Table J.4). Other parameter values derived from the geomorphic survey are summarized in Table J.5. These data are combined with the cross-section, soils and sediment data to generate values for key parameters as described in the following series of calculations.

The following calculations are required to determine the 3 different estimates of the dominant discharge.

Estimate of Geomorphic Referenced Dominant Discharge

1. The longitudinal data are plotted to generate estimates of the channel gradient in order of priority as follows:
   (1) Water surface profile based on estimates of bankfull stage from the Master and ancillary cross-sections.
   (2) Bed slope (riffle crest to riffle crest), and
   (3) Water surface profile (dry weather flow at the time of the survey).
2. The pebble count data (length, width and breadth) are transformed into an equivalent diameter and used to generate a mass curve wherein cumulative percent finer by mass is plotted as a function of particle diameter;
3. The D_{50} and D_{84} particle size values (the particle diameter below which 50 and 84% of the particles are finer by mass, respectively) are determined from the mass curve;
4. Manning's roughness coefficient is estimated at bankfull stage using:
   (1) Standard field guides, and
   (2) Empirical relations such as: the Strickler (1923) and Limerinos (1970) equations.
5. The cross-section ordinates collected at the Master cross-section are plotted to produce a cross-section profile and a stage-area curve;
6. The stage-area curve is combined with the longitudinal gradient (S) and the estimate of Manning's roughness coefficient (n) to generate the stage-discharge curve for the cross-section using Manning's equation,

$$Q = \frac{1.49}{n} A R^{(\frac{2}{3})} S^{\frac{1}{2}}, \quad \text{.....[J.2]}$$

in which Q represents the flow rate (cfs) at depth 'y' above the thalweg, 'A' is the cross-section area of the channel at depth 'y', 'R' represents the hydraulic radius at depth 'y' and 'S' is the longitudinal gradient of the channel (ft/ft). An example of a stage-discharge curve is provided in Figure J.2;

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Table J.5 Summary of Hydraulic and Sediment Parameters

Reach No.	Rosgen Stream Type	Parameter						
		2 Year Flow Q_{2YR} (cfs)	W/d Ratio	Width W_{BFL} (ft)	Depth d_{BFL} (ft)	Flow Q_{BFL} (cfs)	Base B (ft)	Wetted Perimeter P (ft)
1	C3	8.9	3.00	3.00	1.00	4.76	2.00	4.24
2	B3	9.54	3.23	2.75	0.85	5.10	1.90	3.80
3	C3	10.1	2.87	2.83	0.99	5.40	1.85	4.06

Reach No.	Parameter						
	Bed Material Mean Particle Size		Area	Hydraulic Radius	Slope	Velocity	Riparian Vegetation Type
	D_{50} (in)	D_{84} (in)	A_{BFL} (ft^2)	R (ft)	S (ft/ft)	v (fps)	
1	2.8	3.3	2.50	0.590	.00385	1.90	Woody
2	5.1	7.5	1.99	0.521	.0142	2.57	Woody
3	3.7	5.2	2.32	0.570	.00794	2.35	Woody

Reach No.	Parameter									
	Bank Material Composition						Critical Shear Stress		Depth of Stratigraphic Unit	Excess Boundary Shear Stress τ_{CRT} (lbs/ft^2)	
	Soil Class		Soil Consistence Test				Bank (*) τ_{CRT} (lbs/ft^2)	Bed τ_{CRT} (lbs/ft^2)	h (ft)	Bank	Bed
	Class	Unit No.	X1	X2	X3	SCORE					
1	SiLm	1	1	2	1	4		0.548	0.36<h≤1.00	0.057	-0.334
	SiSa	2	0	0	1	1	0.120		0.10<h≤0.36		
	CoGr	3	N/a	N/a	N/a	N/a			0.0<h≤0.10		
2	CoBo	1	N/a	N/a	N/a	N/a	0.573	1.206	0.39<h≤0.85	-0.016	-0.526
	GrCo	2	N/a	N/a	N/a	N/a			0.0<h≤0.39		
3	SiLm	1	2	1	3	6		0.878	0.32<h≤0.99	0.03	-0.446
	SiCl	2	2	2	2	6	0.329		0.12<h≤0.32		
	SiCl	3	2	3	2	7			0.0<h≤0.12		

(*) Least resistant lower bank stratigraphic unit corresponding to the zone of secondary maximum boundary shear stress.

7. The dominant discharge (Q_{GEO}) is determined from the stage-discharge curve and field estimate of bankfull stage (d_{BFL}). For Reach 1 in this example, d_{BFL}=1.0 ft, consequently Q_{GEO}=4.76 cfs (Figure J.2). This procedure is repeated for each cross-section within the reach and the flow rate most common to all cross-sections is adopted as the geomorphic referenced estimate of the dominant discharge. If a wide disparity exists between estimates of (Q_{GEO}) than the determination of slope, Manning's 'n' value and the geomorphic indicators of bankfull stage are revisited to determine if a miss-interpretation of the data or an error in calculations has occurred.

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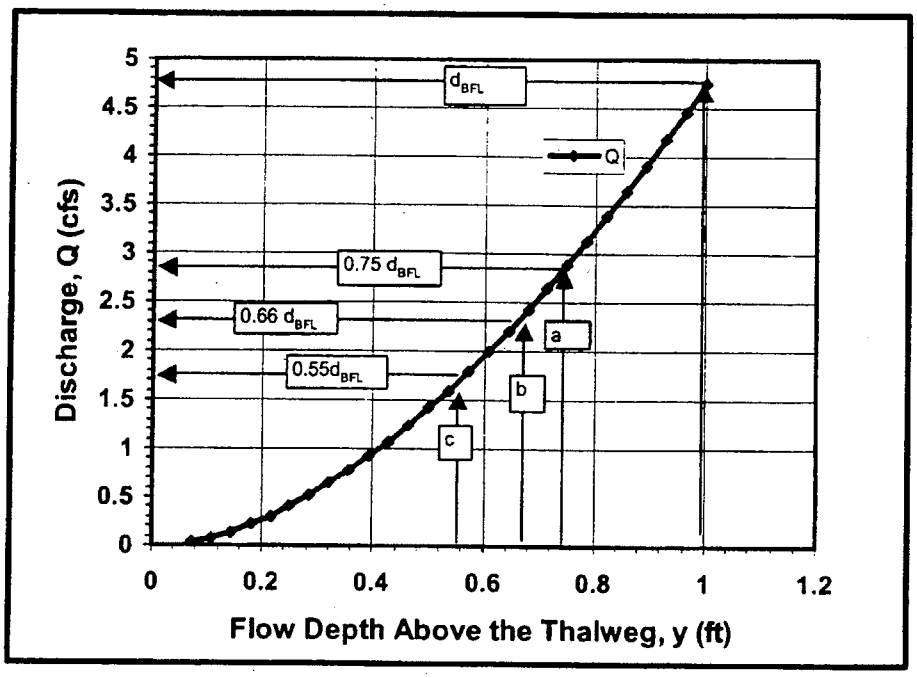

Figure J.2 Stage-Discharge Curve for Reach 1 Downstream of the Proposed Development

Estimate of Bed Material Critical Shear Stress

8. Critical shear stress is estimated for the ϕ_{84} particle size value of the bed material using procedures such as:
   (1) The modified Shield's equation (Vanoni, 1977), or
   (2) Various empirical relations (from the literature) that express critical shear stress as a function of particle size, one such is Eqn J.3 proposed by Lane (1955)

$$(\tau_{CRT})_{BED} = 0.164\phi_{84} \quad \text{.....[J.3]}$$

in which ϕ_{84} is the particle size for which 84% of the materials are finer (inches) and τ_{CRT} represents the critical shear stress (lbs/ft^2). Applying Eqn, [J.3] :

$(\tau_{CRT})_{BED} = 0.164\phi_{84} = 0.164\ (3.34\ \text{in}) = 0.548\ \text{lbs/ft}^2$

at the Master cross-section (Reach 1);

Estimate of Instantaneous Bed Shear Stress

9. A stage-shear stress curve is generated for the Master cross-section using DuBoy's relation for average shear stress and a channel shape adjustment factor proposed by Lane (1955) as follows:

$$\tau_0 = k_b \rho g (d - d_p) S \quad \text{.....[J.4]}$$

and,

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$$k_b = 0.000547\left(\frac{B}{d}\right)^3 - 0.0121\left(\frac{B}{d}\right)^2 + 0.092\left(\frac{B}{d}\right) + 0.75, \ldots\ldots\ldots\ldots\ldots\ldots [J.5]$$

in which τ_0 represents the instantaneous boundary shear stress at point 'P' on the bed (lbs/ft s^2), k_b is a channel shape adjustment factor (dimensionless; Fig. J.3), ρ is the density of the sediment-water mixture being conveyed by the channel (62.4 lbs/ft^3), 'g' is acceleration due to gravity (32.2 ft/s^2), 'd' is the depth of the flow above the thalweg (ft), d_P is the depth of flow above the thalweg at point 'P' (ft), 'S' represents the longitudinal gradient of the flow at depth 'd' and 'B' is the bottom width of the channel (assuming a trapezoidal configuration). In this design case, a mapping of the isovels through the Master cross-section indicates that the point of maximum boundary shear stress occurs at the thalweg. Since the thalweg is the deepest part of the channel, the term d_P=0 in Eqn. J.4. A stage-shear stress curve for Reach 1 is illustrated in Figure J.4. Note that the units for τ_0 are reported in lbs/ft^2 to be consistent with the estimate of critical shear stress reported in Task 8. To obtain units of lbs/ft^2 remove 'g' from Eqn. J.4.

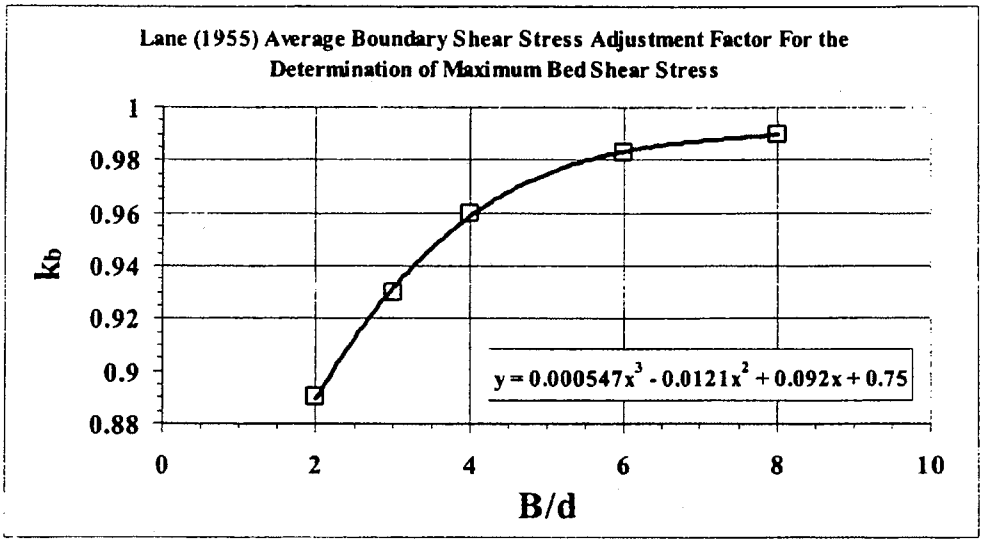

Figure J.3 Determination of k_B for the Adjustment of Average Boundary Shear Stress For Variations in Channel Shape Assuming A Trapezoidal Channel Cross-Section Configuration

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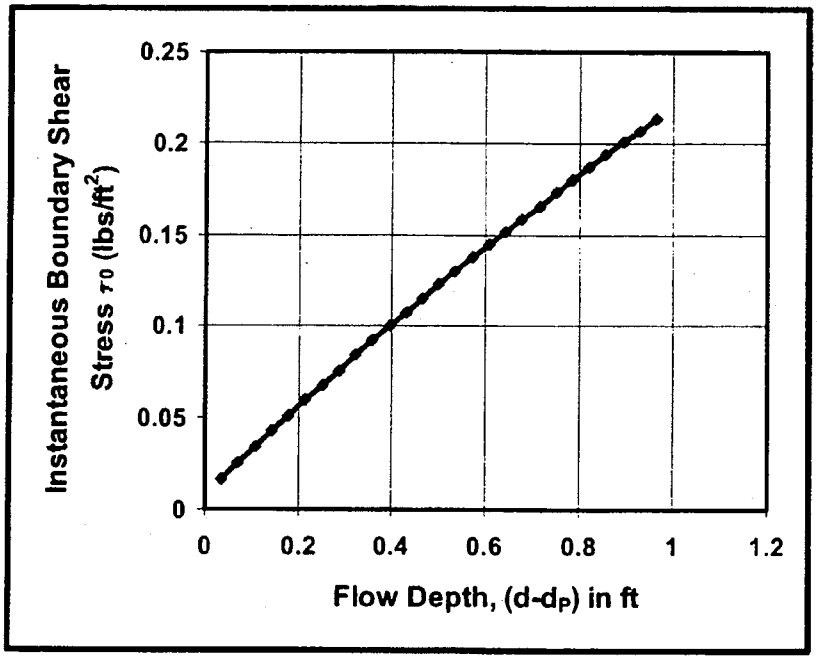

Figure J.4. Stage-Shear Stress Curve for Reach 1 (Master Cross-section): Bed Station.

Estimate the Sediment Referenced Dominant Discharge

10. The stage-shear stress curve is used to determine the depth of flow at which the boundary shear stress on the bed is equal to the critical shear stress of the ϕ_{R4} particle size fraction. This depth is transformed into an estimate of flow rate from the stage-discharge curve (Task 5 above), providing a second, independent estimate of the dominant discharge (Q_{SED}). This calculation also provides a basis for determination of the sensitivity of the bed material to an alteration in the sediment-flow regime. This assessment is described in Task 21 below;

Estimate The Flow Recurrence Interval of the Referenced Dominant Discharge

11. A flow time series is generated using:
    (1) Flow gauge data if available, or
    (2) A continuous hydrologic model to generate a synthetic flow time series of 6 to 13 years in length.
12. The flow time series is used to derive a flood frequency curve from which a third independent estimate of the dominant discharge (Q_{RI}) is determined as the flow having a recurrence interval between 1 and 2 years (average RI=1.5 years);

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Finalize the Estimate of Dominant Discharge

13. The three estimates of dominant discharge are compared for consistency. If consistent (e.g. the range is equal to or less than 20% of the mean), then the mean value of the dominant discharge can be accepted with a higher degree of confidence

Step 3. Determine the Sensitivity of the Boundary Materials

A) Sensitivity of the Bed Material

14. Using the stage-shear stress relationship developed in Task 9 and the estimate of flow depth (d_{BFL}, Task 10) from the dominant discharge (Task 13), determine the boundary shear stress $(\tau_0)_{BED}$ being applied to the bed at point 'P' at the dominant discharge. Point 'P' is located on the bed within the zone of maximum boundary shear stress. In this example the value of maximum instantaneous boundary shear stress at a depth of d_{BFL}= 1.0 ft was found to be $(\tau_0)_{BED}$ = 0.214 lbs/ft^2 at the Master cross-section in Reach 1 (Figure J.4). Similarly, for Reaches 2 and 3 the maximum value of instantaneous boundary shear stress was found to be $(\tau_0)_{BED}$ = 0.680 and 0.432 lbs/ft^2 respectively.
15. Compute the value of $(\tau_c)_{BED}$ for the Master cross-section knowing $(\tau_0)_{BED}$ and $(\tau_{CRT})_{BED}$ as,

$$(\tau_e)_{BED} = (\tau_0 - \tau_{CRT})_{BED} \quad \text{.....[J.6]}$$

in which $(\tau_c)_{BED}$ represents the effective boundary shears stress, τ_0 is the instantaneous boundary shear stress at the dominant discharge and τ_{CRT} is the critical shear stress of the bed material at point 'P'.

16. Repeat the bed shear stress analysis for all Master cross-sections in all reaches of "like" morphology.
17. Compare the value of $(\tau_c)_{BED}$ for all Master cross-sections through the study reach and select the Master cross-section for which the value of $(\tau_c)_{BED}$ is greatest. The reach represented by the Master cross-section having the highest value of $(\tau_c)_{BED}$ is referred to as the "Control Reach".

In this example, effective boundary shear stress on the bed was found to range from between -0.526 and -0.334 (Table J.5). The negative values infer that the channel bed is armored and the bed material is mobile under flood flow events in excess of the dominant discharge. However, of the three Master cross-sections the value of $(\tau_c)_{BED}$ was greatest for Reach 1, consequently, Reach 1 was identified as the "Control Reach".

B) Sensitivity of the Bank Material

18. The bank material for the "Control Reach" is classified according to soil type for each stratigraphic unit using:
    (1) Soil consistency tests; or
    (2) Particle size analysis and Atterberg Limits.

    In this example the bank materials were mapped and differentiated into stratigraphic units as summarized for the three reaches in Table J.5. The soil consistency test results determined using standard soil classification guidelines (as quantified by MacRae, 1991)), are summarized below and reported in Table J.5.
    - i) Assign a value for the stickiness of the material, e.g. not sticky, (X1=0) to extremely sticky (X1=4),
    - ii) Assign a value for the plasticity of the material, e.g. not plastic (X2=0) to extremely plastic (X2=4),
    - iii) Assign a value for the firmness of the material, e.g. loose, no structure (X3=0) to

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stiff (X4=4).

(3) Sum the consistency test values,

$$SCORE = \sum_{i=1}^{3} x_i \quad \text{.....[J.7]}$$

in which SCORE represents the sum of the values assigned for stickiness, plasticity and firmness.

19. Construct stage-shear stress curves for selected bank stations approximated by $0.25d_{BFL}$, $0.33d_{BFL}$, $0.4d_{BFL}$. More than one bank station may be required in a stratigraphic unit depending upon the thickness of the unit. The curves may be approximated as follows:

$$\tau_0 = k_S(\rho g(d - d_p)S) \quad \text{.....[J.8]}$$

in which k_S is a correction factor for points on the channel bank determined as a function of channel shape (see Eqn. J.9, Figure J.5), 'd' is the depth of flow (ft), ρ is the density of water (62.4 lbs/ft^3), 'g' is acceleration due to gravity (32.2 ft/s^2) and d_P is the depth of flow at the elevation of the boundary station (ft).

$$k_S = 0.7236\left(\frac{B}{d}\right)^{0.0241} \quad \text{.....[J.9]}$$

in which B is the channel bottom (ft) width and 'd' is the depth of flow (ft). Note, to obtain units of lbs/ft^2 remove the constant 'g' from Eqn. J.8.

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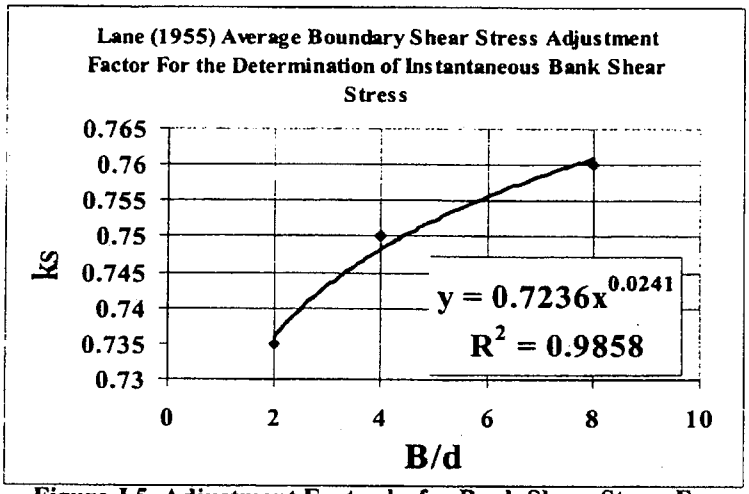

Figure J.5 Adjustment Factor k_S for Bank Shear Stress For Channels Approximating a Trapezoidal Shape

20. Estimate the critical shear stress (τ_{CRT}) within each stratigraphic unit using available empirical relationships. These relations are typically based on percent silt and clay content, degree of compaction, particle size (Vanoni, 1977) or the SCORE value (MacRae, 1991);

21. Compute the excess boundary shear stress for each bank station at a flow depth of between 0.6 and 0.75 feet by reading the boundary shear stress off the stage-shear stress curve for each boundary station and subtracting the critical shear stress as described in DuBoy's relation,

$$(\tau_e)_{BNK} = (\tau_0 - \tau_{CRT})_{BNK}, \quad \text{[J.10]}$$

in which $(\tau_c)_{BNK}$ represents the excess boundary shear stress (lbs/ft^2) at the selected boundary station (P), τ_0 is the instantaneous boundary shear stress (lbs/ft^2) at any specified depth of flow at point P and τ_{CRT} represent the critical shear stress (lbs/ft^2) of the boundary material at point P.

22. Compare the estimates of excess boundary shear stress $(\tau_c)_{BNK}$ at each bank station and select that station having the highest value of $(\tau_c)_{BNK}$ as the bank station controlling bank response (controlling stratigraphic unit) to a change in the flow regime. Using the guidelines presented in Table J.6 determine channel sensitivity to an alteration in the sediment-flow regime and the corresponding Over Control (OC) curve and Inflection Point

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Table J.6 General Guidelines for the Application of the DRC Approach Based on Bank Material Sensitivity Using SCORE Values							
BANK SENSITIVITY		**BED SENSITIVITY**				**DRC PARAMETERS**	
Excess Shear Stress $(\tau_c)_{BED}$	Sensitivity Class	Excess Shear Stress $(\tau_c)_{BNK}$	Bank Resistance		Sensitivity Class	Over Control Multiplier R_{OC}	Inflection Point
			Soil Class	SCORE			
<0	**L**	<0	Very Stiff	N/a	L	1.0 –0.9	a
		≈0	Stiff	10-12	ML	0.9 - 0.7	a
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	**N/a**			**0.5 - 0.2**	**c**
≈0	ML	<0	N/a			0.9 - 0.7	a
		≈0	Stiff	10-12	ML	0.9 - 0.7	a
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	N/a			0.5 - 0.2	c
	M	<0	N/a			0.7 - 0.5	b
		≈0	Stiff	N/a		0.7 - 0.5	b
			Firm	7-9	M	0.7 - 0.5	b
			Soft	≤6	H	0.5 - 0.2	c
		>0	N/a			0.5 - 0.2	c
	H	N/a				0.5 - 0.2	c
>0	H	N/a				0.5 - 0.2	c

The multiplier (R_{OC}) in Table J.6 is used in the following manner:

a) The 2 year peak flow attenuation technique is used to derive the stage-discharge curve for the erosion control component of the SWM pond.

b) A multiplier of unity is equivalent to the traditional 2-year peak flow attenuation approach.

c) The multiplier is used to adjust the 2-year stage-discharge curve to account for differences in the erodability of the boundary materials. The adjustment is performed by multiplying each ordinate of the stage-discharge curve by R_{OC}. For stiff materials, the multiplier approaches unity ($R_{OC} \rightarrow 1.0$). For very sensitive materials, the multiplier is between 0.2 and 0.3, which is equivalent to 80%OC to 70%OC respectively.

Bank materials may be grouped according to the SCORE value if the soil consistency tests apply (i.e. fine-grained material with few stones). For coarse-grained materials, resistance can be determined from observation of bank erosion following a high flow event. As an alternative the resistance of the coarse-grained stratigraphic unit can be inferred from bank form and shear stress distribution through comparison with adjoining strata of fine-grained material.

Finally, relations expressing critical shear stress as a function of particle size are available in the literature. Many of these relations were derived from flume experiments using disturbed material that has been re-compacted. These relations tend to underestimate the resistance of the material as it is observed in the field. Consequently, these relations should be employed with caution or corrected to account for root binding, imbrication, compaction and structurization.

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Step 4. Approximate the Elevation-Discharge Curve For the DRC Pond.

The DRC outflow control structure can be constructed as set of pipes or nested weirs. This design example is for a nested, sharp crested weir.

Determine the stage-discharge curve for the flow rate having a recurrence interval of 2 years for the baseline land use condition. For this example, the baseline condition is the reforested land use scenario. The flow having a recurrence interval 2 years was determined previously as between 8.9 and 10.1 cfs for Reaches 1 through 3 respectively (Table J.5).

Construct the 2 year stage-discharge curve using an equation for sharp crested weirs with end contractions:

$$Q = C_e L_e h_e^{\left(\frac{3}{2}\right)} \quad \text{.....[J.11]}$$

in which, 'Q' represents the rate of flow (cfs), 'C_e' is the effective weir coefficient (C=3.19, Brater and King, 1982), L_e is the effective length of the weir (ft) and 'h_e' is the effective depth of flow above the weir crest (ft). Set the invert of the weir at 628.0 ft. The terms L_e, C_e and h_e are adjusted to account for losses due to end contractions (Brater and King, 1982). In this illustration it is assumed that the stage-volume curve has already been derived and that the approximate head at Q_{BFL}=8.9 cfs is h=2.25 ft.

Re-arranging Eqn. J.11 and solving for 'L_e' at $Q=(Q_{2YR})_{PRE}$=8.9 cfs yields,

$$L_e = \frac{Q}{C_e h_e^{\left(\frac{3}{2}\right)}} = \frac{8.9}{3.19(2.25)^{\left(\frac{3}{2}\right)}} = 0.83\text{ft} \quad \text{.....[J.12]}$$

Compute the stage-discharge curve for the 2-year weir using Eqn. J.11 as illustrated in Figure J.6 (Q_{2YR}, curve AB. This stage-discharge curve represents the rating curve for the 2-year post- to pre-development peak flow attenuation approach.

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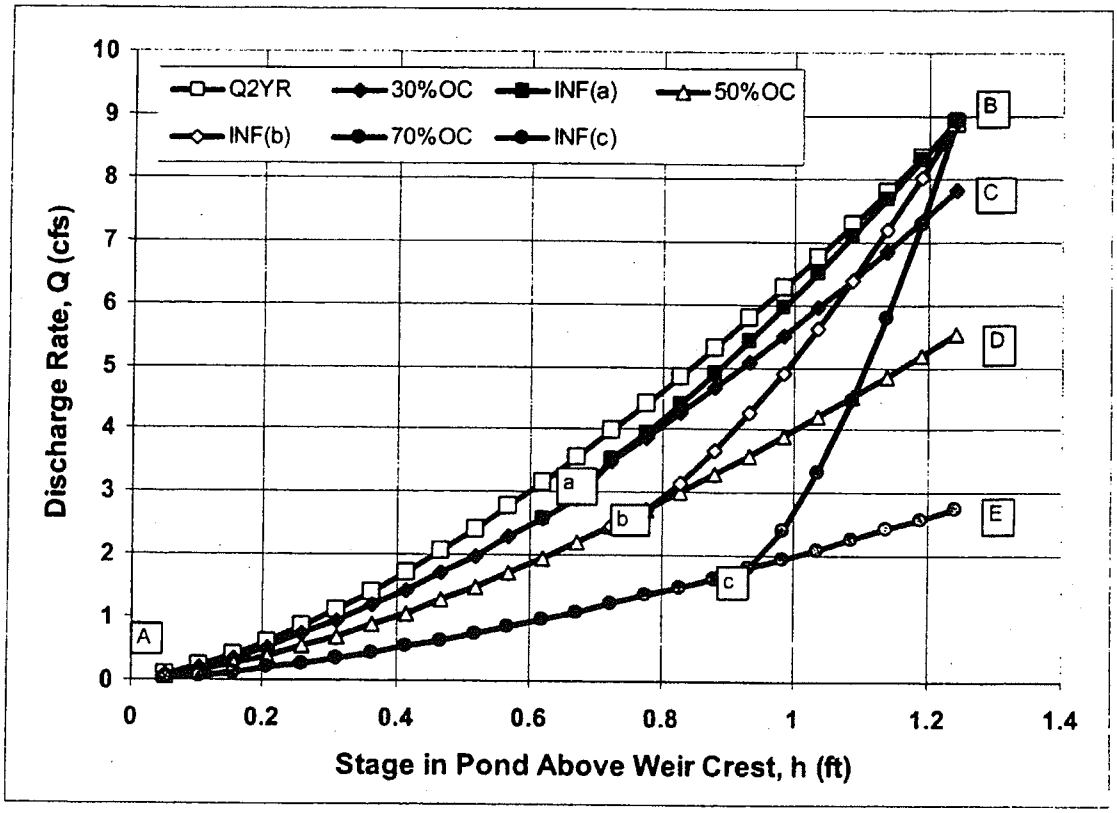

Figure J.6. The 2 Year Peak Flow Attenuation and DRC Rating Curves for 30%OC, 50%OC and 70%OC

Construct the DRC stage-discharge curve as follows:

- Determine the level of OC control and the inflection point from Table J.6.
  - Since $(\tau_c)_{BED}<0$ (Table J.5) then the bed is classified as "Low" sensitivity (shaded boxes in the first two columns of Table J.6);
  - The value of $(\tau_c)_{BNK}>0$ consequently, Row 3 of Column 3 (shaded box in Table J.6) was selected;
  - The bank material was classified as soft (SCORE=1), consequently, the 4th Row of Column 4 was chosen providing a range of R_{OC} between 0.5 and 0.2 with an inflection point at "c". In this case $R_{OC}=0.3$ was selected in accordance with the guidelines in Table J.6. Note: 70%OC means that the multiplier for the 2 year curve is $R_{OC}=0.3$
  - The 70%OC curve (designated as curve AE in Figure J.6) is created by multiplying the ordinance of the 2 year stage-discharge curve (Q_{2YR} in Figure J.6) by the multiplier $R_{OC}=0.3$.
  - The inflection point (c) is determined using the guidelines provided in Table J.7.

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Table J.7 Guidelines For Determination of the Flow Rate for the DRC Curve Inflection Point (Reach 1)					
Inflection Point	Ratio of Inflection Point Depth to Bankfull Depth d_i/d_{BFL} (dim)	Bankfull Depth d_{BFL} (ft)	Inflection Point Depth d_i (ft)	Dominant Discharge Q_{BFL} (cfs)	Flow Rate at Inflection Point Q_i (cfs)
a	.75	1.0	.75	4.76	2.88
b	.67		.67		2.30
c	.55		.55		1.74

The point d_c=0.55 ft, d_{BFL}=1.0 ft, characterize the Control Reach, consequently the ratio,

$$\frac{d_c}{d_{BFL}} = \frac{0.55ft}{1.0ft} = 0.55, \quad \text{[J.12]}$$

- The flow rate at d_c/d_{BFL}=0.55 was estimated from Figure J.6 to be Q_c=1.74 cfs.
- Point (c) can be located on curve AE at a flow corresponding to Q_c=1.74 cfs.

- The DRC stage-discharge curve follows the curve A(c)B in Figure J.6. For the purpose of illustration, the stage-discharge curves for 30%OC (inflection point (a)) and 50%OC (inflection point (b)) are also provided in Figure J.6.

Step 5. Sizing the DRC Weir

After establishing the DRC stage-discharge curve the next step is to size the DRC weir. This is done using a nested weir configuration as illustrated in Figure J.7. The equation for the nested weir can be approximated from Eqn. J.14 for sharp crested weirs as,

$$Q = \left(C_c L_c h_c^{\left(\frac{3}{2}\right)} \right)_{INSET} + \left(C_c (L_c^* - L_c)(h_c^* - h_c)^{\left(\frac{3}{2}\right)} \right), \quad \text{[J.14]}$$

in which Q represents the discharge from the nested weir, 'C_c' is a coefficient (3.19) adjusted to account for end contractions, L_c is the length of the inset weir, h_c represents the height of the inset weir where $0 \le h_c \le h_2$ (h_2 represents the total height of the nested weir) and h_c^* is the depth of flow through the nested weir above the inset weir ($h_c \le h_c^* \le h_2$).

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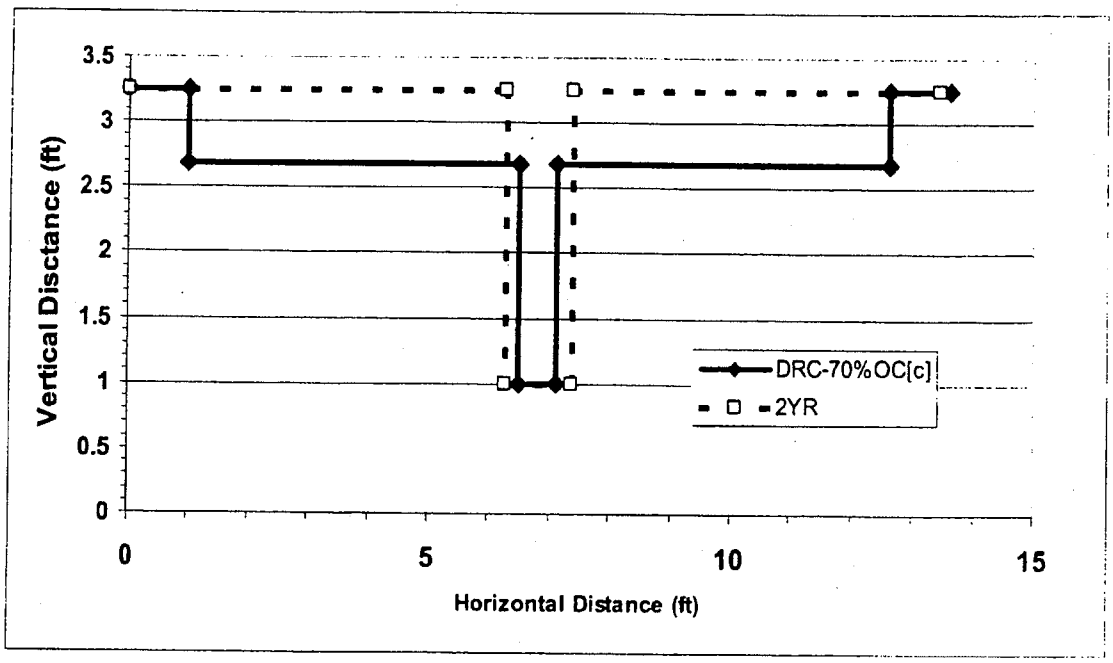

Figure J.7 Comparison of the 70% OC DRC Weir with Inflection Point at [c] and the Traditional 2-year Peak Flow Attenuation Weir

Solving Eqn. D.14 for results in the dimensions and flow values reported in Table J.8.

Table J.8. Summary of Dimensions and Flow Characteristics For a Nested DRC Weir: Reach 1

Parameter	DRC Weir			2 Year Weir
	Inflection Point (a)	Inflection Point (b)	Inflection Point (c)	
L_c (ft)	1.77	1.00	0.62	N/A
h_c (ft)	0.67	0.78	0.93	
Q_i at h_c (cfs)	2.89	2.21	1.74	
L_c (ft)	0.80	4.32	11.0	0.83
h_2 (ft)	2.25			
Q at h_2 (cfs)	8.94			

Parameters in Table J.8 are defined in the preceding text.

Note: the weir dimensions for DRC stage discharge curves 30%OC (inflection point 'a') and 50%OC (inflection point 'b') are provided for comparison with the selected option (inflection point 'c').

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Appendix K

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Appendix K. Miscellaneous Details

Miscellaneous Design Schematics for Compliance with Performance Criteria

Figure K-1: Trash Rack for Low Flow Orifice
Figure K-2: Expanded Trash Rack Protection for Low Flow Orifice
Figure K-3: Internal Control for Orifice Protection
Figure K-4: Observation Well for Infiltration Practices
Figure K-5: On-line Versus Off-line Schematic
Figure K-6: Isolation/Diversion Structure
Figure K-7: Half Round CMP Hood
Figure K-8: Half Round CMP Weir
Figure K-9: Concrete Level Spreader
Figure K-10: Baffle Weir for Cold Climates
Figure K-11: Hooded Outlet with Hood Below Ice Layer
Figure K-12: Shallow Angle Trash Rack to Prevent Icing

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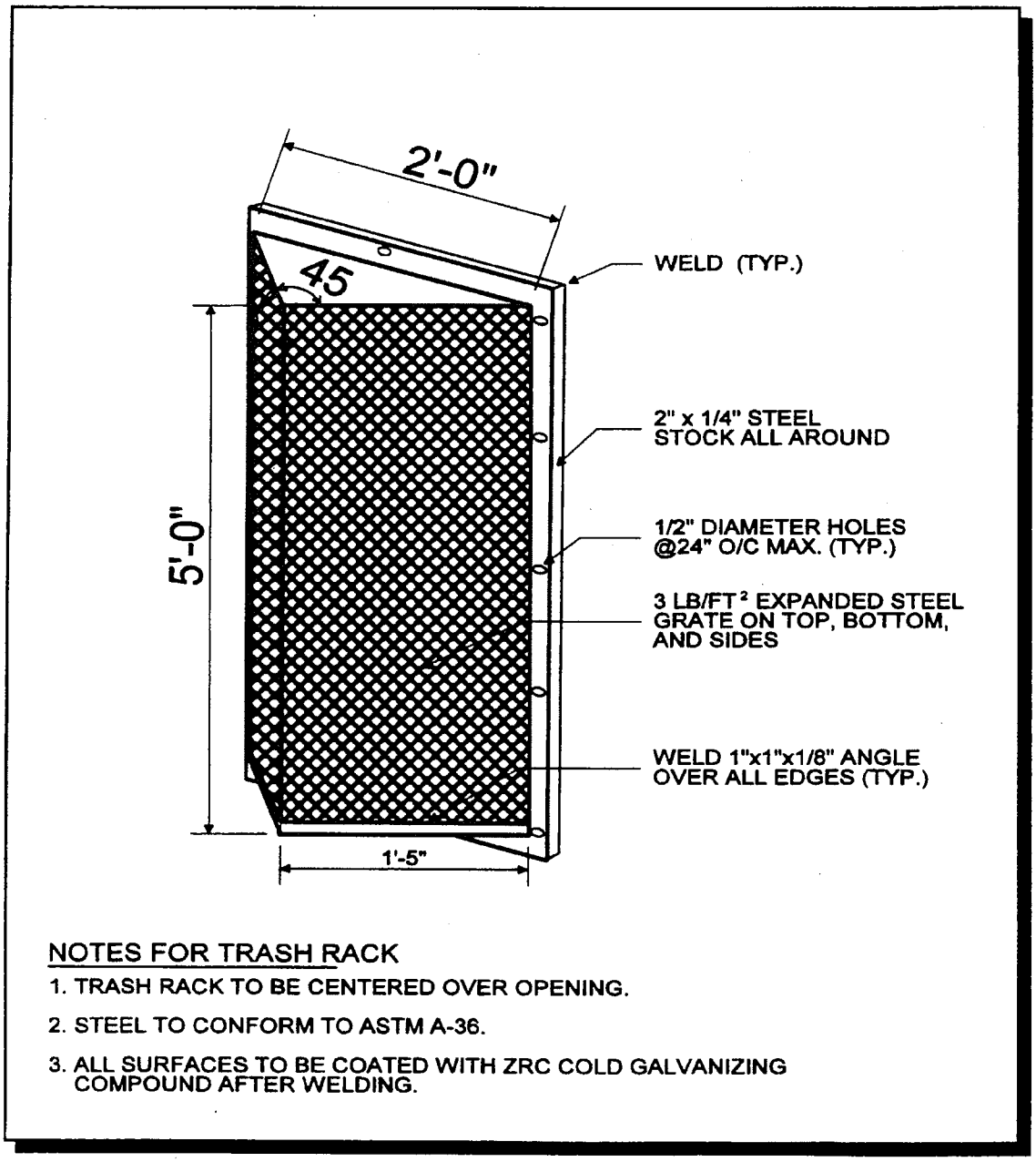
Figure K.1 Trash Rack Protection for Low Flow Orifice



NOTES FOR TRASH RACK

1. TRASH RACK TO BE CENTERED OVER OPENING.
2. STEEL TO CONFORM TO ASTM A-36.
3. ALL SURFACES TO BE COATED WITH ZRC COLD GALVANIZING COMPOUND AFTER WELDING.

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Figure K.2 Expanded Trash Rack Protection for Low Flow Orifice

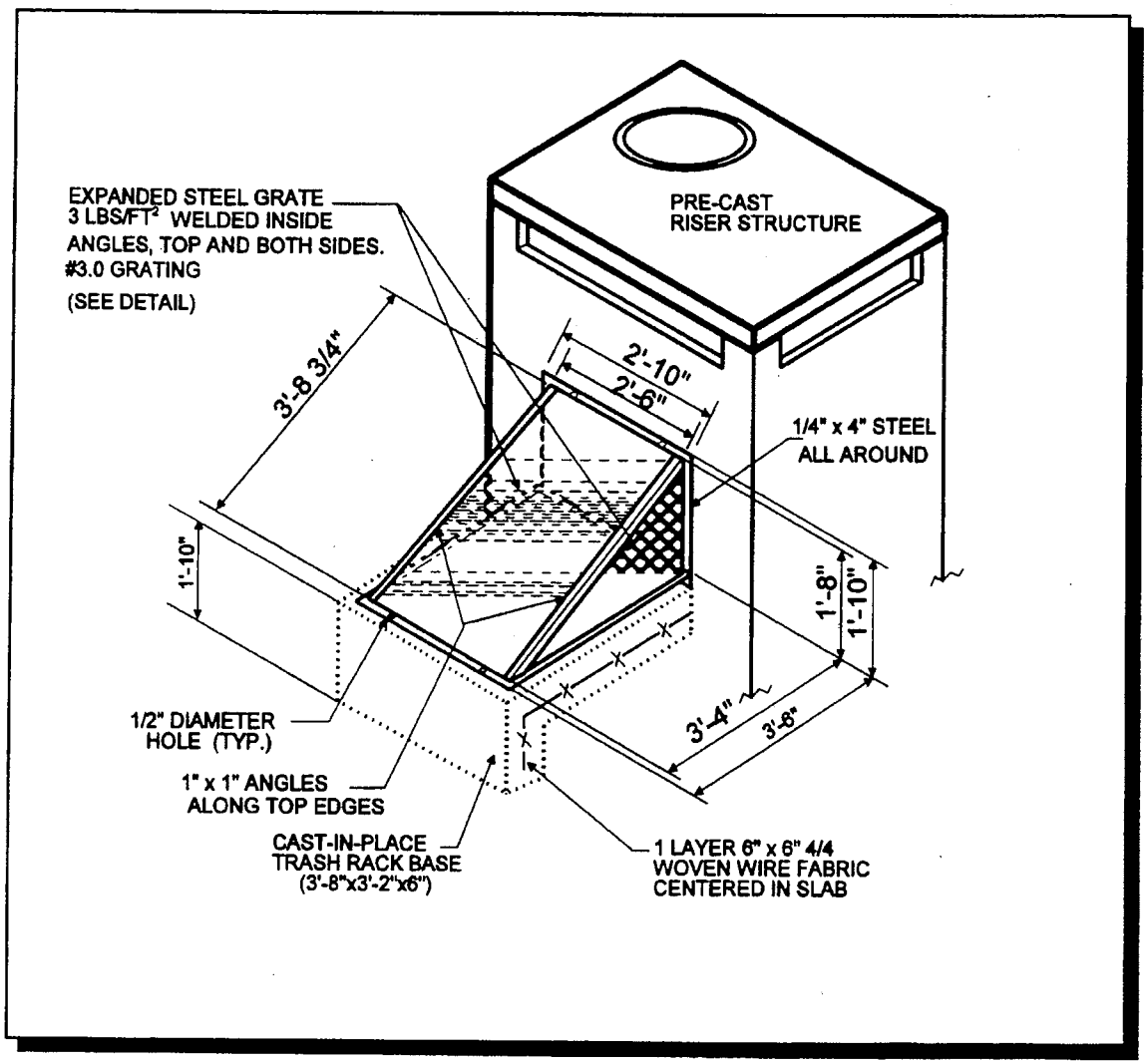

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Figure K.3 Internal Control for Orifice Protection

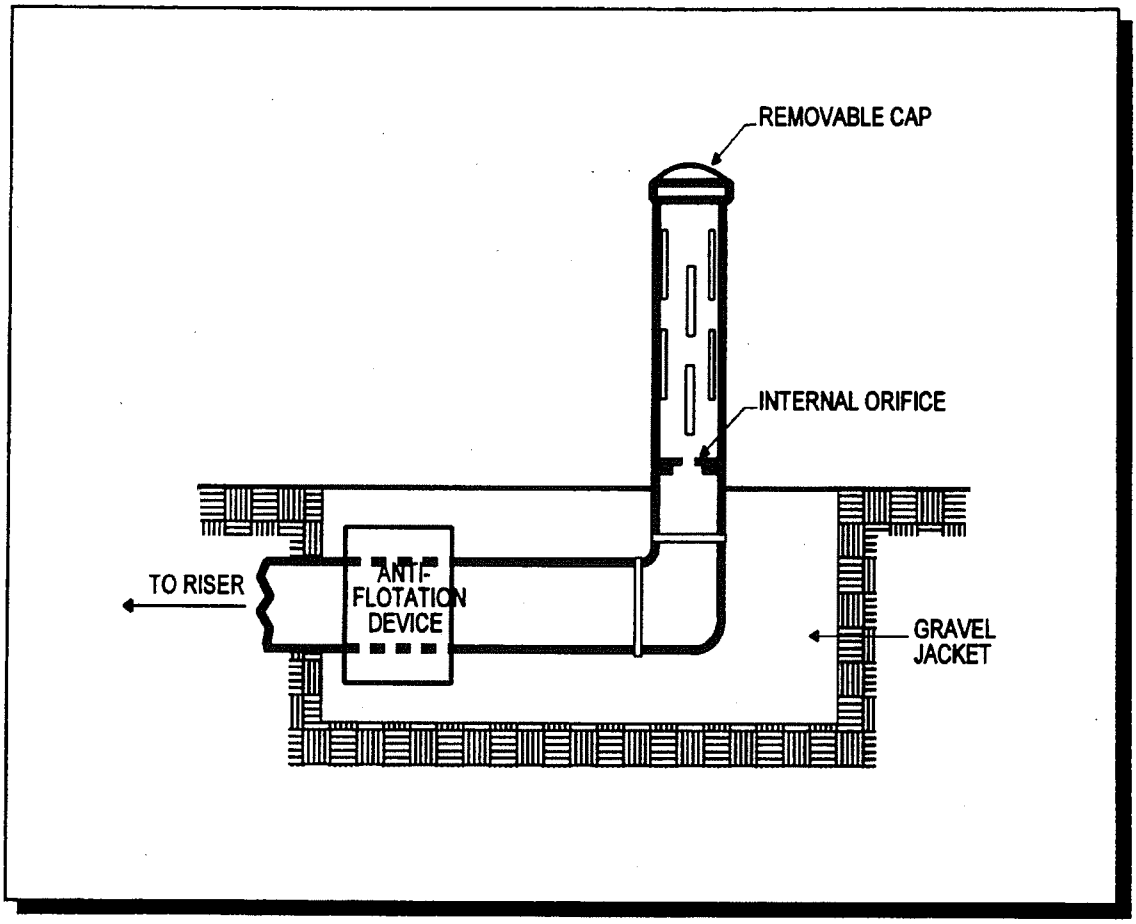

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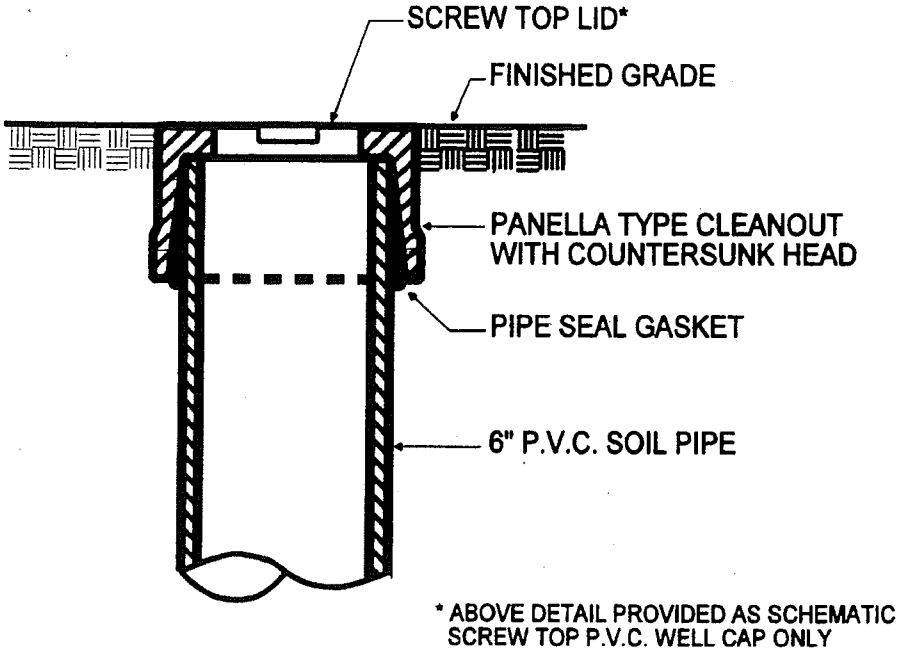
Figure K.4 Observation Well for Infiltration Practices



EACH OBSERVATION WELL / CLEANOUT SHALL INCLUDE THE FOLLOWING:

1. FOR AN UNDERGROUND FLUSH MOUNTED OBSERVATION WELL / CLEANOUT, PROVIDE A TUBE MADE OF NON-CORROSIVE MATERIAL, SCHEDULE 40 OR EQUAL, AT LEAST THREE FEET LONG WITH AN INSIDE DIAMETER OF AT LEAST 6 INCHES.

2. THE TUBE SHALL HAVE A FACTORY ATTACHED CAST IRON OR HIGH IMPACT PLASTIC COLLAR WITH RIBS TO PREVENT ROTATION WHEN REMOVING SCREW TOP LID. THE SCREW TOP LID SHALL BE CAST IRON OR HIGH OMPACT PLASTIC THAT WILL WITHSTAND ULTRA-VIOLET RAYS.

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Figure K.5 On-Line Versus Off-Line Schematic

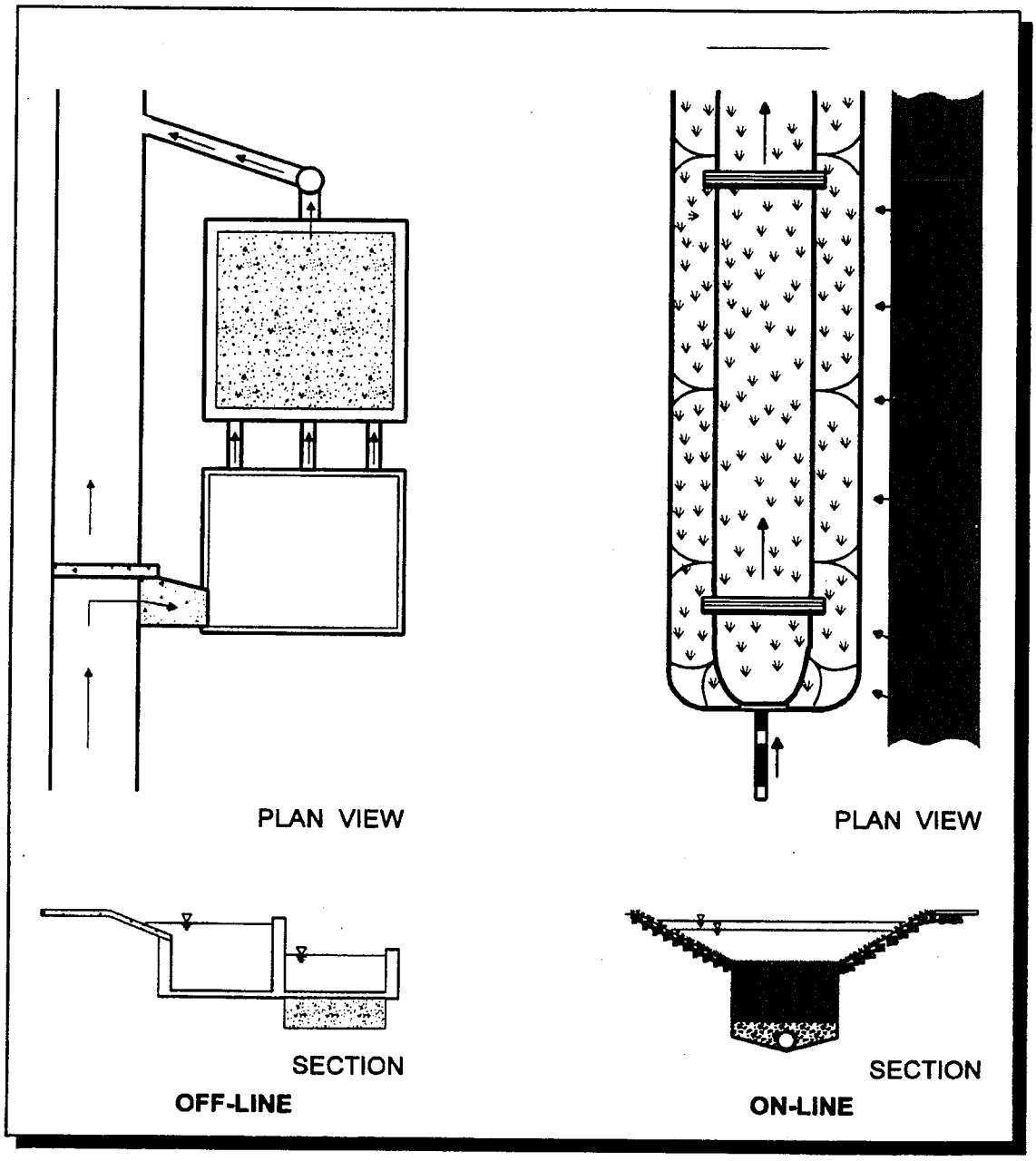

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Figure K. 6 Isolation Diversion Structure

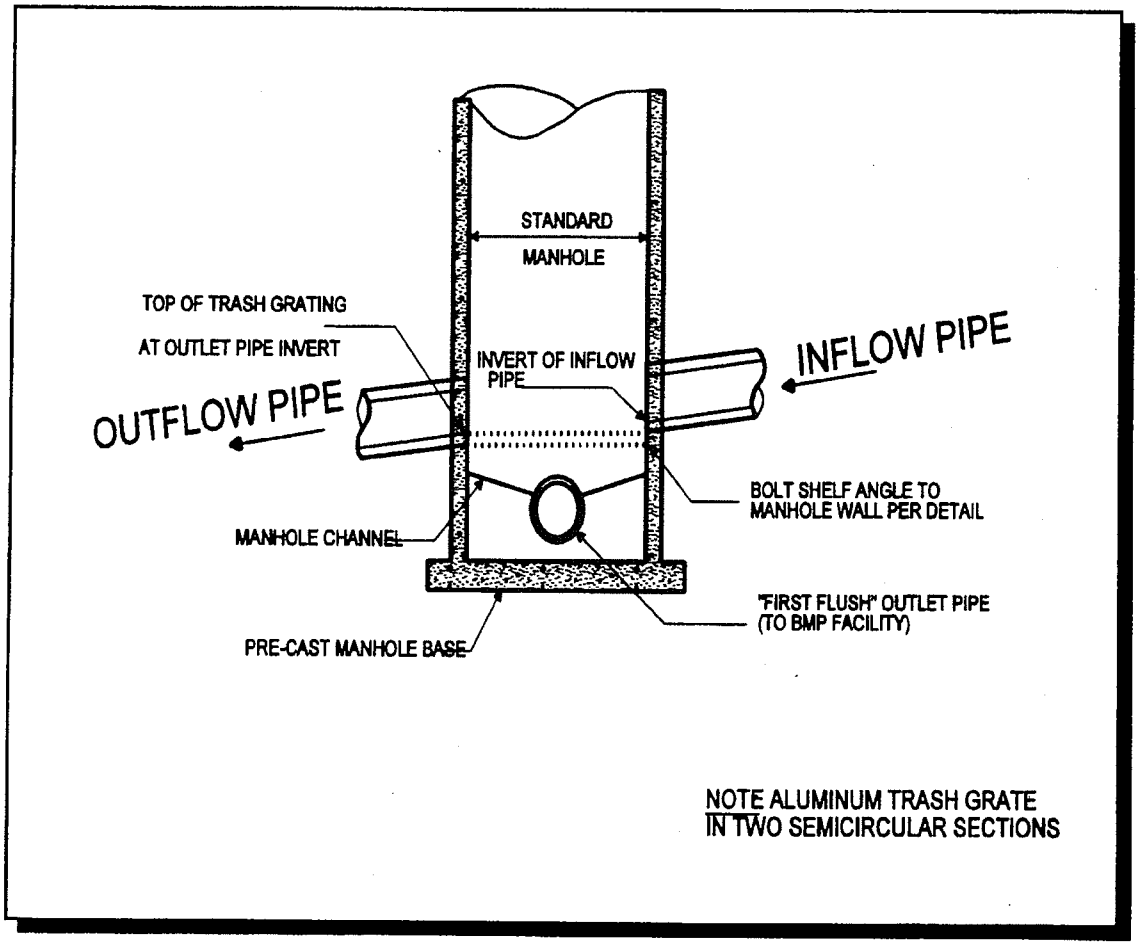

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Figure K.7 Half Round CMP Hood

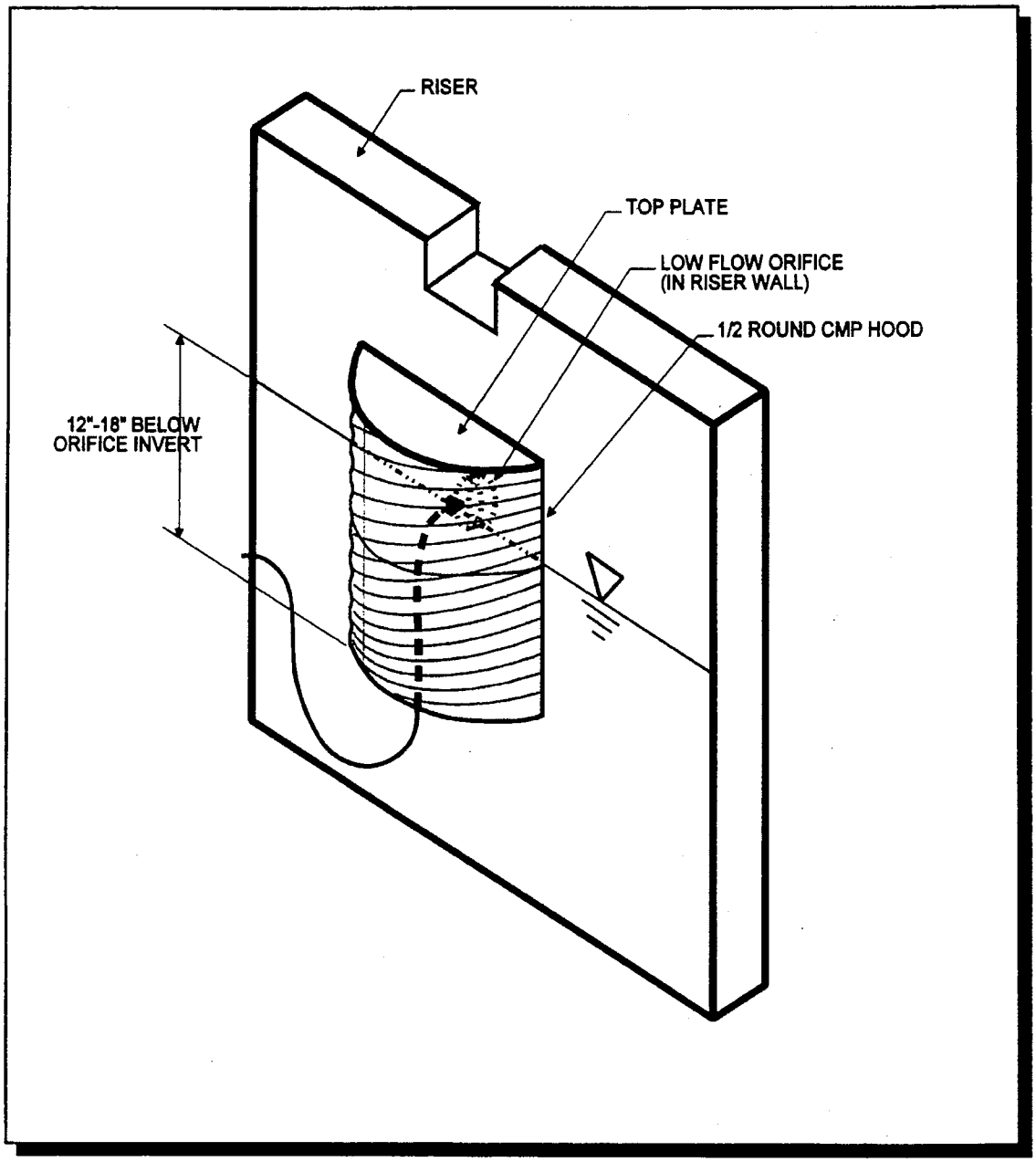

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Figure K.8 Half Round CMP Weir

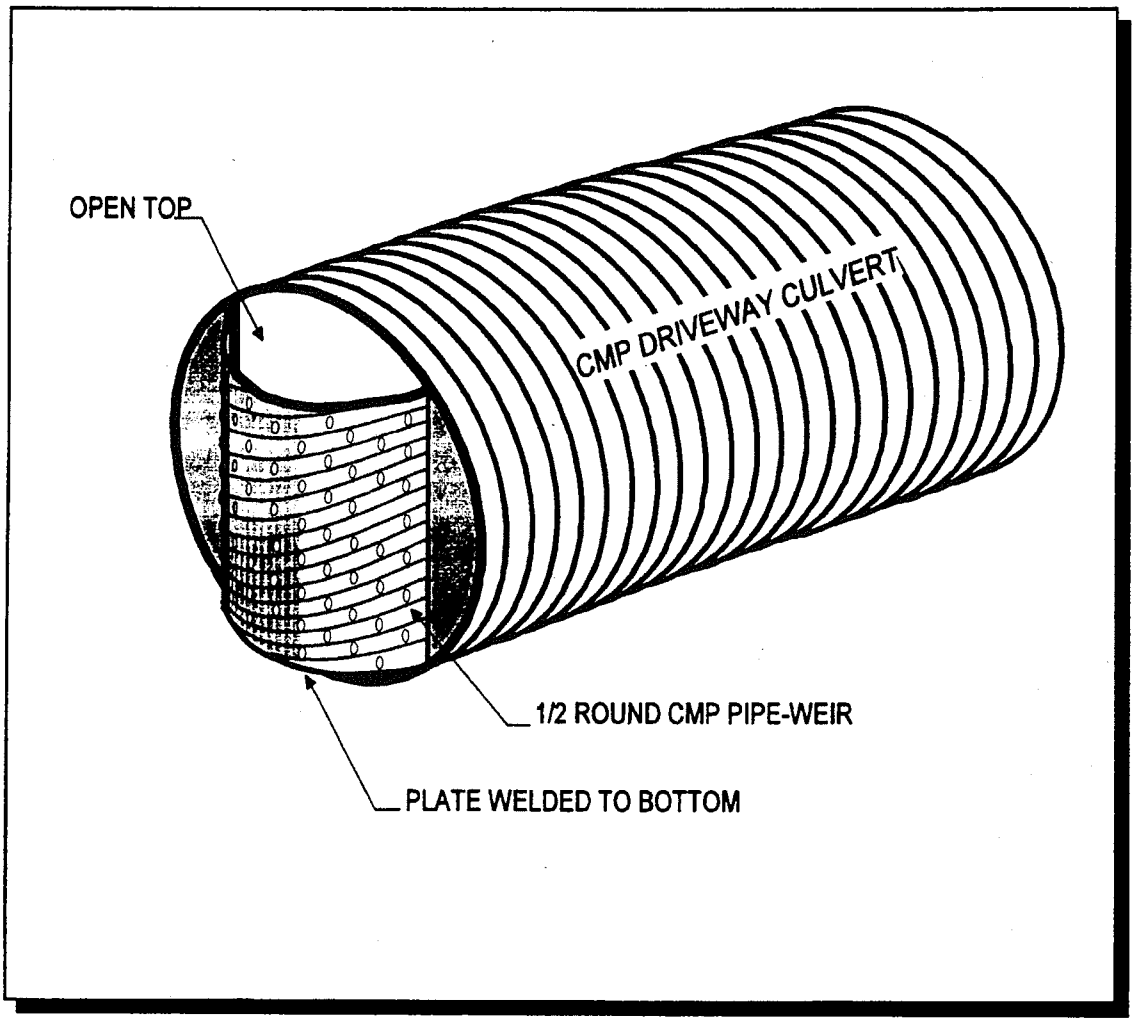

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Figure K.9 Concrete Level Spreader

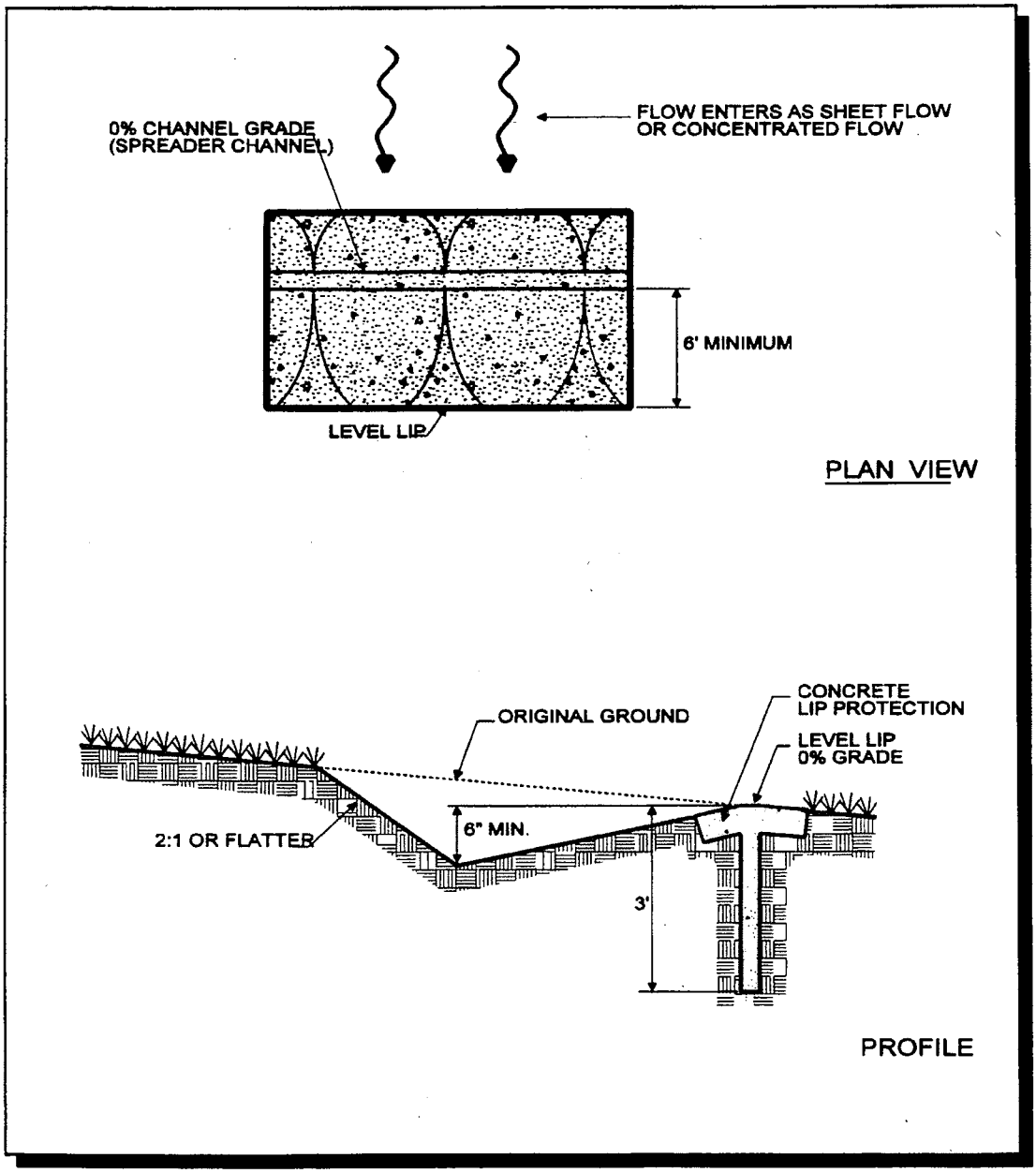

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Figure K.10 Baffle Weir for Cold Climates

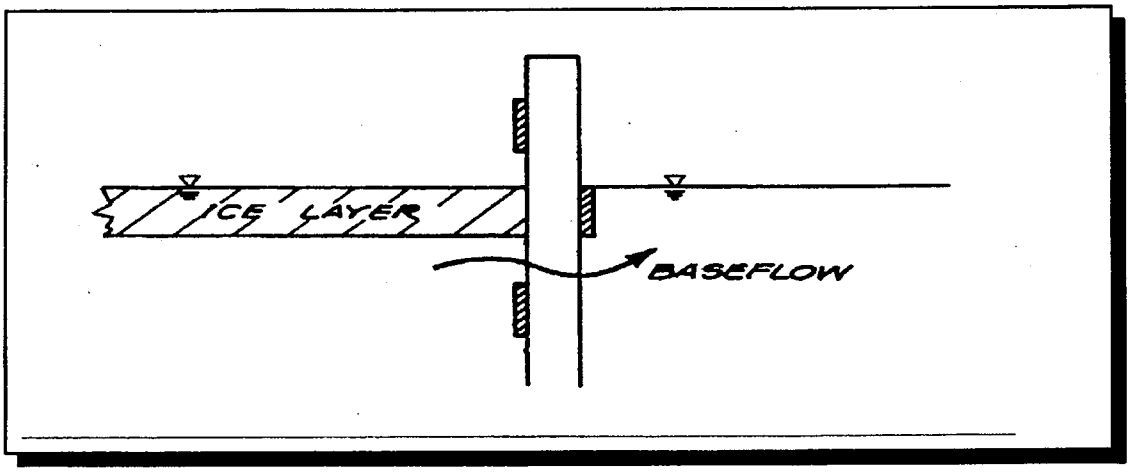

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Figure K.11 Hooded Outlet with Hood Below Ice Layer

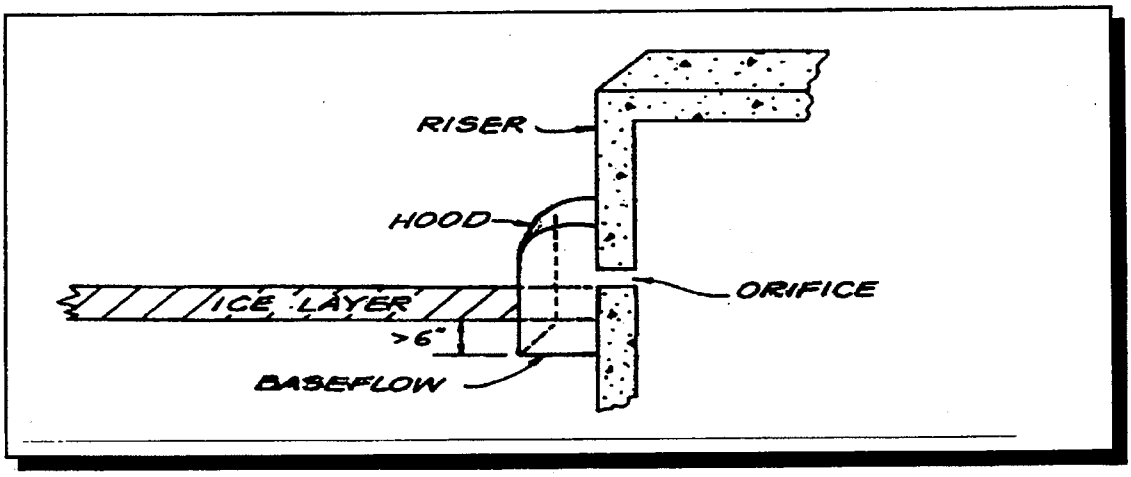

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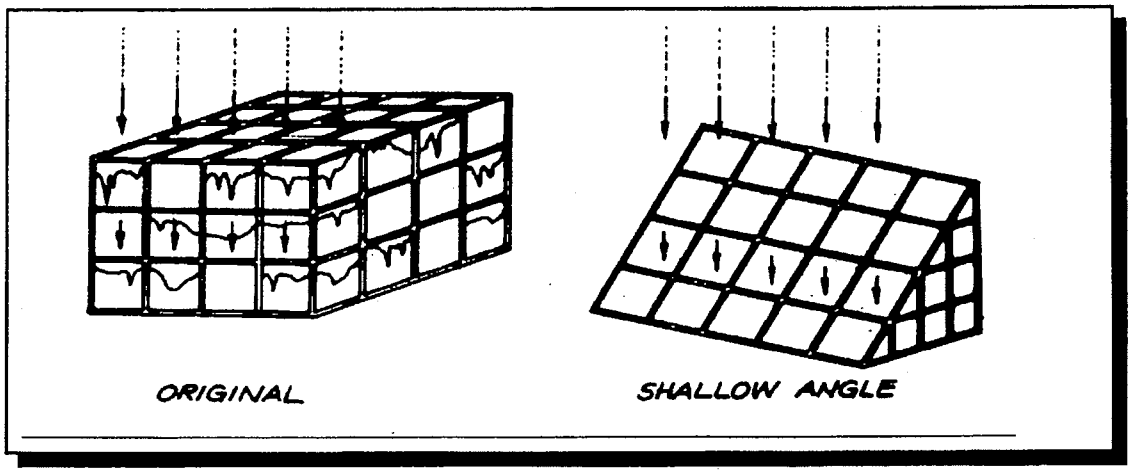
Figure K.12 Shallow Angle Trash Rack to Prevent Icing



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Appendix L

New York State Stormwater Management Design Manual

Appendix L: Critical Erosive Velocities for Grass and Soil

Velocity

Maximum permissible velocities of flow in vegetated channels absent of permanent turf reinforcement matting shall not exceed the values shown in the following table:

Table L.1 Permissible Velocities for Channels Lined with Vegetation

Channel Slope	Lining	Permissible Velocity[1] (ft/sec)
0-5%	Reed canarygrass Tall fescue Kentucky bluegrass	5
	Grass-legume mixture	4
	Red fescue Redtop Serices lespedeza Annual lespedeza Small grains	2.5
5-10%	Reed canarygrass Tall fescue Kentucky bluegrass	4
	Grass-legume mixture	3
Greater than 10%	Reed canarygrass Tall fescue Kentucky bluegrass	3

Source: Soil and Water Conservation Engineering, Schwab, *et al.*

For vegetated earth channels having permanent turf reinforcement matting, the permissible flow velocity shall not exceed 8 ft/sec. Turf reinforcement matting shall be a machine produced mat of nondegradable fibers or elements having a uniform thickness and distribution of weave throughout. Matting shall be installed per manufacturer's recommendations with appropriate fasteners as required. Examples of acceptable products include but are not limited to:

- North American Green "C350" or "P300"
- Greenstreak "PEC-MAT"
- Tensar "Erosion Mat"

1 For highly erodible soils, permissible velocities should be decreased 25%. An erodibility factor (K) greater than 0.35 would indicate a highly erodible soil. Erodibility factors (K-factors) can be obtained from local NRCS offices.

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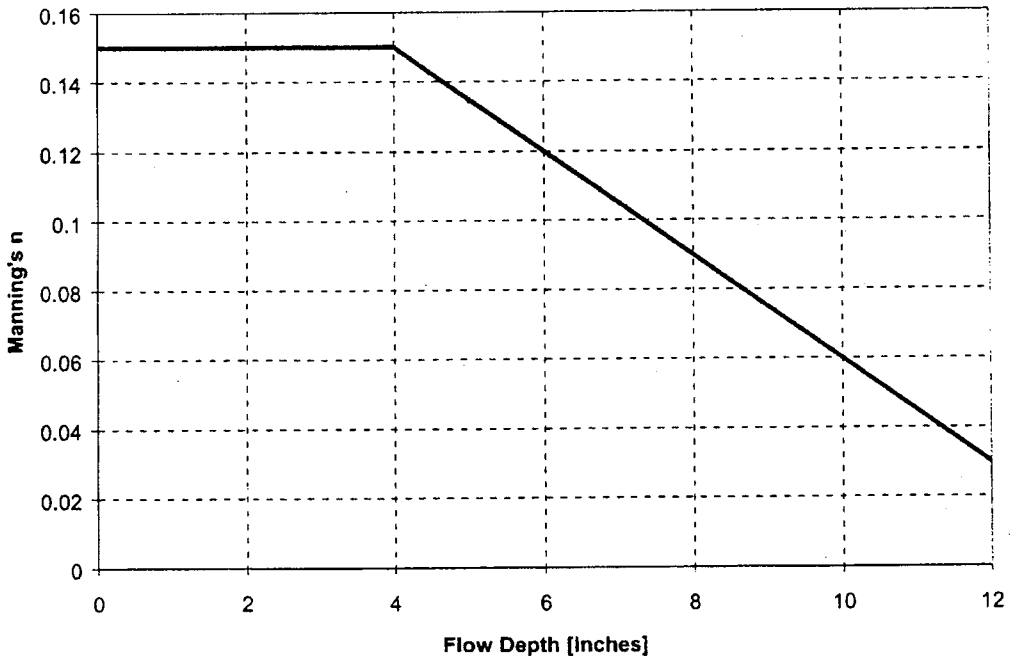
Manning's n value

The roughness coefficient, n, varies with the type of vegetative cover and flow depth. At very shallow depths, where the vegetation height is equal to or greater than the flow depth, the n value should be approximately 0.15. This value is appropriate for flow depths up to 4 inches typically. For higher flow rates and flow depths, the n value decreases to a minimum of 0.03 for grass channels at a depth of approximately 12 inches. The n value must be adjusted for varying flow depths between 4" and 12" (see Figure L.1).

Figure L.1 Manning's n Value with Varying Flow Depth (Source: Claytor and Schueler, 1986)



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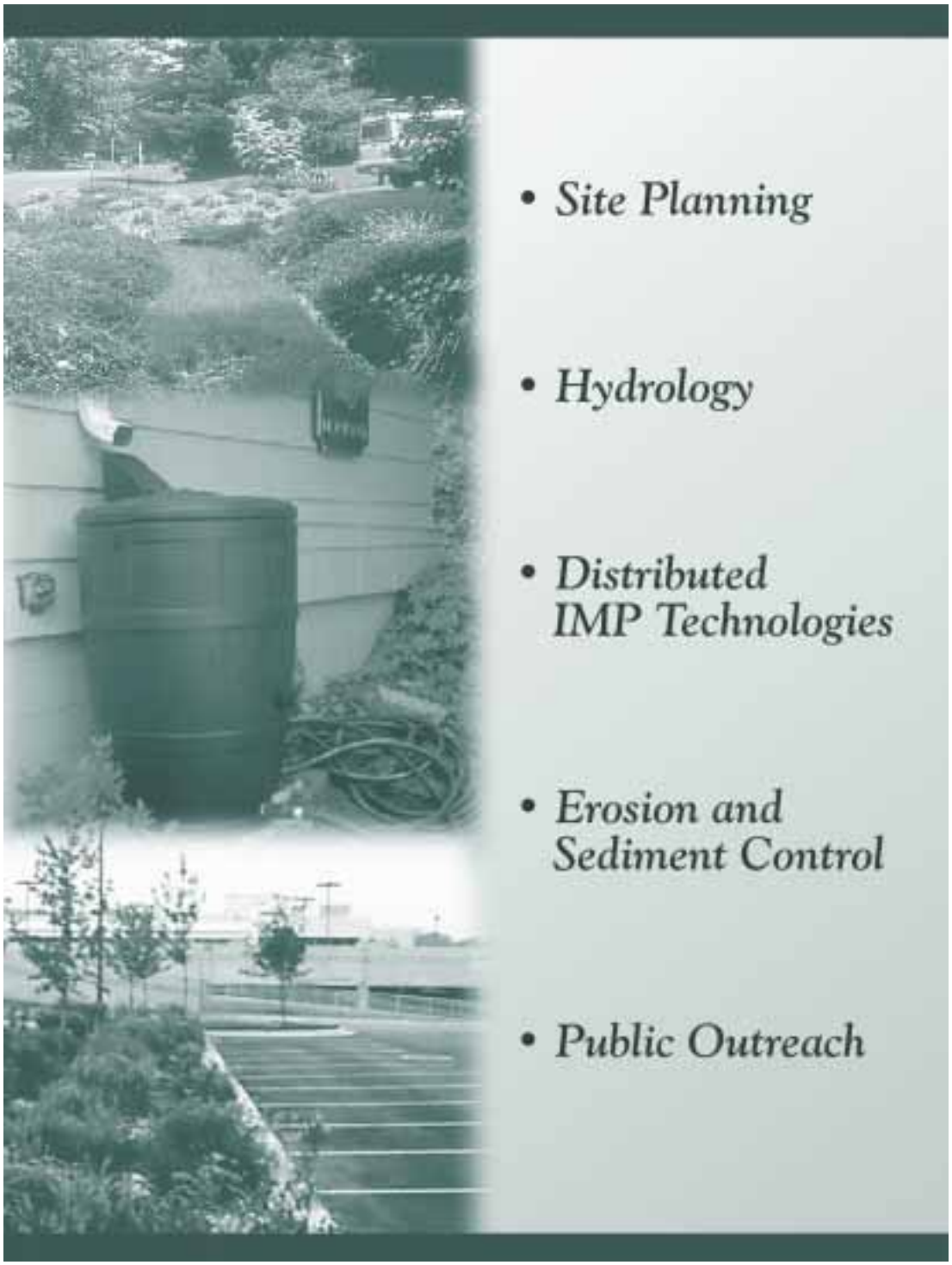
Low-Impact Development Hydrologic Analysis



Prepared by:

Prince George's County, Maryland

Department of Environmental Resources

Programs and Planning Division

July 1999

LOW-IMPACT DEVELOPMENT HYDROLOGIC ANALYSIS

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LOW-IMPACT DEVELOPMENT HYDROLOGIC ANALYSIS

CHAPTER 1. INTRODUCTION

1.1 OBJECTIVES

The purpose of this document is to provide low-impact development (LID) hydrologic analysis and computational procedures used to determine low-impact development stormwater management requirements. The hydrologic analysis presented is based on the Soil Conservation Service (SCS) TR-55 hydrologic model (SCS,1986).

Design concepts are illustrated by the use of runoff hydrographs that represent responses to both conventional and low-impact development. Low-impact development site planning and integrated management practices (IMPs) are defined and categorized into components of low-impact development objectives. Computational procedures for determining IMP requirements are demonstrated through design examples.

The process for developing low-impact development hydrology is illustrated in Figure 1.1. This figure lists the sequential steps and the sections in the manual where the methods to calculate or determine the specific requirements are provided.

1.2 KEY HYDROLOGIC PRINCIPLES

This section of the report provides an overview and general description of the key hydrologic principles involved in low-impact development, and provides guidance on the hydrologic analysis required for the design of low-impact development sites. The key hydrologic principles that are described include: precipitation and design storm events, rainfall abstractions, surface runoff, and groundwater recharge and flow.

Precipitation and Design Storm Events. Data for precipitation, including both snow and rain, are used in site planning and stormwater design. Precipitation occurs as a series of events characterized by different rainfall amount, intensity, and duration. Although these events occur randomly, analysis of their distribution over a long period of time indicates that the frequency of occurrence of a given storm event follows a statistical pattern. This statistical analysis allows engineers and urban planners to further characterize storm events based on their frequency of occurrence or return period. Storm events of specific sizes can be identified to support evaluation of designs. Storms with 2- and 10-year return periods are commonly used for subdivision, industrial, and commercial development design.

The 1- and 2-year storm events are usually selected to protect receiving channels from sedimentation and erosion. The 5- and 10-year storm events are selected for adequate flow conveyance design and minor flooding considerations. The 100-year event is used to define the limits of floodplains and for consideration of the impacts of major floods.

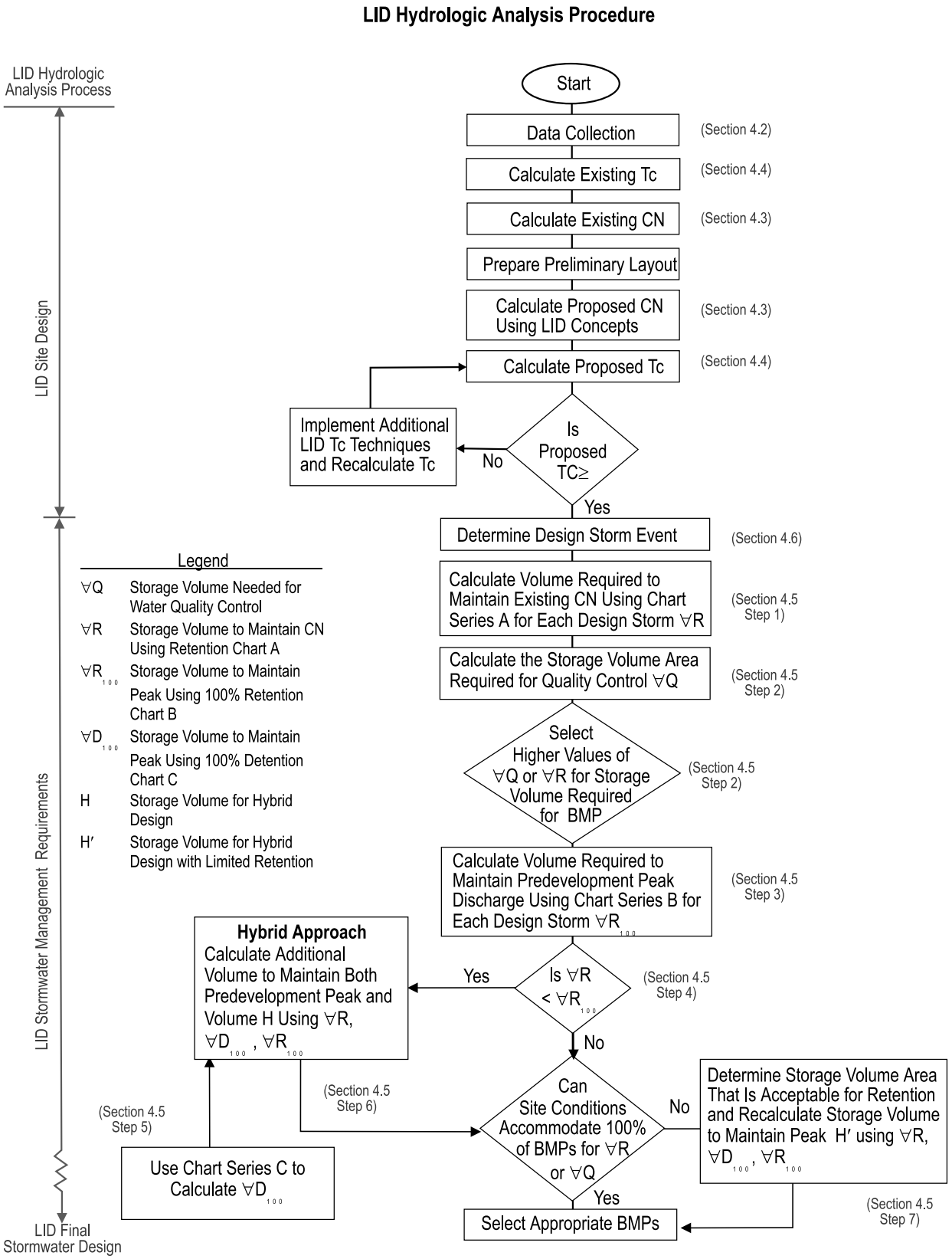

Figure 1.1. Low-impact development analysis procedure

There are numerous excellent texts and handbooks that describe the use of rainfall data to generate a "design storm" for the design of drainage systems (e.g., ASCE , 1994; Chow, 1964; SCS, 1985). For LID, a unique approach has been developed to determine the design storm based on the basic philosophy of LID. This approach is described in Section 4.6.

Storm events commonly used for evaluation of designs differ for the various climatic regions of the United States Summaries of typical storm event characteristics (i.e., amount/intensity, duration, and return period) are provided in national maps in Technical Paper 40 (Department of Commerce, 1963). In humid regions such as the Mid-Atlantic states, the 2-year storm is approximately 3 inches of rainfall and the 10-year storm is approximately 5 inches of rainfall. The 2-year storm has a 50 percent probability of occurring in any given year, while the 10-year storm has a 10 percent probability of occurring in any given year. In dry areas, such as portions of Colorado and New Mexico, the 2-year storm is approximately 1.5 inches of rainfall and the 5-year storm is approximately 2.0 inches of rainfall.

The rainfall time distributions vary throughout the geographic regions of the U.S. They are Type I, Type IA, Type II, and Type III. These differences in the distributions play a very important role in sizing the IMPs.

Rainfall Abstractions. Rainfall abstractions include the physical processes of interception of rainfall by vegetation, evaporation from land surfaces and the upper soil layers, transpiration by plants, infiltration of water into soil surfaces, and storage of water in surface depressions. Although these processes can be evaluated individually, simplified hydrologic modeling procedures typically consider the combined effect of the various components of rainfall abstraction.

The rainfall abstraction can be estimated as a depth of water (inches) over the total area of the site. This depth effectively represents the portion of rainfall that does not contribute to surface runoff. The portion of rainfall that is not abstracted by interception, infiltration, or depression storage is termed the excess rainfall or runoff.

The rainfall abstraction may change depending on the configuration of the site development plan. Of particular concern is the change in impervious cover. Impervious areas prevent infiltration of water into soil surfaces, effectively decreasing the rainfall abstraction and increasing the resulting runoff. Postdevelopment conditions, characterized by higher imperviousness, significantly decrease the overall rainfall abstraction, resulting not only in higher excess surface runoff volume but also a rapid accumulation of rainwater on land surfaces.

The LID approach attempts to match the predevelopment condition by compensating for losses of rainfall abstraction through maintenance of infiltration potential, evapotranspiration, and surface storage, as well as increased travel time to reduce rapid concentration of excess runoff. Several planning considerations combined with supplemental controls using LID integrated management practices can be used to compensate for rainfall abstraction losses and changes in runoff concentration due to site development.

Surface Runoff. The excess rainfall, or the portion of rainfall that is not abstracted by interception, infiltration, or depression storage, becomes surface runoff. Under natural and undeveloped conditions, surface runoff can range from 10 to 30 percent of the total annual precipitation (Figure 1.2). Depending on the level of development and the site planning methods used, the alteration of physical conditions can result in a significant increase of surface runoff to over 50 percent of the overall precipitation. In addition, enhancement of the site drainage to eliminate potential on-site flooding can also result in increases in surface runoff. Alteration in site runoff characteristics can cause an increase in the volume and frequency of runoff flows (discharge) and velocities that cause flooding, accelerated erosion, and reduced groundwater recharge and contribute to degradation of water quality and the ecological integrity of streams.

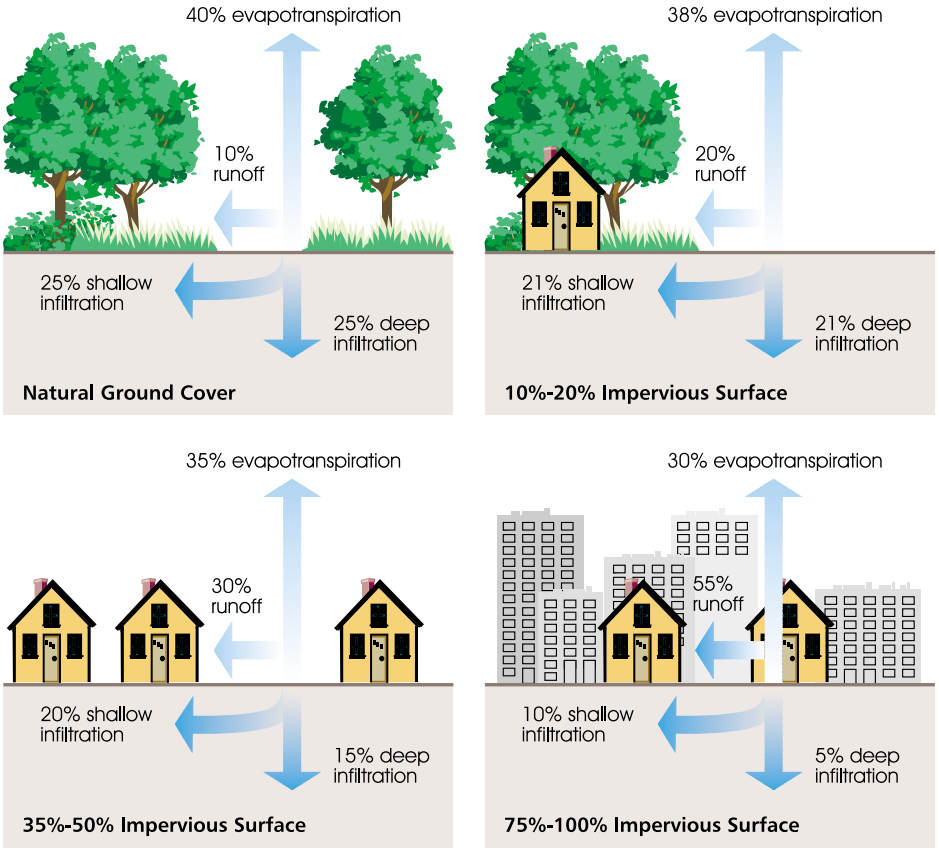

Figure 1.2. Runoff Variability with Increased Impervious Surfaces (FISRWG, 1998)

Groundwater Recharge. A considerable percentage of the rainfall abstraction infiltrates into the soil and contributes to the groundwater. Groundwater may be part of a local, intermediate, or regional water table, as illustrated in Figure 1.3. The local water table is often connected to nearby streams, providing seepage to streams during dry periods and maintaining base flow essential to the biological and habitat integrity of streams. A significant reduction or loss of groundwater recharge can lead to a lowering of the water table and a reduction of base flow in receiving streams during extended dry weather periods. Headwater streams, with small contributing drainage areas, are especially sensitive to localized changes in groundwater recharge and base flow.

1.3 HYDROLOGIC ALTERATIONS TO SITE DEVELOPMENT

Climate coupled with the geological and vegetative features of a watershed produce a unique hydrologic regime. Aquatic, wetland and riparian biota have evolved by adapting to this unique regime (Cairns, 1993). Urban development changes this regime, resulting in a new annual and seasonal hydrologic balance, causing frequency distribution changes of peak flows, magnitude and duration of high flows, and magnitude and duration of low flows.

Changes in the Existing Hydrologic Balance. Both the annual and seasonal water balance can change dramatically as a result of development practices. These changes include increases in surface runoff volume and decrease in evapotranspiration and groundwater recharge rates. For example, eastern hardwood forests typically have an annual water balance comprised of about 40% evapotranspiration, 50% subsurface flows and less than 10% surface runoff volume. Development, depending on its size and location in a watershed, alters the existing hydrologic balance by increasing surface flow volumes up to 43%, reducing subsurface flows to 32%, and reducing evapotranspiration rates to 25%. All this results in major changes to the local hydrology.

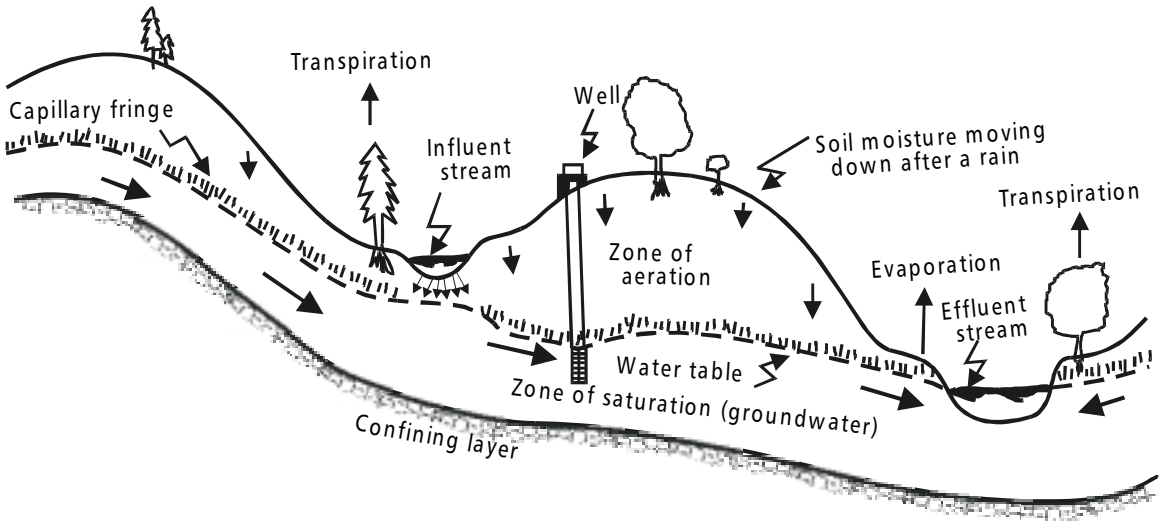

Figure 1.3. Groundwater in Local, Intermediate, or Regional Setting

Changes in Frequency Distribution of High Flows. Increased stream flows due to changes in surface topography result in more rapid drainage and increases in the amount of hydrologically active areas within a watershed. Hydrologically active areas are areas that produce runoff during precipitation events. These areas also increase in size, in comparison to their predevelopment size, due to reductions in depression storage capacity and in the retention capacity of the site's existing natural vegetation. Increases in impervious ground covers also contribute to increasing volumes of runoff. These changes coupled with shorter times of concentration result in sharp modifications to the shape of the resulting hydrograph.

A hydrograph represents diagramatically the changes in stream flow over time and during a storm event. As a site is developed, topography and land surfaces are modified,

with the resulting hydrograph reflecting decreases in base flow, higher and more rapid peak discharge, and more runoff volume. As illustrated in Figure 1.4, development generally results in stream discharges which increase rapidly and recede at rates much greater than under natural conditions. Higher flow velocities also increase the runoff's potential to erode and transport sediment and pollutants. The frequency of that peak flow event also increases. In urbanized watersheds, extreme events, such as the frequency of the bankfull flows, might be expected to occur 2 to 8 times per year compared to less than once per year under natural condition.

Changes in Magnitude, Frequency, and Duration of Low Flows. Impervious surfaces such as roads, rooftops, driveways, and sidewalks reduce infiltration, filtration, and groundwater recharge. This can lower water tables, impacts flow to existing wetlands, and reduce the water available for stream base flow. Similarly, decreases in the time of concentration, or runoff travel time, reduces the time available for water to infiltrate. The problem may be further compounded by the installation of shallow ground water drainage systems to accommodate road or building construction. Lower recharge rates for

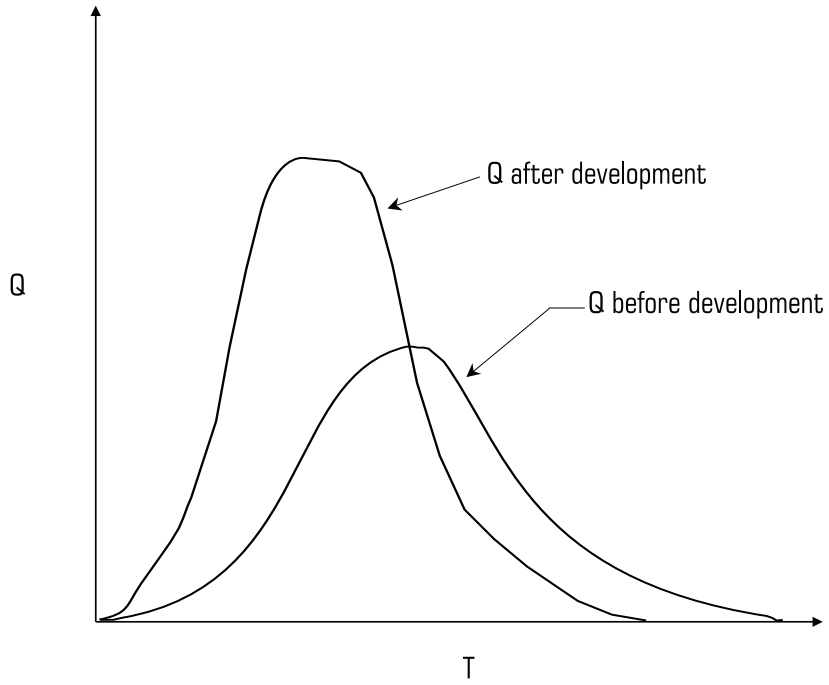

Figure 1.4. Hydrologic Alterations Due to Site Development

groundwater in a watershed are generally reflected in lower stream base flows. Low rates of recharge also extend low flow durations; particularly during prolonged droughts.

Conversely small storms which prior to development did not produce surface runoff now frequently do so.

Typical alterations to the hydrologic regime as a result of development include, but are not limited to, the following;

- Increased runoff volume
- Increased imperviousness
- Increased flow frequency, duration, and peak runoff rate

- Reduced infiltration (groundwater recharge)
- Modification of the flow pattern
- Faster time to peak, due to shorter Tc through storm drain systems
- Loss of storage

1.4 CONVENTIONAL STORMWATER MANAGEMENT

Traditionally, the response of watersheds to urban development has been measured in terms of changes in the flow regime, with management efforts focused on the prevention of property damage from flooding as previously described. Stormwater management efforts historically followed the design storm concept described earlier and focused almost exclusively on runoff collection systems such as curbs and gutters, and pipe conveyance systems which discharged directly to receiving water bodies. Stormwater quantity (peak discharge rate) management was incorporated as IMPs to address concerns about downstream flooding and stream bank erosion. Typically these IMPs, usually ponds or detention basins were located at the lowest point of the site and at the end of the network of inlets and pipes. This approach is often referred to as the "end of pipe" control approach.

Stormwater Quantity. Stormwater quantity controls are set by states or local government agencies to prevent site and downstream flooding and erosion. A typical design criteria requires that "the post development peak discharge for a 2- and 10- year frequency storm event be maintained at a level equal to or less than the respective 2-and 10-year predevelopment peak discharge rates, through the use of stormwater management structures that control the timing and rate of runoff." This requirement is based on the design storm concept described earlier under in this section.

The selection of the 2-year return frequency storm is based on a belief that the 1.5- to 2-year storm dictates the shape and form of natural channels (Leopold, et al., 1964, 1968). The selection of the 10-year storm is based on consideration of possible property damage due to local flooding and stream bank erosion

It is now becoming increasingly recognized that this type of approach is insufficient for a number of reasons:

- It does not address the loss of storage volume provided by rainfall abstractions, and consequently does not provide for groundwater recharge and maintenance of base flow during low flow periods.
- The 2 / 10 year storm policy does not adequately protect downstream channels form accelerated erosion.
- The inspection and maintenance costs of this approach are becoming an increasing burden for local governments

Stormwater Quality. The second stage in stormwater management was the recognition that runoff from urban areas was more polluted than runoff from undeveloped areas and was degrading the water quality of the receiving streams and other water bodies. For the most part this problem was addressed by modifying and improving the end of pipe approach to improve the pollutant removal effectiveness of these IMPs. Extended

detention, forebays, wetlands, permanent pools and numerous other design improvements were introduced.

Also the concept of controlling the "first flush" was introduced. A "first flush" event is defined as the first half inch of runoff from an impervious surface, and is expected to carry with it most of the pollutant load associated with stormwater. In terms of a typical storm hydrograph, the "first flush" represents a small portion of a storm's total discharge, but a larger percentage of the total loading for a particular contaminant.

Designers and modelers discovered that the design storm approach used for peak discharge control was not appropriate foe water quality control issues, since water quality issues were related to the annual volume of runoff which consists of many small storms. For example, the rainfall frequency distribution at National Airport, Arlington, VA, for the period of 1908 to 1985 indicates that the average total annual precipitation is 38.40 inches and storms of 1 inch or less account for 70% of the total annual precipitation (Figure 1.5). In addition, if the first inch of the storm events greater than 1 inch are considered, the total annual volume of 1 inch or less is in the range of 80 to 85%. These relationships are not

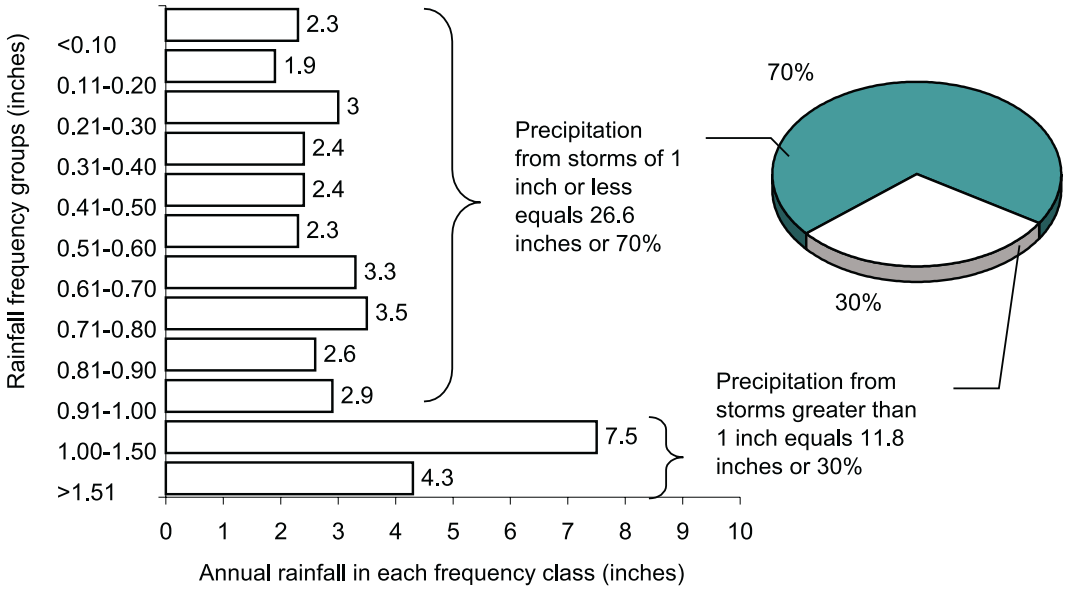

Figure 1.5. Rainfall Frequency Distribution at National Airport —1980 to 1985

considered in the traditional design storm concept because that approach is based on control of infrequent storms that are large enough to produce floods. However, this annual rainfall distribution pattern becomes an important consideration in the selection of appropriate rainfall conditions for low-impact development.

1.5. HYDROLOGIC COMPARISON BETWEEN CONVENTIONAL AND LOW-IMPACT DEVELOPMENT APPROACHES

Conventional stormwater conveyance systems are designed to collect, convey, and discharge runoff as efficiently as possible. Conventional stormwater management controls

(IMPs) are typically sited at the most downstream point of the entire site (end-of-pipe control). The stormwater management requirement is usually to maintain the peak runoff rates at predevelopment levels for a particular design storm event. Therefore, especially where a stormwater management pond is constructed, the peak flow will not be fully controlled for those storm events that are less severe than the design storm event. Low-impact development approaches, on the other hand, will fully control these storm events. This is a very important and significant difference between the two approaches. Figure 1.6 illustrates the hydrologic response of the runoff hydrograph to conventional IMPs.

- Hydrograph 1 represents the response to a given storm of a site in a predevelopment condition (i.e., woods, meadow). The hydrograph is defined by a gradual rise and fall of the peak discharge and volume.
- Hydrograph 2 represents a post development condition with conventional stormwater IMPs, such as a detention pond. Although the peak runoff rate is maintained at the predevelopment level, the hydrograph exhibits significant increases in the runoff volume and duration of runoff from the predevelopment condition.

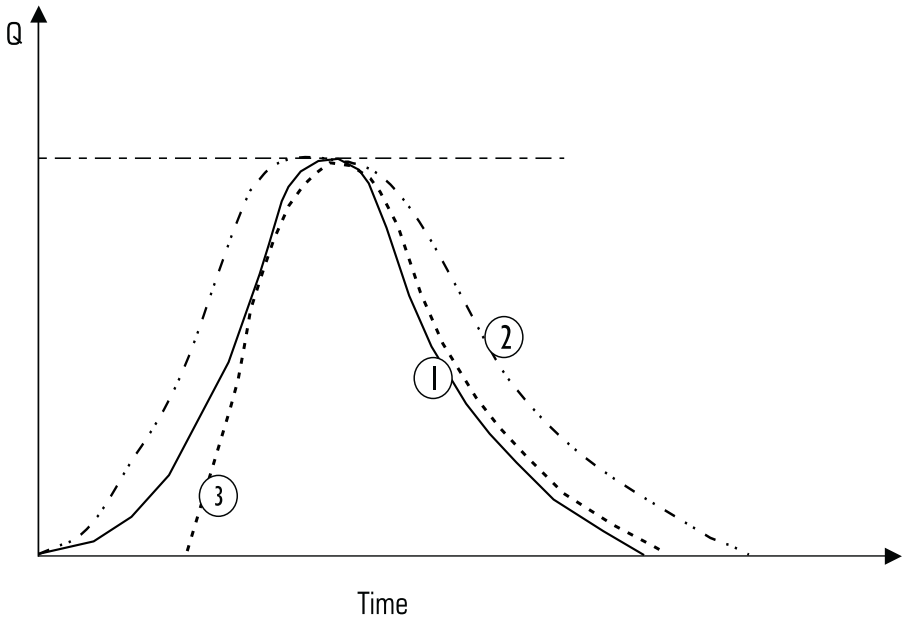

Figure 1.6. Comparison of the Hydrologic Response of Conventional and LID IMPs.

- Hydrograph 3 represents the response of post development condition that incorporates low-impact development stormwater management. Low-impact development uses undisturbed areas and on-lot and distributed retention storage to reduce to reduce runoff volume. The peak runoff rate and volume remain the same as the pre-development condition through the use of on-lot retention and/or detention. The frequency and duration of the runoff rate are also much closer to the existing condition than those typical of conventional IMPs.

The Distributed Control Approach. In comparison with conventional stormwater management, the objective of low-impact development hydrologic design is to retain the post development excess runoff volume is discrete units throughout the site to emulate the predevelopment hydrologic regime. This is called a distributed control approach. Management of both runoff volume and peak runoff rate is included in the design. The approach is to manage runoff at the source rather than at the end of pipe. Preserving the hydrologic regime of the predevelopment condition may require both structural and nonstructural techniques to compensate for the hydrologic alterations of development.

The Hydrologically Functional Landscape. In low-impact development, the design approach is to leave as many undisturbed areas as practical to reduce runoff volume and runoff rates by maximizing infiltration capacity. Integrated stormwater management controls or IMPs are then distributed throughout the site to compensate for the hydrologic alterations of development. The approach of maintaining areas of high infiltration and low runoff potential in combination with small, on-lot stormwater management facilities creates a "hydrologically functional landscape." This functional landscape not only can help maintain the predevelopment hydrologic regime but also enhance the aesthetic and habitat value of the site.

Integrated Management Practices (IMPs). Low-impact development technology employs microscale and distributed management techniques, called integrated management practices (IMPs) to achieve desired post-development hydrologic conditions. LID IMPs are used to satisfy the storage volume requirements described in Section 3.3. They are the preferred method because they can maintain the predevelopment runoff volume and can be integrated into the site design. The design goal is to locate IMPs at the source or lot, ideally on level ground within individual lots of the development. Management practices that are suited to low-impact development include:

- bioretention facilities
- dry wells
- filter/buffer strips and other multifunctional landscape areas
- grassed swales, bioretention swales, and wet swales
- rain barrels
- cisterns
- infiltration trenches

More information on IMPs can be obtained in the publication titled, "Low-Impact Development Design Strategies: An Integrated Design Approach," prepared by Prince George's County, DM, May 1999.

CHAPTER 2. LID HYDROLOGIC ANALYSIS COMPONENTS

The low-impact development "functional landscape" emulates the predevelopment temporary storage (detention) and infiltration (retention) functions of the site. This functional landscape is designed to mimic the predevelopment hydrologic conditions through runoff volume control, peak runoff rate control, flow frequency/duration control, and water quality control.

Runoff Volume Control. The predevelopment volume is maintained by a combination of minimizing the site disturbance from the predevelopment condition and then providing distributed retention IMPs. Retention IMPs are structures that retain the runoff for the design storm event.

Peak Runoff Rate Control. Low-impact development is designed to maintain the predevelopment peak runoff discharge rate for the selected design storm events. This is done by maintaining the predevelopment Tc and then using retention and/or detention IMPs (e.g., rain gardens, open drainage systems, etc.) that are distributed throughout the site. The goal is to use retention practices to control runoff volume and, if these retention practices are not sufficient to control the peak runoff rate, to use additional detention practices to control the peak runoff rate. Detention is temporary storage that releases excess runoff at a controlled rate. The use of retention and detention to control the peak runoff rate is defined as the hybrid approach.

Flow Frequency/Duration Control. Since low-impact development is designed to emulate the predevelopment hydrologic regime through both volume and peak runoff rate controls, the flow frequency and duration for the post development conditions will be almost identical to those for the predevelopment conditions (see Figure 1.3.). The impacts on the sediment and erosion and stream habitat potential at downstream reaches can then be minimized.

Water Quality Control. Low-impact development is designed to provide water quality treatment control for the first ½ inch of runoff from impervious areas using retention practices. Low-impact development also provides pollution prevention by modifying human activities to reduce the introduction of pollutants into the environment.

The low-impact analysis and design approach focuses on the following hydrologic analysis and design components:

- **Runoff Curve Number (CN).** Minimizing change in post development hydrology by reducing impervious areas and preserving more trees and meadows to reduce the storage requirements to maintain the pre development runoff volume.
- **Time of Concentration (Tc).** Maintaining the predevelopment Tc in order to minimize the increase of the peak runoff rate after development by lengthening flow paths and reducing the length of the runoff conveyance systems.
- **Retention.** Providing retention storage for volume and peak control, as well as water quality control, to maintain the same storage volume as the predevelopment condition.

- **Detention.** Providing additional detention storage, if required, to maintain the same peak runoff rate and/or prevent flooding.

Table 2.1 provides a summary of low-impact techniques that affect these components.

Table 2.1. Low-Impact Development Techniques and Hydrologic Design and Analysis Components

	Low-Impact Development Technique															
Low-Impact Hydrologic Design and Analysis Components	Flatten slope	Increase flow path	Increase sheet flow	Increase roughness	Minimize disturbance	Flatten slopes on swales	Infiltration swales	Vegetative filter strips	Constricted Pipes	Disconnected impervious areas	Reduce curb and gutter	Rain barrels	Rooftop storage	Bioretention	Revegetation	Vegetation preservation
Lower Postdevelopment CN					✔		✔	✔		✔	✔			✔	✔	✔
Increase Tc	✔	✔	✔	✔		✔		✔	✔	✔	✔	✔	✔	✔	✔	✔
Retention							✔	✔				✔	✔	✔	✔	✔
Detention						✔			✔			✔	✔			

CHAPTER 3. HYDROLOGIC EVALUATION

The purpose of the hydrologic evaluation is to determine stormwater management requirements for low-impact development sites. The evaluation method is used to determine the amount of retention and/or detention to control the runoff volume and peak discharge rate. Appropriate detention and/or retention techniques are then selected to meet these requirements.

3.1 LOW-IMPACT DEVELOPMENT RUNOFF POTENTIAL

Calculation of the low-impact development runoff potential is based on a detailed evaluation of the existing and proposed land cover so that an accurate representation of the potential for runoff can be obtained. This calculation requires the engineer to investigate several key parameters associated with a low-impact development:

- Land cover type
- Percentage of and connectivity of impervious areas
- Soils type and texture
- Antecedent soil moisture conditions

A comparison of conventional and low-impact development runoff potential using the SCS Curve Number (CN) approach is presented. The CN for conventional development are based on the land cover assumptions and parameters shown in Table 2.2a of TR-55 (SCS, 1986). The low-impact development CN are based on a detailed evaluation of the land cover and parameters listed above. As illustrated in Figure 3.1, customizing the CN for a low-impact development site allows the developer/engineer to take advantage of and get credit for such low-impact development site planning practices as the following:

- Narrower driveways and roads (minimizing impervious areas)
- Maximizing tree preservation or aforestation (tree planting)
- Site fingerprinting (minimal disturbance)
- Open drainage swales
- Preservation of soils with high infiltration rates to reduce CN
- Location of IMPs on high infiltration soils.

Table 3.1 illustrates a comparison of low-impact development CN land covers with those of a conventional development CN, as found in Table 2.2a of TR-55 (SCS, 1986) for a typical 1-acre lot. Figure 3.1 illustrates a comparison of conventional land covers, based on the land covers in Table 2.2a of TR-55, with a low-impact development customized CN for a 1-acre lot.

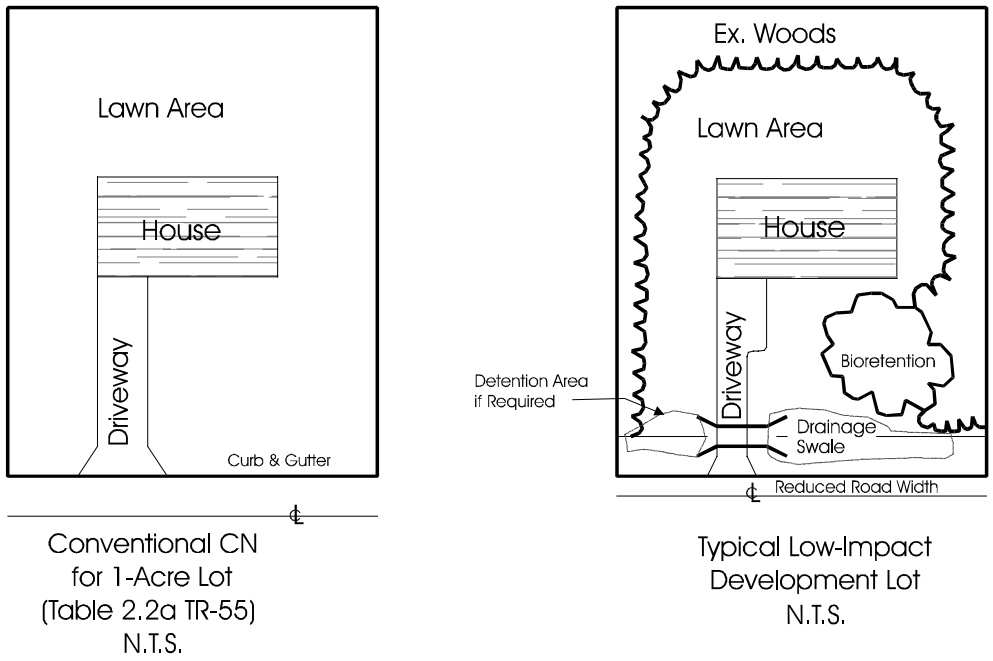

Figure 3.1. Comparison of Land Covers Between Conventional and LID CNs

Table 3.1. Comparison of Conventional and LID Land Covers

Conventional Land Covers (TR-55 Assumptions)	**LID Land Covers**
20% impervious 80% grass	15% imperviousness 25% woods 60% grass

Table 3.2 provides a list of low-impact development site planning practices and their relationship to the components of the low-impact development CN. Key low-impact techniques that will reduce the post development CN, and corresponding runoff volumes, are as follows:

Table 3.2. Low-Impact Development Planning Techniques to Reduce the Postdevelopment Low-Impact Development CN

Suggested Options Affecting Curve Number	Limit use of sidewalks	Reduce road length and width	Reduce driveway length and width	Conserve natural resources areas	Minimize disturbance	Preserve infiltratable soils	Preserve natural depression areas	Use transition zones	Use vegetated swales	Preserve Vegetation
Land Cover Type				✔	✔			✔	✔	✔
Percent of Imperviousness	✔	✔	✔					✔		
Hydrologic Soils Group				✔		✔				
Hydrologic Condition				✔	✔	✔				
Disconnectivity of Impervious Area	✔	✔	✔							
Storage and Infiltration							✔			✔

Preservation of Infiltratable Soils: This approach includes site planning techniques such as minimizing disturbance of soils, particularly vegetated areas, with high infiltration rates (sandy and loamy soils), and placement of infrastructure and impervious areas such as houses, roads, and buildings on more impermeable soils (silty and clayey soils). Care must be taken when determining the suitability of soils for proposed construction practices. Adequate geotechnical information is required for planning practices.

Preservation of Existing Natural Vegetation. Woods and other vegetated areas provide many opportunities for storage and infiltration of runoff. By maintaining the surface coverage to the greatest extent possible, the amount of compensatory storage for IMPs is minimized. Vegetated areas can also be used to provide surface roughness, thereby increasing the Tc. In addition, they function to filter out and uptake pollutants.

Minimization of Site Imperviousness. Reducing the amount of imperviousness on the site will have a significant impact on the amount of compensatory IMP storage required since there is almost a one-to-one corresponding relationship between rainfall and runoff for impervious areas.

Disconnection of Site Imperviousness. Impervious areas are considered disconnected if they do not connect to a storm drain system or other impervious areas through direct or shallow concentrated flow. Directing impervious areas to sheet flow onto vegetated or bioretention areas to allow infiltration results in a direct reduction in runoff and corresponding storage volume requirements.

Creation of Transition Zones and Bioretention: Transition zones are vegetated areas that can be used to store and infiltrate runoff from impervious areas before they discharge from the site. These areas are located at the sheet or discharge points from graded and impervious areas. These areas affect the land cover type calculations of the LID CN.

The use of these techniques will provide incentives in cost savings to the overall site development and infrastructure. It will also reduce costs for stormwater permit fees, inspection, and maintenance of the infrastructure as well as project based costs.

Figure 3.2. illustrates the hydrologic response using LID techniques to reduce the impervious areas and increase the storage volume.

- For hydrograph 1, refer to Figure 1.3 for description.
- Hydrograph 2 represents the response of a post development condition with no stormwater management IMPs. This hydrograph definition reflects a shorter time of concentration (Tc), and an increase in total site imperviousness than that of the predevelopment condition. The resultant hydrograph shows a decrease in the time to reach the peak runoff rate, a significant increase in the peak runoff and discharge rate and volume, and increased duration of the discharge volume.
- Hydrograph 3 represents the resulting post development hydrograph using the low-impact techniques to reduce impervious area and increase storage volume. There is a reduction in both post development peak rate and volume.

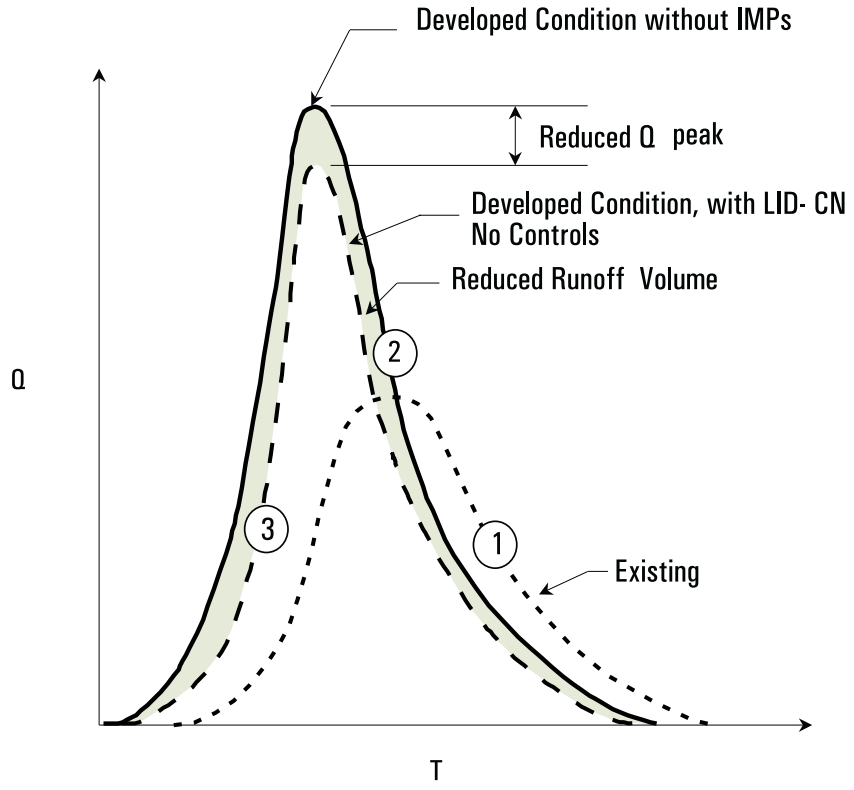

Figure 3.2. Effect of Low-Impact Development CN on the Postdevelopment Hydrograph without Stormwater IMPs

3.2. MAINTAINING THE PREDEVELOPMENT TIME OF CONCENTRATION

The low-impact development hydrologic evaluation requires that the post development time of concentration (Tc) be maintained close to the predevelopment Tc. The travel time (Tt) throughout individual lots and areas should be approximately the same so that the Tc is representative of the drainage. This is critical because low-impact development is based on a homogeneous land cover and distributed IMPs. To maintain the Tc, low-impact developments use the following site planning techniques:

- Maintaining predevelopment flow path length by dispersing and redirecting flows, generally, through open swales and natural drainage patterns
- Increasing surface roughness (e.g., reserving woodlands, using vegetated swales).
- Detaining flows(e.g. open swales, rain gardens).
- Minimize disturbance(minimizing compaction and changes to existing vegetation).
- Flattening grades in impacted areas.
- Disconnecting impervious areas (e.g., eliminating curb/gutter and redirecting downspouts).
- Connecting pervious and vegetated areas (e.g., reforestation, aforestation, tree planting).

To maintain predevelopment Tc, an iterative process that analyzes different combinations of the above appropriate techniques may be required. These site planning techniques are incorporated into the hydrologic analysis computations for post development Tc to demonstrate an increase in post development Tc above conventional techniques and a corresponding reduction in peak discharge rates.

Figure 3.3 illustrates the hydrologic response to maintaining equal predevelopment and post-development Tc.

- For hydrograph 1 refer to Figure 1.3.
- For hydrograph 3 refer to Figure 3.2.
- Hydrograph 4 represents the effects of the low-impact development techniques to maintain the Tc. This effectively shifts the post peak runoff time to that of the predevelopment condition and lowers the peak runoff rate.

The greatest gains for increasing the Tc in a small watershed can be accomplished by increasing the Manning's roughness "n" for the initial surface flow at the top of the watershed and increasing the flow path length for the most hydraulically distant point in the drainage area. After the transition to shallow concentrated flow, additional gains in Tc can be accomplished by:

- Decreasing the slope
- Increasing the flow length
- Directing flow over pervious areas.

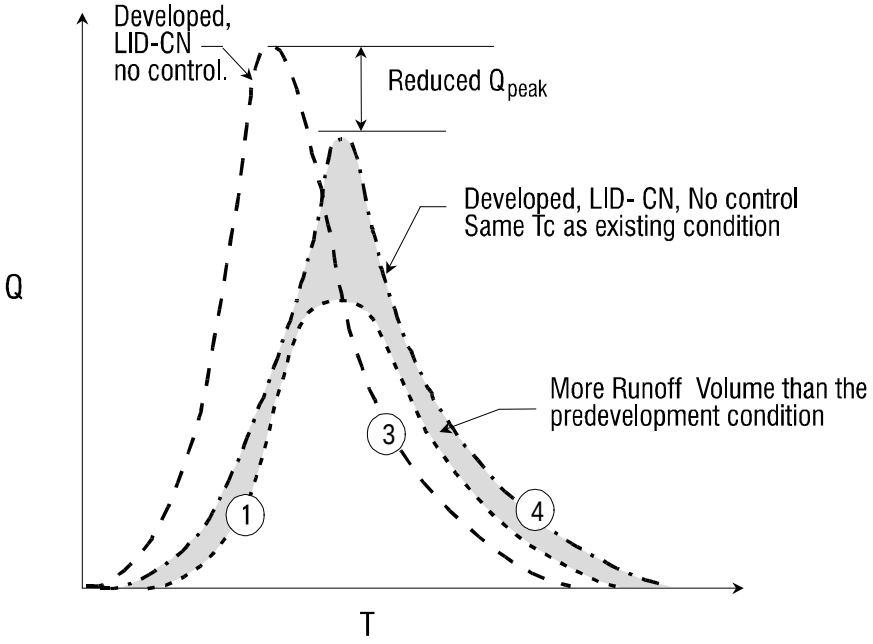

Figure 3.3. Low-Impact Development Hydrograph That Has a Reduced CN and Maintains the Tc Without Stormwater IMPs

In low-impact development sites, the amount of flow in closed channels (pipes) should be minimized to the greatest extent possible. Swales and open channels should be designed with the following features:

- Increase surface roughness to retard velocity
- Maximize sheet flow conditions
- Use a network of wider and flatter channels to avoid fast-moving channel flow
- Increase channel flow path
- Reduce channel gradients to decrease velocity (minimum slope is 2-percent; 1 percent may be considered on a case by case basis).
- The channel should flow over pervious soils whenever possible to increase infiltration so that there is a reduction of runoff to maximize infiltration capacity

Table 3.3 identifies low-impact development techniques and volumes objectives to maintain the predevelopment Tc.

3.3 MAINTAINING THE PREDEVELOPMENT RUNOFF VOLUME

After all the available and feasible options to reduce the runoff potential of a site described have been deployed, and after all the available techniques to maintain the Tc as close as possible to predevelopment levels have been used, any additional reductions in runoff volume must be accomplished through distributed on-site stormwater management techniques. The goal is to select the appropriate combination of management techniques that emulate the hydrologic functions of the predevelopment condition to maintain the

Table 3.3. Low-Impact Development Techniques to Maintain the Predevelopment Time of Concentration

	Low Impact Development Technique									
Low-Impact Development Objective	On-lot bioretention	Wider and flatter swales	Maintain sheet flow	Clusters of trees and shrubs in flow path	Provide tree conservation/ transition zones	Minimize storm drain pipes	Disconnect impervious areas	Save trees	Preserve existing topography	LID drainage and infiltration zones
Minimize disturbance	✔		✔	✔	✔	✔	✔	✔	✔	
Flatten grades		✔	✔			✔			✔	✔
Reduce height of slopes						✔			✔	✔
Increase flow path (divert and redirect)		✔	✔	✔		✔	✔	✔		
Increase roughness "n"	✔		✔	✔	✔	✔	✔	✔		✔

existing runoff curve numbers and corresponding runoff volume. Low-impact development sites use retention to accomplish this goal. These facilities must be sited on individual lots throughout the site to provide volume controls at the source.

Retention storage allows for a reduction in the post development volume and the peak runoff rate. The increased storage and infiltration capacity of IMPs allows the predevelopment volume to be maintained. IMPs that maintain the predevelopment storage volume include, but are not limited to the following:

- Bioretention (rain garden)
- Infiltration trenches
- Vegetative Filter/Buffer
- Rain barrels

As the retention storage volume of the low-impact development IMPs is increased, there is a corresponding decrease in the peak runoff rate in addition to runoff volume reduction. If sufficient amount of runoff is stored, the peak runoff rate may be reduced to a level at or below the predevelopment runoff rate (see Figure 3.4). This storage may be all that is necessary to control the peak runoff rate when there is a small change in runoff curve number (CN) and storage volume. However, when there is a large change in CN, it may be less practical to achieve flow control using volume control only.

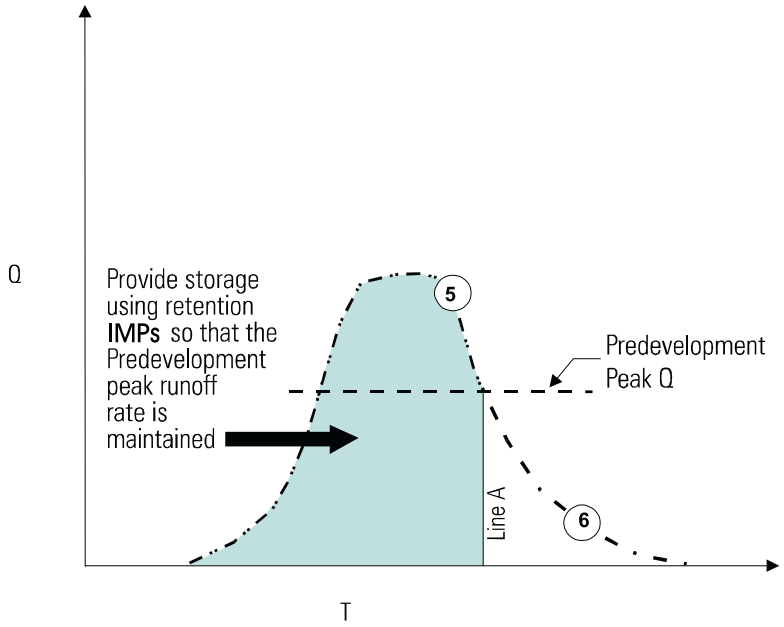

Figure 3.4. Retention Storage Required to Maintain Peak Development Runoff Rate

In Figure 3.4., Hydrograph 5 represents the IMP inflow hydrograph for the post-development condition for a site using low-impact development IMPs. Because of the IMP retention storage, runoff is not released until the maximum retention storage volume is exceeded. Line A represents the limit of retention storage. Hydrograph 6 is the outflow hydrograph from the low-impact development retention IMP. The release begins at the limit of retention storage, represented by line A. The storage maintains the predevelopment volume and controls the peak runoff rate. For this situation, the falling limb of the hydrograph represents a condition where the inflow (hydrograph 5) equals the outflow (hydrograph 6).

3.4 POTENTIAL REQUIREMENT FOR ADDITIONAL DETENTION STORAGE

Even though the post-development Tc and CN are maintained at the predevelopment level, in some cases additional detention storage is needed to maintain the predevelopment peak runoff rate due to the spatial distribution of the retention storage provided (i.e., storage areas are not *uniformly* distributed throughout the site).

The amount of storage that maintains the predevelopment runoff volume might not be sufficient to also maintain the predevelopment peak runoff rate. Therefore, additional on-lot storage is required in the form of ***detention storage.*** Low-impact development stormwater management techniques for providing detention storage include, but are not limited to the following:

- Swales with check dams, restricted drainage pipe, and inlet entrances
- Wider swales
- Rain barrels
- Rooftop storage
- Diversion structures

The effect of this additional detention storage is illustrated in Figure 3.5.

- For hydrograph 1, refer to Figure 1.3.
- Hydrograph 7 represents the response of a post-development condition that incorporates low-impact development retention practices. The amount of retention storage provided is not large enough to maintain the predevelopment peak runoff discharge rate. Additional detention storage is required.
- Hydrograph 8 illustrates the effect of providing additional detention storage to reduce the post-development peak discharge rate to predevelopment conditions.

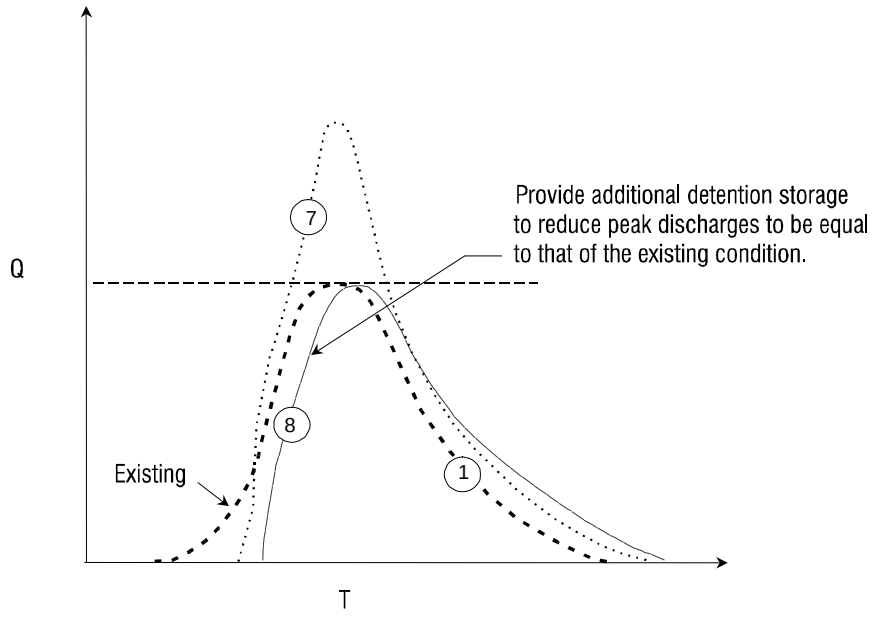

Figure 3.5. Effect of Additional Detention Storage on LID Retention Practices

CHAPTER 4. PROCESS AND COMPUTATIONAL PROCEDURE

4.1 INTRODUCTION

The hydrologic analysis of low-impact development is a sequential decision making process that can be illustrated by the flow chart shown in Figure 1.1. Several iterations may occur within each step until the appropriate approach to reduce stormwater impacts is determined. The procedures for each step are given in the following section. Design charts have been developed to determine the amount of storage required to maintain the existing volume and peak runoff rates to satisfy county storm water management requirements (Appendices A, B, and C).

4.2 DATA COLLECTION

The basic information used to develop the low-impact development site plan and used to determine the Runoff Curve Number (CN) and Time of Concentration (Tc) for the pre- and post-development condition is the same as conventional site plan and stormwater management approaches.

4.3 DETERMINING THE LID RUNOFF CURVE NUMBER

The determination of the low-impact development CN requires a detailed evaluation of each land cover within the development site. This will allow the designer to take full advantage of the storage and infiltration characteristics of low-impact development site planning to maintain the CN. This approach encourages the conservation of more woodlands and the reduction of impervious area to minimize the needs of IMPs.

The steps for determining the low-impact development CN are as follows:

Step 1: Determine Percentage of Each Land Use/Cover.

In conventional site development, the engineer would refer to Figure 2.2.a of TR-55 (SCS, 1986) to select the CN that represents the proposed land use of the overall development (i.e., residential, commercial) without checking the actual percentages of impervious area, grass areas, etc. Because low-impact design emphasizes minimal site disturbance (tree preservation, site fingerprinting, etc.), it is possible to retain much of the pre-development land cover and CN.

Therefore, it is appropriate to analyze the site as discrete units to determine the CN. Table 4.1 lists representative land cover CNs used to calculate the composite "custom" low-impact development CN.

Step 2: Calculate Composite Custom CN.

The initial composite CN is calculated using a weighted approach based on individual land covers *without* considering disconnectivity of the site imperviousness. This is done using Equation 4.1. This weighted approach is illustrated in Example 4.1.

TABLE 4.1. REPRESENTATIVE LID CURVE NUMBERS

Land Use/Cover	Curve Number for Hydrologic Soils Groups[1]			
	A	**B**	**C**	**D**
Impervious Area	98	98	98	98
Grass	39	61	74	80
Woods (fair condition)	36	60	73	79
Woods (good condition)	30	55	70	77

[1]Figure 2.2a, TR-55 (SCS, 1986).

$$CN_c = \frac{CN_1 A_1 + CN_2 A_2 ... + CN_j A_j}{A_1 + A_2 ... + A_j} \quad \text{Eq. 4.1}$$

Where:

CNc = composite curve number;

A_j = area of each land cover; and

CN_j = curve number for each land cover.

Overlays of SCS Hydrologic Soil Group (HSG) boundaries onto homogeneous land cover areas are used to develop the low-impact development CN. What is unique about the low-impact development custom-made CN technique is the way this overlaid information is analyzed as small discrete units that represent the hydrologic condition, rather than a conventional TR-55 approach that is based on a representative national average. This is appropriate because of the emphasis on minimal disturbance and retaining site areas that have potential for high storage and infiltration.

This approach provides an incentive to save more trees and maximize the use of HSG A and B soils for recharge. Careful planning can result in significant reductions in post-development runoff volume and corresponding stormwater management costs.

Step 3: Calculate low-impact development CN based on the connectivity of site impervious area.

When the impervious areas are less than 30 percent of the site, the percentage of the unconnected impervious areas within the watershed influences the calculation of the CN (SCS, 1986). Disconnected impervious areas are impervious areas without any direct connection to a drainage system or other impervious surface. For example, roof drains from houses could be directed onto lawn areas where sheet flow occurs, instead of to a swale or driveway. By increasing the ratio of disconnected impervious areas to pervious areas on the site, the CN and resultant runoff volume can be reduced. Equation 4.2 is used to calculate the CN for sites with less than 30 percent impervious area.

Example 4.1: Detailed CN Calculation

Given:

One-acre residential lot

Conventional CN: 68 (From TR-55 Table 2.2a-Runoff curve numbers for urban areas (SCS, 1986) Table 2.2a assumes HSG B, 20% imperviousness with a CN of 98 and 80% open space in good condition.

Custom-made LID CN: CN for individual land covers based on Table 2.2a. Assume 25% of the site will be used for reforestation/landscaping (see Figure 3.1) HSG B.

Procedure:

Step 1: Determine percentage of each land cover occurring on site and the CN associated with each land cover.

Land Use	HSG (1)	CN (2)	% of Site (3)	Land Coverage (ft^2) (4)
Impervious (Directly Connected)	B	98	5	2,178
Impervious (Unconnected)	B	98	10	4,356
Open Space (Good Condition, Graded)	B	61	60	26,136
Woods (Fair Condition)	B	55	25	10,890

Step 2: Calculate composite custom CN (using Equation 4.1).

$$CN_c = \frac{98 \times 4{,}356 + 98 \times 2{,}178 + 61 \times 26{,}136 + 55 \times 10{,}890}{43{,}560}$$

$$CN_c = 65$$

Step 3: Calculate low-impact development CN based on the connectivity of the site imperviousness (using Equation 4.2).

$$CN_p = \frac{61 \times 26{,}136 + 55 \times 10{,}890}{37{,}026}$$

$$CN_p = 59.2$$

$$R = \frac{10}{15}$$

$$R = 0.67$$

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right) \times (98 - CN_p) \times (1 - 0.5 \times R)$$

$$CN_c = 59.2 + \left(\frac{15}{100}\right) \times (98 - 59.2) \times (1 - 0.5 \times 0.67)$$

$$CN_c = 63.1 (\text{use } 63)$$

LID custom CN of 63 is less than conventional CN of 68 (predevelopment CN is 55).

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right) \times (98 - CN_p) \times (1 - 0.5R) \quad \text{Eq. 4.2}$$

where:

R = ratio of unconnected impervious area to total impervious area;

CN_c = composite CN;

CN_p = composite pervious CN; and

P_{imp} = percent of impervious site area.

Example 4.1 uses steps 1 through 3 to compare the calculation of the curve number using conventional and low-impact development techniques using the percentages of land cover for a typical 1-acre residential lot from Figure 3.1.

4.4 DEVELOPMENT OF THE TIME OF CONCENTRATION (TC)

The pre- and post-development calculation of the Tc for low-impact development is exactly the same as that described in the TR-55 (SCS, 1986) and NEH-4 (SCS, 1985) manuals.

4.5 LOW-IMPACT DEVELOPMENT STORMWATER MANAGEMENT REQUIREMENTS

Once the CN and Tc are determined for the pre- and post-development conditions, the stormwater management storage volume requirements can be calculated. The low-impact development objective is to maintain all the pre-development volume, pre-development peak runoff rate, and frequency. The required storage volume is calculated using the design charts in Appendices A, B, and C for different geographic regions in the nation.

As stated previously, the required storage volume is heavily dependent on the intensity of rainfall (rainfall distribution). Since the intensity of rainfall varies considerably over geographic regions in the nation, the National Resource Conservation Service (NRCS) developed four synthetic 24-hour rainfall distributions (I, IA, II, and III) from available National Weather Service (NWS) duration-frequency data and local storm data. Type IA is the least intense and type II the most intense short duration rainfall. Figure 4.1. shows approximate geographic boundaries for these four distributions.

The remaining low-impact development hydrologic analysis techniques are based on the premise that the post-development Tc is the same as the pre-development condition. If the post-development Tc does not equal the pre-development Tc, additional low-impact development site design techniques must be implemented to maintain the Tc.

Three series of design charts are needed to determine the storage volume required to control the increase in runoff volume and peak runoff rate using retention and detention practices. The required storages shown in these design charts are presented as a depth in hundredths of an inch (over the development site). Equation 4.3 is used to determine the volume required for IMPs.

Volume = (depth obtained from the chart) x (development size) / 100 Eq. 4.3



Figure 4.1. Approximate Geographic Boundaries for NRCS Rainfall Distributions.

It is recommended that 6-inch depth be the maximum depth for bioretention basins used in low-impact development.

The amount, or depth, of exfiltration of the runoff by infiltration or by the process of evapotranspiration is not included in the design charts. Reducing surface area requirements through the consideration of these factors can be determined by using Equation 4.4.

$$\text{Volume of site area for IMPs} = (\text{initial volume}) \times (100 - x) / 100 \qquad \text{Eq. 4.4}$$

where: x = % of the storage volume infiltrated and/or reduced by evaporation or transpiration. x% should be minimal (less than 10% is considered).

Stormwater management is accomplished by selecting the appropriate IMP, or combination of IMPs, to satisfy the surface area and volume requirements calculated from using the design charts. The design charts to be used to evaluate these requirements are:

- Chart Series A: Storage Volume Required to Maintain the Predevelopment Runoff Volume Using Retention Storage (Appendix A).
- Chart Series B: Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Retention (Appendix B).
- Chart Series C: Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Detention (Appendix C).

These charts are based on the following general conditions:

- The land uses for the development are relatively homogeneous throughout the site.
- The stormwater management measures are to be distributed evenly across the development, to the greatest extent possible.
- The design storm is based on 1-inch increments. Use linear interpolation for determining intermediate values.

The procedure to determine the IMP requirements is outlined in Figure 4.2 and described in the following sections.

Step 1: Determine storage volume required to maintain predevelopment volume or CN using retention storage.

The post-development runoff volume generated as a result of the post-development custom-made CN is compared to the predevelopment runoff volume to determine the surface area required for volume control. Use Chart Series A: Storage Volume Required to Maintain the Predevelopment Runoff Volume using Retention Storage. The procedure for calculating the site area required for maintaining runoff volume is provided in Example 4.2. It should be noted that the practical and reasonable use of the site must be considered. The IMPs must not restrict the use of the site.

The storage area, expressed is for runoff volume control only; additional storage may be required for water quality control. The procedure to account for the first ½-inch of runoff from impervious areas, which is the current water quality requirement, is found in Step 2.

Step 2: Determine storage volume required for water quality control.

The surface area, expressed as a percentage of the site, is then compared to the percentage of site area required for water quality control. The volume requirement for stormwater management quality control is based on the requirement to treat the first ½-inch of runoff (approximately 1,800 cubic feet per acre) from impervious areas. This volume is translated to a percent of the site area by assuming a storage depth of 6 inches. The procedure for calculating the site area required for quality control is provided in Example 4.3. The greater number, or percent, is used as the required storage volume to maintain the CN.

From the *results* of Example 4.3, 0.1" of storage is required for water quality using retention; from Example 4.2, 0.35" of storage is required to maintain the runoff volume using retention. Since the volume required to maintain the runoff volume is larger, in this case 0.35" of storage over the site should be reserved for retention IMPs.

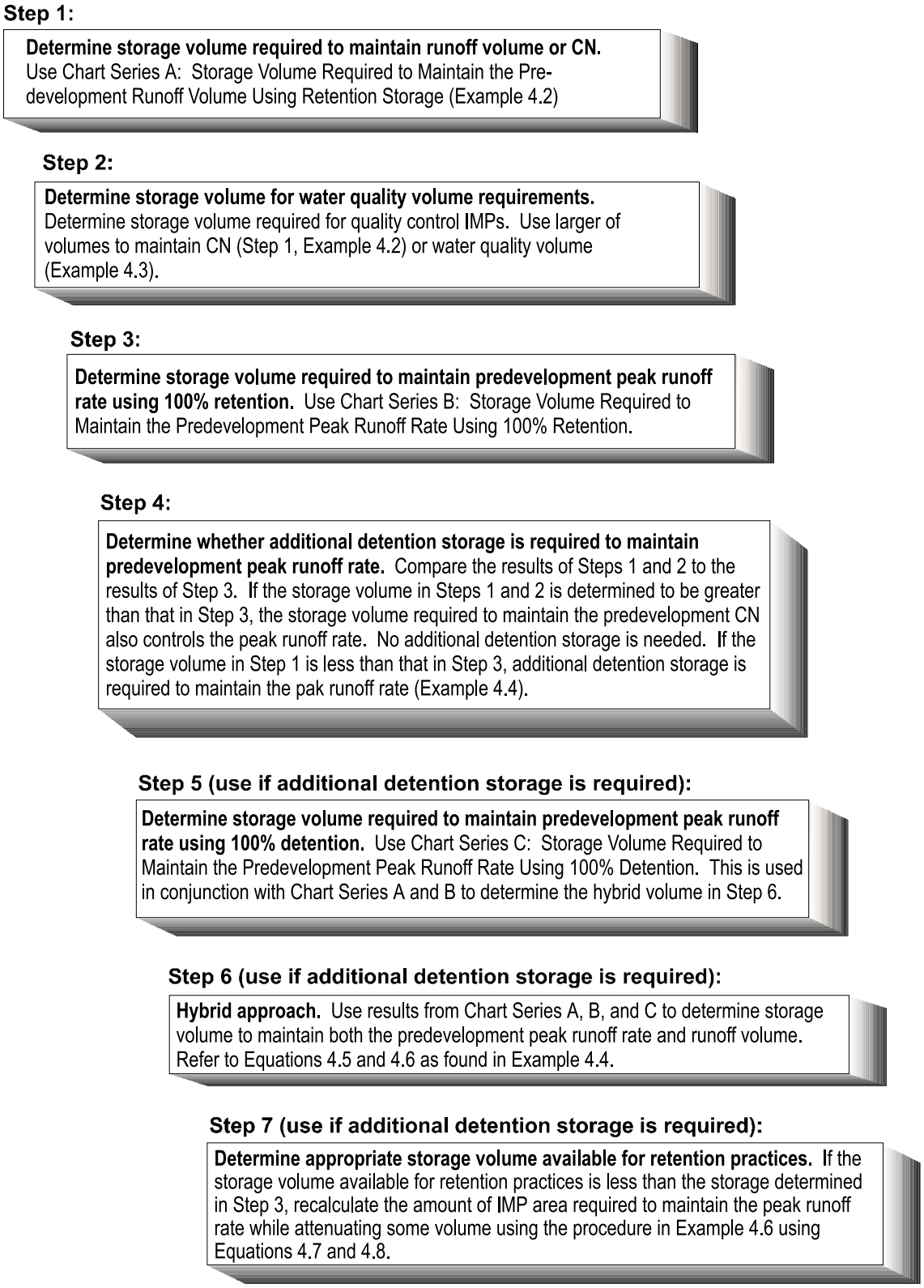

Figure 4.2. Procedure to Determine Storage Volume Required for IMPs to Maintain Predevelopment Runoff Volume and Peak Runoff Rate.

Example 4.2: Determine Site Area Required to Maintain Volume (CN) Using Chart Series A: Storage Volume Required to Maintain the Predevelopment Runoff Volume Using Retention Storage

Given:

Site Area is 18 acres

Existing CN is 60

Proposed CN is 65

Design storm is 5 inches

Design depth of IMP is 6 inches

Solution: Use Chart Series A: Storage Volume Required to Maintain Runoff Volume or CN.

0.35" of storage over the site is required to maintain the runoff volume.

Therefore: if 6" design depth is used, 1.1 acres (18 acres x 0.35 / 6) of IMPs distributed evenly throughout the site are required to maintain the runoff volume, or CN.

Additional Considerations:

1) Account for depths other than 6 inches:

Site of IMP Area = 1.1 acres, if 6" depth is used

Depth of IMPs = 4"

Site of IMP Area = 1.1 x 6"/4"

Site of IMP Area = 1.65 acres

2) Account for infiltration and/or evapotranspiration (using Equation 4.4)

If 10% of the storage volume is infiltrated and/or reduced by evaporation and transpiration.

Site of IMP Area = (storage volume) x (100 - X) / 100

Site of IMP Area =1.1 x (100-10)/100

Area for IMP Storage = 1.0 acre

Example 4.3: Calculation of Volume, or Site Area, for Water Quality Control

Given:

Site area is 18 acres

Impervious area is 3.6 acres (20%)

Depth of IMP is 6 inches

Solution:

Water quality requirement is for the first ½ inch of runoff from impervious areas

(18 acres x 20%) x 0.5" / 18 acres = 0.1" storage for water quality

0.1" is less than 0.35" (from example 4.2). Therefore, use storage for runoff volume control to meet water quality requirement.

Step 3: Determine storage volume required to maintain peak stormwater runoff rate using 100 percent retention.

The percentage of site area or amount of storage required to maintain the predevelopment peak runoff rate is based on *Chart Series B: Percentage of Site Area Required to Maintain Predevelopment Peak Runoff Rate Using 100% Retention (Appendix B).* This chart is based on the relationship between storage volume, $\forall_s / \forall_r$, and discharge, Q_o / Q_i, to maintain the predevelopment peak runoff rate.

Where: *Vs* = volume of storage to maintain the predevelopment peak runoff rate using 100% retention;

Vr = post development peak runoff volume;

Qo = peak outflow discharge rate; and

Qi = peak inflow discharge rate.

The relationship for retention storage to control the peak runoff rate is similar to the relationship for detention storage. Figure 4.3 is an illustration of the comparison of the storage volume/discharge relationship for retention and detention. Curve A is the relationship of storage volume to discharge to maintain the predevelopment peak runoff rate using the detention relationship from Figure 6-1 of the TR-55 manual (SCS, 1986) for a Type II 24-hour storm event. Curve B is the ratio of storage volume to discharge to maintain the predevelopment peak runoff rate using 100 percent retention. Note that the volume required to maintain the peak runoff rate using detention is less than the requirement for retention. This is graphically demonstrated in Figure 4.4.

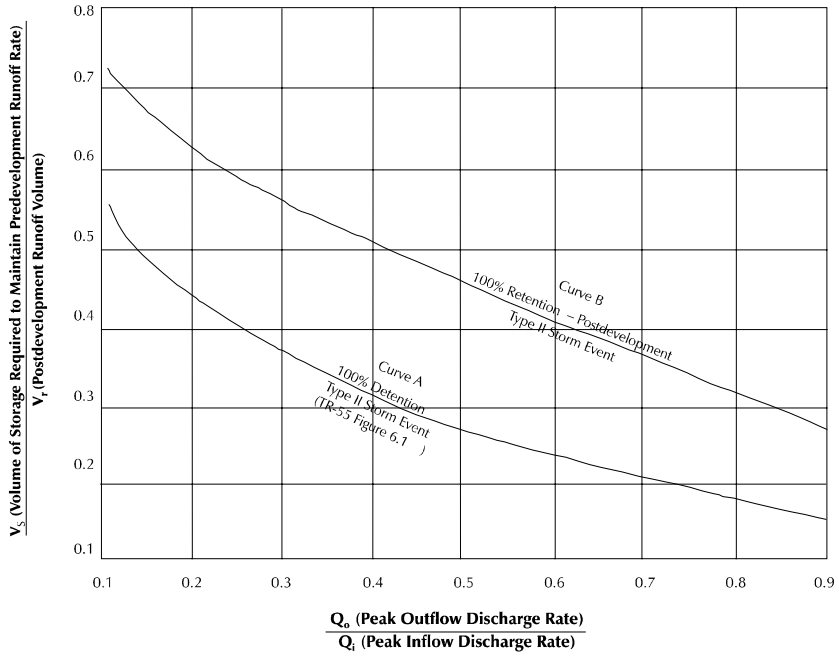

Figure 4.3. Comparison of Retention of Storage Volumes Required to Maintain Peak Runoff Rate Using Retention and Detention.

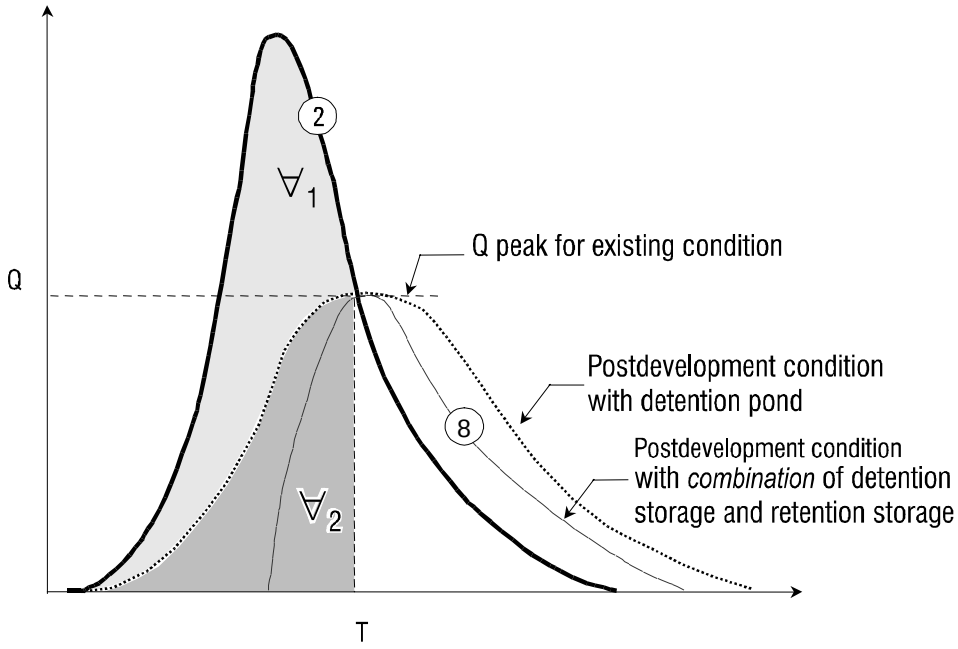

Figure 4.4. Storage Volume Required to Maintain Peak Runoff Rate

- For hydrograph 2, refer to Figure 3.2 for description.
- For hydrograph 8, refer to Figure 3.5 for description.

$\forall_1$ is the storage volume required to maintain the predevelopment peak discharge ratio using 100% detention storage. The combination of $\forall_1$ and $\forall_2$ is the storage volume required to maintain the predevelopment peak discharge rate using 100% retention storage.

The following calculations apply to Design Chart Series B:

- The Tc for the post-development condition is equal to the Tc for the predevelopment condition. This equality can be achieved by techniques such as maintaining sheet flow lengths, increasing surface roughness, decreasing the amount and size of storm drain pipes, and decreasing open channel slopes. Section 3.2 provides more details on these techniques.
- IMPs are to be distributed evenly across the development cite.

If the Tc is equal for the predevelopment and post-development conditions, the peak runoff rate is independent of Tc for retention and detention practices. The difference in volume required to maintain the predevelopment peak runoff rate is practically the same if the Tcs for the predevelopment and post-development conditions are the same. These concepts are illustrated in Figure 4.5. In Figure 4.5, the difference in the required IMP area between a Tc of 0.5 and a Tc of 2.0 is minimal if the predevelopment and post-development Tcs are maintained.

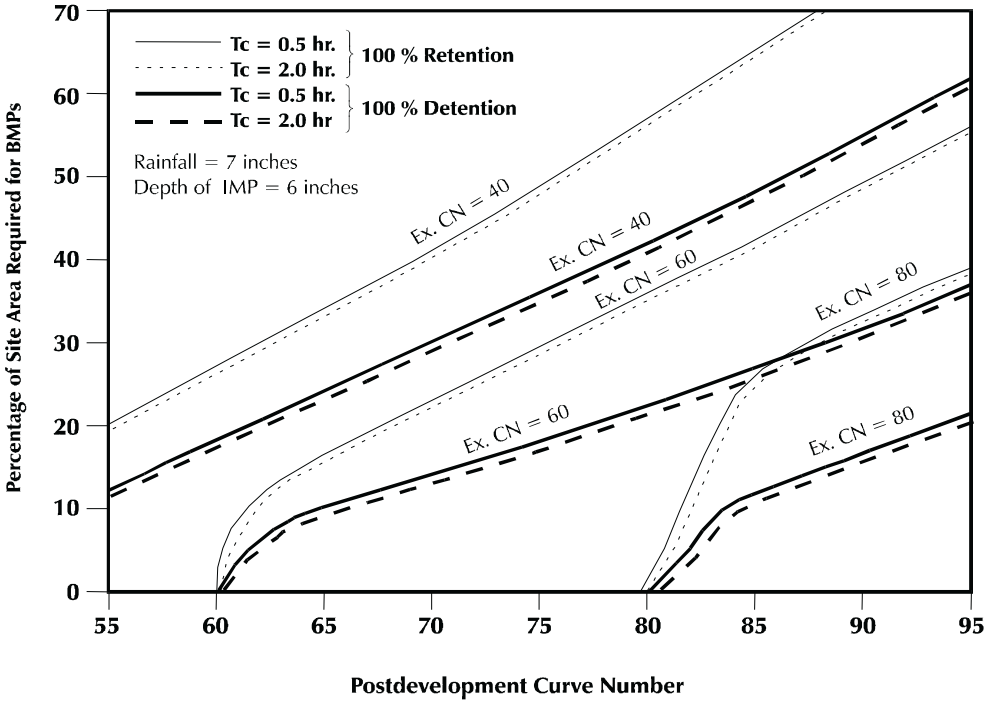

Figure 4.5. Comparison of Storage Volumes for Various Tcs.

Step 4: Determine whether additional detention storage is required to maintain the predevelopment peak runoff rate.

The storage volume required to maintain the predevelopment runoff volume using retention, as calculated in Step 1, might or might not be adequate to maintain both the predevelopment volume and peak runoff rate. As the CNs diverge, the storage requirement to maintain the volume is much greater than the storage volume required to maintain the peak runoff rate. As the CNs converge, however, the storage required to maintain the peak runoff rate is greater than that required to maintain the volume. Additional detention storage will be required if the storage volume required to maintain the runoff volume (determined in Step 1) is less than the storage volume required to maintain the predevelopment peak runoff rate using 100 percent retention (determined in Step 3).

The combination of retention and detention practices is defined as a hybrid approach. The procedure for determining the storage volume required for the hybrid approach is described in Step 5.

Table 4.2 illustrates the percentage of site area required for volume and peak control for representative curve numbers. Using a 5-inch type II 24-hour storm event and 6" design depth, with a predevelopment CN of 60, the following relationships exist:

- For a post-development CN of 65, 5.9 percent of the site area (column 4) is required for retention practices to maintain the predevelopment volume. To maintain the predevelopment peak runoff rate (column 5), 9.5 percent of the site is required. Therefore, additional detention storage or a hybrid approach (calculated in column 7) is required.

Table 4.2. Representative Percentages of Site Required for Volume and Peak Control

Type of 24-Hour Storm Event (1)	Runoff Curve No.		% of Area Needed for IMP				Percent of Volume Retention for Hybrid Design (Eq. 4.5) (8)
	Existing (2)	Proposed (3)	Volume Control Using 100% Retention Chart Series A (4)	Peak Control Using 100% Retention Chart Series B (5)	Peak Control Using 100% Detention Chart Series C (6)	Hybrid Design (Eq. 4.6) (7)	
3"	50	55	1.7	1.6	0.9	1.7	100
		60	4.0	3.4	2.4	4.0	100
		65	6.9	6.2	4.5	6.9	100
		70	10.4	9.3	7.3	10.4	100
		80	19.3	18.0	15.8	19.3	100
	60	65	2.9	3.9	2.3	3.6	80
		70	6.3	6.7	4.4	6.6	96
		75	10.5	10.0	7.1	10.5	100
		90	27.5	24.9	18.7	27.5	100
	70	75	4.1	5.9	3.4	5.3	77
		80	8.9	9.7	5.8	9.5	94
		85	14.6	13.9	8.8	14.6	100
		90	21.2	18.7	12.6	21.2	100
	75	80	4.8	7.5	4.2	6.6	73
		85	10.5	11.8	7.0	11.4	91
		90	17.1	16.6	10.2	17.1	100
5"	50	55	4.8	6.9	4.0	6.3	77
		60	10.1	11.1	6.9	10.9	93
		65	16.0	15.6	10.4	16.0	100
		70	22.4	20.6	14.5	22.4	100
		80	36.7	32.8	23.9	36.7	100
	60	65	5.9	9.5	5.3	8.3	71
		70	12.3	14.6	8.4	13.9	88
		75	19.1	19.8	12.0	19.6	97
		90	42.9	37.2	25.3	42.9	100
	70	75	6.9	13.2	7.2	10.9	63
		80	14.3	18.9	10.7	17.4	82
		85	22.2	24.5	14.3	23.8	93
		90	30.7	30.5	18.2	30.7	100
	75	80	7.4	15.0	8.1	12.3	60
		85	15.3	20.6	11.6	18.9	81
		90	23.8	26.7	15.2	25.7	92
7"	50	55	7.6	12.3	6.8	10.7	71
		60	15.6	18.6	10.7	17.7	88
		65	23.9	25.0	15.1	24.7	97
		70	32.5	31.4	19.6	32.5	100
		80	50.5	44.5	30.0	50.5	100
	60	65	8.3	16.6	9.0	13.6	61
		70	16.9	23.2	13.2	21.2	80
		75	25.8	29.9	17.3	28.7	90
		90	53.7	49.7	30.7	53.7	100
	70	75	8.9	20.4	10.9	16.1	55
		80	17.9	26.8	14.7	23.8	75
		85	27.2	33.4	18.9	31.5	87
		90	36.7	42.3	23.0	39.2	94
	75	80	9.1	22.1	11.5	17.1	53
		85	18.4	28.6	15.6	25.1	73
		90	27.9	35.3	19.8	32.9	85

- For a post-development CN of 90, 42.9 percent of the site area (column 4) is required for retention practices to maintain the predevelopment volume. To maintain the predevelopment peak runoff rate (column 5) 37.2 percent of the site is required. Therefore, the storage required to maintain the runoff volume is also adequate to maintain the peak runoff rate. However, 42.9 percent of the site for IMPs is not a practical and reasonable use of the site. Refer to Step 7, hybrid approach, for a more reasonable combination of retention and detention storage.

Step 5: Determine storage required to maintain predevelopment peak runoff rate using 100 percent detention. (This step is required if additional detention storage is needed.)

Chart Series C: Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Detention is used to determine the amount of site area to maintain the peak runoff rate only. This information is needed to determine the amount of detention storage required for hybrid design, or where site limitations prevent the use of retention storage to maintain runoff volume. This includes sites that have severely limited soils for infiltration or retention practices. The procedure to determine the site area is the same as that of Step 3. Using Chart Series C, the following assumptions apply:

- The Tc for the post-development condition is equal to the Tc for the predevelopment condition.
- The storage volume, expressed as a depth in hundredths of an inch (over the development site), is for peak flow control.

These charts are based on the relationship and calculations from Figure 6.1 (Approximate Detention Basin Routing for Rainfall Types I, IA, II and III) in TR-55 (SCS, 1986).

Step 6: Use hybrid facility design (required for additional detention storage).

When the percentage of site area for peak control exceeds that for volume control as determined in Step 3, a hybrid approach must be used. For example, a dry swale (infiltration and retention) may incorporate additional detention storage. Equation 2.5 is used to determine the ratio of retention to total storage. Equation 2.6 is then used to determine the additional amount of site area, above the percentage of site required for volume control, needed to maintain the predevelopment peak runoff rate.

$$x = \frac{50}{(\forall_{R100} - \forall_{D100})} \times (-\forall_{D100} + \sqrt{\forall^2_{D100} + 4 \times (\forall_{R100} - \forall_{D100}) \times \forall R}\ ) \qquad \text{Eq. 4.5}$$

where

$\forall R$ = Storage Volume required to maintain predevelopment runoff volume (Chart Series A)

$\forall_{R_{100}}$ = Storage Volume required to maintain predevelopment peak runoff rate using 100% retention (Chart Series B)

$\forall_{D_{100}}$ = Storage Volume required to maintain predevelopment peak runoff rate using 100% detention (Chart Series C)

x = Area ratio of retention storage to total storage

and the hybrid storage can be determined as:

$$H = \forall R \text{ x } (100 \div x) \qquad \text{Eq. 4.6}$$

Equations 4.5 and 4.6 are based on the following assumptions:

- *x*% of the total storage volume is the retention storage required to maintain the predevelopment CN calculated from Chart Series A: Storage Volume Required to Maintain Predevelopment Volume using Retention Storage.
- There is a linear relationship between the storage volume required to maintain the peak predevelopment runoff rate using 100% retention and 100% detention (Chart Series B and C)

The procedure for calculating hybrid facilities size is shown in Example 4.4.

Example 4.4: Calculation of Additional Storage Above Volume Required to Maintain CN and Maintain Predevelopment Peak Runoff Rate Using Hybrid Approach

Given:

- 5-inch Storm Event with Rainfall Distribution Type II
- Existing CN = 60
- Proposed CN = 65
- Storage volume required to maintain volume (CN) using retention storage = 0.35" (from Chart Series A)
- Storage volume required to maintain peak runoff rate using 100% retention = 0.62" (from Chart Series B)
- Storage volume required to maintain peak runoff rate using 100% detention = 0.31" (from Chart Series C)

Step 1: Solve for *x* (ratio of retention to total storage) using Equation 4.5:

$$\chi = \frac{50}{(.62-.31)} \times \left(-.31 + \sqrt{.31^2 + 4 \times (.62-.31) \times .35}\right)$$

$$\chi = 68$$

Therefore: 0.35" of storage needed for runoff volume control is 68% of the total volume needed to maintain both the predevelopment volume and peak runoff rates.

Step 2: Solve for the total area to maintain both the peak runoff rate and volume using Equation 4.6.

$$H = .35 \times \frac{100}{68}$$

$$H = 0.51"$$

Therefore , the difference between 0.35" and 0.51" is the additional detention area needed to maintain peak discharge.

Step 7: Determine hybrid amount of IMP site area required to maintain peak runoff rate with partial volume attenuation using hybrid design (required when retention area is limited).

Site conditions, such as high percentage of site needed for retention storage, poor soil infiltration rates, or physical constraints, can limit the amount of site area that can be used for retention practices. For poor soil infiltration rates, bioretention is still an acceptable alternative, but an underdrain system must be installed. In this case, the bioretention basin is considered detention storage.

When this occurs, the site area available for retention IMPs is less than that required to maintain the runoff volume, or CN. A variation of the hybrid approach is used to maintain the peak runoff rate while attenuating as much of the increased runoff volume as possible. First, the appropriate storage volume that is available for runoff volume control (∀R′) is determined by the designer by analyzing the site constraints. Equation 4.7 is used to determine the ratio of retention to total storage. Equation 4.8 is then used to determine the total site IMP area in which the storage volume available for retention practices (∀R') substitutes the storage volume required to maintain the runoff volume.

$$X' = \frac{50}{(\forall_{R100} - \forall_{D100})} \times (-\forall_{D100} + \sqrt{\forall^2_{D100} + 4 \times (\forall_{R100} - \forall_{D100}) \times \forall R'}) \qquad \text{Eq. 4.7}$$

Where ∀R′ = storage volume acceptable for retention IMPs. The total storage with limited retention storage is:

$$H' = \forall R' \text{ x } (100 \div \chi') \qquad \text{Eq. 4.8}$$

where H′ is hybrid area with a limited storage volume available for retention IMPs.

Example 4.5 illustrates this approach.

4.6 DETERMINATION OF DESIGN STORM EVENT

Conventional stormwater management runoff quantity control is generally based on not exceeding the predevelopment peak runoff rate for the 2-year and 10-year 24-hour Type II storm events. The amount of rainfall used to determine the runoff for the site is derived from Technical Paper 40 (Department of Commerce, 1963). For Prince George's County, these amounts are 3.3 and 5.3 inches, respectively. The 2-year storm event was selected to protect receiving channels from sedimentation and erosion. The 10-year event was selected for adequate flow conveyance considerations. In situations where there is potential for flooding, the 100-year event is used.

The criteria used to select the design storm for low-impact development are based on the goal of maintaining the predevelopment hydrologic conditions for the site. The determination of the design storm begins with an evaluation of the predevelopment condition. The hydrologic approach of low-impact development is to retain the same

Example 4.5: Calculation of Percentage of Site Area Required to Maintain the Peak Runoff Rate Using the Hybrid Approach of Retention and Detention

Given:

- 5-inch storm event with rainfall distribution Type II
- Existing CN = 60
- Proposed CN = 65
- Storage volume required to maintain volume (CN) = 0.35" (From Chart Series A)
- Storage volume required to maintain peak runoff rate using 100% retention = 0.62" (from Chart Series B)
- Storage volume required to maintain peak runoff rate using 100% detention = 0.31" (from Chart Series C)
- Only half of the required site area is suitable for retention practices, remainder must incorporate detention. ($\forall R'$ = 0.35 x 0.50 = 0.18")

Step 1: Determine appropriate amount of overall IMP area suitable for retention practices.

Half of area is appropriate (given above). Use Equation 2.7:

$$\chi' = \frac{50}{(.62 - .31)} \times \left(-.31 + \sqrt{.31^2 + 4 \times (.62 - .31) \times .18}\right)$$

$$\chi' = 41.2\%$$

Therefore, 0.18" of storage available for runoff volume control is 41.2% of the total volume needed for maintaining the predevelopment peak runoff rate.

Step 2: Solve for the total area required to maintain the peak runoff rate using Equation 4.8.

Solve for H′

$$H' = 0.18 \times \frac{100}{41.2}$$

$$H' = 0.43"$$

Therefore, totally 0.43" of the site is required to maintain the predevelopment peak runoff rate but not the runoff volume. Of the 0.43" storage, 0.18" of the storage is required for retention volume.

amount of rainfall within the development site as that retained by woods, in good condition, and then to gradually release the excess runoff as woodlands would release it. By doing so, we can emulate, to the greatest extent practical, the predevelopment hydrologic regime to protect watershed and natural habitats. Therefore, the predevelopment condition of the low-impact development site is required to be *woods in good condition*. This requirement is identical to the State of Maryland's definition of the predevelopment condition. The CN for the predevelopment condition is to be determined based on the land cover being woods in good condition and the existing HSG. The design storm is to be the greater of the rainfall at which direct runoff begins from a woods in good condition, with a modifying factor, or the 1-year 24-hour storm event. The rainfall at which direct runoff begins is determined using Equation 4.9. The initial rainfall amount at which direct runoff begins from a woodland is modified by multiplying this amount by a

factor of 1.5 account for the slower runoff release rate under the wooded predevelopment condition.

$$P = 0.2 \times \left(\frac{1000}{CN_c} - 10 \right) \qquad \text{Eq. 4.9}$$

where P is rainfall at which direct runoff begins.

A three-step process, illustrated in Example 4.6, is used to determine the design storm event.

Step 1: Determine the predevelopment CN.

Use an existing land cover of woods in good condition overlaid over the hydrologic soils group (HSG) to determine the composite site CN.

Step 2: Determine the amount of rainfall needed to initiate direct runoff.

Use Equation 4.9 to determine the amount of rainfall (P) needed to initiate direct runoff.

Step 3: Account for variation in land cover.

Multiply the amount of rainfall (P) determined in Step 2 by a factor of 1.5.

Example 4.6 demonstrates this approach.

Example 4.6: Determination of Design Storm

Step 1: Determine the predevelopment CN based on woods (good condition) and HSG.

Given: Site condition of 90% HSG soil type B and 10% HSG soil type C,
$CN_c = 0.9\ (55) + 0.1 \times (70)$
$CN_c \geq 56.5 \approx 57$ use 57

Step 2: Determine the amount of rainfall to initiate direct runoff using Equation 4.9.

$$P = 0.2 \times \left(\frac{1000}{57} - 10 \right)$$

P = 1.5 inches

Step 3: Multiply the amount of rainfall by a factor of 1.5.

Design rainfall = P x 1.5

Design rainfall = 1.5 inches x 1.5

Design rainfall = 2.25 inches

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APPENDIX A

STORAGE VOLUME REQUIRED TO MAINTAIN THE PRE-DEVELOPMENT RUNOFF VOLUME USING RETENTION STORAGE

APPENDIX B

STORAGE VOLUME REQUIRED TO MAINTAIN THE PRE-DEVELOPMENT PEAK RUNOFF RATE USING 100% RETENTION STORAGE

APPENDIX C

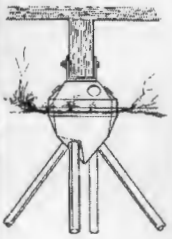
STORAGE VOLUME REQUIRED TO MAINTAIN THE PRE-DEVELOPMENT PEAK RUNOFF RATE USING 100% DETENTION STORAGE



LOW IMPACT DEVELOPMENT

TECHNICAL GUIDANCE MANUAL FOR PUGET SOUND









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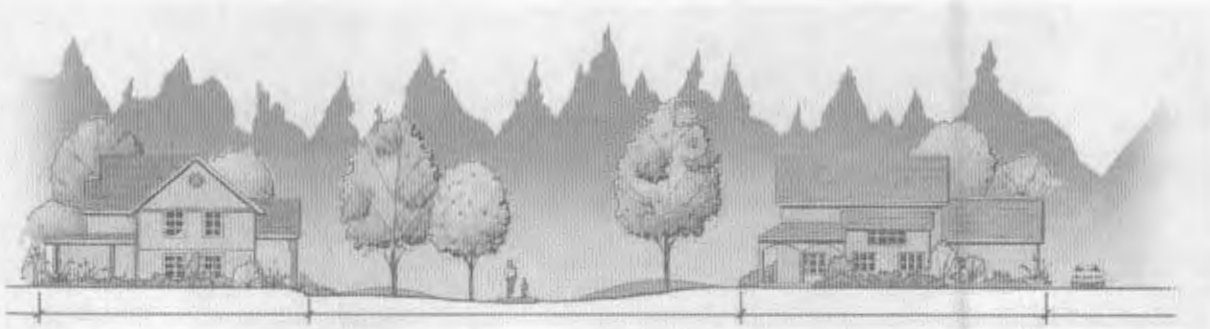

LOW IMPACT DEVELOPMENT

TECHNICAL GUIDANCE MANUAL FOR PUGET SOUND

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Permeable paver detail *(Gary Anderson).*

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Preface

Low impact development (LID) is a stormwater management strategy that emphasizes conservation and use of existing natural site features integrated with distributed, small-scale stormwater controls to more closely mimic natural hydrologic patterns in residential, commercial, and industrial settings.

Many of the tools used for LID are not new. Village Homes in Davis, California, constructed in the early 1970s, is perhaps the earliest recognized example of a residential subdivision that manages stormwater through open conveyance systems and provides storm flow retention in open space integrated throughout the development. During the early 1980's European cities began using distributed, integrated stormwater management practices to reduce flows from combined sewer systems. In the late 1980's, Larry Coffman with the Department of Environmental Resources in Prince George's County, Maryland began working on a plant, soil-microbe filter designed to mimic natural forest hydrologic characteristics (bioretention, or rain gardens). Today LID strategies are an integral part of Prince George's County's stormwater management approach and numerous developments across the U.S., Canada, and Europe include LID practices.

In Puget Sound, state and local government agencies and university extension programs have offered and continue to offer numerous workshops, conferences, and courses for engineers, planners, architects, and elected officials. These focus on the problems associated with stormwater runoff, the limitations of conventional management practices, and the LID approach to protect ground and surface waters. As a result of these efforts, several local governments and state agencies are incorporating LID techniques into their stormwater manuals, development regulations, and regional guidance. Many of the organizations are using LID techniques in commercial, residential, and municipal projects. The most active of these organizations include: the cities of Seattle, Olympia, and Bellingham; King, Snohomish, and Pierce counties; Washington departments of Ecology and Transportation; and the Puget Sound Action Team (Action Team).

Initial findings from limited monitoring in Puget Sound and other studies from the U.S., Europe, Canada, and Japan indicate that LID practices can be valuable tools to reduce the adverse effects of stormwater runoff on streams, lakes, wetlands, and Puget Sound. However, important questions remain regarding relative cost, design, maintenance, and long-term performance. To answer these questions and better understand the full potential and limitations of LID in the Puget Sound region, additional research and monitoring of individual LID techniques and pilot projects are needed.

Demonstration projects and monitoring are needed to understand the long-term performance and maintenance requirements of bioretention swales and cells, permeable paving, and other LID practices in difficult (and common) Puget Sound settings, such as native soils with low infiltration rates and higher urban densities. Pilot projects will also provide data comparing LID construction costs and market performance to conventional development and stormwater management strategies.

While uncertainties regarding LID exist, current data and the need for additional tools to manage stormwater runoff warrant initiating the next steps: (1) implement and

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monitor demonstration projects; (2) develop regulatory guidance for LID practices; and (3) remove local regulatory barriers that discourage use of LID strategies.

New stormwater management tools are needed to address a number of critical environmental issues facing Puget Sound. Chinook and chum salmon and bull trout are listed as threatened under the federal Endangered Species Act, and scientists have cited loss of habitat due to development and stormwater runoff as one factor that has contributed to their population declines. The Washington Department of Ecology (Ecology) estimates that about one-third of all polluted waters on the section 303(d) list are degraded because of stormwater runoff. Puget Sound is one of the best regions in the world to grow clams, oysters, and other shellfish, yet thousands of acres of shellfish growing areas are closed to harvest due to stormwater runoff and other pollutant sources. Finally, more than 70 smaller local governments in Puget Sound will soon be required to comply with a federally mandated stormwater permit under the National Pollutant Discharge Elimination System Program. Newly permitted local governments will be seeking stormwater management techniques that help them comply with permit conditions and protect surface waters in an efficient, cost-effective manner.

To better address these issues, two state offices have taken significant steps related to LID. Ecology, collaborating with local government stormwater managers and Washington State University, has completed initial guidelines for flow reduction credits when LID techniques are used in projects in western Washington. The credits, included in Ecology's 2005 *Stormwater Management Manual for Western Washington* and in Chapter 7 of this manual, will provide designers with additional tools to retain stormwater on-site and reduce the size of conventional facilities that control storm flows. The Action Team, the broad partnership to conserve and recover Puget Sound, has identified LID as a priority action for the 2001-03, 2003-05, and now the 2005-07 biennial work plans to the Washington State Legislature. This emphasis has produced a national conference, regional workshops, local technical and financial assistance, and special projects, including development of this technical guidance manual. The *Puget Sound Water Quality Management Plan*, the state and federal plan to protect and restore Puget Sound, also calls on all local governments in Puget Sound to adopt new or revise existing ordinances to allow and encourage LID techniques.

Purpose of this Manual

The purpose of this manual is to provide stormwater managers and site designers with a common understanding of LID goals, objectives, specifications for individual practices, and flow reduction credits that are applicable to the Puget Sound region.

In addition to the guidelines for specific practices, this manual provides research and data related to those practices to help managers and designers make informed decisions when adapting LID applications to their jurisdictions. Low impact development is a new and evolving management approach; accordingly, this document will evolve and be periodically updated as additional research becomes available and professionals in the region gain more practical experience. This is a technical manual and the information provided is targeted for engineers, planners, landscape architects, technical staff to policy makers, and developers.

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How this Manual is Organized

Chapter one of the manual sets the context for the LID approach with an introduction to Puget Sound lowland hydrology and the effects of urban development on streams, wetlands, and Puget Sound. Chapter one also establishes the goals and objectives for LID. Chapters on site assessment, planning and layout, vegetation protection, and clearing and grading follow, and emphasize the importance of planning and protecting native vegetation and soils in the LID approach. Chapter six provides general guidance for six integrated management practices (IMPs), as well as detailed construction and material specifications for many of the IMPs. Chapter seven provides the new credits in the Western Washington Hydrology Model that will allow engineers to reduce the size of conventional flow control facilities when using LID practices. Finally, several appendices include sample specifications, lists of plants appropriate for LID applications, and tables summarizing bioretention and permeable paving research. Bolded words within the text of the manual are defined in the glossary of terms.

Low Impact Development Applications

The LID approach can be applied in a variety of settings including: large lots in rural areas; low, medium, and high-density development within urban growth boundaries; redevelopment of highly urbanized areas; and commercial and industrial development. LID applications can be designed for use on glacial outwash and alluvium soils, as well as soils with low infiltration rates, such as dense silt loams or till mantled areas.

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1 Introduction

IN THIS CHAPTER...

- *Puget Sound hydrology*
- *Current stormwater management*
- *Impacts of urbanization*
- *Low impact development goals and objectives*

1.1 Puget Sound Hydrology

Native forests of the Puget Sound lowlands intercept, store, and slowly convey precipitation through complex pathways. Water budget studies of wet coniferous forests in western Washington, British Columbia, and the United Kingdom indicate that approximately 50 percent of the annual rainfall is intercepted by foliage and evaporated during the rainy season. Bauer and Mastin (1997) found that interception and evaporation from vegetation during the winter months (approximately 50 percent) far exceeded estimates for western Washington, and attributed the high rate to the large surface area provided by evergreen trees, relatively warm winter temperatures, and the advective evaporation of precipitation. Bidlake and Payne (2001) and Calder (1990) also found that the aerodynamically rough forest canopy and **advection energy** supported evaporation rates of intercepted precipitation that were higher than estimated radiation-based potential **evapotranspiration**.

Water budget studies of wet coniferous forests in western Washington, British Columbia, and the United Kingdom indicate that approximately 50 percent of the annual rainfall is intercepted by foliage and evaporated during the rainy season.

Native soils also play a critical role in storage and conveyance of Pacific Northwest (PNW) rainfall. Typically, 2 to 4 feet of soil, high in organic material and biologically active near the surface, overlays the subsurface geology. Solar radiation and air movement provide energy to evaporate surface soil moisture that contributes to the overall evapotranspiration component. Soil biota and organic matter chemically and physically bind mineral particles into stable aggregates that build soil structure, increase soil porosity, and provide 20 to 30 percent of active water storage by volume. Shallow subsurface flow (interflow) moves slowly down slope or down gradient over many hours, days or weeks through these upper soil layers. Depending on the underlying soil type and structure, 10 to 40 percent of the annual precipitation moves to deeper groundwater (Bauer and Mastin, 1997).

For most storm events, the gentle rainfall intensities are less than the combined capacity of the interception loss, and vegetation and soil storage in native Puget Sound forests; as a result, overland flow does not occur or is minimal (Booth, Hartley and Jackson, 2002). Instead, the storm flow moves downslope below the surface at a much slower rate than overland flow and displaces antecedent, subsurface water in areas near streams, lakes and wetlands (Bauer and Mastin, 1997). The displaced soil water adjacent to water bodies contributes to stream flows or wetland and lake levels rather than the entire watershed. As storms and the wet season progress, available soil storage capacity declines and the saturated or contributing areas near receiving waters increase as does the response to storm events (Booth et al., 2002).

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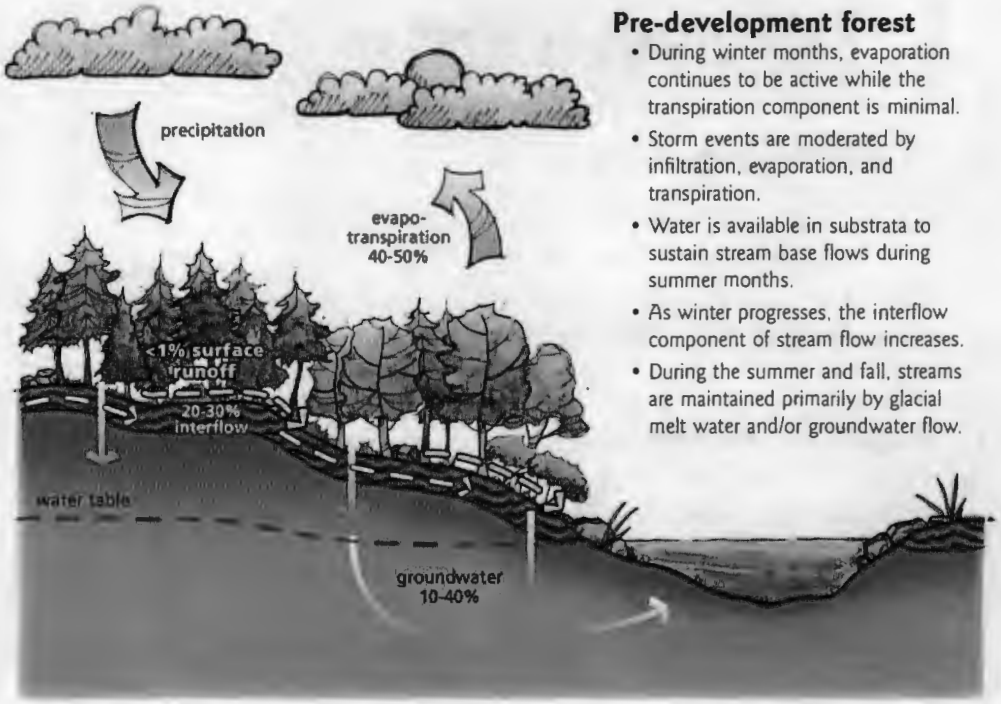

Figure 1.1 Water budget for pre-development Puget Sound lowland forests.

Graphic by AHBL Engineering

1.2 Impacts of Urbanization

The transition from a native landscape to a built environment increases the impervious surface coverage of roads, parking areas, sidewalks, rooftops, and landscaping. These changes reduce, disrupt or entirely eliminate native vegetation, upper soil layers, shallow depressions, and native drainage patterns that intercept, evaporate, store, slowly convey, and infiltrate stormwater. As development progresses, the area in small watersheds that contribute overland flow to receiving waters in minutes increases while the area that stores and delivers subsurface flow over periods of hours, days or weeks diminishes (Booth et al., 2002).

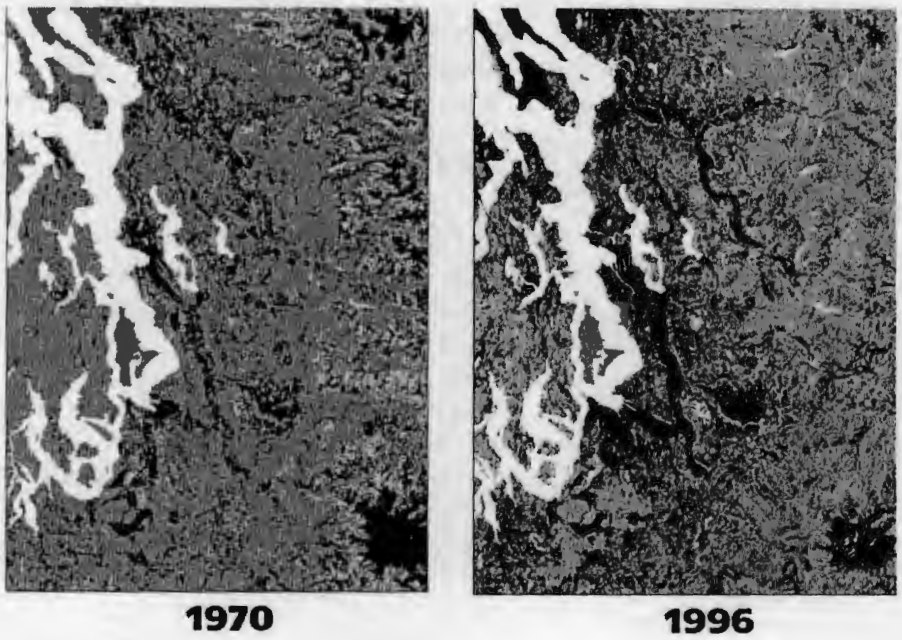

Figure 1.2 Satellite images of Puget Sound in 1970 and 1996. (Dark color in lowlands areas indicates clearing of vegetation and development.)

Source: American Forests

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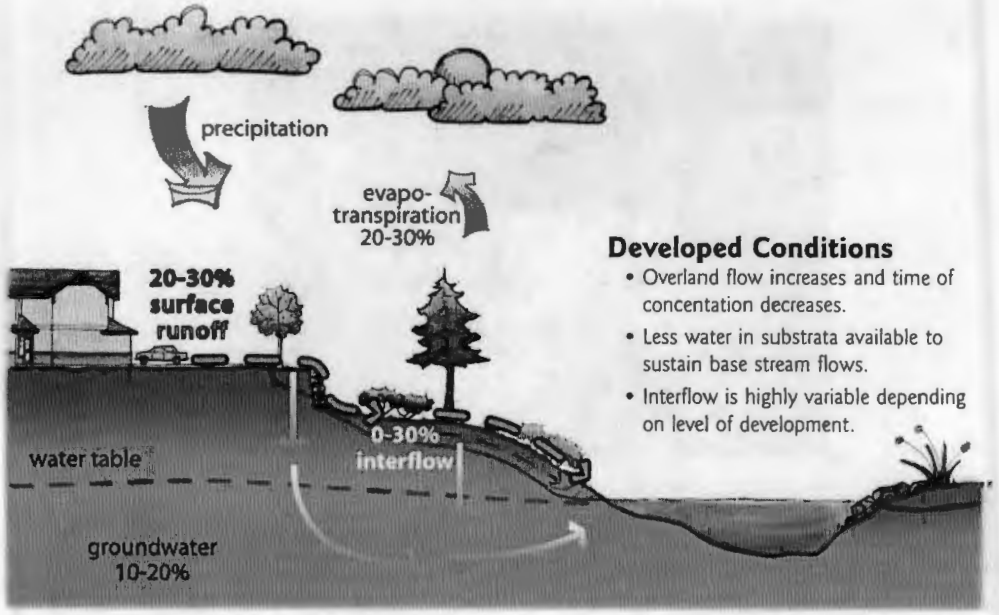

Figure 1.3 Water budget for typical suburban development in the Puget Sound lowlands.

Graphic by AHBL Engineering

Loss of native soils and vegetation within the watershed and associated changes in hydrologic regimes can significantly degrade stream habitat (Booth, 1991). **Bankful discharges**–the 1- to 1.5-year return storm flow that does much of the work to form a stream channel–increase in magnitude and frequency (Center for Watershed Protection [CWP], 2000a). Typical responses in streams exposed to high flows for longer periods of time include: excessive streambed and stream bank instability (May, Horner, Karr, Mar, and Welch, 1997); increased stream channel cross-sectional area (typically, cross sectional area is enlarged 2 to 5 times depending on the amount of total impervious area and other development factors (CWP, 2000a and March 2000); and overall loss of habitat structure, and hydraulic diversity (Booth, 1991). While water quality conditions (as defined by dissolved oxygen, temperature, sediment, various pollutant concentrations, and other parameters) are critical considerations for managing stream health, altered watershed hydrologic regimes and associated channel instability are a leading cause for in-stream physical habitat degradation and initial loss of **biotic integrity** (May et al., 1997).

Altered watershed hydrologic regimes and associated channel instability are a leading cause for in-stream physical habitat degradation and initial loss of biotic integrity.

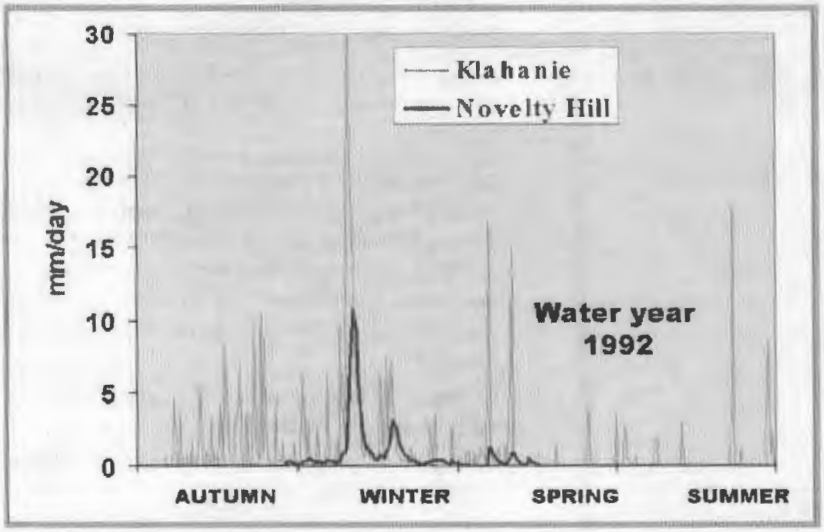

Figure 1.4 Hydrograph for an urban (Klahanie) and a rural watershed (Novelty Hill) in the Puget Sound lowlands. Storm flows increase in magnitude and frequency in the urban watershed.

Source: 'Hydrological Effects of Land-use Change in a Zero-order Catchment.' *Burges, Wigmosta and Meema, 1998.* Journal of Hydrologic Engineering. *Material reproduced with permission from the American Society of Civil Engineers.*

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Figure 1.5 Down-cut stream channel resulting from increased storm flow generated by nearby development (Gig Harbor Peninsula).
Photo courtesy of Hans Hunger

Streams respond to watershed urbanization through several other important mechanisms as outlined in Table 1.1 (MacCoy and Black, 1998; May et al., 1997; Staubitz, Bortleson, Semans, Tesoriero, and Black 1997; and Washington Department of Ecology [Ecology], 1999).

Table 1.1 Degradation of watershed conditions and stream response.

Change in watershed condition	Response
Increased drainage density due to road networks, road crossings and stormwater outfalls	Increased storm flow volume and frequency, and channel erosion Increased fine sediment and urban water pollutant loads Increased fish passage barriers
Increased fine sediment deposition	Reduced intergravel dissolved oxygen levels in streambed Loss of salmonid spawning and macroinvertebrate habitat
Loss or fragmentation of riparian areas	Reduced delivery of large woody debris Reduced bank stability and loss of bank habitat structure and complexity Reduced shading and temperature control
Reduced quantity and quality of large woody debris	Reduced channel stability, sediment storage, instream cover for fish and insects, loss of pool quality and quantity
Increased pollutant loads	Synthetic organic compounds and trace elements: some acutely toxic; tumors in fish; salmon and trout will alter spawning and migration behavior in presence of metals as low as <1% of lethal concentration; **endocrine disruptors** (18 of 45 suspected endocrine disrupting trace elements found in Puget Sound fish tissue) Nutrients: excessive aquatic plant growth; excessive **diurnal oxygen fluctuations** Synergistic influence of multiple pollutants unknown

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The cumulative impact of hydrologic alteration and the various other changes in watershed conditions can result in channel instability and degraded biotic integrity at low or typically rural levels of watershed development. Studies conducting empirical stream assessments observed physical degradation of channels with **effective impervious area** (EIA) percentages of less than 10 percent within the contributing watersheds (Booth et al., 2002). While impervious surface coverage generally is low at this density, forest clearing for pasture, lawns and hobby farms can be extensive across the rural landscape. Hydrologic analysis of the same watersheds (see Figure 1.6) observed the same relationship between low levels of imperviousness, changes in modeled stream flows (recurrence of pre-developed forest and developed flows), and stream channel stability. Booth, Hartley and Jackson (2002) note that observed channel instability is a relatively insensitive evaluation tool and the lack of observed degradation does not guarantee the absence of subtle, but important consequences for the physical or biologic health of streams.

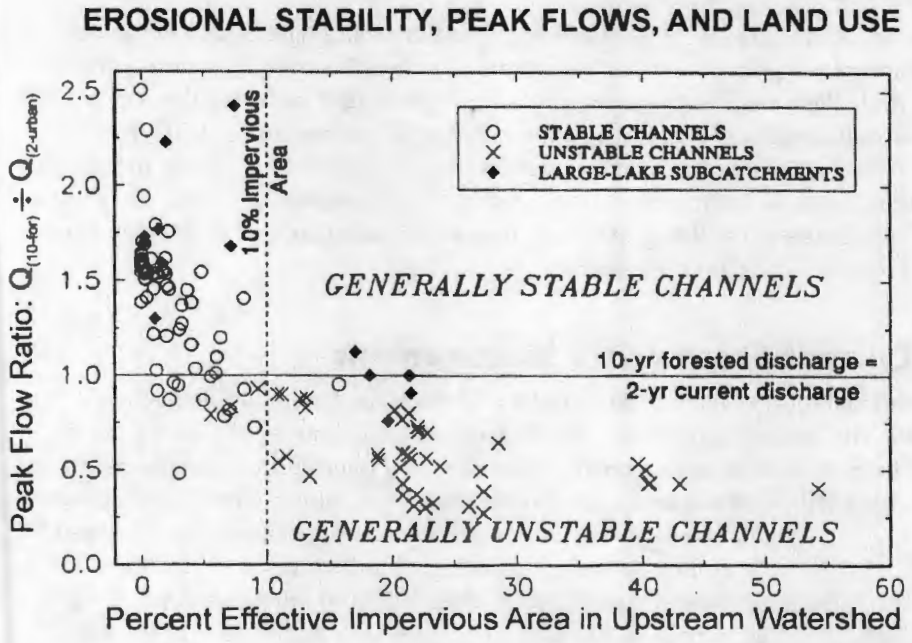

Figure 1.6 Observed stable and unstable stream channels in the Puget Sound lowlands plotted by percent EIA and ratio of modeled 10-year forested and 2-year urbanized discharges. Stable channels in this study consistently meet the apparent thresholds of EIA <10% and $Q_{(2\text{-urban})} \leq Q_{(10\text{-forest})}$ (Booth et al., 2002).

Graph courtesy of Booth and Jackson, 1997

The physical and chemical composition of wetlands and lakes are altered in response to land development as well. Typically, water levels in wetlands gradually rise in the beginning of the wet season and then subside slowly as the wet season ends. Wetland plant species have adapted to this fairly narrow and stable range of water depths and soil saturation (CWP, January 2000c). As development proceeds and impervious surfaces replace native vegetation and soils, water levels can rise rapidly in response to individual storms. A major finding in the Puget Sound Wetlands and Stormwater Management Program was that "hydrologic changes were having more immediate and measurable effects on composition of vegetation and amphibian communities than other conditions [monitored]" (Azous and Horner, 2001). Decline in wetland plant and amphibian species richness are likely when:

- Mean annual water level fluctuations exceed 20 centimeters per year.
- The frequency of **stage excursions** of 15 cm above or below pre-development condition exceeds an annual average of six.
- The duration of stage excursions of 15 cm above or below pre-development condition exceeds 72 hours per excursion.

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- The total dry period (when pools dry down to the soil surface everywhere in the wetland) increases or decreases by more than two weeks in any year (Azous and Horner, 2001).
- Increased water level fluctuations occur early in the growing season (CWP, January 2000c).

Increased water level fluctuations of this nature are observed when total impervious area within the drainage area exceeds 10 to 15 percent (Taylor, 1993).

Lakes and estuaries, while not as prone to morphological change due to altered hydrology, are highly susceptible to shoreline modifications and water quality degradation from urbanization. Phosphorus, bacteria and sediment are typical urban stormwater pollutants impacting lakes. Phosphorus is often a limiting nutrient in fresh water systems, and contributes to increased plant growth and diurnal oxygen level fluctuations that degrade wildlife habitat, recreational opportunities and other beneficial uses.

Bacteria can restrict or close shellfish growing areas in Puget Sound to harvest. Nonpoint source pollution (including stormwater runoff) is now "the most common cause of shellfish classification downgrades in Puget Sound, reducing the region's commercially approved acreage by approximately 25 percent since 1980" (PSAT, 2004). Toxic pollutants associated with stormwater sediments (e.g., heavy metals and polycyclic aromatic hydrocarbons) that settle in urban estuaries and near shore areas have contributed to the listing of several urban bays as Superfund (federal) or Model Toxic Control Act (state) clean-up sites.

1.3 Current Stormwater Management

Conventional tools to manage stormwater are mitigation-based and flood-control focused. This strategy emphasizes the efficient collection and rapid conveyance of runoff from residential and commercial development to central control ponds. Several factors have led to the implementation and continuation of this approach: stormwater has been perceived as a liability and applications have evolved from wastewater technology; hard conveyance structures and central control ponds are considered reliable and relatively simple to maintain; the conveyance and collection approach is relatively simple to model for regulatory requirements; and construction costs are readily estimated.

Conventional tools to manage stormwater are mitigation-based and flood-control focused.

Newer conveyance and pond strategies, if properly designed and maintained, can match modeled pre-development peak flows and runoff rates discharged from development sites; however, a number of problems will continue to challenge current management strategies. These include:

- *Peak and volume control.* Typical residential and commercial development practice in the Puget Sound removes most, if not all, vegetation and topsoil. Suburban development in the region is estimated to have 90 percent less stormwater storage than the native forested condition, and BMP applications (circa 1994) are estimated to recover approximately 25 percent of that storage (May et al., 1997). Without infiltration, excess volume generated above the onsite storage capacity is released to receiving waters. If flows exceed **critical shear stresses,** stream channels are exposed to excessive erosion over prolonged periods (Booth et al., 2002). (See Figure 1.7 for graphic representation of actual storage needed to replace loss of native soil and vegetation.)

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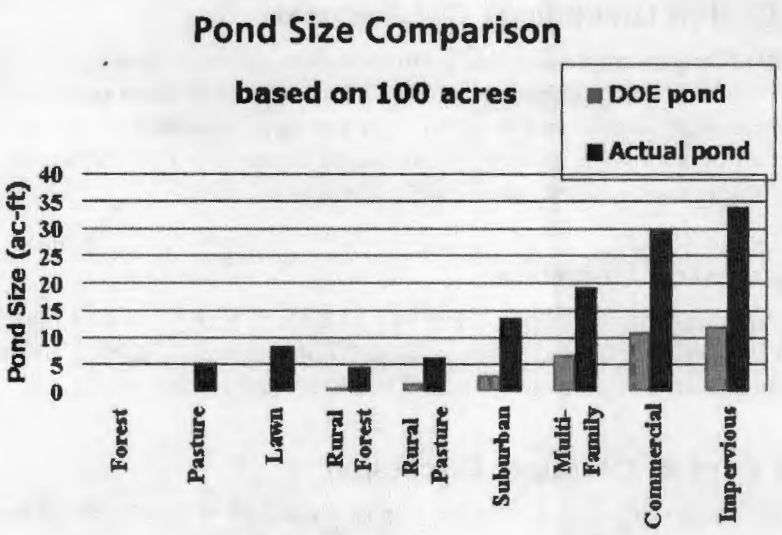

Figure 1.7 Storage required to meet Washington State Department of Ecology's stormwater management requirement (DOE Pond) and actual storage needed (actual pond) to replace loss of native soil and vegetation storage on a 100-acre site.

Source: Beyerlein, 1999.

- *Spatial Distribution.* Conventional management converts spatially distributed subsurface flows to point discharges. No analysis is currently available that focuses on the larger hydrologic impacts of this transition; however, locally severe erosion, disturbed riparian habitat, and degraded in-stream habitat can result at point discharge locations (Booth et al., 2002).
- *Density and Market Implications.* Duration-control design standards in Washington Department of Ecology's (Ecology) 2005 *Stormwater Management Manual for Western Washington* will require larger ponds. As a larger percentage of land is designated for stormwater management within the development, stormwater infrastructure costs will increase and the number of buildable lots will likely decrease.

1.4 Low Impact Development

The conventional, purely structural approach to manage stormwater runoff has limitations for recovering adequate storage and spatially distributed flow paths necessary to more closely approximate pre-development hydrologic function and protect aquatic resources from adverse effects of development. Low impact development (LID) principles and applications present a significant conceptual shift from a purely structural approach. LID is primarily a source reduction approach. Site planning and stormwater management are integrated at the initial design phases of a project to maintain a more **hydrologically functional landscape**. Hydrology and natural site features that influence water movement guide road, structure, and other infrastructure layout. Native soil and vegetation protection areas and landscaping that are strategically distributed throughout the project to slow, store, and infiltrate storm flows are designed into the project as amenities, as well as hydrologic controls.

Pre-development or natural hydrologic function is the relationship among the overland and subsurface flow, infiltration, storage, and evapotranspiration characteristics of the forested landscape predominant in the Puget Sound lowland (see Section 1.1). Low impact development strategies focus on evaporating, transpiring, and infiltrating stormwater on-site through native soils, vegetation, and bioengineering applications to reduce and treat overland flow that is characteristically negligible in the forested setting.

Low Impact Development defined

Low impact development is a stormwater management and land development strategy applied at the parcel and subdivision scale that emphasizes conservation and use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely mimic pre-development hydrologic functions.

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1.4.1 The Goal of Low Impact Development

The goal of LID is to prevent measurable harm to streams, lakes, wetlands, and other natural aquatic systems from commercial, residential, or industrial development sites. The impact to receiving waters (and determining if a project has achieved the above goal) is estimated by hydrologic models and measured by monitoring surface and ground water quality and quantity, and biological health.

1.4.2 Flow Control Objective

The primary stormwater management objective for LID is to match pre-development forested hydrologic condition (or prairie condition if historic records indicate that as the native setting) over the full range of rainfall intensities and durations.

1.4.3 Flow Control Objective Discussion

Maintaining the pre-development hydrologic regime cannot be achieved everywhere or at all times given current development practices. The hydrologic system of our region evolved from, and is dependent on, the characteristics of undisturbed Pacific Northwest watersheds–mature forest canopy, uncompacted soils, ungullied hillslopes–and cannot be expected to have the same hydrologic regime when significant portions of a site are disturbed. The objectives of any given low impact development, therefore, must be strategically chosen, recognizing both the opportunities and the limitations of any given site. Regulatory requirements, typical zoning and housing types, and costs of sophisticated control technology required on sites with poor soils and higher densities, as well as site topography, soil permeability and depth, and groundwater movement create significant challenges for reducing or eliminating hydrologic impacts from development sites. These challenges are likely to be most prominent during periods of extended rainfall, where the distributed on-site infiltration reservoirs common to most LID designs will experience their highest water levels and approach, or reach, full saturation.

Initial monitoring in the Puget Sound region suggests that LID strategies can be effective for maintaining pre-development hydrologic condition for light to moderate storm events typical of a maritime climate (Horner, Lim and Burges, 2002). Effectiveness in mimicking pre-development hydrology for large storms and during extended wet periods is not well documented. On difficult sites with low infiltration rates and higher densities, additional storage using conventional retention or detention pond facilities may be necessary in concert with LID strategies. Properly designed and implemented LID applications will, however, significantly reduce pond size requirements (Derry, Butchart and Graham, 2004 and Horner et al., 2002).

Properly designed and implemented LID applications will significantly reduce the size requirements of ponds.

1.4.3.1 Rural setting

Empirical data coupled with hydrologic modeling analysis, at the watershed scale, suggest that retaining 65 percent mature forest cover is necessary to mimic pre-development hydrologic conditions and maintain stable stream channels on moderately sloping till soils and typical rural development settings (EIA 3 to 5 percent). While this is an estimate of complex hydrologic processes, the 65 percent cover is a defensible target for forest protection in rural densities (see Figure 1.8) (Booth et al., 2002).

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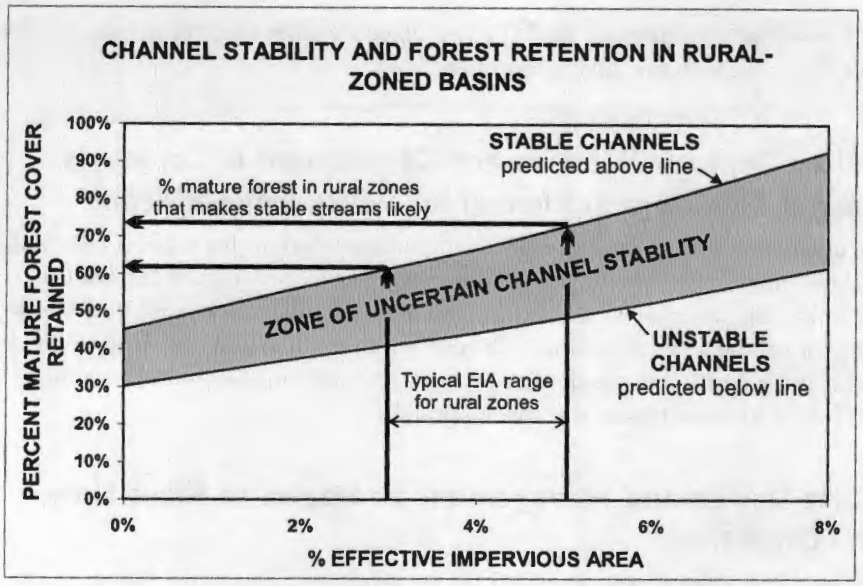

Figure 1.8 Modeled channel stablity plotted by percent forest cover retained and percent EIA (Booth et al., 2002).

Forested glacial outwash soils produce less overland flow than forested till soil conditions during storm events. As a result, forest clearing and increased impervious surface coverage can produce relatively larger peak-flows and increases in volume on outwash soils without adequate infiltration practices (Booth et al., 2002). The impact of concentrating infiltration facilities at a single location on outwash soils is not known; however, shallow subsurface flows may alter hydrologic characteristics if the development and facility are located proximate to a headwater stream.

Stormwater pollutant treatment is required when infiltrating stormwater on outwash soils from pollution generating surfaces (Washington Department of Ecology [Ecology], 2001). Processing pollutants in a facility that collects storm flows from an entire development can significantly increase infrastructure requirements and costs. Accordingly, 65 percent native soil and vegetation protection and *application of dispersed LID infiltration practices* is recommended for protecting stream and wetland habitat in the forested outwash soil and the rural setting.

1.4.3.2 Medium and high-density settings (6 or more dwelling units per acre)

The 65 percent target for mature native vegetation coverage may be achievable in medium and high-density settings by applying multifamily, cottage, or condominium type development. Sixty-five percent native vegetation and soil protection is not feasible with conventional single family detached housing at such densities. In the higher density setting, *comprehensive application of LID practices* is necessary to reduce the hydrologic changes and pollutant loads to surface and ground waters where less forest protection area is possible (see Chapter 3: Site Planning and Layout for design strategies).

Initial research modeling experimental, medium-density, residential LID designs indicates that pre-development hydrologic conditions may be approximated on soils with low infiltration rates when using the full suite of LID practices and 40 to 50 percent open space protection (CH2M HILL, 2001). In this difficult type of development scenario it is essential to apply a full complement of LID practices. Soil enhancement, bioretention, open conveyance, dispersion to open space, minimal excavation foundation systems, aggregate storage under paving, and roof water harvesting techniques must be integrated into the design to minimize hydrologic impacts. Eliminating the roof water contribution through roof water harvesting

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systems is essential for achieving the LID flow objective where higher density projects are located on soils with low infiltration rates.

1.4.4 Flow Control Objective and Department of Ecology's *Stormwater Management Manual for Western Washington*

This document or the flow control objective recommended in this manual does not supercede Ecology's 2005 *Stormwater Management Manual for Western Washington.* Where the Ecology manual is adopted, the minimum flow control standard for new development will be required to match 50 percent of the two-year event up to the full 50-year peak flows for a pre-developed forested condition (or prairie conditions if historic records indicate that as the native setting).

1.4.5 Site Design and Management Strategies to Meet Flow Control Objectives

The goal and flow control objective for LID are achieved through the following site design objectives. The objectives are grouped into four basic elements that constitute a complete LID design.

Conservation measures

- Maximize retention of native forest cover and restore disturbed vegetation to intercept, evaporate, and transpire precipitation.
- Preserve permeable, native soil and enhance disturbed soils to store and infiltrate storm flows.
- Retain and incorporate topographic site features that slow, store, and infiltrate stormwater.
- Retain and incorporate natural drainage features and patterns.

Site planning and minimization techniques

- Utilize a multidisciplinary approach that includes planners, engineers, landscape architects and architects at the initial phases of the project.
- Locate buildings and roads away from critical areas and soils that provide effective infiltration.
- Minimize total impervious surface area and eliminate effective impervious surfaces.

Distributed and integrated management practices

- Manage stormwater as close to its origin as possible by utilizing small scale, distributed hydrologic controls.
- Create a hydrologically rough landscape that slows storm flows and increases **time of concentration.**
- Increase reliability of the stormwater management system by providing multiple or redundant LID flow control practices.
- Integrate stormwater controls into the development design and utilize the controls as amenities–create a multifunctional landscape.
- Reduce the reliance on traditional conveyance and pond technologies.

Maintenance and Education

- Develop reliable and long-term maintenance programs with clear and enforceable guidelines.

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- Educate LID project homeowners and landscape management personnel on the operation and maintenance of LID systems and promote community participation in the protection of those systems and receiving waters.

Subsequent sections of the manual–Chapter 3: Site Planning and Layout; Chapter 4: Vegetation Protection, Reforestation and Maintenance; Chapter 5: Site Clearing and Grading; Chapter 6: Integrated Management Practices; and Chapter 7: Flow Modeling Guidance–will provide information on low impact development tools and techniques that can be used to meet the objectives and strategies listed above. The manual outlines many of the tools available for designing a low impact development system, but it does not provide an exhaustive list of practices. The LID approach is creative and designers must consider the attributes of individual sites in the context of the local jurisdiction and community setting. Designers should apply sound science, an interdisciplinary approach and, at times, unique applications to meet LID goals and objectives. See Table 1.2 for a list of some LID techniques.

Table 1.2 LID techniques (checked items are examined in this manual).

X	Site assessment	X	Maintenance		Downspout dispersion
X	Site planning and design	X	Amending construction site soils	X	Roof stormwater harvesting systems
X	Site phasing and fingerprinting	X	Permeable asphalt		Filter strips
X	Preserving native soils and vegetation	X	Permeable concrete		Media filtration
X	Clearing and grading	X	Permeable gravel pave systems		
X	Bioretention cells	X	Permeable pavers		
X	Sloped biodetention	X	Vegetated roofs		
X	Bioretention swales	X	Minimal excavation foundations		
	Tree box filters		Homeowner education		

While the focus of low impact development and this manual is to more effectively manage stormwater, LID can and should address other livability issues including:

- Residential road design that reduces traffic speeds and promotes walking and biking as alternative transportation methods.
- Development at appropriate densities that meets Growth Management Act goals, and increases access to, and connection between, public transportation modes.
- Subdivision layout and building design that promote interaction between neighbors and the connection to open space and recreation areas.

1.4.6 Low Impact Development in the Watershed Context

LID is a tool for retrofitting existing or constructing new commercial and residential development at the parcel and subdivision scale. Maintaining aquatic habitat, water quality, species of special concern, and healthy aquatic systems in general requires protection or restoration of processes (for example the movement of water and recruitment of large woody debris) and structures (forest canopy, soils, etc.) at the sub-watershed, watershed or regional scale.

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To protect high quality, sensitive stream systems the following critical area designations and associated land use controls are necessary:

- Extensive and near continuous riparian buffer protection.
- Floodplain protection.
- Aggressive native forest and soil protection.
- Limit EIA to approximately 10 percent.

(Horner, May, Livingston, Blaha, Scoggins, Tims, Maxted, 2001 and May et al., 1997)

Where higher levels of EIA and development exist or are proposed and ecological function is good or impaired (but not entirely lost), several strategies can be employed for protection and enhancement including, but not limited to: forest and soil restoration; comprehensive drainage design addressing cumulative impacts and implementing regional stormwater control facilities; and other mitigation and enhancement measures (May et al., 1997).

To improve sub-watershed or regional scale ecosystem functions, basin assessments must evaluate the quality and sensitivity of resources, and the cumulative impacts of existing development, future growth and other activities in sub-watersheds. Through the assessment and planning process, managers should set priorities for resource protection for sub-watersheds based on resource sensitivity and growth pressures. Various landscape analysis tools are available that allow managers to assign appropriate densities and types of development based on the projected cumulative impacts of different land use scenarios.

1.4.7 Low Impact Development and Comprehensive Stormwater Management

LID does not compensate for the cumulative and adverse effects from road networks and other land clearing activities that occur outside the development site. Low impact development can, however, be used in the various sub-basin development scenarios to help achieve larger-scale, sub-watershed protection goals. Implemented comprehensively, native soil and vegetation protection, soil improvement, and increased on-site storage and infiltration capacity at the site level are necessary to protect or enhance larger-scale hydrologic function and other watershed attributes.

While LID works with and supports the effective implementation of regional stormwater management plans and land use planning under the Growth Management Act, it is not a substitute for these local government responsibilities. The use of LID techniques should be part of a local, comprehensive stormwater management program that includes:

- Adoption and use of Ecology's 2005 *Stormwater Management Manual for Western Washington* (or an alternative manual that is technically equivalent).
- Regular inspections of construction sites.
- Maintenance of temporary and permanent facilities.
- Source control.
- Elimination of illicit discharges.
- Identification and ranking of existing stormwater problems.
- Public education and involvement.
- Watershed or basin planning.
- Stable funding.
- Programmatic and environmental monitoring.

(Puget Sound Action Team, 2000)

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2 Site Assessment

In this chapter...

Inventory and assessment of:

- *Soil analysis*
- *Hydrologic patterns and features*
- *Native forest and soil conservation areas*
- *Wetlands*
- *Riparian areas*
- *Floodplains*

Comprehensive inventory and assessment of on-site and adjacent off-site conditions are the initial steps for implementing low impact development (LID). The inventory and assessment process provides information necessary to implement the site planning and layout activities (examined in the next chapter) by identifying the current and estimating the pre-disturbance conditions. Specifically, the site assessment process should evaluate hydrology, topography, soils, vegetation, and water features to identify how stormwater moves through the site prior to development. The site design should align roads, lots, and structures and implement construction practices to preserve and utilize these features to retain natural hydrologic functions. In almost all cases, low impact development requires on-site inventory and assessment and cannot be properly planned and implemented through map reconnaissance alone.

The site assessment process should evaluate hydrology, topography, soils, vegetation, and water features to identify how stormwater moves through the site prior to development.

Jurisdictions in the Puget Sound region have various requirements for identification and assessment of site characteristics and site plan development. Some or all of the following existing conditions are included by most local governments for identification and evaluation:

Geotechnical/soils	Streams	Wetlands
Floodplains	Lakes	Closed depressions
Springs/seeps	Other minor drainage features	Groundwater
Existing hydrologic patterns	Slope stability and protection	Geology
Habitat conservation areas	Aquifer recharge areas	Topography
Vegetation/forest cover	Anadromous fisheries impacts	Existing development
Erosion hazard areas	Offsite basin and drainage	Down-stream analysis

(King County, 1998; Washington State Department of Community, Trade and Economic Development, 2003; and Washington State Department of Ecology, 2001)

Inventory and evaluation to successfully implement an LID project will include some or all of the above existing conditions depending on the physical setting and regulatory requirements; however, the objective of the analysis and the level of detail necessary may vary. This section presents six steps in the LID site evaluation process that are essential and will likely require more focused attention than in a conventional project. Management recommendations for wetlands, riparian management areas, and floodplains are provided at the end of each evaluation step. Management

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recommendations for soils, hydrologic features, and native soil and vegetation protection areas are provided in subsequent chapters focusing on those issues.

2.1 Soil Analysis

LID requires detailed understanding of site soils. In-depth soil analyses in appropriate locations are often necessary to determine operating infiltration rates for two primary reasons: (1) LID emphasizes evaporation, storage, and infiltration of stormwater in smaller-scale facilities distributed throughout the site; and (2) on sites with mixed soil types, the LID site plan should locate impervious areas over less permeable soils and preserve and utilize permeable soils for infiltration.

2.1.1 Inventory and Assessment

Methods recommended for determining infiltration rates fall into two categories:

- Texture or grain size analysis using U.S. Department of Agriculture (USDA) Soil Textural Classification (Rawls survey) or ASTM D422 Gradation Testing at Full Scale Infiltration Facilities.
- In-situ infiltration measurements using a Pilot Infiltration Test, small-scale test infiltration pits (septic test pits), and groundwater monitoring wells.

Grain size analysis and infiltration tests present important but incomplete information. Soil stratigraphy should also be assessed for low permeability layers, highly permeable sand/gravel layers, depth to groundwater, and other soil structure variability necessary to assess subsurface flow patterns. Soil characterization for each soil unit (soil strata with the same texture, color, density, compaction, consolidation and permeability) should include:

- Grain size distribution.
- Textural class.
- Percent clay content.
- Cation exchange capacity.
- Color/mottling.
- Variations and nature of stratification.

(Ecology, 2001)

A few strategically placed soil test pits are generally adequate for initial site assessment. Pit locations are determined by topography, estimated soil type, hydrologic characteristics, and other site features. Consult a geotechnical engineer or soil scientist for initial assessment and soil pit recommendations.

A more detailed soil pit assessment is necessary once the preliminary site layout with location of LID stormwater controls is determined. Specific recommendations for assessing infiltration rates for bioretention areas and permeable paving installations are located in sections 6.1: Bioretention Areas and 6.3: Permeable Paving.

For management of on-site soils, see Section 6.2: Amending Construction Site Soils.

Assessing highly permeable gravel conditions

Special considerations are necessary for areas with highly permeable gravel. Signs of high groundwater will likely not be present in gravel lacking finer grain material such as sand and silt. Test pit and monitoring wells may not show high groundwater levels during low precipitation years. Accordingly, sound professional judgment, considering these factors and water quality treatment needs, is required to design multiple and dispersed infiltration facilities on sites with gravel deposits *(personal communication, Larry West, January 2004).*

2.2 Hydrologic Patterns and Features

Hydrology is a central design element that is integrated into the LID process at the initial site assessment and planning phase. Using hydrology as a design element begins by identifying and maintaining on-site hydrologic processes, patterns, and physical features (streams, wetlands, native soils and vegetation, etc.) that influence those patterns.

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2.2.1 Inventory and Assessment

In addition to identifying prominent hydrologic features, additional analysis will likely be required to adequately assess water movement over and through the site including:

- Identify and map minor hydrologic features including seeps, springs, closed depression areas, and drainage swales.
- Identify and map surface flow patterns during wet periods, and identify signs of duration and energy of storm flows including vegetation composition, and erosion and deposition patterns.
- If seasonally high groundwater is suspected and if soil test pits do not provide sufficient information to determine depth to groundwater, map groundwater table height and subsurface flow patterns in infiltration and dispersion areas using shallow monitoring wells. Note: in many sites, shallow hand-augured monitoring wells can be installed at low cost.

The conservation and use of on-site native soil and vegetation for stormwater management is a central principle for an LID design.

For management of on-site hydrologic features see Section 1.4.5: Site Design and Management Strategies, Section 2.5: Riparian Management Areas, Chapter 3: Site Planning and Layout, and Chapter 5: Clearing and Grading.

2.3 Native Forest and Soil Conservation Areas

The conservation and use of on-site native soil and vegetation for stormwater management is a central principle of LID design. Protecting these features accomplishes three objectives: (1) reducing total impervious area; (2) increasing stormwater storage, infiltration, and evaporation; and (3) providing potential dispersion areas for stormwater. In addition to maintaining natural hydrologic processes, forest protection can provide other benefits including critical habitat buffers, open space, and recreation opportunity.

2.3.1 Inventory and Assessment

The following are steps to conduct a basic inventory and assessment of the function and value of on-site native vegetation:

- Identify any forest areas on the site and identify species and condition of ground cover and shrub layer, as well as tree species, **seral stage**, and canopy cover.
- Identify underlying soils utilizing soil pits and soil grain analysis to assess infiltration capacity. See Soil Analysis section above and consult a geotechnical engineer for site-specific analysis recommendations.

Soil surveys and vegetation surveys are necessary to determine baseline conditions, establish long-term management strategies, and determine appropriate application of dispersion techniques if stormwater is directed to the protection area.

For management of native vegetation and soil protection areas see Chapter 4: Vegetation Protection, Reforestation and Maintenance.

2.4 Wetlands

Determining appropriate assessment and management protocols for wetlands requires clear goals and objectives, as well as estimates of pre-development and evaluation of current conditions. Appropriate goals and objectives are determined through

Steep slope and shoreline bluff considerations

Special care must be taken when developing on or near steep slopes, including coastal bluffs, especially those composed of layers of unconsolidated glacial sediment that occur in many areas of Puget Sound. Clearing of vegetation, increasing surface runoff, and hydraulic loading through infiltration of surface runoff can destabilize these areas, and in some cases lead to dramatic slope failures. A detailed analysis of the site's geology and hydrology should be prepared by a qualified professional prior to site clearing and development.

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the development application process and involve government permitting entities, consultants, and the developer. Core assessment and management objectives for a project that is in a drainage basin with a wetland designated as high quality and sensitive should include: (1) protect native riparian vegetation and soils; (2) protect diverse native wetland habitat characteristics to support the native assemblage of wetland biota; and (3) maintain or approximate pre-development hydrology and **hydroperiod** within the wetland. Note: Washington State Department of Ecology (Ecology) guidance includes Category 1 or 2 wetlands and Category 3 wetlands that meet most of the criteria in Appendix 1-D of Ecology's 2005 *Stormwater Management Manual for Western Washington* (SMMWW) as high quality and sensitive. If the project is within the drainage area for a wetland that can be considered for structural or hydrological modification then the development may incorporate use of the wetland into the stormwater management strategy. Ecology recommends use of criteria in the 2005 SMMWW Appendix 1-D page D-10 for wetland assessment guidelines.

2.4.1 Inventory and Assessment

The following steps should be used as a starting point to adequately inventory and provide an assessment of wetlands:

- Identify wetland category using local jurisdiction regulations and/or Ecology's *Washington State Wetlands Rating System for Western Washington.*
- If the wetland qualifies for protection:
  - Measure existing hydroperiods and estimate future hydroperiods resulting from the proposed development.
  - Identify hydrologic pathways into and out of wetland.
  - Determine whether the wetland has breeding, native amphibians (conduct survey in spring).

2.4.2 Management

- If the wetland qualifies for protection, utilize LID strategies to increase stormwater infiltration and storage on the project site in order to meet the following guidelines (Azous and Horner, 2001):
  - The increase or decrease of the pre-development mean monthly water level fluctuations should be maintained to less than 5 inches.
  - The increase or decrease of 6 inches or more to the pre-development water level fluctuation should be restricted to less than 6 times during an average year.
  - The duration of stage excursions of 6 inches or more above or below the pre-development water level fluctuations should not exceed 72 hours per excursion.
  - Total dry period (when pools dry down to the soil surface everywhere in the wetland) should not increase or decrease by more than two weeks in any year.
  - For priority peat wetlands, the duration of stage excursions above or below the pre-development water level fluctuations should not exceed 24 hours in a year.
  - For wetlands inhabited by breeding amphibians, increases or decreases in pre-development water level fluctuations should not exceed 3 inches for more than 24 hours in any 30-day period.

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- See Guidesheets 2A through 2D in Appendix 1-D of the 2005 SMMWW for additional criteria.

- Designate buffer widths consistent with best available science (see Washington State Department of Community, Trade and Economic Development *Critical Areas Assistance Handbook*, 2003 and *Citations of Recommended Sources of Best Available Science*, 2002).
- Map wetlands and wetland buffer areas on all plans and delineate these areas on the site with fencing to protect soils and vegetation from construction damage. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2001 SMMWW BMP C103 and C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.
- Install signs to identify and explain the use and management of the natural resource protection areas.
- See Riparian Management Areas section for additional management strategies within buffer areas.

2.5 Riparian Management Areas

The riparian zones are defined as areas adjacent to streams, lakes, and wetlands that support native vegetation adapted to saturated or moderately saturated soil conditions. When there is adequate mature vegetation, stable land-form, and large woody debris, riparian areas perform the following functions:

- Dissipate stream energy and erosion associated with high flow events.
- Filter sediment, capture bedload, and aid in floodplain development.
- Improve flood water retention and groundwater recharge.
- Develop diverse ponding and channel characteristics that provide habitat necessary for fish and other aquatic life to spawn, feed, and find refuge from flood events.
- Provide vegetation litter and nutrients to the aquatic food web.
- Provide habitat for a high diversity of terrestrial and aquatic biota.
- Provide shade and temperature regulation.
- Provide adequate soil structure, vegetation, and surface roughness to slow and infiltrate stormwater delivered as precipitation or low velocity sheet flow from adjacent areas (Prichard et al., 1998).

2.5.1 Inventory and Assessment

The objective for riparian area assessment and management is to protect, maintain, and restore mature native vegetation cover that provide the above functions and structures. See sections 2.4: Wetlands, 2.6: Floodplains, and Chapter 4: Vegetation Protection, Reforestation, and Maintenance for assessing the extent and quality of riparian management areas (RMA) in various settings.

Riparian Management Areas

Adequately sized and maintained riparian management areas are necessary for protecting streams, lakes, and wetlands from many of the impacts of surrounding urbanization.

2.5.2 Management

RMAs are used to buffer streams, lakes, wetlands and other aquatic resources from adjacent land disturbance. While managing RMAs to maintain vegetation cover, soils, and stable land-form to buffer aquatic resources is standard practice, managing overland stormwater flows from adjacent developed is not the primary function of

riparian management areas. However, if the riparian area will receive storm flow, the following minimum riparian buffer design criteria are recommended to dissipate, infiltrate, and remove pollutants from overland flow:

- Maintain overland flow as sheet flow and do not allow stormwater entering or within buffers to concentrate.
- Maintain (and restore if necessary) mature, native plant community and soils within the buffer.
- Designate buffer widths consistent with best available science (see Washington State Department of Community, Trade and Economic Development *Critical Areas Assistance Handbook,* 2003 and *Citations of Recommended Sources of Best Available Science,* 2002).
- If buffer averaging is used, the following minimum site features and objectives should be considered when determining the extent of the buffer: soils, slope, vegetation, pollutant loads, water quantity and quality targets, and sensitivity of resource.
- Map RMAs on all plans, and delineate with fencing to protect soils and vegetation from construction damage. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2005 SMMWW BMP C103 and C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.
- Install signs to identify and explain the use and management of the natural resource protection areas.
- Buffers should include 100-year floodplain, wetlands and steep slopes adjacent to streams, and the channel migration zone.
- Flow velocities reaching and within buffer areas should not exceed 1 ft/second.
- Unrestricted overland flow distance should not exceed 150 ft for pervious areas and 75 ft for impervious areas before reaching buffers (Schueler, 1995).
- See Chapter 7: Flow Modeling Guidance for detailed dispersion guidelines.
- Do not allow effective impervious surface within the buffer.
- Activity within the RMA should be limited to:
  - passive, confined recreation (i.e., walking and biking trails) constructed from pervious surfaces.
  - platforms for viewing streams, lakes, and wetlands constructed with techniques to minimize disturbance to soils and vegetation.
- Establish a long-term management entity and strategy to maintain or enhance the structural integrity and capacity of the buffer to protect water quality and habitat.

2.6 Floodplains

The objective for floodplain area assessment and management is to maintain or restore: (1) the connection between the stream channel, floodplain, and off channel habitat; (2) mature native vegetation cover and soils; and (3) pre-development hydrology that supports the above functions, structures, and flood storage.

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2.6.1 Inventory and Assessment

The following steps, at a minimum, should be used to inventory and provide baseline conditions of the floodplain area:

- Identify the 100-year floodplain and channel migration zone.
- Identify active channel.
- Inventory composition and structure of vegetation within the floodplain area.

2.6.2 Management

- Map the extent of the 100-year floodplain or channel migration zone on all plans and delineate these areas on the site with fencing to protect soils and vegetation from construction damage. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2005 SMMWW BMP C103 and C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.
- See Section 2.5: Riparian Management Areas for additional management strategies.
- Install signs to identify and explain the use and management of the natural resource protection areas.

A project should not be considered low impact development if it is located within the 100-year floodplain or channel migration zone.

2.7 Site Mapping Process

Through the assessment process, map layers are produced to delineate important site features. The map layers are combined to provide a composite site analysis that guides the road layout and overall location and configuration of the development envelopes (see figures 2.1 and 2.2, following pages). See Chapter 3: Site Planning and Layout for details on utilizing assessment information for site design.

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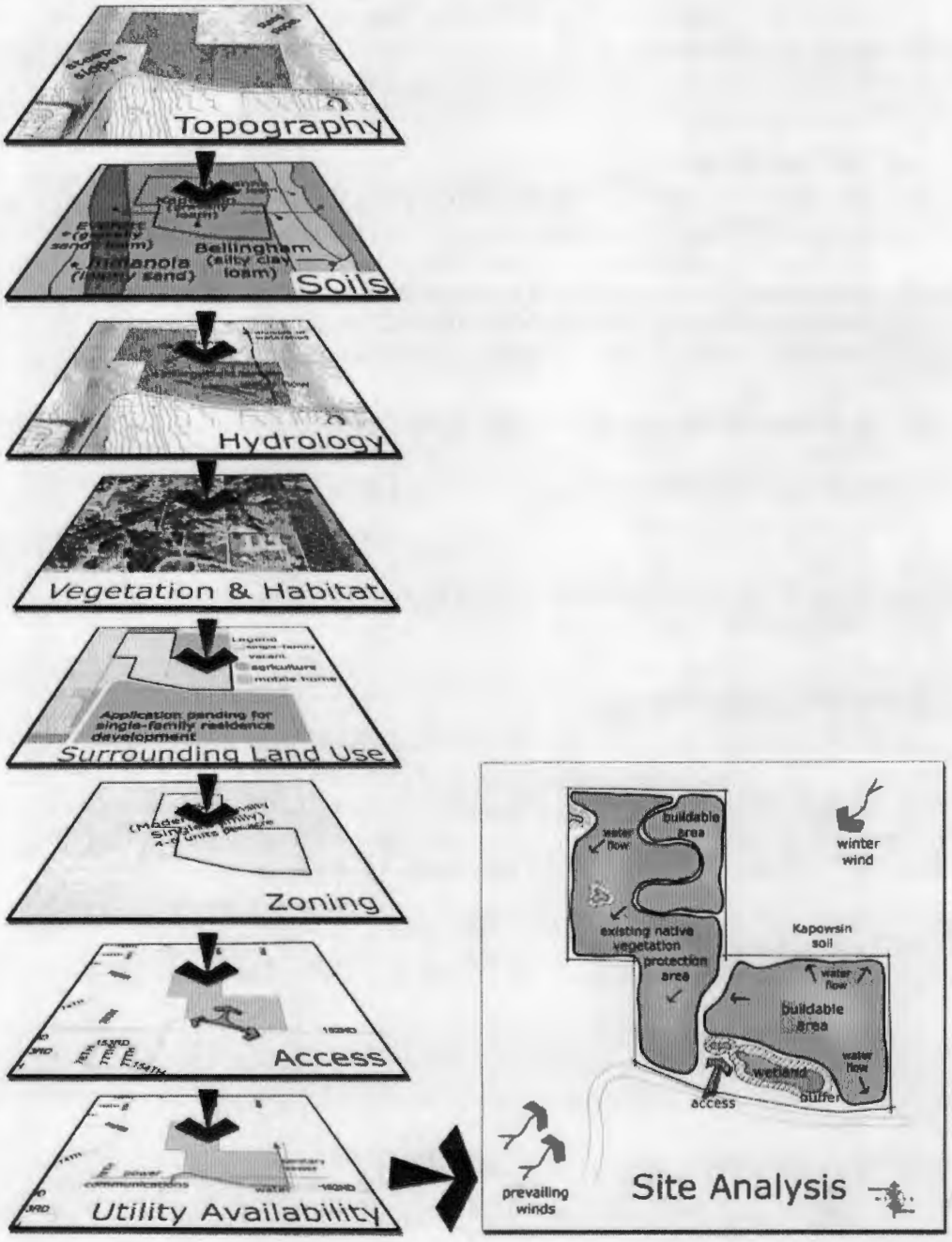
Figure 2.1 Composite site analysis for a residential subdivision.

Graphic by AHBL Engineering



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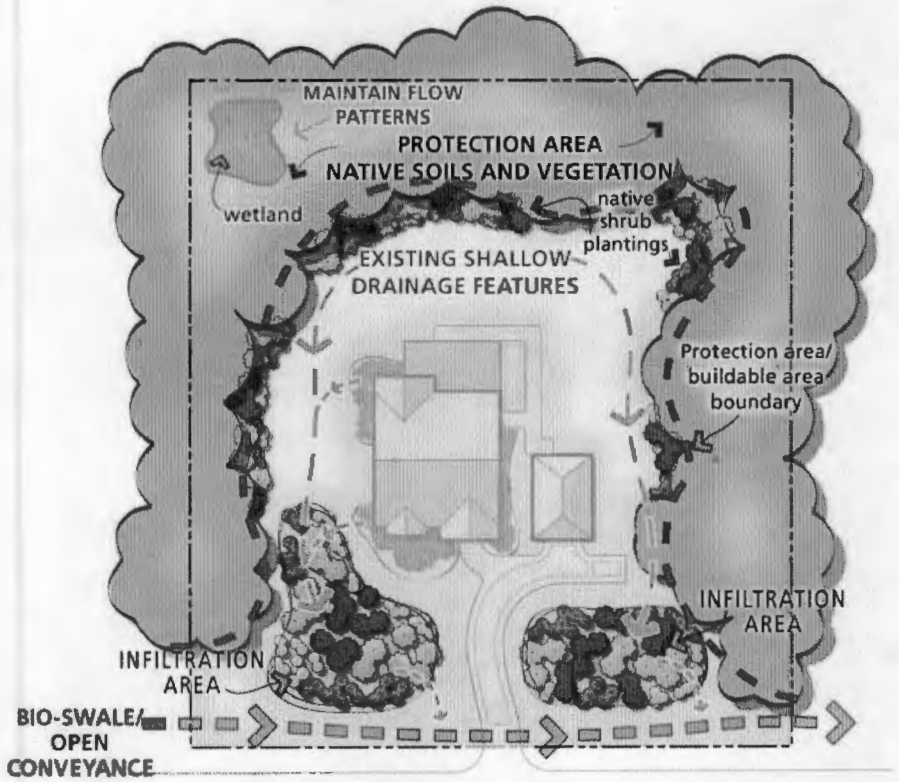

Figure 2.2 Large lot composite site analysis.

Graphic by AHBL Engineering

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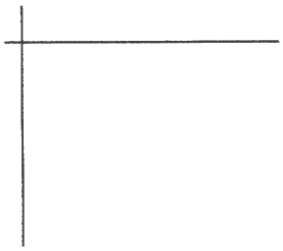

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3 Site Planning and Layout

In this chapter...

- *Road, driveway, and parking layouts for medium to high density subdivisions, large lots, and commercial sites*
- *Road crossings*
- *Street trees*
- *Lot layout for medium to high density clusters, large lots, and rural clusters*
- *Building design*

Site assessment and site planning are iterative processes. Existing and native environmental conditions strongly influence the extent and location of the development envelope for a low impact development (LID) project. The regulatory, market, and architectural context of the location are integrated with the site assessment findings to produce a road and lot configuration that strategically uses site features for isolating impervious surface and dispersing and infiltrating storm flows. As site planning progresses and details for roads, structures, and LID practices are considered, additional evaluation of site conditions may be necessary.

Context is essential for developing any successful residential or commercial project. The designer must consider the appropriate plat design and housing type given the existing character and possible future conditions of the area when developed. Architectural considerations influence how the project integrates with the surroundings while at the same time creating neighborhood identity (personal communication Len Zickler, January 2004). A low impact development project incorporates these same design considerations; however, the following stormwater and other environmental management elements are elevated to equal standing:

Hydrology is an organizing principle that is integrated into the initial site assessment and planning phases.

- Hydrology is an organizing principle that is integrated into the initial site assessment and planning phases.
- Individual LID practices are distributed throughout the project site and influence the configuration of roads, house lots, and other infrastructure.
- LID practices are amenities that provide multiple functions, including aesthetic landscaping, visual breaks that increase a sense of privacy within a variety of housing densities, and a design element (of equal importance to architectural and plat design) that promotes neighborhood identity.

Assessment of natural resources outlined in the previous section will produce a series of maps identifying streams, lakes, wetlands, buffers, steep slopes, and other hazard areas, significant wildlife habitat areas, and permeable soils offering the best available infiltration potential. Maps can be combined as GIS or CAD layers to delineate the best areas to direct development. Building sites, road layout, and stormwater infrastructure should be configured within these development areas to minimize soil and vegetation disturbance and take advantage of a site's natural stormwater processing capabilities.

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Initial site management strategies include:

- Establish limits of disturbance to the minimum area required for roads, utilities, building pads, landscape areas, and the smallest additional area needed to maneuver equipment.
- Map and delineate natural resource protection areas with appropriate fencing and signage to provide protection from construction activities.
- Meet and walk the property with the owner, engineers, landscape architects, and others directing project design to identify problems and concerns that should be evaluated for developing the site plans.
- Meet and walk the property with equipment operators prior to clearing and grading to clarify construction boundaries and limits of disturbance (see Chapter 4: Vegetation Protection, Reforestation, and Maintenance and Chapter 5: Site Clearing and Grading for more detailed information).

The following section is organized under two main categories: (1) Roads, Driveways and Parking; and (2) Lot Layout. The first category is examined by medium to high density, individual large lot, and commercial type development, and the second by medium to high density cluster, rural cluster, and large lot development.

3.1 Roads, Driveways and Parking

Residential roads in the early 1900s were primarily laid out in grid patterns to allow efficient access to services and transit, and were dominated by a mix of uses including pedestrian, bicycle, and vehicle transportation. The grid configuration has evolved over the past century to modified grids and the current prevailing designs that use curvilinear layouts with relatively disconnected loops and cul-de-sacs. The transition has been driven primarily by the increased mobility offered by the automobile and the perceived safety and privacy of dead end roads (Canadian Mortgage and Housing Corporation [CMHC], 2002).

An analysis in south Puget Sound found that the transportation component of the suburban watershed accounts for approximately 60 percent of the total impervious area (City of Olympia, 1995). At the national level, the American Association of State Highway and Transportation Officials (AASHTO) estimates that the urban and rural local access roads typically account for 65 to 80 percent of the total road network (AASHTO, 2001). Design standards for roads in residential areas focus on efficient and safe movement of traffic and rapid conveyance of stormwater. As a result, streets contribute higher storm flow volumes and pollutant loads to urban stormwater than any other source area in residential developments (City of Olympia, 1995 and Bannerman, Owens, Dodds and Hornewer, 1993).

Streets contribute higher storm flow volumes and pollutant loads to urban stormwater than any other source area in residential developments.

The overall objectives for low impact development road designs are:

- Reduce **total impervious area** (TIA) by reducing the overall road network coverage.
- Minimize or eliminate effective impervious area (EIA) and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures (pipes or curbs and gutters).
- Infiltrate and slowly convey storm flows in roadside bioretention cells and swales, and through permeable paving and aggregate storage systems under the pavement.

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- Design the road network to minimize site disturbance, avoid sensitive areas, and reduce fragmentation of landscape.
- Create connected street patterns and utilize open space areas to promote walking, biking and access to transit and services.
- Provide efficient fire and safety vehicle access.

Local access and small-collector road design is influenced at the individual parcel and subdivision scale and is the focus of this section. Road design is site specific; accordingly, this section does not recommended specific road designs. Instead, the strengths and weaknesses of different road layouts are examined in the context of LID to assist designers in the process of providing adequate transportation systems while reducing impervious surface coverage.

3.1.1 Medium to High Density Subdivision and Planned Community

Road layout

The Urban Land Institute (ULI), Institute of Transportation Engineers (ITE), National Association of Home Builders, and American Society of Civil Engineers state in a 2001 collaborative publication that: "The movement of vehicles is only one of a residential street's many functions. A residential street is also part of its neighborhood and provides a visual setting for the homes as well as a meeting place for residents." Additionally, ULI recommends that the land area devoted to streets should be minimized (National Association of Home Builders [NAHB], American Society of Civil Engineers, Institute of Transportation Engineers, and Urban Land Institute, 2001). These recommendations are derived primarily from a livability and safety perspective; however, the guidelines also integrate well with the low impact development design approach.

Designs for residential roads generally fall into three categories: grid, curvilinear and hybrids. Figure 3.1 illustrates the grid and curvilinear road layouts and Table 3.1 summarizes the strengths and weaknesses of the grid and curvilinear approaches.

Table 3.1 Strengths and weaknesses of the grid and curvilinear approaches.

Road Pattern	Impervious Coverage	Site Disturbance	*Biking, Walking, Transit	Safety	Auto Efficiency
Grid	27-36% (Center for Housing Innovation, 2000 and CMHC, 2002)	less adaptive to site features and topography	promotes by more direct access to services and transit	may decrease by increasing traffic throughout residential area	more efficient–disperses traffic through multiple access points
Curvilinear	15-29% (Center for Housing Innovation, 2000 and CMHC, 2002)	more adaptive for avoiding natural features, and reducing cut and fill	generally discourages through longer, more confusing, and less connected system	may increase by reducing through traffic in dead end streets	less efficient–concentrates traffic through fewer access points and intersections

** Note: biking, walking and transit are included for livability issues and to reduce auto trips and associated pollutant contribution to receiving waters.*

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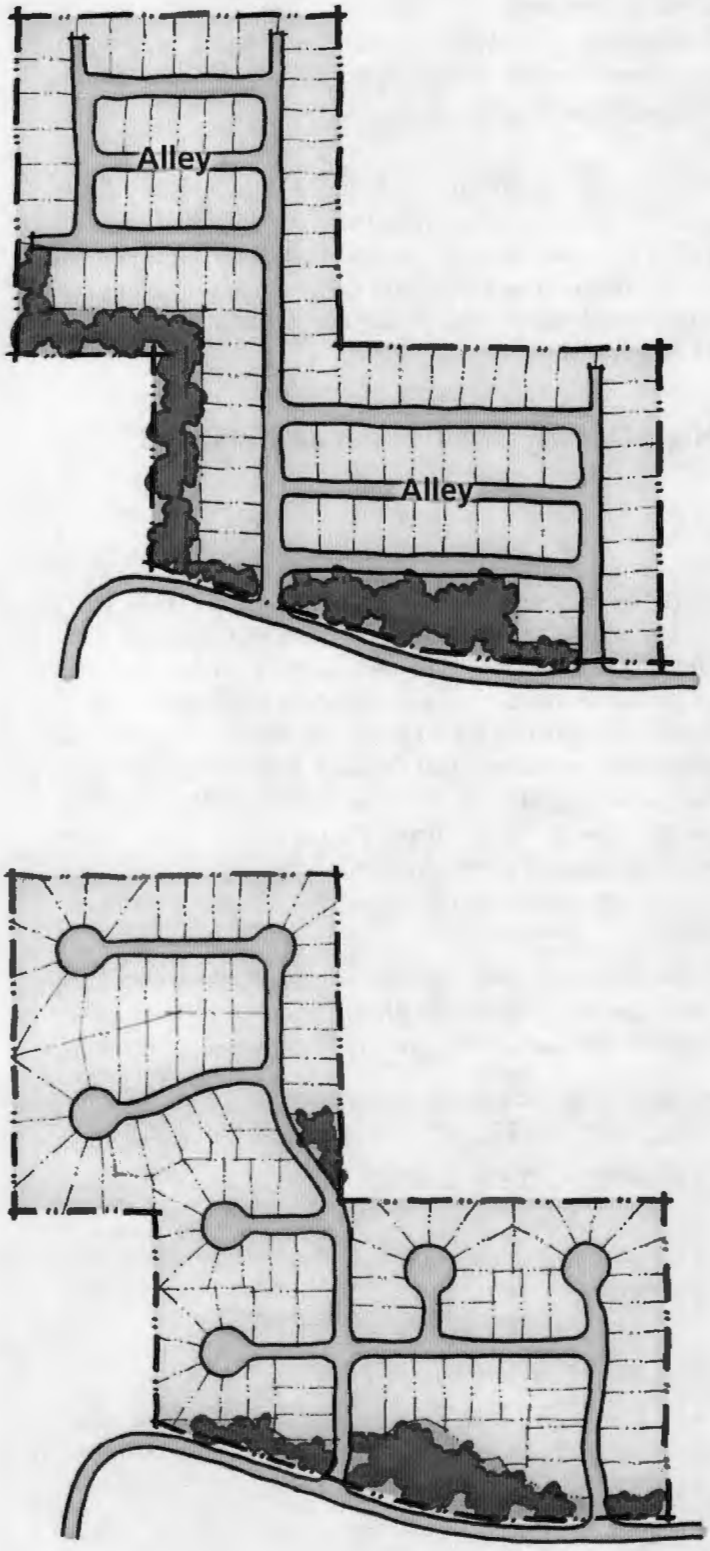
Figure 3.1
Top: Typical grid road layout with alleys.
Lower: Typical curvilinear road layout with cul-de-sacs.

Graphic by AHBL Engineering



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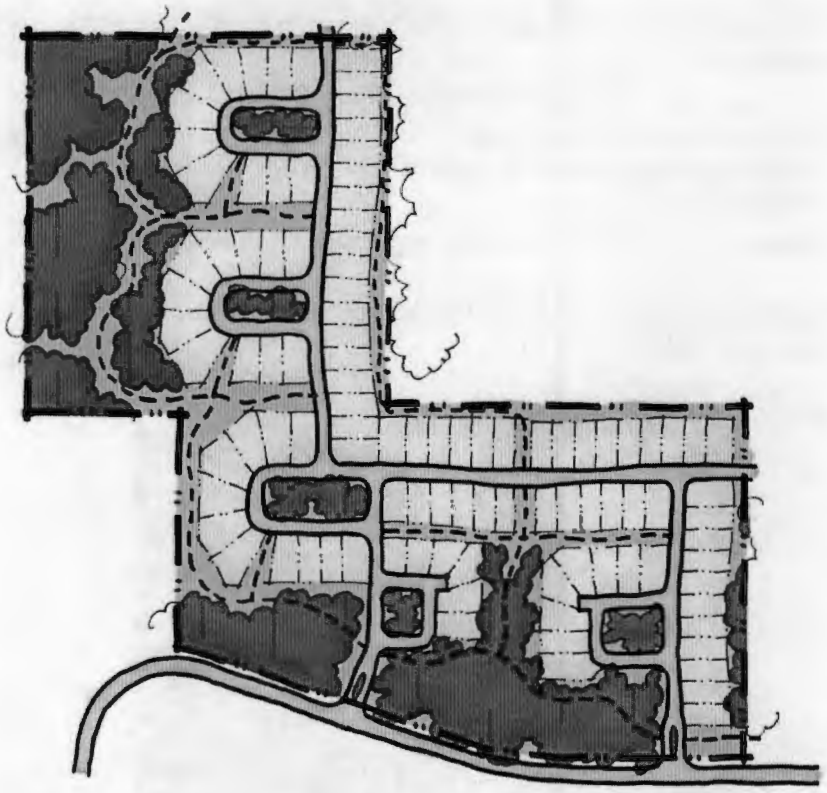

Figure 3.2 Hybrid, or open space, road layout.

Graphic by AHBL Engineering

The grid and curvilinear systems both have advantages and disadvantages. However, grid street patterns with alleys have one large drawback in the LID context: grids typically require 20 to 30 percent more total street length than curvilinear patterns (CWP, 1998 and Table 3.1). Recently, planners have integrated the two prevalent models to incorporate the strengths of both. These street networks have several names including open space, hybrid, and headwater street plans (Figure 3.2).

The following are strategies used to create road layouts in medium to higher density low impact residential developments that provide effective transportation networks and minimize impervious surface coverage:

- Cluster homes to reduce overall development envelope and road length (Schueler, 1995).
- Narrow lot frontages to reduce overall road length per home (see Figure 3.2) (Schueler, 1995).
- For grid or modified grid layouts, lengthen street blocks to reduce the number of cross streets and overall road network per home, and provide mid-block pedestrian and bike paths to reduce distances to access transit and other services (Center for Housing Innovation [CHI], 2000).
- Where cul-de-sacs are used, provide pedestrian paths to connect the end of the street with other pathways, transit or open space (Ewing, 1996).
- Provide paths in open space areas to increase connection and access for pedestrians and bicyclists (Ewing, 1996).
- Create pedestrian routes to neighborhood destinations that are direct, safe and aesthetically pleasing (CHI, 2000).

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- Reduce road widths and turn around area coverage (see road widths, parking and driveway sections).
- Reduce front yard set backs to reduce driveway length.
- Minimize residential access road right-of-way to only accommodate needed infrastructure next to road (residential access roads are rarely widened) (Schueler, 1995).
- Eliminate, or reduce to an absolute minimum, all stream crossings.

The road and pedestrian pathway networks in figures 3.3 and 3.4 illustrate multifunctional road layout designs.

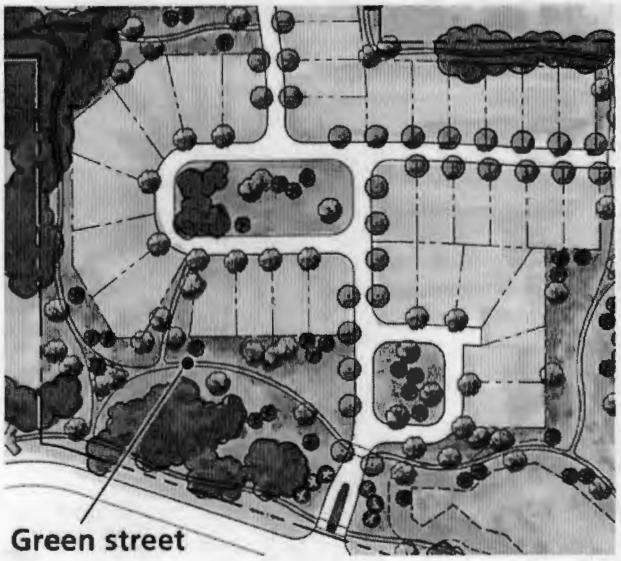

Figure 3.3 Loop road design.
Graphic by AHBL Engineering



Figure 3.4 Green street section.
Graphic by AHBL Engineering

The loop road design:

- Minimizes impervious road coverage per dwelling unit.
- Provides adequate turning radius for fire and safety vehicles.
- Provides through traffic flow with two points of access.
- Provides a large bioretention area in the center of the loop and a visual landscape break for homes facing the road.

The open space pathways between homes (green streets):

- Provide a connected pedestrian system that takes advantage of open space amenities.

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- Provide additional stormwater conveyance and infiltration for infrequent, large storm events.

The Sherbourne project in figures 3.5 and 3.6 is designed with one access to the development; however, ample traffic flow through the subdivision is provided by the loop and along home frontages, allowing for easier movement of fire and safety vehicles. Open space in the center of the loop provides stormwater storage, a visual landscape break for homes facing the road, and a creative example of integrating a regulatory requirement with a site amenity.

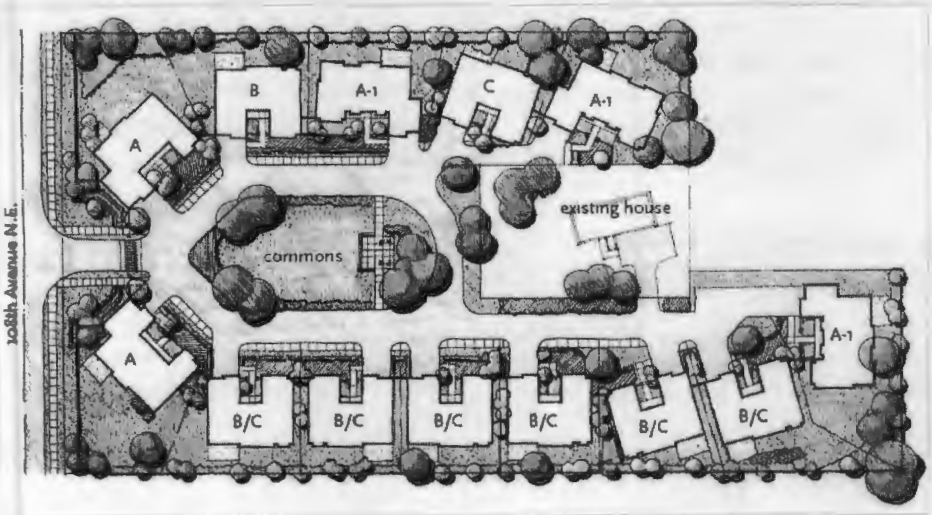

Figure 3.5 Sherbourne plan view.
Graphic courtesy of Mithun



Figure 3.6 Combined commons and stormwater facility at Sherbourne.
Photo by Colleen Owen

Road width

Residential road widths and associated impervious surface have, for various reasons, increased by over 50 percent since the mid-1900's (Schueler, 1995). Road geometry, including road widths, are derived primarily from two sources: American Association of State Highway Transportation Officials (AASHTO) and ITE (Schueler, 1995). A standardized guideline for residential roads that responds to general safety, traffic flow, emergency access, and parking needs is often adopted from these sources to

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fit various development scenarios. For example, AASHTO recommends 26-foot pavement widths and 50-foot right of way for residential roads across various density and traffic load demands. Additionally, many communities continue to equate wider streets with better and safer streets. Studies indicate, however, that residential accidents may increase exponentially as the street gets wider, and narrower roads that reduce traffic speeds are safer (CHI, 2000; NAHB et al., 2001; and Schueler, 1995).

Total and effective impervious area can be significantly reduced by determining specific traffic, parking, and emergency vehicle access needs and designing for the narrowest width capable of meeting those requirements. Examples of narrow street widths tailored to traffic need from different U.S. locations and from ULI are provided in Table 3.2. Reducing the street width from 26 to 20 feet reduces TIA by 30 percent. In the road network represented in Figure 3.2, the 30 percent reduction represents a storm flow reduction from 15,600 cubic feet to 12,000 cubic feet for a 2 inch 24-hour storm.

Table 3.2 Examples of narrow street widths from various jurisdictions.

Location or Source	Street Type	Width	Volume (ADT*)	Parking
Buck's County, PA	local access	18 ft	200	none
Buck's County, PA	residential collector	20 ft	200-1,000	none
Portland, OR	queuing	26 ft	not reported	both sides
ULI	shared driveway (5-6 homes)	16 ft	not reported	not reported
ULI	local	18 ft	not reported	one side only
ULI	local	22-26 ft	not reported	both sides
ULI	alley	12 ft	not reported	none
City of Seattle	local access	14 ft	125 (from traffic counts)	none
City of Seattle	local access	20 ft	250 (from traffic counts)	one side
City of Olympia	local access (2-way)	18 ft	0-500	none
City of Olympia	local access (queuing)	18 ft	0-500	one side alternating
City of Olympia	neighborhood collector	25 ft	500-3000	one side alternating

** ADT: Average daily traffic*

Turnarounds

Dead end streets with excessive turn around area (particularly cul-de-sacs) can needlessly increase impervious area. In general, dead end or cul-de-sac streets should be discouraged; however, a number of alternatives are available where topography, soils or other site specific conditions suggest this road design. Thirty-foot radius turnarounds are adequate for low volume residential roads servicing primarily passenger vehicles (AASHTO, 2001 and NAHB et al., 2001). A 40-foot radius with a landscaped center will accommodate most service and safety vehicle needs when a minimum 20-foot internal turning radius is maintained (Schueler, 1995). The turning area in a cul-de-sac can be enhanced by slightly enlarging the rear width of the radius. A hammerhead turnaround requires vehicles to make a backing maneuver, but this

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inconvenience can be justified for low volume residential roads servicing 10 or fewer homes (NAHB et al., 2001). A 10-foot reduction in radius can reduce impervious coverage by 44 percent and the hammerhead configuration generates approximately 76 percent less impervious surface than the 40-foot cul-de-sac. Four turnaround options and associated impervious surface coverage are presented in Figure 3.7.

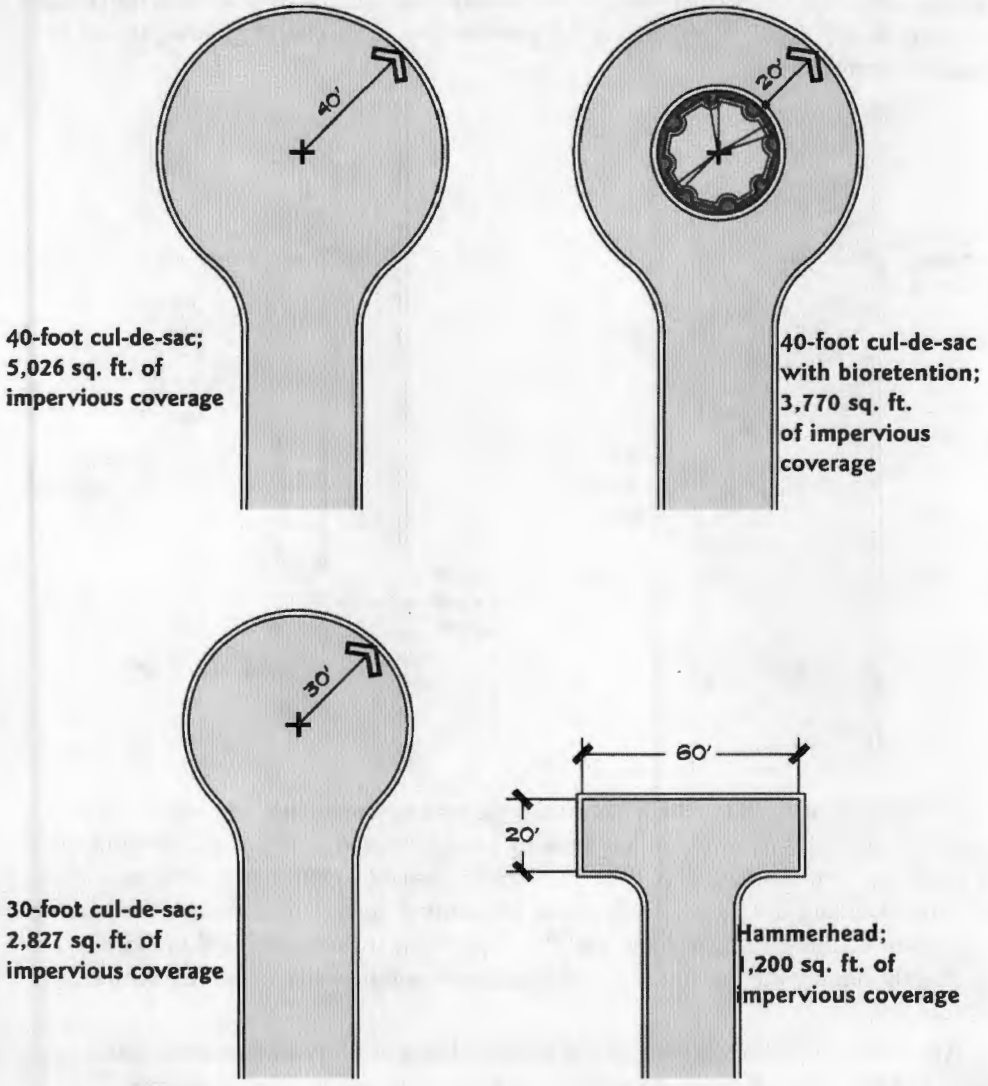

Figure 3.7 Turnaround areas and associated impervious coverage.

Graphic by AHBL Engineering

Islands in cul-de-sacs should be designed as bioretention or detention facilities. Either a flat concrete reinforcing strip or curb-cuts can be utilized to allow water into the facility (see Section 6.3: Permeable Paving for details).

The loop road configuration is an alternative to the dead end street and provides multiple access points for emergency vehicles and residents (see figures 3.3 and 3.5). For similar impervious surface coverage, the loop road has the additional advantage of increasing available storm flow storage within the loop compared to the cul-de-sac design.

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Parking

Many communities require 2 to 2.5 parking spaces per dwelling. Driveways and garages can accommodate this need in most cases, and providing curb side parking on both sides of the street and two travel lanes (i.e., the 36-foot wide local residential street) creates excess impervious surface. Parking needs and traffic movement can be met on narrowed roads where one or two on-street parking lanes serve as a traffic lane (queuing street) (CWP, 1998). Figure 3.8 provides two examples of queuing streets for local residential streets.

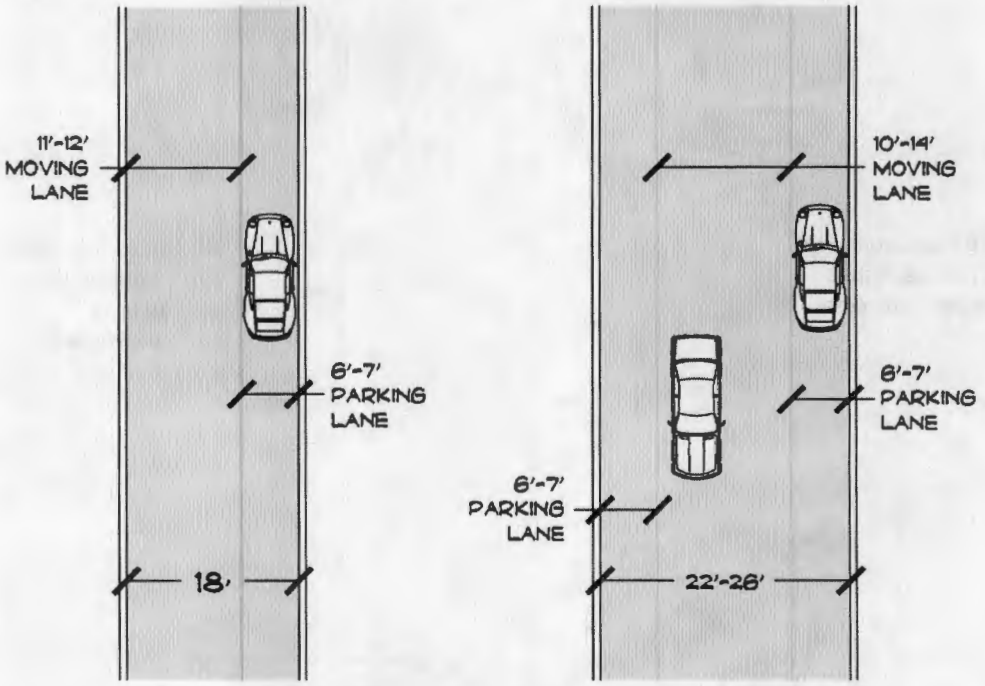

Figure 3.8
Left: 18-ft street with parking on one side.
Right: 22 to 26-ft street with parking on both sides.
(Adapted from National Association of Home Builders et al., 2001)

In higher density residential neighborhoods with narrow roads and where no on-street parking is allowed, pullout parking can be utilized. Pullouts (often designed in clusters of 2 to 4 stalls) should be strategically distributed throughout the area to minimize walking distances to residences. Depending on the street design, the parking areas may be more easily isolated and the impervious surface rendered ineffective by slightly sloping the pavement to adjacent bioretention swales or bioretention cells (Figure 3.9).

All or part of pullout parking areas, queuing lanes or dedicated on-street parking lanes can be designed using permeable paving (see Figure 3.10 for an example design). Permeable asphalt, concrete, pavers, and gravel pave systems can support the load requirements for residential use, reduce or eliminate storm flows from the surface, and may be more readily acceptable for use on lower-load parking areas by jurisdictions hesitant to use permeable systems in the travel way. Particular design and management strategies for subgrade preparation and sediment control must be implemented where pullout parking or queuing lanes receive storm flows from adjacent impervious areas (see Section 6.3: Permeable Paving for details).

Traffic calming strategies

Several types of traffic calming strategies are used on residential roadways to reduce vehicle speeds and increase safety. These design features also offer an opportunity for storm flow infiltration and/or slow conveyance to additional LID facilities downstream (figures 3.11 and 3.12).

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Figure 3.9 Pullout parking adjacent to a 14-foot residential access road, Seattle.
Photo by Colleen Owen

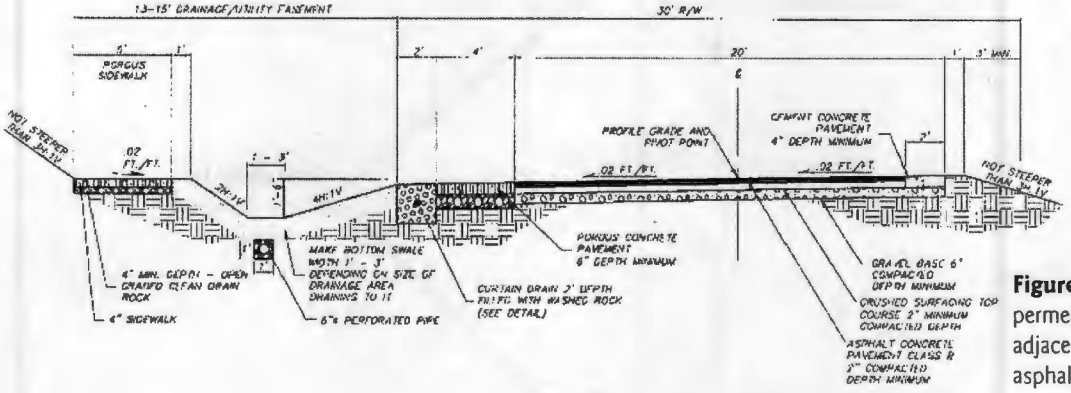

Figure 3.10 Four-foot permeable paving section adjacent to conventional asphalt roadway.
Courtesy of Pierce County Department of Public Works and Utilities

Alleys

Alleys should be the minimum width required for service vehicles, constructed of permeable paving materials, and allow any surface flows to disperse and infiltrate to adjacent bioretention swales, shoulders or yards (Figure 3.13). Strategies to reduce TIA associated with alleys include:

Maximum alley width should be 10 to 12 feet with 14- to 16-foot right-of-ways respectively.

Several permeable paving materials are applicable for low speeds and high service vehicle weights typically found in alleys including:

- Gravel pave systems.
- Permeable concrete.
- Permeable pavers.
- Systems integrating multiple permeable paving materials.

See Section 6.3: Permeable Paving for details.

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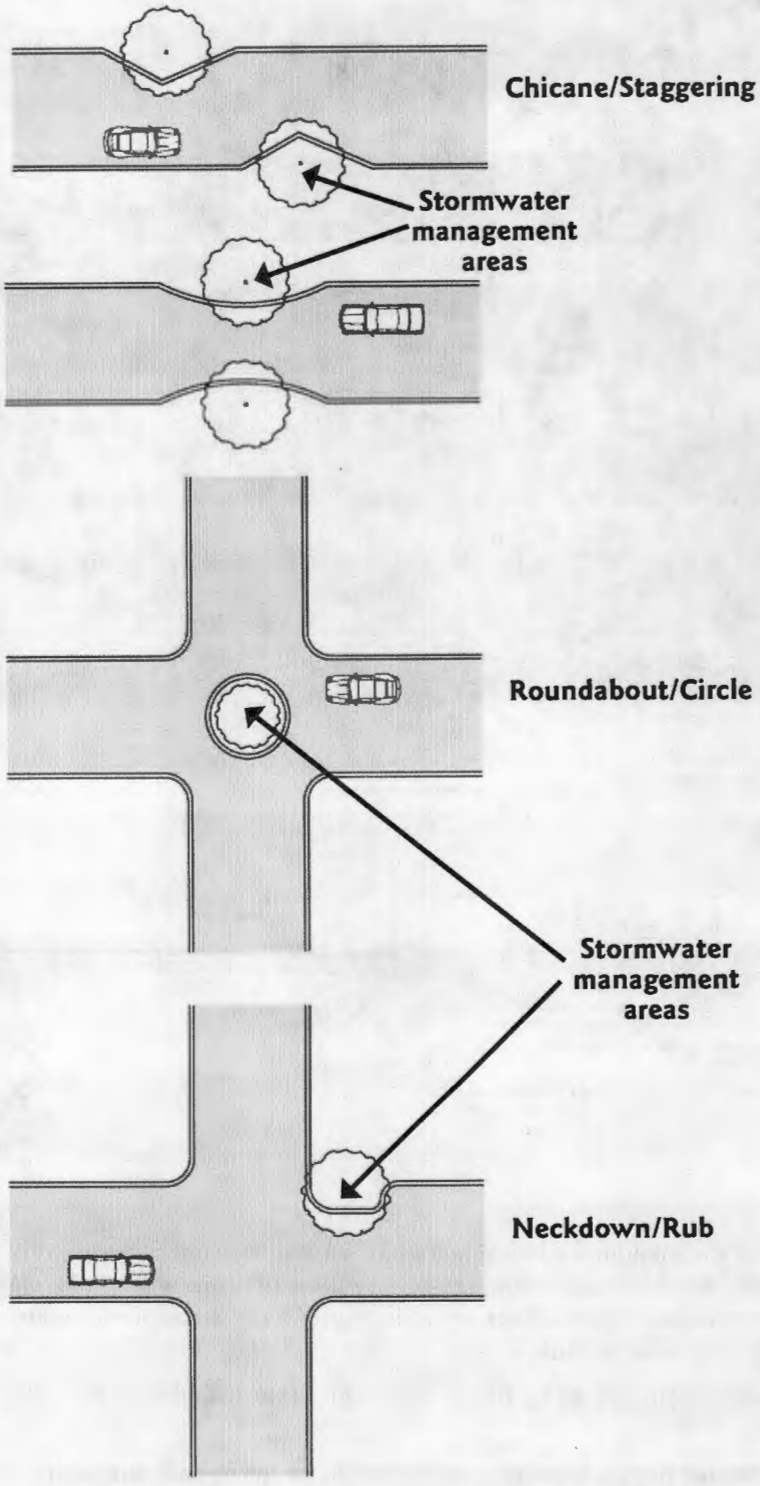

Figure 3.11 Combination stormwater management and traffic calming. (Note: These areas are slightly lower than road surface.)

Graphic by AHBL Engineering

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Figure 3.12 Siskiyou project in Portland, Oregon uses traffic calming designs to manage stormwater. Note curb cuts that allow stormwater to enter bioretention area in narrow section of road.
Photo by Erica Guttman



Figure 3.13 Vancouver, BC Country Lane alley uses a combination of concrete wheel strips, permeable pavers, reinforced plastic grid with grass, and under-drains to attenuate storm flows and create an aesthetic design objective.
Photo by Curtis Hinman

Driveways

As much as 20 percent of the impervious cover in a residential subdivision can be attributed to driveways (CWP, 1998). Several techniques can be used to reduce impervious coverage associated with driveways including:

- Shared driveways provide access to several homes and may not have to be designed as wide as local residential roads (Figure 3.14). Recommendations range from 9 to 16 feet in width serving 3 to 6 homes (NAHB et al., 2001 and Prince George's County, Maryland, 2000). A hammerhead or other configuration that generates minimal impervious surface may be necessary for turnaround and parking area.
- Minimize front yard setbacks to reduce driveway length.
- Reduce minimum driveway width from 20 (common standard) to 18 feet. Driveways can be reduced further to 10 feet with a bulb-out at the garage.

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Figure 3.14 Issaquah Highlands shared driveway.
Photo by Curtis Hinman

- Use permeable paving materials and aggregate storage under wearing surface.
- Limit impervious surface to two tracks with remainder in reinforced grass or other pervious surface (California strips).
- Direct surface flow from driveways to compost-amended soils, bioretention areas or other dispersion and infiltration areas (see Section 6.2: Amending Construction Site Soils and Section 6.1: Bioretention Areas for details).

Sidewalks

Many jurisdictions require sidewalks on both sides of residential roads for safety and perceived consumer demand. Studies indicate that pedestrian accident rates are similar in areas with sidewalks on one or both sides of the street (CWP, 1998). Limited assessments suggest that there is no appreciable market difference between homes with sidewalks on the same side of the street and homes with sidewalks on the opposite side of the road (CWP, 1998). The Americans with Disabilities Act (ADA) does not require sidewalks on both sides, but rather at least one accessible route from public streets (WAC 51-40-1100, 2003). Impervious surface coverage generated by sidewalks can be reduced using the following strategies:

- Reduce sidewalk to a minimum of 44 inches (ADA recommended minimum) or 48 inches (AASHTO, 2001 and NAHB et al., 2001 recommended minimum).
- For low speed local access roads eliminate sidewalks or provide sidewalks on one side of the road. A walking and biking lane, delineated by a paint stripe, can be included along the roadway edge.
- Design a bioretention swale or bioretention cell between the sidewalk and the street to provide a visual break and increase the distance of the sidewalk from the road for safety (NAHB et al., 2001).
- Install sidewalks at a two percent slope to direct storm flow to bioretention swales or bioretention cells–do not direct sidewalk water to curb and gutter or other hardened roadside conveyance structures.
- Use permeable paving material to infiltrate or increase time of concentration of storm flows (see Section 6.3: Permeable Paving for details).

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Figure 3.15 Permeable concrete walkway and parking area on Whidbey Island.
Courtesy of Greg McKinnon

3.1.2 Low Density/Large Lots

Dispersion

Low density or large lot development offer increased opportunities or land area to integrate LID dispersion, storage, and infiltration strategies. The greater distances between residences can, however, increase the overall road network and total impervious coverage per dwelling (Schueler, 1995). Preserving or restoring native soils and vegetation along low density road networks and driveways, and dispersing storm flows to those areas offers a low cost and effective LID strategy. Designs for dispersion should minimize surface flow velocities and not concentrate storm flows.

The strategies for road, driveway, parking and other LID designs appropriate in medium to high density settings (see Section 3.1.1) can be applied in large lot settings as well.

Dispersion flow control credit

See Chapter 7 for design of dispersion techniques and flow control guidelines when using the Western Washington Hydrologic Model.

Driveways

Shared driveways are applicable in large lot as well as higher density settings. Figure 3.16 is a large lot conservation design for protecting open space and uses shared driveways to access homes.

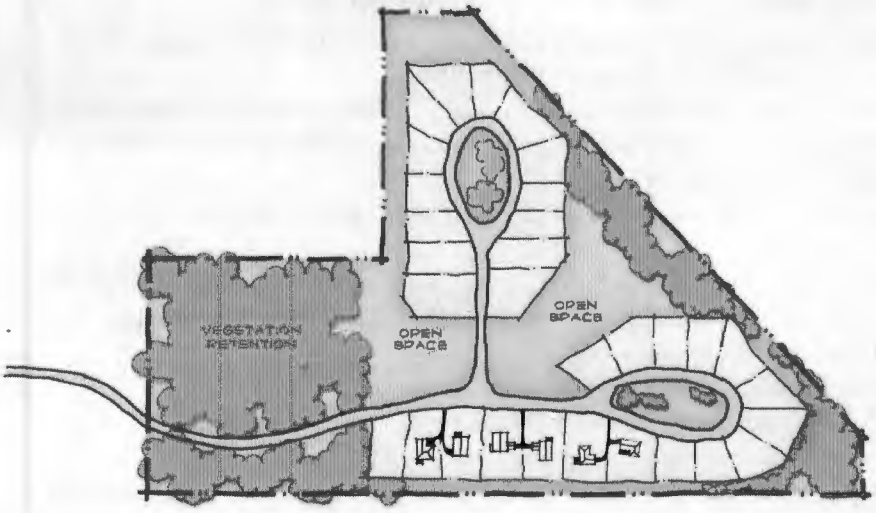

Figure 3.16 Large lot cluster design with shared driveway.
Graphic by AHBL Engineering

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3.1.3 Commercial

Parking

Parking lots and roof tops are the largest contributors to impervious surface coverage in commercial areas. Typical parking stall dimensions are approximately 9 to 9.5 feet by 18.5 to 19 feet, totaling 166.5 and 180.5 square feet respectively (Schueler, 1995 and City of Olympia, 1995). Considering the total space associated with each stall including overhangs, access isle, curbs, and median islands, a parking lot can require up to 400-square feet per vehicle or approximately one acre per 100 cars (CHI, 2000). The large effective impervious coverage associated with parking areas accumulates high pollutant loads from atmospheric deposition and vehicle use (auto pollutant contributions can be particularly heavy during stopping and starting a vehicle). As a result, commercial parking lots can produce greater levels of petroleum hydrocarbons and trace metals (cadmium, copper, zinc, lead) than many other urban land uses (Schueler, 1995 and Bannerman et al., 1993).

Many jurisdictions specify parking demand ratios as a minimum number of spaces that must be provided for the development type, number of employees, gross floor area or other parking need indicator. While parking infrastructure is a significant expense for commercial development, providing excess parking is often perceived as necessary to attract (or not discourage) customers. As a result, minimum standards are often exceeded in various regions of the U.S. by 30 to 50 percent (Schueler, 1995). In a local study, the city of Olympia found that 70 percent of all parking lots surveyed had at least 25 percent additional capacity during normal and peak hours (City of Olympia, 1995). The same study concluded that a 20 percent reduction in parking stalls was feasible without significantly impacting business activity.

The city of Olympia found that 70 percent of all parking lots surveyed had at least 25 percent additional capacity during normal and peak hours.

Capping parking demand ratios to reflect actual need is the most effective of several methods used to reduce impervious coverage in parking areas. In a commercial parking area selected in the Olympia study (526 stalls), a 20 percent reduction (105 stalls) would reduce surface flows by approximately 4,000 cubic feet for a typical two-year event (City of Olympia, 1995).

To reduce impervious coverage, storm flows, and pollutant loads from commercial parking areas, several LID strategies can be employed including:

- Assess parking demand ratios to determine if ratios are within national or, if available, actual local ranges (Schueler, 1995).
- Establish minimum and maximum or median parking demand ratios and allow additional spaces above the maximum ratio only if parking studies indicate a need for added capacity.
- Dedicate 20 to 30 percent of parking to compact spaces (typically 7.5 by 15 feet).
- Use a diagonal parking stall configuration with a single lane between stalls (reduces width of parking isle from 24 to 18 feet and overall lot coverage by 5 to 10 percent) (Schueler, 1995).
- Where density and land value warrant, or where necessary to reduce TIA below a maximum allowed by land use plans, construct underground, under building or multi-story parking structures.
- Use permeable paving materials for the entire parking area or, at a minimum, for spillover parking that is used primarily for peak demand periods (Figure 3.17).

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- Integrate bioretention into parking lot islands or planter strips distributed throughout the parking area to infiltrate, store, and/or slowly convey storm flows to additional facilities.
- Encourage cooperative parking agreements to coordinate use of adjacent or nearby parking areas that serve land uses with non-competing hours of operation–for example a cooperative agreement between a church and an office or retail store (City of Olympia, 1995).

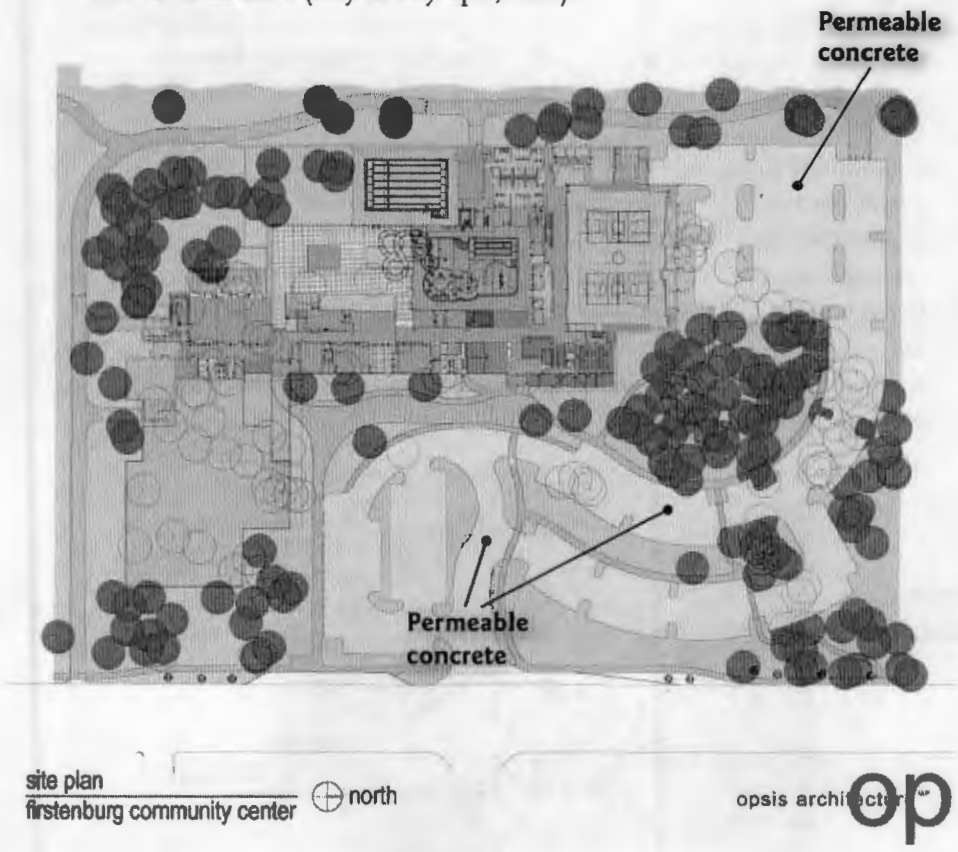

Figure 3.17 Firstenburg project in Vancouver, Washington includes 100,000 square feet of permeable concrete. *Courtesy of 2020 Engineering*

3.2 Road Crossings

Numerous studies have correlated increased total impervious area with declining stream and wetland conditions (Azous and Horner, 2001; Booth et al., 2002; May et al., 1997). Recent research in the Puget Sound region suggests that the number of stream crossings per stream length may be a relatively stronger indicator of stream health (expressed through Benthic Index of Biotic Integrity) than TIA (Avolio, 2003). In general, crossings place significant stress on stream ecological health by concentrating and directing storm flows and contaminants to receiving waters through associated outfall pipes, fragmenting riparian buffers, altering hydraulics, and disrupting in-channel processes such as meander migration and wood recruitment (Avolio, 2003 and May, 1997). Culvert and bridge design that place supporting structures in the floodplain or active channel confine stream flows. The confined flow often increases bank and bed erosion resulting in channel enlargement downstream of the structure (Avolio, 2003). Bank armoring associated with crossings further disrupts hydraulics and channel processes and can increase the impacts of all crossing types including less damaging bridge designs (Avolio, 2003).

Road crossings place significant stress on stream ecological health by directing concentrated storm flows and contaminants to receiving waters, fragmenting riparian buffers, altering hydraulics, and disrupting in-channel processes.

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Improperly designed crossings using culverts can also inhibit or completely block fish passage. Design considerations for minimizing road crossing impacts include:

- Eliminate, or reduce to an absolute minimum, all stream crossings.
- Where stream crossings are unavoidable, bridges are preferable to culverts.
- Locate bridge piers or abutments outside of the active channel or channel migration zone.
- If culverts are utilized, install slab, arch or box type culverts, preferably using bottomless designs that more closely mimic stream bottom habitat.
- Utilize the widest possible culvert design to reduce channel confinement.
- Minimize stream bank armoring and establish native riparian vegetation and large woody debris to enhance bank stability and diffuse increased stream power created by road crossing structures. (Note: consult a qualified fluvial geomorphologist and/or hydrologist for recommendations.)
- All crossings should be designed to pass the 100-year flood event.
- Cross at approximately 90 degrees to the channel to minimize disturbance.
- Do not discharge storm flows directly from impervious surfaces associated with road crossing directly to the stream—disperse and infiltrate stormwater or detain and treat flows.

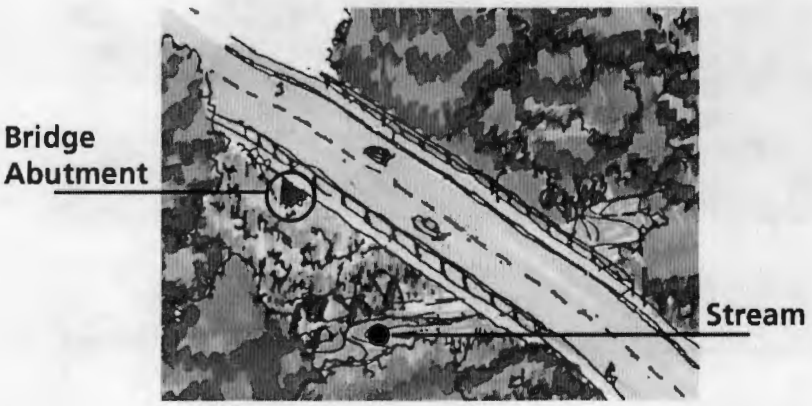

Figure 3.18 Minimal impact stream crossing. Locate abutments outside of active channel or channel migration zone. Cross at approximately 90° to channel to minimize shading and other disturbances.
Courtesy of Portland Metro Green Streets Program

3.3 Street Trees

Trees can be used as a stormwater management tool in addition to providing more commonly recognized benefits such as energy conservation, air quality improvement, and aesthetic enhancement. Tree surfaces (foliage, bark, and branches) intercept, evaporate, store or convey precipitation to the soil before it reaches surrounding impervious surfaces. In bioretention cells or swales, tree roots build soil structure that enhances infiltration capacity and reduces erosion (Metro, 2003).

Appropriate placement and selection of tree species is important to achieve desired benefits and reduce potential problems such as pavement damage by surface roots and poor growth performance. When selecting species, consider the following site characteristics:

- Available growing space.
- Type of soil and availability of water.
- Overhead wires.
- Vehicle and pedestrian sight lines.
- Proximity to paved areas and underground structures.

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Figure 3.19 Street trees–Queen Anne neighborhood, Seattle.
Photo by Colleen Owen

- Proximity to neighbors, buildings, and other vegetation.
- Prevailing wind direction and sun exposure.
- Additional functions desired, such as shade, aesthetics, windbreak, privacy screening, etc.

Local jurisdictions often have specific guidelines for the types and location of trees planted along public streets or rights-of-way. The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with under-drain structures or near paved areas such as driveways, sidewalks or streets. Other important tree characteristics to consider when making a selection include:

- Longevity or life-span (ideally a street tree will be "long-lived", meaning it has a life span of 100 years or more. However, the longevity of a tree will need to be balanced with other selection priorities).
- Tolerance for urban pollutants.
- Growth rate.
- Tolerance to drought, seasonally saturated soils, and poor soils.
- Canopy spread and density (trees that provide a closed street canopy maximize interception and evapotranspiration).
- Foliage texture and persistence.

Appendix 1 lists the growth pattern and appropriate site characteristics for a variety of trees appropriate for street, parking lot, residential yard, and bioretention applications.

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3.4 Lot Layout

Typical residential development determines lot size by dividing the total plat acreage, minus the roads and regulated sensitive areas, by the number of lots allowed under the applicable zoning. Most, if not all, of the site is cleared and graded. In contrast, LID projects employ clustering and other planning strategies to minimize site disturbance, maximize protection of native soil and vegetation, and permanently set aside the open tracts for multiple objectives including stormwater management. Four general objectives should guide the placement and orientation of lots for LID projects:

- Minimize site disturbance.
- Strategically locate lots for dispersing stormwater to open space areas.
- Orient lots and buildings to maximize opportunities for on-lot infiltration or open conveyance through bioretention swales or cells to downstream LID facilities.
- Locate lots adjacent to, or with views of, open space to improve aesthetics and privacy.

The following examines three prevalent development strategies applied in a low impact development context–medium to high density cluster, rural cluster, and large lot development.

3.4.1 Medium to High Density Cluster (4 or More Dwelling Units Per Acre)

Clustering is a type of development where buildings are organized together into compact groupings that allow for portions of the development site to remain in open space (Maryland Office of Planning, 1994). In the U.S., the primary focus of cluster development has been to preserve natural and cultural features, provide recreation, preserve rural character, and produce more affordable housing (Schueler, 1995).

The LID cluster may include the above objectives; however, the primary purpose of the low impact development cluster is to minimize the development envelope, reduce impervious coverage, and maximize native soil and forest protection or restoration areas. Natural resource protection areas (the preferred strategy) are undisturbed conservation areas. Restoration areas (appropriate where land is or will be disturbed) can be enhanced through soil amendments and native planting to improve the hydrologic function of the site. Both can provide dispersion for overland flows generated in developed areas. Demonstration projects indicate that significant open space protection can still be achieved over conventional development projects designed with relatively small lot sizes when using cluster strategies (Figure 3.20).

Objectives for medium to high density clustering:

- Medium density (4 to 6 dwelling units per acre): reduce the development envelope in order to retain a minimum of 50 percent open space.
- High density (more than 6 dwelling units per acre): protect or restore to the greatest extent possible. Note: in medium to high density settings, reducing the development envelope and protecting native forest and soil areas will often require multifamily, cottage, condominium or mixed attached and detached single family homes.

Techniques to meet objectives for medium to high density clustering include:

- Minimize individual lot size (3,000 to 4,000 square-foot lots can support a medium sized home designed to occupy a compact building footprint).

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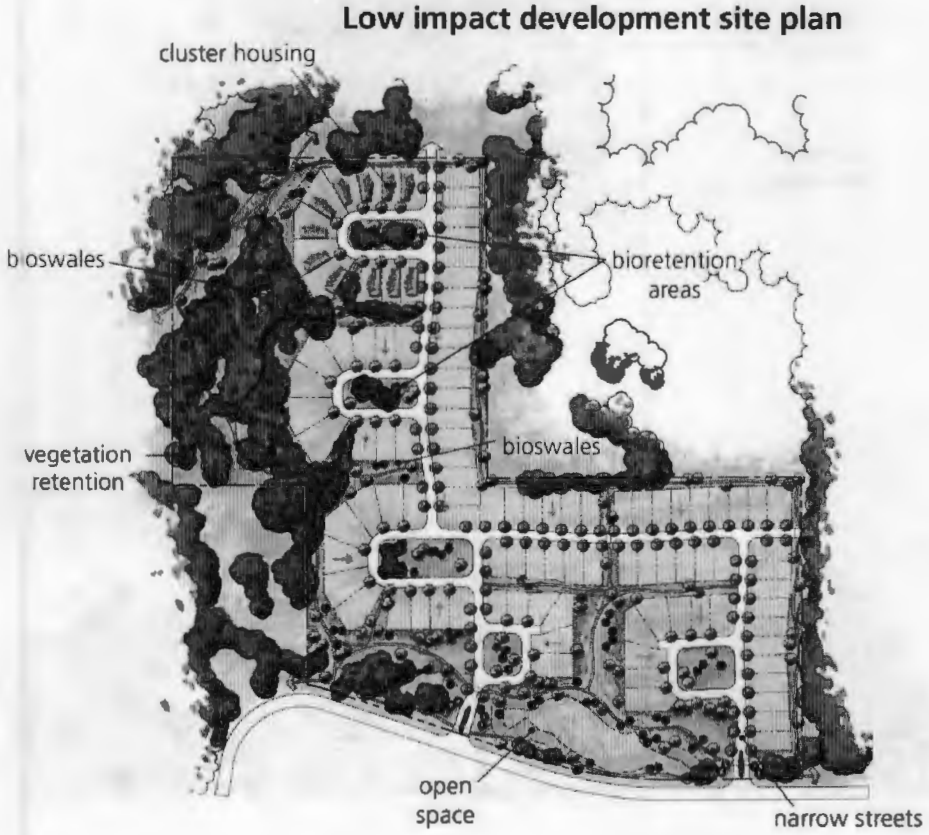

Figure 3.20 Conventional small lot development compared to LID cluster design.

Graphic by AHBL Engineering

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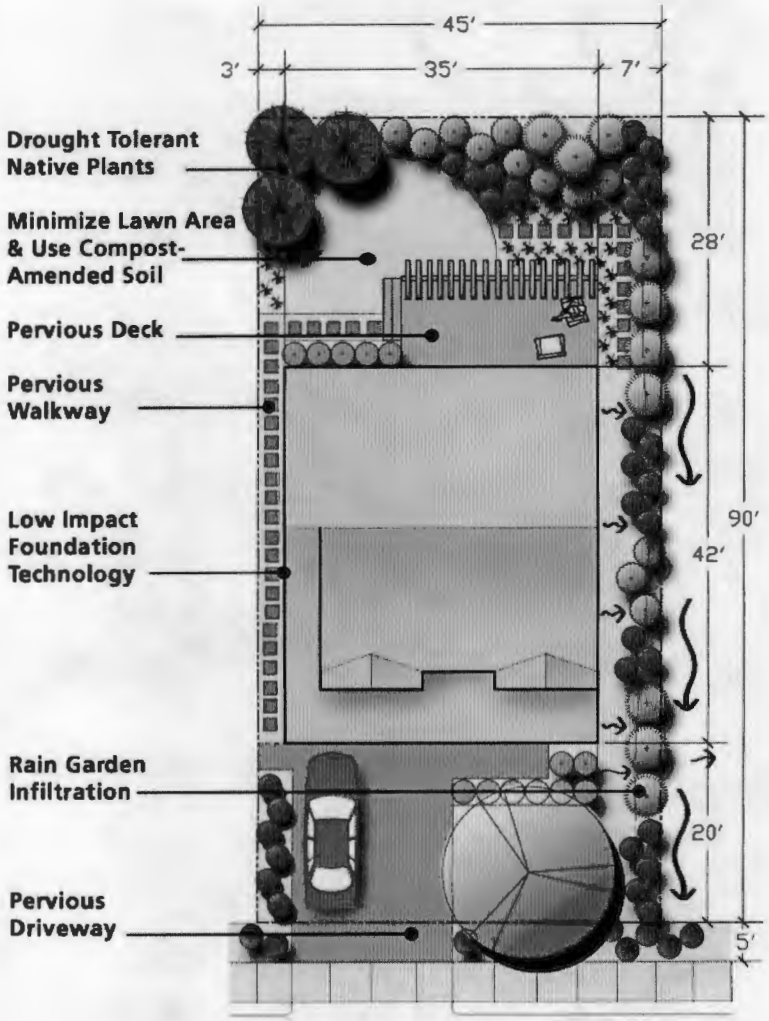

Figure 3.21 Example of medium- to high-density lot using low impact development practices.

Graphic by AHBL Engineering



Figure 3.22 Zero lot line configuration.

Graphic by AHBL Engineering

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Figure 3.23 Shared courtyard in a cottage development in Seattle.
Photo by Curtis Hinman



Figure 3.24 Cluster of homes designed with vegetated roofs in Berlin, Germany.
Photo courtesy of Patrick Carey

- Minimize setbacks. Examples of minimum setbacks include:
  - o 25-foot front yard.
  - o 3-foot side yard (minimum side yard set backs should allow for fire protection ladder access, and structures with narrow side yards should use fire resistant siding materials).
- Use zero lot line set back to increase side yard area (Figure 3.22).
- Use cottage designs for a highly compact development envelope.
- Amend disturbed soils to regain stormwater storage capacity (see Section 6.2: Amending Construction Site Soils).
- Drain rooftops to cisterns for non-potable reuse within the house or garden (see Section 6.6: Roof Rainwater Collection Systems).
- Utilize vegetated roof systems to evaporate and transpire stormwater (see Section 6.4: Vegetated Roofs).
- Lay out roads and lots to minimize grading to the greatest extent possible.
- Stormwater from lots not adjacent to forested/open space infiltration areas can be conveyed in swales or dispersed as low velocity (< 1fps) sheet flow to the infiltration areas.
- Orient lots to use shared driveways to access houses along common lot lines.
- To maximize privacy and livability within cluster developments, locate as many lots as possible adjacent to open space, orient lots to capture views of open space, and design bioretention swales and rain gardens as visual buffers.
- Set natural resource protection areas aside as a permanent tract or tracts of open space with clear management guidelines.

A little known, but effective, cluster strategy is Air Space Condominium design. In this design scenario (applicable for most single family residential development),

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the property is not divided into separate lots. Instead, designated areas, or air space, that include the dwelling and some additional yard space (optional) are available for purchase with the remaining property held in common and managed by a homeowners association. The stormwater management practices are held within an easement for local jurisdiction access and require a long-term management agreement followed by the homeowners. The advantage of the condominium classification is increased design flexibility including:

- The entire road network can be considered as driveway reducing design standards for road widths, curb and gutter, etc.
- No minimum lot size.
- Reduced overall development envelope.

Note: fire and vehicle safety requirements must still be satisfied.

3.4.2 Rural Cluster and Large Lot Development

Substantial reduction of impervious surfaces can be realized through clustering large lot development. In a study comparing 100-lot subdivision designs, the Maryland Office of State Planning found a 30 percent reduction in impervious surface when lot size was reduced from a typical rural density of 1.4 to 0.25 acres. Additional road network and driveway lengths are the primary reasons for increased imperviousness associated with large lot development (Delaware Department of Natural Resources and Environmental Control and the Environmental Management Center of the Brandywine Conservancy, 1997). The increased storm flows from the additional road network required to serve rural cluster and large lot designs should be dispersed to bioretention swales, adjacent open space, and/or lawn areas amended with compost (figures 3.25 and 3.26).

Objectives for rural clustering and large lots:

- Reduce the development envelope in order to retain a minimum of 65 percent of the site in native soil and vegetation.
- Reduce EIA to zero (fully disperse stormwater).

Medium to high density cluster guidelines can be used in large lot settings. The increased land area in the rural cluster and large lot scenarios offer additional opportunities including:

- Integrate bioretention and open bioretention swale systems into the landscaping to store, infiltrate, slowly convey, and/or disperse stormwater on the lot.
- Disperse road and driveway stormwater to adjacent open space and lawn areas (see Chapter 7: Flow Modeling Guidance for dispersion details).
- Maintain pre-development flow path lengths in natural drainage patterns.
- Preserve or enhance native vegetation and soil to disperse, store, and infiltrate stormwater.
- Disperse roof water across the yard and to open space areas or infiltrate roof water in infiltration trenches.
- Lots may be organized into cluster units separated by open space buffers as long as road networks and driveways are not increased significantly, and the open space tract is not fragmented.
- Place clusters on the site and use native vegetation to screen or buffer higher density clusters from adjacent rural land uses.

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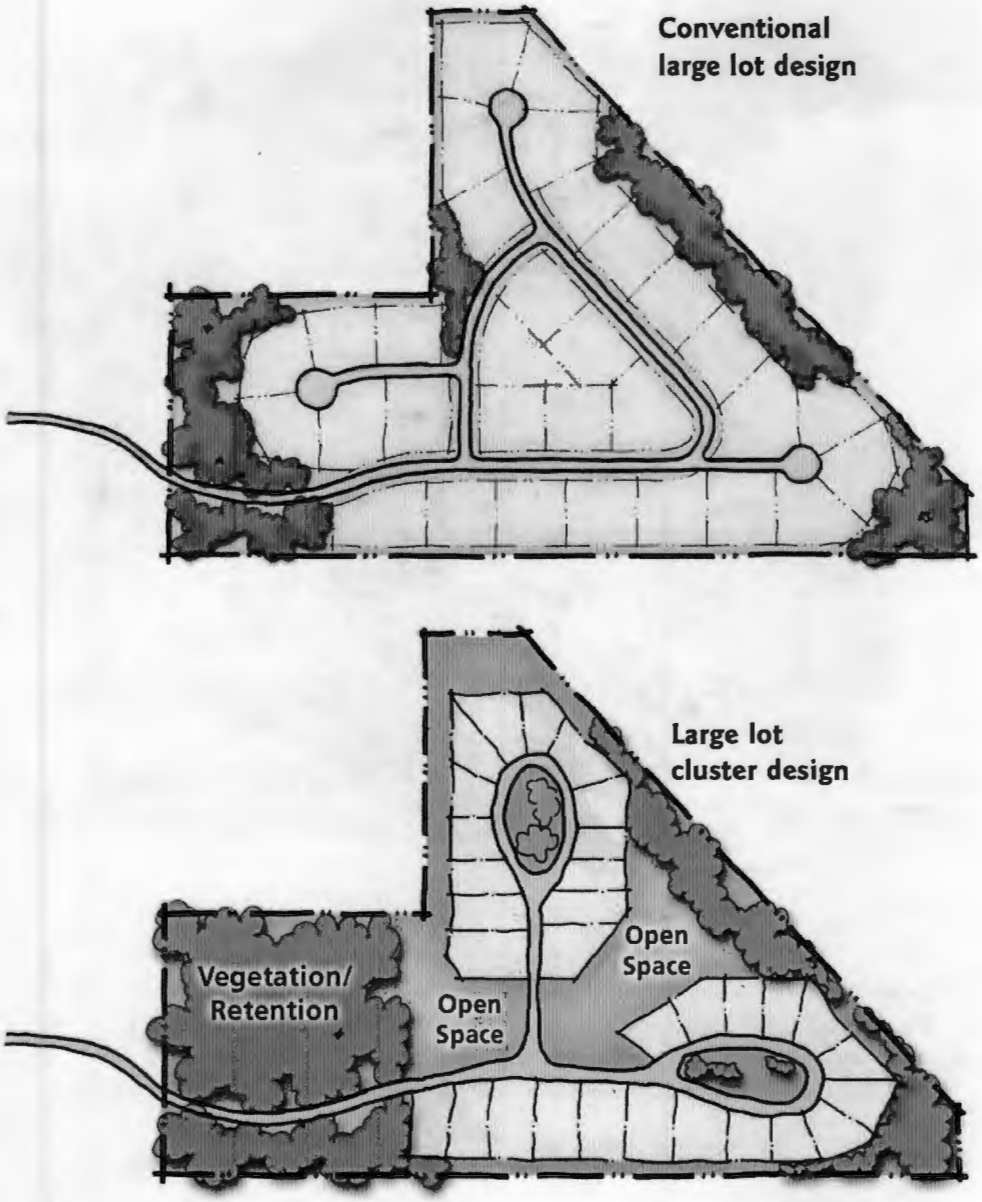

Figure 3.25 Conventional and large lot cluster designs.

Graphic by AHBL Engineering

3.5 Building Design

Impervious surface associated with roofs ranges from approximately 15 percent for single family residential, 17 percent for multifamily residential, and 26 percent for commercial development (City of Olympia, 1995). As densities increase for detached single-family residential development, opportunities for infiltrating roof stormwater decrease; however, other strategies to process this water can be applied.

Objectives for building design strategies are to disconnect roof stormwater from stormwater conveyance and pond systems (i.e., eliminate roofs as effective impervious surface), and reduce site disturbance from the building footprint. Strategies for minimizing storm flows and disturbance include:

- Reduce building footprint. Designing taller structures can reduce building footprints and associated impervious surface by one-half or more in comparison to a single story configuration. Proposals to construct taller buildings can also

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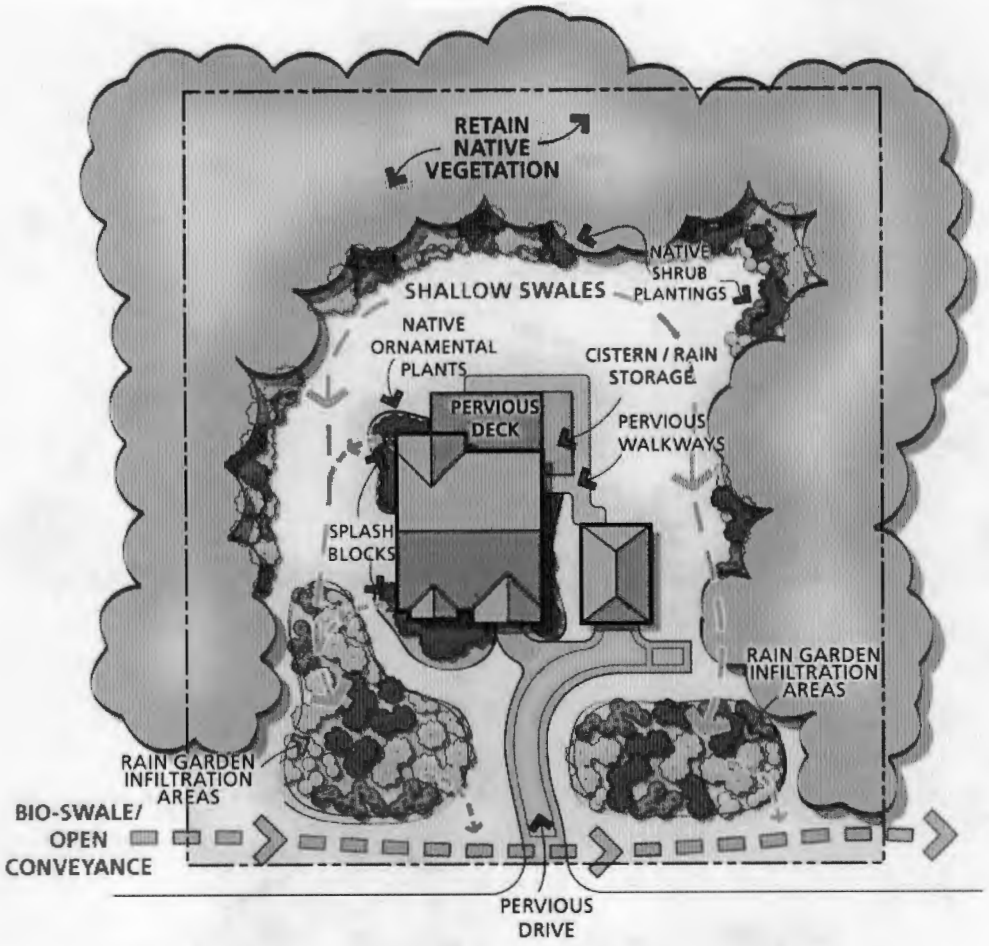
Figure 3.26 Large lot LID design example.

Graphic by AHBL Engineering



present specific fire, safety, and health issues that may need to be addressed. For example, any residence over two stories requires a fire escape and a sprinkler system. These additional costs may be partially reduced by a reduction in stormwater conveyance and pond systems and stormwater utility fees.

- Orient the long axis of the building along topographic contours to reduce cutting and filling.
- Control roof water onsite (see Section 6.4 Vegetated Roofs and Section 6.6 Roof Rainwater Collection Systems for design guidelines).
- Use low impact foundations (see Section 6.5: Minimal Excavation Foundations).
- Limit clearing and grading to road, utility, building pad, landscapé areas, and the minimum amount of extra land necessary to maneuver machinery. All other land should be delineated and protected from compaction with construction fencing. (see Chapter 4: Vegetation Protection, Reforestation, and Maintenance, and Chapter 5: Clearing and Grading).

LID in Green Cove Basin

The city of Olympia is using low impact development strategies and other environmental protection measures to preserve high quality forest and aquatic resources in Green Cove basin. One measure includes setting a maximum total impervious surface coverage of 2,500 square feet per lot (Title 18 Unified Development Code: Article II. Land Use Districts).

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4 Vegetation Protection, Reforestation, and Maintenance

IN THIS CHAPTER...

- *Native vegetation protection*
- *Reforestation:*
  Plant evaluation and selection
  Plantings
- *Maintenance*

Mature native vegetation and soil are necessary to maintain watershed hydrology, stable stream channels, wetland hydroperiods, and healthy aquatic systems (Booth et al., 2002). While necessary to maintain aquatic systems, native vegetation and soils are also the most cost-effective and efficient tools for managing stormwater quantity and quality. Hydrologic modeling comparing conventional development and low impact development (LID) designs suggests that of the various LID applications, reducing the development envelope and increasing vegetation and soil conservation areas can provide the single largest reduction of storm flows (Table 4.1) (AHBL, 2002).

Table 4.1 Hydrologic modeling comparing a conventional development and the flow reduction benefits from individual practices for a low impact development design. The 24-acre till-mantled site in southern Puget Sound has 103 lots and was modeled with the Western Washington Hydrologic Model (adapted from AHBL, 2000).

	Detention storage reduced (ft^3)	Detention storage required (ft^3)
Conventional development	0	**270,000**
Low impact development		
Reduce development envelope, 24' wide road	- 149,019	
And use bioretention swales and cells	- 40,061	
And use minimal excavation foundations	- 7,432	
And use 20' wide permeable paving road	-29,988	
Total	-226,500	**43,500**

Retaining native soil and vegetation protection areas is a primary objective for low impact development in order to: (1) reduce total impervious surface coverage; (2) provide infiltration areas for overland flows generated in adjacent developed portions of the project; and (3) maintain or more closely mimic the natural hydrologic function of the site. The protection areas provide additional benefits, including critical area and habitat protection, open space corridors for passive recreation, visual buffers, and erosion and sediment control.

While necessary to maintain aquatic systems, native vegetation and soils are also the most cost-effective and efficient tools for managing stormwater quantity and quality.

Objectives for on-site native vegetation coverage:

- Rural and large lot development: 65 percent minimum.
- Medium density (4 to 6 dwelling units per acre): 50 percent minimum.

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- High density (more than 6 dwelling units per acre): protect or restore to the greatest extent practical. Note: in medium to high density settings, reducing the development envelope and protecting native forest and soil areas will often require multifamily, condominium, cottage or mixed attached and detached single family homes (see Chapter 3: Site Planning and Layout).
- Riparian Management Areas can be included as a part of the native vegetation retention area and are the highest priority for native vegetation retention.

The 65 percent forest retention objective is a watershed level target based on best available science for maintaining watershed hydrologic functions (Booth et. al, 2002). Not all projects can achieve 65 percent protection at the project site. However, projects attaining 40, 50 or 60 percent native vegetation protection and using a full complement of LID practices still play a critical role in achieving overall watershed protection objectives when part of a larger planning process that strategically conserves riparian and other sensitive resources at a regional scale.

The following sections provide guidelines for native vegetation protection during the construction phase, enhancement or rehabilitation of impacted areas, and strategies for long-term maintenance.

4.1 Native Vegetation Protection

Native vegetation and soil protection areas in today's urban, suburban, and rural settings are fragments of pre-European contact forests and prairie. Natural successional forces have been altered and active management is required to compensate for the loss of natural processes and the addition of new stressors (Matheny and Clark, 1998). Vegetation protection areas not directly adjacent to structures (or located where they may potentially impact a structure) should be managed to encourage natural successional patterns and develop diverse multilayer canopy structure, snags, large woody debris, understory vegetation, and forest duff. The protection, reforestation, and management strategies provided below are designed to maintain vegetation cover, adequate soil building, and plant regeneration processes necessary for retaining these areas for the long term.

Assessment of natural resources and the site planning process will identify and delineate critical areas and native vegetation offering the best suite of benefits, including greatest infiltration potential. The final delineation and details of the management program for the vegetation protection areas requires assessment by a qualified urban forester or landscape architect that considers size of the area, type of soil, exposure, vegetation type and structure, invasive species impacts, human use, condition of existing vegetation, and existing and post-development hydrologic patterns in the area.

Selection of dispersed individual trees and tracks of native vegetation may be necessary to meet native forest and soil protection objectives. Individual trees selected for protection should have developed as individuals with well-tapered trunks and good live crown ratios (total tree height in relation to the height of the live crown). Trees from dense stands with tall, poorly tapered trunks and high irregular shaped crowns generally do not adapt to wind and sun exposure and are not good candidates to preserve as single trees (Figure 4.1) (Matheny and Clark, 1998). As a general guideline, conifers with live crown ratios of less than 30 percent tend to break in winds while trees with ratios greater than 50 percent tend to be more stable (Matheny and Clark, 1998).

LID in Green Cove Basin

To protect sensitive aquatic resources, the city of Olympia requires all development in the Green Cove basin to have approximately 55 percent tree cover.

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Figure 4.1 These native trees that were retained during clearing have low live crown ratios.
Photo by Curtis Hinman

Trees and other native vegetation that developed in forests or woodlands are best retained in groups of sufficient size to maintain adequate growing space characteristics and the integrity of the unit. Growing space characteristics include soil moisture, sunlight, humidity, wind, competition among adjacent plants, and other growth factors. Retaining small fragments of mature, single species trees adapted to the interior of a forest stand is seldom successful (Matheny and Clark, 1998). Additional stressors along newly exposed edges of larger preserved vegetation tracts can affect unit integrity and result in high initial plant mortality on the perimeter. Replacement of unhealthy trees and other vegetation with material adapted to edge environments, as well as invasive species control, may be necessary (Matheny and Clark, 1998).

Delineation and management of larger tracts and smaller scale, dispersed protection areas are necessary to meet retention objectives on most sites. Larger contiguous tracts are more likely to sustain healthy soils, retain diverse and dense vegetation coverage, and have less area affected by edge stress factors (increased sunlight, wind, and invasive species). Small-scale dispersed protection areas can be located to intercept storm flows at the source, reduce flow volumes within small contributing areas, and maintain time of concentration. Specific site and design requirements will influence the type and distribution of protection areas; however, the location and type of area can influence the extent of benefit and long-term viability.

The following provides a list of native vegetation and soil protection areas prioritized by location and type of area:

1. Large tracts of riparian areas that connect and create contiguous riparian protection areas.
2. Large tracts of critical and wildlife habitat area that connect and create contiguous protection areas.
3. Tracts that create common open space areas among and/or within developed sites.
4. Protection areas on individual lots that connect to areas on adjacent lots or common protection areas.
5. Protection areas on individual lots.

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4.1.1 Protection During the Construction Phase

Soil compaction is a leading cause of death or decline of mature trees in developed areas (World Forestry Center, 1989). Most tree roots are located within 3 feet of the ground surface and the majority of the fine roots active in water and nutrient absorption are within 18 inches. Root systems can extend 2 to 3 times beyond the diameter of the crown (World Forestry Center and Morgan, 1993 and Matheny and Clark, 1998). Equipment activity on construction sites can severely compact soil, essentially eliminating soil pore structure at 6 to 8 inches below the ground surface. Compaction can extend as deep as 3 feet depending on soil type, soil moisture, and total axle load of the equipment. Foot traffic can exert per unit area pressure similar to that of a vehicle and significantly compact soil as well (Corish, 1995 and World Forestry Center and Morgan, 1989). Soil compaction results in a reduction of soil oxygen and an increase in **soil bulk density**. In response to soil compaction, tree root penetration, root respiration, and associated uptake of nutrients and minerals decline, **mycorrhizal** activity is reduced, and susceptibility to root disease increases (Matheny and Clark, 1998).

Soil compaction is a leading cause of death or decline of mature trees in developed areas.

Several other direct and indirect impacts can influence vegetation health during land development including:

- Direct loss of roots from trenching, foundation construction, and other grade changes.
- Application of fill material that can compact soil, reduce oxygen levels in existing grade, and change soil chemistry.
- Damage to trunks or branches from construction equipment and activities.
- Exposure of forest interior areas to new stresses of forest edges as land is cleared.
- Changes in surface and subsurface water flow patterns.

Detrimental impacts to native vegetation and soil protection areas can be minimized through the following strategies:

- Map native soil and vegetation protection areas on all plans and delineate these areas on the site with appropriate fencing to protect soils and vegetation from construction damage. Fencing for forest protection areas should be located at a minimum of 3 feet beyond the existing tree canopy along the outer edge of the tree stand. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2005 SMMWW BMP C103 and C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.
- Install signs to identify and explain the use and management of the natural resource protection areas.
- Meet and walk property with equipment operators to clarify construction boundaries and limits of disturbance.
- Protect drainage areas during construction. Channel or drainage swales that provide a hydrologic connection to vegetation protection area(s) should be protected throughout the construction phase by fencing and erosion control measures to prevent untreated construction site runoff from entering the channel.

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- Protect trees and tree root systems utilizing the following methods:
  - o Minimize soil compaction by protecting critical tree root zones. The network of shallow tree roots, active in nutrient and water uptake, extends beyond the **tree canopy dripline**. Several methods can be used to assess the area necessary to protect tree roots. The dripline method may be applicable for broad-canopy trees; however, this method will likely underestimate the extent of roots and lead to extensive root damage for narrow-canopied trees and leaning trees with canopies extending to one side more than the other. As a general guideline, the trunk diameter method provides more design flexibility for variable growth patterns. This method provides a protection area with a 1-foot radius for every 1 inch of trunk diameter at chest height (DBH ~ 4.5ft). Factors that influence the specific distance calculated include the tree's tolerance to disturbance, age, and vigor (Matheny and Clark, 1998).
  - o Limit to an absolute minimum any excavation within the critical root zone. Tree species and soils will influence the ability of a tree to withstand disturbance. If the tree(s) are to be preserved and excavation in the critical root zone is unavoidable, consult a certified arborist for recommendations.
  - o Prohibit the stockpiling or disposal of excavated or construction materials in the vegetation retention areas to prevent contaminants from damaging vegetation and soils.
  - o Avoid excavation or changing the grade near trees that have been designated for protection. If the grade level around a tree is to be raised, a retaining wall (preferably with a discontinuous foundation to minimize excavation) should be constructed around the tree. The diameter of the wall should be at least equal to the diameter of the tree canopy plus five feet. If fill is not structural, compact soil to a minimum (usually 85 percent proctor) (World Forestry Center and Morgan, 1993). Some trees can tolerate limited fill if proper soils and application methods are used. Subsoil irrigation may be required. Consult a certified arborist for recommendations.
  - o Tree root systems tend to tangle and fuse among adjacent trees. Trees or woody vegetation that will be removed and that are next to preserved trees should be cut rather than pushed over with equipment (World Forestry Center and Morgan, 1993). Stumps can be ground if necessary.
  - o Restrict trenching in critical tree root zone areas. Consider boring under or digging a shallow trench through the roots with an air spade if trenching is unavoidable.
  - o Prevent wounds to tree trunks and limbs during the construction phase.
  - o Prohibit the installation of impervious surfaces in critical root zone areas. Where road or sidewalk surfaces are needed under a tree canopy, non-mortared porous pavers or flagstone (rather than concrete or asphalt) or bridging techniques should be used.
  - o Prepare tree conservation areas to better withstand the stresses of the construction phase by watering, fertilizing, pruning, and mulching around them well in advance of construction activities.

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4.2 Reforestation

Soil and vegetation protection areas that have been disturbed and do not have vegetation of sufficient size, quantity, and quality to achieve the necessary coverage may require soil enhancement and replanting with native trees and vegetation in order to achieve the full hydrologic benefits of the site (see Section 6.2: Amending Construction Site Soils for soil guidelines). Consult with a qualified urban forester or landscape architect to develop a long-term vegetation and soil management plan.

4.2.1 Existing Plant Evaluation and Site Preparation

Trees remaining in the protection area should have the following characteristics:

- No major pest or pathological problems.
- No extensive crown damage.
- No weakly attached co-dominant trunks if located in areas where failure could cause damage or safety problems.
- Relatively sound trunks without extensive decay or damage.
- Wind-firm in the post development condition.

(Matheny and Clark, 1998).

Trees identified as having significant wildlife value such as snags and nesting sites should be retained regardless of the health of the tree, unless the tree poses an imminent safety threat as determined by a qualified arborist or urban forester (Pierce County Ordinance No 2003-66, 18H.40.040, Tree Conservation Standards).

Intensive inventories and individual tree health evaluation is generally limited to areas where trees can damage existing or proposed structures. Depending on the physical setting, regulatory requirements, aesthetics, and other specific management needs, inventories and subsequent evaluations may be necessary in portions or all of the protection area's interior. If inventories and management plans indicate deficiencies in protected area vegetation structure, removing unhealthy trees may be desirable to free growing space, encourage new seedlings and create age and species diversity. The site should be prepared for planting by removing invasive species, stabilizing erosion areas, and enhancing soil with compost amendment where necessary.

4.2.2 Plant Selection

The native vegetation species should be selected based on the underlying soils and the historic, native indigenous plant community type for the site (Pierce County Ordinance No 2003-66, Exhibit B, Chapter 10, Low Impact Development). Coniferous trees provide greater interception, storage, and evaporation potential in the wet months and should be the major component of the protection area if ecologically compatible with the site. A single species of vegetation should not be used for replacement purposes.

Coniferous trees provide greater interception, storage, and evaporation potential in the wet months and should be the major component of the protection area if ecologically compatible with the site.

The following general guidelines are recommended for installing a self-sustaining native plant community that is compatible with the site and minimizes long-term maintenance requirements:

- The plantings should provide a multilayer canopy structure of large trees, small trees, and shrubs.
- Emphasize climax species, for example Douglas fir (*psuedotsuga menziesii*), on drier sites with more sun exposure, and western red cedar (*thuja plicata*),

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western hemlock *(tsuga heterophylla)*, or sitka spruce (*picea sitchensis*) on wetter sites with less sun exposure.

- For many sites, a ratio of 2 evergreens to 1 deciduous tree will provide a mix similar to native forests.
- To create a multilayer canopy, install 50 percent large structure trees to 50 percent small trees and shrubs.
- Space large trees at 15 to 20 feet and shrubs at 4 feet on center.
- The installation should be designed to develop to a dense closed canopy (when compatible with the site) to provide interception and evaporation of precipitation in the wet months and shade the site to exclude invasive vegetation species.

(Personal communication, Bill Barnes August, 2004)

Plants should conform to the standards of the current edition of *American Standard for Nursery Stock* as approved by the American Standards Institute, Inc. All plant grades should be those established in the current edition of *American Standards for Nursery Stock* (current edition: ANSI Z60.1-2004). All plant materials for installation should:

- Have normal, well-developed branches and a vigorous root system.
- Be healthy and free from physical defects, diseases, and insect pests.
- Not have weakly attached co-dominant trunks.

4.2.3 Plant Size

Selecting the optimum size of plant material for installation includes several factors. In general, small plant material requires less careful handling, less initial irrigation, experiences less transplant shock, is less expensive, adapts more quickly to a site, and transplants more successfully than larger material (Sound Native Plants, 2000). Smaller plant material is, however, more easily overgrown by weeds and invasive species such as reed canary grass, is more susceptible to browse damage, and is more easily damaged by maintenance personnel or landowners (Kantz, 2002). Accordingly, the following recommendations are provided:

- Where invasive species are not well established, weeds and browsing are controlled regularly, and maintenance personnel and landowners are trained in proper maintenance procedures, smaller material will likely have a lower mortality rate, is less expensive, and is recommended. Small trees and shrubs are generally supplied in pots of 3 gallons or less.
- Where invasive species are prevalent and weed and browse control is not ensured, larger plant material is recommended. Larger plants will require additional watering during the establishment period.
- For larger tree stock, coniferous and broadleaf evergreen material should be a minimum of 3 feet in height and deciduous trees should have a minimum caliper size of 1 inch (Kantz, 2002).

Native species should be used for vegetation and soil protection areas not adjacent to residential lots or commercial development. Depending on aesthetic needs, cultivars adapted to the region for hardiness may be used in transition areas between protection areas and structures. For growth characteristics and site suitability of trees and shrubs native or adapted to the Pacific Northwest see Appendix 1: Street Trees and Appendix 3: Bioretention Area Plants.

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4.2.4 Reference Documents for Planting

Vegetation restoration/planting methods should conform to published standards. The following guidance documents are examples:

- *Restoring the Watershed: A Citizen's Guide to Riparian Restoration in Western Washington,* Washington Department of Fish and Wildlife, 1995.
- *Plant It Right Restoring Our Streams,* Washington State University Extension http://wawater.wsu.edu
- *Integrated Streambank Protection Guidelines*, Washington Department of Fish and Wildlife, 2000.
- *Surface Water and Groundwater on Coastal Bluffs: A Guide for Puget Sound Property Owners*, Washington Department of Ecology, Shorelands and Coastal Zone Management Program Publication No. 95-107, 1995.
- *Vegetation Management: A Guide for Puget Sound Bluff Property Owners*, Washington Department of Ecology, Shorelands and Coastal Zone Management Program Publication No. 93-31, 1993.
- *Relative Success of Transplanted/Outplanted Plants*, Sound Native Plants, 2000.

Plants installed in the fall generally outperform late winter or spring plantings. In fall, the soil is warmer and more aerated than in the spring and transpiration requirements are less than in the spring and summer months. During the fall and winter, plants can develop sufficient root systems, recover from transplant shock, and prepare for the top growth and water demands of the growing season (Sound Native Plants, 2000).

4.3 Maintenance

In a low impact development, native vegetation and soil protection areas serve as stormwater management facilities. Clearly written management plans and protection mechanisms are necessary for maintaining the benefits of these areas over time. Some mechanisms for protection include dedicated tracts, conservation and utility easements, transfer to local land trusts (large areas), and homeowner association covenants. Property owner education should be part of all these strategies.

Ongoing maintenance should include weeding, watering, erosion and sediment control, and replacement of dead plant material for a minimum of three years from installation in order to achieve a minimum 80 percent survival of all plantings. If during the three-year period survival of planted vegetation falls below 80 percent, additional vegetation should be installed to achieve the required survival percentage. Additionally, the likely cause of the plant mortality should be determined (often poor soils and compaction) and corrected. If it is determined that the original plant choices are not well suited to site conditions, these plants should be replaced with plant species better suited to the site.

In a low impact development, native vegetation and soil protection areas serve as stormwater management facilities. Clearly written management plans and protection mechanisms are necessary for maintaining the benefits of these areas over time.

Permanent signs should be installed explaining the purpose of the area, the importance of vegetation and soils for managing stormwater, and that removal of trees or vegetation and compaction of soil is prohibited within the protected area. Permanent fencing, rock barriers, bollards or other access restriction at select locations or around the perimeter of protection areas may be required to limit encroachment.

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5 Clearing and Grading

In this chapter...

- *Techniques to minimize site disturbance*

Protecting native soil and vegetation and retaining hydrologic function during the clearing and grading phase presents one of the most significant challenges within the development process. Upper soil layers contain organic material, soil biota, and a structure favorable for storing and slowly conducting stormwater down gradient. Clearing and grading exposes and compacts underlying subsoil, producing a site with significantly different hydrologic characteristics. On till soil, precipitation is rapidly converted to overland flow. Surface and interflow are usually less on sites with native outwash soils and vegetation compared to native till conditions. Accordingly, the increase in overland flow from pre- to post-construction conditions can be greater on outwash than till sites if impervious areas are not minimized and soil structure is not protected for infiltration.

In addition to hydrologic modifications, sediment yield from clearing, grading and other construction activities can significantly affect receiving waters. Gammon found that stream biota was significantly reduced at suspended solids levels of 50 to 80mg/L (Corish, 1995). Schueler reported a median total suspended solids concentration of 4,145 mg/L leaving construction sites without erosion and sediment control and 283 mg/L at sites with controls (the range of concentrations with controls–11 to 2,070 mg/L in the study–was highly variable) (Corish, 1995). Typically, sediment and erosion is managed through structural practices; however, reliance on structural approaches alone to compensate for widespread vegetation loss can add unnecessary construction costs and may not provide adequate protection for aquatic habitat and biota. Minimizing site disturbance as a primary strategy to control erosion reduces the extent of grading, retains vegetation cover, and is the most cost-efficient and effective method for controlling sediment yield (Corish, 1995).

Minimizing site disturbance as a primary strategy to control erosion reduces the extent of grading, retains vegetation cover, and is the most cost-efficient and effective method for controlling sediment yield.

Several factors including topography, hydrology, zoning density and plat design, and housing type influence the timing and extent of clearing and grading activities. The scope of this section does not include the regulatory and market structure influencing clearing and grading, but rather focuses on planning and implementation techniques to reduce impacts to native soils, vegetation, and hydrology on the site.

Proper installation and maintenance of erosion and sediment control **best management practices** (BMPs) are required during the clearing, grading, and construction phases of a project. For detailed guidelines and specifications for erosion and sediment control BMPs see Washington State Department of Ecology 2005 *Stormwater Management Manual for Western Washington* Volume II chapter 4.

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5.1 Techniques to Minimize Site Disturbance

Planning and implementation techniques to minimize site disturbance fall into four categories:

- **Site design**
- **Construction planning**
- **Training**
- **Equipment**

5.1.1 Efficient Site Design

- Reduce the overall development envelope and maximize protection of native soils and vegetation with efficient road layout and cluster design (see Chapter 3: Site Planning and Layout).
- Retain natural topographic features that slow and store storm flows.
- Do not increase steep continuous slopes.
- Limit overall project cut and fill through efficient road design and lot layout.
- Minimize cut and fill by orienting the long axis of buildings along contours or staggering floor levels for buildings to adjust to gradient changes.
- Use minimal excavation foundation systems to reduce grading (see Section 6.5 Minimal Excavation Foundations for details).
- Limit clearing and grading disturbance to road, utility, building pad, landscape areas, and the minimum additional area needed to maneuver equipment (a 10-foot perimeter around the building site can provide adequate work space for most activities).
- Limit the construction access to one route if feasible, and locate access where future roads and utility corridors will be placed.

5.1.2 Coordinated Planning and Activities among Construction Entities

- Begin clearing, grading and heavy construction activity during the driest months and conclude by late fall when rainfall and associated soil compaction, erosion, and sediment yield from equipment activity increases. Late fall is also when conditions are most favorable for establishing vegetation.
- Plan efficient sequencing of construction phases to reduce equipment activity and potential damage to soil and vegetation protection areas.
- Establish and maintain erosion and sediment controls before or immediately after clearing and grading activity begins.
- Phase project to complete operations in one section of the site before clearing and grading the next. Project phasing is challenging when coordinating utility, road, and other activities (Corish, 1995). The greatest potential to implement and benefit from phasing will be on large projects where extensive exposed areas are difficult to stabilize over long periods.
- Map native soil and vegetation protection areas on all plans and delineate these areas on the site with appropriate fencing to protect soils and vegetation from clearing, grading, and construction damage. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2005 SMMWW BMP C103 and

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C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.

- Stockpile materials in areas designated for clearing and grading (avoid areas within the development envelope that are designated for bioretention or other bioretention areas).
- Stockpile and reuse excavated topsoil to amend disturbed areas (see Section 6.2: Amending Construction Site Soils for details).
- Small stockpiles of soil should be covered and larger piles seeded for erosion control during wet months.
- Inspections (Corish, 1995):
  - Conduct a pre-construction inspection to determine that adequate barriers have been placed around vegetation protection areas and structural controls are implemented properly.
  - Routine inspections should be conducted to verify that structural controls are maintained and operating effectively throughout construction, and that soil structure and vegetation are maintained within protection areas.
  - Conduct a final inspection to verify that re-vegetated areas are stabilized and that stormwater management systems are in place and functioning properly.

5.1.3 Training Personnel Implementing Project Activities

- Install signs to identify limits of clearing and grading, and explain the use and management of the natural resource protection areas.
- Meet and walk the property with equipment operators regularly to clarify construction boundaries, limits of disturbance, and construction activities.
- Require erosion and sediment control training for operators.

5.1.4 Proper Equipment

Research in the agricultural setting indicates that ground contact pressure generally determines the potential for compaction in the upper 6 to 8 inches of soil while total axle load can influence compaction in the deeper subsoil layers. Vehicles with tracks or tires with axle loads exceeding 10 tons per axle can compact soils as deep as 3 feet (Delong-Hughes, Moncrief, Voorhees and Swan, 2001). A majority of the total soil compaction (70 to 90 percent) can occur in the first pass with equipment (Balousek, 2003).

To minimize the degree and depth of compaction, use equipment with the least ground pressure to accomplish tasks. For smaller projects, many activities can be completed with mini-track loaders that are more precise, require less area to operate, exert less contact pressure than equipment with deep lugged tires, and have lower total axle weight (personal communication, James Lux, August 2004).

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6 Integrated Management Practices

IN THIS CHAPTER...

Specifications for:

- *Bioretention areas*
- *Amending construction site soils*
- *Permeable paving*
- *Vegetated roofs*
- *Minimal excavation foundations*
- *Roof rainwater collection systems*

Integrated management practices (IMPs) are the tools used in a low impact development (LID) project for water quality treatment and flow control. The term IMP is used instead of best management practice or BMP (used in a conventional development) because the controls are integrated throughout the project and provide a landscape amenity in the LID design.

6.1 Bioretention Areas

The bioretention concept originated in Prince George's County, Maryland in the early 1990s and is a principal tool for applying the LID design approach. The term bioretention was created to describe an integrated stormwater management practice that uses the chemical, biological, and physical properties of plants, microbes, and soils to remove, or retain, pollutants from stormwater runoff. Numerous designs have evolved from the original application; however, there are fundamental design characteristics that define bioretention across various settings.

Bioretention areas (also known as rain gardens) are:

- Shallow landscaped depressions with a designed soil mix and plants adapted to the local climate and soil moisture conditions that receive stormwater from a small contributing area.
- Facilities designed to more closely mimic natural conditions, where healthy soil structure and vegetation promote the infiltration, storage, and slow release of stormwater flows.
- Small-scale, dispersed facilities that are integrated into the site as a landscape amenity.
- An IMP designed as part of a larger LID approach. Bioretention can be used as a stand-alone practice on an individual lot, for example; however, best performance is achieved when integrated with other LID practices.

Bioretention is an integrated stormwater management practice that uses the chemical, biological, and physical properties of plants, microbes, and soils to remove, or retain, pollutants from stormwater.

The term bioretention is used to describe various designs using soil and plant complexes to manage stormwater. The following terminology is used in this manual:

- Bioretention cells: Shallow depressions with a designed planting soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants. Bioretention cells may or may not have an under-drain and are not designed as a conveyance system.

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- Bioretention swales: Incorporate the same design features as bioretention cells; however, bioretention swales are designed as part of a conveyance system and have relatively gentle side slopes and flow depths that are generally less than 12 inches.
- Bio*detention:* A design that uses vegetative barriers arranged in hedgerows across a slope to disperse, infiltrate, and treat stormwater (see sloped biodetention description in this chapter).

The following section outlines various applications and general design guidelines, as well as specifications, for individual bioretention components. Design examples are also included in Appendix 2 to provide designers with a pool of concepts and specifications useful for developing bioretention facilities specific to local needs. This section draws information from numerous sources; however, many of the specifications and guidelines are from extensive work and experience developed in Prince George's County, Maryland and the city of Seattle.

6.1.1 Applications

While the original concept of bioretention focused on stormwater pollutant removal, the practice is also used for water quantity control. Where the surrounding native soils have adequate infiltration rates, bioretention can be used as a retention facility. Underdrain systems can be installed and the facility used to filter pollutants and detain flows that exceed infiltration capacity of the surrounding soil. However, designs utilizing under-drains provide less flow control benefits.

Rain gardens are a landscape amenity and a stormwater control practice that can be applied in various settings, including:

- Individual lots for rooftop, driveway, and other on-lot impervious surface infiltration.
- Shared facilities located in common areas for individual lots.
- Areas within loop roads or cul-de-sacs.
- Landscaped parking lot islands.
- Within right-of-ways along roads (linear bioretention swales and cells).
- Common landscaped areas in apartment complexes or other multifamily housing designs.



Figure 6.1.1 Bioretention area in center of apartment building courtyard, Portland, Oregon.
Photo by Curtis Hinman

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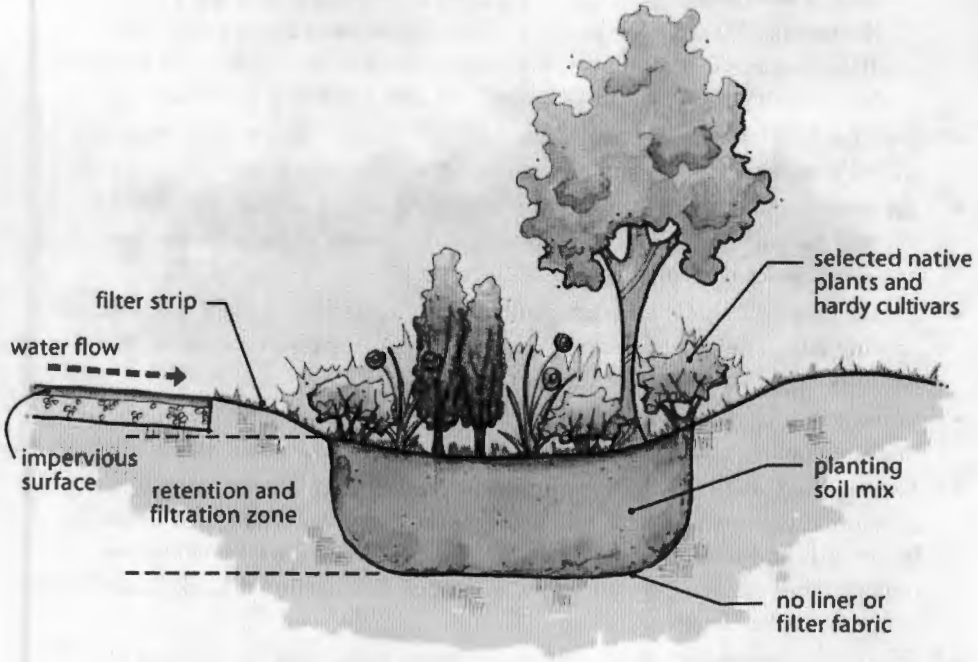

Figure 6.1.2 Cross-section of a basic bioretention cell with no under-drain.

Graphic by AHBL Engineering

6.1.2 Design

Bioretention systems are placed in a variety of residential and commercial settings, and are a visible and accessible component of the site. Design objectives and site context are, therefore, important factors for successful application.

The central design considerations include:

- *Soils:* The soils underlying and surrounding bioretention facilities are a principal design element for determining infiltration capacity, sizing, and rain garden type. The planting soil placed in the cell or swale is highly permeable and high in organic matter (e.g., loamy sand, USDA soil texture classification, mixed thoroughly with compost amendment) and a surface mulch layer. See Section 6.1.2.3: Bioretention Components for details.
- *Site topography:* For slopes greater than 10 percent, sloped biodetention and weep garden designs can be used. See Section 6.1.2.1: Types of bioretention areas.
- *Depth-to-water table:*
  - o A minimum separation of 1 foot from the seasonal high water mark to the bottom of the bioretention area is recommended where the contributing area of the bioretention has less than 5,000 square feet of pollution-generating impervious surface; and less than 10,000 square feet of impervious surface; and less than ¾ acres of lawn. Recommended separation distances for bioretention areas with small contributing areas are less than the new Department of Ecology (Ecology) recommendation of 3 feet for two reasons: (1) bioretention soil mixes provide effective pollutant capture; and (2) hydrologic loading and potential for groundwater mounding is reduced when managing flows from small contributing areas.
  - o A minimum separation of 3 feet from the seasonal high water mark to the bottom of the bioretention area is recommended where the contributing

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area of the bioretention area is equal to or exceeds any of the following limitations: 5,000 square feet of pollution-generating impervious surface; or 10,000 square feet of impervious surface; or ¾ acres of lawn and landscape. See Bioretention Areas in Chapter 7 for flow modeling guidance.

- *Expected pollutant loading:* See sections 6.1.2.3: Bioretention components and 6.1.4: Performance for recommended designs by pollutant type.
- *Site growing characteristics and plant selection:* Appropriate plants should be selected for sun exposure, soil moisture, and adjacent plant communities. Invasive species control may also be necessary.
- *Transportation safety:* The design configuration and selected plant types should provide adequate sight distances, clear spaces, and appropriate setbacks for roadway applications.
- *Visual buffering:* Bioretention facilities can be used to buffer structures from roads, enhance privacy among residences, and for an aesthetic site feature.
- *Ponding depth and surface water draw-down:* Flow control needs, as well as location in the development, will determine draw-down timing. For example, front yards and entrances to residential or commercial developments may require rapid surface dewatering for aesthetics. See Section 6.1.2.3: Bioretention components for details.
- *Impacts of surrounding activities:* Human activity influences the location of the facility in the development. For example, locate bioretention areas away from traveled areas on individual lots to prevent soil compaction and damage to vegetation, and provide barriers to restrict vehicle access in roadside applications.
- *Setbacks:* Local jurisdiction guidelines should be consulted for appropriate bioretention area setbacks from wellheads, on-site sewage systems, basements, foundations, and utilities.

6.1.2.1 Types of bioretention areas

Numerous designs have evolved from the original bioretention concept as designers have adopted the practice to different physical settings. Types of bioretention designs include:

- Bioretention cells integrated into gardens on individual lots.



Figure 6.1.3 Bioretention cell integrated into landscaping.
Photo by Larry Coffman

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- Curb or curbless bioretention in landscaped parking lot islands.



Figure 6.1.4 Bioretention landscaped island with curb cut to allow flows to enter.
Photo by Larry Coffman

- **Off-line bioretention** areas (Figure 6.1.5) are placed next to a swale with a common flow entrance and flow exit, and the bioretention invert placed below the swale **invert** to provide the proper ponding depth (often 6 to 12 inches).





Figure 6.1.5 (left) Off-line bioretention area adjacent to roadside swale.
Photo by Larry Coffman

Figure 6.1.6 (right) Bioretention swale in Seattle.
Photo courtesy of Seattle Public Utilities

- **In-line bioretention** swales are hybrid facilities usually installed along roadways that incorporate bioretention cell and swale characteristics (see Figure 6.1.6 and Appendix 2: Bioretention Examples for design details).

- Sloped or weep garden bioretention areas (Figure 6.1.7) are used for steeper gradients where a retaining wall is used for structural support and for allowing storm flows, directed to the facility, to seep out.

- Sloped biodetention-use vegetative barriers, designed for a specific hydraulic capacity, placed along slope contours (see Figure 6.1.8 and Appendix 2: Bioretention Examples for design details).

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Figure 6.1.7 Sloped or weep garden bioretention area.
Photo courtesy of LID Center



Figure 6.1.8 Sloped biodetention area.
Photo courtesy of Murphee Engineering

- Tree box filters are street tree plantings with an enlarged planting pit for additional storage, a storm flow inlet from the street or sidewalk, and an underdrain system.



Figure 6.1.9 Tree box filter.
Photo by Puget Sound Action Team

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6.1.2.2 Determining infiltration rates

Infiltration rates are necessary to determine flow reduction benefits for bioretention areas when using the Western Washington Hydrologic Model (WWHM) or MGS Flood. See Figure 6.1.10 for a graphic representation of the process to determine infiltration rates.

The assumed infiltration rate for determining the flow reduction benefits of bioretention areas should be the lower of the estimated long-term rate of the planting soil mix or the initial (short-termed or measured) infiltration rate of the underlying soil profile. The overlying planting soil mix protects the underlying native soil from sedimentation; accordingly, the underlying soil does not require a correction factor. See Chapter 7 for more detail on flow control modeling for bioretention areas.

The following provides recommended tests for the soils underlying and planting soil mixes within bioretention areas.

1. Underlying native soils:

- Method 1: Use Table 3.7 of the Ecology 2005 *Stormwater Management Manual for Western Washington* (SMMWW) to determine the short-term infiltration rate of the underlying soil. Soils not listed in the table cannot use this approach. Use 1 as the infiltration reduction factor.
- Method 2: Determine the D_{10} size of the underlying soil. Use the upperbound line in Figure 4-17 of the Washington State Department of Transportation (WSDOT) 2004 *Highway Runoff Manual* to determine the corresponding infiltration rate. Use 1 as the infiltration reduction factor.
- See the 2005 SMMWW Volume III for details on methods 1 and 2.
- Method 3: Field infiltration tests (the specific test depends on scale of the project).
    - o Small bioretention cells (bioretention facilities receiving water from 1 or 2 individual lots or < 1/4 acre of pavement or other impervious surface): Small-scale infiltration tests such as the U.S. Environmental Protection Agency (USEPA Falling Head or double ring infiltrometer tests, ASTM 3385-88). Small-scale infiltration tests, such as a double ring infiltrometer, may not adequately measure variability of conditions in test areas and, if used, measurements should be taken at several locations within the area of interest. Soil pit excavation may still be necessary if highly variable soil conditions or seasonal high water tables are suspected. Use 1 as an infiltration correction factor.
    - o Large bioretention cells (bioretention facilities receiving water from several lots or 1/4 to 1/2-acre of pavement or other impervious surface): Pilot Infiltration Test (PIT) or small-scale test infiltration pits (septic test pits) at a rate of 1 pit/cell excavated to a depth of at least 5 feet and preferably 6 to 8 feet. See 2005 SMMWW Appendix III-D (formerly V-B) for PIT method description. Use 1 as an infiltration correction factor.
    - o Bioretention swales: approximately 1 pit/50 feet of swale to a depth of at least 5 feet (personal communication, Larry West, Ed O'Brien, 2004).
    - o Consult a geotechnical engineer for site-specific analysis recommendations.
- Use the measured infiltration rate of the underlying native soil as the assumed infiltration rate of the bioretention area if it is lower than the planting soil mix.

2. Compost-amended planting mix soils: Depending on the size of contributing area use one of the following two recommended test protocols.

Flow Modeling Guidance

See Chapter 7 for guidelines for applying infiltration rates when using the WWHM to determine flow control credits for bioretention areas.

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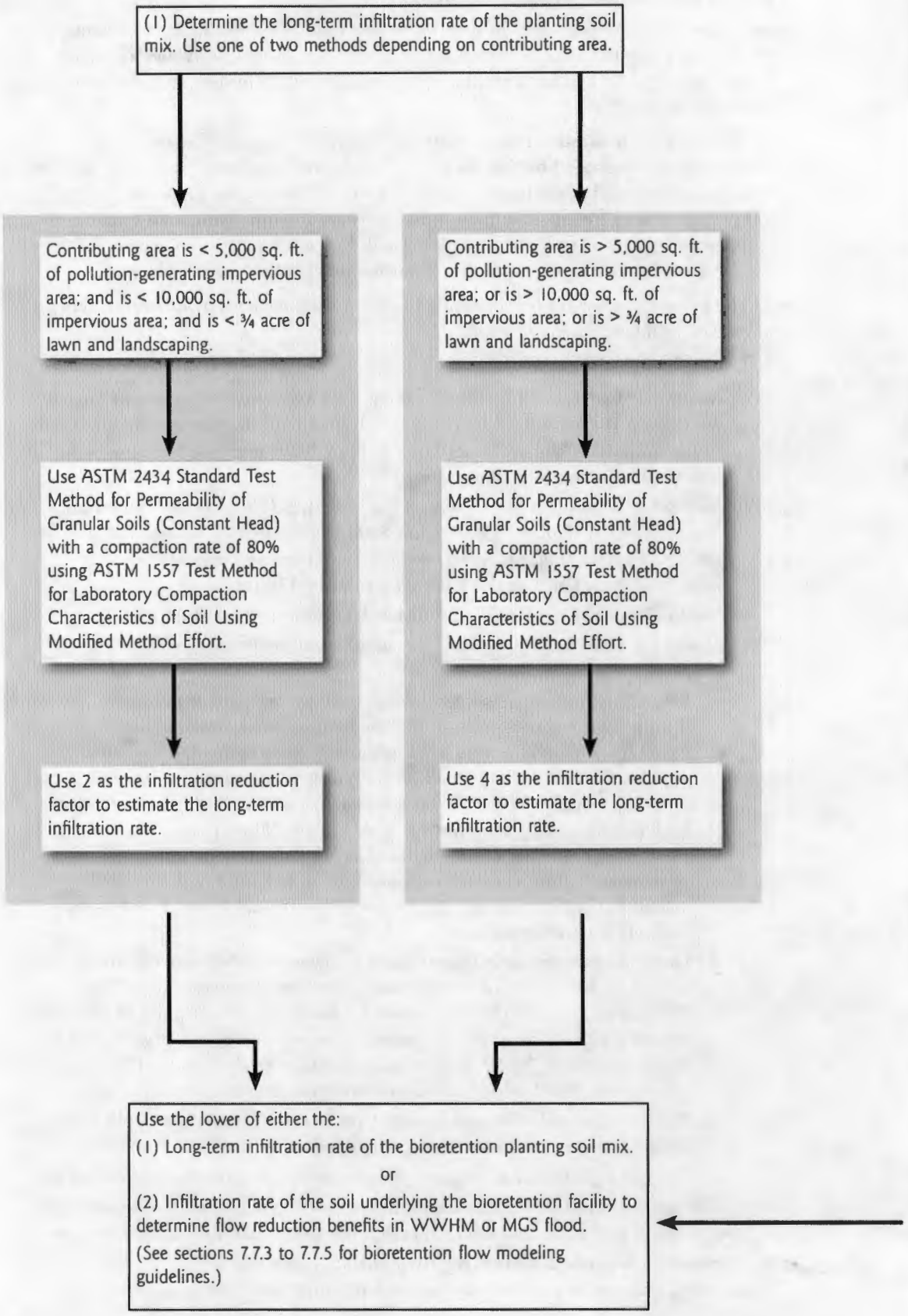
Figure 6.1.10
Recommendations for determining infiltration rates of soils in bioretention areas.
(See sections 7.7.3 to 7.7.5 for using infiltration rates and bioretention flow modeling guidelines.)



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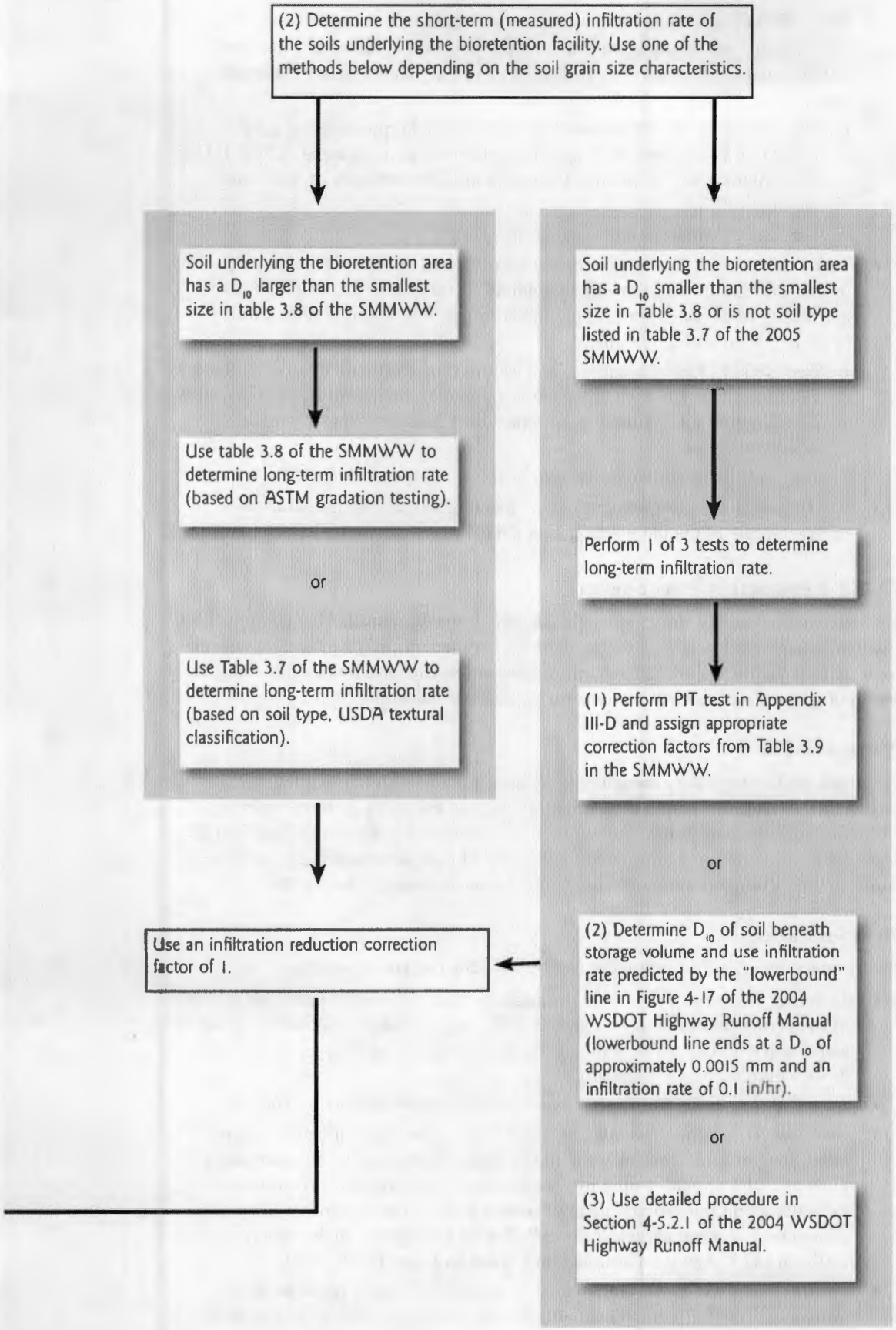
(2) Determine the short-term (measured) infiltration rate of the soils underlying the bioretention facility. Use one of the methods below depending on the soil grain size characteristics.
Soil underlying the bioretention area has a D_{10} larger than the smallest size in table 3.8 of the SMMWW.
Use table 3.8 of the SMMWW to determine long-term infiltration rate (based on ASTM gradation testing).
or
Use Table 3.7 of the SMMWW to determine long-term infiltration rate (based on soil type, USDA textural classification).
Soil underlying the bioretention area has a D_{10} smaller than the smallest size in Table 3.8 or is not soil type listed in table 3.7 of the 2005 SMMWW.
Perform 1 of 3 tests to determine long-term infiltration rate.
(1) Perform PIT test in Appendix III-D and assign appropriate correction factors from Table 3.9 in the SMMWW.
or
(2) Determine D_{10} of soil beneath storage volume and use infiltration rate predicted by the "lowerbound" line in Figure 4-17 of the 2004 WSDOT Highway Runoff Manual (lowerbound line ends at a D_{10} of approximately 0.0015 mm and an infiltration rate of 0.1 in/hr).
or
(3) Use detailed procedure in Section 4-5.2.1 of the 2004 WSDOT Highway Runoff Manual.
Use an infiltration reduction correction factor of 1.

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- Test 1: If the contributing area of the bioretention cell or swale has less than 5,000 square feet of pollution-generating impervious surface; and less than 10,000 square feet of impervious surface; and less than ¾ acre of lawn and landscape:
  - Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
  - Use 2 as the infiltration reduction factor.
- Test 2: If the contributing area of the bioretention cell or swale is equal to or exceeds any of the following limitations: 5,000 square feet of pollution-generating impervious surface; or 10,000 square feet of impervious surface; or ¾ acre of lawn and landscape:
  - Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
  - Use 4 as the infiltration reduction factor.
- Use the long-term infiltration rate of the planting soil mix as the assumed infiltration rate of the bioretention area if it is lower than the underlying native soil.

6.1.2.3 Bioretention components

The following provides a description and suggested specifications for the components of bioretention cells and swales. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Also see Appendix 2 for various bioretention design examples.

Pretreatment

Vegetated buffer strips slow incoming flows and provide an initial settling of particulates. Design will depend on topography, flow velocities, volume entering the buffer, and site constraints. Flows entering a rain garden should be less than 1.0 ft/second to minimize erosion potential. Engineered flow dissipation (e.g., rock pad) should be incorporated into curb-cut or piped (concentrated) flow entrances.

Flow entrance

Five primary types of flow entrances can be used for bioretention cells:

- *Dispersed, low velocity flow across a landscape area:* This is the preferred method of delivering flows to the rain garden cell. Dispersed flow may not be possible given space limitations or if the facility is controlling roadway or parking lot flows where curbs are mandatory.
- *Dispersed flow across pavement or gravel and past wheel stops for parking areas.*
- *Curb cuts for roadside or parking lot areas:* Curb cuts should include rock or other erosion protection material in the channel entrance to dissipate energy. Flow entrance should drop 2 to 3 inches from curb line and provide an area for settling and periodic removal of sediment and coarse material before flow dissipates to the remainder of the cell (Prince George's County, Maryland, 2002, and U.S. Army Environmental Center and Fort Lewis, 2003).
- *Pipe flow entrance:* Piped entrances should include rock or other erosion protection material in the channel entrance to dissipate energy and/or flow dispersion.

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- *Catch basin:* Catch basins can be used to slowly release water to the bioretention area through a grate for filtering coarse material.

Woody plants can restrict or concentrate flows and can be damaged by erosion around the root ball and should not be placed directly in the entrance flow path (Prince George's County, 2002).



Figure 6.1.11 Bioretention with curb cuts in parking lot islands.
Photo by Larry Coffman

Ponding area

The ponding area provides surface storage for storm flows, particulate settling, and the first stages of pollutant treatment within the cell. Pool depth and draw-down rate are recommended to provide surface storage, adequate infiltration capability, and soil moisture conditions that allow for a range of appropriate plant species (Prince George's County, 2002).

- Maximum ponding depth: 12 inches recommended.
- Surface pool drawdown time: 24 hours recommended.
- Soils must be allowed to dry out periodically in order to:
  - Restore hydraulic capacity to receive flows from subsequent storms.
  - Maintain infiltration rates.
  - Maintain adequate soil oxygen levels for healthy soil biota and vegetation.
  - Provide proper soil conditions for biodegradation and retention of pollutants. (Ecology, 2001)

Under-drain

The area above an under-drain pipe in a bioretention area provides detention and pollutant filtering; however, only the area below the under-drain invert and the bottom of the bioretention facility can be used in the WWHM for flow control benefit (see Chapter 7 for bioretention area flow control credits). Under-drain systems (see Figure 6.1.12) should be installed only when the bioretention area is:

- Located near sensitive infrastructure (e.g., unsealed basements) and potential for flooding is likely.
- Used for filtering storm flows from gas stations or other pollutant hotspots (requires impermeable liner).
- In soils with infiltration rates that are not adequate to meet maximum pool and system dewater rates.

The under-drain can be connected to a downstream open conveyance (bioretention swale), to another bioretention cell as part of a connected treatment system, daylight to a dispersion area using an effective flow dispersion practice, or to a storm drain.

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The pipe diameter will depend on hydraulic capacity required (4 to 8 inches is common). The preferred material is slotted 6-inch, thick-walled plastic pipe. The slot opening should be smaller than the smallest aggregate gradation for the gravel blanket to prevent migration of material into the drain. This configuration allows for pressurized water cleaning and root cutting if necessary (personal communication, Tracy Tackett, 2004). Example specification:

- Slotted subsurface drain PVC per ASTM D1785 SCH 40.
- Slots should be cut perpendicular to the long axis of the pipe and be 0.04 to 0.069 inches by 1 inch long and be spaced 0.25 inches apart (spaced longitudinally). Slots should be arranged in four rows spaced on 45-degree centers and cover ½ of the circumference of the pipe. See Filter Materials section for aggregate gradation appropriate for this slot size.

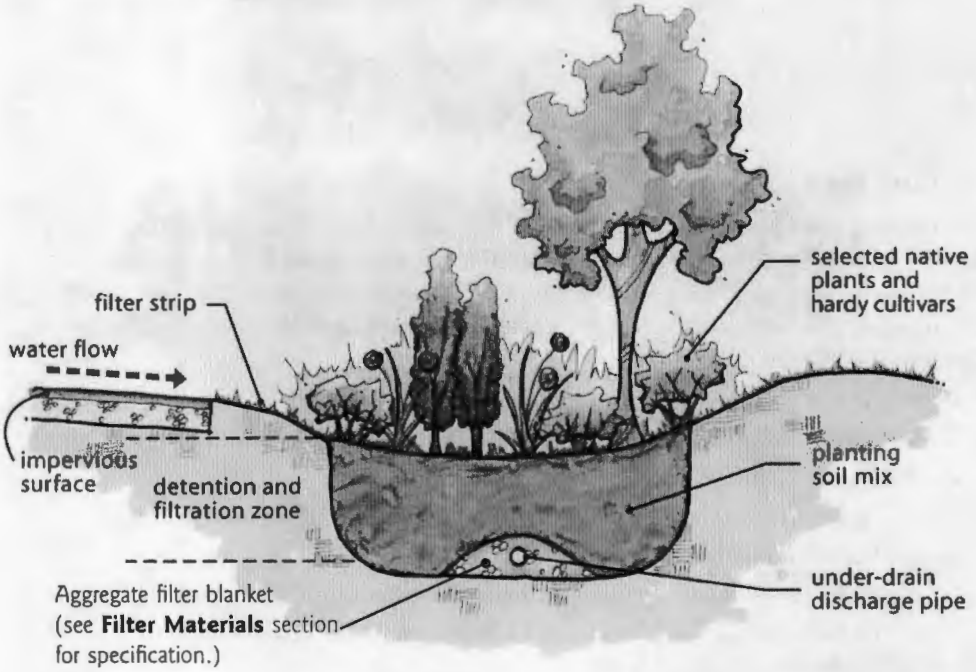

Figure 6.1.12 Bioretention with under-drain.

Graphic by AHBL Engineering

Perforated PVC or flexible slotted HDPE pipe can be used; however, cleaning operations, if necessary, can be more difficult or not possible. Under-drains should be sloped at a minimum of 0.5 percent unless otherwise specified by an engineer (Low Impact Development Center, 2004). Wrapping the under-drain pipe in filter fabric increases chances of clogging and is not recommended (Low Impact Development Center, 2004). A 6-inch rigid non-perforated observation pipe or other maintenance access should be connected to the under-drain every 250 to 300 feet to provide a clean-out port, as well as an observation well to monitor dewatering rates (Prince George's County, 2002 and personal communication, Tracey Tackett, 2004).

Bioretention areas do not effectively remove nitrate. Where nitrate is a concern, the under-drain can be elevated from the bottom of the bioretention facility and within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe (Figure 6.1.13). **Denitrification** within the anaerobic zone is facilitated by microbes using forms of nitrogen (NO_2 and NO_3) instead of oxygen for respiration. Adding a suitable carbon source (e.g., wood chips) to the gravel layer provides a nutrition source for the microbes, enables anaerobic respiration, and can enhance the denitrification process (Kim, Seagren and Davis, 2003).

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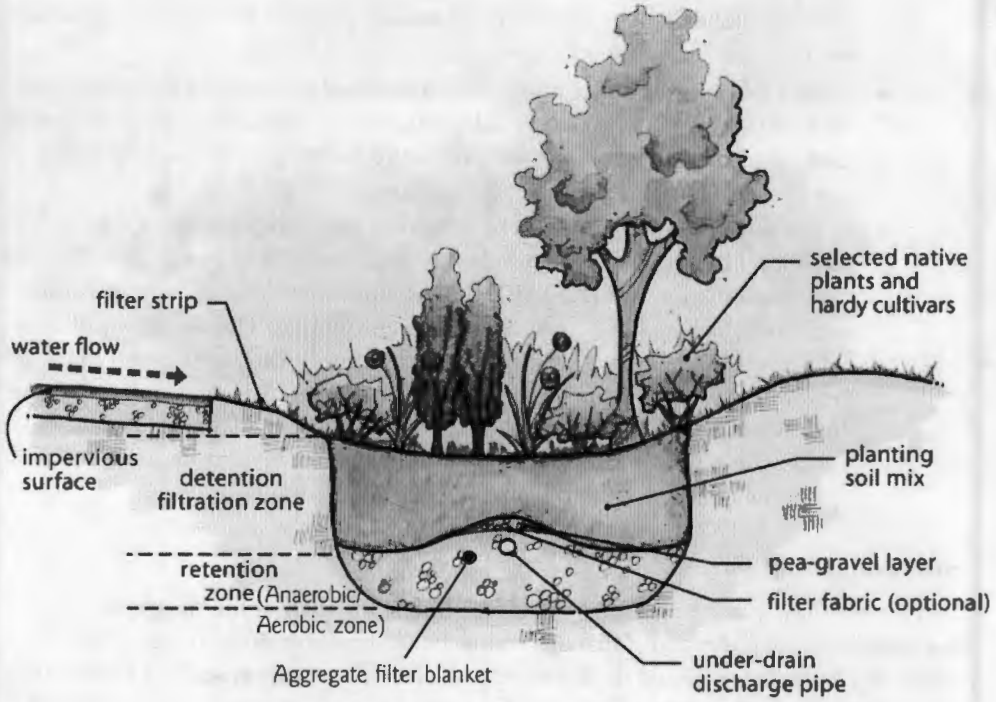

Figure 6.1.13 Bioretention with elevated under-drain.

Graphic by AHBL Engineering

Filter materials

Gravel blankets and filter fabrics buffer the under-drain system from sediment input and clogging. Properly selected for the soil gradation, geosynthetic filter fabrics can provide adequate protection from the migration of fines. Aggregate filter blankets, with proper gradations, provide a larger surface area for protecting under-drains and are preferred.

Suggested specifications for filter materials include:

1. For use with heavy walled slotted pipe (see under-drain specification above):
   - Type 26 mineral aggregate (gravel backfill for drains, city of Seattle)

Sieve size	Percent Passing
¾ inch	100
¼ inch	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-1

   - Place under-drain on a 3-foot wide bed of the Type 26 aggregate at a minimum thickness of 6 inches and cover with Type 26 aggregate to provide a 1-foot minimum depth around the top and sides of the slotted pipe.

2. If proper gradation and/or slotted pipe are not available and perforated PVC or flexible HDPE pipe is used:
   - The under-drain pipe should be placed on a 3-foot wide bed of ½ to 1½-inch drain rock (ASTM No. 57 aggregate or equivalent) at a minimum thickness of 3 inches, and covered with 6 inches of No. 57 aggregate.

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Double-washed stone is preferred to reduce suspended solids and potential for clogging (Low Impact Development Center, 2004).

- If filter fabric is used, use a non-woven material placed over the drain rock and extending 2 feet on either side of the under-drain. Wrapping the gravel blanket in filter fabric can cause premature failure due to clogging and is not recommended (Prince George's County, 2002).
- A pea gravel diaphragm (with or without a filter fabric) reduces the likelihood of clogging when used with drain rock. Use ¼ to ½-inch diameter double-washed gravel (ASTM D 448 or equivalent) placed over the drain rock to a thickness of 3 to 8 inches (Prince George's County, 2002). If filter fabric is used, place between the drain rock and pea gravel extending 2 feet on either side of the under-drain. The strip of filter fabric placed above the under-drain acts as an impediment to direct gravitational flow and causes the water to move laterally and then down toward the under-drain (personal communication, Derek Winogradoff, August 2004).

Surface overflow

Surface overflow can be provided by surface drains installed at the designed maximum ponding elevations that are connected to under-drain systems, or by overflow channels connected to downstream surface conveyance, such as bioretention swales and open space areas. Safe discharge points are necessary to convey flows that exceed the capacity of the facility and to protect adjacent natural site features and property.

Hydraulic restriction layers

Adjacent roads, foundations or other infrastructure may require that infiltration pathways are restricted to prevent excessive hydrologic loading. Three types of restricting layers can be incorporated into bioretention designs:

- Filter fabric can be placed along vertical walls to reduce lateral flows.
- Clay (bentonite) liners are low permeability liners. Where clay liners are used under-drain systems are necessary. See 2005 SMMWW Volume IV section 4.4.3 for guidelines.
- Geomembrane liners completely block flow and are used for groundwater protection when bioretention facilities are used for filtering stormflows from pollutant hotspots. Where geomembrane liners are used under-drain systems are necessary. The liner should have a minimum thickness of 30 mils and be ultraviolet (UV) resistant.

Plant materials

Plant roots aid in the physical and chemical bonding of soil particles that is necessary to form stable aggregates, improve soil structure, and increase infiltration capacity. During the wet months in the Pacific Northwest (November through March) interception and evaporation are the predominant above-ground mechanisms for attenuating precipitation in the native forest setting. Transpiration during the non-growing wet months is minimal (see Introduction for details). In a typical bioretention cell, transpiration is negligible unless the cell has a dense planting of trees, the stand is relatively mature (10 to 20 years), and the canopy structure is closing and varied. The relatively mature and dense canopy structure is necessary for adequate interception and advective evaporation in winter months. The primary and significant

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benefits of small trees, shrubs, and ground cover in bioretention areas during the wet season are the presence of root activity and contribution of organic matter that aids in the development of soil structure and infiltration capacity. See Appendix 3 for a bioretention plant table describing plant characteristics and optimum location within the bioretention area.

The primary design considerations for plant selection include:

- *Soil moisture conditions:* Plants should be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for the lengths of time anticipated by the facility design.
- *Expected pollutant loadings:* Plants should tolerate typical pollutants and loadings from the surrounding land uses.
- *Above and below ground infrastructure in and near the facility:* Plant size and wind firmness should be considered within the context of the surrounding infrastructure. Rooting depths should be selected to not damage underground utilities if present. Slotted or perforated pipe should be more than 5 feet from tree locations (if space allows).
- *Adjacent plant communities and potential invasive species control.*
- *Site distances and setbacks for roadway applications.*
- *Visual buffering:* Plants can be used to buffer structures from roads, enhance privacy among residences, and provide an aesthetic amenity for the site.
- *Aesthetics:* Visually pleasing plant designs add value to the property and encourage community and homeowner acceptance. Homeowner education and participation in plant selection and design for residential projects should be encouraged to promote greater involvement in long-term care.

In general, the predominant plant material utilized in bioretention areas are facultative species adapted to stresses associated with wet and dry conditions (Prince George's County, 2002). Soil moisture conditions will vary within the facility from saturated (bottom of cell) to relatively dry (rim of cell). Accordingly, wetland plants may be used in the lower areas, if saturated soil conditions exist for appropriate periods, and drought-tolerant species planted on the perimeter of the facility or on mounded areas (Figure 6.1.14). See Appendix 3 for recommended plant species.

Planting schemes will vary with the surrounding landscape and design objectives. For example, plant themes can reflect surrounding wooded or prairie areas. Monoculture planting designs are not recommended. As a general guideline, a minimum of three tree, three shrubs, and three herbaceous groundcover species should be incorporated to protect against facility failure due to disease and insect infestations of a single species (Prince George's County, 2002). See Figure 6.1.15 for a sample planting plan.

Native plant species, placed appropriately, tolerate local climate and biological stresses and usually require no nutrient or pesticide application in properly designed soil mixes. Natives can be used as the exclusive material in a rain garden or in combination with hardy cultivars that are not invasive and do not require chemical inputs. In native landscapes, plants are often found in associations that grow together well given specific moisture, sun, soil, and plant chemical interactions. Native plant associations can, in part, help guide planting placement. For example, in partial sun and well-drained soils, beaked hazelnut (*Corylus cornuta*) and common snowberry (*Symphoricarpos albus*) are a common association in western Washington (Leigh, 1999). To increase survival rates and ensure quality of plant material, the following guidelines are suggested:

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Figure 6.1.14 Examples of plants appropriate for different soil moisture zones in a bioretention area.

See Appendix 3 for a bioretention plant list organized by soil moisture zones.

Graphic by AHBL Engineering

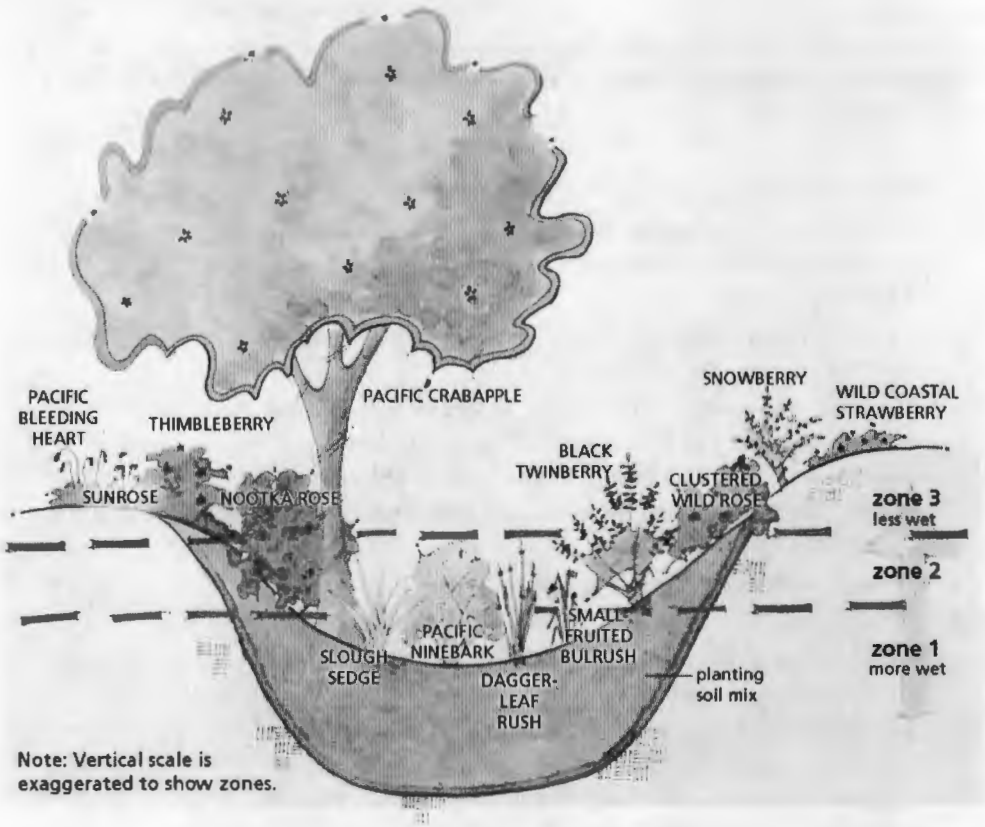
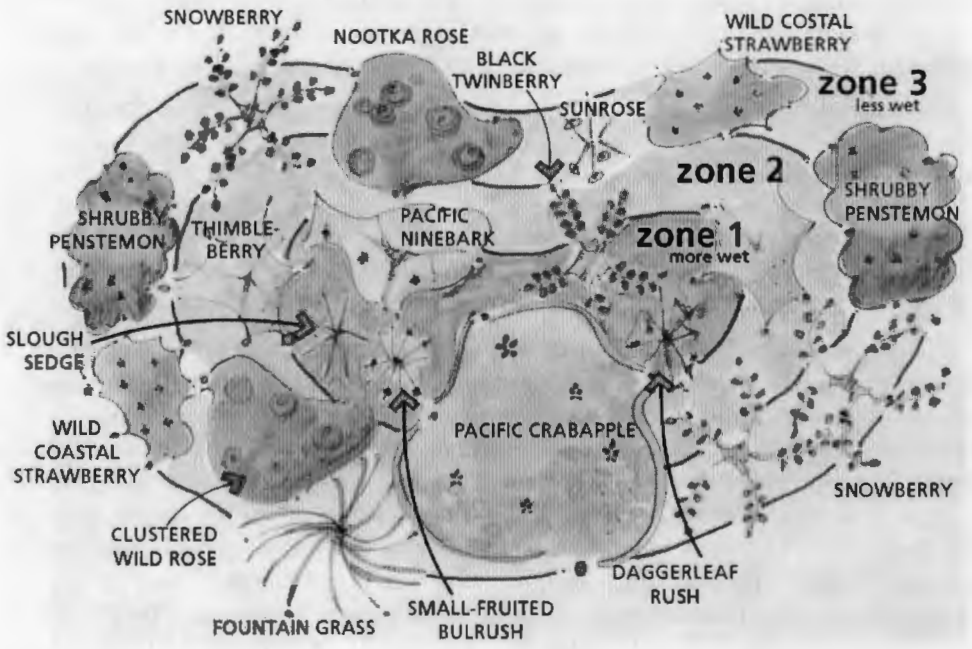


Figure 6.1.15 Sample planting plan for a bioretention area.

Graphic by AHBL Engineering



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- Plants should conform to the standards of the current edition of *American Standard for Nursery Stock* as approved by the American Standards Institute, Inc. All plant grades shall be those established in the current edition of *American Standards for Nursery Stock* (current edition: ANSI Z60.1-2004) (Low Impact Development Center, 2004).
- All plant materials should have normal, well-developed branches and vigorous root systems, and be free from physical defects, plant diseases, and insect pests.
- Plant size: Bioretention areas provide excellent soil conditions and should have well defined maintenance agreements. In this type of environment small plant material provides several advantages and is recommended. Specifically, small plant material requires less careful handling, less initial irrigation, experiences less transplant shock, is less expensive, adapts more quickly to a site, and transplants more successfully than larger material (Sound Native Plants, 2000). Small trees and shrubs are generally supplied in pots of 3 gallons or less.
- All plants should be tagged for identification when delivered.
- Optimum planting time is fall (beginning early October). Winter planting is acceptable; however, extended freezing temperatures shortly after installation can increase plant mortality. Spring is also acceptable, but requires more summer watering than fall plantings. Summer planting is the least desirable and requires regular watering for the dry months immediately following installation.

Mulch layer

Bioretention areas can be designed with or without a mulch layer; however, there are advantages to providing a mulch application or a dense groundcover. Research indicates that most attenuation of heavy metals in bioretention cells occurs in the first 1 to 2 inches of the mulch layer. That layer can be easily removed or added to as part of a standard and periodic landscape maintenance procedure. No indications of special disposal needs are indicated at this time from older bioretention facilities in the eastern U.S. (personal communication, Larry Coffman). Properly selected mulch material also reduces weed establishment, regulates soil temperatures and moisture, and adds organic matter to soil. When used, mulch should be:

- Compost in the bottom of the facilities (compost is less likely to float and is a better source for organic materials) and shredded or chipped hardwood or softwood in surrounding areas.
- Free of weed seeds, soil, roots and other material that is not **bole** or branch wood and bark.
- A maximum of 2 to 3 inches thick (thicker applications can inhibit proper oxygen and carbon dioxide cycling between the soil and atmosphere) (Prince George's County, 2002).

Mulch should **not** be:

- Grass clippings (decomposing grass clippings are a source of nitrogen and are not recommended for mulch in bioretention areas).
- Pure bark (bark is essentially sterile and inhibits plant establishment).

Dense groundcover enhances soil structure from root activity, does not have the tendency to float during heavy rain events, inhibits weed establishment, provides additional aesthetic appeal, and is recommended when heavy metal loading is not anticipated (Prince George's County, 2002). Mulch is recommended in conjunction with the groundcover until groundcover is established.

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Soil

Proper soil specification, preparation and installation are the most critical factors for bioretention performance. Soil specifications can vary according to the design objectives. Five different soil specifications are provided in Appendix 2 to illustrate various design approaches. In general, soil designed for bioretention areas should have the following characteristics:

- The texture for the soil component of the bioretention soil mix should be loamy sand (USDA Soil Textural Classification).
- The final soil mix (including compost and soil) should have a minimum long-term hydraulic conductivity of 1.0 inch/hour per ASTM Designation D 2434 (Standard Test Method for Permeability of Granular Soils) at 80 percent compaction per ASTM Designation D 1557 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort) (Tackett, 2004). Infiltration rate and hydraulic conductivity are assumed to be approximately the same in a uniform mix soil.
- The final soil mixture should have a minimum organic content of 10 percent by dry weight per ASTM Designation D 2974 (Standard Test Method for Moisture, Ash and Organic Matter of Peat and Other Organic Soils) (Tackett, 2004). Currently, gravelly sand bioretention soil mixtures for bioretention areas are being developed and installed to provide adequate infiltration rates at 85 to 95 percent compaction. While designers anticipate good performance from this specification, the mix may be slightly less than optimal for plant growth and has not been tested long-term for plant health performance (see Engineered Soil Mix and Bioretention Soil Mix 2 and 3 in Appendix 2).
- Achieving the above recommendations will depend on the specific soil and compost characteristics. In general, the recommendation can be achieved with 60 to 65 percent loamy sand mixed with 35 to 40 percent compost or 30 percent sandy loam, 30 percent course sand, and 40 percent compost.
- The final soil mixture should be tested by an independent laboratory prior to installation for fertility, micronutrient analysis, and organic material content. Soil amendments per laboratory recommendations (if any) should be uniformly incorporated for optimum plant establishment and early growth (Tackett, 2004).
- Clay content for the final soil mix should be less than 5 percent.
- The pH for the soil mix should be between 5.5 and 7.0 (Stenn, 2003). If the pH falls outside of the acceptable range, it may be modified with lime to increase the pH or iron sulfate plus sulfur to lower the pH. The lime or iron sulfate must be mixed uniformly into the soil prior to use in bioretention area (Low Impact Development Center, 2004).
- Soil depth should be a minimum of 18 inches to provide acceptable minimum pollutant attenuation and good growing conditions for selected plants. A minimum depth of 24 inches should be selected for improved phosphorus and nitrogen (TKN and ammonia) removal. Deeper soil profiles (> 24 inches) can enhance phosphorus, TKN and ammonia removal (Davis, Shokouhian, Sharma and Minami, 1998). Nitrate removal in bioretention cells can be poor and in some cases cells can generate nitrate due to nitrification (Kim et al., 2003). See under-drain section for design recommendations to enhance nitrate removal. Deeper or shallower profiles may be desirable for specific plant, soil, and storm flow management objectives.
- The soil mix should be uniform and free of stones, stumps, roots or other similar material > 2 inches.

Organic matter content of soil mixes

A quick way to determine the approximate organic matter content of a soil mix:

- Compost is typically 40-50% organic matter (use 50% as an average).
- Compost weighs approximately 50% as much as loam.
- A mix that is 40% compost measured by volume is roughly 20% organic matter by volume.
- Compost is only 50% as dense as the soil, so the mix is approximately 10% organic matter by weight (the organic matter content in soil is determined by weighing the organic material before combustion and then weighing the ash post-combustion).

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- To reduce transportation and disposal needs, on-site excavated soil, rather than imported soil, can be used. However, using on-site excavated soil for the amended soil mix may reduce control over gradation, organic content, and final product performance, can increase project costs, and can complicate construction logistics when attempting to blend soil mix components in restricted space or during winter months (personal communication, Tracy Tackett). If on-site excavated soil is used, representative samples should be tested for gradation and adjusted, if necessary, to attain adequate infiltration capability.
- The above guidelines should provide a soil texture, organic content, and infiltration rate suitable to meet Ecology's SSC-6 "Soil Physical and Chemical Suitability for Treatment" recommendations for designing infiltration systems. A soils report evaluating these parameters should be provided to verify the treatment capability of the soil mix.

Compost

See Section 6.2.2 for compost specifications.

6.1.2.4 Installation

Excavation

Soil compaction can lead to facility failure; accordingly, minimizing compaction of the base and sidewalls of the bioretention area is critical (Prince George's County, 2002). Excavation should not be allowed during wet or saturated conditions. Excavation should be performed by machinery operating adjacent to the bioretention facility and no heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires should be allowed on the bottom of the bioretention facility (Tackett, 2004). If machinery must operate in the bioretention cell for excavation, use light weight, low ground-contact pressure equipment and rip the base at completion to refracture soil to a minimum of 12 inches (Prince George's County, 2002).

Sidewalls of the facility, to the height of the grade established by the designed soil mix, can be vertical if soil stability is adequate. Exposed sidewalls should be no steeper than 3H:1V. The sidewalls and bottom should be roughened where scraped and sealed by excavation equipment (Prince George's County, 2002). The bottom of the facility should be flat.

Vegetation protection areas with intact native soil and vegetation should not be cleared and excavated for bioretention facilities.

Soil installation

On-site soil mixing or placement should not be performed if soil is saturated. The bioretention soil mixture should be placed and graded by excavators and/or backhoes operating adjacent to the bioretention facility. If machinery must operate in the bioretention cell for soil placement or soil grading, use light weight, low ground-contact pressure equipment. The soil mixture should be placed in horizontal layers not to exceed 12 inches per lift for the entire area of the bioretention facility.

The soil mixture will settle and proper compaction can be achieved by allowing time for natural compaction and settlement. To speed settling, each lift can be watered until just saturated. Water for saturation should be applied by spraying or sprinkling.

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An appropriate sediment control device should be used to treat any sediment-laden water discharged from an under-drain (Low Impact Development Center, 2004).

Sediment Control

Erosion and sediment problems are most difficult during clearing, grading, and construction; accordingly, minimizing site disturbance to the greatest extent practicable is the most effective sediment control. Bioretention facilities should not be used as sediment control facilities and all drainage should be directed away from bioretention facilities after initial rough grading. Flow can be directed away from the facility with temporary diversion swales or other approved protection (Prince George's County, 2002). Bioretention facilities should not be constructed until all contributing drainage areas are stabilized according to erosion and sediment control BMPs and to the satisfaction of the engineer. Erosion and sediment control practices must be inspected and maintained on a regular basis. If deposition of fines occurs in the bioretention area, material should be removed and the surface scarified to the satisfaction of the project engineer (Prince George's County, 2002).

6.1.3 Maintenance

Bioretention areas require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. In general, bioretention maintenance requirements are typical landscape care procedures and include:

- *Watering:* Plants should be selected to be drought tolerant and not require watering after establishment (2 to 3 years). Watering may be required during prolonged dry periods after plants are established.
- *Erosion control:* Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace soil, plant material, and/or mulch layer in areas if erosion has occurred. Properly designed facilities with appropriate flow velocities should not have erosion problems except perhaps in extreme events. If erosion problems occur the following should be reassessed: (1) flow volumes from contributing areas and bioretention cell sizing; (2) flow velocities and gradients within the cell; and (3) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioretention area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits.
- *Plant material:* Depending on aesthetic requirements, occasional pruning and removing dead plant material may be necessary. Replace all dead plants and if specific plants have a high mortality rate, assess the cause and replace with appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule should become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants excluded.
- *Nutrient and pesticides:* The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and may degrade the pollutant processing capability of the bioretention area, as well as contribute pollutant loads to receiving waters. By design, bioretention facilities are located in areas where phosphorous and nitrogen levels are often elevated and these should not be limiting nutrients. If in question, have soil analyzed for fertility.

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- *Mulch:* Replace mulch annually in bioretention facilities where heavy metal deposition is likely (e.g., contributing areas that include parking lots and roads). In residential lots or other areas where metal deposition is not a concern, replace or add mulch as needed to maintain a 2 to 3 inch depth at least once every two years.
- *Soil:* Soil mixes for bioretention facilities are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems (see Performance section below). Replacing mulch in bioretention facilities where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels.

6.1.4 Performance

Pollutant removal processes in bioretention

All primary pathways for removing pollutants from storm flows are active in bioretention systems. Schueler and Clayton (1996) list the following as the primary pathways:

- *Sedimentation* is the settling of particulates (not effective for removing soluble components). Sedimentation occurs in the pretreatment (if provided) and ponding area of the facility.
- *Filtration* is the physical straining of particulates (not an effective mechanism for removing soluble components). Some filtration occurs in the ponding area as stormwater moves through plants, but the soil is the primary filtering media. Pitt et al., (1995) report that 90 percent of small particles commonly found in urban storm flows (6 to 41 microns) can be trapped by an 18-inch layer of sand. This level of performance can be anticipated for bioretention soils typically high in sand content.
- *Adsorption* is the binding of ions and molecules to electrostatic receptor sites on the filter media particles. This is the primary mechanism for removing soluble nutrients, metals, and organics that occur in the soil of bioretention areas as storm flows infiltrate. Adsorption increases with increased organic matter, clay, and a neutral to slightly alkaline pH.
- *Infiltration* is the downward movement of surface water to interstitial soil water. This process initiates adsorption, microbial action, etc., for pollutant removal.
- *Phytoremediation* processes include degradation, extraction by the plant, containment within the plant (assimilation) or a combination of these mechanisms (USEPA, 2000). Studies have shown that vegetated soils are capable of more effective degradation, removal, and mineralization of total petroleum hydrocarbons (TPHs), polycyclic aromatic hydrocarbons (PAHs), pesticides, chlorinated solvents, and surfactants than are non-vegetated soils (USEPA, 2000). Certain plant roots can absorb or immobilize metal pollutants, including cadmium, copper, nickel, zinc, lead, and chromium, while other species are capable of metabolizing or accumulating organic and nutrient contaminants. A University of Maryland study found significant metal accumulation in creeping juniper plants in pilot-scale bioretention cells. Copper increased by a factor of 6.3, lead by a factor of 77, and zinc by a factor of 8.1 in the tissue of junipers after receiving synthetic stormwater applications compared to pre-application tissue samples (Davis, Shokouhian, Sharma,

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Minami and Winogradoff, 2003). An intricate and complex set of relationships and interactions between plants, microbes, soils, and contaminants make these various phytoremediation processes possible (see Appendix 5 for a more detailed discussion of phytoremediation and stormwater).

- *Plant resistance* occurs as plant materials reduce flow velocities and increase other pollutant removal pathways such as sedimentation, filtering, and plant uptake of pollutants during growth periods.
- *Volatilization* occurs when a substance is converted to a more volatile vapor form. Transforming complex hydrocarbons to carbon dioxide is an example of volatilization active in bioretention cells (Prince George's County, 2002).
- *Thermal attenuation* reduces water temperatures as storm flows move through subsurface soil layers. A field study in Maryland found that the temperature of the input water was reduced by approximately 12 degrees C after infiltrating through a bioretention cell located in a parking lot (USEPA, 2000a).

Pollutant removal efficiency in bioretention areas

Metals

Laboratory and field research indicates that bioretention areas have excellent removal capabilities for heavy metals. Duration and flow rate can influence removal at shallow depths (10 inches), but not deeper in the soil profile (36 inches). Metal adsorption in soil is typically influenced by pH; however, the buffering capacity in the bioretention soil mix effectively negates the influence of pH variations in synthetic pollutant mixtures applied to pilot-scale systems (Davis et al., 2003). The most significant metal uptake occurs in the mulch layer that can retain a large portion of the total metals loads (Davis et al., 2001).

Table 6.1.1 summarizes percentages of pollutants removed from pilot-scale laboratory studies performed at University of Maryland. Also see Appendix 4 for summaries of bioretention swale and bioretention cell research. Table 6.1.2 provides data summarizing research on other typical stormwater BMPs for comparison.

Table 6.1.1 Percent pollutant removal by depth in bioretention facilities.

Depth (inches)	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	P (mg/L)	TKN (mg/L)	NH4 (mg/L)	NO3 (mg/L)	TN (mg/L)
10	90	93	87	0	37	54	-97	-29
22	93	>97	>96	73	60	86	-194	0
36	93	>97	>96	81	68	79	23	43

Adapted from Davis et al., 1998 (removal percentages are for total metals)

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Table 6.1.2 Comparative pollutant removal capability of stormwater treatment practices (in percentages).

Pollutant	Dry Extended Detention Pond	Wetlands	Water Quality Swales	Ditches
TN (mg/L)	31	30	84	-9
NO3 (mg/L)	ND	ND	ND	ND
P (mg/L)	20	49	34	-16
Cu (µg/L)	26	40	51	14
Pb (µg/L)	54	68	67	17
Zn (µg/L)	26	44	71	0

Adapted from CWP, 2000b (removal percentages are for total metals)

Nutrients

Phosphorus removal in bioretention soils increases with depth of facility. Sorption of phosphorus onto aluminum, iron, and clay minerals in the soil is the likely mechanism of removal (Davis et al., 2001). Phosphorus can **desorb** if low pH or low oxygen conditions are present; accordingly, bioretention planting soil dewatering rate and drying should be maintained and pH monitored annually. Nitrate removal is highly variable, but generally poor and at times nitrate production and export has been observed (Kim et al., 2003). Production or export of nitrate is a result of organic and ammonia nitrogen that is converted to nitrate between storms (presumably through the **ammonification** and **nitrification** process). Nitrate is then washed from the facility during subsequent storm events (Kim et al., 2003).

Where nitrate is a concern, an under-drain can be elevated from the bottom of the bioretention facility and within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe. With a suitable carbon source (e.g., wood chips mixed in the gravel) acting as an electron donor, the anaerobic zone can enhance the denitrification process (see Figure 6.1.13 in the Under-drain section) (Kim et al., 2003).

Hydrocarbons and bacteria

Hong, Seagren and Davis (2002) examined the capacity of a mulch layer to capture oil and grease via sorption and filtration. Simulated stormwater runoff carrying naphthalene was applied to a bench-scale "reactor" with a 3-cm thick leaf compost layer. During the simulated storm event approximately 90 percent of dissolved naphthalene was removed from aqueous phase via sorption. After the simulated storm event (37 and 40 hours) approximately 32 percent of the naphthalene was removed from the solid phase via biodegradation in the mulch layer where the microbial population had been inhibited. Approximately 72 percent of the naphthalene was removed from the solid phase via biodegradation in the mulch layer at 37 and 40 hours and 95 percent after 74 hours where the microbial population was not inhibited. Losses due to volatilization were negligible. See bioretention research in Appendix 4 for more detail. No research for bacteria removal in bioretention areas has currently been located.

Stormwater pollutants can disrupt normal soil function by lowering cation exchange capacity. The oldest bioretention facilities operating in the U.S. (approximately 10 years) appear to develop soil structure and maintain soil functions that actually enhance pollutant processing capability (Prince George's County, 2002). Estimates from research suggest that metal accumulation would not present an environmental concern for at least 20 years in bioretention systems (Davis et al., 2003).

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Flow control processes in bioretention

- *Evaporation* can occur as precipitation is intercepted by vegetation, from surface water in the ponding area, and from exposed soil or mulch layers in bioretention areas. Evaporation from vegetation is relatively minor unless the cell has a well developed, closed, and varied canopy.
- *Infiltration* is the downward migration of runoff through the planting soil and into the surrounding soils. Infiltration is the primary mechanism for attenuating storm flows in bioretention areas. In general, long-term infiltration rates degrade over time in typical infiltration facilities due to large hydrologic loads, biofilm, and sedimentation. Anecdotal information suggests that properly designed bioretention area soil infiltration rates do not degrade as rapidly and may improve over time due to biological, chemical, and physical processes that build soil structure. Focused studies have not confirmed this. The surrounding soil will be the limiting infiltration rate in till, compacted silt or clay or other tight soils; however, there are no studies quantifying vertical and lateral subsurface flows from bioretention areas in the Puget Sound region.

Flow control performance

In the city of Seattle, Seattle Public Utilities narrowed 660 feet of conventional residential road and installed bioretention swales within the right-of-way as part of the Street Edge Alternatives (SEA) Street project. A v-notch weir installed at the ultimate outfall of the project measured surface flow volumes and timing. The contributing area with swales is approximately 2.3 acres. Soils underlying the bioretention swales are heterogeneous till-like material with lens of silt, sand, and gravel of varying permeability. Some of the swales are lined with bentonite to restrict infiltration and reduce concerns of wet basements in homes near the swales. Flows for the conventional pre-construction street were compared to the retrofit design. During the pre-construction period (March-July 2000), 7.96 inches of rainfall produced 4979 cubic feet of runoff. During the post-construction period (March-July 2001), 9.00 inches of precipitation produced 132 cubic feet of runoff. Post-construction runoff volumes were reduced by approximately 97 percent compared to pre-construction volumes. An October 2003 record storm event (4.22 inches with a 32.5 hour storm duration) produced no runoff (Horner et al., 2002).

6.1.5 Costs

The city of Seattle is implementing a new Natural Drainage System Program (NDS) for retrofitting residential streets that replaces conventional curb and gutter or roadside ditches with bioretention swales. Two designs are used depending on the gradient. The SEA Street swales are designed for the lower gradient north-south streets, and the Cascade type (which incorporate catch basins or check dams between longer gravel bottom swales) are used on the higher gradient east-west streets. Both types use compost-amended soil and small trees, shrubs, and groundcover within the swale to provide enhanced storage, infiltration, and pollutant removal. (See Figure 6.1.16 for SEA Street design example.) Table 6.1.3 compares the estimated costs of a traditional curb and gutter street retrofit to a bioretention swale design with no curb and gutter and enhanced landscaping. Costs shown include comparable water quality treatment and detention volume.

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Table 6.1.3 Cost comparisons for the NDS and conventional drainage designs

Street Type	Local Street SEA Street	Local Street conventional	Collector Street Cascade	Collector Street Conventional	Broadview Green Grid
Transportation & aesthetics	• 1 sidewalk per block • New street paving • Traffic calming • Enhanced landscaping	• 2 sidewalks per block • New street paving • No traffic calming • Conventional landscaping	• No street improvement • Enhanced landscaping	• No street improvement • Conventional landscaping	• Incorporates SEA Street and Cascade type designs • 1 sidewalk per block • New paving • Enhanced landscaping
Stormwater management	• Higher protection for aquatic biota • More closely mimics natural hydrology • Bio-remediate pollutants	• Flood protection focus • Water quality treatment	• Improved water quality treatment • Some flood protection	• Flood protection focus • Water quality treatment	• Higher water quality and aquatic biota protection • Some flood protection
% impervious area	35%	35%	35%	35%	35%
Cost per block (330 linear ft)	$325,000	$425,000	$285,000	$520,400	Average/block $280,000

Adapted from *Cost Analysis of Natural vs. Traditional Drainage Systems Meeting NDS Stormwater Goals*, 2004



Figure 6.1.16 SEA Street bioretention swale, Seattle. *Photo by Colleen Owen*

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6.2 Amending Construction Site Soils

Native soils are highly complex systems that provide essential environmental benefits including biofiltration of pollutants, nutrients for plant growth, and the storage and slow release of storm flows. The ability of soil to effectively store and slowly release water is dependent on soil texture, structure, depth, organic matter content, and biota (Washington Organic Recycling Council [WORC], 2003). Plant roots, macro fauna, and microbes tunnel, excavate, penetrate and physically and chemically bond soil particles to form stable aggregates that enhance soil structure and porosity. Micro-and macro-pores provide a balance of environments that improve water-holding capability, increase infiltration capacity, increase oxygen levels, and provide a variety of habitats necessary to support thousands of different organisms within the soil (Allen, 1994 and CH2M HILL, 2000).

Organic matter is a critical component of a functioning soil system. Mixed into the soil, organic matter absorbs water, physically separates clay and silt particles, and reduces erosion (Balousek, 2003 and WORC, 2003). Microbial populations and vegetation depend on the replenishment of organic matter to retain and slowly release nutrients for growth (Chollak, n.d.). Typically, native Puget Sound forest soils have an organic matter content of 4 to 6 percent and the sub-soils less than 1 percent (Chollak, n.d.). Construction activity removes the upper layers of soil, compacts exposed sub-soils low in organic matter, and alters the site's hydrologic characteristics by converting the predominantly subsurface flow regime of the pre-disturbance site to primarily overland flow.

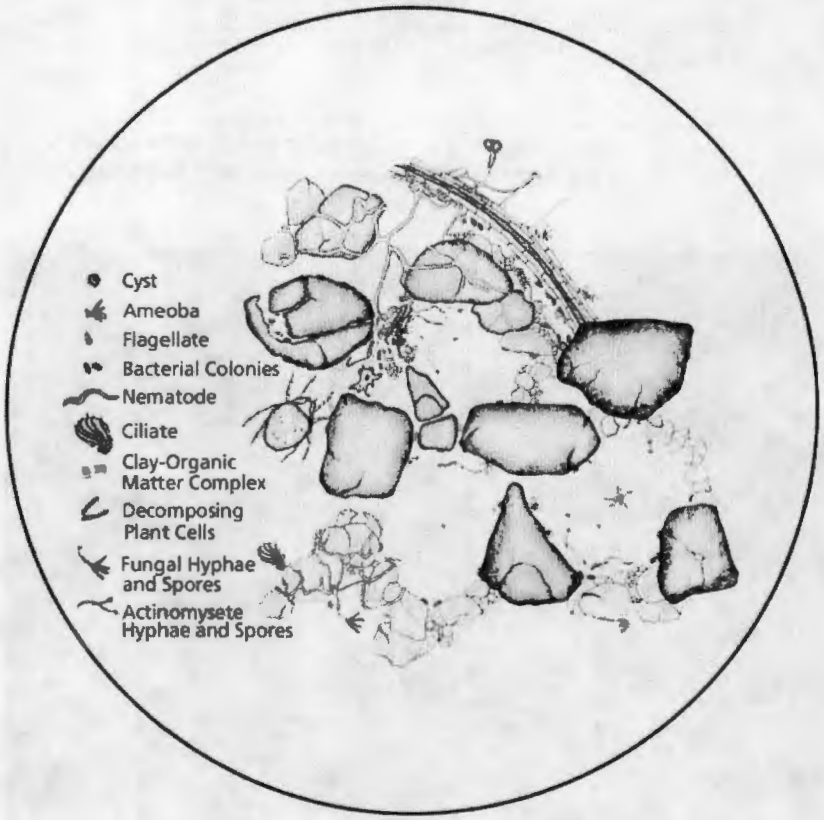

Figure 6.2.1 Close up of healthy soil structure.
Graphic courtesy of S. Rose and E.T. Elliott

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Current landscape practices often do not encourage adequate preparation of turf and planting bed areas in order to regain any of the hydrologic benefits of native soils. As a result, compacted, unamended soil in landscape areas can behave similarly to impervious surfaces by generating considerable overland or shallow subsurface flows that rapidly reach receiving waters. A three-year study of a 17-hectare developed catchment near Seattle (approximately 71 percent coverage in lawn, gardens, and common areas) found that 60 percent of the total overland and rapid subsurface flow came from landscaped areas during large storms (Wigmosta, Burges and Meena, 1994). Without proper treatment and maintenance, compacted soil in lawn areas can take several years to decades to recover any beneficial infiltration and water storage characteristics of the pre-development condition (Leg, Bannerman and Panuska, 1996).

Compacted, unamended soil in landscaped areas can have similar characteristics of impervious surfaces and generate considerable overland or shallow subsurface flows that rapidly reach receiving waters.

The following section focuses on soil amendment guidelines for general landscape and vegetation protection areas. For specific application of soils in bioretention facilities see Section 6.1: Bioretention Areas.

6.2.1 Applications

The hydrologic characteristics of disturbed construction site soils for commercial, residential, and industrial projects, whether new or retrofit, can be enhanced with the addition of organic matter (CH2M HILL, 2000). In a low impact development, the landscape component of the project enhances water storage, attenuates storm flows, and is integral to the stormwater management design. When properly implemented and maintained, incorporating compost into the disturbed soils provides hydrologic, as well as other important environmental, functions including:

In a low impact development, the landscape component of the project enhances water storage, attenuates storm flows, and is integral to the stormwater management design.

- Reduced erosion.
- Increased sediment filtration.
- Pollutant adsorption and biofiltration.
- Improved plant growth, disease resistance, and overall aesthetics of the landscaping.
- Reduced (or elimination of) pesticide and fertilizer inputs for plant maintenance.
- Reduced peak summer irrigation needs (Chollak, n.d.).

Organic matter derived from compost, stockpiled on-site soil, or imported topsoil can be beneficial in all areas subject to clearing and grading. Engineered structural fill or LID drainage facilities will have specific design requirements for soil (see Section 6.1 for soil specifications in bioretention facilities). Application rates and techniques for incorporating amendments will vary with the use and plant requirements of the area. For example, application depths will be less in tree root protection zones than in turf and planting beds, and turf requiring maintenance or supporting foot traffic during the wet months will require different application rates than general landscaping areas (see Section 6.2.2: Design for details).

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6.2.2 Design

Much of the information supplied here is a summary of *Guidelines and Resources for Implementing Soil Depth and Quality BMP T.5.13 in WDOE Western Washington Stormwater Manual* (Stenn, 2003). An update of this guidance is available at: http://www.soilsforsalmon.org. For details on specifications, verification, and inspection procedures, and additional resources consult the above cited manual.

To enhance the hydrologic and other environmental benefits of disturbed soils in a low impact development, the topsoil should have the following characteristics:

- A minimum organic matter content of 10 percent by dry weight for all planting beds and other landscaped areas (except turf requiring access during wet months).
- Organic matter content in turf areas that requires maintenance or supports foot traffic during the wet months should be 5 percent by dry weight.
- pH between 5.5 and 7.0 or a pH appropriate for installed plants.
- A minimum depth of 8 inches (except in tree root protection areas–see next page).
- Planting beds should be mulched with 2 to 3 inches (maximum) of organic material.
- Subsoils below topsoil applications should be scarified to a depth of at least 4 inches and some topsoil material incorporated to prevent stratification. See tilling recommendations below for specific application methods.

The minimum organic matter content may be achieved by using the pre-approved amendment methods as outlined below, or by calculating a custom amendment rate for the existing site soil conditions. The pre-approved method simplifies planning and implementation; however, the organic matter content of the disturbed on-site soils may be relatively good and not require as extensive an application of amendment material. In many cases, calculating a site-specific rate may result in significant savings in amendment material and application costs. Calculating a custom rate requires collecting soil samples from the area to be amended and samples from the compost material. The soil is then tested for bulk density and percent organic matter. The compost is tested for bulk density, percent organic matter, moisture content, carbon-to-nitrogen ratio, and heavy metals. Compost and topsoil producers can often supply the required information for the amendment material; however, on-site analysis would be necessary if vendor-supplied analysis is not available. See *Guidelines and Resources for Implementing Soil Depth and Quality BMP T.5.13 in WDOE Western Washington Stormwater Manual* (Stenn, 2003) for additional information on testing procedures.

Determining the site-specific compost application rate is calculated with the following equation:

$$CR = D\,(X)\ \frac{SBD\,(SOM\% - FOM\%)}{SBD\,(SOM\% - FOM\%) - CBD\,(COM\% - FOM\%)}$$

Where:

CR = compost application rate (inches)
D = depth of incorporation (inches)
SBD = soil bulk density *(lb/cubic yard dry weight)*
SOM% = initial soil organic matter (%)
FOM% = final target soil organic matter (%) *(target will be 5% or 10% depending on landscape area)*
CBD = compost bulk density *(lb/cubic yard dry weight)*
COM% = compost organic matter (%)

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Recommended soil characteristics can be achieved by the following methods: (1) Set aside and protect native soil and vegetation areas; (2) Amend existing disturbed topsoil or subsoil; (3) Stockpile on-site topsoil from cleared and graded areas and replace prior to planting; or (4) Import topsoil with required organic matter content standards.

1. **Set aside and protect native soil and vegetation areas.** The most effective and cost efficient method for providing the hydrologic benefits of healthy soil is to designate and protect native soil and vegetation areas. See Chapter 4: Vegetation Protection, Reforestation and Maintenance and Chapter 5: Clearing and Grading for conservation techniques.

The most effective and cost efficient method for providing the hydrologic benefits of healthy soil is to designate and protect native soil and vegetation areas.

2. **Amend existing disturbed topsoil or subsoil.** Scarify or till soil to an 8-inch depth (or to depth needed to achieve a total depth of 12 inches of uncompacted soil after the calculated amount of amendment is added). The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within the drip-line of existing trees to be retained. Within 3 feet of the tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

   Landscaped Areas (10 percent organic content): Place and till 3 inches (or custom calculated amount) of composted material into 5 inches of soil (a total depth of about 9.5 inches, for a settled depth of 8 inches). Rake beds smooth, remove rocks larger than 2 inches diameter and mulch areas with 2 inches of organic mulch.

   Turf Areas (5 percent organic content): Place and till 1.75 inches (or custom calculated amount) of composted material into 6.25 inches of soil (a total amended depth of about 9.5 inches, for a settled depth of 8 inches). Water or roll to compact soil to 85 percent of maximum. Rake to level, and remove surface woody debris and rocks larger than 1-inch diameter.

3. **Stockpile on-site topsoil from cleared and graded areas and replace prior to planting.** Stockpile and cover soil with weed barrier or other breathable material that sheds moisture yet allows air transmission, in approved location, prior to grading. Test the stockpiled material and amend with organic matter or topsoil if required to achieve organic content to 8-inch depth. Replace stockpiled topsoil prior to planting.

   If replaced topsoil plus compost or other organic material will amount to less than 12 inches, scarify or till subgrade to a depth needed to achieve 12 inches of loosened soil after topsoil and amendment are placed. The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within drip-line of existing trees to be retained. Within 3 feet of tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

   Landscaped Areas (10 percent organic content): Place and till 3 inches of composted material into 5 inches of replaced soil (a total depth of about 9.5 inches, for a settled depth of 8 inches). Rake beds to smooth, remove rocks larger than 2 inches diameter, and mulch areas with 2 inches of organic mulch or stockpiled duff.

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Turf Areas (5 percent organic content): Place and till 1.75 inches of composted material into 6.25 inches of replaced soil (a total amended depth of about 9.5 inches, for a settled depth of 8 inches). Water or roll compact soil to 85 percent of maximum. Rake to level, and remove surface woody debris and rocks larger than 1-inch diameter.

4. **Import topsoil with required organic matter content standards.**
   Scarify or till subgrade in two directions to a 6-inch depth. The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within drip-line of existing trees to be retained. Within 3 feet of tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

   Landscaped Areas (10 percent organic content): Use imported topsoil mix containing 10 percent organic matter (typically around 40 percent compost). The soil portion must be sand or sandy loam as defined by the USDA soil classification system. Place 3 inches of imported topsoil mix on surface and till into 2 inches of soil. Place 3 inches of topsoil mix on the surface. Rake smooth, remove surface rocks over 2 inches in diameter, and mulch planting beds with 2 inches of organic mulch.

   Turf Areas (5 percent organic content): Use imported topsoil mix containing 5 percent organic matter (typically around 25 percent compost). Soil portion must be sand or sandy loam as defined by the USDA soil classification system. Place 3 inches of topsoil mix on surface. Water or roll to compact soil to 85 percent maximum. Rake to level and remove surface rocks larger than 1-inch diameter.

   The soil portion of the topsoil must be sand or sandy loam as defined by the USDA soil classification system. The soil and compost mix should have less than 25 percent pass through a #200 sieve and 100 percent should pass through a ¾-inch screen (WORC, 2003).

Compost

Organic soil amendment, suitable for landscaping and stormwater management, should be a stable, **mature compost** derived from organic waste materials including yard debris, manures, bio-solids, wood wastes or other organic materials that meet the intent of the organic soil amendment specification. **Compost stability** indicates the level of microbial activity in the compost and is measured by the amount of CO_2 produced over a given period of time by a sample in a closed container. Unstable compost can render nutrients temporarily unavailable and create objectionable odors.

Compost quality can be determined by examining the material and qualitative tests. A simple way to judge compost quality is to smell and examine the finished product, which should have the following characteristics (WORC, 2003):

- Earthy smell that is not sour, sweet or ammonia like.
- Brown to black in color.
- Mixed particle sizes.
- Stable temperature and does not get hot when re-wetted.
- Crumbly texture.

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Qualitative tests and producer documentation should have the following specifications:

- Material must meet the definition for "composted materials" in WAC 173-350 section 220. This code is available online at http://www.ecy.wa.gov/programs/swfa/facilities/350.html.
- Organic matter content between 35 and 65 percent as determined by loss of ignition test method (ASTM D 2974).
- pH between 5.5 and 7.0.
- Carbon:nitrogen ratio between 20:1 and 35:1 (a CN ratio of 35:1 is preferred for native plantings).
- Maximum electrical conductivity of 3 ohms/cm.
- Moisture content range between 35 and 50 percent.
- No viable weed seeds.
- Manufactured inert material (plastic, concrete, ceramics, etc.) should be less than 1 percent on a dry weight or volume basis.
- Metals should not be in excess of limits in the following table:

Metal	Limit (mg/kg dry weight)
Arsenic	≤ 20 ppm
Cadmium	≤ 10 ppm
Copper	≤ 750 ppm
Lead	≤ 150 ppm
Mercury	≤ 8 ppm
Molybdenum	≤ 9 ppm
Nickel	≤ 210 ppm
Selenium l	≤ 18 ppm

(Stenn, 2003)

Determining final grade with amended soils

To achieve the appropriate grade, changes in soil depth from tilling and incorporating soil amendments need to be estimated.

The difference in volume of the dense versus the loose soil condition is determined by the "fluff factor" of the soil. The fluff factor of compacted subsoils in the Puget Sound area tends to be between 1.3 and 1.4. Tilling typically penetrates the upper 6 to 8 inches of the existing soil. Assuming a 6-inch depth is achieved, the depth adjusted by the fluff factor will correspond to a 7.8 to 8.4-inch depth of loose soil. This loose volume is then amended at a 2:1 ratio of loose soil to compost, corresponding to an imported amendment depth of approximately 4 inches for this example. In the loose state, both the soil and compost have a high percentage of pore space (volume of total soil not occupied by solids), and the final amended soil elevation must account for compost settling into void spaces of the loose soil and compaction (this example assumes that 15 percent of the soil's void spaces become occupied by compost particles). For a fluff factor of 1.3, use a compression factor of 1.15 and for soils with a fluff factor of 1.4 use a compression factor of 1.2 (i.e., 15 to 20 percent of the soils' void spaces will become occupied by compost particles). The resulting increase in elevation for soils amended to a 6-inch depth will be approximately 3 inches. See Table 6.2.1 for an example calculation.

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Table 6.2.1 Example for estimating soil depth and height changes.

Procedure	Calculation	Relative Elevation Inches
Beginning Elevation		0
Rototill soil to a depth of 6 inches and assuming 1.4-inch fluff factor	Depth achieved by machinery x fluff factor of soil: (6 x 1.4) = 8.4 8.4 - 6 = 2.4	+2.4
Add compost, 2 units soil to 1 unit compost, by loose volume	Depth of soil ÷ 2: 8.4 ÷ 2 = 4.2	+4.2
Filling of pore spaces	Depth of loose soil x percentage of pore space filled by compost addition: 8.4 x (-.15) = -1.3	-1.3
Rototill compost into soil and roll site to compact soil, assuming compression factor of 1.2	(Amended soil depth ÷ compression factor) - amended soil depth:	-2.1
Resulting Elevation Change	Sum	+3.2

Turf areas

If the site is well drained and acceptable for traditional lawn installation, then a compost-amended soil lawn will drain equally well while providing superior storm flow storage, pollutant processing, and growth medium (see Section 6.2.4: Performance for details).

If the site being considered for turf establishment does not drain well, an alternative to planting a lawn should be considered. If the site is not freely draining, turf is still being attempted, and maintenance or other activity is required during the wet months, compost amendment will still provide stormwater benefits. However, the ratio of organic matter to soil should be reduced to a maximum of 30 percent by volume. This upper limit is suggested for the Puget Sound region to reduce the spongy feel of soils with high organic matter content and potential compaction during the wet months (Chollak, n.d.). A drainage route or subsurface collection system may be necessary for composted or non-composted turf applications in poorly draining soils.

Steep slopes

WSDOT has been applying compost to condition soils on slopes ranging up to 33 percent since 1992. No stability problems have been observed as a result of the increased water holding capacity of the compost (Chollak, n.d.). Steep slope areas, which have native soils with healthy native landscapes, should be protected from disturbance. On steep slopes where native soils and vegetation are disturbed or removed, soils should be amended and re-vegetated with deep rooting plants to improve slope stability. Compost can be applied to the ground surface without incorporation to improve plant growth and prevent erosion on steep slopes that cannot be accessed by equipment.

WSDOT has been applying compost to condition soils on slopes ranging up to 33 percent since 1992. No stability problems have been observed as a result of the increased water holding capacity of the compost.

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6.2.3 Maintenance

- Incorporate soil amendments at the end of the site development process.
- Protect amended areas from excessive foot traffic and equipment to prevent compaction and erosion.
- Plant and mulch areas immediately after amending soil to stabilize site as soon as possible.
- Minimize or eliminate use of pesticides and fertilizers. Landscape management personnel should be trained to adjust chemical inputs accordingly and manage the landscape areas to minimize erosion, recognize soil and plant health problems, and optimize water storage and soil permeability.

6.2.4 Performance

The surface bulk density of construction site soils generally range from 1.5 to 2.0 gm/cc (CWP, 2000a). At 1.6 to 1.7 gm/cc plant roots cannot penetrate soil and oxygen content, biological activity, nutrient uptake, porosity, and water holding capacity are severely degraded (CWP, 2000a and Balousek, 2003). Tilling alone has limited effect for reducing the bulk density and enhancing compacted soil. A survey of research examining techniques to reverse soil compaction by Schueler found that tilling reduced bulk density by 0.00 to 0.15 gm/cc. In contrast, tilling with the addition of compost amendment decreased bulk density by 0.25 to 0.35 gm/cc (CWP, 2000a).

Balousek (2003) prepared combinations of deep tillage, chisel plow, and compost amended plots on an area with silt loam soil that was cleared and graded to simulate construction site conditions. The deep-tilled plots increased runoff volume compared to the control, and the combined chisel plow and deep-tilled treatment reduced runoff volume by 36 to 53 percent. With compost added to the combined plow and till treatment, runoff volume was reduced by 74 to 91 percent.

Research plots at University of Washington, prepared with various amounts and types of compost mixed with till soil and planted with turf, generated 53 to 70 percent of the runoff volume observed from the unamended control plots. The greatest attenuation was observed in treatments with a ratio of 2 parts soil to 1 part fine, well-aged compost. The study indicates that using compost to amend lawn on till soils can "significantly enhance the ability of the lawn to infiltrate, store and release water as baseflow" (Kolsti, Burges, and Jensen, 1995).

6.3 Permeable Paving

Permeable paving surfaces are designed to accommodate pedestrian, bicycle, and vehicle traffic while allowing infiltration, treatment, and storage of stormwater. The general categories of permeable paving systems include:

- *Open-graded concrete or hot-mix asphalt pavement,* which is similar to standard pavement, but with reduced or eliminated fine material (sand and finer) and special admixtures incorporated (optional). As a result, channels form between the aggregate in the pavement surface and allow water to infiltrate.
- *Aggregate or plastic pavers* that include cast-in-place or modular pre-cast blocks. The cast-in-place systems are reinforced concrete made with reusable forms. Pre-cast systems are either high-strength Portland cement concrete or plastic blocks. Both systems have wide joints or openings that can be filled with soil and grass or gravel.

Permeable paving surfaces accommodate pedestrian, bicycle, and vehicle traffic while allowing infiltration, treatment and storage of stormwater.

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- *Plastic grid systems* that come in rolls and are covered with soil and grass or gravel. The grid sections interlock and are pinned in place.

6.3.1 Applications

Typical applications for permeable paving include industrial and commercial parking lots, sidewalks, pedestrian and bike trails, driveways, residential access roads, and emergency and facility maintenance roads. Highways and other high traffic load roads have not been considered appropriate for permeable paving systems. However, porous asphalt has proven structurally sound and remained permeable in a highway application on State Route 87 near Phoenix, Arizona and permeable concrete and pavers have been successfully used in industrial settings with high vehicle loads (Hossain, Scofield and Meier, 1992).



Figure 6.3.1 The residential access road at Jordan Cove Urban Monitoring Project in Connecticut is paved entirely with permeable pavers.
Photo by Tom Wagner

Benefits of permeable pavement

Initial research indicates that properly designed and maintained permeable pavements can virtually eliminate surface flows for low intensity storms common in the Pacific Northwest; store or significantly attenuate subsurface flows (dependent on underlying soil and aggregate storage design); and provide water quality treatment for nutrients, metals, and hydrocarbons (see Section 6.3.4: Performance for additional information).

Permeable paving systems have been designed with aggregate storage to function as infiltration facilities with relatively low subgrade infiltration rates (as low as 0.1 inch/hour). When water is not introduced from adjacent areas, these systems have a lower contribution to infiltration area ratio than conventional infiltration facilities (i.e., 1 to 1) and are less likely to have excessive hydraulic loading. Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. If design constraints require that surface flow be introduced from adjacent areas, particular caution should be taken to ensure that excessive sediment is not directed to the system or that additional flows will not exceed the hydraulic loading capability.

The permeable paving systems examined in this section provide acceptable surfaces for disabled persons. WAC 51-40-1103 Section 1103 (Building Accessibility) states that abrupt changes in height greater than ¼ inch in accessible routes of travel shall be beveled to 1 vertical in 2 horizontal. Changes in level greater than ½ inch shall be accomplished with an approved ramp. Permeable asphalt and concrete, while rougher than conventional paving, do not have abrupt changes in level when properly installed. The concrete pavers have small cells filled with aggregate to a level just under the top of the paver, as well as beveled edges. Gravel pave systems use a specific aggregate with a reinforcing grid that creates a firm and relatively smooth surface (see Section 6.3.2: Design).

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Two qualifications for use of permeable paving and disabled access should be noted. Sidewalk designs incorporate scoring, or more recently, truncated domes, near the curb ramp to indicate an approaching traffic area for the blind. The rougher surfaces of permeable paving may obscure this transition; accordingly, standard concrete with scoring or concrete pavers with truncated domes should be used for curb ramps (Florida Concrete and Products Association [FCPA], n.d.). Also, the aggregate within the cells of permeable pavers (such as Eco-Stone) can settle or be displaced from vehicle use. As a result, paver installations for disabled parking spaces and walkways may need to include solid pavers. Individual project designs should be tailored to site characteristics and local regulatory requirements.

Many individual products with specific design requirements are available and cannot all be examined in this manual. To present a representative sample of widely applied products, this section will examine the design, installation, maintenance, and performance of permeable hot-mix asphalt, Portland cement concrete, a concrete paver system, and a flexible plastic grid system.

6.3.2 Design

Handling and installation procedures for permeable paving systems are different from conventional pavement. For the successful application of any permeable paving system three general guidelines must be followed.

For successful application of any permeable paving system follow these three general guidelines:

- *Use correct design specifications.*
- *Use qualified contractors.*
- *Strictly control erosion and sediment.*

1. **Correct design specifications**
   Proper site preparation, correct aggregate base and wearing course gradations, separation layer, and under-drain design (if included) are essential for adequate infiltration, storage, and release of storm flows, as well as structural integrity. For example, over compaction of the underlying soil and excessive fines present in the base or top course will significantly degrade or effectively eliminate the infiltration capability of the system.

2. **Qualified contractors**
   Contractors must be trained and have experience with the product, and suppliers must adhere to material specifications. Installation contractors should provide data showing successful application of product specifications for past projects. If the installation contractor does not have adequate experience the contractor should retain a qualified consultant to monitor production, handling, and placement operations (U.S. Army Corps of Engineers, 2003). Substituting inappropriate materials or installation techniques will likely result in structural or hydrologic performance problems. For example, using vibrating plate compactors (typical concrete installation procedure) with excessive pressures and frequencies will seal the void spaces in permeable cast-in-place concrete.

3. **Sediment and erosion control**
   Erosion and introduction of sediment from surrounding land uses should be strictly controlled during and after construction to reduce clogging of the void spaces in the base material and permeable surface. Filter fabric between the underlying soil and base material is required to prevent soil fines from migrating up and into the aggregate base. Muddy construction equipment should not be allowed on the base material or pavement, sediment laden runoff

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should be directed to pre-treatment areas (e.g., settling ponds and swales), and exposed soil should be mulched, planted, and otherwise stabilized as soon as possible.

The preceding guidelines are not optional for the installation of permeable paving systems. Past design failures are most often attributed to not adhering to the above general guidelines, and failure is likely without qualified contractors and strict adherence to correct installation specifications.

Properly designed permeable paving installations have performed well in the Midwestern and Northeastern U.S. where freeze-thaw cycles are severe (Adams, 2003 and Wei, 1986). Risk of freeze damage can be minimized by extending the base of the permeable paving system to a minimum of half the freeze depth. For example, a total minimum depth for the wearing course and aggregate base material would be 6 inches in the Seattle area, where the freeze-thaw depth is 12 inches (Diniz, 1980).

Determining infiltration rates

Depending on the design, permeable paving installations can be modeled as landscaped area over the underlying soil type or as an infiltration basin. If the installation is modeled as an infiltration basin, determining the infiltration rate of the underlying soil is necessary to equate flow reduction benefits when using the WWHM or MGS Flood. For details on flow modeling guidance see Chapter 7. See Figure 6.3.2 for a graphic representation of the process to determine infiltration rates. The following tests are recommended for soils below the aggregate base material:

- Small permeable paving installations (patios, walkways, and driveways on individual lots): The flow control credits on private property do not include subsurface storage; accordingly, no infiltration field tests are necessary. Soil texture, grain size analysis, or soil pit excavation and infiltration tests may still be prudent if highly variable soil conditions or seasonal high water tables are suspected.
- Large permeable paving installations (sidewalks, alleys, parking lots, roads) that include storage volume using base material below the grade of the surrounding land and the installations are modeled as an infiltration basin:
  - Method 1: Use USDA Soil Textural Classification (Rawls survey) every 200 feet of road or every 5,000 square feet.
  - Method 2: Use ASTM D422 Gradation Testing at Full Scale Infiltration Facilities every 200 feet of road or every 5,000 square feet. See the 2005 SMMWW Volume III for details on methods 1 and 2. This method uses the *2004 WSDOT Highway Runoff Manual* protocol.
  - Method 3: Use small-scale infiltrometer tests every 200 feet of road or every 5,000 square feet. Small-scale infiltrometer tests such as the USEPA Falling Head or double ring infiltrometer tests (ASTM 3385-88) may not adequately measure variability of conditions in test areas. If used, measurements should be taken at several locations within the area of interest.
  - Method 4: Pilot Infiltration Test (PIT) or small-scale test infiltration pits (septic test pits) at a rate of 1 pit/500 feet of road or 10,000 ft^2. This infiltration test better represents soil variability and is recommended for highly variable soil conditions or where seasonal high water tables are suspected. See the 2005 SMMWW Appendix III-D (formerly V-B) for PIT method description.

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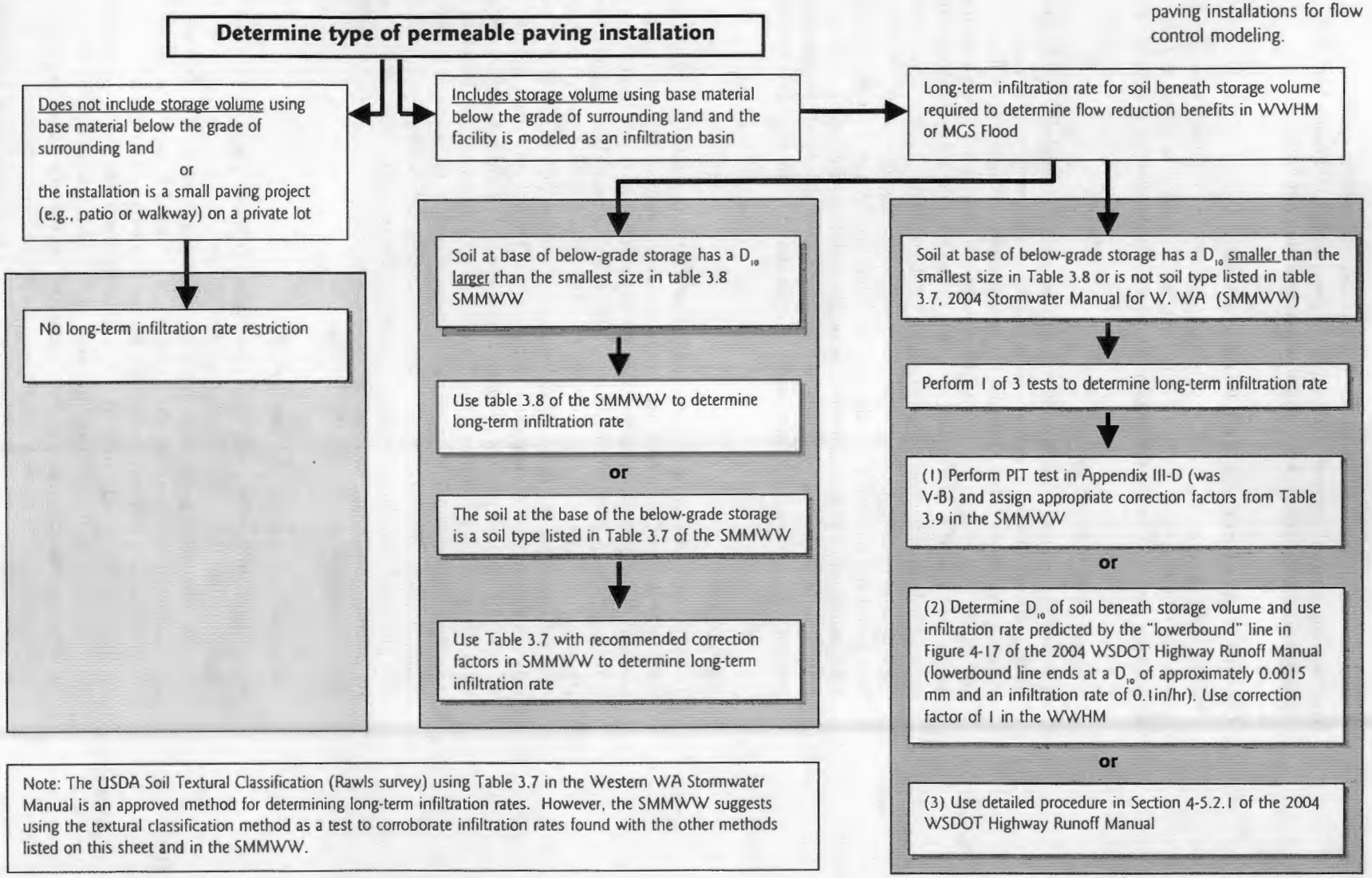
Figure 6.3.2 Determining long-term infiltration rates in soils under permeable paving installations for flow control modeling.



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Utility excavations under or beside the road section can provide pits for soil classification, textural analysis, stratigraphy analysis, and/or infiltration tests and minimize time and expense for permeable paving infiltration tests.

Components of permeable paving systems

The following provides a general description and function for the components of permeable paving systems. Design details for specific permeable paving system components are included in the section describing specific types of permeable paving.

Wearing course or surface layer

The wearing course provides compressive and flexural strength for the designed traffic loads while maintaining adequate porosity for storm flow infiltration. Wearing courses include cast-in-place concrete, asphalt, concrete and plastic pavers, and plastic grid systems. In general, permeable top courses have very high initial infiltration rates with various asphalt and concrete research reporting 28 to 1750 inches per hour when new (see Appendix 7: Porous Paving Research for details). Various rates of clogging have been observed in wearing courses and should be anticipated and planned for in the system design (see Section 6.3.5: Performance for research on infiltration rates over time). Permeable paving systems allow infiltration of storm flows; however, the wearing course should not be allowed to become saturated from excessive water volume stored in the aggregate base layer.

Aggregate base

The aggregate base provides: (1) a stable base for the pavement; (2) a highly permeable layer to disperse water downward and laterally to the underlying soil; and (3) a temporary reservoir that stores water prior to infiltration in the underlying soil or collection in under-drains for conveyance (Washington State Department of Transportation [WSDOT], 2003). Base material is often composed of larger aggregate (1.5 to 2.5 inches) with smaller stone (leveling or choker course) between the larger stone and the wearing course. Typical void space in base layers ranges from 20 to 40 percent (WSDOT, 2003 and Cahill, Adams and Marm, 2003). Depending on the target flow control standard and physical setting, retention or detention requirements can be partially or entirely met in the aggregate base. Aggregate base depths of 18 to 36 inches are common depending on storage needs and provide the additional benefit of increasing the strength of the wearing course by isolating underlying soil movement and imperfections that may be transmitted to the wearing course (Cahill et al., 2003).

Separation and water quality treatment layer

The separation layer is a non-woven geotextile fabric that provides a barrier to prevent fine soil particles from migrating up and into the base aggregate. If required, the water quality treatment layer filters pollutants from surface water and protects groundwater quality (generally, a treatment layer will be necessary in critical aquifer recharge areas). The treatment media can consist of a sand layer or an engineered amended soil. Engineered amended soil layers should be a minimum of 18 inches and incorporate compost, sphagnum peat moss or other organic material to provide a **cation exchange capacity** of ≥ 5 milliequivalents/100 grams dry soil (Ecology, 2001). Soil gradation and final mix should provide a minimum infiltration rate of 0.5 inch/hour at final compaction.

Flow modeling guidance

See Chapter 7 for guidance and flow reduction credits for permeable paving systems when using the WWHM.

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A treatment layer is not required where the subgrade soil has a long-term infiltration rate of < 2.4 inches/hour and a cation exchange capacity of ≥ 5 milliequivalents/100 grams dry soil.



Figure 6.3.3 Permeable pavers were installed at this Marysville parking lot for infiltration. Organic material was mixed with sand as part of the sub-base to enhance treatment.
Photo by Colleen Owen

Types of permeable paving

The following section provides general design specifications for permeable hot-mix asphalt, Portland cement concrete, a flexible plastic grid system, a cement paver, and a rigid plastic block product. Each product has specific design requirements. Most notably the permeable Portland cement concrete and hot-mix asphalt differ from the paver systems in subgrade preparation. Concrete and asphalt systems are designed and constructed to minimize subgrade compaction and maintain the infiltration capacity of the underlying soils. Paver systems require subgrade compaction to maintain structural support. Some soils with high sand and gravel content can retain useful infiltration rates when compacted; however, many soils in the Puget Sound region become essentially impermeable when compacted to 95 percent modified proctor or proctor rates.

The specifications below are provided to give designers general guidance. Each site has unique characteristics and development requirements; accordingly, qualified engineers and other design disciplines should be consulted for developing specific permeable paving systems.

1. Permeable hot-mix asphalt

Permeable asphalt is similar to standard hot-mix asphalt; however, the aggregate fines (particles smaller than No. 30 sieve) are reduced, leaving a matrix of pores that conduct water to the underlying aggregate base and soil (Cahill et al., 2003). Porous asphalt can be used for light to medium duty applications including residential access roads, driveways, utility access, parking lots, and walkways; however, porous asphalt has been used for heavy applications such as airport runways (with the appropriate polymer additive to increase bonding strength) and highways (Hossain, Scofield and Meier, 1992). While freeze-thaw cycles are not a large concern in

Properly installed and maintained permeable asphalt should have a service life that is comparable or longer than conventional asphalt.

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the Puget Sound lowland, permeable asphalt can and has been successfully installed in wet, freezing conditions in the Midwestern U.S. and Massachusetts with proper section depths (Cahill et al., 2003 and Wei, 1986). Properly installed and maintained permeable asphalt should have a service life that is comparable or longer than conventional asphalt (personal communication, Tom Cahill, 2003).

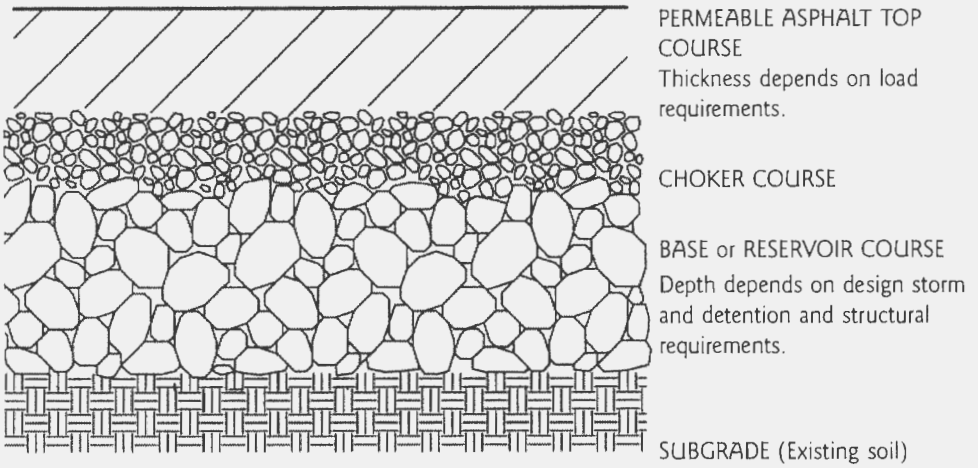

Figure 6.3.4 Permeable asphalt section.

Graphic by AHBL Engineering

Design

Several permeable bituminous asphalt mixes and design specifications have been developed for friction courses (permeable asphalt layer over conventional asphalt) and as wearing courses that are composed entirely of a porous asphalt mix. The friction courses are designed primarily to reduce noise and glare off standing water at night and hydroplaning; however, this design approach provides minimal attenuation of stormwater during the wet season in the Puget Sound region. The following provides specifications and installation procedures for permeable asphalt applications where the wearing top course is entirely porous, the base course accepts water infiltrated through the top course, and the primary design objective is to significantly or entirely attenuate storm flows.

Application: parking lots, driveways, and residential and utility access roads.

Soil infiltration rate

- As long as runoff is not directed to the permeable asphalt from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have under-drains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading. However, it may be acceptable to direct flows after treatment to the subgrade if storage volume and infiltration rates allow.

Subgrade

- Soil conditions should be analyzed by a qualified engineer for load bearing given anticipated soil moisture conditions.

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- After grading, the existing subgrade should not be compacted or subjected to excessive construction equipment traffic.
- If using the base course for retention in parking areas, excavate the storage bed level to allow even distribution of water and maximize infiltration across entire parking area.
- Immediately before base aggregate and asphalt placement, remove any accumulation of fine material from erosion with light equipment and scarify soil to a minimum depth of 6 inches.

Aggregate base/storage bed

- Minimum base depth for structural support should be 6 inches (Washington State Department of Transportation, 2003).
- Maximum depth is determined by the extent to which the designer intends to achieve a flow control standard with the use of a below-grade storage bed. Aggregate base depths of 18 to 36 inches are common depending on storage needs.
- Coarse aggregate layer should be a 2.5- to 0.5-inch uniformly graded crushed (angular) thoroughly washed stone (AASHTO No. 3).
- Choker course should be 1 to 2 inches in depth and consist of 1.5-inch to U.S. sieve size number 8 uniformly graded crushed washed stone for final grading of base reservoir. The upper course is needed to reduce rutting from construction vehicles delivering and installing asphalt and to more evenly distribute loads to the base material (Diniz, 1980).

Installation of Aggregate base/storage bed

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- Install approved non-woven filter fabric on subsoil according to manufacturer's specifications. Where installation is adjacent to conventional paving surfaces, filter fabric should be wrapped up sides to top of base aggregate to prevent migration of fines from densely graded material to the open graded base, maintain proper compaction, and avoid differential settling.
- Overlap adjacent strips of fabric at least 24 inches. Secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of area storage reservoir.
- Install coarse (1.5 to 2.5 inch) aggregate in maximum of 8-inch lifts and lightly compact each lift.
- Install a 1 to 2-inch choker course evenly over surface of course aggregate base.
- Following placement of base aggregate and again after placement of the asphalt, the filter fabric should be folded over placements to protect installation from sediment inputs. Excess filter fabric should not be trimmed until site is fully stabilized (U.S. Army Corps of Engineers, 2003).

Top course

- Parking lots: 2 to 4 inches typical.
- Residential access roads: 2 to 4 inches typical.
- Permeable asphalt has similar strength and flow properties as conventional asphalt; accordingly, the wearing course thickness is similar for either surface given equivalent load requirements (Diniz, 1980).

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Aggregate grading:	U.S. Standard Sieve	Percent Passing
	1/2	100
	3/8	92-98
	4	32-38
	8	12-18
	16	7-13
	30	0-5
	200	0-3

- A small percentage of fine aggregate is necessary to stabilize the larger porous aggregate fraction. The finer fraction also increases the viscosity of the asphalt cement and controls asphalt drainage characteristics.
- Total void space should be approximately 16 percent (conventional asphalt is 2 to 3 percent) (Diniz, 1980).

Bituminous asphalt cement

- Content: 5.5 to 6.0 percent by weight dry aggregate. The minimum content assures adequate asphalt cement film thickness around the aggregate to reduce photo-oxidation degradation and increase cohesion between aggregate. The upper limit is to prevent the mixture from draining during transport.
- Grade: 85 to 100 penetration recommended for northern states (Diniz, 1980).
- An elastomeric polymer can be added to the bituminous asphalt to reduce drain-down.
- Hydrated lime can be added at a rate of 1.0 percent by weight of the total dry aggregate to mixes with granite stone to prevent separation of the asphalt from the aggregate and improve tensile strength.

General installation

- Install permeable asphalt system toward the end of construction activities to minimize sediment problems. The subgrade can be excavated to within 6 inches of final grade and grading completed in later stages of the project (Cahill et al., 2003).
- Erosion and introduction of sediment from surrounding land uses should be strictly controlled during and after construction. Erosion and sediment controls should remain in place until area is completely stabilized with soil amendments and landscaping.
- Adapting aggregate specifications can influence bituminous asphalt cement properties and permeability of the asphalt wearing course. Before final installation, test panels are recommended to determine asphalt cement grade and content compatibility with the aggregate (Diniz, 1980).
- Insulated covers over loads during hauling can reduce heat loss during transport and increase working time (Diniz, 1980). Temperatures at delivery that are too low can result in shorter working times, increased labor for hand work, and increased cleanup from asphalt adhering to machinery (personal communication Leonard Spodoni, April 2004).

Backup systems for protecting permeable asphalt systems

- For backup infiltration capacity (in case the asphalt top course becomes clogged) an unpaved stone edge can be installed that is hydrologically connected to the storage bed (see Figure 6.3.5).

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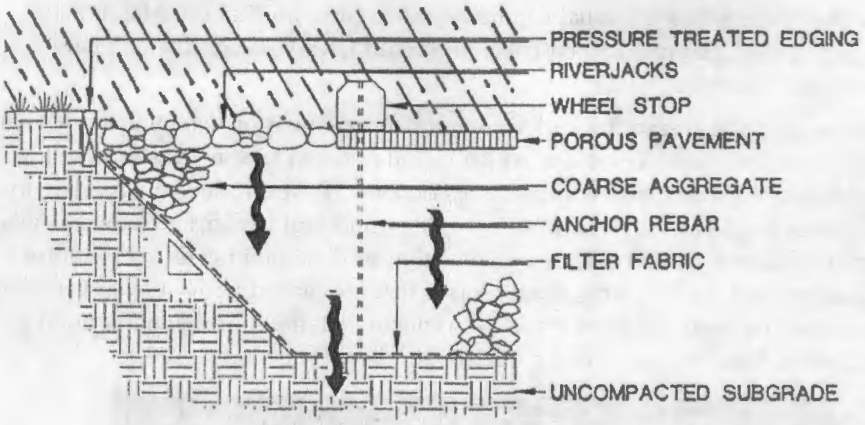

Figure 6.3.5 Unpaved section (river jacks) provides backup infiltration.
Graphic courtesy of Cahill Associates

- As with any paving system, rising water in the underlying aggregate base should not be allowed to saturate the pavement (Cahill et al., 2003). To ensure that the asphalt top course is not saturated from excessively high water levels in the aggregate base (as a result of subgrade soil clogging), a positive overflow can be installed.

For a sample specification for permeable asphalt paving see Appendix 8.

Cost

Materials and mixing costs for permeable asphalt are similar to conventional asphalt. In general, local contractors are currently not familiar with permeable asphalt installation, and additional costs for handling and installation should be anticipated. Estimates for porous pavement material and installation are approximately $.60 to .70/square foot and will likely be comparable to standard pavement as contractors become more familiar with the product. Due to the lack of experience regionally, this is a rough estimate. The cost for base aggregate will vary significantly depending on base depth for stormwater storage and is not included in the cost estimate.

2. Portland cement permeable concrete

Florida and Georgia use permeable concrete extensively for stormwater management. The material and installation specifications in Washington are derived primarily from the field experience and testing through the Florida Concrete and Products Association. In the Puget Sound region, the cities of Seattle and Olympia and Stoneway Concrete have tested materials and installed several projects including parking lots, sidewalks, and driveways.

Permeable Portland cement concrete is similar to conventional concrete without the fine aggregate (sand) component. The mixture is a washed coarse aggregate (3/8 or 5/8 inch), hydraulic cement, admixtures (optional) and water, yielding a surface with a matrix of pores that conducts water to the underlying aggregate base and soil. Permeable concrete can be used for light to medium duty applications including residential access roads, driveways, utility access, parking lots, and walkways. Permeable concrete can also be used in heavy load applications. For example, test sections in a city of Renton aggregate recycling yard have performed well

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structurally after being subjected to regular 50,000- to 100,000-pound vehicle loads for the past three years (personal communication, Greg McKinnon, March 2004). Properly installed and maintained concrete should have a service life comparable to conventional concrete.

Designing the aggregate base to accommodate retention or detention storage will depend on several factors, some of which include project specific stormwater flow control objectives, costs, and regulatory restrictions. However, deeper subgrade to base courses (e.g., 12 to 36 inches) can provide important benefits including significant reduction of above ground stormwater retention or detention needs and uniform subgrade support (FCPA, n.d.). Base courses that are placed above the surrounding grade cannot be used, or given credit for, reducing retention or detention pond sizes. (See Chapter 7 for flow modeling guidance and flow reduction credits.)



Figure 6.3.6 Permeable concrete adjacent to stamped concrete in Des Moines.
Photo by Curtis Hinman

Design and installation

Three general classes of permeable concrete are prevalent: (1) the standard mix using washed course aggregate (3/8 or 5/8 inch), hydraulic cement, admixtures (optional) and water; (2) a Stoneycrete mixture which is similar to the standard mix, but incorporates a strengthening additive; and (3) Percocrete which uses a higher percentage of sand, incorporates an additive to enhance strength and the pore structure, and produces a smoother surface texture. The following design section examines the standard concrete mix. Additional information for Stoneycrete is available at Stoney Creek Materials L.L.C. Austin, Texas and for Percocrete at Michiels International Inc., Kenmore, Washington.

Application: parking lots, driveways, sidewalks, utility access, and residential roads.

Soil infiltration rate

- If runoff is not directed to the permeable concrete from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have under-drains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading.

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However, it may be acceptable to direct flows after treatment to the subgrade if storage volume and infiltration rates allow.

Subgrade

- Soil conditions should be analyzed for load bearing given anticipated soil moisture conditions by a qualified engineer.
- After grading, the existing subgrade should not be compacted or subject to excessive construction equipment traffic (U.S. Army Corps of Engineers, 2003).
- Immediately before base aggregate and concrete placement, remove any accumulation of fine material from erosion with light equipment and scarify soils to a minimum depth of 6 inches if compacted (U.S. Army Corps of Engineers, 2003).

Aggregate base/storage bed

- Minimum base depth for structural support should be 6 inches (FCPA, n.d.).
- Maximum depth is determined by the extent to which the designer intends to achieve a flow control standard with the use of a below-grade storage bed. Aggregate base depths of 18 to 36 inches are common when designing for retention or detention.
- The coarse aggregate layer varies depending on structural and stormwater management needs. Typical placements include round or crushed washed drain rock (1 to 1.5 inches) or 1.5 to 2.5-inch crushed washed base rock aggregate (e.g., AASTHO No. 3).
- The concrete can be placed directly over the coarse aggregate or a choker course (e.g., 1.5 inch to US sieve size number 8, AASHTO No 57 crushed washed stone) can be placed over the larger stone for final grading.

Installation of aggregate base/storage bed

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- If using the aggregate base for retention in parking areas, excavate storage bed level to allow even distribution of water and maximize infiltration across entire parking area.
- Install approved non-woven filter fabric on subsoil according to manufacturer's specifications. Where concrete installations are adjacent to conventional paving surfaces the filter fabric should be wrapped up the sides and to the top of base aggregate to prevent migration of fines from the densely graded base to the open graded base material, maintain proper compaction, and avoid differential settling.
- Overlap adjacent strips of fabric at least 24 inches. Secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of storage reservoir.
- Install coarse aggregate in maximum of 8-inch lifts and lightly compact each lift (U.S. Army Corps of Engineers, 2003).
- If utilized, install a 1-inch choker course evenly over surface of coarse aggregate base (typically No. 57 AASHTO) and lightly compact.
- Following placement of base aggregate and again after placement of concrete, the filter fabric should be folded over placements to protect installation from sediment inputs. Excess filter fabric should not be trimmed until site is fully stabilized (U.S. Army Corps of Engineers, 2003).

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Top course

- Parking lots: 4 inches typical.
- Roads: 6 to 12 inches typical.
- Unit weight: 120 to 130 pounds per cubic foot (permeable concrete is approximately 70 to 80 percent of the unit weight of conventional concrete) (FCPA, n.d.).
- Void space: 15 to 21 percent according to ASTM C 138.
- Water cement ratio: 0.27 to 0.35.
- Aggregate to cement ratio: 4:1 to 4.5:1.
- Aggregate: several aggregate specifications are used including:
  - 3/8-inch to No. 16 washed crushed or round per ASTM C 33.
  - 3/8-inch to No. 50 washed crushed or round per ASTM D 448.
  - 5/8-inch washed crushed or round.
  - In general the 3/8-inch crushed or round produces a slightly smoother surface and is preferred for sidewalks, and the 5/8-inch crushed or round produces a slightly stronger surface.
- Portland cement: Type I or II conforming to ASTM C 150 or Type IP or IS conforming to ASTM C 595.
- Admixtures: Can be used to increase working time and include: Water Reducing/Retarding Admixture in conformance with ASTM C 494 Type D and Hydration stabilizer in conformance with ASTM C 494 Type B.
- Water: Use potable water.
- Fiber mesh can be incorporated into the cement mix for added strength.

Installation of top course

- See testing section below for confirming correct mixture and proper installation.
- If mixture contains excess water the cement paste can flow from the aggregate, resulting in a weak surface layer and reduced void space in the lower portion of surface. With the correct water content, the delivered mix should have a wet metallic sheen, and when hand squeezed the mix should not crumble or become a highly plastic mass (FCPA, n.d.).
- Cement mix should be used within 1 hour after water is introduced to mix, and within 90 minutes if an admixture is used and concrete mix temperature does not exceed 90 degrees Fahrenheit (U.S. Army Corps of Engineers, 2003).
- Base aggregate should be wetted to improve working time of cement.
- Concrete should be deposited as close to its final position as possible and directly from the truck or using a conveyor belt placement.
- A manual or mechanical screed can be used to level concrete at 1/2 inch above form.
- Cover surface with 6-mil plastic and use a static drum roller for final compaction (roller should provide approximately 10 pounds per square inch vertical force).
- Edges that are higher than adjacent materials should be finished or rounded off to prevent chipping (standard edging tool is applicable for pervious concrete).
- Cement should be covered with plastic within 20 minutes and remain covered for curing time.
- Curing: 7 days minimum for Portland cement Type I and II. No truck traffic should be allowed for 10 days (U.S. Army Corps of Engineers, 2003).

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- Placement widths should not exceed 15 feet unless contractor can demonstrate competence to install greater widths.
- High frequency vibrators can seal the surface of the concrete and should not be used.
- Jointing: Shrinkage associated with drying is significantly less for permeable than conventional concrete. Florida installations with no control joints have shown no visible shrink cracking. A conservative design can include control joints at 60 foot spacing cut to 1/4 the thickness of the pavement (FCPA, n.d. and U.S. Army Corps of Engineers, 2003). Expansion joints can also facilitate a cleaner break point if sections become damaged or are removed for utility work.

Testing

Differences in local materials, handling, and placement can affect permeable concrete performance. The following tests should be conducted even if the contractor or consultant has experience with the material to ensure proper performance.

- The contractor should place and cure two test panels, each covering a minimum of 225 square feet at the required project thickness, to demonstrate that specified unit weights and permeability can be achieved on-site (Georgia Concrete and Products Association [GCPA], 1997).
- Test panels should have two cores taken from each panel in accordance with ASTM C 42 at least 7 days after placement (GCPA, 1997).
- Untrimmed cores should be measured for thickness according to ASTM C 42.
- After determining thickness, cores should be trimmed and measured for unit weight per ASTM C 140.
- Void structure should be tested per ASTM C 138.
- If the measured thickness is greater than 1/4 inch less than the specified thickness, or the unit weight is not within ± 5 pounds per cubic foot, or the void structure is below specifications, the panel should be removed and new panels with adjusted specifications installed (U.S. Army Corps of Engineers, 2003). If test panel meets requirements, panel can be left in place as part of the completed installation.
- Collect and sample delivered material once per day to measure unit weight per ASTM C 172 and C 29 (FCPA, n.d.).

Backup systems for protecting permeable concrete systems

- For backup infiltration capacity (in case the concrete top course becomes clogged) an unpaved stone edge can be installed that is connected to the base aggregate storage reservoir (see Figure 6.3.5).
- As with any paving system, rising water in the underlying aggregate base should not be allowed to saturate the pavement (Cahill et al., 2003). To ensure that the top course is not saturated from excessively high water levels (as a result of subgrade soil clogging), a positive overflow can be installed in the base.

Cost

Permeable concrete material and installation is approximately $3.00 to $5.00 per square foot depending on surface thickness and site conditions. Cost for base aggregate will vary significantly depending on base depth for stormwater storage and is not included in the cost estimate.

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3. Eco-Stone permeable interlocking concrete pavers

Eco-Stone is a high-density concrete paver that allows infiltration through a built-in pattern of openings filled with aggregate. When compacted, the pavers interlock and transfer vertical loads to surrounding pavers by shear forces through fine aggregate in the joints (Pentec Environmental, 2000). Eco-Stone interlocking pavers are placed on open graded sub-base aggregate topped with a finer aggregate layer that provides a level and uniform bedding material. Properly installed and maintained, high-density pavers have high load bearing strength and are capable of carrying heavy vehicle weight at low speeds. Properly installed and maintained pavers should have a service life of 20 to 25 years (Smith, 2000).

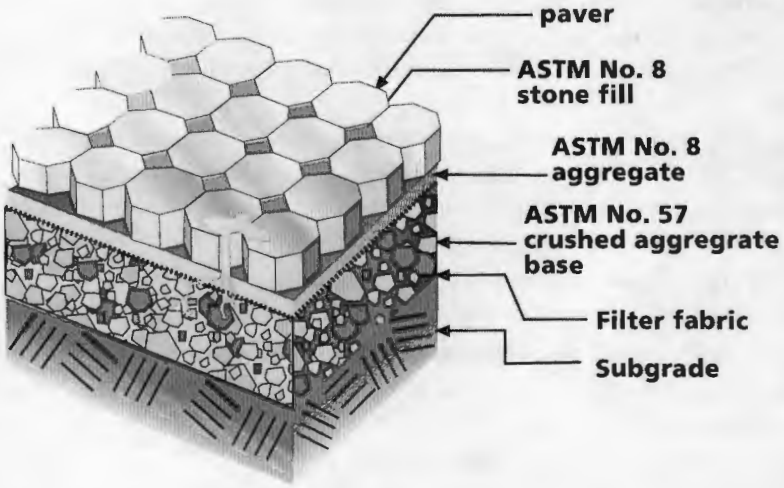

Figure 6.3.7 Permeable interlocking concrete paver section.
Graphic by Gary Anderson



Figure 6.3.8 Close-up view of permeable pavers.
Photo by Curtis Hinman

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Design

Application: Industrial and commercial parking lots, utility access, residential access roads, driveways, and walkways. Experienced contractors with a current certificate in the ICPI Contractor Certification Program should perform installations.

Soil infiltration rate

- If runoff is not directed to the permeable pavers from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.5 inch/hour. Soils with lower infiltration rates should have under-drains at the bottom of the base course to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section. Drain-down time for the base should not exceed 24 hours.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading. However, it may be acceptable to direct flows after treatment to the subgrade if storage volume and infiltration rates allow.

Subgrade

- Soils should be analyzed by a qualified engineer for infiltration rates and load bearing, given anticipated soil moisture conditions. **California Bearing Ratio** values should be at least 5 percent.
- For vehicle traffic areas, grade and compact to 95 percent modified proctor density (per ASTM D 1557) and compact to 95 percent standard proctor density for pedestrian areas (per ASTM D698) (Smith, 2000). Soils with high sand and gravel content can retain useful infiltration rates when compacted; however, many soils in the Puget Sound region become essentially impermeable at this compaction rate. For detention designs on compacted soils that will provide very low permeability, adequate base aggregate depths and under-drain systems should be incorporated to reduce risk of continued saturation that can weaken subgrades subject to vehicle traffic (Smith, 2000).

Aggregate base/storage bed

- Minimum base thickness depends on vehicle loads, soil type, stormwater storage requirements, and freeze thaw conditions. Typical depths range from 6 to 22 inches; however, increased depths can be applied for increased storage capacity (Smith, 2000). Interlocking Concrete Paver Institute guidelines for base thickness should be followed.
- Minimum base depth for pedestrian and bike applications should be 6 inches (Smith, 2000).
- ASTM No. 57 crushed aggregate or similar gradation is recommended for the sub-base (Smith, 2000).
- ASTM No. 8 is recommended for the leveling or choker course.

Installation of aggregate base/storage bed

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- If using the base course for retention in parking areas, excavate storage bed level to allow even distribution of water and maximize infiltration across entire parking area.

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- Install approved non-woven filter fabric to bottom and sides of excavation according to manufacturer's specifications. Where paver installation is adjacent to conventional paving surfaces, filter fabric should be wrapped up sides to top of base aggregate to prevent migration of fines from densely graded base to the open graded base material, maintain proper compaction, and avoid differential settling. A concrete curb the depth of the base can also be used to separate the open graded and dense graded bases.
- Overlap adjacent strips of fabric at least 24 inches. Secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of area storage reservoir (Smith, 2000).
- Install No. 57 aggregate in 4 to 6-inch lifts.
- Compact the moist No. 57 aggregate with at least 4 passes of a 10-ton (minimum) steel drum roller. Initial passes can be with vibration and the final two passes should be static (Smith, 2000). Testing for appropriate density per ASTM D 698 or D 1557 will likely not provide accurate results. The Interlocking Concrete Pavement Institute specification recommends that adequate density and stability are developed when no visible movement is observed in the open-graded base after compaction (personal communication, Dave Smith ICPI).
- Install three inches of No. 8 aggregate for the leveling or choker course and compact with at least 4 passes of a 10-ton roller. Surface variation should be within ± 1/2 inch over 10 feet. The No. 8 aggregate should be moist to facilitate compaction into the sub-base (Smith, 2000).
- Asphalt stabilizer can be used with the No. 57 stone if additional bearing support is needed, but should not be applied to the No. 8 aggregate. To maintain adequate void space, use a minimum of asphalt for stabilization (approximately 2 to 2.5 percent by weight of aggregate). An asphalt grade of AC20 or higher is recommended. The addition of stabilizer will reduce storage capacity of base aggregate and should be considered in the design (Smith, 2000).
- Following placement of base aggregate and again after placement of pavers, the filter fabric should be folded over placements to protect installation from sediment inputs. Excess filter fabric should not be trimmed until site is fully stabilized.
- Designs for full infiltration of stormwater to the subgrade should have a positive overflow to prevent water from entering the surface layer during extreme events. Designs with partial or no **exfiltration** require under-drains. All installations should have an observation well (typically 6-inch perforated pipe) installed at the furthest downslope area (Smith, 2000).

Top course installation

- Pavers should be installed immediately after base preparation to minimize introduction of sediment and to reduce the displacement of base material from ongoing activity (Smith, 2000).
- Loosen and evenly smooth 3/4 to 1 inch of the compacted No. 8 stone.
- Place pavers by hand or with mechanical installers and compact with a 5000 lbf, 75 to 90 Hz plate compactor. Fill openings with No. 8 stone and compact again. Sweep to remove excess stone from surface. The small amount of finer aggregate in the No. 8 stone will likely be adequate to fill narrow joints between pavers in pedestrian and light vehicle applications. If the installation is subject

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to heavy vehicle loads, additional material may be required for joints. Sweep in additional material (ASTM No. 89 stone is recommended) and use vibratory compaction to place joint material (Smith, 2000).



Figure 6.3.9 Mechanical installation of Eco-Stone pavers.
Photo by Curtis Hinman

- Do not compact within 3 feet of unrestrained edges (Pentec Environmental, 2000).
- Sand placed in paver openings or used as a leveling course will clog and should not be applied for those purposes.
- Cast-in-place or pre-cast concrete (approximately 6 inches wide by 12 inches high) are the preferred material for edge constraints. Plastic edge confinement secured with spikes is not recommended (Smith, 2000).

Cost

Eco-Stone material and installation costs range from $2.50 to $4.50 per square foot for the pavers, aggregate leveling layer, aggregate for the paver openings and joints, and installation. Costs for base aggregate will vary significantly depending on stormwater storage needs. Base material and installation, geotextile, excavation, and sediment controls are not included in this price estimate. Large jobs (e.g., 150,000 square feet) utilizing mechanical placement of pavers would qualify for the lower end of the cost range and smaller jobs (e.g., 40,000 square feet) with mechanical installation would likely be at the higher end of the cost range (personal communication, Brian Crooks and Dave Parisi, July 2004).

4. Gravelpave2 flexible plastic grid system

Gravelpave2 is a lightweight grid of plastic rings in 20" wide x 20" long x 1" high units with a geotextile fabric heat fused to the bottom of the grid. The grid and fabric is provided in pre-assembled rolls of various dimensions (Invisible Structures, 2003). This and other similar plastic grid systems have a large amount of open cell available for infiltration in relation to the solid support structure. Flexible grid systems conform to the grade of the aggregate base, and when backfilled with appropriate aggregate top course, provide high load bearing capability (Gravelpave2 load capacity is approximately 5700 psi) (Invisible Structures, 2003). Gravelpave2 is not impacted by the degree of freeze-thaw conditions found in the Puget Sound region. Properly installed and maintained, Gravelpave2 has an expected service life of approximately 20 years (Bohnhoff, 2001).

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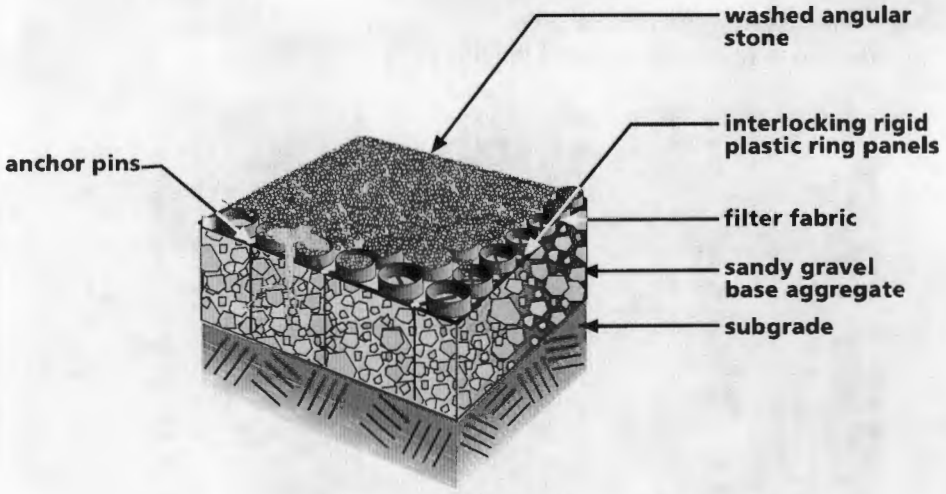

Figure 6.3.10 Gravelpave2 system.
Graphic by Gary Anderson

Design

Application: Typical uses include alleys, driveways, utility access, loading areas, trails, and parking lots with relatively low traffic speeds (15 to 20 mph maximum). Higher speeds may require use of a binder at 10 percent cement by weight with fill stone (Bohnhoff, 2001).

Soil infiltration rate

- If runoff is not directed to the Gravelpave system from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.5 inch/hour. Soils with lower infiltration rates should have under-drains in the base course to prevent prolonged saturated soil conditions within the top course section.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading. However, it may be acceptable to direct flows after treatment to the subgrade if storage volume and infiltration rates allow.

Subgrade

- Soil conditions should be analyzed for load bearing given anticipated soil moisture conditions by a qualified engineer.
- After grading, the existing subgrade should not be compacted or subject to excessive construction equipment traffic.
- Immediately before base aggregate and top course, remove any accumulation of fine material from erosion with light equipment.

Aggregate base/storage bed

- Minimum base thickness depends on vehicle loads, soil type, and stormwater storage requirements. Typical minimum depth is 4 to 6 inches for driveways, alleys, and parking lots (less base course depth is required for trails) (personal communication, Andy Gersen, July 2004). Increased depths can be applied for increased storage capacity.

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- Base aggregate is a sandy gravel material typical for road base construction (Invisible Structures, 2003).

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	3/4	100
	3/8	85
	4	60
	8	15
	40	30
	200	<3

Base course installation

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- If using the base course for retention in parking areas, excavate storage bed level to allow even distribution of water and maximize infiltration across entire parking area.
- Install approved non-woven filter fabric to bottom and sides of excavation according to manufacturer's specifications. Where the installation is adjacent to conventional paving surfaces, the filter fabric should be wrapped up the sides and to the top of base aggregate to prevent migration of fines from the densely graded base to the open graded base aggregate, maintain proper compaction, and avoid differential settling.
- Overlap adjacent strips of fabric at least 24 inches. Secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of area storage reservoir.
- Install aggregate in 6-inch lifts maximum.
- Compact each lift to 95 percent modified proctor.

Top course aggregate

Aggregate should be clean, washed angular stone with a granite hardness.

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	4	100
	8	80
	16	50
	30	30
	50	15
	100	5

Top course installation

- Grid should be installed immediately after base preparation to minimize introduction of sediment and to reduce the displacement of base material from ongoing activity.
- Place grid with rings up and interlock male/female connectors along unit edges.
- Install anchors at an average rate of 6 pins per square meter. Higher speed and transition areas (for example where vehicles enter a parking lot with a plastic grid system from an asphalt road) or where heavy vehicles execute tight turns will require additional anchors (double application of pins).
- Aggregate should be back dumped to a minimum depth of 6 inches so that delivery vehicle exits over aggregate. Sharp turning on rings should be avoided.

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- Spread gravel using power brooms, flat bottom shovels or wide asphalt rakes. A stiff bristle broom can be used for finishing.
- If necessary, aggregate can be compacted with a plate compactor to a level no less than the top of the rings or no more than 0.25 inch above the top of the rings (Invisible Structures, 2003).
- Provide edge constraints along edges that may have vehicle loads (particularly tight radius turning). Cast-in-place or pre-cast concrete edging is preferred.

6.3.3 Maintenance

The following provides maintenance recommendations applicable to all permeable paving surfaces.

- Erosion and introduction of sediment from surrounding land uses should be strictly controlled after construction by amending exposed soil with compost and mulch, planting exposed areas as soon as possible, and armoring outfall areas.
- Surrounding landscaped areas should be inspected regularly and possible sediment sources controlled immediately.
- Clean permeable paving surfaces to maintain infiltration capacity once or twice annually following maintenance recommendations under each paving type.
- Utility cuts should be backfilled with the same aggregate base used under the permeable paving to allow continued conveyance of stormwater through the base, and to prevent migration of fines from the standard base aggregate to the more open graded permeable base material (Diniz, 1980).

The following provides maintenance recommendations for specific permeable paving surfaces.

- Permeable asphalt and concrete
  - Clean surfaces using suction, sweeping with suction or high-pressure wash and suction (sweeping alone is minimally effective). Street cleaning equipment using high-pressure wash with suction provides the best results on asphalt and concrete for improving infiltration rates. However, there are currently no high-pressure wash and suction machines for cleaning pavement in the U.S. The city of Olympia will be importing the first machine of this type and expects delivery early 2005 (personal communication, Mark Blosser, July 2004). Hand held pressure washers are effective for cleaning void spaces and appropriate for smaller areas such as sidewalks.
  - Small utility cuts can be repaired with conventional asphalt or concrete if small batches of permeable material are not available or are too expensive.
- Eco-Stone permeable pavers
  - Washing should not be used to remove debris and sediment in the openings between the pavers. Sweeping with suction can be applied to paver openings when surface and debris are dry. Vacuum settings may have to be adjusted to prevent excess uptake of aggregate from paver openings or joints (Smith, 2000).
  - Pavers can be removed individually and replaced when utility work is complete.
  - Replace broken pavers as necessary to prevent structural instability in the surface.

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- The structure of the top edge of the paver blocks reduces chipping from snowplows. For additional protection, skids on the corner of plow blades are recommended.

- Gravelpave2
  - Remove and replace top course aggregate if clogged with sediment or contaminated (vacuum trucks for stormwater collection basins can be used to remove aggregate).
  - Remove and replace grid segments where three or more adjacent rings are broken or damaged.
  - Replenish aggregate material in grid as needed.
  - Snowplows should use skids to elevate blades slightly above the gravel surface to prevent loss of top course aggregate and damage to plastic grid.

6.3.4 Limitations

Permeable paving materials are not recommended where:

- Excessive sediment is deposited on the surface (e.g., construction and landscaping material yards).
- Steep erosion prone areas that are likely to deliver sediment and clog pavement are upslope of the permeable surface.
- Concentrated pollutant spills are possible such as gas stations, truck stops, and industrial chemical storage sites.
- Seasonally high groundwater creates prolonged saturated conditions at or near ground surface and within the pavement section.
- Fill soils can become unstable when saturated.
- Maintenance is unlikely to be performed at appropriate intervals.
- Sealing of surface from sealant application or other uncontrolled use is likely. Residential driveways can be particularly challenging and clear, enforceable guidelines, education, and backup systems should be part of the stormwater management plan for a residential area utilizing permeable paving for driveways.
- Regular, heavy application of sand is used for maintaining traction during winter.
- Permeable paving should not be placed over solid rock without an adequate layer of aggregate base.

Slope restrictions result primarily from flow control concerns and to a lesser degree structural limitations of the permeable paving. Excessive gradient increases surface and subsurface flow velocities and reduces storage and infiltration capacity of the pavement system. Baffle systems placed on the subgrade can be used to detain subsurface flow and increase infiltration (personal communication, Tracy Tackett). See Chapter 7 for the flow control credit associated with permeable paving and subgrade baffles.

- Permeable asphalt is not recommended for slopes exceeding 5 percent.
- Permeable concrete is not recommended on slopes exceeding 6 percent.
- Eco-Stone is not recommended for slopes exceeding 10 percent.
- Gravelpave2 is not recommended for slopes exceeding 6 percent (primarily a traction rather than infiltration or structural limitation).

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6.3.5 Permeable Paving Performance

Infiltration

Initial research indicates that properly designed and maintained permeable pavements can virtually eliminate surface flows for low intensity storms common in the Pacific Northwest, store or significantly attenuate subsurface flows (dependent on underlying soil and aggregate storage design), and provide water quality treatment for nutrients, metals, and hydrocarbons. A six-year University of Washington permeable pavement demonstration project found that nearly all water infiltrated various test surfaces (included Eco-Stone, Gravelpave, and others) for all observed storms (Brattebo and Booth, 2003). Observed infiltration was high despite minimal maintenance conducted. See Figure 6.3.11 for infiltration plotted with precipitation for one of the permeable paving test surfaces (turfstone).

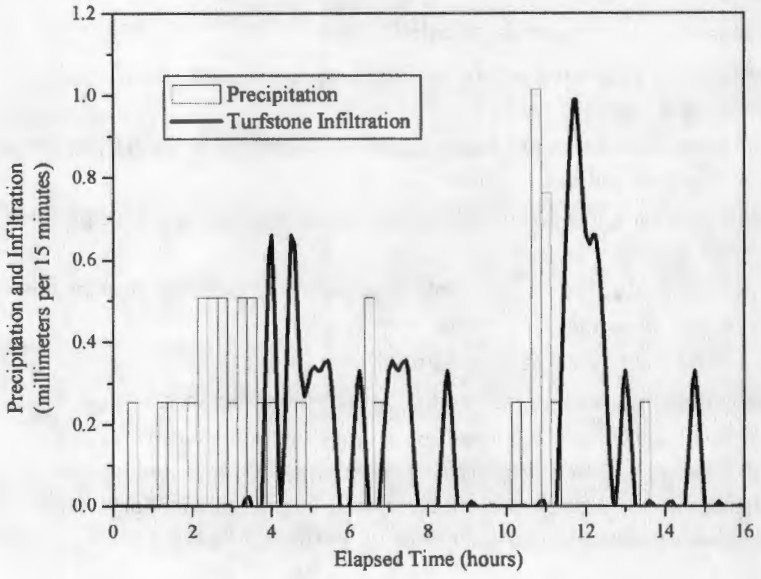

Figure 6.3.11 Infiltration plotted with precipitation at a test permeable pavement parking stall in the city of Renton. Note that essentially all precipitation infiltrates.
Source: Brattebo and Booth, 2003

Initial infiltration rates for properly installed permeable pavement systems are high. Infiltration rates for in-service surfaces decline to varying degrees depending on numerous factors, including initial design and installation, sediment loads, and maintenance. Ranges of new and in-service infiltration rates for research cited in the Appendix 7: Porous Paving Research are summarized below. To provide context for the infiltration rates below, typical rainfall rates are approximately 0.05 inch/hour in the Puget Sound region with brief downpours of 1 to 2 inches/hour.

Porous asphalt:
- highest initial rate (new installation): 1750 in/hr
- lowest initial rate (new installation): 28 in/hr
- highest in-service rate: 1750 in/hr (1 year of service, no maintenance)
- lowest in-service rate: 13 in/hr (3 years of service no maintenance)

Pervious concrete:
- highest initial rate: 1438.20 in/hr
- lowest in-service rate: 240 in/hr (6.5 years of service, no maintenance)
- Note: City of Olympia has observed (anecdotal) evidence of lower infiltration rates on a sidewalk application; however, no monitoring data have been collected to quantify observations (personal communication Mark Blosser, August 2004).

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Pervious pavers:
highest initial infiltration rate (new installation): none reported
lowest initial rate (new installation): none reported
highest in-service rate: 2000 in/hr
lowest in-service rate: 0.58 in/hr

Clogging from fine sediment is a primary mechanism that degrades infiltration rates. However, the design of the porous surface (i.e., percent fines, type of aggregate, compaction, asphalt density, etc.) is critical for determining infiltration rates and performance over time as well.

Various levels of clogging are inevitable depending on design, installation, and maintenance and should be accounted for in the long-term design objectives. Studies reviewed in the Porous Paving Research (see Appendix 7) and a review conducted by St. John (1997) indicate that a 50 percent infiltration rate reduction is typical for permeable pavements.

European research examining several permeable paver field sites estimates a long-term design rate at 4.25 inches per hour (Borgwardt, 1994). David Smith from Interlocking Concrete Pavement Institute, however, recommends using a conservative 1.1-inch per hour infiltration rate for the base course (surface intake can be higher) for the typical 20-year life span of permeable paver installations (Smith, 2000).

The lowest infiltration rate reported for an in-service permeable paving surface that was properly installed was approximately 0.58 inches/hour (Uni Eco-Stone parking installation).

Results from the three field studies evaluating cleaning strategies indicate that infiltration rates can be restored. Pervious paver research in Ontario, Canada indicates that infiltration rates can be maintained for Eco-Stone with suction equipment (see Appendix 7: Porous Paving Research). Standard street cleaning equipment with suction may need to be adjusted to prevent excessive uptake of aggregate in paver cells (Gerrits and James, 2001). Washing should not be used to remove debris and sediment in the openings between pavers. Suction should be applied to paver openings when surface and debris are dry.

Street cleaning equipment with sweeping and suction perform adequately on moderately degraded porous asphalt while high pressure washing with suction provides the best performance on highly degraded asphalt (Dierkes, Kuhlmann, Kandasamy and Angelis, 2002 and Balades, Legret and Madiec, 1995). Sweeping alone does not improve infiltration on porous asphalt.

Water Quality

Research indicates that the pollutant removal capability of permeable paving systems is very good for constituents examined. Laboratory evaluation of aggregate base material in Germany found removal capability of 89 to 98 percent for lead, 74 to 98 percent for cadmium, 89 to 96 percent for copper, and 72 to 98 percent for zinc (variability in removal rates depended on type of stone). The same study excavated a 15-year old permeable paver installation in a commercial parking lot and found no significant concentrations of heavy metals, no detection of PAHs, and elevated, but still low concentrations of mineral oil in the underlying soil (Dierkes et al., 2002).

Pratt, Newman and Bond recorded a 97.6 percent removal of automobile mineral oil in a 780 mm (approximately 31-inch) deep permeable paver section in England. Removal was attributed largely to biological breakdown by microbial activity within the pavement section, as well as adhesion to paving materials (Pratt, Newman and Bond, 1999).

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A study in Connecticut compared driveways constructed from conventional asphalt and permeable pavers (UNI group Eco-Stone) for runoff depth (precipitation measured on-site), infiltration rates, and pollutant concentrations. The Eco-Stone driveways were two years old. During 2002 and 2003, mean weekly runoff depth recorded for asphalt was 1.8 mm compared to 0.5mm for the pavers. Table 6.3.1 summarizes pollutant concentrations from the study (Clausen and Gilbert, 2003).

Table 6.3.1 Mean weekly pollutant concentration in stormwater runoff, Jordan Cove, CT.

Variable	Asphalt	Paver
TSS	47.8 mg/L	15.8 mg/L
NO_3-N	0.6 mg/L	0.2 mg/L
NH_3-N	0.18 mg/L	0.05 mg/L
TP	0.244 mg/L	0.162 mg/L
Cu	18 ug/L	6 ug/L
Pb	6 ug/L	2 ug/L
Zn	87 ug/L	25 ug/L

(Adapted from Clausen and Gilbert, 2003)

In the Puget Sound region, a six-year permeable parking lot demonstration project conducted by the University of Washington found toxic concentrations of copper and zinc in 97 percent of the surface runoff samples from an asphalt control parking stall. In contrast, copper and zinc in 31 of 36 samples from the permeable parking stall–that produced primarily subsurface flow–fell below toxic levels and a majority of samples fell below detectable levels. Motor oil was detected in 89 percent of the samples from the surface flow off the asphalt stall. No motor oil was detected in any samples that infiltrated through the permeable paving sections. (Brattebo and Booth, 2003).

6.4 Vegetated Roofs

Vegetated roofs (also known as green roofs and eco-roofs) fall into two categories: intensive and extensive. Intensive roofs are designed with a relatively deep soil profile (6 inches and deeper) and are often planted with ground covers, shrubs, and trees. Intensive green roofs may be accessible to the public for walking or serve as a major landscaping element of the urban setting. Extensive vegetated roofs are designed with shallow, light-weight soil profiles (1 to 5 inches) and ground cover plants adapted to the harsh conditions of the roof top environment. This discussion focuses on the extensive design.

Vegetated roofs improve energy efficiency and air quality, reduce temperatures and noise in urban areas, improve aesthetics, extend the life of the roof, and reduce stormwater flows.

Extensive green roofs offer a number of benefits in the urban landscape including: increased energy efficiency, improved air quality, reduced temperatures in urban areas, noise reduction, improved aesthetics, extended life of the roof, and central to this discussion, improved stormwater management (Grant, Engleback and Nicholson, 2003).

Companies specializing in vegetated roof installations emerged in Germany and Switzerland in the late 1950s, and by the 1970s extensive green roof applications were common in those countries. In 2003, 13.5 million square meters of green roofs were installed in Germany (Grant et al., 2003; Peck, Callaghan, Kuhn and Bass, 1999; and Peck, Kuhn and Arch, n.d.). While roof gardens are not as prevalent in the U.S., designers in North America are discovering the value of the technology and green

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roofs are becoming more common with installations on large buildings and individual residences in Portland, Philadelphia, Chicago, Seattle, and other cities.



Figure 6.4.1 Vegetated roof on the Multnomah County building in Portland, Oregon.
Photo by Erica Guttman

6.4.1 Applications

Initial vegetated roof installations in the 1970s were prone to leaking. New technologies and installation techniques have improved and essentially eliminated past problems. Green roofs can be installed on almost any building with slopes up to 40 degrees and are effective strategies for managing stormwater in highly urbanized settings where rooftops comprise a large percentage of the total impervious surface (Scholtz-Barth, 2001).

6.4.2 Design

Native soils are heavy and would exert unnecessarily heavy loads for an extensive green roof installation, particularly when wet. Extensive roofs utilize light-weight soil mixes to reduce loads. Installations often range from 1 to 6 inches in depth and research from Germany indicates that, in general, a 3-inch soil depth offers the best environmental and aesthetic benefit to cost ratio (Miller, 2002).

While roof gardens can be installed on slopes up to 40 degrees, slopes between 5 and 20 degrees (1:12 and 5:12) are most suitable, and can provide natural drainage by gravity (depending on design, sloped roofs may also require a drainage layer). Flat roofs require a drainage layer to move water away from the root zone and the waterproof membrane. Roofs with slopes greater than 20 degrees require a lath grid to hold the soil substrate and drainage aggregate in place (Scholtz-Barth, 2001).

Vegetated roofs are comprised of four basic components: waterproofing membrane, drainage layer, growth medium, and vegetation. (See Figure 6.4.2 for a typical cross-section of a green roof.)

Waterproof membranes are made from PVC, Hypolan, rubber (EPDM) or polyolifins. Sixty to 80-mil reinforced PVC with heat sealed seams provides a highly durable and waterproof membrane. EPDM seams must be glued and may be more susceptible to leakage. Thermoplastic polyolifins are currently not well tested in the U.S., and U.S. manufacturers use bromides in the manufacturing process as a fire

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retardant which may interfere with long-term performance. Asphalt-based roofing material should be covered with high-density polyethylene membrane to prevent roots and other organisms from utilizing the organic asphalt as an energy source (Scholtz-Barth, 2001). Some membranes are not compatible with asphalt-based or other roofing materials. Follow manufacturer's recommendations for material compatibility.

The *drain layer* consists of either aggregate and/or a manufactured material that provides channels designed to transmit water at a specific rate. This layer can include a separation fabric, which with the drainage layer, reduces moisture contact with the waterproof membrane and provides additional protection from root penetration (Peck et al., n.d.).

The light-weight growth medium is designed to support plants and infiltrate and store water at a specific rate. The growth medium typically has a high mineral to organic material content and can be a mixture of various components including: gravel, sand, crushed brick, pumice, perlite, encapsulated Styrofoam, compost, and soil (Peck et al., n.d.). Saturated loads of 15 to 50 pounds/square foot are typical for extensive roofs with 1- to 5-inch soil depths (Scholtz-Barth, 2001). Currently, vegetated roofs weighing 15 pounds/square foot (comparable to typical gravel ballast roofs) have been installed and are functioning in the U.S. At 15 to 50 pounds, many roofs can be retrofitted with no or minimal reinforcement. Separating the growth medium from the building perimeter and roof penetrations with a non-combustible material (e.g., gravel) can provide increased protection against spread of fire, easier access to flashing and membrane connections, and additional protection from root penetration (Peck et al., n.d.).

Vegetation is typically succulents, grass, herbs, and/or wildflowers adapted to harsh conditions (minimal soils, seasonal drought, high winds, and strong sun exposure–i.e., alpine conditions) prevalent on rooftops. Plants should be adapted or native to the installation area. Some examples of species include: sempervivum, sedum, creeping thyme, allium, phloxes, and anntenaria. (Scholtz-Barth, 2001). Plants can be installed as vegetated mats, individual plugs, spread as cuttings, or by seeding. Vegetated mats and plugs provide the most rapid establishment for sedums. Cuttings spread over the substrate are slower to establish and will likely have a high mortality rate; however, this is a good method for increasing plant coverage on a roof that is in the process of establishing a plant community (Scholtz-Barth, 2001). During the plant establishment period soil erosion can be reduced by using a biodegradable mesh blanket.

A bonus for eco-roofs

The city of Portland encourages the application of eco-roofs in the central city to reduce stormwater runoff. Buildings using eco-roofs can earn bonus floor area (exceeding maximum floor area ratios) depending on the extent of coverage. For example, if the total area of the eco-roof is at least 60 percent of the building's footprint, each square foot of eco-roof earns three square feet of additional floor area.

Flow modeling guidance

See Chapter 7 for flow modeling guidelines for vegetated roofs when using WWHM.

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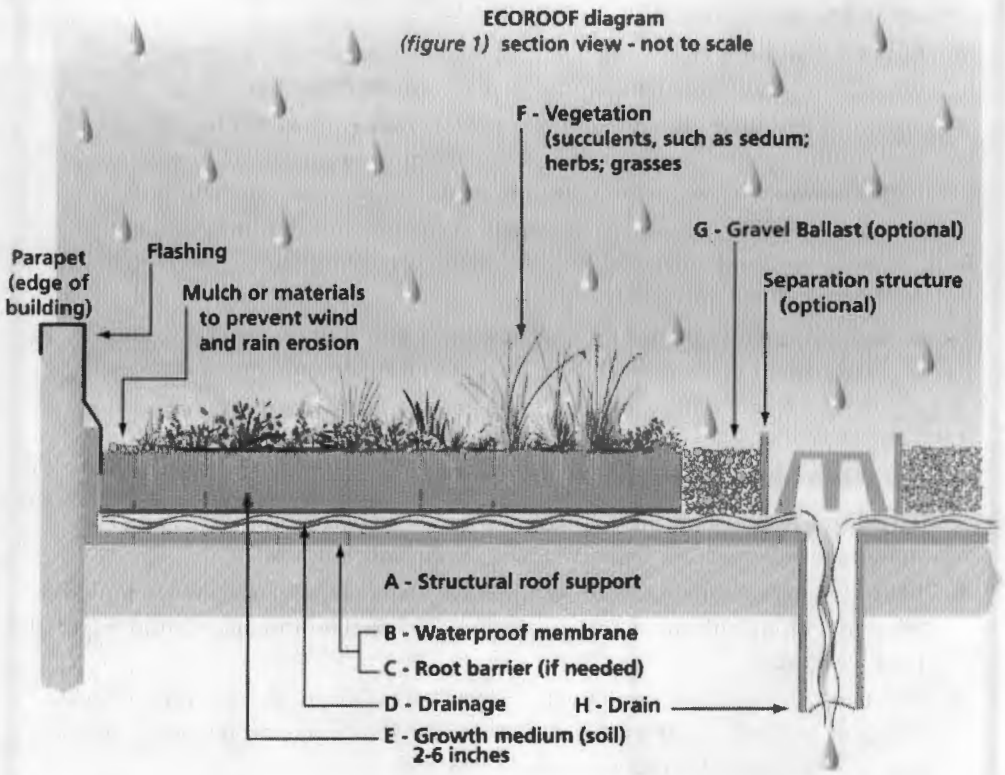

Figure 6.4.2 Cross section of vegetated roof garden. © *Environmental Services, Portland, Oregon*

For a sample vegetated roof specification, see Appendix 9.

6.4.3 Maintenance

Proper maintenance and operation are essential to ensure that designed performance and benefits continue over the full life cycle of the installation. Each roof garden installation will have specific design, operation, and maintenance guidelines provided by the manufacturer and installer. The following guidelines provide a general set of standards for prolonged roof garden performance. Note that some maintenance recommendations are different for extensive versus intensive roof gardens. The procedures outlined below are focused on extensive roof systems and different procedures for intensive roof recommendations are noted.

Schedule

- All facility components, including structural components, waterproofing, drainage layers, soil substrate, vegetation, and drains should be inspected for proper operation throughout the life of the roof garden.
- The property owner should provide the maintenance and operation plan, and inspection schedule.
- All elements should be inspected twice annually for extensive installations and four times annually for intensive installations.
- The facility owner should keep a maintenance log recording inspection dates, observations, and activities.
- Inspections should be scheduled to coincide with maintenance operations and with important horticultural cycles (e.g., prior to major weed varieties dispersing seeds).

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Structural and drainage components

- Structural and drainage components should be maintained according to manufacturer's requirements and accepted engineering practices.
- Drain inlets should provide unrestricted stormwater flow from the drainage layer to the roof drain system unless the assembly is specifically designed to impound water as part of an irrigation or stormwater management program:
  - o Clear the inlet pipe of soil substrate, vegetation or other debris that may obstruct free drainage of the pipe. Sources of sediment or debris should be identified and corrected.
  - o Inspect drain pipe inlet for cracks, settling and proper alignment, and correct and re-compact soils or fill material surrounding pipe if necessary.
- If part of the roof design, inspect fire ventilation points for proper operation.

Vegetation Management

- The vegetation management program should establish and maintain a minimum of 90 percent plant coverage on the soil substrate.
- During regularly scheduled inspections and maintenance, bare areas should be filled in with manufacturer recommended plant species to maintain the required plant coverage.
- Normally, dead plant material will be recycled on the roof; however specific plants or aesthetic considerations may warrant removing and replacing dead material (see manufacturer's recommendations).
- Invasive or nuisance plants should be removed regularly and not allowed to accumulate and exclude planted species. At a minimum, schedule weeding with inspections to coincide with important horticultural cycles (e.g., prior to major weed varieties dispersing seeds).
- Weeding should be done manually and without herbicide applications.
- Extensive roof gardens should be designed to not require fertilization after plant establishment. If fertilization is necessary during plant establishment or for plant health and survivability after establishment, use an encapsulated, slow release fertilizer (excessive fertilization can contribute to increased nutrient loads in the stormwater system and receiving waters).
- Intensive green roofs installations require fertilization. Follow manufacturer and installer recommendations.
- Avoid application of mulch on extensive roof gardens. Mulch should be used only in unusual situations and according to the roof garden provider guidelines. In conventional landscaping mulch enhances moisture retention; however, moisture control on a vegetated roof should be through proper soil/growth media design. Mulch will also increase establishment of weeds.

Irrigation

- Surface irrigation systems on extensive roof gardens can promote weed establishment and root development near the drier surface layer of the soil substrate, and increase plant dependence on irrigation. Accordingly, subsurface irrigation methods are preferred. If surface irrigation is the only method available, use drip irrigation to deliver water to the base of the plant.
- Extensive roof gardens should be watered only when absolutely necessary for plant survival. When watering is necessary (i.e., during early plant

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establishment and drought periods), saturate to the base of the soil substrate (typically 30 to 50 gallons per 100 square feet) and allow the soil to dry completely.

Operation and Maintenance Agreements

- Written guidance and/or training for operating and maintaining roof gardens should be provided along with the operation and maintenance agreement to all property owners and tenants.

Contaminants

- Measures should be taken to prevent the possible release of pollutants to the roof garden from mechanical systems or maintenance activities on mechanical systems.
- Any cause of pollutant release should be corrected as soon as identified and the pollutant removed.

Insects

- Roof garden design should provide drainage rates that do not allow pooling of water for periods that promote insect larvae development. If standing water is present for extended periods, correct drainage problem.
- Chemical sprays should not be used.

Access and Safety

- Egress and ingress routes should be clear of obstructions and maintained to design standards.

(City of Portland, 2002 and personal communication, Charlie Miller, February 2004)

6.4.4 Cost

Costs for vegetated roofs can vary significantly due to several factors including size of installation, complexity of system, growth media depth, and engineering requirements. Costs for new construction including structural support range from $10 to $15 per square foot. Retrofit costs range from $15 to $25 per square foot (Portland Bureau of Environmental Services, 2002). While initial installation costs are higher than for conventional roof systems, they are competitive on a full life cycle basis. Vegetated roofs increase the energy efficiency of a building and significantly reduce associated cooling and heating costs. European evidence indicates that a correctly installed green roof can last twice as long as a conventional roof, thereby deferring maintenance and replacement costs (Peck et al., n.d.). The above costs do not include savings on conventional stormwater management infrastructure as a result of reduced flows from a green roof or reduced stormwater utility fees.

6.4.5 Performance

Vegetated roof designs require careful attention to the interaction between the different components of the system. **Saturated hydraulic conductivity**, porosity and moisture retention of the growth media, and **transmissivity** of the drainage layer strongly influence hydrologic performance and reliability of the design (Miller and Pyke, 1999).

Research in Europe, in climates similar to the northeastern U.S., has consistently indicated that roof gardens can reduce up to 50 percent of the annual rooftop

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European research, in climates similar to the northeastern U.S., has consistently indicated that roof gardens can reduce up to 50 percent of the annual rooftop stormwater runoff.

stormwater runoff (Miller and Pyke, 1999). During a 9-month pilot test in eastern Pennsylvania, 14 and 28 square foot trays with test vegetated roof sections received a total of 44 inches of precipitation and generated 15.5 inches of runoff (runoff was negligible for storm events producing less than 0.6 inches of rainfall). The pilot section was 2.74 inches thick, including the drainage layer (USEPA, 2000b).

In Portland Oregon, a 4- to 4.5-inch eco-roof retained 69 percent of the total rainfall during a 15-month monitoring period. In the first January-to-March period (2002), rainfall retention was 20 percent and during the January-to-March (2003) period retention increased to 59 percent. The most important factors likely influencing the different retention rates are vegetation and substrate maturity, and rainfall distribution. The 2002 period was a more even rainfall distribution and the 2003 period more varied with longer dry periods between storms (Hutchison, Abrams, Retzlaff and Liptan, 2003). This supports observations by other researchers that vegetated roofs are likely more effective for controlling brief (including relatively intense) events compared to long-duration storms (Miller, 2002).

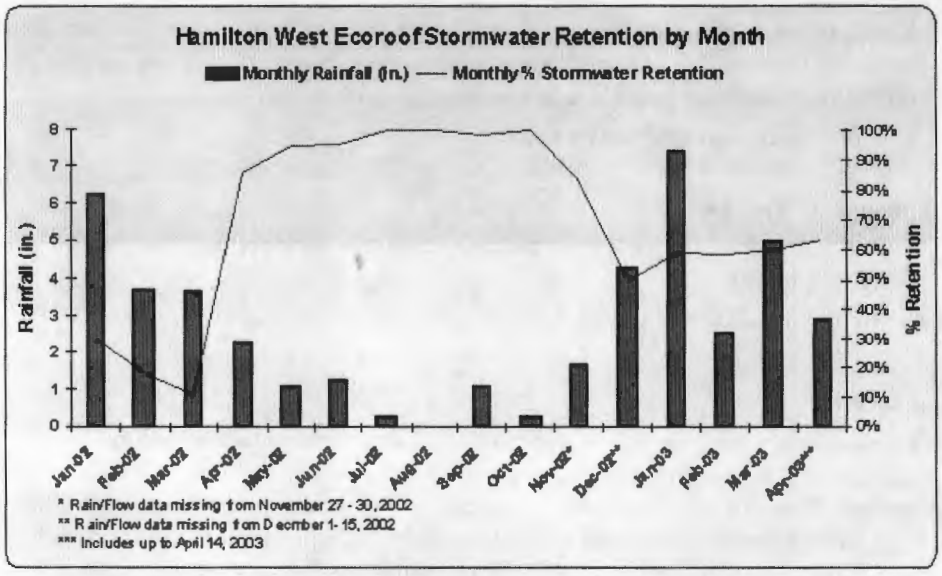

Figure 6.4.3 Precipitation and percent stormwater retained on a 4- to 4.5-inch eco-roof, Portland, OR. *Graphic from Hutchison et al.. 2003*

6.5 Minimal Excavation Foundation Systems

Excavation and movement of heavy equipment during construction compacts and degrades the infiltration and storage capacity of soils. Minimal excavation foundation systems limit soil disturbance and allow storm flows to more closely approximate natural shallow subsurface flow paths. When properly dispersed into the soils adjacent to and in some cases under the foundation, roof runoff that would otherwise be directed to bioretention areas or other LID facilities can be significantly reduced.

Minimal excavation foundation systems can take many forms, but in essence are a combination of driven piles and a connection component at, or above, grade. The piles allow the foundation system to reach or engage deep load-bearing soils without having to dig out and disrupt upper soil layers, which infiltrate, store and filter stormwater flows. These piles are a more "surgical" approach to earth engineering, and may be vertical, screw-augured or angled pairs that can be made of corrosion protected steel, wood or concrete. The connection component handles

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the transfer of loads from the above structure to the piles and is most often made of concrete. Cement connection components may be pre-cast or poured on site, in continuous perimeter wall, or isolated pier configurations. For a given configuration the appropriate engineering (analyzing gravity, wind and earthquake loads) is applied for the intended structure. Several jurisdictions in the Puget Sound region have permitted minimal excavation foundations for the support of surface structures, including Pierce and King counties and the city of Olympia.

Minimal excavation foundation systems limit soil disturbance and allow storm flows to more closely approximate natural shallow subsurface flow paths under and around the foundation.

6.5.1 Applications

Minimal excavation foundations in both pier and perimeter wall configurations are suitable for residential or commercial structures up to three stories high. Secondary structures such as decks, porches, and walkways can also be supported, and the technology is particularly useful for elevated paths and foot-bridges in nature reserves and other environmentally sensitive areas. Wall configurations are typically used on flat to sloping sites up to 10 percent, and pier configurations flat to 30 percent. Some applications may be "custom" or "one-off" designs where a local engineer is employed to design a combination of conventional piling and concrete components for a specific application. Other applications may employ pre-engineered, manufactured systems that are provided by companies specifically producing low-impact foundation systems for various markets.

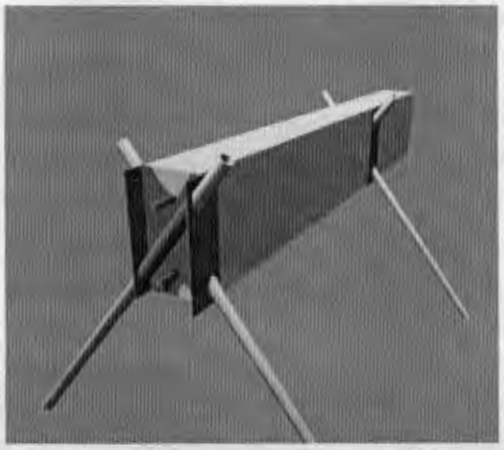

Figure 6.5.1 Typical minimal excavation foundation wall.
Graphic courtesy of Pin Foundations, Inc.



Figure 6.5.2 Building a house on Bainbridge Island using minimal excavation pier system.
Photo courtesy of R. Gagliano

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The minimal excavation foundation approach can be installed on A/B and C/D soils (USDA Soil Classification) provided that the material is penetrable and will support the intended type of piles. Typical soils in the Puget Sound region, including silt loams, sandy loams, fine gravels, tight soils with clay content, and partially cemented tills are applicable. Soils typically considered problematic due to high organic content (top soils or peats) or overall bearing characteristics may often remain in place provided their depth is limited and the pins have adequate bearing in suitable underlying soils. These systems may be used on fill soils if the depth of the fill does not exceed the **reaction range** of the intended piles. Fill compaction requirements for support of such foundations may be below those of conventional development practice in some applications. In all cases, both for custom and pre-engineered systems, a qualified engineer should determine the appropriate pile and connection components, and define criteria for specific soil conditions and construction requirements.

Flow modeling guidance

See Chapter 7 for flow modeling guidelines for minimal excavation foundation systems when using the WWHM.

6.5.2 Design

Grading

In general, wall configurations require some site blading or surface terracing to accommodate the wall component itself. The lightest possible tracked equipment should be used for preparing or grading the site. Permeability of some soil types can be significantly reduced even with minimal equipment activity. Consult a qualified hydrological engineer for soil recommendations.

On relatively flat sites, blading should be limited to knocking down the highs and lows to provide a better working surface. Removing the top organic "duff" layer is not typically necessary. A free draining, compressible buffer material (pea gravel, corrugated vinyl or foam product) should be placed on surface soils to prepare the site for the placement of pre-cast or site poured wall components. This buffer material separates the base of the grade beam from surface of the soil to prevent impact from expansion or frost heave, and in some cases is employed to allow the movement of saturated flows under the wall.



Figure 6.5.3 Minimal excavation foundation pins driven with machine-mounted automatic hammer.
Photo courtesy of R. Gagliano

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On sloped sites, the soils may be bladed smooth at their existing pitch to receive pier systems, pre-cast walls with sloped bases, or slope cut forms for pouring continuous walls. Grading should be limited to knocking down the superficial highs and lows on the site to provide a better working surface only. This technique will result in the least disturbance to the upper permeable soil layers on sloped sites.

While creating more soil disturbance, the site may be terraced to receive conventional square cut forms or pre-cast walls. The height difference between terraces will be a result of the slope percentage and the width of the terrace itself. The least soil impacts will be achieved by limiting the width of each terrace to the width of the equipment blade and cutting as many terraces as possible. Some footprint designs will be more conducive to limiting these cuts, and should be considered by the architect. The terracing technique removes more of the upper permeable soil layer, and this loss should be figured into any analysis of storm flows through the site. Buffer material as described above should be used on sloping sites regardless of the grading style employed.

Additional soil may remain from foundation construction depending on grading strategy and site conditions. The material may be used to backfill the perimeter of the structure if the impacts of the additional material and equipment used to place the backfill are considered for runoff conditions.

Construction

Minimal excavation systems may be installed "pile first" or "post pile." The pile first approach involves driving or installing all the required piles in specified locations to support the structure, and then installing a connecting component (such as a formed and poured concrete grade beam) to engage the piles. Post pile methods require the setting of pre-cast or site poured components first, through which the piles are then driven. Pile first methods are typically used for deep or problematic soils where final pile depth and embedded obstructions are unpredictable. Post pile methods are typically shallower—using shorter, smaller diameter piles—and used where the soils and bearing capacities are definitive. In either case, the piles are placed at specified intervals correlated with their capacity in the soil, the size and location of the loads to be supported, and the carrying capacity of the connection component. Soil conditions are determined by geotechnical analysis. Depending on the pile system type, the size or scale of the supported structure, and the nature of the site and soils, a complete soils report including slope stability and **liquifaction** analysis may be required. For other systems a simple statement of soil properties to a limited depth, such as dry unit weight, angle of internal friction, and/or cohesive strength, may be sufficient.

The piles are driven with a machine mounted, frame mounted, or hand-held automatic hammer. The choice of driving equipment should be considered based on the size of pile and intended driving depth, the potential for equipment site impacts, and the limits of movement around the structure. Corrosion rates for buried galvanized or coated steel piling, or degradation rates for buried concrete piling, are typically low to non-existent, and piling for these types of foundations are usually considered to last the life of the structure. Special conditions such as exposure to salt air or highly caustic soils in unique built environments such as industrial zones should be considered. Wood piling typically has a more limited lifetime. Some foundation systems allow for the removal and replacement of pilings, which can extend the life of the support indefinitely.

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Figure 6.5.4 Using an automatic hand-held hammer to drive pins. *Photo courtesy of R. Gagliano*

Stormwater Dispersion

Where the top or upper levels of soils have been sufficiently retained without significant loss of their permeability and storage characteristics, roof runoff and surrounding storm flows may be allowed to infiltrate without the intervention of man-made conveyance.

Where possible, roof runoff should be infiltrated uphill of the structure and across the broadest possible area. Infiltrating upslope more closely mimics natural (pre-construction) conditions by directing subsurface flows through minimally impacted soils surrounding, and in some cases, under the structure. This provides infiltration and subsurface storage area that would otherwise be lost in the construction and placement of a conventional "dug-in" foundation system. Passive gravity systems for dispersing roof water are preferred; however, active systems can be used if back-up power sources are incorporated and a consistent and manageable maintenance program is ensured.

Garage slabs, monolithic poured patios or driveways can block dispersed flows from the minimal excavation foundation perimeter, and dispersing roof runoff uphill of these areas is not recommended or must be handled with conventional means. Some soils and site conditions may not warrant intentionally directing subsurface flows directly beneath the structure, and in these cases, only the preserved soils surrounding the structure and across the site may be relied on to mimic natural flow pathways.

6.5.3 Performance

From 2000 to 2001 a minimal excavation foundation system was monitored on the Gig Harbor Peninsula. The study site was a two-story, 2300-square foot single-family residence located on a slightly sloped south facing lot with grass surrounding the house and second growth forest on the perimeter. Preparation for the foundation installation involved applying a thin layer of pea gravel directly on the existing lawn to separate the grade beam from the soil, pouring the grade beam from a pump truck, and driving steel pin piling with a hand held pneumatic hammer. The surface organic material was not removed from the construction area. Roof drains fed perforated weep hoses buried 2 to 3 inches in shallow perimeter landscape beds upslope of the house to infiltrate roof runoff and direct it along its natural pre-existing downslope path below the structure.

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Soil pits were excavated around and within the foundation perimeter and gravimetric sampling was conducted to measure soil moisture content on a transect from high slope to low slope within the foundation perimeter. Relative humidity in the crawl space below the house was assessed by comparing the minimum excavation foundation system with two conventional foundation crawl spaces in the same area. The soil analysis found 2 to 6 inches of topsoil overlying a medium dense to very dense silty, fine to coarse sand with small amounts of rounded gravel. Bulk density analysis of the upper 6 inches of the soil profile found no indication of compaction after construction (0.89 to 1.46g/cc or below average to average) and the original lawn vegetation had degraded to a fine brown loam under the plastic vapor barrier in the crawl space. Soil moisture readings indicated that roof runoff was infiltrating into the soils under the house and moving downslope through the subsurface soils. At no time was water ponded above the surface, either outside or under the house. The humidity readings in the crawl space under the minimal excavation foundation system were slightly drier than the conventional crawl space, but statistically equivalent, given the variance of the monitoring equipment (Palazzi, 2002).

Additional structures installed on similar systems over the last three years, though not monitored for subsurface flows, have shown similar reductions in soil compaction impacts to the site and foundation perimeter soils.

6.6 Roof Rainwater Collection Systems

Collecting or harvesting rainwater from rooftops has been used for centuries to satisfy household, agricultural, and landscape water needs. Many systems are operating in the Puget Sound region in a variety of settings. On Marrowstone and San Juan islands, where overuse, saltwater intrusion or natural conditions limit groundwater availability, individual homes use rainwater collection for landscaping and potable supplies. In Seattle, the King Street Center building harvests approximately 1.2 million gallons of rainwater annually to supply 60 to 80 percent of the water required for flushing the building's toilets (CH2M HILL, 2001).

6.6.1 Application

Typically, rainwater collection is used where rainfall or other environmental conditions limit the availability of domestic water supply. In a low impact development, rainwater harvesting serves two purposes: water conservation and, most importantly, elimination or the large reduction of the stormwater contribution from rooftops. This practice is particularly applicable in medium to high-density development where the roof is likely to be equal to or greater than the road, driveway, and sidewalk impervious surface contribution. In the medium to high density residential setting with detached single family homes and till soil conditions, the primary LID objective of approximating pre-development hydrology is likely not feasible without reducing or eliminating the stormwater contribution from rooftops through rainwater harvesting applications.

Roof rainwater harvesting systems can be used in residential, commercial or industrial development for new or retrofit projects. The focus of this section is on residential applications. Rainwater harvesting technology is well developed and components readily available; however, system design and construction is relatively complex and should be provided by a qualified engineer or experienced designer.

In a low impact development, rainwater harvesting serves two purposes: water conservation and, most importantly, elimination or a large reduction of the stormwater contribution from rooftops.

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6.6.2 Design

Collection systems should be sized according to precipitation inputs, indoor and/or outdoor water needs, and the flow reduction required to approximate pre-development hydrology. Rainwater harvesting should work in concert with other LID practices and therefore reduce the flow reduction requirements from the roof contribution and additional costs of the system.

In the Pacific Northwest the highest precipitation (supply) and lowest demand months are November to May. June through October is relatively dry and demand, driven primarily by landscape needs, is greatest during this period. To collect and remove adequate storm flows during the higher precipitation months and provide a reliable water source, large storage reservoirs or cisterns are required. Where stormwater is a primary incentive for installation and municipal or groundwater supplies are available, the rainwater collection system is installed with, and augmented by, a conventional water source.

Components of a rainwater collection system

Catchment or roof area

The roof material should not contribute contaminants (such as zinc, copper or lead) to the collection system. The National Sanitation Foundation (NSF) certifies products for rainwater collection systems. Products meeting NSF protocol P151 are certified for drinking water system use and do not contribute contaminants at levels greater than specified in the USEPA Drinking Water Regulations and Health Advisories (Stuart, 2001).

Roof materials

- Rainfall present in the Pacific Northwest is surprisingly acidic and will tend to leach materials from roofing material.
- Currently, few roof materials have been tested and the only recommendation for common roof coverings is to not use treated wood shingles or shakes.
- Metal, ceramic tile or slate are durable and smooth, presumed to not contribute significant contaminants, and are the preferred materials for potable supply. Composition or 3-tab roofing should only be used for irrigation catchment systems. Composition roofing is not recommended for irrigation supply if zinc has been applied for moss treatment.
- Lead solder should not be used for roof or gutter construction and existing roofs should be examined for lead content.
- Galvanized surfaces may deliver elevated particulate zinc during initial flushing and elevated dissolved zinc throughout a storm event (Stuart, 2001).
- Copper should never be considered for roofing or gutters. When used for roofing material, copper can act as an herbicide if rooftop runoff is used for irrigation. Copper can also be present in toxic amounts if used for a potable source.

The following general guidelines are used for calculating water production for a rainwater collection system:

- The catchment area is equal to the length times width of the guttered area (slope is not considered).

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- One inch of rain falling on one square foot of rooftop will produce 0.6233 gallons of water or approximately 600 gallons per 1,000 square feet of roof without inefficiencies.
- Assume that the system will lose approximately 25 percent of the total rainfall due to evaporation, initial wetting of the collection material, and inefficiencies in the collection process (Texas Water Development Board, 1997). Precipitation loss is the least with metal, more with composition, and greatest with wood shake or shingle.

Roof washers

Roof washers collect and route the first flush away from the collection system. The first flush can contain higher levels of contaminants from particulates settling on the roof, bird droppings, etc. A simple roof washer consists of a downspout (located upstream of the downspout to the cistern) and a pipe that is fitted and sealed so that water does not back flow into the gutter. Once the pipe is filled, water flows to the cistern downspout. The pipe often extends to the ground and has a clean out and valve.

The Texas Rainwater Guide recommends that 10 gallons be diverted for every 1000 square feet of roof (applicable for areas with higher storm intensities) (Texas Water Development Board, 1997). However, local factors such as rainfall frequency, intensity, and pollutants will influence the amount of water diverted. In areas with low precipitation and lower storm intensities such as the San Juan Islands, roof washing may divert flows necessary to support system demands. Additionally, the gentle rainfall prevalent in western Washington may not be adequate to wash contaminants from the roof in the first flush. In this scenario, pre-filtration for coarse material before the storage reservoir and fine filtration (e.g., 5 microns) before disinfection is likely more effective (personal communication Tim Pope, August 2004).

Storage tank or cistern

The cistern is the most expensive component of the collection system. If the system will be used for a potable water source, the tank and any sealants and paints used in the tank should be approved by the Food and Drug Administration (FDA), USEPA or NSF. Tanks can be installed above ground (either adjacent to or remote from a structure), under a deck, or in the basement or crawl space. Above ground installations are less expensive than below ground applications. Aesthetic preferences or space limitations may require that the tank be located below ground, or away from the structure. Additional labor expenditures for excavation and structural requirements for the tank will increase costs of subsurface installations compared to above ground storage (Stuart, 2001). Multiple tank systems are generally less expensive than single tank and the multi-reservoir configurations can continue to operate if one of the tanks needs to be shut down for maintenance.

Cisterns are commonly constructed of fiberglass, polyethylene, concrete, metal, or wood. Larger tanks for potable use are available in either fiberglass for burial or corrugated, galvanized steel with PVC or Poly liners for above ground installations. Tanks should have tight fitting covers to exclude contaminants and animals, and above ground tanks should not allow penetration of sunlight to limit algae growth (Texas Water Development Board, 1997).

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Figure 6.6.1 Buried tanks on San Juan Island.
Photo courtesy of Tim Pope



Figure 6.6.2 Collection tanks being installed under deck of a home on San Juan Island.
Photo courtesy of Tim Pope



Figure 6.6.3 Collection tanks hidden under the deck of a home on San Juan Island.
Photo courtesy of Tim Pope

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Figure 6.6.4 Storage tank on Lopez Island.
Photo courtesy of Tim Pope

Conveyance

Gutters are commonly made from aluminum, galvanized steel, and plastic. Rainwater is slightly acidic; accordingly, collected water entering the cistern should be evaluated for metals or other contaminants associated with the roof and gutters, and appropriate filters and disinfection techniques installed. Screens should be installed in the top of each downspout. Screens installed along the entire length of the gutter do not prevent most debris from entering the gutter; however, they can complicate cleaning. Leaf guard type gutters will exclude leaves and needles, but do not prevent pollen and dust (the most important contaminant to remove) from entering the gutter.

Unless the tank is elevated sufficiently above the point of delivery, pumps are required to provide acceptable pressure. Municipal water supply pressures are typically between 40 to 60 psi. Pressure tanks are often installed in addition to the pump to prolong the life of the pump and provide a more constant delivery pressure (Stuart, 2001).

Water treatment

Water treatment falls into three broad categories: filtration, disinfection, and buffering.

Filtration

Filters remove leaves, sediment, and other suspended particles and are placed between the catchment and the tank or in the tank. Filtering begins with screening gutter downspouts to exclude leaves and other debris and routing the first flush through roof washers, if compatible with precipitation and water needs (filtration can be incorporated with the roof washer). Types of filters for removing the smaller remaining particles include single cartridges (similar to swimming pool filters) and multi-cartridge filters (Texas Water Development Board, 1997). For potable systems, water must be filtered and disinfected after the water exits the storage reservoir and immediately before point of use.

Disinfection technologies include:

- *Ultra-violet (UV) radiation* uses short wave UV light to destroy bacteria, viruses, and other microorganisms. UV disinfection requires pre-filtering of fine particles

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where bacteria and viruses can lodge and elude the UV light. This disinfection strategy should be equipped with a light sensor and a readily visible alert to detect adequate levels of UV light (Texas Water Development Board, 1997).

- *Ozone* is a form of oxygen produced by passing air through a strong electrical field. Ozone kills microorganisms and oxidizes organic material to CO_2 and water. The remaining ozone reverts back to dissolved O_2 (Texas Water Development Board, 1997). Care must be exercised in the choice of materials used in the system using this disinfection technique due to ozone's aggressive properties.
- *Activated carbon* removes chlorine and heavy metals, objectionable tastes, and most odors.
- *Membrane technologies* include reverse osmosis and nano-filtration and are used primarily to filter dissolved materials such as salts or metals.
- *Chlorine* (commonly in the form of sodium hypochlorite) is a readily available and dependable disinfection technique. Household bleach can be applied in the cistern or feed pumps that release small amounts of solution while the water is pumped (Texas Water Development Board, 1997). There are two significant limitations of this technique: chlorine leaves an objectionable taste (which can be removed with activated charcoal); and prolonged presence of chlorine with organic matter can produce chlorinated organic compounds (e.g., trihalomethanes) that can present health risks (Texas Water Development Board, 1997).

Buffering

As stated previously, rainwater is usually slightly acidic (a pH of approximately 5.6 is typical). Total dissolved salts and minerals are low in precipitation and buffering with small amounts of a common buffer, such as baking soda, can adjust collected rainwater to near neutral (Texas Water Development Board, 1997). Buffering should be done each fall after tanks have first filled.

6.6.3 Barriers to Implementation

Two factors present the largest barriers to implementing rainwater harvesting:

1. **Regulatory**

   Authorizing agencies for rainwater collection include the Washington Department of Health, Ecology, and the local jurisdiction. The Department of Health does not recommend rainwater harvesting for potable supplies; however, there are no laws restricting the practice other than appropriate pollutant level criteria for human consumption. The USEPA classifies roof water collection as a surface water system and requires that the water be filtered to federal standards if for potable use. Ecology technically requires that all systems collecting surface water for consumption apply for a water right. Currently, Ecology is not enforcing its authority over roof collection for small systems (e.g., individual homes) (Stuart, 2001). Many local jurisdictions are not familiar with or restrict rainwater harvesting from roofs. In most locations, installing these systems will require special permit considerations.

2. **Cost**

   Roof water harvesting systems can add significant costs to residential construction. Systems that provide adequate storage for reliable indoor use and detain sufficient precipitation require large storage tanks, filtration and

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disinfection. In the example provided in Section 6.6.5: Perfomance, the system (10,000 gallon storage capacity for supplying toilets and clothes washing) added approximately $8,000/home to the construction costs. Roof water harvesting systems can, on the other hand, provide cost savings. New stormwater management requirements will increase infrastructure costs on challenging sites with medium to high density zoning and soils with low infiltration rates. Much, if not all, of the additional costs associated with a rainwater collection system may be offset by reducing conventional conveyance and pond infrastructure and expenditures. Building owners who use a rainwater harvest system will also reduce monthly expenses by significantly reducing their water bills.

6.6.4 Maintenance

Maintenance requirements for rainwater collection systems include typical household and system specific procedures. All controls, overflows and cleanouts should be readily accessible and alerts for system problems should be easily visible and audible. The following procedures are operation and maintenance requirements recorded with the deed of homes using roof water harvesting systems in San Juan County (personal communication, Tim Pope, August 2004).

- Debris should be removed from the roof as it accumulates.
- Gutters should be cleaned as necessary (for example in September, November, January, and April. The most critical cleaning is in mid to late-spring to flush the pollen deposits from surrounding trees.
- Screens at the top of the downspout should be maintained in good condition.
- Pre-filters should be cleaned monthly.
- Filters should be changed every six months or as pressure drop is noticed.
- UV units should be cleaned every six months and the bulb should be replaced every 12 months (or according to manufacturer's recommendation).
- Storage tanks should be chlorinated quarterly to 0.2ppm to 0.5ppm at a rate of 1/4 cup of household bleach (5.25 percent solution) to 1,000 gallons of stored water.
- Storage tanks should be inspected and debris removed periodically as needed.
- When storage tanks are cleaned, the inside surface should be rinsed with a chlorine solution of 1 cup bleach to 10 gallons water.
- When storage tanks are cleaned, the carbon filter should be removed and all household taps flushed until chlorine odor is noticed. Chlorinated water should be left standing in the piping for 30 minutes. Replace the carbon filter and resume use of the system.

6.6.5 Performance

In 2001, CH2M HILL performed an LID study on a 24-acre subdivision with 103 lots in Pierce County (CH2M HILL, 2001). The site was selected for its challenging conditions—medium density development (4 to 6 dwelling units/acre) located on a topographically closed depressional area and type C soils (USDA soils classification) with low infiltration rates. The study utilized LID principles and practices to redesign the project (on paper only) with the goal of approximating pre-development (forested) hydrologic conditions. LID practices used in the design included reducing the development envelope, minimizing impervious surfaces, increasing native soil and vegetation areas, amending disturbed soils with compost, and bioretention. Hydrologic analysis using continuous simulation (HSPF) was performed to assess the effectiveness of the selected LID practices for achieving the project goal.

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The hydrologic simulations of the proposed low impact development design indicated that the goals of the project could not be achieved by site planning and reducing impervious surfaces alone while maintaining four or more dwelling units per acre. The challenging site conditions required that additional LID tools be utilized to approximate forested hydrology. Accordingly, the potential to collect and use rooftop stormwater was considered to reduce surface flows.

A 1,300-sq. ft. impervious footprint was used to reflect the compact, two-story design for the detached single-family homes. At this density the rooftop contributing to the total impervious surface in the development was almost 60 percent. Only non-potable uses such as laundry, toilet, and irrigation were investigated to reduce design costs and regulatory barriers. To estimate the storage volume required for non-potable uses, the amount of water used inside the house was first estimated. The average inside water use for homes that conserve water is approximately 49.2 gallons per person per day (Maddaus, William O., 1987, Water Conservation, American Water Works Association). Table 6.6.1 contains a breakdown of average daily water use per person/day.

Table 6.6.1 Household water use.

Type of Use	Gallons per person per day	Percent of Total*
Showers	8.2	17
Toilets	6.4	13
Toilet leakage	4.1	8
Baths	7.0	14
Faucets	8.5	17
Dishwashers	2.4	5
Washing machines	12.6	26

* The average inside water use for homes that conserve water is approximately 49.2 gallons per person per day

The project considered using captured rainwater in toilets and washing machines. Stormwater collected from roof runoff may also be used for irrigation but because of the small lot sizes, this use was not factored into the calculation for storage requirements. However, the calculations assume that the storage system will be empty at the beginning of the wet season, so any excess stored water during the summer months should be used for irrigation.

To estimate the amount of storage required, the volume of rainfall from a 1300-sq. ft. surface was plotted over time against curves showing water usage based on a 5-gallon toilet, a 3.3-gallon toilet, a low-flow toilet (1.6 gallon), and a low-flow toilet combined with a washing machine. Monthly average rainfall for Pierce County was used (41.5 inches annually). Although the 5-gallon toilet resulted in the smallest required storage volume, new construction requires the use of low flow toilets, so the storage required for a combination low flow toilet and washing machine was used. This resulted in a required storage volume of approximately 10,000 gallons, or 1,333 cu. ft. Accounting for evaporation and other inefficiencies in the collection process, the 103 houses on the LID site would capture and use approximately 8 acre-ft of water annually.

From a hydrologic standpoint, collecting and using rooftop runoff reduces or removes the roof contribution from the surface water system. Collecting the appropriate percentage of total precipitation can simulate the amount of water that is naturally transpired and evaporated in a forested environment. As a result, the surface water system in the low impact development responds more like a forested system.

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7 Washington Department of Ecology Low Impact Development Design and Flow Modeling Guidance

In this chapter...

Flow control "credits" for:

- *Permeable pavements*
- *Dispersion*
- *Vegetated roofs*
- *Rainwater harvesting*
- *Reverse slope sidewalks*
- *Minimal excavation foundations*
- *Bioretention*

The Washington Department of Ecology (Ecology) encourages the use of the Western Washington Hydrology Model (WWHM) and other approved runoff models to estimate surface runoff and size stormwater control and treatment facilities. Other currently approved models are the King County Runoff Time Series and MGS Flood. This guidance suggests how to represent various LID techniques within those models so that their benefit in reducing surface runoff can be estimated. The lower runoff estimates should translate into smaller stormwater treatment and flow control facilities. In certain cases, the use of various techniques can result in the elimination of those facilities.

An LID credit committee comprised of stormwater managers from various local jurisdictions, Washington State University Extension, and Ecology developed the flow control credits presented in this chapter. The guidance is also available through Ecology's web site as an addendum to the 2005 *Stormwater Management Manual for Western Washington* (SMMWW).

This section identifies seven categories of LID techniques. For each category, the guidance includes basic design criteria that Ecology considers necessary in order to justify use of the suggested runoff "credit" or "runoff model representation." More detailed design guidance is available in Chapter 6: Integrated Management Practices.

As the Puget Sound community gains more experience with and knowledge of LID techniques, the design criteria will evolve. Also, our ability to model their performance will change as modeling techniques improve. Therefore, we anticipate this guidance will be updated periodically to reflect new knowledge and modeling approaches. Meanwhile, we encourage all to use the guidance, and to give us feedback on its usefulness and accuracy. Comments can be sent to Ed O'Brien of Ecology at eobr461@ecy.wa.gov.

Note that the terminology for grass has changed in the WWHM. The term "grass" has been replaced with "landscaped area."

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7.1 Permeable Pavements

7.1.1 Credits

7.1.1.1 Porous Asphalt or Concrete

Description of public road or public parking lot	**Model Surface as**
(1) Base material laid above surrounding grade:	
(a) Without underlying perforated drain pipes to collect stormwater	Landscaped area over underlying soil type (till or outwash)
(b) With underlying perforated drain pipes for stormwater collection:	
at or below bottom of base layer	Impervious surface
elevated within the base course	Impervious surface
(2) Base material laid partially or completely below surrounding grade:	
(a) Without underlying perforated drain pipes	Option 1: Landscaped area over underlying soil type Option 2: Impervious surface routed to an infiltration basin[1]
(b) With underlying perforated drain pipes:	
at or below bottom of base layer	Impervious surface
elevated within the base course[2]	Model as impervious surface routed to an infiltration basin[1]
Description of private facilities (driveways, parking lots, walks, patios)	
1. Base material below grade without underlying perforated drain pipes	50% landscaped area on underlying soil; 50% impervious
2. Base material below grade with underlying perforated drain pipes	Impervious surface

7.1.1.2 Grid/lattice Systems (Non-concrete) and Paving Blocks

Description of public road or public parking lot	**Model Surface as**
(1) Base material laid above surrounding grade	
(a) Without underlying perforated drain pipes	*Grid/lattice systems:* landscaped area on underlying soil (till or outwash). *Paving Blocks:* 50% landscaped area on underlying soil; 50% impervious.
(b) With underlying perforated drain pipes	Impervious surface

[1] See Section 7.8 for detailed instructions concerning how to represent the base material below grade as an infiltration basin in the Western Washington Hydrology Model.

[2] If the perforated pipes function is to distribute runoff directly below the wearing surface, and the pipes are above the surrounding grade, follow the directions for 2a above.

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(2) Base material laid partially or completely below surrounding grade	
(a) Without underlying perforated drain pipes	Option 1: *Grid/lattice systems:* landscaped area on underlying soil. *Paving blocks:* 50% landscaped area; 50% impervious. Option 2: Impervious surface routed to an infiltration basin.[1]
(b) With underlying perforated drain pipes	
at or below bottom of base layer	Impervious surface
elevated within the base course[2]	Model as impervious surface routed to an infiltration basin.[1]

Description of private facilities (driveways, parking lots, walks, patios)

Base material laid partially or completely below surrounding grade	
(a) Without underlying perforated drain pipes	50% landscaped area; 50% impervious
(b) With underlying drain pipes	Impervious surface

7.1.2 Design Criteria for Permeable Pavements

Subgrade

- Compact the subgrade to the minimum necessary for structural stability. Use small static dual wheel mechanical rollers or plate vibration machines for compaction. Do not allow heavy compaction due to heavy equipment operation. The subgrade should not be subject to truck traffic.
- Use on soil types A through C.

Geotextile

- Use geotextile between the subgrade and base material/separation layer to keep soil out of base materials.
- The geotextile should pass water at a greater rate than the subgrade soils.

Separation or bottom filter layer (recommended but optional)

- A layer of sand or crushed stone (0.5 inch or smaller) graded flat is recommended to promote infiltration across the surface, stabilize the base layer, protect underlying soil from compaction, and serve as a transition between the base course and the underlying geotextile material.

Base material

- Many design combinations are possible. The material must be free draining. For more detailed specifications for different types of permeable pavement, see Section 6.3: Permeable Paving.
  - o Driveways (recommendation):
    - ✓ > 4-inch layer of free-draining crushed rock, screened gravel, or washed sand.

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- ✓ < 5 percent fines (material passing through #200 sieve) based on fraction passing #4 sieve.

o Roads: The standard materials and quantities used for asphalt roads should be followed. For example:

- ✓ Pierce County cites larger rock on bottom, smaller on top (e.g., 2" down to 5/8"); compacted; minimal fines; 8 inches total of asphaltic concrete and base material.
- ✓ Washington State Department of Transportation (WSDOT) lists coarse crushed stone aggregate (AASHTO Grading No. 57: 1.5 inch and lower); stabilized or unstabilized with modest compaction; meets fracture requirements.
- ✓ The Federal Highway Administration suggests three layers between the porous pavement and geotextile. Typical layers would be:

  Filter course: 13 mm diameter gravel, 25 to 50 mm thick.

  Stone reservoir: 40 to 75 mm diameter stone.

  Filter course: 13 mm diameter gravel, 50 mm thick.

Wearing layer

- For all surface types, a minimum initial infiltration rate of 10 inches per hour is necessary. To improve the probability of long-term performance, significantly higher infiltration rates are desirable.
- *Porous Asphalt:* Products must have adequate void spaces through which water can infiltrate. A void space within the range of 12 to 20 percent is common.
- *Porous Concrete:* Products must have adequate void spaces through which water can infiltrate. A void space within the range of 15 to 21 percent is common.
- *Grid/lattice systems filled with gravel, sand, or a soil of finer particles with or without grass*: The fill material must be at least a minimum of 2 inches of sand, gravel, or soil. It should be underlain with 6 inches or more of sand or gravel to provide an adequate base. The fill material should be at or slightly below the top elevation of the grid/lattice structure. Modular-grid openings must be at least 40 percent of the total surface area of the modular grid pavement. Provisions for removal of oil and grease contaminated soils should be included in the maintenance plan.
- *Paving blocks:* 6 inches of sand or aggregate materials should fill spaces between blocks and must be free draining. Do not use sand for the leveling layer or filling spaces with Eco-Stone.
- The block system should provide a minimum of 12 percent free draining surface area.
- Provisions for removal of oil and grease contaminated soils should be included in the maintenance plan.

Drainage conveyance

Roads should still be designed with adequate drainage conveyance facilities as if the road surface was impermeable. Roads with base courses that extend below the surrounding grade should have a designed drainage flow path to safely move water away from the road prism and into the roadside drainage facilities. Use of perforated storm drains to collect and transport infiltrated water from under the road surface will result in less effective designs and less flow reduction credit.

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Acceptance test

- Driveways can be tested by simply emptying a bucket of water on the surface. If anything other than a scant amount puddles or runs off the surface, additional testing is necessary prior to accepting the construction.
- Roads may be initially tested with the bucket test. In addition, test the initial infiltration with a 6-inch ring, sealed at the base to the road surface, or with a sprinkler infiltrometer. Wet the road surface continuously for 10 minutes. Begin test to determine compliance with 10 inches per hour minimum rate.

Limitations

- No run-on from pervious surfaces is preferred. If runoff comes from minor or incidental pervious areas, those areas must be fully stabilized.
- Slope impervious runoff away from the permeable pavement to the maximum extent practicable. Sheet flow from up-gradient impervious areas is not recommended, but permissible if porous surface flow path ≥ impervious surface flow path. Impervious surface that drains to a permeable pavement can also be modeled as noted in Section 7.1.1 as long as the flow path restriction is met.
- Do not use on "high use sites" (as defined in the 2005 SMMWW, Volume V, Section 3.2), auto commercial services (gas stations, mini-marts, commercial fueling stations, auto body and auto repair shops, auto wash), commercial truck parking areas, areas with heavy industrial activity (as defined by U.S. EPA regulations), or areas with high pesticide use.
- Soils must not be tracked onto the wear layer or the base course during construction.
- Slopes:
  - Asphalt: Works best on level slopes and up to 2 percent. Do not use on slopes ≥ 5 percent.
  - Concrete: Maximum recommended slope of 6 percent.
  - Interlocking pavers: Maximum recommended slope of 10 percent.
  - Grid/lattice systems: Maximum generally in 5 to 6 percent range.
- Do not use in areas subject to heavy, routine sanding for traction during snow and ice accumulation.
- Comply with local building codes for separation distances from buildings and wells. Inquire with the local jurisdiction concerning applicable setbacks.

Maintenance

- Inspect project upon completion to correct accumulation of fine material. Conduct periodic visual inspections to determine if surfaces are clogged with vegetation or fine soils. Clogged surfaces should be corrected immediately.
- Surfaces should be swept with a high-efficiency or vacuum sweeper twice per year; preferably once in the autumn after leaf fall and again in early spring. For porous asphalt and concrete surfaces, high-pressure hosing should follow sweeping once per year.

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7.2 Dispersion

7.2.1 Full Dispersion for the Entire Development Site (fulfills treatment and flow control requirements)

Developments that preserve 65 percent of a site (or a **threshold discharge area** of a site) in a forested or native condition can disperse runoff from the developed portion of the site into the native vegetation area as long as the developed areas draining to the native vegetation do not have impervious areas that exceed 10 percent of the entire site. Runoff must be dispersed into the native area in accordance with the BMPs cited in BMP T5.30 of the 2005 SMMWW. Additional impervious areas are allowed, but should not drain to the native vegetation area and are subject to the thresholds, and treatment and flow control requirements of the stormwater manual.

7.2.2 Full Dispersion for all or Part of the Development Site

Developments that cannot preserve 65 percent or more of the site in a forested or native condition may disperse runoff into a forested or native area in accordance with the BMPs cited in BMP T5.30 of the 2005 SMMWW if:

- The effective impervious surface of the area draining into the native vegetation area is ≤ 10 percent; and
- The development maintains ratios proportional to the 65 percent forested or native condition and 10 percent effective impervious area. Examples of such ratios are:

% Native Vegetation Preserved (min. allowed)	% Effective Impervious (max. allowed)	% Lawn/Landscape (max. allowed)
65	10	35
60	9	40
55	8.5	45
50	8	50*
45	7	55*
40	6	60*
35	5.5	65*

* Where lawn/landscape areas are established on till soils, and exceed 50 percent of the total site, they should be developed using guidelines in Section 6.2: Amending Construction Site Soils or a locally approved alternative specification for soil quality and depth.

Within the context of this dispersion option, the only impervious surfaces that are ineffective are those that are routed into an appropriately sized dry well or into an infiltration basin that meets the flow control standard and does not overflow into the forested or native vegetation area.

Note: For options in 7.2.1 and 7.2.2, native vegetation areas must be protected from future development. Protection must be provided through legal documents on record with the local government. Examples of adequate documentation include a conservation easement, conservation parcel, and deed restriction.

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7.2.3 Partial Dispersion on Residential Lots and Commercial Buildings

If roof runoff is dispersed on single-family lots greater than 22,000 square feet according to the design criteria and guidelines in BMP T5.10 of the 2005 SMMWW, and the vegetative flow path is 50 feet or longer through undisturbed native landscape or lawn/landscape area that meets the guidelines in Section 6.2: Amending Construction Site Soils, the roof area may be modeled as landscaped area. This is done by clicking on the "Credits" button in the WWHM and entering the percent of roof area that is being dispersed.

The vegetated flow path is measured from the downspout or dispersion system discharge point to the downstream property line, stream, wetland, or other impervious surface.

Where BMP T5.11 (concentrated flow dispersion) or BMP T5.12 (sheet flow dispersion) of the 2005 SMMWW is used to disperse runoff into a native vegetation area or an area that meets the guidelines in Section 6.2: Amending Construction Site Soils, the impervious area may be modeled as landscaped area. This can be done by entering the impervious area as landscaped area rather than entering it as impervious area.

7.2.4 Road Projects

(1) Uncollected or natural dispersion into adjacent vegetated areas (i.e., sheet flow into the dispersion area)

Full dispersion credit (i.e., no other treatment or flow control required) is given to projects that meet the following criteria:

(a) *Outwash soils* (Type A – sands and sandy gravels, possibly some Type B – loamy sands) that have an initial saturated infiltration rate of 4 inches per hour or greater. The infiltration rate must be based on one of the following: (1) A D_{10} size (10 percent passing the size listed) greater than 0.06 mm (based on the estimated infiltration rate indicated by the upper-bound line in Figure 4-17 of the WSDOT Highway Runoff Manual) for the finest soil within a three foot depth; (2) field results using procedures (Pilot Infiltration Test) identified in Appendix III-D (formerly V-B) of the 2005 SMMWW.

- 20 feet of impervious flow path needs 10 feet of dispersion area width.
- Each additional foot of impervious flow path needs 0.25 feet of dispersion area width.

(b) *Other soils:* (Types C and D and some Type B not meeting the criterion in 1(a) above)

- Dispersion area must have 6.5 feet of width for every 1-foot width of impervious area draining to it. A minimum distance of 100 feet is necessary.

(c) *Criteria applicable to all soil types:*

- Depth to the average annual maximum groundwater elevation should be at least 3 feet.
- Impervious surface flow path must be $\leq$ 75 ft. Pervious flow path must be $\leq$ 150 feet. Pervious flow paths are up-gradient road side slopes that run onto the road and down-gradient road side slopes that precede the dispersion area.

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- Lateral slope of impervious drainage area should be ≤ 8 percent. Road side slopes must be ≤ 25 percent. Road side slopes do not count as part of the dispersion area unless native vegetation is re-established and slopes are less than 15 percent. Road shoulders that are paved or graveled to withstand occasional vehicle loading count as impervious surface.
- Longitudinal slope of road should be ≤ 5 percent.
- Length of dispersion area should be equivalent to length of road.
- Average longitudinal (parallel to road) slope of dispersion area should be ≤ 15 percent.
- Average lateral slope of dispersion area should be ≤ 15 percent.

(2) Channelized (collected and re-dispersed) stormwater into areas with (a) native vegetation or (b) cleared land in areas outside of urban growth areas that do not have a natural or man-made drainage system

Full dispersion credit (i.e., no other treatment or flow control required) is given to projects that meet the following criteria:

(a) *Outwash soils* (Type A – sands and sandy gravels, possibly some Type B – loamy sands) that have an initial saturated infiltration rate of 4 inches per hour or greater. The infiltration rate must be based on one of the following: (1) A D_{10} size (10% passing the size listed) greater than 0.06 mm (based on the estimated infiltration rate indicated by the upper-bound line in Figure 4-17 of the WSDOT Highway Runoff Manual) for the finest soil within a 3-foot depth; 2 field results using procedures (Pilot Infiltration Test) identified in Appendix III-D (previously V-B) of the 2005 SMMWW.

- Dispersion area should be at least ½ of the impervious drainage area.

(b) *Other soils:* (Types C and D and some Type B not meeting the criterion in 2a above)

- Dispersion area must have 6.5 feet of width for every 1-foot width of impervious area draining to it. A minimum distance of 100 feet is necessary.

(c) *Other criteria applicable to all soil types*:

- Depth to the average annual maximum groundwater elevation should be at least 3 feet.
- Channelized flow must be re-dispersed to produce the longest possible flow path.
- Flows must be evenly dispersed across the dispersion area.
- Flows must be dispersed using rock pads and dispersion techniques as specified in BMP T5.30 of the 2005 SMMWW.
- Approved energy dissipation techniques may be used.
- Limited to on-site (associated with the road) flows.
- Length of dispersion area should be equivalent to length of the road.
- Average longitudinal and lateral slopes of the dispersion area should be ≤ 8 percent.

(3) Engineered dispersion of stormwater runoff into an area with engineered soils

Full dispersion credit (i.e., no other treatment or flow control required) is given to projects that meet the following criteria:

- Stormwater can be dispersed via sheet flow or via collection and re-dispersion in accordance with the techniques specified in BMP T5.30 of the 2005 SMMWW.

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- Depth to the average annual maximum groundwater elevation should be at least 3 feet.
- Type C and D soils must be compost-amended following guidelines in Section 6.2: Amending Construction Site Soils. The guidance document *Guidelines and Resources for Implementing Soil Depth & Quality BMP T5.13 in WDOE Western Washington Stormwater Manual*, 2003 (revised 2005) can be used, or an approved equivalent soil quality and depth specification approved by Ecology.
  - o Dispersion area must meet the 6.5 to 1 ratio for full dispersion credit.
- Type A and B soils that meet the 4 inches per hour initial saturated infiltration rate minimum (See Section 7.2.4 a above) must be compost-amended in accordance with guidelines in Section 6.2: Amending Construction Site Soils. Compost may be incorporated into the soil in accordance with the guidance document cited above, or can be placed on top the native soil.
  - o 20 feet of impervious flow path needs 10 feet of dispersion area width.
  - o Each additional foot of impervious flow path needs 0.25 feet of dispersion area width.
- Average longitudinal (parallel to road) slope of dispersion area should be ≤ 15 percent.
- Average lateral slope of dispersion area should be ≤ 15 percent.
- The dispersion area should be planted with native trees and shrubs.

(4) Other characteristics for dispersal areas

- Dispersal areas inside the urban growth area must be protected through legal agreements (easements, conservation tracts, public parks).
- If outside urban growth areas, legal agreements should be reached with property owners of dispersal areas subject to stormwater that has been collected and is being re-dispersed.
- An agreement with the property owner is advised for uncollected, natural dispersion via sheet flow that is a continuation of past practice. If not a continuation of past practice, an agreement should be reached with the property owner.

7.3 Vegetated Roofs

7.3.1 Option 1 Design Criteria

- 3 to 8 inches of soil/growing media

Runoff Model Representation

- till landscaped area

7.3.2 Option 2 Design Criteria

- > 8 inches of soil/media

Runoff Model Representation

- till pasture

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7.3.3 Other Necessary Design Criteria

- Soil or growth media that has a high field capacity, and a saturated hydraulic conductivity that is ≥ 1 inch/hour (i.e., equivalent to a sandy loam or soil with a higher hydraulic conductivity).
- Drainage layer that allows free drainage under the soil/media.
- Vegetative cover that is both drought and wet tolerant.
- Waterproof membrane between the drain layer and the structural roof support.
- Maximum slope of 20 percent.

7.4 Rainwater Harvesting

7.4.1 Design Criteria

- 100 percent reuse of the annual average runoff volume (use continuous runoff model to get annual average for drainage area).
- System designs involving interior uses must have a monthly water balance that demonstrates adequate capacity for each month and reuse of all stored water annually.

Runoff Model Representation:

- Do not enter drainage area into the runoff model.

7.4.2 Other Criteria

- Restrict use to 4 homes/acre housing and lower densities when the captured water is solely for outdoor use.

7.5 Reverse Slope Sidewalks

Reverse slope sidewalks are sloped to drain away from the road and onto adjacent vegetated areas.

7.5.1 Design Criteria:

- ≥ 10 feet of vegetated surface downslope that is not directly connected into the storm drainage system.
- Vegetated area receiving flow from sidewalk must be undisturbed native soil or meet guidelines in Section 6.2: Amending Construction Site Soils.

7.5.2 Runoff Model Representation:

- Enter sidewalk area as landscaped area.

7.6 Minimal Excavation Foundations

Low impact foundations are defined as those techniques that do not disturb, or minimally disturb, the natural soil profile within the footprint of the structure. This preserves most of the hydrologic properties of the native soil. Pin foundations are an example of a minimal excavation foundation.

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7.6.1 Runoff Model Representation

- Where residential roof runoff is dispersed on the up gradient side of a structure in accordance with the design criteria and guidelines in BMP T5.10 of the 2005 SMMWW, the tributary roof area may be modeled as pasture on the native soil.
- Where "step forming" is used on a slope, the square footage of roof that can be modeled as pasture must be reduced to account for lost soils. In "step forming," the building area is terraced in cuts of limited depth. This results in a series of level plateaus on which to erect the form boards. The following equation (suggested by Rick Gagliano of Pin Foundations, Inc.) can be used to reduce the roof area that can be modeled as pasture.

$$A_1 - \frac{dC(.5)}{dP} \times A_1 = A_2$$

A_1 = roof area draining to up gradient side of structure
dC = depth of cuts into the soil profile
dP = permeable depth of soil (The A horizon plus an additional few inches of the B horizon where roots permeate into ample pore space of soil)
A_2 = roof area that can be modeled as pasture on the native soil

- If roof runoff is dispersed down gradient of the structure in accordance with the design criteria and guidelines in BMP T5.10 of the 2005 SMMWW AND there is at least 50 feet of vegetated flow path through native material or lawn/landscape area that meets the guidelines in Section 6.2: Amending Construction Site Soils, the tributary roof areas may be modeled as landscaped area.

7.6.2 Limitations

- To minimize soil compaction, heavy equipment cannot be used within or immediately surrounding the building. Terracing of the foundation area may be accomplished by tracked, blading equipment not exceeding 650 psf.

7.7 Bioretention Areas (Rain Gardens)

The design criteria provided below outlines basic guidance on bioretention design specifications, procedures for determining infiltration rates, and flow control guidance. For details on design specifications see Section 6.1: Bioretention Areas.

7.7.1 Design Criteria

Soils

- The soils surrounding bioretention facilities are a principle design element for determining infiltration capacity, sizing, and rain garden type. The planting soil mix placed in the cell or swale is a highly permeable soil mixed thoroughly with compost amendment and a surface mulch layer.
- Soil depth should be a minimum of 18 inches to provide acceptable minimum pollutant attenuation and good growing conditions for selected plants.
- The texture for the soil component of the bioretention soil mix should be a loamy sand (USDA Soil Textural Classification). Clay content for the final soil mix should be less than 5 percent. The final soil mix (including compost and soil) should have a minimum long-term hydraulic conductivity of 1.0 inch/hour

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per ASTM Designation D 2434 (Standard Test Method for Permeability of Granular Soils) at 80 percent compaction per ASTM Designation D 1557.

- The final soil mixture should have a minimum organic content of approximately 10 percent by dry weight.
- The pH for the soil mix should be between 5.5 and 7.0.

Mulch layer

- Bioretention areas can be designed with or without a mulch layer.

Compost

- Material must be in compliance with WAC chapter 173-350 Section 220 and meet Type 1, 2, 3 or 4 feedstock.
- pH between 5.5 and 7.0.
- Carbon nitrogen ratio between 20:1 and 35:1 (35:1 CN ratio recommended for native plants).
- Organic matter content should be between 40 and 50 percent.

Installation

- Minimize compaction of the base and sidewalls of the bioretention area. Excavation should not be allowed during wet or saturated conditions. Excavation should be performed by machinery operating adjacent to the bioretention facility and no heavy equipment with narrow tracks, narrow tires or large lugged, high pressure tires should be allowed on the bottom of the bioretention facility.
- On-site soil mixing or placement should not be performed if soil is saturated. The bioretention soil mixture should be placed and graded by excavators and/or backhoes operating adjacent to the bioretention facility.

Plant materials

- Plants should be tolerant of ponding fluctuations and saturated soil conditions for the length of time anticipated by the facility design and drought during the summer months.
- In general, the predominant plant material utilized in bioretention areas are facultative species adapted to stresses associated with wet and dry conditions.

Maximum ponding depth

- A maximum ponding depth of 12 inches is recommended.
- A maximum surface pool drawdown time of 24 hours is recommended.
- Ponding depth and system drawdown should be specified so that soils dry out periodically in order to:
  - Restore hydraulic capacity to receive flows from subsequent storms.
  - Maintain infiltration rates.
  - Maintain adequate soil oxygen levels for healthy soil biota and vegetation.
  - Provide proper soil conditions for biodegradation and retention of pollutants.

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7.7.2 Limitations

- A minimum of 3 feet of clearance is necessary between the lowest elevation of the bioretention soil, or any underlying gravel layer, and the seasonal high groundwater elevation or other impermeable layer, if the area tributary to the rain garden meets or exceeds any of the following limitations:
  - o 5,000 square feet of pollution-generating impervious surface; or
  - o 10,000 square feet of impervious area; or
  - o ¾ acre of lawn and landscape.
- If the tributary area to an individual rain garden does not exceed the areal limitations above, a minimum of 1 foot of clearance is adequate between the lowest elevation of the bioretention soil (or any underlying gravel layer) and the seasonal high groundwater elevation or other impermeable layer.

7.7.3 Runoff Model Representation

Pothole Design (Bioretention Cells)

The rain garden is represented as a pond with a steady-state infiltration rate. Proper infiltration rate selection is described below. The pond volume is a combination of the above ground volume available for water storage and the volume available for storage within the planting soil mix. The latter volume is determined by multiplying the volume occupied by the planting soil mix by the soil's percent porosity. Use 40 percent porosity for bioretention planting mix soils recommended in Section 6.1.2.3: Bioretention components. That volume is presumed to be added directly below the surface soil profile of the rain garden. The theoretical pond dimensions are represented in the Pond Information/Design screen. The Effective Depth is the distance from the bottom of the theoretical pond to the height of the overflow. This depth is less than the actual depth because of the volume occupied by the soil. Approximate side slopes can be individually entered. On the Pond Information/ Design screen, a button asks: "Use Wetted Surface Area?" Pushing that button is an affirmative response. Do not push the button if the rain garden has sidewalls steeper than 2 horizontal to 1 vertical.

Rain gardens with underlying perforated drain pipes that discharge to the surface can also be modeled as ponds with steady-state infiltration rates. However, the only volume available for storage (and modeled as storage as explained herein) is the void space within the imported material (usually sand or gravel) below the invert of the drain pipe.

Linear design: (bioretention swale or slopes)

Swales

Where a swale design has a roadside slope and a back slope between which water can pond due to an elevated, overflow/drainage pipe at the lower end of the swale, the swale may be modeled as a pond with a steady state infiltration rate. This method does not apply to swales that are underlain by a drainage pipe.

If the long-term infiltration rate through the imported bioretention soil is lower than the infiltration rate of the underlying soil, the surface dimensions and slopes of the swale should be entered into the WWHM as the pond dimensions and slopes. The effective depth is the distance from the soil surface at the bottom of the swale to the invert of the overflow/drainage pipe. If the infiltration rate through the underlying

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soil is lower than the estimated long-term infiltration rate through the imported bioretention soil, the pond dimensions entered into the WWHM should be adjusted to account for the storage volume in the void space of the bioretention soil. Use 40 percent porosity for bioretention planting mix soils recommended in Section 6.1.2.3: Bioretention components. For instance, if the soil is 40 percent voids, and the depth of the imported soils is 2 feet throughout the swale, the depth of the pond is increased by 0.8 feet. If the depth of imported soils varies within the side slopes of the swale, the theoretical side slopes of the pond can be adjusted.

This procedure to estimate storage space should only be used on bioretention swales with a 1 percent slope or less. Swales with higher slopes should more accurately compute the storage volume in the swale below the drainage pipe invert.

Slopes

Where a bioretention design involves only a sloped surface such as the slope below the shoulder of an elevated road, the design can also be modeled as a pond with a steady state infiltration rate. This procedure only applies in instances where the infiltration rate through the underlying soil is less than the estimated long-term infiltration rate of the bioretention planting soil mix. In this case, the length of the bioretention slope should correspond to the maximum wetted cross-sectional area of the theoretical pond. The effective depth of the theoretical pond is the void depth of the bioretention soil as estimated by multiplying the measured porosity times the depth of the bioretention soils. Use 40 percent porosity for bioretention planting mix soils recommended in Section 6.1.2.3: Bioretention components.

7.7.4 Infiltration Rate Determinations

The assumed infiltration rate for the pond must be the lower of the estimated long-term rate of the planting soil mix or the initial (a.k.a. short-term or measured) infiltration rate of the underlying soil profile. Using one of the procedures explained below, the initial infiltration rates of the two soils must be determined. Then after applying an appropriate correction factor to the planting soil mix placed in the rain garden, the designer can compare and determine the lower of the long-term infiltration rate of the planting soil mix and the initial infiltration rate of the underlying native soil. The underlying native soil does not need a correction factor because the overlying planting soil mix protects it. Below are explanations for how to determine infiltration rates for the planting soil mix and underlying soils, and how to use them with the WWHM.

7.7.4.1 Planting soil mix for the rain garden

1. Method for determining the infiltration rate for the planting soil mix in a rain garden with a tributary area of or exceeding any of the following limitations: 5,000 square feet of pollution-generating impervious surface; or 10,000 square feet of impervious surface; or ¾ acre of lawn and landscape:
   - o Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
   - o Use 4 as the infiltration reduction correction factor.
   - o Compare this rate to the infiltration rate of the underlying soil (as determined using one of the methods below). If the long-term infiltration

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rate of the imported soil is lower, enter that infiltration rate and the correction factor into the corresponding boxes on the pond information/ design screen of the WWHM.

2. Method for determining the infiltration rate for the planting soil mix in a rain garden with a tributary area less than 5,000 square feet of pollution-generating impervious surface; and less than 10,000 square feet of impervious surface; and less than ¾ acre of lawn and landscape:
   - o Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
   - o Use 2 as the infiltration reduction correction factor.
   - o Compare this rate to the infiltration rate of the underlying soil (as determined using one of the methods below). If the long-term infiltration rate of the imported soil is lower, enter that infiltration rate and the correction factor into the corresponding boxes on the pond information/ design screen of the WWHM.

7.7.4.2 Underlying soil

- Method 1: Use Table 3.7 of the 2005 SMMWW to determine the short-term infiltration rate of the underlying soil. Soils not listed in the table cannot use this approach. Compare this short-term rate to the long-term rate determined above for the bioretention-imported soil. If the short-term rate for the underlying soil is lower, enter it into the measured infiltration rate box on the pond information/design screen in the WWHM. Enter 1 as the infiltration reduction factor.
- Method 2: Determine the D_{10} size of the underlying soil. Use the "upperbound line" in Figure 4-17 of the WSDOT Highway Runoff Manual to determine the corresponding infiltration rate. If this infiltration rate is lower than the long-term infiltration rate determined for the bioretention planting soil mix, enter the rate for the underlying soil into the measured infiltration rate box on the pond/ information design screen. Enter 1 as the infiltration reduction factor.
- Method 3: Measure the in-situ infiltration rate of the underlying soil using procedures (Pilot Infiltration Test) identified in Appendix III-D (formerly V-B) of the 2005 SMMWW. If this rate is lower than the long-term infiltration rate determined for the imported bioretention soil, enter the underlying soil infiltration rate into the corresponding box on the pond information/design screen of the WWHM. Enter 1 as the infiltration reduction factor.

7.7.5 WWHM Routing and Runoff File Evaluation

In WWHM2 (the most recent WWHM iteration), all infiltrating facilities must have an overflow riser to model overflows that occur should the available storage be exceeded. In the Riser/Weir screen for the Riser head, enter a value slightly smaller than the effective depth of the pond (e.g., 0.1 foot below the Effective Depth), and for the Riser diameter enter a large number (e.g., 10,000 inches) to ensure that there is ample capacity for overflows.

Within the model, route the runoff into the pond by grabbing the pond icon and placing it below the tributary "basin" area. Be sure to include the surface area of the bioretention area in the tributary "basin" area. Run the model to produce the effluent

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runoff file from the theoretical pond. For projects subject to the flow control standard, compare the flow duration graph of that runoff file to the target pre-developed runoff file for compliance with the flow duration standard. If the standard is not achieved a downstream retention or detention facility must be sized (using the WWHM standard procedures) and located in the field. A conveyance system should be designed to route all overflows from the bioretention areas to centralized treatment facilities, and to flow control facilities if flow control applies to the project.

7.7.6 Modeling of Multiple Rain Gardens

Where multiple rain gardens are scattered throughout a development, it may be possible to represent those as one rain garden (a "pond" in the WWHM) serving the cumulative area tributary to those rain gardens. For this to be a reasonable representation, the design of each rain garden should be similar (e.g., same depth of soil, same depth of surface ponded water, and approximately the same ratio of impervious area to rain garden volume).

7.7.7 Other Rain Garden Designs

Guidance for modeling other bioretention designs is not yet available. However, where compost-amended soils are used along roadsides the guidance in Section 7.2: Dispersion can be applied.

7.8 WWHM Instructions for Estimating Runoff Losses in Road Base Material Volumes that are Below Surrounding Grade

Pre-requisite

Before using this guidance to estimate infiltration losses, the designer should have sufficient information to know whether adequate depth to a seasonal high groundwater table, or other infiltration barrier (such as bedrock) is available. The minimum depth necessary is 3 feet as measured from the bottom of the base materials.

7.8.1 Instructions for Roads on Zero- to 2-percent Grade

For road projects whose base materials extend below the surrounding grade, a portion of the below grade volume of base materials may be modeled in the WWHM as a pond with a set infiltration rate.

First, place a "basin" icon in the "Schematic" grid on the left side of the "Scenario Editor" screen. Left clicking on the basin icon will create a "basin information" screen on the right in which you enter the appropriate pre-developed and post-developed descriptions of your project site (or threshold discharge area of the project site). By placing a pond icon below the basin icon in the Schematic grid, we are routing the runoff from the road and any other tributary area into the below grade volume that is represented by the pond.

The dimensions of the infiltration basin/pond to be entered in the Pond Information/Design screen are: the length of the base materials that are below grade (parallel to the road); the width of the below grade material volume; and the

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Effective Depth. Note that the storage/void volume of the below grade base has to be estimated to account for the percent porosity of the gravel. This can be done by multiplying the below grade depth of base materials by the fractional porosity (e.g., a project with a gravel base of 32 percent porosity would multiply the below grade base material depth by 0.32). This is the Effective Depth. If the below grade base course has perforated drainage pipes elevated above the bottom of the base course, but below the elevation of the surrounding ground surface, the Effective Depth is the distance from the invert of the lowest pipe to the bottom of the base course multiplied by the fractional porosity.

Also in WWHM2, all infiltrating facilities must have an overflow riser to model overflows that occur should the available storage be exceeded. In the Riser/Weir screen, for the Riser head enter a value slightly smaller than the effective depth of the base materials (e.g., 0.1 foot below the Effective Depth), and for the Riser diameter enter a large value (e.g., 10,000 inches) to ensure that there is ample capacity should overflows from the trench occur.

On the Pond Information/Design screen, there is a button that asks, "Use Wetted Surface Area?" Pushing that button is an affirmative response. Do not push the button.

Using the procedures explained in Volume III, Chapter 3 and Appendix III-D of the 2005 SMMWW, or in Section 4-5.2 of the 2004 WSDOT Highway Runoff Manual, estimate the long-term infiltration rate of the native soils beneath the base materials. If using Method 1 from Chapter III of the 2005 SMMWW, enter the appropriate "short-term infiltration rate" from Table 3.7 into the "measured infiltration rate" box on the "Pond Information Design" screen of WWHM. Enter the correction factor from that table as the "Infiltration Reduction Factor." If using Method 2, enter the appropriate long-term infiltration rate from Table 3.8 into the "measured infiltration rate" box. Enter 1 as the correction factor. Note that Table 3.8 is restricted to the soil types in the table. For soils with a D_{10} size smaller than .05 mm, use the "lowerbound" values from Figure 4-17 on page 4-56, Chapter 4 of the 2004 WSDOT Highway Runoff Manual. If using Method 3, enter the measured in-situ infiltration rate as the "Measured Infiltration Rate" in the Pond Information/Design Screen. Also enter the appropriate cumulative correction factor determined from Table 3.9 as the "Infiltration Reduction Factor." Wherever practicable, Ecology recommends using Method 3, in-situ infiltration measurements (Pilot Infiltration Test) in accordance with Appendix III-D of the 2005 SMMWW.

Run the model to produce the overflow runoff file from the base materials infiltration basin. Compare the flow duration graph of that runoff file to the target pre-developed runoff file for compliance with the flow duration standard. If the standard is not achieved a downstream retention or detention facility must be sized (using the WWHM standard procedures) and located in the field. The road base materials should be designed to direct any water that does not infiltrate into a conveyance system that leads to the retention or detention facility.

7.8.2 Instructions for Roads on Grades Above 2 Percent

Road base material volumes that are below the surrounding grade and on a slope can be modeled as a pond with an infiltration rate and a nominal depth. Represent the below grade volume as a pond. Grab the pond icon and place it below the "basin" icon so that the computer model routes all of the runoff into the infiltration basin/pond.

The dimensions of the infiltration basin/pond to be entered in the Pond Information/Design screen are: the length (parallel to and beneath the road) of the

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base materials that are below grade; the width of the below grade base materials; and an Effective Depth of 1 inch. In WWHM2, all infiltrating facilities must have an overflow riser to model overflows should the available storage be exceeded. In the Riser/Weir screen, enter 0.04 foot (½ inch) for the Riser head and a large Riser diameter (e.g., 1000 inches) to ensure that there is no head build up.

Note: If a drainage pipe is embedded and elevated in the below grade base materials, the pipe should only have perforations on the lower half (below the spring line) or near the invert. Pipe volume and trench volume above the pipe invert cannot be assumed as available storage space.

Estimate the infiltration rate of the native soils beneath the base materials. See Section 7.8.1: Roads on zero to 2 percent grade for estimating options and how to enter infiltration rates and infiltration reduction factors into the "Pond Information/ Design" Screen of WWHM. Enter the appropriate information for the theoretical pond of ½-inch maximum depth.

On the Pond Information/Design screen, there is a button that asks, "Use Wetted Surface Area?" Pushing that button is an affirmative response. Do not push the button.

Run the model to produce the effluent runoff file from the base materials. Compare the flow duration graph of that runoff file to the target pre-developed runoff file for compliance with the flow duration standard. If the standard is not achieved a downstream retention or detention facility must be sized (using the WWHM standard procedures) and located in the field. The road base materials should be designed to direct any water that does not infiltrate into a conveyance system that leads to the retention or detention facility.

7.8.3 Instructions for Roads on a Slope With Internal Dams Within the Base Materials that are Below Grade

In this option, a series of infiltration basins are created by placing relatively impermeable barriers across the below grade base materials at intervals. The barriers inhibit the free flow of water down the grade of the base materials. The barriers must not extend to the elevation of the surrounding ground. Provide a space sufficient to pass water from upgradient to lower gradient basins without causing flows to surface out the sides of the base materials that are above grade.

Each stretch of trench (cell) that is separated by barriers can be modeled as an infiltration basin. This is done by placing pond icons in a series in the WWHM. For each cell, determine the average depth of water within the cell (Average Cell Depth) at which the barrier at the lower end will be overtopped.

Specify the dimensions of each cell of the below grade base materials in WWHM on the screen which asks for pond dimensions. The dimensions of the infiltration cell entered in the Pond Information/Design screen are: the length of the cell (parallel to the road); the width; and the Effective Depth (in this case, it is okay to use the total depth of the base materials that are below grade).

Also in WWHM2, all infiltrating facilities must have an overflow riser to model overflows should the available storage be exceeded. For each trench cell, the available storage is the void space within the Average Cell Depth. The storage/void volume of the trench cell has to be estimated to account for the percent porosity of the base materials. For instance, if the base materials have a porosity of 32 percent, the void volume can be represented by reducing the Average Cell Depth by 68 percent (1 to 32 percent). This depth is entered in the Riser/Weir screen as the Riser

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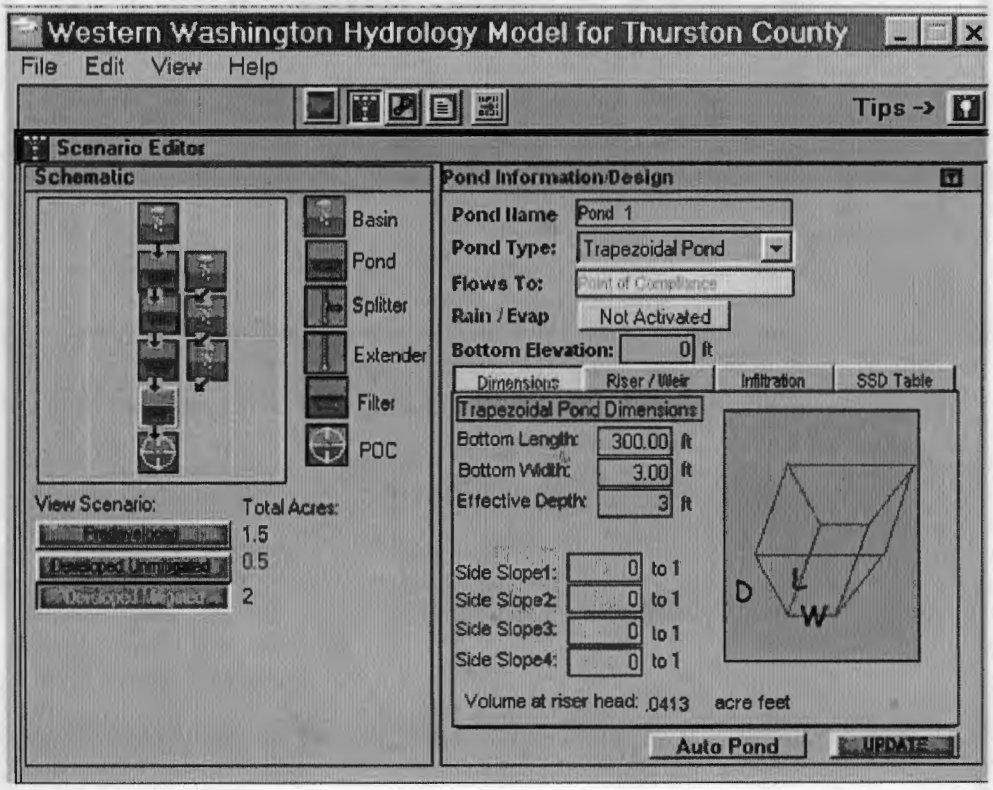
head. The gross adjustment works because WWHM2 (as of March 2004) does not adjust infiltration rate as a function of water head. If the model is amended so that the infiltration rate becomes a function of water head, this gross adjustment will introduce error and therefore other adjustments should be made. For the riser diameter in the Riser/Weir screen, enter a large number (e.g., 10,000 inches) to ensure that there is ample capacity if overflows from the below-grade trench occur.

Each cell should have its own tributary drainage area that includes the road above it, any project site pervious areas whose runoff drains onto and through the road, and any off-site areas. Each drainage area is represented with a "basin" icon.

Up to four pond icons can be placed in a series to represent the below grade trench of base materials. The computer graphic representation of this appears as follows:



It is possible to represent a series of cells as one infiltration basin (using a single pond icon) if the cells all have similar length and width dimensions, slope, and Average Cell Depth. A single "basin" icon is also used to represent all of the drainage area into the series of cells.

On the Pond Information/Design screen (see screen below), there is a button that asks, "Use Wetted Surface Area?" Pushing that button is an affirmative response. Do not push the button if the below grade base material trench has sidewalls steeper than 2 horizontal to 1 vertical.

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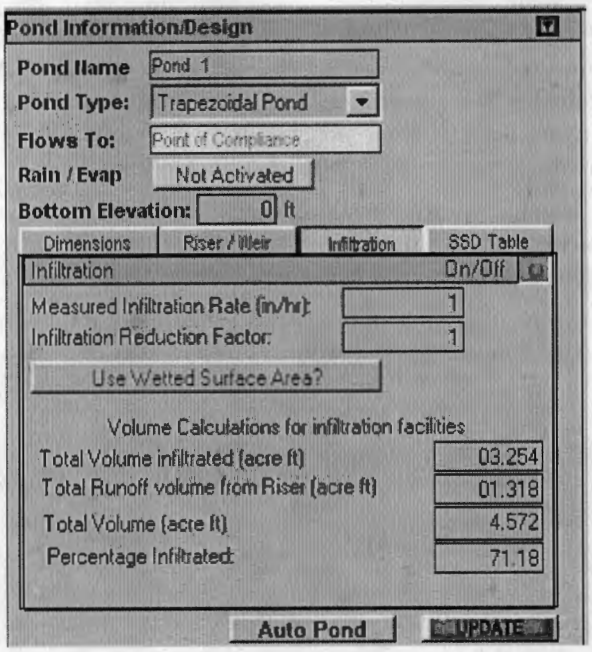

Using the procedures explained above for roads on zero grade, estimate the infiltration rate of the native soils beneath the trench. Also as explained above, enter the appropriate values into the "Measured Infiltration Rate" and "Infiltration Reduction Factor" boxes of the "Pond Information/Design" screen.

Run the model to produce the effluent runoff file from the below grade trench of base materials. Compare the flow duration graph of that runoff file to the target pre-developed runoff file for compliance with the flow duration standard. If the standard is not achieved a downstream retention or detention facility must be sized (using the WWHM standard procedures) and located in the field. The road base materials should be designed to direct any water that does not infiltrate into a conveyance system that leads to the retention or detention facility.

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8 Hydrologic Analysis

In this chapter...

- *Emerging techniques for modeling LID*

Several methods of hydrologic analysis have been developed for modeling low impact development (LID) designs. Single event models have been most commonly used and a national method based on the Soil Conservation Service TR-55 model is available through the U.S. Environmental Protection Agency (EPA publication 841-B-00-02).

Single event methods, however, have limitations for modeling western Washington stormwater facilities. For example, a single event method does not account for the effects of storms that occur just before or after a single storm event and the associated antecedent soil moisture conditions.

The Washington Department of Ecology (Ecology) recommends that local jurisdictions in western Washington adopt the Western Washington Hydrologic Model (WWHM), an HSPF (Hydrologic Simulation Program-Fortran)-based model. Ecology recommends WWHM for several reasons, including:

- WWHM uses long-term and local precipitation data that accounts for various rainfall regimes in western Washington.
- The modeling methodology better accounts for previous storm events and antecedent soil moisture conditions.
- The various land categories describing hydrologic factors that influence runoff characteristics are calibrated using data collected by the U.S. Geological Service (USGS) in western Washington watersheds.

While WWHM provides advantages for designing stormwater facilities in western Washington, there are challenges for applying the model to low impact development designs. LID utilizes multiple, small-scale stormwater controls that are distributed yet often connected throughout the development. Flows are directed to these facilities from small contributing areas and stormwater that is not infiltrated, evaporated or transpired in one facility is directed to the next. This presents two challenges when using WWHM in this design setting:

- WWHM has limited routing capability, and while the model has been expanded to allow routing through multiple facilities, the procedure remains time and computing intensive for the large number of facilities in LID projects (AHBL, 2004).
- Pervious land category values (PERLNDs) for WWHM are based on local USGS studies. Pervious surfaces and soil treatments in a low impact development include compost amended soil, bioretention areas with engineered soil mixes, and pervious pavement with aggregate storage. The LID pervious surface treatments, or land categories, will likely behave differently than the calibrated PERLNDs in the WWHM. Pilot projects and associated monitoring are needed to provide necessary data to help further calibrate the WWHM to these new strategies.

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8.1 Emerging Modeling Techniques

8.1.1 Micro-Basin Characterization

AHBL Engineers in Tacoma developed a micro-basin characterization technique to compensate for the routing limitations of the WWHM:

- The project is divided into small basins according to topography, lot, and street layout and LID stormwater facility configuration (see Figure 8.1 for a conceptual representation of the basin delineation).
- The contributing area is based on the bioretention cell or segment of bioretention swale and the area that contributes surface flows to that cell or swale.
- Areas are derived from design plans for roof areas, driveways, landscaping, and undisturbed areas for each basin.
- Storm flows from the basin are then routed through the bioretention cell or portion of the bioretention swale.
- An equivalent basin is generated that has characteristics that match the outflow from the bioretention cell or segment of swale.
- After all individual basins are defined, they are combined and routed to the next facility or used for the final development runoff.
  (AHBL, 2004)

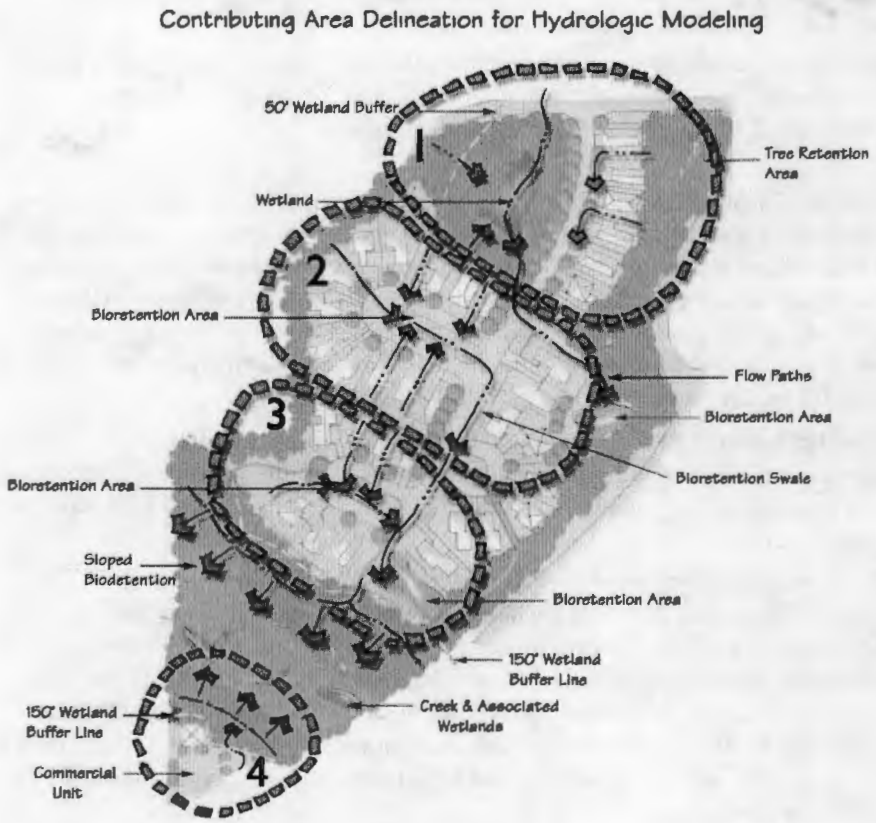

Figure 8.1 Basin delineation.

Graphic by AHBL Engineering

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8.1.2 WWHM and LID Flow Control Credits

See Chapter 7: Washington Department of Ecology Low Impact Development Design and Flow Modeling Guidance for flow control credits when using bioretention, green roofs, rooftop rainwater harvesting, permeable paving, minimal excavation foundations, and dispersion techniques.

8.1.3 An Approach for Modeling Bioretention Swales and Compost Amended Soils

Herrera Environmental Consultants performed hydrologic modeling to evaluate the expected performance of a Natural Drainage System (NDS) for the High Point Revitalization Project in Seattle. The primary objectives of the hydrologic modeling were to evaluate compliance with overall stormwater performance goals for the site, cost effectiveness, and design optimization for the NDS.

Key elements of the proposed NDS include bioretention and conveyance swales that are distributed throughout the site within the public rights-of-way, disconnection of rooftop runoff from the storm drain system, and extensive use of compost amended soils.

Existing models are not ideally suited for examining the microscopic surface and subsurface dynamics of bioretention swales and their complex interaction with other stormwater management practices (e.g., rooftop dispersion and compost amended soil). Accordingly, Herrera developed new modeling techniques to more accurately assess the detailed performance of the bioretention swales at the city block-scale, as well as the cumulative performance of all elements of the NDS strategy for the entire High Point site.

The bioretention swales for High Point are complex in design, with multiple distinct layers governing their flow control capacity. These layers consist of a grass-lined or vegetated swale surface, a 6-foot thick engineered soil layer, and a 6-foot thick gravel under-drain layer. The swale is designed to retain stormwater at the surface long enough to allow infiltration into the underlying engineered soil layer. The engineered soil provides the primary mechanism for flow control. Stormwater is retained for longer periods of time and is exfiltrated through the sides of the swale to surrounding native soils. Moisture that does not exfiltrate within the engineered soil layer drains to the underlying gravel layer, which allows for additional exfiltration through the sides and bottom of the swale.

The bioretention swales were modeled in HSPF as a series of interconnected stage-storage-discharge relationships, or functional tables (FTABLEs). One FTABLE was used to represent each distinct layer of the swale. For the grass-lined or vegetated surface swale, FTABLE development was based on Manning's equation for open channels. The FTABLE for the engineered soil layer was of critical importance for predicting the overall performance of the bioretention swales, since this layer provides the primary flow control mechanism for the swales. This FTABLE was developed based on detailed modeling performed using MODRET software, which is a groundwater model capable of predicting dynamic surface water and groundwater interactions. The FTABLE for the under-drain layer was based on Darcy's Law for saturated flow through gravel. The FTABLEs for each layer were connected within HSPF, allowing for exfiltration to the native soils as well as one-way flow between layers (e.g., from the surface swale to the engineered soil layer, or from the engineered soil to the under-drain layer).

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For the overall site-scale modeling, compost amended soils were modeled in HSPF as PERLNDs with lateral inflow from disconnected rooftop downspouts. Model parameters for these PERLNDs were modified from the USGS regional calibration parameters for till soils with grass cover in order to represent the enhanced infiltration offered by amended soils (Dinicola, 1990). The parameter adjustments were based on an HSPF calibration study by Kurtz (1996), which used data obtained from experimental plots at the University of Washington's Center for Urban Horticulture.

Runoff from rooftops was modeled as lateral inflow to lawns, or compost amended soil, down gradient from the downspouts. Lateral inflow is analogous to additional rainfall input to these receiving areas. For purposes of reflecting reasonable hydraulic loading rates, the areas receiving rooftop runoff were estimated using the following approach:

- Each building structure was assumed to have four downspouts contributing to the adjacent pervious area.
- Downspout discharge was assumed to spread at a 45 degree angle and sheet flow a distance of 10 feet onto the adjacent pervious area.

This modeling approach was successful for meeting the objectives of the study. Long-term monitoring of the site is scheduled to begin Fall 2004. Results from the monitoring study will be used to verify the modeling approach.

8.1.4 CH2M HILL LIFE™ Model

CH2M HILL developed the Low Impact Feasibility Evaluation (LIFE™) model specifically for evaluating the performance of various LID techniques. The LIFE™ model provides a continuous simulation of the runoff and infiltration from new or redeveloped areas, or from a watershed or sub-catchment with multiple land use categories utilizing the following inputs:

- Continuous rainfall data (typically in time increments of 1 hour or less) and evapotranspiration data (typically daily time increments) evaluated for time periods of one year or more.
- Site design parameters and land cover characteristics for each land category being modeled (e.g., road width, rooftop coverage, surface parking, etc.).
- Information on LID techniques that are applied for each land use type including:
  - Extent of source control application (e.g., percent of road and building lots with specific source controls).
  - Source control design parameters (e.g., area and depth of infiltration facilities, soil depth for green roofs, volume of rainwater harvesting cisterns, etc.).
- Soils information including:
  - Surface parameters (e.g., maximum water content, rooting depth of vegetation).
  - Subsurface parameters (e.g., saturated hydraulic conductivity).

The model provides total runoff volume, flow duration curves, and flow hydrographs as outputs to assess the performance of LID designs (CH2M HILL, 2004).

The LIFE™ model has not had extensive calibration. Pilot projects and associated monitoring will provide necessary data to help further calibrate the model to specific LID practices and expected overall performance of projects using multiple LID techniques.

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Appendix 1

Street Tree List

The following list provides information on the growth patterns and favorable site characteristics for trees that are appropriate in the street landscape. Bioretention cells and swales located along streets may have specific soil and moisture conditions that differ from conventional roadside planting areas. Trees in this list may be applicable in bioretention areas depending on the physical setting and project objectives. See Appendix 3 for trees specifically recommended in bioretention cells or swales.

Local jurisdictions often have specific guidelines for the types and location of trees planted along public streets or rights-of-way. The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with under-drain structures or near paved areas such as driveways, sidewalks or streets. The city of Seattle, for example, has the following requirements for tree planting location:

- 3½ feet back from the face of the curb.
- 5 feet from underground utility lines.
- 10 to 15 feet from power poles.
- 7½ to 10 feet from driveways.
- 20 feet from street lights or other existing trees.
- 30 feet from street intersections.
- Planting strips for trees should be at least 5 feet wide.

Trees included in the "small" tree section of this list typically remain at or below a 30-foot mature height, which is compatible (unless indicated otherwise) with clearances for most overhead utility/electrical lines. Some jurisdictions may not recommend planting street trees that are fruit bearing or are otherwise "messy." Contact local authorities to determine if there are guidelines or restrictions to consider when making tree selections in your area.

Minimum ranges for planting strip widths are included and are compiled from various local and regional jurisdiction recommendations. Generally, larger planting widths are recommended for optimal tree health and longevity. Under certain circumstances, the use of root barriers or root guards may assist in preventing or delaying damage to adjacent paved surfaces. Consult a certified arborist for specifications and information on root barriers and installation.

Note on conifers: Jurisdictions often recommend very large planting areas for conifers due to potential visibility or safety issues associated with lower limbs. If properly trimmed and maintained, however, conifers can be incorporated safely into the urban streetscape and provide excellent year-round interception of precipitation.

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Indicates a tree that does well in wet areas | * Denotes native species

SMALL TREES (under 30 feet in height)

Space evenly every 20 to 30 feet

Species/ Common Name	Exposure	MatureHt./ Spread	Planting Strip Width	Comments
Acer campestre Hedge maple	Sun/partial shade	To 30 feet/ To 30 ft. spread	4-5 feet	Deciduous; prefers moist, rich soils; slow growing tree tolerant of air pollution and soil compaction; yellow fall color; cultivars available including Queen Elizabeth maple ('Evelyn') with dark green, glossy foliage
*Acer circinatum** Vine maple	Sun/partial shade	20-25 feet/ 10 ft. spread	8 feet	Deciduous; prefers moist, well-drained soils; tolerates seasonal saturation and varying soil types; drought tolerant once established; bushy shrub or small tree; most often multi-trunked and does well in small groups; white flowers April-June; orange and red fall color
Acer ginnala Amur maple	Sun/partial shade	To 20 feet/ 20 ft. spread	4 feet	Deciduous; prefers moist, well-drained soils, but is tolerant of drought; is often multi-trunked, but can be pruned to a single stem; rounded form; fragrant, yellowish-white flowers in spring; cultivars are available such as 'Flame' and 'Embers' with differing fall colors
Acer griseum Paperbark maple	Sun/partial shade	15-25 feet/ 15-25 ft. spread	4 feet	Deciduous; prefers moist, well-drained soils, but is moderately drought tolerant; bronze peeling bark provides year-round visual interest; often multi-trunked, but can be trained to a single stem; scarlet fall color; slow growing; disease and pest resistant
Acer palmatum Japanese maple	Partial shade/Sun	15-25 feet/ 10-25 ft. spread	4 feet +	Prefers moist, well-drained soils; deciduous; slow to moderate growth rate; multi-trunked with spreading branches; intolerant of inundation but moderately drought resistant; vibrant fall colors; many cultivars available including 'Emperor I', 'Katsura', and 'Osakazuki'
Acer platanoides 'Globosum' Globe Norway maple	Sun/partial shade	15-20 feet/ 15-20 ft. spread	4-5 feet +	Moist soils preferred, but tolerates drought and seasonal inundation; tolerant of urban pollution; dense, compact, round form; slow-growing deciduous tree with brilliant fall color; shallow root system may make mowing under the tree slightly difficult; good selection for locations under power lines; another cultivar well suited for such a location is *A. platanoides* 'Almira,' reaching only 20-25 ft.
Acer triflorum Roughbark maple	Sun/partial shade	25-30 feet/ 20-25 ft. spread	Check with jurisdiction	Deciduous; prefers moist soils, but somewhat drought tolerant once established; apricot and gold fall color; rough, knobby trunk provides interest in winter; disease and pest resistant; non-aggressive roots do not damage sidewalks or driveways
Acer truncatum Purpleblow maple	Sun	20-25 feet/ 20-25 ft. spread	5 feet	Prefers moist, well-drained soil, but drought tolerant; very cold hardy deciduous tree; moderate growth rate; yellow flowers in spring; an additional maple cultivar of interest is 'Pacific sunset'

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Species/ Common Name	Exposure	MatureHt./ Spread	Planting Strip Width	Comments
Amelanchier x *grandiflora* 'Autumn Brilliance' Serviceberry	Sun/partial shade	20-25 feet/ To 15 ft. spread	4 feet +	Moist to dry, well-drained soils; shrub or small tree; drought tolerant; white clustered flowers in spring; red or yellow fall color; also try 'Princess Diana' for bright red fall color and the slightly taller 'Robin Hill' (20-30 feet)
Carpinus caroliniana American hornbeam	Sun/partial shade	20-30 feet/ 20-30 ft. spread	4-6 feet	Deciduous; prefers moist, rich soils; grows near saturated areas but is only weakly tolerant of saturation; blooms March-May; slow growing; deep coarse laterally spreading roots; medium life span; also consider *Carpinus japonica* (Japanese hornbeam)
Cercis Canadensis Eastern redbud	Partial shade/sun	25 feet/ 30 ft. spread	4 feet +	Deciduous; prefers moist, rich soils; tolerant of shade; somewhat drought resistant, but not in full sun; purple-lavender flowers; medium longevity; often multi-trunked; shallow, fibrous roots become deeper on drier sites; fairly short-lived; blooms March-May
Cornus kousa var. 'Chinensis' Chinese kousa dogwood	Sun/partial shade	To 20 feet/ To 20 ft. spread	3 feet +	Prefers moist soils; tolerant of varying soil types; moderate growth rate; deciduous; white flowers in June and large red fruits that resemble a raspberry in September; red to maroon fall color; more disease resistant than other dogwoods; many additional cultivars available
Crataegus x *lavalii* Lavalle hawthorn	Sun	To 25 feet/ 15-20 ft. spread	4-5 feet	Deciduous; prefers moist, well-drained soil, but tolerant of varying soil types; bronze and coppery red fall color; white flowers in spring; fruit can be a bit messy
Malus spp. Flowering crabapple	Sun/partial shade	15-25 feet/ 6-15 ft. spread	4-5 feet	Tolerant of prolonged soil saturation; somewhat untidy; short lived; tolerant of drought and seasonally saturated soils; deciduous; white or faintly pink flowers in spring; numerous *Malus* species and cultivars provide a variety of foliage and flower colors, forms, and fruit. Many cultivars and varieties available including *M.* 'Adirondack' (to 10 ft. height), *M. floribunda* (Showy crab); *M.* 'Sugar Tyme' (to 18 ft. height); native *M. fusca** (Pacific crabapple) reaches 30-40 ft in height
Parrotia persica Persian ironwood	Sun/light shade	15-35 feet/ 15-30 ft. spread	4 feet	Moist to dry soils; drought tolerant when established, deciduous tree with moderate growth rate; brilliant fall color; often multi-trunked, but can be trained to have just one; tolerates urban pollution and soil compaction; surface roots do not generally cause problems; virtually disease and pest-free
Prunus serrulata 'Shirofugen' Japanese flowering cherry	Sun	To 25 feet/ To 25 ft. spread	4 feet	Deciduous flowering tree; moist, well-drained soils; double pink to white blooms in spring; vigorous grower; additional desirable choices include *P. serrulata* 'Snowgoose', 'Kwanzan', and 'Shirotae'
Quercus ilex Holly oak	Sun/partial shade	20+ feet/ 20 ft. spread	5 feet +	Prefers moist soils, but grows in varying soils; hearty, slow-growing evergreen tree; light pink flowers May-June; pruning will keep tree small for a hedge, without pruning may grow considerably larger – not appropriate under utility lines; tolerates salt water spray

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Medium Trees (30 to 50 feet in height)

Space evenly every 25 to 35 feet

Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
Acer platanoides 'Columnare' Columnare Norway maple	Sun/partial shade	40-50 feet/ 15-20 ft. spread	5-6 feet	Deciduous; adapts to varying soils; upright or columnar in form making this cultivar a better choice for narrow locations; tolerant of drought and seasonal inundation; tolerates urban pollution and displays brilliant fall color; shallow rooting necessitates locating at least 4-6 feet from sidewalks and driveways to prevent heaving of pavement
Acer rubrum Red maple	Sun/partial shade	35-50 feet/ 15-40 ft. spread	5-6 feet	Deciduous tree known for fall color; prefer wet or moist soils; tolerant of summer drought and urban pollutants; fast growing with roots that may heave sidewalks or interfere with mowing; many cultivars of varying heights available including: *A. rubrum*, 'Armstrong,' Bowhall', Karpick,' 'Scarsen,' and 'Red Sunset'
Carpinus betulus European hornbeam	Sun/shade	40-60 feet/ 30-40 ft. spread	5 feet	Deciduous tree; tolerant of urban pollution and poor soils; can also be used as a hedge or screen cultivars available and suggested include 'Fasigiata' (30-40 ft. height) and 'Franz Fontaine' (30-35 ft height)
Fraxinus americana 'Autumn Applause' Ash	Sun	To 40 feet/ 25 ft. spread	5-6 feet	Deciduous; prefers moist, well-drained soils; dense, wide spreading canopy; long-lived; purple fall color; moderate growth rate; also try *F. Americana* 'Junginger'
Fraxinus oxycarpa Raywood ash	Sun	25-50 feet/ 25 ft. spread	5 feet +	Deciduous; drought and variable soil tolerant; can take extreme temperatures; does not tolerate constant wind or fog; resists pests and disease better than do other ashes; inconspicuous flowers in spring
Fraxinus pennsylvanica Green ash/red ash	Sun	To 50 feet/ To 40 ft spread	4-5 feet +	Deciduous; prefers moist soils; fast growth rate; tolerant of wind, salt, seasonal drought and urban pollution; numerous cultivars including Patmore' (50-60 ft. height), 'Summit' (to 45 ft. height), and 'Urbanite' (to 50 ft. height)
Ginkgo biloba 'Autumn Gold' Maidenhair tree	Partial sun/partial shade	25-50 feet/ 25-30 ft. spread	5-6 feet	Moist soils; deciduous ornamental tree; fast growing and long-lived; tolerant of urban pollution, summer drought and winter inundation; showy fall color; grows in soils of varying quality; provides dense canopy; additional cultivars available
Gleditsia triacanthos inermis 'Shademaster' Thornless honeylocust	Sun/partial shade	To 45 feet/ 35 ft. spread	5-6 feet	Deciduous; prefers moist, rich soils, but will grow in varying soil types; a thornless cultivar tolerant of drought and seasonal inundation; adapts to urban pollution and displays vigorous growth; deciduous tree with showy yellow fall color; additional cultivars available such as 'Imperial,' which grows 30-35 feet, 'Moraine,' and 'Rubylace'
Koelreuteria paniculata Goldenrain tree	Sun/partial sun	20-35 feet/ 10-30 ft. spread	4 feet +	Deciduous; prefers moist well-drained soils, but is tolerant of poor soils; medium rate of growth and longevity; tolerant of periods of drought and seasonal inundation; tolerates urban pollution; provides a dense, wide-spreading canopy

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Species/ **Common Name**	**Exposure**	**Mature Ht./ Spread**	**Planting Strip Width**	**Comments**
Platanus x acerifolia 'Liberty' London planetree	Sun	To 50 feet/ 45 ft. spread	8 feet	Prefers moist, rich soils, but tolerant of a variety of soils; tolerant of seasonal drought and inundation, urban pollution and poor soils; deciduous tree resistant to sycamore anthracnose, powdery mildew, and inward spread of wood decay due to trunk wounds; patchy ornamental bark; pruning of lower branches may be required for visibility; shallow roots can cause uplifting of sidewalks and pavement – use care when locating near pavement; also try 'Bloodgood' and 'Yarwood'
Pyrus calleryana 'Chanticleer' Flowering pear	Sun	To 40 feet/ 15 ft. spread	4-5 feet	Deciduous tree that grows well in a variety of soil types; orange to reddish fall color; white flowers in spring; additional cultivars of interest include *P. calleryana* 'Redspire' and 'Aristocrat'
Tilia cordata Littleleaf linden	Sun	30-50 feet/ 30 ft. spread	5-6 feet	Deciduous; prefers moist, well-drained soils, but tolerant of a variety of soil types; tolerant of wind and urban pollution; fast growing and long-lived; tolerates summer drought and seasonal inundation; provides a dense canopy; *C. cordata* is the hardiest linden; many forms available including, *T. cordata* 'Chancellor', 'Corzam', and 'Greenspire'

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LARGE TREES (50 feet+ in height)

Space evenly every 35 to 45 feet

Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
*Abies grandis** Grand Fir	Sun/partial shade	100 feet/ 40 ft. spread	Check with jurisdiction	Evergreen; tolerant of fluctuating water tables and floods; medium rate of growth; root structure depends on site conditions – shallow in moist areas, deep taproot in drier conditions
Acer platanoides 'Emerald Queen' Emerald Queen Norway maple	Sun/partial shade	To 50 feet/ 40 ft. spread	5-8 feet	Deciduous; fast growing with an erect, spreading form; prefers moist soils, but is tolerant of summer drought and seasonal inundation; tolerates urban pollution; avoid locating near structures due to shallow, vigorous rooting; additional cultivars available including *A. platanoids* 'Parkway'
Acer pseudoplatanus Sycamore maple	Sun/partial shade	40-60 feet/ 25-40 ft. spread	5-8 feet	Deciduous; prefers moist, well-drained soils but is adaptable to may soil types; tolerates summer drought and seasonal inundation; tolerant of urban pollution with a moderate growth rate; sturdy, resistant to wind and salt spray; a number of cultivars are available including: *A. pseudoplatanus* 'Atropurpureum,' ' Brilliantissimum,' 'Cox' (Lustre), and 'Puget Pink'
Acer saccharum Sugar maple		60-75 feet/ 35 ft. spread	6 feet +	Deciduous; prefers moderately moist, well-drained soils; long-lived and tolerant of urban pollutants; slow to medium growth rate; needs large planting area; yellow and orange fall color; a variety of cultivars available including *A. saccharum* 'Legacy'
*Calocedrus decurrens** Incense cedar	Sun/partial shade	75-90 feet/ 10-20 ft. spread	Check with jurisdiction	Evergreen; tolerant of poor soils; drought tolerant after established; tolerant of wind and urban conditions; narrow growth habit makes this a good choice for smaller spaces and ideal for screening, fragrant tree; slow growing and long-lived
Cedrus deodara Deodar cedar		40-60 feet/ 20-40 ft. spread	Check with jurisdiction	Evergreen; prefers moist, well-drained soils, but drought tolerant when established; fairly fast growing and long-lived; dense, wide spreading canopy; attractive cultivars available
*Fraxinus latifolia** Oregon ash	Sun/partial shade	40-80 feet/ 30 ft. spread	6 feet +	Deciduous; saturated, ponded or moist soils; flood tolerant; small green-white flowers; tolerant of poor soils
Gleditsia triacanthos inermis Thornless honeylocust	Sun/partial shade	60-70 feet/ 40 ft. spread	5-6 feet	Deciduous; prefers moist soils, but will grow in poor soils; tolerant of drought, seasonal inundation, and urban pollution; occasionally fruit pods can create litter during winter months; thornless; cultivars available (see *G. triacanthos inermis* 'Shademaster' below in Medium trees)
Metasequoia glyptostroboides Dawn redwood	Sun	70-100 feet/ 25 ft. spread	5 feet +	Deciduous; prefers moist, deep, well-drained soils, but tolerates compacted and poor soils; long-lived, fast growing conifer; tolerant of seasonal inundation and drought; can grow in standing water; needles turn russet in the fall; needs large growing area; lower growing cultivars available such as *M. glyptostroboides* 'Gold Rush' and 'Sheridan Spire'

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Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
Picea omorika Serbian spruce	Sun/partial shade	50-60 feet/ 20-25 ft. spread	Check with jurisdiction	Slow growing; tolerant of varying soils and urban pollution; moderately drought tolerant once established; elegant evergreen spruce, good for narrow locations; lower growing cultivars available
*Pseudotsuga menziesii** Douglas fir	Sun to shade	75-120 feet/ 40 ft. spread	Check with jurisdiction	Evergreen conifer; moist to dry soils; long-lived with a medium to fast rate of growth; tolerant of summer drought, winter inundation, and poor soils; withstands wind and urban pollution; provides a nice canopy, but potential height will restrict placement
Quercus bicolor Swamp white oak	Sun	60 feet/ 45 ft. spread	6-8 feet	Deciduous; grows in wet or moist sites, but is tolerant of drought conditions; withstands poorly drained soils; long-lived with moderate rate of growth
Quercus coccinea Scarlet oak	Sun	50-60 feet/ 45 ft. spread	6-8 feet	Deciduous; grows in a variety of soil types; long-lived with a moderate growth rate; tolerant of summer drought and urban pollution; does not tolerate saturated soils or shade; brilliant scarlet to red fall foliage
Quercus macrocarpa Burr Oak	Sun	70-80 feet/ 30-40 ft. spread	8 feet	Prefers moist soils, but is adaptable to varying soils; slow growing and long-lived; rugged looking deciduous tree; tolerant of seasonal drought and inundation; tolerates urban pollution and city conditions; provides a wide-spreading, dense canopy
Quercus phellos Willow oak	Sun/partial shade	60-70 feet/ 50 ft. spread	6 feet	Deciduous; prefers moist, well-drained soils, but grows in a wide range of soils types; long-lived tree with moderate growth rate and fibrous root system; tolerant of seasonal drought and inundation, as well as urban pollution; provides a wide-spreading, dense canopy; small delicate leaves
Quercus robur English oak	Sun	40-60+ feet/ 40 ft. spread	4-8 feet	Prefers well-drained soil; slow to moderate growth rate; long-lived deciduous tree; tolerant of seasonal drought and inundation; tolerates urban pollution, poor soils and constrained root space; susceptible to powdery mildew; many varieties and cultivars available including: 'Concordia,' 'Fastigiata,' 'Foliis Variegatis, and 'Westminster Globe.'
Quercus rubra Northern red oak	Sun/partial shade	60-75 feet/ 50 ft. spread	6-8 feet	Prefers moist, well-drained soils, but drought tolerant when established; tolerates seasonal inundation, urban pollution and salt spray; moderate rate of growth and longevity; provides a dense, wide-spreading canopy; susceptible to oak wilt fungus
Quercus shumardii Shumard's oak	Sun	To 70 feet/ 50 ft. spread	8 feet	Prefers moist, well-drained soils; deciduous, long-lived tree; tolerant of seasonal drought and inundation, urban pollution and poor soils
Taxodium distichum Bald cypress	Sun/partial shade	To 75 feet/ 40 ft. spread	Check with jurisdiction	Deciduous conifer; wet, mucky soils; tolerant of summer drought and seasonal flooding; will grow in poor soils; slow growing; long-lived with a wide-spreading canopy; roots do not appear to lift sidewalks as readily as other species; prune lower branches for sight-lines; cultivars include *T. distichum* 'Shawnee Brave'

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Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
*Thuja plicata** Western red cedar	Partial shade/ shade	200 + feet/ 60 ft. spread	Check with jurisdiction	Moist to swampy soils; evergreen tree tolerant of seasonal flooding and saturated soils; a good tree for screening; long-lived; cultivars 'Pumilio' and 'Cuprea' are shorter versions, 'Aurea' and 'Atrovirens' have distinctive foliage
Tilia platyphyllos Bigleaf linden	Sun	60-80 feet/ 60 ft. spread	Check with jurisdiction	Prefers moist, well-drained soils, but grows in a variety of soil types; deciduous tree with medium growth rate; long-lived; tolerant of seasonal drought and inundation; tolerates urban pollutants; provides a wide-spreading, dense canopy; yellowish-white flowers attract bees
Ulmus ssp. Elm hybrids	Sun	50-60 feet/ 35-50 ft. spread	6-8 feet	Deciduous; prefers moist, well-drained soils, but drought tolerant; rapid grower; attractive yellow fall color; a hybrid elm resistant to Dutch elm disease; suggested hybrids include 'Accolade', 'Homestead' and 'Pioneer'
Umbellularia californica Oregon myrtle	Sun/partial shade	40-75+ feet/ To 50 ft. spread	Check with jurisdiction	Prefers moist, well-drained soils; slow growing evergreen tree with aromatic leaves; tolerates seasonal drought and inundation; tolerant of urban pollution; provides a wide-spreading, dense canopy; resistant to pests and disease; good for tall hedges or, when trunks are thinned, as a street tree; requires summer watering until established

SARB_010757

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Appendix 2

Bioretention Design Examples

The following examples, from different locations in the U.S., illustrate a variety of concepts and specifications useful for developing bioretention facilities specific to local needs.

1. Bioretention Cell: Prince George's County, Maryland

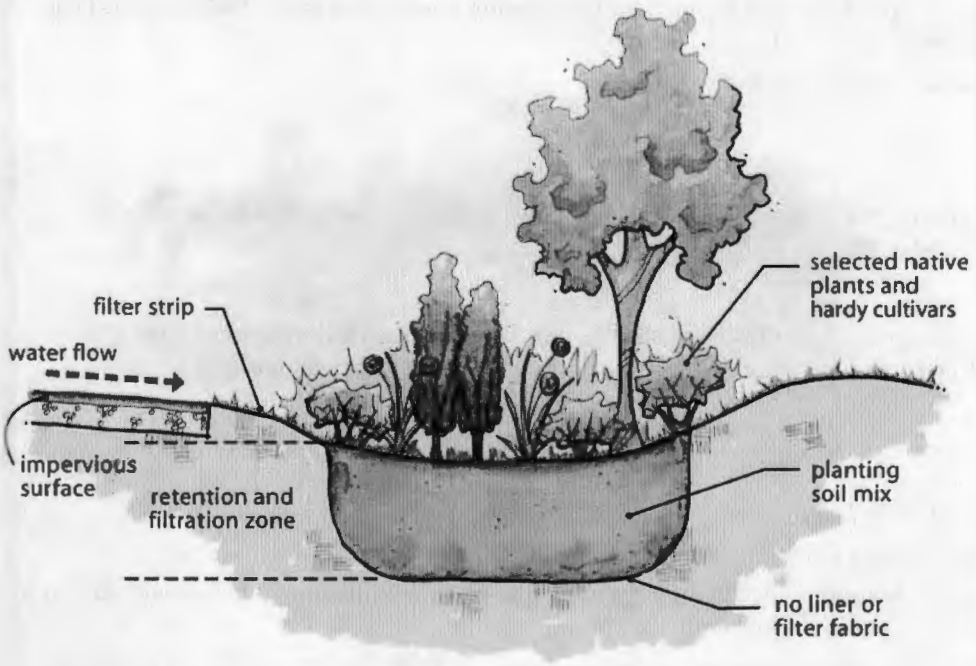

Figure 1 Typical bioretention design section.
Graphic by AHBL Engineering

Type of facility

- General application for infiltration and recharge, not recommended for contaminant hotspots.
- The initial bioretention design applied in the U.S. and the most simple design type.

Contributing area: 1-acre maximum with a maximum of ½-acre impervious area recommended.

Sizing: modified TR 55.

Flow path: off-line preferred, in-line permitted.

Planting soil depth: 2.5 feet minimum–allows for adequate filtration above native soil.

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Soil:

Native soil (outside of excavated area)

- Minimum infiltration rate of 1 inch/hour.

Planting soil mix

- 50 to 60% sand, 20 to 30% leaf compost, and 20 to 30% topsoil.
- Infiltration rate not reported; however, recommended porosity for soil mix is approximately 25%.
- Topsoil is sandy loam, loamy sand or loam texture (USDA texture triangle).
- Maximum clay content < 5%.
- pH range 5.5 to 6.5.
- Uniform mix free of stones, stumps, roots or other similar material > 2 inches.
- Clean sand (0.02 to 0.04 inches) meeting AASHTO M-6 or ASTM C-33.

Comments

This is the initial planting soil specification developed for bioretention areas in the early 1990s and has been successfully applied in facilities operating for the past 10 years.

Pretreatment: provide grass or vegetated strip if space allows.

Under-drain: none

Gravel blanket: none

Filter fabric: none unless placed along sides to reduce lateral flows under adjacent pavement areas (e.g. median strip or parking lot island).

Mulch:

- 3-inch maximum, well-aged (12 months min.) shredded hardwood (shredded minimizes floating of material during surface water ponding), use fresh bark mulch when additional nitrogen retention desirable.

Compaction:

- Place soil in lifts of 12 to 18 inches.
- Do not use heavy equipment in bioretention basin.
- If compaction occurs at bottom of facility during excavation, rip to a minimum 12 inches and till 2 to 3 inches of sand into base before backfilling.
- If final grading of soil mix cannot be accomplished by hand, use light, low ground-contact pressure equipment.

Surface pool dewater: 3 to 4 hours.

System dewater: less than 48 hours.

Max ponding depth: 6 inches.

(Prince George's County, 2002)

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2. Bioretention cell: Prince George's County, Maryland

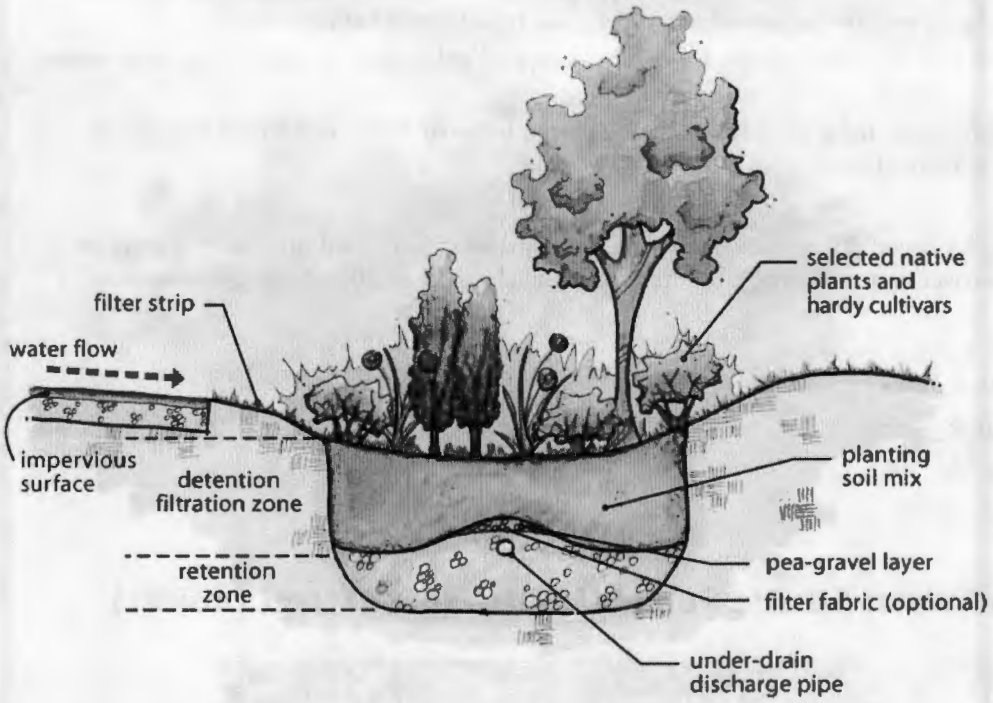

Figure 2 Bioretention design with elevated under-drain and fluctuating aerobic/anaerobic zone.
Graphic by AHBL Engineering

Type of facility:

- General application for infiltration, filtration, and recharge where high nitrogen loadings are anticipated.
- Design allows for a fluctuating aerobic/anaerobic zone below the raised under-drain discharge pipe.
- Design can be used for contaminant hotspot areas with liner.

Contributing area: 2-acre maximum with a maximum of 1-acre impervious area recommended.

Sizing: modified TR 55.

Flow path: off-line preferred, in-line permitted.

Planting soil depth: 2.5 feet minimum

Soil:

Native soil (outside of excavated area)

- Minimum infiltration rate can be less than 1 inch/hour with under-drain.

Planting soil (see Example #1)

Pretreatment: provide grass or vegetated strip if space allows.

Under-drain:

- 6 to 8-inch diameter rigid schedule 40, ½-inch perforations, 6 inches center to center.

Gravel blanket:

- Under-drain gravel bed: ½ to 1½-inch diameter washed stone AASHTO M-43.
- Pea gravel diaphragm (placed between planting soil and drain rock for improved sediment filtration): ¼ to ½-inch diameter washed stone ASTM D 448, 3 to 8 inches thick.

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Filter fabric:

- Non-woven ASTM D-4491, permittivity 75 gal/min/ft^2 minimum, installed horizontally on top of the drain rock extending 1 to 2 feet either side of under-drain pipe located below.
- Filter fabric on bottom or sides of facility is not recommended unless used to restrict lateral or vertical flow.
- If pea gravel diaphragm is used, filter fabric can be placed between drain rock and diaphragm to impede direct gravitational flow.

Mulch:

- 3-inch maximum, well-aged (12 months min.) shredded hardwood (shredded minimizes floating of material during surface water ponding), use fresh bark mulch when additional nitrogen retention desirable.

Surface pool dewater: 3 to 4 hours.

System dewater: less than 48 hours.

Max ponding depth: 6 inches.

(Prince George's County, 2002)

3. Bioretention Swale: Seattle Public Utilities (SEA Street project)



Figure 3 SEA Street bioretention swale. *Photo by Colleen Owen*

Type of facility: Redesign of 660-foot existing street using bioretention swales within right-of-way for infiltration and conveyance.

Construction date: 1999 to 2000.

Contributing area: 2.3 acres (approximately 35% total impervious area).

Sizing: Santa Barbara Unit Hydrograph.

Flow path: in-line.

Planting soil depth: approximately 1 foot.

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Soil:

Native soil

- Heterogeneous till-like material (not true lodgement till) with lens of silt, sand, and gravel material of varying permeability.

Planting soil

- Bottom of swales: 50% approved native soil and 50% decomposed organic compost by volume, thoroughly mixed. Remaining areas: 70 to 75% approved native soil and 25 to 30% compost by volume, thoroughly mixed.
- Infiltration rate not reported.

Comments

This soil specification has proven successful for infiltration requirements and plant growth and health at the SEA Street project; however, Seattle has modified the specification as noted in the Broadview Green Grid project (see example #4).

Pretreatment: none.

Under-drain:

- 6- to 8-inch slotted PVC pipe with surface drains set at designed flow depth elevations, solid iron pipe under driveways.
- Ultimate outfall to existing roadside ditch at end of block.
- Some areas lined with clay to restrict infiltration and possible subsurface flow to residential basements.

Gravel blanket: Seattle type 26 (sand gravel mix, see Section 6.1.2.3 Bioretention components for specification).

Filter fabric: none.

Mulch: 3-inch depth minimum (same as compost used for soil mix).

Compaction:

- No heavy equipment allowed in bioretention swale area during construction.
- No excavation during wet or saturated conditions.
- Soil installed in maximum lifts of 6 inches and foot compacted.

Surface pool dewater: not available.

System dewater: not available.

Max ponding depth: Live storage: 12 inches. Dead storage: 0 inches.

(Tackett, 2004; Seattle Public Utilities, 2000; personal communication, Tracy Tackett 2004)

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4. Bioretention Swale: Seattle Public Utilities (Broadview Green Grid project)



Figure 4 Broadview green grid bioretention swale. *Photo courtesy of Seattle Public Utilities.*

Type of facility: Redesign of existing streets using bioretention swales within right-of-way for infiltration and conveyance (several blocks in length).

Construction date: 2003 to 2004.

Facility depth: 1 to 2.5 feet.

Contributing area: 2.9 to 3.7 acres (34 to 42% TIA) plus 32 acres (34% TIA) east-west streets. North-south street shown in Figure 4.

Sizing: XP-WSM

Flow path: in-line.

Soil:

Native soil (outside excavation area)

- C soils (SCS)

Planting soil mix

- Three different soil mixes are used in the Broadview Green Grid project depending on required infiltration rate, load bearing, and timing of installation.

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1. Engineered Soil Mix

The Engineered Soil Mix is used in bioretention swale areas where higher infiltration rates and additional detention is desired. This mix is also used in road shoulder areas adjacent to bioretention/swales and is expected to maintain relatively good infiltration rates at 85% to 90% compaction.

- Design infiltration rate: 2 inches/hour.

Soil mix:

- 65% to 70% gravelly sand and 30% to 35% compost (see specification below).
- Gravelly sand gradation per ASTM D 422:

Sieve size	Percent Passing
2-inch	100
¾-inch	70-100
¼-inch	50-80
US No. 40	15-40
US No. 200	0-3

- The soil mixture should be uniform, free of stones, stumps, roots or other similar objects larger than 2 inches.
- On-site soil mixing or placement not allowed if soil is saturated or subject to water within 48 hours.
- Cover and store soil accordingly to prevent wetting or saturation.
- Test soil for fertility and micronutrients and, if necessary, amend mixture to create optimum conditions for plant establishment and early growth at rates recommended by an independent laboratory soil test.
- Place soil in lifts not exceeding 6 inches.

Comments

This soil specification maintains a higher infiltration rate at typical compaction rates. While the city of Seattle anticipates good performance from this specification, the mix may be slightly less optimum for plant growth than bioretention soil mixes 1 and 2 (see specification below) and has not been tested long-term for plant health performance.

2. Bioretention Soil Mix 1

Bioretention Soil Mix 1 uses on-site excavated soil mixed with compost.

Design infiltration rate: 0.3 to 1.0 inch/hour (varies with properties of native soils).

Soil mix:

- Approximately 65% approved on-site soil and 35% compost material thoroughly mixed.
- Excavated soil for mixing should be free of large woody debris or garbage (concrete or asphalt chunks, old pipe, etc.).
- Collect and test representative samples of excavated soil for gradation.
- Using on-site excavated soil is not appropriate for on-site soils with high clay content. The excavated soil should be sandy loam, loamy sand or loam texture (USDA texture triangle). The excavated soil can be amended with appropriate aggregate (e.g. sand) to achieve the appropriate texture.
- Cover and store soil accordingly to prevent wetting or saturation.
- Test soil for fertility and micronutrients and, if necessary, amend mixture to create optimum conditions for plant establishment and early growth at rates recommended by an independent laboratory soil test.
- Organic content of the soil mixture should be 8% to 12%.

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Comments

On-site excavated soil, rather than imported soil, is specified as part of an overall sustainability strategy for Seattle. Using on-site excavated soil for the amended soil mix may reduce control over gradation, organic content, and final product performance, can increase project costs, and can complicate construction logistics when attempting to blend soil mix components in restricted space (personal communication, Tracy Tackett, 2004).

3. Bioretention Soil Mix 2

Bioretention Soil Mix 2 is mixed off-site and delivered ready for installation.

Design infiltration rate: 1 inch/hour.

Soil mix:

- 65% to 70% gravelly sand and 30% to 35% compost (see specification below).
- Gravelly sand gradation per ASTM D 422.

Sieve size	Percent Passing
US No. 4	100
US No. 6	88-100
US No. 8	79-97
US No. 50	11-35
US No. 200	5-15

- Maximum clay content should be less than 5%.
- Soil mixture should be uniform, free of stones, stumps, roots or other similar objects larger than 2 inches.
- On-site soil mixing or placement not allowed if soil is saturated or subjected to water within 48 hours.
- Cover and store soil accordingly to prevent wetting or saturation.
- Test soil for fertility and micronutrients and, if necessary, amend mixture to create optimum conditions for plant establishment and early growth at rates recommended by an independent laboratory soil test.
- Organic content of the soil mixture should be 8% to 12%.

Comments

The city of Seattle uses soil mix 2 during the wet season when maintaining dry native soil for mixing on-site is difficult. Bioretention soil mix 2 is a "vegetable garden mix" supplied by Cedar Grove Composting of Washington.

Compost material (for all 3 soil mixes)

- Material must be in compliance with WAC chapter 173-350 section 220 and meet Type 1, 2, 3 or 4 feedstock.
- See Section 6.2: Amending Construction Site Soils for compost specification.

Pretreatment: none.

Under-drain:

- 6 to 8-inch slotted PVC pipe, solid iron pipe under driveways.
- Under-drains connected to next downstream swale.

Gravel blanket: Seattle type 26 (sand gravel mix, see Section 6.1: Bioretention Areas for specification).

Filter fabric: none.

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Mulch: 3-inch depth minimum. Compost used for mulch in bottom of swale and shredded tree trimmings in surrounding areas.

Compaction:

- No heavy equipment allowed in bioretention/swale area during construction.
- No excavation during wet or saturated conditions.
- Soil installed in maximum lifts of 6 inches and foot compacted.

Surface pool dewater: 24 hours.

System dewater: not reported.

Max ponding depth: 12 inches (total live and dead storage).

(Tackett, 2004; personal communication Tracy Tackett, 2004)

5. Sloped Bio*detention*: Austin, Texas



Figure 5 This sloped biodetention facility was a more cost-effective design for an Austin, Texas subdivision than a conventional pond. *Photo courtesy of Murphee Engineering.*

Type of facility: sloped biodetention using grassy vegetative barriers (hedgerows) on contour to detain storm flows and reduce pollutant loads.

Contributing area: not known.

Flow path: in-line.

Planting soil depth: 12-inch deep by 8-inch wide trenches excavated for planting vegetated barriers.

Soil:

Native soil

- C and D soils (SCS) on Karst formations.
- Infiltration rate not reported.

Planting soil:

- Native soil with slow release fertilizer.
- Infiltration rate not reported.

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Pretreatment: rock berm used as a level spreader to distribute and release flow across slope and vegetative barriers down slope.

Under-drain: none.

Gravel blanket: not applicable.

Filter fabric: none.

Mulch: none.

Hedge plantings:

- Alamo switchgrass (*Panicum zizanioides*) in 8-inch wide rows on contour.
- Species should be adapted to local soil and climate conditions, easily established, long-lived, as well as have stiff stems that remain erect through the year. Grass species that can emerge through sediment deposits and resume growth from buried stem nodes, rhizomatous or stoloniferous growth habit are desired (Natural Resources Conservation Service, 2001).
- First row receiving discharges is double planted (one row a few inches down slope of the first row) using 4-inch slips on 4-inch centers.
- Planted at 110 stems per square foot.
- Area between hedgerows planted in grass for slope and soil stability and additional filtering.

Spacing: 25 feet between hedgerows (2 to 2.5% slope). Spacing will depend on slope.

Sizing and Hedgerow length:

- 2-year design storm (2.64 inches/3 hours) used for sizing.
- Hedgerows designed to manage 0.2 cfs discharge from contributing area per foot of hedgerow.

(Murphee, Scaief and Whelan, 1997)

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Appendix 3

Bioretention Plant List

The following table includes both native and non-native plant species commonly available in the Puget Sound region and suitable for bioretention cells and swales. Individual site characteristics and goals may exclude some species or require modifications or additions to plant suggestions provided here.

Bioretention cells and swales generally feature three planting zones characterized by soil moisture and periodic inundation.

Zone 1: Area of periodic or frequent standing or flowing water. Zone 1 plants will also tolerate the seasonally dry periods of summer in the Pacific Northwest without extra watering and may also be applicable in zone 2 or 3.

Zone 2: Periodically moist or saturated during larger storms. Plants listed under Zone 2 will also be applicable in Zone 3.

Zone 3: Dry soils, infrequently subject to inundation or saturation. This area can be used to transition or blend with the existing landscape.

Special Considerations

Drought tolerance–Several plants included on the list do not tolerate dry conditions. For these plants, irrigation will be necessary during dry periods. In general, all plantings require watering during dry periods for the first two or three years after planting until established.

Placement of large trees–Consider height, spread, and extent of roots at maturity. Use caution in plant selection for areas with under-drain pipes or other structures. Lower limbs of plants placed close to a road or driveway may cause problems with visibility or safety. See Appendix 1: Street Trees for more information on tree selection and placement suggestions.

Phytoremediation–Appendix 5 includes a list of plants that have been studied for their ability to filter, absorb, and/or degrade specific contaminants. While most of these plants are not included in the following lists, varieties of some of the species known for phytoremediation are listed.

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▶ ZONE 1

* denotes native species

TREES

Species/ Common Name	Exposure	Mature Size/ Spread	Time of Bloom	Comments
*Alnus rubra** Red alder	Sun/partial shade	30-120 feet/ 25 ft. spread		Prefers moist, rich soils, highly adaptable, drought tolerant; nitrogen fixer; rapid growing, relatively short-lived (60-90 years)
*Fraxinus latifolia** Oregon ash	Sun/partial shade	40-80 feet/ 30 ft. spread		Moist, saturated or ponded soils; flood tolerant; small green-white flowers
*Malus fusca** Pacific crabapple	Sun/partial shade	To 40 feet/ 35 ft. spread	Spring	Tolerant of prolonged soil saturation; produces fruit (do not plant near public walkways)
*Salix lucida** Pacific willow	Sun	40-60 feet/ 30 ft. spread		Wet soils; tolerates seasonal flooding; should not be planted in areas near pavement or underground structures

SHRUBS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Cornus sericea** Red-osier dogwood Red-twig dogwood	Sun/partial shade	To 15 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; tolerates seasonal flooding; small white flowers; berrylike fruits
Cornus sericea 'Kelseyi' Dwarf dogwood	Sun	To 1.5 feet	June – August	Prefers wet to moist organically rich soils, but is adaptable; small white flowers; berrylike fruit; low growing, compact form; good ground cover
Cornus sericea 'Flaviramea' Yellow dogwood	Sun/partial shade	6-8 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; easily transplanted and grown; small, white flowers; yellow stems and reddish, purple fall color
Cornus sericea 'Isanti' Isanti dogwood	Sun/partial shade	4-5 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; deciduous shrub; tiny white flowers; red stems; purple fall color
*Lonicera involucrata** Black twinberry	Partial shade/shade	2-8 feet	April - May	Moist soils; prefers loamy soils; tolerant of shallow flooding; yellow, tubular flowers attract hummingbirds
*Myrica californica** Pacific wax myrtle	Sun/partial shade	To 30 feet	May - June	Evergreen shrub preferring moist soils; inconspicuous spring flowers; drought tolerant; if drought tolerance is not an issue try the smaller Washington native, *Myrica gale**
*Physocarpus capitatus** Pacific ninebark	Sun/partial shade	6-13 feet	May - June	Moist or dry soils; drought tolerant; snowball shaped; white flowers; seeds persist into winter
*Rosa pisocarpa** Clustered wild rose	Sun/partial shade	6-8 feet	May - July	Moist soils, tolerates seasonal flooding but also tolerant of dry conditions; pink clustered flowers; fruits persist
Salix purpunea 'Nana' Dwarf Arctic willow	Sun/partial shade	3-5 feet		Grows well in poor soils; moderately drought tolerant; small yellow flowers in the fall
*Spiraea douglasii** Douglas spirea Steeplebush	Sun/partial shade	4-7 feet		Moist or dry, to seasonally inundated soils; spikes of small, pink flower clusters

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▶ ZONE 1

EMERGENTS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Carex obnupta** Slough sedge	Sun/partial shade	1-5 feet		Moist to seasonally saturated soils; shiny foliage; excellent soil binder; drought tolerant
*Carex stipata** Sawbeak sedge	Partial shade	10 inches-3 feet		Wet soils; excellent soil binder
*Juncus effusus** Common rush	Sun/partial shade	1-2 feet	Summer	Wet soils; evergreen perennial; hardy and adaptable; drought tolerant; small, non-showy flowers
*Juncus ensifolius** Daggerleaf rush	Sun	12-18 inches		Wet soils; shallow water; excellent soil binder
*Juncus tenuis** Slender rush	Sun	.5–2.5 feet		Moist soils; tufted perennial
*Scirpus acutus** Hardstem bulrush	Sun	4-8 feet		Wet soils; favors prolonged inundation; excellent soil binder
*Scirpus microcarpus** Small-fruited bulrush	Sun/shade	2-4 feet		Wet soils; tolerates prolonged inundation; good soil binder; drought tolerant

▶ ZONE 2

TREES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Acer truncatum Pacific sunset maple	Sun	To 25 feet/ 20 ft. spread		Prefers moist, well-drained soils, but drought tolerant; very cold hardy; deciduous tree with moderate growth rate
*Amelanchier alnifolia** Western serviceberry	Sun/partial shade	10-20 feet/ 25 ft. spread	April - May	Moist to dry, well-drained soils; drought tolerant; large white flowers; purple to black berries; deciduous
*Corylus cornuta** Beaked hazelnut	Sun/partial shade	20–30 feet/ 15 ft. spread	April - May	Moist, well-drained soils; edible nuts; intolerant of saturated soils; catkins throughout winter add interest; deciduous
*Crataegus douglasii** Black hawthorn	Sun/partial shade	3-30 feet/ 25 ft. spread	Spring	Moist to dry, well drained, gravelly soils; small white flowers, black berries; 1" spines; forms thickets; deciduous
Fraxinus oxycarpa Raywood ash	Sun	25-50 feet/ 25 ft. spread	Spring	Drought tolerant; grows in varying soil types; deciduous; can take extreme temperatures; does not tolerate constant wind or fog; resists pests and disease better than other non-native ashes; inconspicuous flowers
*Rhamnus purshiana** Cascara sagrada	Sun/shade	20-40 feet/ 25 ft. spread		Moist to fairly dry soils; small greenish-yellow flowers; deciduous; sensitive to air pollution; yellow fall color
*Salix scouleriana** Scouler willow	Sun/partial shade	6-40 feet/ 15 ft. spread		Moist to dry soils; drought tolerant; deciduous tree; do not plant near paved surfaces or underground structures
*Salix sitchensis** Sitka willow	Sun/partial shade	3-26 feet/ 25 ft. spread		Moist soils; tolerates seasonal flooding; deciduous tree; do not plant near paved surfaces or underground structures
*Thuja plicata** Western red cedar	Partial shade/shade	200 feet+/ 60 ft. spread		Moist to swampy soils; tolerates seasonal flooding and saturated soils; long-lived; prefers shade while young

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▶ ZONE 2

SHRUBS - Deciduous

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Acer circinatum** Vine maple	Filtered sun/shade	To 25 feet	Spring	Dry to moist soils; tolerant of shade and clay soils; excellent soil binder; beautiful fall color
Hamamelis intermedia Diane Diane witchhazel	Sun/partial shade	10-20 feet/ 10 ft. spread	January - March	Moist, fertile, acidic soil; showy fall color – yellow to yellow-orange; long-lasting, slightly fragrant, coppery-red flowers; not drought tolerant; may require watering in dry season
*Oemleria cerasiformis** Indian plum/Osoberry	Sun/partial shade	5-16 feet	February - March	Moist to dry soils; prefers shade; tolerates fluctuating water table
Philadelphus x lemoinei 'Belle Etoile' Mock-orange	Sun/partial shade	5-6 feet	May - June	Prefers moist, well-drained soils, high in organic matter, but soil and pH adaptable; easily transplanted and established; fragrant, large white flowers, tinged red at the base; other cultivars available
*Ribes lacustre** Black swamp gooseberry	Partial shade	1.5–3 feet		Moist soils; deciduous shrub; reddish flowers in drooping clusters; dark purple berries; *R. divaricatum** (Wild gooseberry) grows to 5 feet and is also an option; attracts butterflies, but is very thorny
*Rosa nutkana** Nootka rose	Sun/partial shade	6-10 feet	April - June	Moist to fairly dry soils; tolerates inundation and saturated soils; aggressive spreader; fruits persist; less thorny that *R. rugosa*
Rosa rugosa Rugosa rose	Sun	To 8 feet		Drought resistant; hardy, vigorous and aggressive; highly prickly; fragrant white to purple flowers; fruits persist
*Rubus parviflorus** Thimbleberry	Sun/partial shade	4-10 feet	May - June	Moist to dry soils; white flowers; red berries; makes thickets and spreads easily
*Rubus spectabilis** Salmonberry	Partial sun/shade	5-10 feet	February - April	Prefers moist, wet soils; good soil binder; magenta flowers; yellow/ orange fruit; early nectar source for hummingbirds; makes thickets
*Sambucus racemosa** Red elderberry	Partial sun/partial shade	To 20 feet	April - May	Moist to dry soils; small white flowers; bright red berries; vase shaped; pithy stems lead to "messy" form – prune for tidiness
*Symphoricarpos albus** Snowberry	Sun/shade	2-6 feet		Wet to dry soils, clay to sand; excellent soil binder; drought and urban air tolerant; provides good erosion control; spreads well in sun; white berries; flowers attract hummingbirds
*Vaccinium parvifolium** Red huckleberry	Partial shade/shade	4-10 feet		Slightly moist to dry soils; prefers loamy, acid soils or rotting wood; tolerant of dry, shaded conditions; red fruit; tricky to transplant

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▶ ZONE 2

HERBACEOUS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Aquilegia formosa** Western columbine	Sun/partial shade	1-3 feet	Spring	Moist soils of varying quality; tolerant of seasonal flooding; red and yellow flowers attract hummingbirds and butterflies
*Asarum caudatum** Wild ginger	Partial shade/shade	To 10 inches	Mid spring	Moist organic soils; heart-shaped leaves; reddish-brown flowers
*Aster chilensis** Common California aster	Sun	1.5 - 3 feet	June - September	Moist soils; white to purple flowers
*Aster subspicatus** Douglas aster	Sun	.5 - 2.5 feet	June - September	Moist soils; blue to purple flowers
*Camassia quamash** Common camas	Sun/partial shade	To 2.5 feet	May - June	Moist to dry soils; lots of watering needed to establish; loose clusters of deep blue flowers
Camassia leichtlinii Giant camas		2-4 feet	May - June	Moist to dry soils; lots of watering to establish; large clusters of white, blue or greenish-yellow flowers
*Iris douglasiana** Pacific coast iris	Sun/partial shade	1-2 feet	Spring	Tolerates many soils; withstands summer drought and seasonal flooding; white, yellow, blue, reddish purple flowers; fast growing; velvety purple flowers; vigorous
Iris foetidissima Gladwin iris	Sun/partial shade	1-2 feet	May	Moist to dry, well-drained soils; pale lilac flower; also called Stinking Iris
*Juncus tenuis** Slender rush	Sun	6 inches - 2.5 feet		Moist soils; yellow flowers
Iris sibirca Siberian Iris	Sun	1-2.5 feet	Late spring - early summer	Moist soils; deep blue, purple to white flowers
*Tellima grandiflora** Fringecup	Partial sun/shade	1-3 feet	March - June	Perennial preferring moist soils; yellowish-green to pink flowers
*Tiarella trifoliata** Foamflower	Partial sun/shade	To 1 foot	Early - mid summer	Moist soils; perennial with some drought tolerance after established; can form dense colonies; white flowers
*Tolmiea menziesii** Youth-on-age/Piggy-back plant	Partial shade/shade	1-2 feet	April - August	Moist soils; brownish-purple flowers; also makes and effective groundcover
Viola species* Violets	Partial shade/shade	6-12 inches	Late spring - early summer	Moist soils; yellow to blue flowers

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▶ ZONE 3

TREES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Arbutus unedo Strawberry tree	Sun/partial shade	8-35 feet/ 8-20 ft. spread	November - December	Tolerant of extremes; tolerant of urban/ industrial pollution; white or greenish white flowers
*Calocedrus decurrens** Incense cedar	Sun	75-90 feet/ 12 ft. spread		Tolerant of poor soils; drought tolerant after established; fragrant evergreen with a narrow growth habit; slow growing
Chamaecyparis obtusa Hinoki false cypress	Sun/partial shade	40-50 feet/ 15-30 ft. spread		Moist, loamy, well-drained soils; very slow growing; prefers sun, but tolerates shade; does not transplant well or do well in alkaline soils. Note there are many alternative varieties of false cypress of varying sizes and forms from which to choose
Cornus spp. Dogwood	Sun/partial shade	20-30 feet/ 30 ft. spread	May	Reliable flowering trees with attractive foliage and flowers; may need watering in dry season; try *C. florida* (Eastern dogwood), or *C. nuttallii** (Pacific dogwood) or hybrid 'Eddie's White Wonder'. Also, *C. kousa* for small tree/ shrub which is resistant to anthracnose
Pinus mugo Swiss mountain pine	Sun/partial shade	15-20 feet/ 25-30 ft. spread		Prefers well-drained soil; slow growing, broadly spreading, bushy tree; hardy evergreen
Pinus thunbergiana Japanese black pine	Sun	To 100 feet/ 40 ft. spread		Dry to moist soils; hardy; fast growing
*Prunus emarginata** Bitter cherry	Sun/partial shade	20-50 feet/ 20 ft. spread	May - June	Dry or moist soils; intolerant of full shade; bright red cherries are attractive to birds; roots spread extensively
Prunus virginiana Choke cherry		15-25 feet/ 15-20 ft. spread	Late spring – Early summer	Dry or moist soils; deep rooting; attractive white fragrant flowers; good fall color
*Pseudotsuga menziesii** Douglas-fir	Sun	100-250 feet/ 50-60 ft. spread		Does best in deep, moist soils; evergreen conifer with medium to fast rate of growth; provides a nice canopy, but potential height will restrict placement
*Quercus garryana** Oregon white oak	Sun	To 75 feet		Dry to moist, well-drained soils; slow growing; acorns

SHRUBS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Holodiscus discolor** Oceanspray	Sun/partial shade	To 15 feet	June - July	Dry to moist soils; drought tolerant; white to cream flowers; good soil binder
*Mahonia aquifolium** Tall Oregon grape	Sun/partial shade	6-10 feet	March - April	Dry to moist soils; drought resistant; evergreen; blue-black fruit; bright yellow flowers; 'Compacta' form averages 2 feet tall; great low screening barrier
*Philadelphus lewisii** Mock-orange	Sun/partial shade	5-10 feet	June - July	Adapts to rich moist soils or dry rocky soils; drought tolerant; fragrant flowers

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▶ ZONE 3

SHRUBS Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Pinus mugo pumilio Mugho pine	Sun	3-5 feet/ 4-6 ft. spread		Adapts to most soils; slow growing and very hardy; newer additions with trademark names such as 'Slo-Grow' or 'Lo-Mound' are also available
Potentilla fruticosa Shrubby cinquefoil	Sun	To 4 feet	May - September	Moist to dry soils; several cultivars available with varying foliage and flower hues; try 'Tangerine' or 'Moonlight'
*Ribes sanguineum** Red-flowering currant	Sun/partial shade	8-12 feet	March - April	Prefers dry soils; drought tolerant; white to deep-red flowers attract hummingbirds; dark-blue to black berries; thornless
*Rosa gymnocarpa** Baldhip rose	Partial shade	To 6 feet	May - July	Dry or moist soils; drought tolerant; small pink to rose flowers

SHRUBS-Evergreen Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Abelia x grandiflora Glossy abelia	Partial Sun/Partial shade	To 8 feet/ 5 foot spread	Summer	Prefers moist, well-drained soils, but drought tolerant; white or faintly pink flowers
Arbutus unedo 'Compacta' Compact strawberry tree	Sun/partial shade	To 10 feet	Fall	Prefers well drained soils; tolerant of poor soils; good in climate extremes; white to greenish-white flowers; striking red-orange fruit
Cistus purpureus Orchid rockrose	Sun	To 4 feet	June - July	Moist to dry well-drained soils; drought resistant; fast growing; reddish purple flowers
Cistus salvifolius White rockrose	Sun	2-3 feet/ 6 ft spread	Late spring	Moist to dry well-drained soils preferred, but can tolerate poor soils; tolerant of windy conditions and drought; white flowers
Escallonia x exoniensis 'fradesii' Pink Princess	Sun/partial sun	5-6 feet	Spring - Fall	Tolerant of varying soils; drought tolerant when established; pink to rose colored flowers; good hedge or border plant; attracts butterflies
Osmanthus delavayi Delavay Osmanthus	Sun/partial shade	4-6 feet	March - May	Tolerant of a broad range of soils; attractive foliage and clusters of white fragrant flowers; slow growing
Osmanthus x burkwoodii Devil wood	Sun/partial shade	4-6 feet	March - April	Drought tolerant once established; masses of small, white fragrant flowers
Rhododendron 'PJM' hybrids	Sun/partial shade	To 4 feet	Mid - late April	Moist to fairly dry soils; well drained organic soil; lavender to pink flowers
Stranvaesia davidiana	Sun	6-20 feet	June	Moist soils; white flowers in clusters; showy red berries
Stranvaesia davidiana undulata	Sun	To 5 feet	June	Moist soils; lower growing irregularly shaped shrub; great screening plant
*Vaccinium ovatum** Evergreen huckleberry	Partial shade/ shade	3-15 feet	March	Moist to slightly dry soils; small pinkish-white flowers; berries in August

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▶ ZONE 3

GROUNDCOVER - Evergreen

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Arctostaphylos uva-ursi** Kinnikinnik	Sun/partial shade		April - June	Prefers sandy/rocky, well-drained soils; flowers pinkish-white; bright red berries; slow to establish; plant closely for good results
*Gaultheria shallon** Salal	Partial shade/ shade	3-7 feet	March - June	Dry and moist soils; white or pinkish flowers; reddish-blue to dark-purple fruit
*Fragaria chiloensis** Wild/Coastal strawberry	Sun/partial shade	10 inches	Spring	Sandy well drained soils; flowers white; small hairy strawberries; evergreen; aggressive spreader
Helianthemum nummularium Sunrose	Sun	To 2 feet/ 2 ft. spread	May - July	Prefers well-drained soils, but will tolerate various soils; low-growing, woody sub shrub; many varieties are available with flowers in salmon, pink, red, yellow and golden colors
Lavandula angustifolia Lavender	Sun/partial shade	To 1.5 feet	June - August	Adaptable to various soils; blue, lavender, pink to white flowers, semi-evergreen aromatic perennial
*Mahonia nervosa** Cascade Oregon grape/Dull Oregon grape	Partial shade/ shade	To 2 feet	April – June	Dry to moist soils; drought resistant; evergreen; yellow flowers; blue berries
Mahonia repens Creeping mahonia	Sun/partial shade	3 feet	April - June	Dry to moist soils; drought resistant; yellow flowers; blue berries; native of Eastern Washington
*Penstemon davidsonii** Davidson's penstemon	Sun	To 3 inches	June - August	Low growing evergreen perennial; prefers well-drained soils; drought tolerant; blue to purple flowers

PERENNIALS & ORNAMENTAL GRASSES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Achillea millefolium** Western yarrow	Sun	4 inches - 2.5 feet	June - September	Dry to moist, well-drained soils; white to pink/reddish flowers; many other yarrows are also available
Anaphalis margaritaceae Pearly everlasting	Sun/partial shade	To 18 inches		Drought tolerant perennial; spreads quickly; attracts butterflies
*Bromus carinatus** Native California brome	Sun/partial shade	3-5 feet		Dry to moist soils; tolerates seasonal saturation
Carex buchannii Leather leaf sedge	Sun/partial shade	1-3 feet		Prefers well-drained soils; copper-colored foliage; perennial clumping grass; tolerant of a wide range of soils; inconspicuous flowers
Carex comans 'Frosty curls' New Zealand hair sedge	Sun/partial shade	1-2 feet	June - August	Prefers moist soils; finely textured and light green; compact, clumping perennial grass; drought tolerant when established; inconspicuous flowers

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PERENNIALS & ORNAMENTAL GRASSES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Coreopsis spp.	Sun	1-3 feet		Dry to moist soils; drought tolerant; seeds attract birds; annual and perennial varieties; excellent cut flowers
Echinacea purpurea Purple coneflower	Sun	4-5 feet		Prefers well drained soils; hardy perennial; may need occasional watering in dry months
*Elymus glaucus** Blue wildrye	Sun/partial shade	1.5-5 feet		Dry to moist soils; shade tolerant; rapid developing, but short lived (1-3 years); not good lawn grass
*Dicentra formosa** Pacific bleeding-heart	Sun/shade	6-20 inches	Early spring - early summer	Moist, rich soils; heart-shaped flowers
*Erigeron speciosus** Showy fleabane	Sun/partial shade	To 2 feet	Summer	Moist to dry soils; dark violet or lavender blooms; fibrous roots
Festuca ovina 'Glauca' Blue fescue	Sun/partial shade	To 10 inches	May - June	Prefers moist, well-drained soils; blue-green evergreen grass; drought tolerant; shearing will stimulate new growth
*Festuca idahoensis** Idaho fescue	Sun/partial shade	To 1 foot		Bluish-green bunching perennial grass; drought tolerant
*Fragaria vesca** Wood strawberry	Partial shade	To 10 inches	Late spring - early summer	Dry to moist soils; white flowers
Gaura lindheimeri Gaura	Sun	2.5-4 feet		Perennial; fairly drought tolerant and adaptable to varying soil types; long blooming period
*Geum macrophyllum** Large-leaved avens	Sun/partial shade	To 3 feet	Spring	Moist, well-drained soil; bright yellow flowers; other *Geum* cultivars available, some which may require supplemental watering
Geranium maculatum Spotted geranium	Sun/shade	To 1.5 feet	July	Moist, well-drained soils; low perennial; pale pink, blue to purple flowers
Geranium sanguineum Cranesbill	Sun/partial shade	To 1.5 feet	May - August	Moist soils; deep purple almost crimson flowers
Helichrysum italicum Curry Plant	Sun	To 2 feet	Summer	Moist or dry soils; hardy evergreen perennial; a good companion to lavender; bright yellow flowers; fragrant
Helictotrichon sempervirens Blue oat grass	Sun/partial shade	1-1.5 feet	June - August	Tolerant of a variety of soil types but prefers well-drained soil; clumping bright blue evergreen grass; bluish white flowers
Hemerocallis fulva Day lilies	Sun/partial shade	1-4 feet	Summer	Tolerant of a variety of soil types; easy to grow and tolerant of neglect; hardy perennial; entire plant is edible
Heuchera americana Coral bells (alumroot)	Sun/partial shade	1-2 feet	June - August	Moist to dry, well-drained soils; never wet; easily transplantable perennial; red, greenish-white flowers; may need supplemental watering in dry season
Heuchera micrantha 'Palace purple' (alumroot)	Sun/partial shade	1-2 feet	June - August	Moist, well-drained soils; bronze to purple foliage in shade; small, yellowish-white flowers; perennial, evergreen; a number of other species and varieties are available. Try *H. sanguinea* for bright red flowers
*Lupinus** spp. Lupines	Sun	3-5 feet	March - September	Moist to dry soils; various native varieties; blue to purple, violet to white flowers; both native and non-native varieties

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PERENNIALS & ORNAMENTAL GRASSES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Lupinus bicolor** Two-color lupine	Sun	4 inches-1.5 feet	Spring	Dry gravelly soils; small-flowered; annual
*Lupinus latifolius** Broadleaf lupine	Sun	To 1 foot	June - August	Dry to moist soils; perennial; bushy herb; bluish flowers
*Lupinus polyphyllus** Large-leafed lupine	Sun	To 3 feet	Spring - summer	Dry to moist, sandy to gravelly soils; perennial
*Maianthemum dilatatum** False lily-of-the-valley	Partial shade/ shade	3-12 inches	Spring	Prefers moist soils; small, white flowers; light-green to red berries
Pennisetum alopecuroides Fountain grass	Sun/partial shade	1-2 feet	August - September	Moist, well-drained soils; tolerant of many soil types; clump-forming grasses. A number of varieties are available in different heights and bloom times. Try *P. caudatum* (White-flowering fountain grass) and *P. alopecuroides* cultivars 'Hameln' and 'Little Bunny' (Dwarf fountain grass)
Pennisetum orientale Oriental fountain grass	Sun/partial shade	1-3 feet	June - October	Prefers moist, well-drained soils; somewhat drought tolerant; small clumping, blooming grass, showy pink flowers; fountain grasses will benefit from annual shearing in late winter/early spring, but not required
Penstemon fruticosus Shrubby penstemon	Sun	8-10 inches	May	Prefers well-drained soils; evergreen perennial; drought tolerant; violet-blue flowers 1" long attract hummingbirds
*Polystichum munitum** Swordfern	Partial shade/ Deep shade	2-4 feet		Prefers moist, rich soil conditions, but drought tolerant; large evergreen fern
*Potentilla gracilis** Graceful cinquefoil	Sun	1-2 feet	July	Moist to dry soils; yellow flowers
Rudbeckia hirta Black-eyed susan	Sun/partial shade	3-4 feet	Summer	Moist to dry soils; showy flowers, hardy and easy to grow; several other varieties are available
*Smilacina racemosa** False Solomon's seal	Partial sun/shade	1-3 feet	April - May	Moist soils; creamy white flowers; red berries
*Solidago canadensis** Canadian goldenrod	Sun/partial shade	1-2 feet	Late summer - early fall	Dry to moist soils; yellow flowers

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Bog Garden Plants

A bog garden presents a unique design option for managing stormwater on site. A lined depression filled with an organic soil mix and wetland vegetation can be an attractive method for promoting evaporation and transpiration of collected runoff. A functioning bog garden generally displays no standing water, but soils are saturated much of the time, necessitating facultative wetland plant selections.

To select plant species appropriate for a bog garden refer to those listed in this appendix, **Zone 1**, as well as those found in the following table. The list below includes additional native and non-native plant species (not listed in the bioretention plant list) that have been successfully applied in Pacific Northwest bog gardens. It may be necessary to provide additional water to the bog system during seasonal dry periods due to a lack of stormwater runoff.

As with any system, plant species in a bog garden setting have various preferences for moisture and sun. Check listed comments below and research plant needs to optimize growth in the conditions specific to individual bog garden systems.

Bog Garden

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Adiantum aleuticum** Western maidenhair fern	Shade/partial shade	1-2 feet		Moist to wet soils; graceful, delicate fern; vivid bright green with black stems; spreads through creeping rhizomes; often called *A. pedatum*, but this refers to the related East Coast maidenhair fern; also try *A. capillis-veneris* (Venus-hair fern)
*Andromeda polifolia** Bog rosemary	Sun/partial shade	1-1.5 feet	Spring	Moist to wet soils; low-growing evergreen shrub; white to pink flower clusters; ornamental varieties include 'Blue Ice', 'Grandiflora' and 'Nana'
*Blechnum spicant** Deer fern	Shade/partial shade	1-3 feet		Moist to wet soils; has both evergreen and deciduous leaves; prefers soils high in organic material; is sensitive to frost
Carex spp. Sedges	Sun/shade	varies		A number sedge choices are great options for a bog garden setting; two are listed in Zone 1 of this appendix, but there are many alternative species to investigate, including *Carex mertensii** (Mertens' sedge) and *C. lyngbyei** (Lyngby's sedge)
*Eleocharis palustris** Creeping spike-rush	Sun	To 3.5 feet		Wet soils to shallow water; perennial forming small clumps
*Empetrum nigrum** Crowberry	Sun	To 8 inches	Early spring	Dry to wet/boggy soils; low-growing evergreen shrub; small purplish flowers and purplish-black berries
*Equisetum hyemale** Scouring-rush	Sun/partial shade	2-5 feet		Moist to wet soils; hollow-stemmed, evergreen perennial; spreads through creeping rhizomes; vigorous and persistent; with high silica content; also *E. scirpoides* (Dwarf horsetail); use both with caution - *Equisetum* can be very invasive and difficult to remove once established
*Gaultheria ovatifolia** Oregon wintergreen/ Western teaberry	Partial shade	To 1 foot	Late spring - summer	Moist to wet soils; low-growing evergreen shrub; pink or whitish flowers and red berries; also *G. humifusa** (Alpine wintergreen)
*Glyceria elata** Tall mannagrass	Sun/partial shade	3-4.5 feet		Moist to wet soils; loosely tufted perennial, spreads through creeping rhizomes; also try the taller *G. grandis** (Reed mannagrass)

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Bog Garden

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Gunnera manicata Gunnera	Sun/partial shade	4-6 feet/ 4-8 ft. spread		Moist to wet organic soils; prefers humid setting; non-native from Brazil and Columbia needing mulching protection in the winter; also referred to as 'giant rhubarb'; huge rounded leaves; needs plenty of space; also *G. tinctoria* from Chile
Hakonechloa macra Japanese forest grass	Shade/partial shade	1-3 feet		Prefers moist, rich soil; slowly spreading perennial grass; green leaves turn coppery orange in the fall
Hosta Plantain lily	Shade/partial sun	To 2.5 feet	Summer	Prefer moist, rich soil; many varieties and hybrids available in a various sizes, foliage textures and colors; thin spikes of blue or white flowers; some are tolerant of sun, but most prefer shade
Juncus spp. Rushes	Sun/shade	varies		As with the *Carex* species, there are a number of native rushes that would work well in a bog garden. Three options are listed in Zone 1 of this appendix. Others to investigate include *Juncus mertensianus** (Mertens' rush) and *J. acuminatus** (Tapered rush)
*Kalmia occidentalis** Swamp-laurel	Sun	.5-2 feet	Spring - early summer	Also known as *K. polifolia*, prefers moist soils; low shrub with aromatic leaves; rose-purple flowers; also try *K. microphylla** (Western bog-laurel) a mat-forming, evergreen shrublet; generally found in wet subalpine conditions
*Ledum groenlandicum** Labrador tea	Shade/partial sun	1.5-4.5 feet	Summer	Moist to boggy soils; evergreen shrub with small white flower clusters; foliage aromatic when crushed
Ligularia dentata Bigleaf ligularia	Shade/partial shade	3-5 feet	Summer	Moist to wet soils; large-leaved, clumping perennial; yellow-orange blooms; not tolerant of high heat or low humidity; try *L. dentata* cultivars 'Othello' and 'Desdemona'; also *L. przewalskii* (Shavalski's ligularia) and *L. stenocephala* (Narrow-spiked ligularia)
*Linnaea borealis** Twinflower	Shade/partial shade	4-6 inches	June - September	Moist or dry soils; evergreen perennial; pink, fragrant, trumpet-like flowers; trailing ground cover; try *L. borealis* on the less saturated margins of a bog garden; may be difficult to establish
Lobelia cardinalis Cardinal flower	Sun/partial shade	2-4 feet	Summer	Wet to moist, rich soils; clumping perennial; tubular, bright red, inch-long flowers; also try *L. siphilitica* (Blue lobelia), another perennial with blue flowers
*Lysichiton americanum** Skunk cabbage	Shade/partial shade	2-3 feet	March	Prefers wet soils; deciduous perennial; has odor that some consider to be skunky especially when blooming; yellow hooded fleshy flower spike; great leaves dominate
Matteuccia struthiopteris Ostrich fern	Sun/shade	To 6 feet		Moist, rich soils; hardy northern fern; clumping narrowly at base with foliage spreading to 3 feet in width
Mimulus spp. Monkey-flower	Sun/partial shade	1-3 feet	Spring-summer	Wet soils; perennial or annual that reseeds nicely and keeps spreading; many species available including natives, *M. guttatus** (Yellow monkey-flower) and *M. tilingii** (Mountain monkey-flower); also *M. lewisii** with rose-red to pale-pink flowers

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Bog Garden Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Myrica gale** Sweet gale	Sun/partial shade	To 4 feet		Moist to wet soils; aromatic, deciduous perennial shrub; glossy green leaves; a nitrogen fixing species
Oplopanax horridum Devil's club	Shade/partial sun	3-10 feet		Moist to wet soils; forms extensive clumps; aggressive grower, but huge palmate leaves highly decorative; clusters of small whitish flowers; wand-like stems have sharp spines
Osmunda cinnamomea Cinnamon fern	Sun/partial shade	2-5 feet		Moist to wet soils; large deciduous fern; unfolding 'fiddlehead' fronds are edible
*Oxycoccus oxycoccos** Bog cranberry	Sun	4-16 inches		Moist to wet soils, prefers *Sphagnum* moss mats, peat and acidic conditions; evergreen, low-creeping vine-like shrub; pink to red flowers; red berries; shade intolerant
*Polystichum munitum** Sword fern	Shade/partial shade	2-5 feet		Moist soils; large evergreen fern; dark green fronds with dagger shaped leaflets; hardy and easy to grow
*Potentilla palustris** Marsh cinquefoil		To 3 feet		Moist to wet soils; perennial with reddish-purple flowers; stems both prostrate and ascending
*Ribes divaricatum** Wild gooseberry	Partial shade/shade	1.5-6.5 feet		Prefers wet or moist soils; green or purple flowers and smooth, dark purple berries; a hedge or screen provides good habitat for birds and wildlife; beware prickly spines; also try *R. lacustre** (Black gooseberry)
*Salix arctica** Arctic willow	Sun/shade	To 2 feet	Spring	Moist soils; deciduous, prostrate or trailing shrub; leaves are dark green on the bottom and lighter on top; brownish to pink flowers; see Zone 1 of this appendix for details on *S. purpurea* 'Nana'
*Trientalis arctica** Northern starflower	Shade/partial shade	To 8 inches		Wet, boggy soils; small perennial; star-shaped white flowers, or with a pink tinge

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Appendix 4 Bioretention Cell and Bioretention Swale Research: Flow Control and Pollutant Removal Capability

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Davis, A.P., Shokouhian, M., Sharma, H., & Minami, C. (2001 January/February). Laboratory study of biological retention for urban stormwater management. *Water Environment Research, 73,* 5-14.	Laboratory	Two laboratory-scale bioretention boxes were constructed with perforated pipes at 2 different depths to collect effluent. Synthetic stormwater runoff was applied at specific flow rates and durations, and pollutant removal assessed. Soil composition: sandy loam (pH 6.4, CEC 2.9 meq/100 g soil, organic matter content 0.6%) with shredded hardwood bark mulch topcoat. Boxes included creeping juniper plantings.	Pollutant removal: • Copper: 89 to 98%. • Lead and Zinc: > 97 to 98% (lower ports below detectable limits). • Ammonium: -8 to 54% upper ports, 60 to 79% lower ports. • Nitrate: -96% upper port, 24% lower port, (large box only). • Phosphorous: 16 to 73% upper and mid ports, 71 to 81% lower ports.	• High metal removal in upper layers of large and small box. Removal did not increase much with depth. • Significant metal accumulation found in mulch layer samples. • Nutrient removal more variable than metals. Removal increased with depth. • 98 effluent samples taken from upper and lower pipes in the small box and 80 samples from the large box.
Davis, A..P., Shokouhian, M., Sharma, H., Minami, C., & Winogradoff, D. (2003 January/February). Water quality improvement through bioretention: Lead, copper, and zinc removal. *Water Environment Research, 75,* 73-82.	Laboratory and field	Two laboratory-scale bioretention boxes were constructed with perforated pipes at 2 different depths to collect effluent. Synthetic stormwater runoff was applied at varying flow rates, flow durations, metal concentrations, and pH to assess pollutant removal. Soil composition: sandy loam topped with 2.5 cm of mulch. Boxes included creeping juniper plantings. Additionally, synthetic stormwater runoff was applied and effluent measured at 2 field sites with bioretention facilities.	Pollutant removal: Lab • Copper: 87% to 98%. • Lead: 92% to 98%. • Zinc: 85% to 98%. Field Greenbelt facility: • Copper: 97%, lead: 95%, zinc: 95%. Largo facility: • Copper: 43%, lead: 70%, zinc: 64% cadmium: 27%, total phosphorous: 87%, TKN: 67%, nitrate: 15%.	Lab: • Removal for metals was excellent and similar to initial study (see above). • Removal at upper ports was affected slightly by flow rate and duration. • Removal at lower ports was not affected by flow rate and duration. • Removal at upper ports was affected slightly by pH and concentration. • Removal at lower ports was not affected by flow, pH and concentration (soil likely buffering pH changes). Field: • Greenbelt facility showed good agreement with lab analysis. • Largo removal was significantly lower and speculatively attributed to Greenbelt being an older facility with mature groundcover and having a higher fraction of fines in the soil.

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REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Kim, H., Seagren, E.A., & Davis, A.P. (2003, July/August). Engineered bioretention for removal of nitrate from stormwater runoff. *Water Environment Research, 75*, pp. 355-367.	Laboratory	A laboratory pilot-scale bioretention cell engineered with an anoxic zone at bottom of cell was constructed to assess nitrate removal potential (this phase was part of a larger nitrate removal study). A sand layer mixed with newspaper (electron donor for denitrification process) was placed at bottom of cell and used as a saturated anoxic zone. Synthetic stormwater was applied to the cell and effluent collected after passing through sand layer.	Pollutant removal: • First 2-3 hours no nitrate or nitrite observed in effluent during applications at 7 and 42 days after system inoculation. • After 2-3 hours removal for nitrate and nitrite were 70% to 80% for the 7 to 8-hour stormwater applications.	• No nitrate or nitrate in the effluent for the first 2 to 3 hours likely attributed to the following: The amount of effluent released during that period was water stored in system from previous application; accordingly, that water had a longer period exposed to the anoxic zone favorable to denitrification. • Pilot-scale bioretention cell performance suggests that incorporating an anoxic zone in the bottom of bioretention area can be effective for removing nitrate.
Horner, R., Lim, H., & Burges, S.J. (2002, November). *Hydrologic monitoring of the Seattle Ultra-Urban stormwater management projects* (Water Resources Series Technical Report No. 170). Seattle, WA: University of Washington.	Field	660 feet of residential road was narrowed and linear bioretention/ bioswales were installed within the right-of-way. A v-notch weir installed at the ultimate outfall of the project measured surface flow volumes and timing. Flows for the conventional pre-construction street were compared to the retrofit design.	Pre-construction (March-July 2000): • Rainfall: 7.96 inches. • Runoff: 4979 cubic feet. Post construction (March-July 2001): • Rainfall: 9.00 inches. • Runoff: 132 cubic feet. Oct 20 2003 record storm event: • Rainfall: 4.22 inches (32.5 hour storm duration). • Runoff: none.	• Approximately 97% reduction in surface flow volume was recorded from pre- to post-construction conditions. • Contributing area is approximately 2.3 acres and total impervious area is approximately 35%. Total rooftop contribution reaching the streets, swales and monitoring station is not known.

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REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Hon G, E., Seagren, E., Davis, A. P. (2002, June). Sustainable Oil and Grease Removal from Stormwater Runoff Hotspots using Bioretention. Paper for the *74th Annual Conference and Exhibition of the Pennsylvania Water Environment Association*. State College, PA.	Laboratory	The research examined the capacity of a mulch layer to capture oil and grease (O&G) via sorption and filtration. Simulated stormwater runoff carrying selected hydrocarbons was applied to a bench-scale "reactor" with a 3-cm thick leaf compost layer. Stormwater was applied at a rate of 4 cm/hr for 6 hours resulting in a naphthalene concentration of 1.7-2.4 mg/L. To distinguish biodegradation and other removal pathways, experiments with and without microbe populations were conducted. Mulch samples were analyzed for contaminants, volatilized hydrocarbons captured, and microbial population counts conducted to correlate with biodegradation rates.	During simulated storm event: • Approximately 90% removal of dissolved naphthalene from aqueous phase via sorption. After storm event (37 and 40 hours): • Abiotic experiment: approximately 32% removal via biodegradation in the mulch layer. • Biotic experiment: approximately 72% removal via biodegradation in the mulch layer. After storm event (74 hours): • Biotic experiment: approximately 95% removal via biodegradation in the mulch layer. Losses due to volatilization were negligible.	• Naphthalene, in dissolved and particulate-associated phases, was selected because of its toxicity and common presence in stormwater. • Research was designed to test bioretention in automotive-intensive hotspots such as gas stations. • The native microbial population in the mulch was capable of biodegradation and inoculation with specific microorganisms to degrade O&G was not necessary. • The change in microbial numbers corresponded to the loss of naphthalene (i.e., microbial numbers were highest when the most naphthalene was degraded).

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Appendix 5

Phytoremediation

The presence of vegetation can have various effects on contaminants in soil or water. Studies indicate that vegetated soils are capable of more effective degradation, removal, and mineralization of total petroleum hydrocarbons (TPHs), polycyclic aromatic hydrocarbons (PAHs), pesticides, chlorinated solvents, and surfactants than are nonvegetated soils (US EPA, 2000). Certain plant roots can absorb or immobilize metal pollutants including cadmium, copper, nickel, zinc, lead, and chromium, while other plant species are capable of metabolizing or accumulating organic and nutrient contaminants. An intricate and complex set of relationships and interactions between plants, microbes, soils, and contaminants make these various phytoremediation processes possible.

The term phytoremediation is a combination of the Greek prefix *phyto*, for plant, and the Latin root *remidium*, "to correct or remove an evil". Defined, phytoremediation is the utilization of vascular plants, algae, and fungi to control, break down, or remove wastes, or to encourage degradation of contaminants in the rhizosphere, or root region of the plant (McCutcheon & Schnoor, 2003). Phytoremediation processes are most effective where contaminants are present at low to medium levels, as high contaminant levels can inhibit plant and microbial growth and activity (US EPA, 2000).

Metals, organics, and inorganic contaminants in stormwater and soils can be subject to:

- Degradation.
- Extraction by the plant.
- Containment within the plant.
- A combination of these mechanisms.

Plant processes that promote the removal of contaminants from soil and water are either direct or indirect. Direct processes include plant uptake into roots or shoots and transformation, storage, or transpiration of the contaminant (Hutchinson et al., 2003). Indirect plant processing involves the degradation of contaminants by microbial, soil, and root interactions within the rhizosphere (Hutchinson).

1. Degradation *(rhizodegradation, phytodegradation, phytovolatilization)*

Table 1 Phytoremediation processes contributing to degradation or transformation of contaminants in soil and water.

Type	Process	Appropriate contaminants
Rhizodegradation (Plant-assisted bioremediation, phytostimulation)	Plant exudates and other processes enhance soil bacterial growth, spur degradation by mycorrhizal fungi and microbes, and add aeration channels and oxygen to soils	Petroleum hydrocarbons, BTEX, PAHs, PCP, perchlorate, pesticides, PCBs and other organic compounds
Phytodegradation	Aquatic and terrestrial plants take up, store and biochemically degrade or transform organic compounds	Chlorinated solvents, methyl bromide, atrazine, DDT, tetrabromoethene, tetrachloroethane, dichloroethene, Cl and P-based pesticides, PCBs, phenols, anilines, nitriles, nutrients
Phytovolatilization	Plants take up volatile metals and organic compounds and transpire or diffuse contaminant or modified form of contaminant out of roots, leaves or stems	Arsenic, tritium, Se, mercury, m-xylene, chlororbenzene, tetrachloromethane, trichloromethane, trichloroethane, and other chlorinated solvents

(Adapted from information in US EPA, 2000)

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The rhizosphere, or area of soil 1 mm from the plant root, is a dynamic and intricately complex environment (Olson et al., 2003). Increased microbial activity and biomass in this area of plant-microbe interaction has become recognized as the "rhizosphere effect" and is critical for rhizosphere bioremediation to take place (Olson et al.). Plant roots exude enzymes and other organic substances. These releases dramatically enhance microbial numbers and metabolic activity, and increase contaminant degradation and the availability of substances for uptake by the roots (Christensen-Kirsh, 1996). The process of breaking down an organic contaminant in soils through active microbial behavior enhanced by the rhizosphere is known as *rhizodegradation* (McCutcheon & Schnoor, 2003).

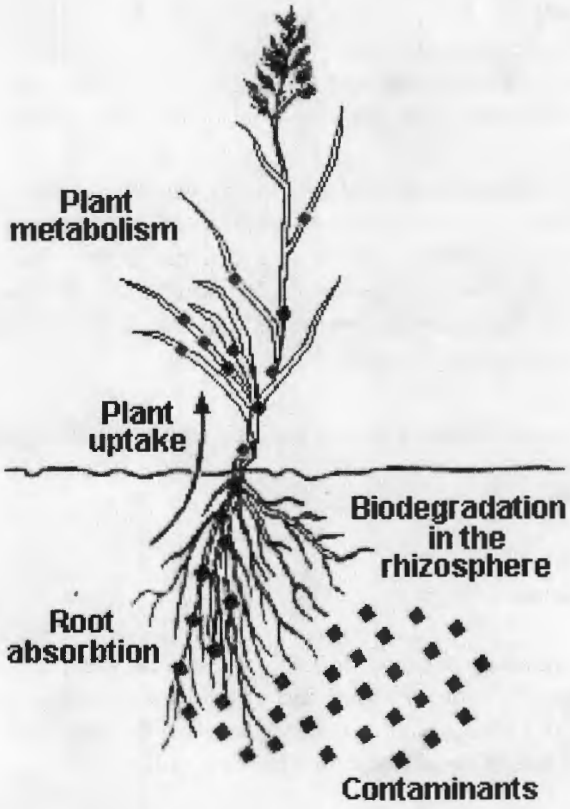

Figure 1 Illustration of basic phytoremediation pathways

The amount and type of compounds released into the soil, and the rhizosphere impacts on associated microbial communities, are specific to plant species (Olson et al., 2003). A synergistic relationship that promotes the exchange of water and nutrients is often established between plant roots and specialized soil fungi or mycorrhizae. This relationship also enhances plant growth (Banks et al., 2000).

Though plants are generally not capable of actually taking in and utilizing highly absorbed contaminants, such as PAHs, the presence of vegetation has been shown to accelerate the degradation of hydrocarbons by enhancing microbial activity (Banks et al., 2000). Root systems can encourage microbial degradation of large molecular organic contaminants (such as PAHs) that tend to bind to soil particles by activating otherwise dormant areas in the soil (Hutchinson et al., 2003). In some instances, the exuded enzymes are capable of detoxifying organic compounds without microbial assistance, a process known as *phytodegradation* (McCutcheon & Schnoor, 2003).

Plants transform certain contaminants through oxidation and reduction reactions, a conjugation phase (foreign compound joined by a plant sugar amino acid, thisol, or glutathione molecule), and deposition of the conjugates into vacuoles and cell walls (Dzantor & Beauchamp, 2002; Subramanian & Shanks, 2003).

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The availability of a contaminant for uptake and transformation is also dependant upon the age of the contaminant and certainly the plant species (US EPA, 2000). This process of breaking down contaminants by plant metabolic activity is referred to as phytodegradation or *phytotransformation;* these terms can also apply to the breakdown of contaminants outside the plant through the release of enzymes produced by the plant and which result in the transformation of the compound (US EPA, 2000).

2. Extraction *(phytoextraction/phytomining, rhizofiltration, phytovolatilization)*

Table 2 Processes involving plant uptake or extraction of contaminants from soils or water.

Type	Process	Appropriate Contaminants
Phytoextraction (Phytomining)	Chemicals taken up with water by vegetation; harvested shoots could be smelted or metals otherwise extracted	Metals, metalloids, radionuclides, perchlorate, BTEX, PCP, organic chemicals not tightly bound to soil particles
Rhizofiltration	Contaminants taken up, sorbed, or precipitated by roots and/or shoots; sorbed to fungi, algae and bacteria	Metals, radionuclides, organic chemicals, nitrate, ammonium, phosphate, and pathogens
Phytovolatilization	Plants take up volatile metals and organic compounds and transpire or diffuse out of roots, leaves or stems	Se, tritium, As, Hg, m-xylene, chlororbenzene, tetrachloromethane, trichloromethane, trichloroethane, and other chlorinated solvents

(Adapted from information in US EPA, 2000)

Depending on the plant type and the contaminant, direct uptake can be considered either a passive and/or an active process (Chiou, 2002). The principal process is passive transport, with the primary transport medium, external water and soil water, carrying the contaminant into the plant. Active transport requires the plant to expend energy and generally applies to nutrients and other organic and inorganic ions required and extracted by the plant (Chiou).

Plants actually need metals, such as zinc and copper, as well as nutrients, to grow. When soil surrounding plant roots is deficient in essential elements, plants will exhibit symptoms indicative of deficiency (loss of leaf color, withering, dead spots, etc.) (Stern, 2000). Some plants, however, referred to as hyperaccumulators, make no distinction between heavy metals (such as cadmium or selenium) and those metals nutritionally necessary for growth (Raskin & Ensley, 2000; Stern). These plants absorb the metals through the root structure and store them in cell vacuoles, where tissues have been measured to contain 1,000 to 10,000 ppm of various heavy metals (Stern).

Potentially hazardous metals present in stormwater, such as zinc, copper, cadmium, and lead, can be absorbed by both terrestrial and aquatic plant roots as well as the shoots of submersed plants (Fritoff & Greger, 2003). The retention time and interactions with other elements in the water affect the bioavailablity of metals within a vegetated system exposed to stormwater (Fritoff & Greger). Metals may be contained by physical sequestration or accumulation in roots of non-harvestable plants.

The most important component of extractive phytoremediation is the availability of the compound (Dzantor & Beauchamp, 2002). The lipophilicity (fat-solubility), or distribution of a chemical from the soil solution to the lipids in the plant cell, is the primary controlling factor in the ability of plants to absorb and translocate organic chemicals (Hutchinson et al., 2003). Once transported into the plant cells, the chemical can be metabolized in a process very similar to mammalian metabolism; thus plants utilizing this process are frequently referred to as "green livers" (Dzantor & Beauchamp).

Using a process called *phytovolatilization,* elemental contaminants can be taken up, transformed to a volatile form, and transpired through roots, stems, or leaves (Doucette, Bugbee, Smith, Pajak, & Ginn, 2003). Selenium, for example, can be transformed into volatile dimethyl selenide, not known to represent any health risk once transported through air. Volatile organic compounds can be taken up and directly transpired or diffused through roots, stems, and foliage (Doucette et al.). Application or use of phytovolatilization requires a thorough examination of potential health risks associated with air transport of the contaminant or modified form of the contaminant in the atmosphere.

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3. Containment/Immobilization *(phytostabilization, rhizofiltration)*

Table 3 Immobilization or containment processes preventing contaminant movement, leaching or transport.

Type	Process	Appropriate Contaminants
Phytostabilization	Vegetation prevents erosion and sorbed contaminant transport; often involves revegetating an area where natural vegetation cannot be sustained due to high contaminant concentrations	Metals, phenols, tetrachloromethane, trichloromethane, and other chlorinated solvents
Rhizofiltration	Contaminants taken up, sorbed, or precipitated by roots and/or shoots; sorbed to fungi, algae and bacteria	Metals, radionuclides, organic chemicals, nitrate, ammonium, phosphate, and pathogens

(Adapted from information in US EPA, 2000)

Root and microbial interactions can immobilize organic and some inorganic contaminants by binding them to soil particles and, as a result, reduce migration of the contaminant to groundwater (Christensen-Kirsh, 1996). The process of holding contaminated soils in place with vegetation, minimizing disturbance of contaminants bound to soil particles, and preventing contaminant movement is referred to as **phytostabilization** (McCutcheon & Schnoor, 2003).

The process where heavy metal contaminants in water are absorbed or precipitated onto or into plant roots is referred to as **rhizofiltration**. The plant may or may not actually take in and translocate the contaminant. The contaminant can be contained, immobilized or accumulated within or on the root structure. Generally this application is associated with contaminants carried in water rather than contaminated soil particles (US EPA, 2000). This process is heavily dependant on pH levels of the solution and harvesting of plants used in this process will often be necessary to reduce the reintroduction of the contaminant into soils or water.

Plant Selection Considerations

Use of native plant species for phytoremediation is generally favored; natives require less maintenance and present fewer environmental and human risks than do non-native or genetically altered species. Non-native species that require fertilizers or large amounts of irrigation will contribute to, rather than reduce, negative effects of stormwater runoff. Properly selected native plant communities are most tolerant of soils, climatic conditions, and seasonal cycles of inundation and drought. However, particular non-native plants may work best in remediation of a specific contaminant and can be safely used under circumstances where the possibility of invasive behavior has been eliminated (US EPA, 2000).

Scientific studies using phytoremediation techniques have focused almost entirely on monoculture trials, while ecosystem and plant community uses and effects remain largely unexplored. The drawbacks of phytoremediation efforts relying on monocultures are increased susceptibility to disease and other natural events damaging the plants, as well as reduced ecological diversity and wildlife habitat benefits (Marmiroli & McCutcheon, 2003).

Limiting Conditions

The primary factors that limit the effectiveness of phytoremediation are climate conditions, particularly temperature, and contaminant exposure to the plant root zone. In temperate regions, dormant periods for many plants that coincide with high precipitation periods may limit contaminant uptake during periods when pollutant loads are potentially largest (Christensen-Kirsh, 1996). Effective phytoremediation requires that root systems extend into the contaminated region or that the contaminants be brought within range of the rhizosphere (US EPA, 2000).

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Microbial populations and their level of activity are strongly influenced by soil pH levels and water availability. Most biological activity occurs in soils with pH levels between 5 and 10 (Hutchinson et al., 2003). Low pH levels are optimal for metal availability, but can have adverse effects on vegetation. Microbial activity is maximized when 60 percent of soil pore space is filled with water. Activity is nearly absent with low water availability. Saturated soils have limited available oxygen, forcing a decline in microbial activity (Hutchinson et al.).

The physical characteristics of soil, such as percentages of clay and/or sand, can alter the availability of oxygen, nutrients, and water for plant and microbial use. Soils with high clay content, for example, have lower hydraulic conductivity and diffusion coefficients, and can render contaminants unavailable to microorganisms. The presence of vegetation can promote the development of soil structure, increase microbial activity within the rhizosphere, and, as a result, enhance the transport of water, nutrients, and contaminants through the soils system (Hutchinson et al., 2003). Adding organic amendments, such as compost, to disturbed urban soils can increase plant root growth, improve water-holding capacity of the soil, and encourage a wide variety of soil organisms.

The importance of optimizing the productivity and interactions between plants and microbes cannot be overstated, and the success of most phytoremediation applications (volatilization, extraction, stabilization, transformation, phytodegradation and rhizodegradation) will be largely dependant on this dynamic relationship (Olson et al., 2003).

Phytoremediation efforts can also be influenced by the presence of multiple contaminants, which, in combination, can inhibit pollutant processing. Understanding which contaminants are present is necessary to inform decisions regarding appropriate plant and soil selection (Dzantor & Beauchamp, 2002).

Concerns and Considerations

Utilization of some phytoremediation techniques, such as the extraction and sequestration of heavy metals in plant tissues, may require harvesting and proper disposal or recycling of contaminated vegetation. Most phytoremediative plants, however, do not accumulate significant levels of contamination and do not require specific treatment or disposal (US EPA, 2000). Existing natural vegetation on sites receiving stormwater runoff likely extract, metabolize, and/or degrade many contaminants (US EPA, 2000). However, the complexity of interactions between variables, such as plant communities, climatic conditions, soils, and combinations of contaminants will undoubtedly prohibit a comprehensive understanding of all interactions at every site for some time to come.

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Appendix 6

Sampling of Plant Species Studied for Phytoremediation

The following is a sampling of plant species that have been studied for phytoremediation. Some plants on this list may not be well suited for growing conditions in Puget Sound. A number of plants with identified phytoremediative abilities have not been included on this list because they are an invasive or potentially invasive weed in Washington state. These plants include such species as:

Amorpha fruticosa	(Indigo bush)	Accumulates lead
Azolla pinnata	(Water velvet)	Biosorbs metals
Bacopa monnieri	(Water hyssop)	Accumulates metals
Hydrilla verticillata	(Hydrilla)	Hyperaccumulates metals
Myriophyllum aquaticum	(Parrot feather)	Transforms and degrades a variety of contaminants
Phragmites australis	(Common reed)	Used in reed bed treatment systems (native genotypes do exist that are not considered invasive)

Related native species may not react to contaminants in the same manner as those specified. Different cultivars of the same species and various species of the same genus may differ in reactions and responses to climatic factors (McCutcheon, 2003).

GRASSES/LEGUMES

Species/Common Name	Contaminant	Process	Comments
Agropyron smithii Western wheat grass	Hydrocarbons	Rhizodegradation	Perennial grass used in pastures/lawns; shown in studies to enhance degradation of TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Agrostis castellana Colonial bentgrass	Metals	Hyperaccumulation	Perennial *A. castellana* has been shown to accumulate As, Pb, Zn, Mn and Al.
Bouteloua gracilis Blue gamma grass	Hydrocarbons	Rhizodegradation	Used for low-water use lawn and pasture grass. Has shown promise in grass mixes to enhance degradation of PAHs in soils (McCutcheon & Schnoor, 2003).
Buchloe dactyloides Buffalo grass	Hydrocarbons	Rhizodegradation/ Accumulation	Perennial grass; low maintenance, drought tolerant lawn requiring little/no mowing. In studies has been shown to reduce TPH and PAHs in soil (McCutcheon & Schnoor, 2003).
Cerastium arvense Field chickweed	Cadmium	Uptake/ Accumulation	Tufted perennial, white flowers. A Northwest (NW) native, a recent study on Vashon Island indicated uptake of cadmium (Institute for Environmental Research and Education, 2003). Additional chickweed varieties found in the NW include *C. beringianum* (Bering chickweed) and *C. fischerianum* (Fisher's chickweed).
Claytonia perfoliata Miner's lettuce	Cadmium	Uptake/ Accumulation	A somewhat succulent annual with white or pink flowers. Also known as *Montia perfoliata*. A smaller attractive variety is *Montia spathulata*. A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Cynodon dactylon Bermuda grass	Hydrocarbons	Rhizodegradation/ Accumulation	Lawn grass; minimum maintenance but needs mowing and can be invasive. In studies where mixed with other grasses, it has reduced TPH and PAHs in soils (McCutcheon & Schnoor, 2003).

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GRASSES/LEGUMES Species/Common Name	Contaminant	Process	Comments
Elymus Canadensis Canadian wild rye	Hydrocarbons	Rhizodegradation/ Accumulation	In combination with other grasses, was shown to reduce PAHs in soils (McCutcheon & Schnoor, 2003). *E. mollis* is a NW native wild rye.
Festuca arundinacea Tall fescue	Pyrene, PAHs	Rhizodegradation/ Phytoextraction	Introduced perennial grass common in the NW; studies have shown enhanced degradation of recalcitrant PAHs (McCutcheon, 2003). Also helpful in uptake of nutrients: nitrogen, phosphorus and potassium (Christensen-Kirsh, 1996).
Festuca rubra Red fescue	Hydrocarbons	Rhizodegradation	Perennial grass often used in lawn mixes; Studies have shown enhanced degradation of TPH and PAHs (McCutcheon & Schnoor, 2003).
Lolium perenne English ryegrass	Hydrocarbons/ Nutrients	Rhizodegradation/ Uptake	Perennial grass shown to uptake nutrients and to significantly enhance degradation of TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Lupinus albus White lupin	Arsenic	Rhizoaccumulation	A nitrogen fixing legume capable of growth in acidic soils with low nutrient availability. A recent study indicated an ability to take up arsenic, primarily stored in the root structure (Esteban, Vazquez & Carpena, 2003). A number of lupine varieties are native to the NW, including: *Lupinus arcticus* (Artic lupine), *L. littoralis* (Seashore lupin), *L. nootkatensis* (Nootka lupine), and *L. polyphyllus* (Large-leaved lupine).
Lotus corniculatus Birds-foot trefoil	Hydrocarbons	Rhizodegradation/ Accumulation	An introduced European annual herb; when mixed with grasses was shown to reduce TPH and PAHs in soils (McCutcheon & Schnoor, 2003). This plant is generally not recommended for introduction into constructed wetlands of the Puget Sound region (Azous & Horner, 2001).
Melilotus officinalis Yellow sweet clover	Hyrdocarbons	Rhizodegradation	Tall, sweet smelling annual; *M. alba* is more common in NW region. When mixed with other grasses was shown to degrade TPH in soils (McCutcheon & Schnoor, 2003). Also helpful in uptake of nutrients: nitrogen, phosphorus and potassium (Christensen-Kirsh, 1996).
Panicum virgatum Switch grass	Hydrocarbons	Rhizodegradation	Enhances degradation of PAHs in soils (McCutcheon & Schnoor, 2003). *P. occidentale* is a species found in the NW.
Stellaria calycantha Northern starwort	Cadmium	Uptake/ Accumulation	Low sprawling perennial. A number of varieties are common in the NW, including, *S. longifolia* (Long-leaved starwort) and *S. longipes* (Long-stalked starwort). A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Stenotaphrum secundatum St. Augustine grass	Hydrocarbons	Rhizodegradation	Perennial grass often used in lawns; coarse-textured. Decreases TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Trifolium pratense Red clover	Hydrocarbons	Rhizodegradation	Introduced perennial herb common in the NW. When mixed with other grasses was shown to degrade TPH in soils (McCutcheon & Schnoor, 2003).
Trifolium repens White clover	Hydrocarbons PCBs	Rhizodegradation/ Metablolization	Introduced perennial herb, deep rooting; enhances microbial activity and degradation of PAHs. Nitrogen fixer, and PCB metabolizer.
Vicia spp. Vetch	Nutrients/ Metals	Uptake	Perennial herb, takes up nutrients (nitrogen, phosphorus and potassium); *V. faba* has been shown to accumulate Al (McCutcheon & Schnoor, 2003).

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OTHER FORBES

Species/Common Name	Contaminant	Process	Comments
Achillea millefolium Yarrow	Cadmium	Uptake/ Accumulation	Perennial aromatic herb native to the NW. Also known as *A. borealis*. A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Allium schoenoprasum Chives	Cadmium	Hyperaccumulation	Perennial onion relative. A recent agricultural study in Israel indicated Cd was accumulated in roots and leaves (Khadka, Vonshak, Dudai & Golan-Goldhirsh, 2003).
Atriplex hortensis Garden Orach	PCBs	Metabolism	Of the spinach family, Orache is an extremely variable species; *A. patula* (Spearscale), *A. subspicata* and *A. patula* common in the NW. Shows promise transforming PAH and Graden Orach metabolizes PCBs (McCutcheon & Schnoor).
Brassica juncea Indian mustard	metals	Rhizofiltration/ Hyperaccumulation	Various species applicable for removing heavy metals (Pb, Zn, Ni, Cu, Cr, Cd and Ur) from soil or water (McCutcheon & Schnoor, 2003); B. campestris (also known as *B. rapa*) and *B. camestris* are common annual herb species in the NW.
Brassica rapa Field mustard	Cadmium, Zinc	Hyperaccumulation	Known to accumulate metals.
Digitalis purpurea Common Foxglove	Cadmium	Phytoextraction	A recent study on Vashon Island indicated uptake of cadmium; *D. lanata* (Grecian foxglove) shown to transform digitoxigenin (McCutcheon & Schnoor, 2003).
Helianthus annuus Sunflower	Metals PAHs	Extraction/ Metabolism Rhizodegradation	The common sunflower has been the subject of numerous studies and is used to extract heavy metals (Pb, Ur, Sr, Cs, Cr, Cd, Cu, Mn, Ni and Zn). Has shown promise in degrading PAHs in soil (McCutcheon & Schnoor, 2003).
Pteris vittata Brake fern	Arsenic	Hyperaccumulation	P. vittata accumulates arsenic in its above ground shoots (Caille et al., 2003).
Senecia glaucus	Crude Oil	Rhizodegradation	Observed to rhizodegrade crude oil in Kuwait; *Senecio triangularis* (Arrow-leaved groundsel), *S. pseudoarnica* (Beach groundsel), and *S. intergerrimus* (Western groundsel) are among the related perennial herbs in the NW.
Solidago hispida Hairy golden rod	Metals	Hyperaccumulation	Shown to accumulate Al. *Solidago* species shows promise for metabolizing TCE (McCutcheon & Schnoor, 2003). Related NW species include S. Canadensis(Canada goldenrod) and *S. multiradiata* (Northern goldenrod).
Thlaspi caerulescens Alpine pennycress	Cadmium, Zinc, Nickel	Hyperaccumulation	This plant is well recognized for its ability to hyperaccumulate metals. *T. arvense* (Field pennycress) is a common NW annual weed.

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TREES, SHRUBS and VINES

Species/Common Name	Contaminant	Process	Comments
Acer rubrum Red maple	Leachate	Uptake	Fairly fast growing deciduous trees that have been utilized to uptake landfill leachate along with hybrid poplars (McCutcheon & Schnoor, 2003). NW species include *A. macrophyllum* (Oregon maple), *A. circinatum* (Vine maple), and *A. glabrum* (Rocky mountain maple).
Betula pendula European white birch	PAHs PCBs	Phytodegradation	Attractive European native, has been shown in laboratory tests to degrade PAHs and PCBs in solution (McCutcheon & Schnoor, 2003).
Gleditsia triacanthos Honey locust	Lead	Phytoextraction	Common honey locust (many cultivars available) has shown promise in the extraction and accumulation of lead (Gawronski, 2003).
Ilex spp. Holly	Cadmium	Accumulation	Evergreen shrub or tree. Recently shown to take up and accumulate cadmium (Institute for Environmental Research and Education, 2003).
Liquidambar styraciflua American sweet gum	Perchlorate	Phytodegradation/ Rhizodegradation	A native of the eastern U.S., grows to 60 ft., and is tolerant of damp soils. Has shown promise for phytoremediation of perchlorate (McCutcheon & Schnoor, 2003).
Maclura pomifera Osage orange	PCBs	Rhizodegradation	A deciduous tree that can withstand heat, cold, wind, drought, and poor soil. Roots have been shown to stimulate PCB-degrading bacteria in the soil (McCutcheon & Schnoor, 2003).
Morus rubra Mulberry	PAHs PCBs	Rhizodegradation	The mulberry is one of a few trees producing phenolic compounds stimulating PCB-degrading bacteria, and thus enhance the degradation of this pollutant. Mulberry has also been shown in the lab to degrade PAHs (McCutcheon & Schnoor, 2003).
Populus spp. Poplars	Chlorinated solvents, PAHs, atrazine, DDT, carbon tetrachloride	Phytodegradation/ Phytovolatilization Phytoextraction	Deciduous trees known for deep rooting and rapid growth. The focus of major attention in the field of phytoremediation, hybrids and clones have been developed for very fast growth and colonization. Poplars can absorb nutrients, such as nitrogen, at a high rate and are used in treatment of land applications of wastewater (McCutcheon & Schnoor, 2003). Known to take up and transform TCE from groundwater (McCutcheon & Schnoor, 2003). Varieties tested include *P. deltoids* (Eastern cottonwood), *P. trichocarpa* (Black cottonwood), *P. simonii* (Chinese poplar) and *P. nigra* (Lombardy poplar). *P. trichocarpa* is a NW native.
Populus tremula Aspen	Pb	Extraction	*P. tremula*, *P. treumloides* (Trembling aspen), and hybrids have shown potential to remediate contaminated water, either from the soil or water table, esp. the extraction of lead (McCutcheon & Schnoor, 2003).
Rosa spp. Paul's scarlet rose	Organic contaminants	Phytodegradation	Paul's scarlet rose is a red, natural climbing rose that can metabolize tetrachlorinated PCB 77. There are, of course many varieties. *R. gymnocarpa* (Dwarf rose) and *R. nutkana* (Nootka rose) are two Washington natives.

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TREES, SHRUBS and VINES

Species/Common Name	Contaminant	Process	Comments
Salix spp. Willow	Perchlorate	Phytodegradation/ Rhizodegradation Phytoextraction	Deciduous trees or shrubs needing plenty of water. *S. caroliniana* (Coastal plain willow) and *S. nigra* (Black willow) shown to uptake and degrade percholate in soils as well as phytoextract metals (Cd, Zn and Cu). Additional *Salix* ssp. and hybrids have extracted metals (Cr, Hg, Se and Zn) (McCutcheon & Schnoor, 2003). Species in the NW include, *S. commutata* (Undergreen willow), *S. lucida* (Pacific willow), and *S. sitchensis* (Sitka willow). A study on Vashon Island indicated uptake/accumulation of cadmium by *S. scouleriana* (Scouler's willow) (Institute of Env. Research & Ed., 2003).
Viola spp. Violets	Metals	Phytoextraction/ Hyperaccumulation	Perennial flowering plants with many varieties. *Hybanthus floribundus* (Shrub violet) from Australia, has been found to accumulate high concentrations of metals. A study on Vashon Island, WA found violets growing naturally to have accumulated cadmium (Institute for Environmental Research and Education, 2003). The many varieties in the NW include: *V. adunca* (Early blue violet), *V. langsdorfii* (Alaskan violet), *V. palustris* (Marsh violet), and *V. glabella* (Yellow wood violet).

Sources: Phytoremediation

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Appendix 7 Permeable Paving Research: Infiltration Performance Over Time and Maintenance Strategies

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Porous Asphalt				
Fwa, T.F., Tan, S.A., & Guwe, Y.K. (1999). Laboratory evaluation of clogging potential of porous asphalt mixtures (Paper No. 99-0087). In *Transportation Research Record: Journal of the Transportation Research Board.* No. 1681, pp. 43-49.	Laboratory	Soil was washed into four different porous asphalt mixtures. Permeability (K) was measured after each clogging attempt until the change in permeability was negligible.	Mix 1: initial K = 300.88 in/hr terminal K = 22.00 in/hr Mix 2: initial K = 820.22 in/hr terminal K = 457.20 in/hr	Analysis utilized falling head test that increases infiltration rates; however, rates for optimum mixes far exceed any design storm infiltration need. All mixes currently used on Singapore roadways are apparently used as a topcoat application.
Wei, I.W. (1986). *Installation and evaluation of permeable pavement at Walden Pond State Reservation - Final report.* Report to the Commonwealth of Massachusetts, Division of Water Pollution Control (Research Project 77-12 & 80-22). Boston, MA: Northeastern University, Department of Civil Engineering.	Field evaluation of Walden Pond State Park parking lot in Massachusetts.	Various asphalt mixes were installed in different locations in the new parking lot and evaluated for infiltration rates using sprinkler systems and collection wells.	Best performing mixes: 1978 1980 1981 K mix: 40 in/hr 38 in/hr 37 in/hr J3 mix: 28 in/hr 4 in/hr 13 in/hr	Test plots were exposed to traffic, but not the heaviest loads in the overall parking area. No maintenance program.
St. John, M.S., & Horner, R.R. (1997). *Effect of road shoulder treatments on highway runoff quality and quantity.* Seattle, WA: Washington State Transportation Center (TRAC).	Field evaluation of road shoulder treatments in Washington state.	Three types of road shoulder treatments (conventional asphalt, gravel, and porous asphalt) were installed on a heavily traveled two-lane road. Flow-weighted composite samples were collected and runoff quality and quantity was evaluated.	After one year of use the porous asphalt shoulders showed no signs of clogging and had an average infiltration rate of 1750 in/hr.	During the year of monitoring approximately 4.2 ft^3 of sand was applied per test section length for routine sanding operations. No maintenance program reported for the porous asphalt shoulders.
Cahill, Thomas, Cahill Associates. Personal communication, April, 2003.	Interview Tom Cahill concerning their porous asphalt installations.	Cahill Associates has installed approximately 80 porous asphalt surfaces (mostly parking lots and recreation facilities) over the past 20 years. Visual inspections are conducted during rain events.	Visual inspections indicate no failures of any installations and Cahill estimates that oldest surfaces are functioning at 80% of initial capacity.	Cahill stresses that proper installation and strict sediment control are critical. Cahill installations use a perimeter infiltration gallery (hydrologically connected to storage under paved surface) as a backup if asphalt infiltration rate is degraded.
Hossain, M., Scofield, L.A., & Meier, W.R. (1992). Porous pavement for control of highway runoff in Arizona: Performance to date. In *Transportation Research Record No. 1354.* Transportation Research Board, National Research Council, Washington, D.C., pp. 45-54.	Field evaluation near Phoenix, Arizona.	Structural integrity and permeability were evaluated for a 3,500 ft-long porous pavement test section installed on the three northbound lanes of Arizona State Route 87 near Phoenix.	• Initial permeability (1986): 100 in/hr. • After 5 years of service (1990): 28 in/hr.	The porous asphalt has performed well in a heavy traffic (highway) application with "no cracking or significant surface deformation having occurred during the 5 years of service."

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REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Permeable Pavers				
Borgwardt, S. (1994). *Expert Opinion.* Hannover, Germany: University of Hannover, Institute for Planning Green Spaces and for Landscape Architecture.	Field evaluation of two train station parking lots in Europe. One lot was two years old and the other five years old.	Sprinklers applied simulated rainfall on test section and measured infiltration utilizing infiltrometer (double ring method). Infiltration rates at 60 minutes are used to represent saturated conditions. Grain size distribution was evaluated to correlate paver design with infiltration rate.	• 2-yr old lot: infiltration rate = 2.84 in/hr after 60-min sprinkling. • 5-yr old lot: infiltration rate = 5.70 in/hr after 60-min. of sprinkling.	Higher infiltration rate for the older as compared to the newer installation likely due to application of sand on top of gravel in drainage openings and fines introduced from inadequately washed aggregate base material in newer parking lot. No reported maintenance program.
Smith, D.R. (2000). *Permeable interlocking concrete pavements: Selection, design, construction, maintenance.* Washington, D.C.: Interlocking Concrete Pavement Institute.	Literature review.	Design, construction, maintenance, and infiltration capacity guidelines developed by the Institute's technical committee from literature review.	Smith recommends 1.1-in/hr infiltration rate and a CN of 65 (all soil types) for permeable interlocking concrete pavements. Infiltration rate is for a 20-year life span.	
Borgwardt, S. (1997 February). Performance and fields of application for permeable paving systems. *Concrete Precasting Plant and Technology,* pp. 100-104.	Field evaluation of various driving surfaces in Europe.	Several permeable driving surfaces of various ages were evaluated using a drip infiltrometer.	Reports a durable infiltration rate of 4.25 in/hr.	No reported maintenance programs.
Pratt, C.J., Mantle, D.G., & Schofield, P.A. (1989). Urban stormwater reduction and quality improvement through the use of permeable pavements. *Water Science and Technology, 21,* pp. 769-778.	Field evaluation of experimental plots.	A 4.6m-wide by 40m-long by 350mm-deep (on average) parking area was excavated and divided into 4 trial areas. Each trial area was filled with a different type base aggregate and water quality and quantity measurements taken from under-drains. The wearing course was cement paving blocks and plots were lined with an impermeable membrane.	Three periods were measured during 30 days with a total rainfall of 80.5mm. The 350mm of various sub-base stone and pavers reduced the following amounts of the total precipitation: • Granite: 25% • Limestone: 39% • Blast furnace slag: 45% • Gravel: 37%	

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Brattebo, B.O., Booth, D.B. (2003, November). *Long-term stormwater quantity and quality performance of permeable pavement systems.* Water Research, 37, 4368-4376.	Field evaluation in Puget Sound.	Two plastic grid systems (1 filled with soil and grass and 1 with gravel), a concrete block lattice filled with soil and grass, and concrete blocks with gravel filled cells were installed in a parking lot in the city of Renton, WA. Each stall was evaluated for infiltration capability, infiltrate water quality, and durability. Two parking stalls with each type of permeable paving material and a conventional asphalt stall, for a control, were installed in 1996.	Surface runoff was measured throughout Nov. 2001 and from Jan. to early March 2002. Total rainfall during the collection period was 570mm delivered in 15 distinct precipitation events. The most intense storm event delivered 121mm of rain in 72 hours. The permeable stalls infiltrated virtually all stormwater. Surface runoff occurred for 6 events (other measurable surface runoff was detected, but attributed to leaks in the system). The most significant runoff volume of the 6 events was 4mm during the largest storm noted above (3% of total precipitation).	The permeable parking facility was monitored for the first year following construction. This study is a follow up to that work. The parking stalls were used constantly during the 6 years previous to this monitoring cycle. None of the permeable paving surfaces showed signs of major wear.
Dierkes, C., Kuhlmann, L., Kandasamy, J., & Angelis, G. (2002, September). Pollution retention capability and maintenance of permeable pavements. In *"Global solutions for urban drainage". Proceedings of the Ninth International Conference on Urban Drainage.* Portland, OR.	Field evaluation.	The infiltration rate of a parking stall in a 15-year old permeable paver installation in a shopping center was determined. The stall was then excavated to examine contaminant levels in the underlying base aggregate and soil. Stall was selected with high content of spilled oil on surface. A drip infiltrometer was used to measure infiltration rates.	The paving structure consisted of: pavers with 1-3 mm joints, 5-8 cm thick bedding material (2-5 mm), and a 20-25 cm base of crushed stone (8-45 mm). Infiltration rate: 440 liters/second/hectare in the central region of the stall and 2000l iters/second/hectare at the edges of the stall.	
Clausen, J.C., & Gilbert, J.K. (2003, September). *Annual report: Jordan Cove urban watershed section 319 national monitoring program project.* Storrs-Mansfield, CT: University of Connecticut, College of Agriculture and Natural Resources.	Field evaluation in southeastern Connecticut.	Two conventional asphalt, two conventional crushed aggregate, and two permeable paver (UNI group Eco-Stone) driveways were monitored during a 12-month period for runoff, infiltration rate, and pollutant discharge. Trench drains at the bottom of the driveways with tipping buckets measured runoff volume. Infiltration rates were assessed using 2 methods: a single ring infiltrometer and a perforated hose for a flowing test. Contributing area for each driveway and land cover type (roof, lawn, etc.) was assessed.	Infiltration rates for the permeable pavers: • Infiltrometer 2002: 7.7 in/hr. • Infiltrometer 2003: 6.0 in/hr. • Flowing infiltration 2003: 8.1 in/hr. • Runoff coefficient for pavers (runoff depth/rainfall depth) = 24%.	No maintenance program reported. The Eco-Stone driveways were two years old at the time of the study.

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REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Pervious Concrete				
Wingerter, R., & Paine, J.E. (1989). *Field performance investigation: Portland Cement Pervious Pavement.* Orlando, FL: Florida Concrete and Products Association.	Laboratory and field evaluation in Florida.	Test slabs of pervious concrete were poured, 18" cores removed, and infiltration rates tested. Cores were then clogged by adding 2" of sand and pressure washing for 1.5 hrs. Existing porous concrete installations were also evaluated by coring and measuring infiltration rates and percent of void space infiltrated by fines.	Laboratory core • Pre-clogging infiltration rate = 23.97 in/min. • Post-clogging infiltration rate with 1" sand remaining on surface = 3.66 in/min and 10.22in/min with sand removed from surface. Field tests • Naples FL restaurant parking lot 6.5 yrs. old: infiltration rate = 4 in/min, 3.4% infiltrated by fines. • Fort Myers parking area 8 yrs. old: infiltration rate = 7 in/min, 0.16% infiltrated by fines.	Analysis utilized falling head test that increases infiltration rates, however, rates far exceed any design storm infiltration need. No reported maintenance programs.
Maintenance				
Balades, J.D., Legret, M., & Madiec, H. (1995). Permeable pavements: Pollution management tools. *Water Science and Technology, 32,* 49-56.	Field evaluation in France.	Various street cleaning techniques were applied to different permeable pavements, including parking lots and roads with heavy traffic. Infiltration rates measured before and after cleaning.	Sweeping followed by suction: • Highly clogged surfaces (< 14 in/hr) no improvement. • Partially clogged surfaces (112–140 in/hr) original infiltration rates (210.60–224.64 in/hr) were obtained after two passes. Suction only • 1st site: initial infiltration rate = 7.02 in/hr, after two passes infiltration rate = 28.08 in/hr. • 2nd site: initial infiltration rate = 210.60 in/hr, after two passes infiltration rate = 280.80 in/hr. High pressure wash with suction • Shopping mall: initial infiltration rate = 9.83 in/hr (parking area) and 28 in/hr (roadway), after two passes infiltration rates = 84.24 in/hr for both parking and roadway. • Residential road: initial infiltration = approximately 0 in/hr, after treatment infiltration rate = 112 in/hr.	The analysis does suggest that restoring a percentage or all of the initial infiltration rate of a permeable pavement installation is possible. However, the type of permeable surface and the cleaning technique applied to that specific surface was not reported.

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REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Gerrits, C., & James, W. (2001). *Restoration of infiltration capacity of permeable pavers.* Master's thesis, University of Guelph. Guelph, Ontario, Canada.	Field evaluation of pervious paver (Eco-Stone) parking lot surfaces at University of Guelph in Ontario.	110 9m x 9m plots in the parking lot were tested for infiltration rates. Material in the drainage cells was excavated to various depths and tests repeated to evaluate regenerating infiltration capacity. Plots were categorized by low, medium and high average daily traffic, and paver bedding material. Parking lot was approximately 8 years old at time of research. Lot is sanded and plowed for snow during winter.	• 3" gravel bed: low traffic: initial = 5.85 in/hr excavate 20 mm = 7.8 in/hr med traffic: initial = 0.58 in/hr excavate 20 mm = 7.80 in/hr • 4" sand bed: low traffic: initial = 0.35 in/hr excavate 20 mm = 0.94 in/hr med traffic: initial = 0.12 in/hr excavate 20mm = no change	Authors find that vacuuming upper 5-20 mm of drainage cell material can regenerate infiltration, and that amounts of material removed to improve infiltration rates can be achieved by modern street sweeping equipment. Sand bed with high traffic most difficult to regenerate and medium traffic with gravel bed easiest to regenerate. Areas with pine needles and vegetation on drainage cells had higher infiltration rates than plots without vegetation material.
Dierkes, C., Kuhlmann, L., Kandasamy, J., & Angelis, G. (2002, September). Pollution retention capability and maintenance of permeable pavements. In *"Global solutions for urban drainage", Proceedings of the Ninth International Conference on Urban Drainage.* Portland, OR.	Field evaluation.	A high-pressure wash and vacuum street cleaning machine was used to clean a school yard permeable paver installation (approximately 4 yr old). The pavers were 10 cm x 20 cm x 8 cm installed on a 2-5 mm pea gravel leveling layer, and the joints filled with 1-3 mm basalt aggregate. Infiltration rates before and after cleaning were evaluated using a drip infiltrometer.	• Infiltration rate before cleaning at 3 selected points: less than 1 mm/second/hectare. • Infiltration rates after cleaning at same 3 points: 1545-5276 liters/second/hectare.	

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Appendix 8

Permeable Hot-mix Asphalt Sample Specification

Origin: Cahill Associates, Westchester, Pennsylvania (Cahill Associates, Section 02725-General porous paving and groundwater infiltration beds, 2004).

Application: Parking lots with aggregate base for retention storage.

Soil infiltration rate: Required soil infiltration varies depending on contributing area, aggregate base storage and infiltration capacity, and design storm. In general, minimum long-term infiltration rate should be 0.1 inch/hour.

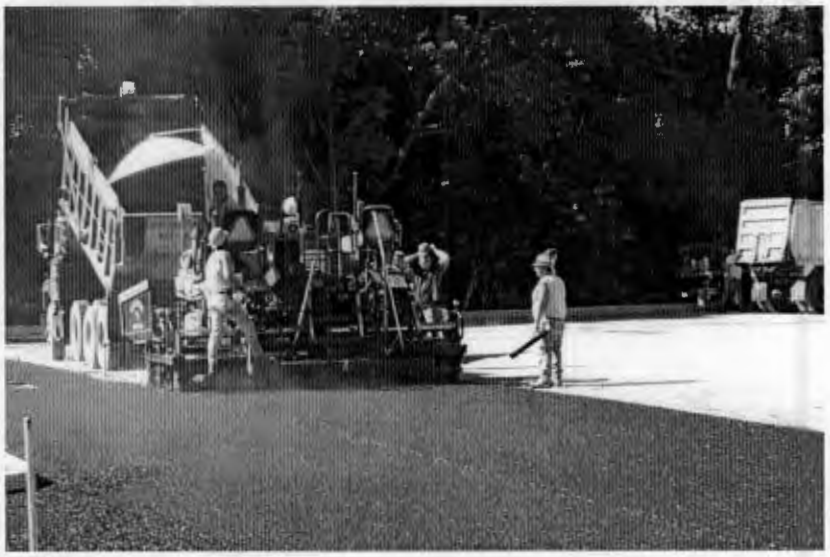

Figure 1 Parking installation, *Courtesy of Cahill Associates*

Top course: 2.5 inches thick

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	1/2	100
	3/8	92-98
	4	32-38
	8	12-18
	16	7-13
	30	0-5
	200	0-3

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Bituminous asphalt cement

- 5.75% to 6.00% by weight dry aggregate.
- Drain down of asphalt binder should be no greater than 0.3% in accordance of ASTM D6390.
- Use a neat asphalt binder modified with an elastomeric polymer to produce a binder meeting requirements of performance or PG 76-22 (PG recommendation for mid-Atlantic states).
- Elastomeric polymer is a styrene-butadiene-styrene or equal applied at a rate of 3% by total weight of the binder. Thoroughly blend polymer and binder at asphalt refinery prior to loading and transportation. The polymer modified asphalt binder should be heat and storage stable.
- Hydrated lime is added at a rate of 1.0% by weight of the total dry aggregate to mixes with granite stone to prevent separation of the asphalt from the aggregate and achieve a required tensile strength ratio of at least 80%. Hydrated lime should meet ASTM C 977.
- The asphalt mix should be tested for resistance to stripping by water in accordance with ASTM D 3625. If estimated coating area is not above 95%, anti-stripping agents should be added to the asphalt.

Asphalt installation

- Bituminous surface course mix is laid in one 2.5-inch lift directly over aggregate storage base.
- Laying temperature of the mix should be between 240 and 250 degrees Fahrenheit and ambient temperature should not be below 40 degrees Fahrenheit.
- Compaction of the surface course should occur when the surface is cool enough to resist a 10-ton roller. One or two passes is all that is required for proper compaction and additional rolling can cause a reduction in surface course porosity.

Aggregate base/storage bed material

- Coarse aggregate is 0.5- to 2.5-inch uniformly graded stone with a wash loss of no more than 0.5% (AASHTO size number 3).

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	2 ½"	100
	2"	90-100
	1 ½"	35-70
	1"	0-15
	½"	0-5

- Choker base course aggregate should be 3/8- to 3/4-inch uniformly graded stone with a wash loss of no more than 0.5% (AASHTO size number 57).

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	1 ½"	100
	1"	95-100
	½"	25-60
	4	0-10
	8	0-5

Aggregate base/storage installation

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- Existing subgrade under base should NOT be compacted or subject to excessive construction equipment traffic prior to installation.

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- Storage bed should be excavated level to allow even distribution of water and maximize infiltration across parking entire area.
- Immediately before base aggregate and asphalt placement remove any accumulation of fine material from erosion with light equipment and scarify soil to a minimum depth of 6 inches.
- Geotextile fabric is a Mirafi 160N or approved equal. Overlap adjacent strips 16 inches and secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of area.
- Install course (0.5 to 2.5 inch, AASHTO size number 3) aggregate in lifts no greater than 8 inches and lightly compact each lift.
- Install 1-inch choker course (No. 8 to 1.5-inch aggregate, AASHTO size number 57) evenly over surface of course aggregate base.
- Storage and infiltration bed depth will depend on infiltration rates, storage requirement and design storm; however, Cahill Associates often install 18- to 36-inch sections designed for full retention of storm flows.
- All erosion and sediment control should remain in place until area is completely stabilized with soil amendments, landscaping or other approved controls.

Backup systems

- For backup infiltration capacity (in case the asphalt top course becomes clogged) an unpaved stone edge is usually installed that is hydrologically connected to the storage bed (see Figure 2).

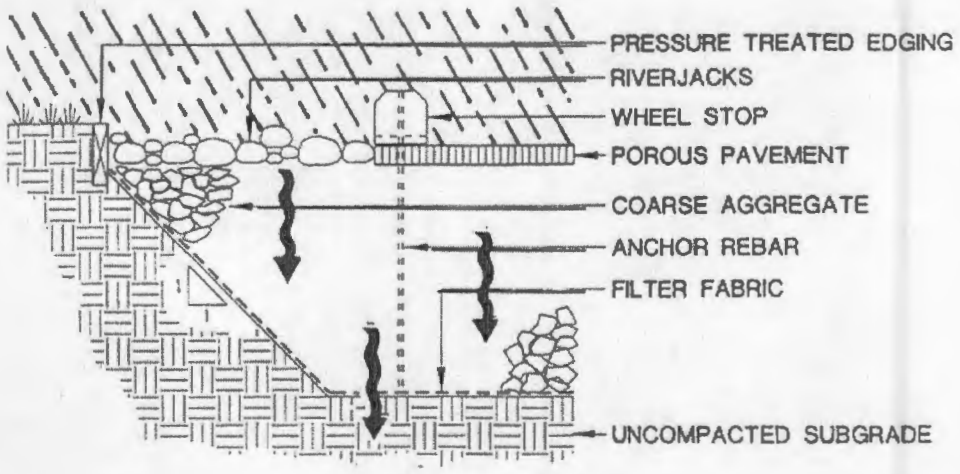

Figure 2 Backup infiltration system for permeable parking lot installations.
Graphic courtesy of Cahill Associates

- To ensure that the asphalt top course is not saturated from high water levels in the aggregate base (as a result of subgrade soil clogging), a positive overflow is usually installed.

Cahill Associates design some systems to infiltrate storm flows from adjacent buildings. Water is collected from roof downspouts, conveyed through a catch basin (to remove debris), and distributed in perforated pipes throughout the storage and infiltration aggregate base.

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Appendix 9

Vegetated Roof Design Specification Example

Designers: Boxwood of Seattle, WA and Roofscapes Inc., Philadelphia, PA.

Roof location: Point Defiance Zoo animal health care facility, Tacoma. WA.

The specification that follows is provided by Boxwood of Seattle and Roofscapes, Inc., and was used in the construction of this vegetated roof.



Figure 1 Vegetated roof at Point Defiance Zoo animal health care facility. *Photo by Curtis Hinman*

Summary

- The vegetated cover is a two-layer system, consisting of a 2.5-inch growth media layer installed over the Meadowflor™ drainage system. The weight of this system at Maximum Water Capacity and with rainfall runoff occurring is less than or equal to 15 pounds per square foot.
- The system is not irrigated. However, it may require periodic hand watering during the initial 12 months of the establishment period.

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Thermoplastic Sheet Waterproofing Membrane

- Materials:
  - o Sarnafil G476 fiberglass reinforced membrane and compatible sealant.
  - o Minimum thickness: 60 mils.
  - o All roofing components should be compatible with the membrane.
- Quality Assurance:
  - o Only an approved contractor authorized by the manufacturer prior to bid should apply the waterproofing system.
  - o Installation of waterproofing membrane, flashing, membrane expansion joints, membrane containment grids, membrane protection layers, drainage layer and insulation should be the responsibility of the membrane applicator to ensure undivided responsibility.
  - o Obtain primary waterproofing materials, membrane, and flashing from a single manufacturer with not less than 10 years of successful experience in waterproofing applications. Provide other system components only as approved by manufacturer of primary materials.
  - o Waterproofing contractor should arrange with the membrane manufacturer to have the services of a competent field representative at the site to accept the substrate surface before installation of waterproofing materials. The field representative of the membrane manufacturer should check and test all heat-welded seams before the water test, and prior to installation of separation and protection layers.
  - o Before construction begins the owner, architect, contractor's field superintendent, waterproofing foreman, waterproofing membrane manufacturer's field representative, and other involved trades should meet to discuss waterproofing practices applicable to this project.
  - o There should be no deviation made from the contract specification or the approved shop drawings without prior written approval by the owner, the owner's representative and/or design professional, and membrane manufacturer.
  - o Water testing of the completed waterproofing system should be for a minimum of 24 hours. Water testing should be witnessed and confirmed in writing by the owner's representative and/or design professional, the waterproofing contractor, and membrane manufacturer.
  - o Trained and authorized personnel should complete all work.
- Installation
  - o The surface substrate should be clean, dry, free from debris, and smooth with no surface roughness or contamination. Broken, delaminated, wet or damaged insulation or recover boards should be removed and replaced.
  - o Overlap rolls by 3 inches. Shingle seam overlaps with the flow of draining rainwater when possible.
  - o Hot-air welding of seam overlaps:
    - ✓ Seams should be 3-inch when using an automatic machine welding, and 4-inch when hand welding.
    - ✓ All membrane to be welded should be clean and dry. Follow manufacturer's specifications for welding.
  - o Flashings: all flashings should be installed concurrently with the waterproofing membrane as the job progresses per manufacturer's directions. No temporary flashings will be allowed. All flashings should be inspected and accepted by the membrane manufacturer.
  - o Temporary cut off: when a break in the day's work occurs, install a temporary watertight seal by sealing the membrane to the deck or substrate. When work resumes, the contaminated membrane should be removed. If any water is allowed to enter under the completed waterproofing, the affected area should be removed and replaced at the contractor's expense.
  - o Membrane is incompatible with asphalt, oil-based and plastic-based cements, creosote and penta-based materials. If contact occurs, the material should be cut out and discarded. The

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contractor should consult the manufacturer with respect to material compatibility, precautions, and recommendations.

- o Contaminants, such as grease, fats, oils, and solvents, should not be allowed to come into direct contact with the waterproofing membrane.

Protection Fabric

- Material: 22-ounce per square yard polypropylene non-woven needled geotextile.
- The surface of the waterproofing system should be swept and washed.
- Until the drain sheet is installed, traffic over the working area should be strictly controlled and limited to essential personnel only.
- Heavily traveled areas (e.g., corridors for transporting material to the working areas) must be protected in a manner approved by the waterproofing installer.
- Suitably protect lay-down areas using ½-inch plywood over 1-inch sheets of expanded polystyrene, or similar sheathing material.
- Roll out the protection fabric on top of the completed waterproofing system.
- Overlap seams a minimum of 6 inches and tack seams using a hot-air welding gun (Leister, or equivalent).

MEADOWFLOR™ Drainage System

- The vegetated cover system should be underlain everywhere by the Meadowflor™ system. This consists of:
  - o Roofmeadow® perforated polyethylene drain sheet with adhered polypropylene separation fabric. The sheet is a dimpled sheet. The composite system satisfies the following specifications:

Membrane thickness	≥ 20 mil
Compressive strength	≥ 5,200 lb/ft^2
Tensile strength (ASTM-D4594)	≥ 1,000 lb/ft
Brittleness temperature (ASTM-D746)	≤ -50° F
Softening temperature	≥ 250° F
Transmissivity (between platens)	≥ 24 gal/min/ft
Permittivity (ASTM-D4491)	≥1.5 sec^{-1}
Height (varies according to position)	0.39 to 0.78 in

  - o Separation Fabric
    - ✓ Needled non-woven polypropylene geotextile fabric. This component should satisfy the following specifications:

Unit Weight (ASTM-D5261)	≥ 4.25 oz/yd^2
Puncture Resistance (ASTM-D4833)	≥ 35 lbs
Mullen Burst Strength (ASTM-D4632)	≥ 135 lb/in
Permittivity (ASTM-D4491)	≥ 1.5 sec^{-1}

- Install the drain sheet, together with separation sheet. The drain sheet should be installed with the studs and fabric layer facing up to enhance rapid drainage of the overlying media.
- Assemble the perforated conduit on top of the drain sheet, as shown on the drawings.
- Weigh down the drainage layer with temporary ballast, as necessary.

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Border Elements

- Roofmeadow® cantilever, fabricated from 1/8-inch aluminum.
- Height: ≥ 0.25 inch higher than the top of the growth media layer.
- Base Length: 7 inches, or 1.5 times the height of the element, whichever is greater.
- Install border elements as required to prevent mixing of ballast and growth media.

Growth Media Layer

- Roofmeadow® Type M1 Extensive Growth Media. This material is a mixture of mineral and organic components that satisfies the following specifications:
  - o Void ratio at Field Capacity (0.333 bar) ≥ 15% (vol)
  - o Moisture content at Field Capacity ≥ 10% (vol)
  - o Maximum Water Capacity ≥ 20% (vol)
  - o Density at Maximum Water Capacity ≤ 62 lb/ft^3
  - o Saturated Hydraulic Conductivity ≥ 1.5 in/hr, and ≤ 15.0 in/hr
  - o Volatile fraction (organic matter) ≤ 10% (dry wt.)
  - o pH 5.5 - 7.9
  - o Soluble salts ≤ 0.30 mmhos/cm (1:20 dilution)
  - o Grain-size distribution of the mineral fraction (ASTM-D422)

Clay fraction (2 micron)	≤ 1%
Pct. Passing US#200sieve	≤ 5% (i.e., silt fraction)
Pct. Passing US#60 sieve	≤ 10%
Pct. Passing US#18 sieve	5 - 50%
Pct. Passing 1/8-inch sieve	20 - 70%
Pct. Passing 3/8-inch sieve	75 -100%

- Macro and micronutrients should be incorporated in the formulation in initial proportions suitable to support the specified planting.
- Thoroughly blend at a batch facility. Moisten, as required, to prevent separation and loss of fine particles during installation.
- Quality control samples should be collected and submitted for testing for each 100 CY provided to the job.
- Placing the growth media layer: The media should be dispensed at the roof level in a manner that will not suddenly increase the load to the roof. It should be immediately spread to the specified thickness, plus 10 percent (after moderate compaction).
- Set the media back from the curbs and parapets as directed in the specifications. The set back for this project is 12 inches. At the margins of the media spread a 2-foot wide strip of separation fabric.
- Cover the media layer with the wind blanket and secure, unless direct seeding (see below).
- Thoroughly soak with water using a sprinkler or hand sprayer. For a 4-inch growth media layer, expect to use about 30 gallons per 100 square feet.

Gravel Margin

- Fill the area between the flashed wall and growth media with gravel as specified.

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Planting (plug installation)

- The following plant list should be installed. Any alternatives must be approved by the green roof installer.
- All extensive planting schemes must incorporate *Sedum* species. *Sedum* must represent at least 50 percent of the installed plants. Additionally, the plant mixture should include a minimum of four different species of *Sedum* in approximately equal quantities.
- Non-*Sedum* varieties should be selected that are adapted to the specific growing conditions.
- Plant installation should occur May-June or September-October, unless an active irrigation system is included.
- Plants should be established from 32-cell plugs propagated in sterile nursery medium, according to the plant provider's recommendations. Plugs larger than this can be used; however, the establishment rate is typically better with the smaller plants. The recommended minimum planting rate is 640 plants per 1000 square feet.
- Thoroughly soak the growth media prior to planting.
- The plugs should be set into the media to their full depth and the media pressed firmly around the installed plug. At the end of each day, soak those areas that have been newly planted.
- Do not mulch.

Plant List:

Allium schoenprasm

Delopserma nubigenum

D. cooperii

Echeveria sp.

Petrohagia saxifraga

Sedum floriferum

S. album

S. sexangulare

S. spurium roseum

S. pinofolium

S. reflexum

S. sarmentosum

S. boehmii (orostachys)

Sempervivum sp.

Wind Blanket

- Roofmeadow® photo/bio-degradable covering is used to protect the media from wind erosion during the 24-month plant establishment period. The provider must demonstrate that the wind blanket will remain securely in place during high winds and that it will not interfere with the growth of the plants. It must satisfy the following specifications:
  - o Aperture ≥ 0.04 in, and ≤ 0.125 inch
  - o Tensile strength (ASTM D4632) ≥ 20 lb
  - o Satisfies smolder resistance criteria (FTMA-CCC-%-191B)
- The Roofmeadow® Wind Blanket includes a method for firmly securing the protective layer to the green roof system.

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Glossary

Advection	Transfer or change of a property of the atmosphere (e.g., humidity) by the horizontal movement of a mass of fluid (e.g., air current).
Allelopathic	Suppression of growth of one plant species as a result of the release of a toxic substance by another plant species.
Ammonification	Process in which organic forms of nitrogen (e.g., nitrogen present in dead plant material compounds) are converted to ammonium ($NH4^+$) by decomposing bacteria.
Bankful discharge	Stream discharge that fills the channel to the top of the banks and just begins to spread onto the floodplain. Bankful discharges occur on average every 1 to 1.5 years in undisturbed watersheds and are primarily responsible for controlling the shape and form of natural channels.
Bedload	Sediment particles that are transported as a result of shear stress created by flowing water, and which move along, and are in frequent contact with, the streambed.
Biotic integrity	Condition where the biologic or living community of an aquatic or terrestrial system is unimpaired and species diversity and richness expected for that system are present.
Bole	Trunk of a tree.
California Bearing Ratio	Test using a plunger of a specific area to penetrate a soil sample to determine the load bearing strength of a road subgrade.
Cation exchange capacity	Amount of exchangeable cations that a soil can adsorb at pH 7.0 expressed in terms of milliequivalents per 100 grams of soil (me/100 g).
Compost maturity	Term used to define the effect that compost has on plant growth. Mature compost will enhance plant growth; immature compost can inhibit plant growth.
Compost stability	Level of microbial activity in compost that is measured by the amount of carbon dioxide produced by a sample in a sealed container over a given period of time.
Critical shear stress	Lift and drag forces that move sediment particles. Forces are created as faster moving water flows past slower water.
Denitrification	Reduction of nitrate (commonly by bacteria) to di-nitrogen gas.

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Desorb	To remove (a sorbed substance) by the reverse of adsorption or absorption.
Diurnal oxygen fluctuations	Fluctuations in dissolved oxygen in water as photosynthetic activity increases during the day and decreases during the night.
Effective impervious area (EIA)	Subset of total impervious area that is hydrologically connected via sheet flow or discrete conveyance to a drainage system or receiving body of water. The Washington State Department of Ecology considers impervious areas in residential development to be ineffective if the runoff is dispersed through at least 100 feet of native vegetation using approved dispersion techniques.
Endocrine disruptors	Substances that stop the production or block the transmission of hormones in the body.
Evapotranspiration	Collective term for the processes of water returning to the atmosphere via interception and evaporation from plant surfaces and transpiration through plant leaves.
Exfiltration	Movement of soil water from an infiltration integrated management practice to surrounding soil.
Exudates	Substances exuded from plant roots that can alter the chemical, physical and biological structure of the surrounding soil.
Hydrologically functional landscape	Term used to describe a design approach for the built environment that attempts to more closely mimic the overland and subsurface flow, infiltration, storage, evapotranspiration, and time of concentration characteristic of the native landscape of the area.
Hydroperiod	Seasonal occurrence of flooding and/or soil saturation that encompasses the depth, frequency, duration, and seasonal pattern of inundation.
In-line bioretention	Bioretention area that has a separate inlet and outlet.
Invert	Lowest point on the inside of a sewer or other conduit.
Liquefaction	Temporary transformation of a soil mass of soil or sediment into a fluid mass. Liquefaction occurs when the cohesion of particles in the soil or sediment is lost.
Mycorrhizal	Symbiotic association of the mycelium of a fungus with the roots of a seed plant.
Nitrification	Process in which ammonium is converted to nitrite and then nitrate by specialized bacteria.
Off-line bioretention	Bioretention area where water enters and exits through the same location.

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Phytoremediation	The utilization of vascular plants, algae and fungi to control, break down, or remove wastes, or to encourage degradation of contaminants in the rhizosphere (the region surrounding the root of the plant).
Reaction range	Length of the pin or pile in a minimal excavation foundation system that is in direct contact with and bears against the soil to support the above-ground structure.
Saturated hydraulic conductivity	Ability of a fluid to flow through a porous medium under saturated conditions; is determined by the size and shape of the pore spaces in the medium, their degree of interconnection, and by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.
Seral stage	Any stage of development or series of changes occurring in the ecological succession of an ecosystem or plant community from a disturbed, un-vegetated state to a climax plant community.
Soil bulk density	Ratio of the mass of a given soil sample to the bulk volume of the sample.
Soil stratigraphy	Sequence, spacing, composition, and spatial distribution of sedimentary deposits and soil strata (layers).
Stage excursions	Departures, or changes, in pre-development water depth (either higher or lower) that occur after development takes place.
Threshold discharge area	Onsite area draining to a single natural discharge location or multiple natural discharge locations that combine within one-quarter mile downstream (as determined by the shortest flow path).
Time of concentration	Time that surface runoff takes to reach the outlet of a sub-basin or drainage area from the most hydraulically distant point in that drainage area.
Total impervious area (TIA)	Total area of surfaces on a developed site that inhibit infiltration of stormwater. The surfaces include, but are not limited to, conventional asphalt or concrete roads, driveways, parking lots, sidewalks or alleys, and rooftops.
Transmissivity	Term that relates to movement of water through an aquifer. Transmissivity is equal to the product of the aquifer's permeability and thickness (m^2/sec).
Tree canopy dripline	Outer most perimeter of a tree canopy; defined on the ground by a vertical line from the perimeter of the leaves of a tree canopy to the ground directly below.

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Frequently used acronyms

AASHTO.....American Association of State Highway and Transportation Officials

ASTM.....American Society for Testing and Materials

CEC .....Cation exchange capacity

CN.....Curve number

CRZ .....Critical root zone

IMPs .....Integrated management practices

SMMWW .....*Stormwater Management Manual for Western Washington*

USDA.....United States Department of Agriculture

WAC .....Washington Administrative Code

WWHM.....Western Washington Hydrologic Model

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Review of Low-Impact Development Techniques

Produced through Funding from the Department of Ecology and Administered by the Puget Sound Action Team

PREPARED FOR: Puget Sound Action Team

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DATE: January 16, 2004

1. Introduction

The Puget Sound Action Team (PSAT) is interested in developing additional information on low-impact development (LID) practices for the Puget Sound region. PSAT contracted with CH2M HILL to develop this additional information in three primary phases: Phase 1, review of selected LID techniques; Phase 2, analyses and recommendations for the use of LID techniques in Puget Sound; and Phase 3, analysis and recommended changes to selected best management practices (BMPs) in the *Stormwater Management Manual for Western Washington* to include the benefits of LID techniques.

This project will produce three technical memoranda. They are:

1. Review of Low-Impact Development Techniques
2. Analysis and Recommendations for the use of LID Techniques in Puget Sound
3. Suggested Adaptations to BMPs in the Washington Stormwater Management Manual to Include Benefits of LID Techniques

This Technical Memorandum 1 covers the first phase of the project, Low-Impact Development in Puget Sound, review of LID techniques. It includes background, application, and design criteria, as well as case studies, for LID techniques that PSAT would like to expand upon. PSAT is aware that there are additional LID techniques, such as rainwater harvesting, planter boxes, disconnecting impervious surfaces, and forest preservation; however, for this project the selected LID techniques include bioretention cells, engineered landscapes/amended soils, green roofs, dispersion of runoff from impervious surfaces, and pervious pavement.

2. Low-Impact Development Stormwater Management

Germany and other European counties have responded to development with regulations that require open space and pervious surfaces to be integrated during the site planning process. For decades, Europe has been progressive in developing and implementing site design LID techniques with the objective of reducing stormwater runoff and the overloading of storm sewers.

LID stormwater management is a relatively new concept in the United States. LID principles were pioneered by Prince George's County, Maryland, in the early 1990s and have been put into practice in other parts of the country as well, particularly on the east and west coasts. The most common LID practices that are applicable for residential, commercial, and municipal projects (both new development and redevelopment) include bioretention cells, engineered landscapes/amended soils, green roofs, dispersion of runoff from impervious surfaces, and pervious pavement.

LID techniques can be applied to a range of project sizes and uses. However, they may need to be used with more traditional structural stormwater techniques to achieve watershed objectives. The appropriate LID practice depends on site conditions and is not based on spatial limitations alone. Factors affecting LID implementation include soil permeability, slope, and water table depth. Other factors that may affect the use of LID practices include development rules that restrict innovative practices, such as subdivision codes, zoning regulations, parking and street standards, and other local ordinances (EPA, 2000).

3. Low-Impact Development Stormwater Practices

This section provides information regarding the background, application, and design criteria, as well as case studies, for five selected LID techniques: bioretention cells, engineered landscapes/amended soils, green roofs, dispersion of runoff from impervious surfaces, and pervious pavement.

3.1 Bioretention Cells

Background

Bioretention areas are landscaping features adapted to attenuate and treat stormwater runoff on development sites. Originally developed by the Prince George's County, Maryland, Department of Environmental Resources in the early 1990s as an alternative to traditional stormwater treatment techniques, the method combines physical filtering and adsorption with biological processes.

A number of laboratory and field experiments have been conducted by the University of Maryland in conjunction with the Prince George's County Department of Environmental Resources and the National Science Foundation to quantify the effectiveness of bioretention cells for pollutant removal. These studies indicate that shallow bioretention facilities with a significant mulch layer can be effective in urban areas where heavy metals are the focal pollutants. In residential areas, however, where the primary pollutants of concern are nitrogen and phosphorus, the facilities require deeper cells that reach approximately 2 to 3 feet (LID Center, 2003a).

Originally designed for providing an element of water quality control, bioretention cells can achieve *quantity control* as well. By infiltrating and temporarily storing runoff water, bioretention cells reduce a site's overall runoff volume and help to maintain the predevelopment peak discharge rate and timing. The volume of runoff that needs to be controlled to replicate natural watershed conditions changes with each site, based on the impact of development and the site's existing soil.

Application

Bioretention cells are commonly located in parking lot islands or within small pockets in residential land uses. Surface runoff is directed into shallow, landscaped depressions. These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. The depressions above a mulch and soil system allow stormwater to filter through the mulch and prepared soil mix (CWP, 2002).

Design Criteria

Bioretention system designs are based on rainfall characteristics, soil types, site conditions, and land uses. A bioretention area can be a mix of functional components, each performing a different function in the removal of pollutants and stormwater runoff mitigation. Six typical components are found in bioretention cells:

1. **Grass buffer strips** reduce runoff velocity and filter particulate matter.
2. **Ponding area** provides storage of excess runoff and facilitates the settling of particulates and evaporation of excess water.
3. **Groundcover area** promotes decomposition of organic material by providing a medium for biological growth (such as microorganisms) to degrade petroleum-based pollutants. It also filters pollutants and prevents soil erosion.
4. **Planting soil** provides the area for stormwater storage and nutrient uptake by plants. Planting soils contain some clay to adsorb pollutants such as hydrocarbons, heavy metals, and nutrients.
5. **Vegetation (plants)** helps to remove water through evapotranspiration and helps to remove pollutants through nutrient cycling (EPA, 2000).
6. **Sand bed** provides aeration and drainage of the planting soil and assists in flushing pollutants from soil materials.

Design considerations for bioretention systems include:

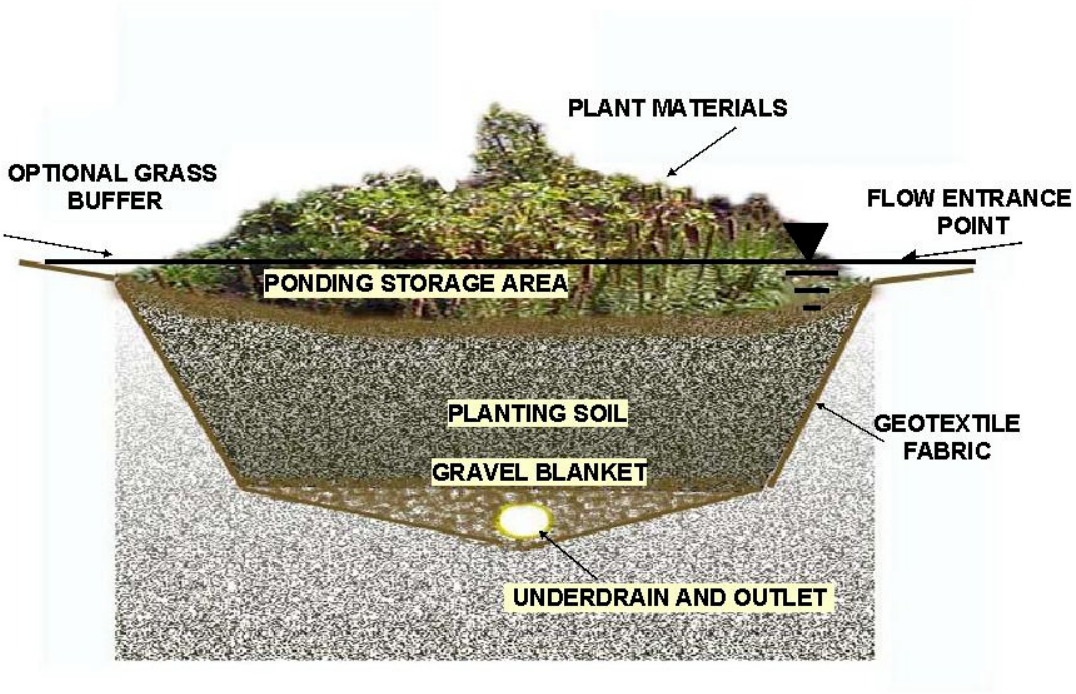
- Low points of bioretention facilities should be planted with flood-tolerant plants.
- Higher areas should be planted with streamside or upland species. Examples of appropriate bioretention plants are shown below.

Frequency of Flooding	Botanical Name	Common Name
Winter standing water	*Juncus* spp.	Rush
Occasional standing water	*Carex* spp.	Sedge
Rare flooding	*Spiraea douglasii*	Hardhack
No flooding	*Rosa* spp.	Shrub rose

  These plants work best in coastal climates. Appropriate plant species will vary across Washington State, depending on biogeoclimatic zone.

- Soils in bioretention areas should have the characteristics of absorbent soils and may be mixed with sand and mulch to form a bioretention soil mixture (BSM). An example of an appropriate BSM is 30 percent absorbent soil, 20 percent bark mulch, 50 percent sand.
- Bioretention facilities should be constructed in the dry season whenever possible, or they should be totally isolated from flows during construction.

- In areas where soils are relatively impermeable, bioretention facilities can be designed with a subdrain to slowly remove water that infiltrates through the absorbent soil layer (or BSM). This filters out sediments and many pollutants.



Typical bioretention system with drain

Source: Low Impact Development Center

The following pictures, provided by the Low Impact Development Center, Inc., show various applications of bioretention systems.



Rain garden with well defined borders



Rain garden swale



Newly planted rain garden. Note the water in the depression.

Case Studies

SEA Streets Project, Washington

The SEA Streets project in Seattle, Washington, demonstrates how bioretention and engineered landscaping can reduce stormwater runoff and improve water quality. A neighborhood block was selected to implement LID practices in the existing right of way to improve function, appearance, and maintenance of the street and drainage elements (City of Seattle, 2000).

The drainage system incorporated amended soils with combined contoured swales, along with traditional drainage infrastructure using surface retention, to reduce the 2-year, 24-hour storm event. The landscape elements of this project provided aesthetics and contributed to rainfall management. Vegetation helped to filter and slow the flow of stormwater, while trees helped restore evapotranspiration (City of Seattle, 2000). Wetland

plants were planted on the bottom of the swales while 100 evergreen trees and 1,100 drought-tolerant native shrubs were planted in this project.

The following plant list is for the City of Seattle's Broadview Green Grid project. The City does not have a list for the plants used for the SEA Street project but the plants are much the same as the ones used for the Green Grid project.

Broadview Green Grid – List of Plants

Deciduous Trees
Flame Ash - 35 to 40' mature height / equal spread, small leaflets, reddish fall color.
Katsura Tree – 35 to 40' mature height / equal spread, yellow to orange fall color.
Norwegian Sunset Maple – 30-35' mature height, pyramidal form, orange fall color.
Pacific Sunset Maple – 25-30' mature height, round form, red fall color.
"Eddie's White Wonder" Dogwood – 25-30' mature height, pyramidal form, white flowers.
Galaxy Magnolia – 30' mature height, 15' spread, reddish purple flowers.
Autumn Brilliance Serviceberry – 20' mature height, 15' spread, white flowers, red fall color.
Ballerina Magnolia – 20' mature height, 20' spread, light pink to white flowers.
European Mountain Ash – 35' mature height, 25' spread, white flowers, red fruit, rust fall color.
Korean Mountain Ash – 40' mature height, 30' spread, white flowers, red fruit, orange to red fall color.
Purple-Leaf Hazelnut – 20' height, 15' spread, purple foliage spring through summer.

Evergreen Trees
Japanese Black Pine – 50+' mature height, 30+' spread, irregular form, slow grower.
Austrian Pine – 50+' mature height, 20+' spread, pyramidal form, fast grower.
Hinoki Cypress – 20+' mature height, 15+' spread, irregular sculptural form, very slow grower.

Deciduous (screening) Shrubs
Vine Maple – 15' mature height, 10-15' spread, multi-stemmed, orange to red fall color.
Diane Witchhazel – 10' mature height, 10' spread, red flower, orange-red fall color.
Belle Etoile Mock Orange – 6' mature height, 6' spread, white flowers.
Red-Flowering Currant – 6' mature height, 6' spread, pink to reddish flowers, fruit attracts birds.
Red-Twig Dogwood – 6' mature height, 8' spread, white flowers, ornamental red twigs
Yellow-Twig Dogwood – 6' mature height, 8' spread, white flowers, ornamental yellow twigs.
Oak-Leaf Hydrangea – 6' mature height, 6' spread, cream flowers, bronze to crimson fall color.
Blueberry – 6' mature height, 4' spread, edible fruit.
Salmonberry – 5' mature height, 4' spread, purple flowers, fruit attracts birds.
Wild Rose – 5' mature height, 4' spread, pink flowers, rose hips of visual interest.

Evergreen (screening) Shrubs
Strawberry Tree – 8+'mature height, 8+' spread, cream flowers, non-edible fruit resembles a strawberry
Compact Strawberry Tree – 5' mature height, 5' spread, densely branched.
Evergreen Huckleberry – 5-8' mature height, 6' spread, white flowers, black berries.
PJM Rhododendron – 5' mature height. 5' spread, purple flowers, bronze fall color.

Deciduous (low growing) Shrubs
Pavement Rose – 2-4' mature height, 4-6' spread, profuse flowers of many colors bloom all summer.
Kelsey Dogwood – 2' mature height, 3' spread, light green summer foliage, fine-textured red twigs.
Snowberry – 3' mature height, 3' spread, ornamental white berries in winter.
Tangerine Potentialla – 2' mature height, 3' spread, yellow flowers with orange-red flush.
Isanti Dogwood – 3-4' mature height, 4-6' spread, like Red-Twig, above but lower growing.

Evergreen (low growing) Shrubs
Salal – 4' mature height, 4' spread, reliable native plant with cream flowers.
White Rockrose – 3-4' mature height, 4-5 foot spread, white flowers.
Creeping Mahonia – 2' mature height, 3-4' spread, reddish fall color can remain into the winter.
Lavender – 2-3' mature height, near equal spread, lavender-blue flower spikes, grayish foliage.

Perennials and Ferns
Swordfern – reliable, evergreen native fern.
Day Lily – 2-4' tall many colorful varieties blend well with native wetland plants.
Gladwin Iris – 1-2' tall with large ornamental seed capsules in the fall.
Douglasiana Iris – 1-2' tall native variety, with white, cream or lavender blooms.
Cranesbill – low perennial with blue to purple flowers.
Purple Palace Heuchera – large bronzy-purple leaves, delicate pink flower spikes
Coral Bells – large green leaves, delicate bright pink flower spikes
Sunrose – low-growing , multicolored, flowering perennial, grows well in full sun.
Gaura – fine-textured perennial with small pink flowers, blends well with native wetland plants.
Epimedium "Rose Queen" – large, evergreen leaves, small pink flowers
Lupine – 1-4' tall, blue-, purple- or red-blooming native plant.

Two years of monitoring show that the SEA Street LID project has reduced the total volume of stormwater runoff by 98 percent for a 2-year storm event (Horner et. al., 2002).



SEA Streets
Source: PSAT Website

The City of Seattle LID projects are categorized as either "biological" planting strips or bioretention facilities. The following soil specifications are from Seattle's *Soil Strategies for Stormwater Goals*, provided to CH2M HILL by the City of Seattle (City of Seattle, 2003).

- The City's soil mix must include 25 percent Decomposed Organic Mulch (Seattle City Ordinance Section 9-14.4(8)) by volume (plus or minus 2.5 percent), and the remaining volume shall be aggregate with the following gradations:

Sieve Size	Percent Passing
¾ inch	100
¼ inch	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-3

- Infiltration of planting soil mix shall have a minimum permeability rate of 3 inches per hour at field density.
- The soil and decomposed organic mulch components shall be combined to create a consistent, homogeneous mixture.
- The planting soil shall be evenly placed in 12 lifts not exceeding 12 inches and distributed in the trench such that the compaction does not exceed 80 percent of

maximum dry density per American Society for Testing and Materials (ASTM) Standard D-698.

- Use of mechanical vibratory compaction is not permitted.

Three soil mixes were used for Seattle's SEA Streets project to meet different bioretention facility needs:

1. Planting Soil Type A, per the City's standard specifications, was used on all areas of the project outside of the swale and road shoulder areas.
2. Planting Soil B was used within the detention swale areas. The high percentage of compost in the soil mix is intended to create conditions favorable for wetland vegetation.
3. Roadside Planting Soil was used in the 2-foot road shoulder areas. This soil mix was designed to support occasional vehicular traffic with minimal rutting, while also supporting vegetation growth.

Planting Soil Type A is required to consist of approximately two-thirds soil and one-third Decomposed Organic Mulch (Seattle City Ordinance Section 9-14.4(8)) by volume, thoroughly mixed together. The soil component is specified to be sandy loam or loamy sand consisting largely of sand, but with enough silt and clay present to give it a small amount of stability. The soil component must meet the following gradation requirements:

Sieve Size	Percent Passing
3/8	100
#35	85-100
#100	40-60
#270	10-30

Planting Soil Type B is required to comprise approximately 50 percent native soil and 50 percent Decomposed Organic Compost (Seattle City Ordinance Section 9-14.4(9)) by volume, thoroughly mixed together. Soil Type B is amended to create optimum conditions for plant establishment and early growth using materials such as calcium carbonate or dolomite lime, ureaform or ureaformaldeyde, calcium nitrate, superphosphate, and sulfate of potash magnesium. The percentages of these materials are to be indicated from a soil test and recommended by an approved independent laboratory, or as directed by the Engineer.

Roadside planting soil is Hendrikus Schraven Lawn Mix™ and is available from Hendrikus Schraven Landscape Construction and Design, Inc.

Decomposed Organic Mulch must consist entirely of recycled organic materials that have been sorted, ground, aerated, and aged for 1 year. The mulch must have a pH between 5.5 and 7.0 and a carbon-to-nitrogen ratio between 20:1 and 40:1, with maximum electrical conductivity of 3 ohms per centimeter.

The SEA Street project has 70 percent native soils mixed with 30 percent amended soils, for a depth of 1 foot. This layer sits on top of about 6 feet of reasonably good till soil, underlain by clay.

Bioretention System in Inglewood Plaza Parking Lot, Maryland

A bioretention system in Inglewood Plaza parking lot, Maryland, proved to be an effective pollutant-removal LID technique. The bioretention area acted as a natural means of controlling pollutants from entering the urban water bodies. The hydrological functional landscape acted as a mechanism for pollutant removal through physical and biological treatment processes occurring in the plant and soil complex (EPA, 2000).

This project demonstrated that parking lots are good sites for bioretention systems because the systems can be retrofit into existing lots with little or no loss of parking space, and the green space is also valued (EPA, 2000).

3.2 Amended Soils

Background

As land use intensifies, surface water runoff increases and evapotranspiration diminishes. This pattern is common in the urban environment and highlights the need for creative alternatives that can help reduce water runoff and increase groundwater infiltration in the face of continued growth.

It is widely recognized that urbanization brings increased peak storm flows and decreased summer flows to streams. This results from the increase in impervious surface and decrease in groundwater infiltration. It has been clearly demonstrated that minimizing development impact on native soils and forests, and restoring impacted soils with compost, can reduce peak storm flows and increase infiltration (Washington Organic Recycling Council, 2003).

Compost and other organic amendments improve soil function regarding plant growth, soil moisture and nutrient retention, and stormwater detention. Soil amendments increase spacing between soil particles, allowing the soil to absorb and hold more moisture. This in turn reduces runoff and the damaging effects of excessive runoff on local streams. Soil amendments also change other physical, chemical, and biological characteristics such that the soils become more effective in promoting water quality (LID Center, 2003b).

Application

Amended soils are effective for removal of pollutants, control of peak flows, and control of erosion. The College of Forestry Resources performed a field study of compost-amended soils at the University of Washington to determine the infiltration and water holding capacity of glacial till soils in the Seattle area. Due to the wide distribution and inherent stability, most residential housing developments in the Seattle area are sited on the Alderwood soil series, which is characterized by a compacted subsurface layer that restricts vertical water flow. Alderwood soil and compost mixtures were compared during varied storm events and intervals. The compost-amended Alderwood soils demonstrated that water-holding capacity of the compost mix was nearly doubled with a 2:1 compost soil amendment. Water runoff rates were attenuated, showing greater lag time to peak flow at

the initiation of a rainfall event and greater base flow in the interval following a rainfall event (EPA, 1999).

The study surmised that using compost amendments during the wettest parts of the winter would likely have minimal effects on the runoff from the Alderwood soils because there is very little transpiration during this time. However, during the early fall and late spring, the additional water-holding capacity of the compost-amended soils would result in additional transpiration.

If the site is not freely draining, compost in excess of 30 percent by volume should not be incorporated. This upper limit is suggested in the Pacific Northwest because winter's extended saturated conditions may create waterlogging. Saturated soils are easily compacted, thereby losing aeration and creating a poor rooting environment that reverses desired improvements (Chollak, 1998).

Instability could result from increased moisture content of amended soils on steep slopes; however, observations of amended sites on steep slopes indicate that this presents minimal risk and therefore should not be disqualified as an option but rather evaluated on a site-specific basis. The Washington State Department of Transportation has been incorporating compost-amendment in almost all of its vegetated sites since 1992. Even at the steepest end of the slopes with amended soil (33 percent slope), no problems have been created by the increased moisture holding capacity of compost amended soils. This observation includes all types of soils encountered in the Puget Sound Lowlands (Chollak, 1998).

Design Criteria

Soil analysis is needed for existing subsoil or redistributed native soil to determine amendment quantities. Amendments include compost, nutrients, lime, and gypsum. The optimum quantities of each of these amendments must be determined to receive the maximum benefits from compost amending.

Determining compost quantity to be incorporated into the native soil should be based on the organic content goal. Undisturbed sites in the Puget Sound Lowland comprise up to 3.5 feet of forest duff soil. This native topsoil usually has an organic content from 4 to 6 percent, significantly higher than the average subsoil organic content of less than 1 percent (Chollak, 1998). The final organic content target of amended soil is between 8 and 13 percent by soil weight. The organic content of all existing subsoil exposed during site construction is expected to be less than 1 percent. As a rule of thumb, a 2 to 1 ratio of existing soil to compost, by loose volume, will achieve the desired organic level. To maximize the benefits of compost incorporation, a minimum of the top 6 inches of soil should be amended (Chollak, 1998).

Nitrogen and sulfur are the most commonly deficient macronutrients in Puget Sound Lowland soils. Potassium, phosphorus, magnesium, and calcium levels are sometimes also insufficient for optimal vegetation growth. Micronutrients (the nutrients needed by vegetation in small quantities) will be supplied by the addition of compost, with the possible exception of boron (Chollak, 1998).

It is recommended to add lime to soils with a pH below 6.0. Lime has an added benefit of correcting calcium and magnesium shortages. Gypsum is used for three primary purposes

in soil: adding calcium and sulfur without increasing the pH, displacing sodium ions in extremely salty soils, and binding clay particles to enhance macropore abundance. Gypsum is not generally needed in the Puget Sound Lowlands (Chollak, 1998).

The City of Seattle has completed several construction projects using engineered soil mixes to help achieve stormwater detention goals. The projects are categorized as either "biological" planting strips or bioretention facilities. Amended soil is used with planting strips to detain and purify runoff. Please refer to section 3.1, Case Studies, SEA Streets Project, for the City of Seattle's soil mix criteria.

Case Studies

SEA Streets

Seattle Public Utilities implemented various aggregates and soil mixes below grade in the SEA Streets design that uses grading, soil science, plant selection, and layout combined with traditional drainage infrastructure to function more like an undeveloped ecosystem.

The SEA Streets project has prevented the discharge of all dry season flow and 98 percent of the wet season runoff (Horner et al., 2002).

Guidelines for Landscaping with Compost-Amended Soils, Redmond, Washington

The City of Redmond analyzed the environmental and economic benefits of incorporating compost as a soil amendment for turf establishment and landscaping. The environmental aspects included reducing both stormwater runoff (with high concentrations of fertilizers and pesticides) and irrigation needs (Chollak, 1998). The economic criteria included peak summer water rates, fertilizer, and turf installation costs.

The study concluded that turf grown on tilled, compost-amended soil by hydroseed application pays for itself in a variety of timeframes when compared to the following alternatives:

1. Between the fifth and sixth years when compared to topsoil-seed
2. During the first year when compared to topsoil-sod
3. Between the sixth and seventh years when compared to minimum-seed
4. Between the second and third years when compared to minimum-sod

Most landscapes in urban and suburban areas of the Puget Sound region consist of lawns. Amending a soil with compost increases the soil's permeability and water holding capacity, thereby delaying and often reducing the peak stormwater runoff flow rate and decreasing irrigation requirements. The benefits of compost-amended turf over lawn include reductions in maintenance and watering requirements.

The following pictures, show the "before" and "after" effect of compost-amended soils.



Compost being incorporated on an embankment of the Oaks of Terra Nova West subdivision detention basin.



The same area on the Oaks of Terra Nova West detention basin 3 years later. Note the heavily riffled, sparsely vegetated embankment to the right of the compost area.

Source: Sherri Dunlap, 1998.

3.3 Green Roofs

Background

Green roofs are an innovative stormwater management solution that can simultaneously reduce stormwater runoff and improve the energy performance of buildings, air quality, and the urban ecology - all without taking up additional land.

Research in Europe and North America shows that green roofs offer a wide range of environmental, social, and economic benefits, including:

- Stormwater management and flood prevention
- Reduction in greenhouse gas emissions
- Improved air quality (up to 85 percent of dust particles can be filtered out of the air)
- Cooler temperatures and higher humidity, achieved through natural evaporation
- Storage of 30 to 100 percent of annual rainfall, relieving storm drains and feeder streams
- A more aesthetically pleasing landscape
- Decreased need for other stormwater management practices
- Decreased heating and cooling costs
- Increased life of the conventional roof underneath the grass roof
- Replacement of the open space where the structure now sits
- Habitat for wildlife
- Reduction of the "heat island" effect in cities

Green roofs have been used extensively in Germany and elsewhere in Europe for more than 25 years, and results in temperate climates have shown up to 50 percent reduction in annual runoff (LID Center, 2003a). This has been the direct result of government legislative and financial support at both the state and municipal level. Such support recognizes the many tangible and intangible benefits of green roofs. This support has led to the creation of a multimillion-dollar market for green roof products and services in Germany, France, Austria, and Switzerland, among others. The industry continues to experience growth, with 13.5 million square meters (m^2) of green roofs constructed in 2001; this is up from 9 million m^2 built in 1994.

Many opportunities exist to retrofit these systems in older, highly urbanized areas in the United States; however, the benefits of green roof technology are poorly understood, and the market remains immature despite the efforts of several industry leaders.

The greatest concern about green roofs is leaks. The first green roofs in the1970s (then called sod roofs) were not properly insulated, and leaks were widespread. Many of these roofs were removed because of the high maintenance required.

Today the situation is different: manufacturers have greatly improved the quality of waterproofing membranes. In retrofit applications, load restrictions are usually the main limitation. Load reserves of at least 15 pounds per square foot (psf) beyond snow load requirements are needed to install a green roof. Green roofs are typically expected to last twice as long as comparable conventional roofs.

Application

Manufacturing facilities, office buildings, shopping malls, churches, and other buildings with a wide roof area are all potential applications for green roofs. Green roofs can be installed over any properly designed and constructed deck, including concrete, wood, and steel.

There are two types of green roof: intensive and extensive. Intensive green roofs require a minimum of 1 foot of soil depth to create a more traditional roof garden, with large trees,

shrubs, and other manicured landscapes. They are multilayer constructions with elaborate irrigation and drainage systems. Intensive green roofs add considerable load, from 80 to 150 psf, to a structure and require intensive maintenance. These roof gardens are designed to be accessible and are used as parks or building amenities. To support the added weight, the building may require additional load-bearing capacity.

In contrast, an extensive green roof requires 1 to 5 inches of soil depth and mainly supports shallow root plants. Typically, it resembles a meadow. It is not designed to support pedestrian traffic and does not require much maintenance. It adds a load of typically 15 to 50 psf. This type of roof does not usually require structural modifications. Extensive green roofs are primarily built for their environmental benefits (Scholz-Barth, 2001).

Roof slope can be a challenge for retrofits. Contrary to common opinion, flat roofs are not the ideal surface for a green roof. A flat roof requires an additional layer to drain excess water away from the root zone. A roof slope between 5 and 20 degrees works best because water drains naturally due to gravity. Roofs with up to a 40-degree slope can be greened, but slopes greater than 20 degrees require a wooden lath grid that forms small fields to hold soil substrate in place until plants form a thick vegetation mat.



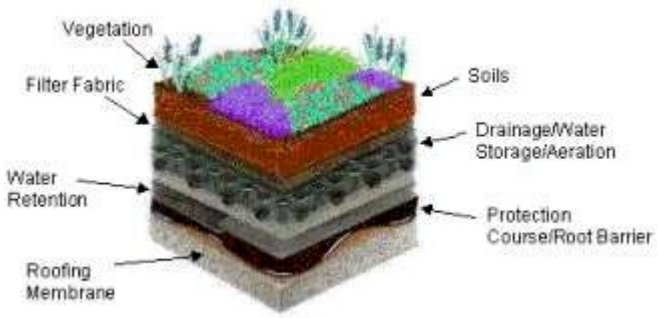
A green roof in Portland, Oregon

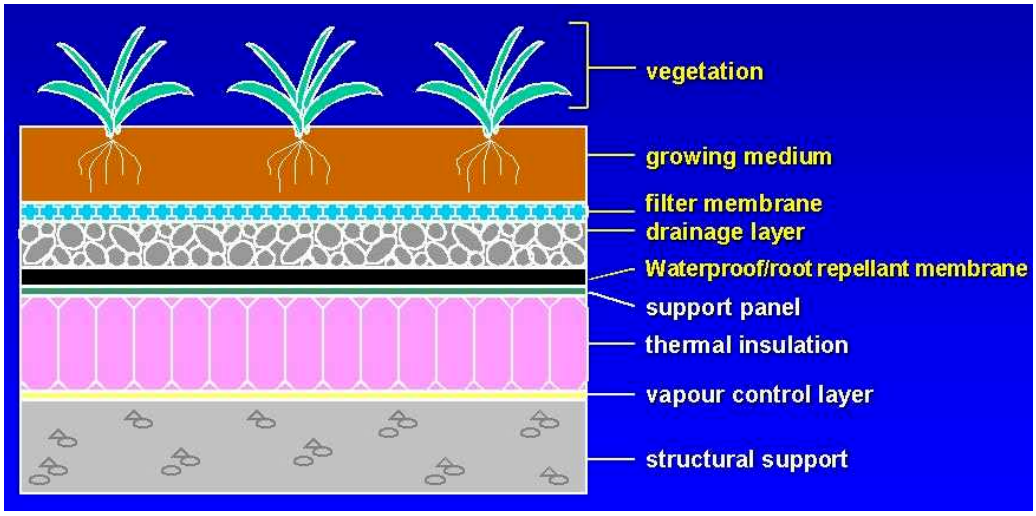
Source: Northwest EcoBuilding Guild, 2003

Design Criteria

A green roof is a multilayered constructed material consisting of a vegetative layer, a growing medium, a geotextile layer, and a synthetic drain layer.

A typical green roof has a rubber or plastic waterproof liner laid over the traditional rooftop. Either above or below the waterproof layer is a layer of insulation material such as perlite. Over or at the end of the insulation layer, a drainage layer may be added, depending on the pitch of the roof. Finally, a thin layer of soil mix is added and planted with grasses, ground covers, or drought-tolerant plants (NEMO, 2003).





Typical cross sections for green roofs

Sources: Puget Sound Action Team, 2003 (top) and NRDC, 2002 (bottom)

Case Studies

International

Many successful green roof examples exist, particularly in Germany, where 43 percent of municipalities provide incentives for green roof construction. The descriptions provided here (Kortright, 2001) are intended simply to give an idea of the different reasons why green roofs are installed and the different ways they may be used.

- **Company Group Gegenbauer Golf Course (Berlin)** - The entire 1,400-square-meter intensive green roof is a miniature golf course. It was constructed on the existing building using ZinCo International's Floradrain™ FD 25 + FD 60.
- **York University Computer Sciences Building (Toronto)** – A largely inaccessible green roof, built mainly to help retain stormwater.
- **Merchandise Lofts (Toronto)** – A large accessible green roof, which includes a 150-foot prairie meadow, a wetland garden, and birch trees, all growing on Soprema's Sopraflor™ growing medium, nourished by an in-ground irrigation system.

- **YMCA Environmental Learning Centre (Kitchener-Waterloo, Ontario)** - 8 inches of dirt and natural grasses, which cover two partly earth-sheltered buildings.
- **Northwest Territories Legislative Building (Yellowknife, NWT)** - Green roof planted with native Canadian species.

See Peck et al. (1999), available on the web or in hard copy from the Canadian Mortgage and Housing Corporation, for 12 additional Canadian examples.

United States

Kortright (2001) provides several examples from the United States:

- **Point Defiance Zoo and Aquarium (Tacoma, WA)** - Point Defiance Zoo and Aquarium implemented a 10,000-square-foot (ft^2) green roof in 2002. The vegetated cover is composed primarily of sedum varieties. An unusual feature of this project is the use of tumbled glass scraps as a margin gravel.
- **Two-story residential house (Anne Arundel County, MD)** - A two-story residential house applied a green roof to absorb stormwater, improve air quality, and keep the house from heating up too much in the summer sun. A rubber membrane covered by sod prevents water from passing through to the underlying roof.
- **Chicago City Hall (Chicago) –** A 38,800-ft^2 inaccessible green roof was installed on an existing structure. The roof is a mix of intensive and extensive plantings, with soil depths ranging from 3.5 inches, planted with sedums, to 24 inches over supporting columns, which can support trees and shrubs.
- **City of Portland green roof demonstration projects (Portland, OR)** - Two demonstration sites have been established in connection with a new program to reduce stormwater management lot level fees for buildings with green roof systems. One site compares 3- and 5-inch growing mediums, monitored for energy benefits and level of flow. The other is planted with species native to the West Coast and is not being irrigated in order to determine which plants are most successful in the green roof environment.
- **Patricia Neal Rehabilitation Centre (Knoxville)** - A rooftop therapy park, constructed in 1994 to provide a rejuvenative environment for recovering patients. The intensive green roof design includes small trees.
- **Northwest EcoBuilding Guild –** The Central Puget Sound Chapter of this organization has a 2-year project to develop a cost-effective and reproducible model(s) of the eco-roof building technology appropriate for wide-scale residential application in the Northwest (Northwest EcoBuilding Guild, 2003).

3.4 Dispersion of Runoff from Impervious Surfaces

Background

Dispersing stormwater runoff is the concept of evenly spreading out concentrated runoff to enhance infiltration and reduce overall offsite runoff. A level spreader is an outlet designed

to convert concentrated runoff to sheet flow and disperse it uniformly across a slope without causing erosion. Alternative designs to minimize concentrated runoff include hardened structures, stiff grass hedges, and segmenting discharge flows into a number of smaller, adjacent spreaders (NCSU, 2003).

Application

Level spreaders are most often used as an outlet for temporary or permanent stormwater conveyances or dikes (runoff diversions) (Salt Lake County, 1999).

This structure is particularly well suited for returning natural sheet flows to existing drainage that has been altered by development, especially for returning sheet flows to receiving ecosystems such as wetlands where dispersed flow may be important for maintaining preexisting hydrologic regimes (BCLSS, 2000).

Design Criteria

Level spreaders can be used to convey sheet flow runoff from impervious areas within graded areas to infiltration areas. The receiving area of the outlet must be uniformly sloped and not susceptible to erosion. Particular care must be taken to construct the outlet lip completely level in a stable, undisturbed soil to avoid formation of rilling and channeling. Erosion-resistant matting can be used across the outlet lip, depending on expected flows (Prince George's County, 1999).

The length of the spreader depends upon the amount of water that flows through the conveyance. In general, the length of the level spreader in feet should be equal to the number of cubic feet per second (cfs) of runoff expected from the storm event (inches). The minimum acceptable width for this measure is 6 feet. The depth of the level spreader should be at 6 inches, measured from the lip, and must be uniform across the length of the measure.

Level spreaders are generally used with filter strips. The depressions are seeded with vegetation. The grade of the channel for the last 15 feet before entering the level spreader must be less than or equal to 1 percent. The level lip of the spreader must be constructed at zero percent grade to ensure even spreading of storm runoff to produce sheet flow. The entrance to the spreader must be carefully graded to divert runoff directly into the zero-percent-graded channel. The level spreader must be constructed on undisturbed soils (not on fill), and the sheet flow must discharge onto undisturbed, stabilized areas. Stormwater must not be allowed to reconcentrate below the point of discharge (Salt Lake County, 1999; U. of Georgia, 2003).

Case Studies

No case studies were found at time of publication.

3.5 Pervious Pavement

Background

Pervious pavement is a special type of pavement that allows stormwater to pass through it, thereby reducing site runoff. In addition, pervious pavement provides runoff treatment through filtration and allows for groundwater recharge (Ecology, 2001).

This type of pavement has been in use throughout Europe for about 50 years. In the United States, pervious pavement was pioneered by researchers at the Franklin Institute in Philadelphia and the Florida Concrete & Products Association in the early 1970s. The Florida Concrete & Products Association created a domestic formula called Portland Cement Pervious Pavement. This formula has since proved effective in the U.S.

Cahill Associates, a Philadelphia environmental engineering firm, has been designing and constructing pervious pavement/recharge bed installations on the East Coast for more than 22 years (Cahill Associates, 1994).

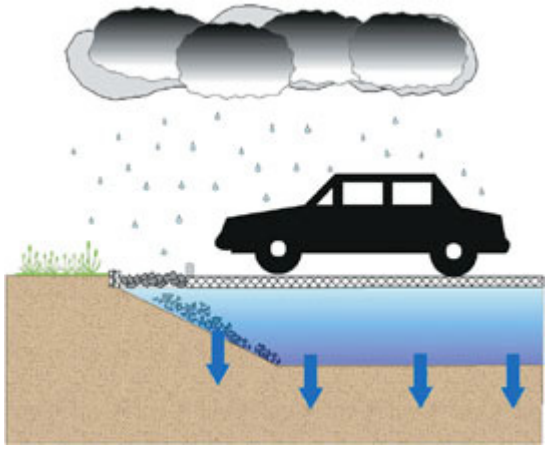
Since the early 1970s, pervious pavement parking lots have been installed successfully in several states (Delaware, Pennsylvania, and Texas) with encouraging results for road use and local water retention. In England, when pervious pavement was laid over a conventional airport runway surface, it improved landing safety and withstood the abuse of commercial aircraft landings (Miller, 2002).

In the parking lot shown below (photo A), rainfall runs off traditional impervious asphalt (center drive) but drains through the pervious asphalt parking spaces. The schematic (B) is a cross-section of pervious asphalt, showing the subsurface infiltration bed beneath.



A.

Rainfall runs off traditional impervious asphalt (center drive) and drains through pervious asphalt parking spaces



B.

Cross-section through pervious asphalt

Source: LID Center, 2003a

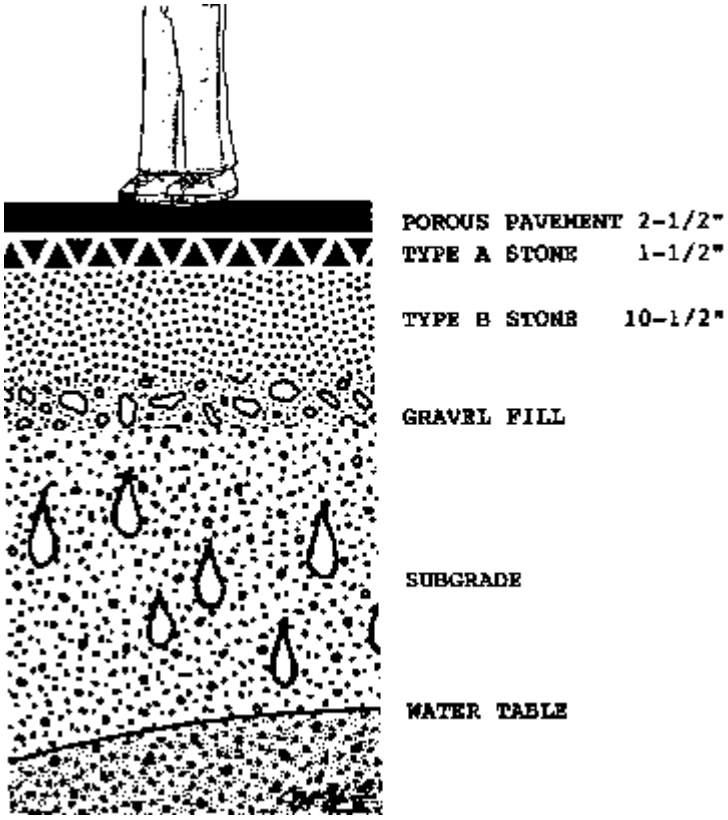
Application

Pervious pavement can be applied in most regions of the country, but the practice has unique challenges in cold climates. Pervious pavement cannot be used where sand is applied to the pavement surface because the sand will clog the surface of the material. Care also needs to be taken when applying salt to a pervious pavement surface because chlorides from road salt may migrate into the groundwater. For block pavers, plowing may be challenging because the edge of the snowplow blade can catch the edge of the blocks, damaging the surface. Another concern in cold climates is that infiltrating runoff below pavement may cause frost heave, although design modifications can reduce this risk.

These difficulties do not imply that it is impossible to use pervious pavement in cold climates. Pervious pavement has been used successfully in Norway (Stenmark, 1995), incorporating design features to reduce frost heave. Furthermore, some experience suggests that snow melts faster on a pervious surface because of rapid drainage below the snow surface (Cahill Associates, 1993).

Pervious pavement is a good option in densely developed urban areas where little pervious surface exists. It is not ideal for high-traffic areas, however, because of the potential for failure due to clogging (Galli, 1992).

Since pervious pavement is an infiltration practice, it should not be applied on stormwater "hotspots" due to the potential for groundwater contamination. Stormwater hotspots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. These areas include: commercial nurseries, auto recycle facilities, high-use commercial parking lots (100 vehicles per 1,000 square foot gross building area or 25 or more vehicles over 10 tons gross weight), fueling stations, storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading/unloading facilities, public works storage areas, hazardous materials generators (if containers are exposed to rainfall), vehicle service and maintenance areas, and vehicle and equipment washing/steam cleaning facilities.



Pervious Pavement Section
Source: NRDC

Pervious pavement has the same siting considerations as other infiltration practices. Sites need to meet the following criteria for pervious pavement to be effective:

- Soils need to have permeability between 0.5 and 3.0 inches per hour.
- The bottom of the stone reservoir (water storage area underlying the pavement) should be completely flat so that infiltrated runoff can infiltrate through the entire surface.
- Pervious pavement should be sited at least 2 to 5 feet above the seasonally high groundwater table and at least 100 feet away from drinking water wells.
- Pervious pavement should be sited on low-traffic or overflow parking areas that are not sanded for snow removal.

Design Criteria

Pervious concrete is a structural, open-textured, pervious concrete paving surface consisting of standard Portland cement, fly ash, open-graded coarse aggregate, admixtures, fibers, and potable water. When properly handled and installed, pervious concrete has a high percentage of void space (approximately 17 to 22 percent), which allows rapid percolation of stormwater through the pavement (Ecology, 2001).

Porous asphalt paving material consists of an open graded coarse aggregate cemented together by asphalt cement into a coherent mass with sufficient interconnected voids to provide a high rate of permeability to water (ECOLOGY, 2001).

Some basic features should be incorporated into all pervious pavement practices. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

1. **Pretreatment.** In pervious pavement designs, the pavement itself acts as pretreatment to the stone reservoir below. Because the surface serves this purpose, frequent maintenance of the surface is critical to prevent clogging. Another pretreatment item can be the incorporation of a fine gravel layer above the coarse gravel treatment reservoir.
2. **Treatment.** The stone reservoir below the pavement surface should be composed of layers of small stone directly below the pavement surface, and the stone bed below the permeable surface should be sized to attenuate storm flows for the storm event to be treated. Typically, pervious pavement is sized to treat a small event, such as a water quality storm. As in infiltration trenches, water can be stored only in the void spaces of the stone reservoir.
3. **Conveyance.** Water is conveyed to the stone reservoir through the surface of the pavement and infiltrates into the ground through the bottom of this stone reservoir. A geosynthetic liner and sand layer should be placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom. Designs must also include methods to convey larger storms to the storm drain system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would bypass flows when the surface clogs or when the flows are too large to be treated by the system.
4. **Maintenance Reduction.** One nonstructural component that can help ensure proper maintenance of pervious pavement is the use of a carefully worded maintenance agreement that provides specific guidance, including how to conduct routine

maintenance and how to repave the surface. Ideally, signs should be posted on the site identifying pervious pavement areas. One design option incorporates an "overflow edge," which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the surface of the pavement. Although this feature does not in itself reduce maintenance requirements, it acts as a backup in case the surface clogs. If the surface clogs, stormwater will flow over the surface and into the trench, where some infiltration and treatment will occur.

5. **Landscaping.** For pervious pavement, the most important landscaping feature is a fully stabilized upland drainage. Reducing sediment loads entering the pavement can help to prevent clogging.

In one design variation, the stone reservoir below the filter can also treat runoff from other sources, such as rooftop runoff. In this design, pipes are connected to the stone reservoir to direct flow throughout the bottom of the storage reservoir (Cahill Associates, 1993; Schueler, 1987). If used to treat offsite runoff, pervious pavement should incorporate pretreatment, as with all structural stormwater management practices.

In cold climates, the base of the stone reservoir should be below the frost line. This modification will help to reduce the risk of frost heave.

The following pictures show various parking lot projects across the county that have implemented pervious pavement to reduce stormwater runoff.



Hockessin, Delaware, City Library: pervious pavement parking lot with gravel-filled recharge beds underneath.

Source: Cahill Associates



Atlantic City, New Jersey, McDonald's: pervious pavement light commercial parking lot with recharge beds.

Source: Cahill Associates

The next three techniques are pervious pavement alternatives that are strong enough to support vehicle loads, yet provide more pervious area and are more aesthetically pleasing.

3.6 GrassPave™

GrassPave is a high-density polypropylene grid structure that minimizes grass and root compaction while maintaining infiltration capability. It provides load-bearing strength while protecting vegetation root systems. Void spaces within the cross-sections enable root development and provide storage capacity for rainfall from storm events. Stormwater is slowed in movement through and across GrassPave surfaces, depositing suspended sediment and increasing time to discharge. Suspended pollutants and moderate amounts of engine oils are consumed by active soil bacteria, which are aided by the system's oxygen exchange capacity (Invisible Structures, Inc., 2002a**).**

Grass paving can be used with low- to medium-use parking surfaces such as drive aisle and parking stall applications. Grass paving is most successful when the subbase is designed to suit the soil conditions and loading requirement while allowing for drainage. Wood blocking or edging is not required and may create a dam effect in heavy rain.

The following pictures illustrate grass pavers and their uses in parking lot structures.



Grasspave²
Pervious Paving System,
Invisible Structures



Portland Trailblazers Basketball Facility
Tualatin, Oregon, Grasspave² Firelane



Orange Bowl Stadium
Miami, Florida, Grasspave2 Parking Lot

Source: Invisible Structures, Inc., 2002a

3.7 GravelPave™

GravelPave is a structure that provides load-bearing support and containment of gravel to create a pervious pavement surface for traffic volume and parking. If used with a proper pervious base course material, GravelPave can provide a void space of up to 35 percent for storage volume of rainfall during rain events. Although beneficial bacteria (biotic community) concentrations within the gravel are lower than with GrassPave, polluted runoff and vehicle drippings are still consumed prior to reaching the water table (Invisible Structures, 2002b).

GravelPave can be applied to:

- All parking aisles and bays
- Handicap parking spaces
- Automobile and truck storage yards
- All service and access drives/loading dock areas
- Trails for multiple uses, boat ramps
- Outdoor bulk storage areas (lumber, steel, etc.)
- Infiltration basins and high-use pedestrian areas

The following pictures illustrate the GravelPave system and two project sites where they were used in Colorado and Arizona.



GravelPave²
Pervious Paving System,
Invisible Structures



The Nature Conservancy
Tucson, Arizona, GravelPave² Parking Lot



Private Residence
Nederland, Colorado,
ADA-Accessible Trail

Source: Invisible Structures, Inc., 2002b

3.8 Paving Blocks

Paving blocks are interlocking concrete pavers that form drainage openings in the pavement surface. Blocks can be installed in running bond, basketweave, and herringbone patterns. The drainage openings facilitate rainwater infiltration. Paving blocks are durable enough to support vehicular loads (UNI-Group USA, 2002).

Application

Paving blocks can be used for a wide array of paving applications, including residential, commercial, municipal, and industrial projects, such as:

- Patios, walkways, terraces, pool decks, and driveways
- Courtyards, pedestrian malls, plazas, and parks
- Sidewalks, streets, medians, and parking areas
- Roof plaza decks, roof parking decks, and roof ballast
- Farm roads and yards, stable flooring
- Gas stations, highway ramps, and rest areas
- Bridge underpasses, slope and erosion control
- Storage depots, industrial parks, and ports
- Military installations, factory yards and streets
- Loading docks, container and bus terminals
- Airport taxiways, maintenance and hangar areas

The following pictures show UNI Eco-Stone paving blocks applied to projects in New Hampshire and Canada.





The UNI Eco-Stone Paving System



Plymouth College
Plymouth, New Hampshire



Intersection, Ontario, Canada

Source: UNI-Group USA, 2002

Case Studies

Pervious Pavement, Pennsylvania and Delaware

Cahill Associates, Inc., which has been active with pervious pavement implementation for 20 years, provides a number of case studies of pervious pavements in parking lots. Two of the larger studies include Morris Arboretum, Pennsylvania, and Hockessin Library, Delaware. From observation, Cahill Associates states that all of their projects have effective long-term infiltration performance (Cahill, 2002).

Permeable Pavement, Florida Aquarium Parking Lot

The Florida Aquarium Parking Lot in Tampa, Florida, used permeable pavements and swales to reduce stormwater runoff and pollutant loading. Four different sections of asphalt or concrete pervious pavement, with and without swales, were developed over the entire parking lot. Larger rainfall amounts showed fewer differences in runoff amounts between the different pavement types, but basins with swales have approximately 40 percent less runoff than the basins without swales. Comparisons of rainfall with storm runoff amounts showed that swales reduced runoff for all rainfall events and paving types.

University of Washington Study on Permeable Pavements

The University of Washington, Seattle, conducted a study on types and characteristics of permeable pavements. The study site is an employee parking lot on the southeast corner of the King County Public Works Facility in Renton, Washington (Booth, 2002).

Four different pavement types were constructed: plastic network with grass infilling (GrassPave), equivalent plastic network with gravel infilling (GravelPave), impervious blocks with grass infilling (Turfstone™), and impervious blocks with gravel infilling (UNI Eco-Stone) (Booth, 2002). The permeable pavement systems were evaluated after 6 years of daily parking usage for structural durability, ability to infitrate precipitation, and impacts on infiltrate water quality.

GrassPave and GravelPave experienced a little local shifting under the drive wheels, but Turfstone and UNI Eco-Stone held up as well as asphalt. Virtually all rainwater infiltrated through the permeable pavements, with almost no surface runoff (Brattebo, et al., 2003). The infiltrated water had significantly lower levels of copper and zinc than the direct surface runoff from the asphalt area. Motor oil was detected in 89 percent of samples from the asphalt runoff, but in no samples of stormwater infiltrated through the permeable pavement. Neither lead nor diesel fuel was detected in any sample (Brattebo, et al., 2003).

Pierce County Research on Pervious Paving

Pierce County, Washington, examined existing research on pervious paving, including pervious asphalt, pervious concrete, interlocking pervious pavers, and gravel-surface systems. The study concentrated on infiltration capability over time and the potential to restore degraded infiltration through various maintenance strategies. The objective of this study was to increase credits, designated by the Washington State Department of Ecology (Ecology), for the use of pervious pavement.

The driving surface, not the underlying soils and base materials, was the focus in this study. Research performed in the U.S., Europe, and Canada was reviewed to provide a starting

point for determining the appropriate level of credit to assign pervious pavement in Ecology's *Stormwater Management Manual for Western Washington* (Ecology, 2001).

A summary of infiltration rates, long-term performance, and maintenance requirements was presented in the report. The study found that the design of the pervious surface is critical for determining infiltration rates and performance over time. Proper procedures for design and installation prevent introduction of fine material, allow the driving surface to compact properly, and prevent introduction of sediment-laden surface flows (Hinman, 2002).

Research indicated clogging as the primary mechanism that degrades infiltration rates. The studies examined indicate that a 50 percent loss of infiltration capacity is typical for pervious pavement surfaces (the rate-of-infiltration decline was not given in the report). This reduction, from initial infiltration rates that range from 100 to 1,700 inches per hour, still provides infiltration rates well above Puget Sound design storms. Introduction of fines from vehicles and, more significantly, sediment from surface flows are cited as the primary mechanisms for clogging (Hinman, 2002).

As a result of the study, Pierce County recommends modeling pervious pavement at 100 percent grass (rather than 15 percent of the surface), based on the fact that the infiltration rates of these systems are above the largest design storms for the Puget Sound region (Hinman, 2002).

Various LID practices implemented throughout the Puget Sound region are summarized in Table 3.1.

TABLE 3.1
Various LID projects implemented in the Puget Sound Region

Organization	Contact name	Project description	Project site	Year built	Maintenance	Results
City of Seattle	Tracey Tackett	Pervious concrete sidewalk	N 145th Street from Dayton Ave N to approximately 300 feet east of Fremont Ave N	January 2002	No maintenance is planned for the walkway	N/A
City of Seattle	Tracey Tackett	Pervious concrete road installations	High Point housing development	Future planning	Vacuum sweep roads once per year	N/A
City of Seattle, Seattle Public Utilities	John Arneson	Raingardens/landscaping to promote infiltration/decrease runoff. Drought-tolerant swales along side of roadway. Decreased roadway width to reduce imperviousness.	SEA Streets Project, 2nd Ave NW between NW 117th St and NW 120th St	2001	Replace and remulch once a year	Project demonstrated that stormwater detention and mitigation can effectively be distributed locally, be managed near its source, and be considered an amenity
City of Seattle, Seattle Public Utilities	Thor Peterson	Green roof consisting of a multilayered waterproofing membrane integrated with a soil support system.	Justice Center in Seattle	N/A	N/A	N/A
Snohomish County, Public Works	Nat Washington	Private development using pervious concrete roadway and driveways	Maltby Joint Ventures-Chinook Homes.	In progress	Homeowners responsible for maintenance	N/A
City of Marysville	Jesse Thompson, Perteet Engineering	Eco-Stone concrete pavers	Ash Street Park-n-Ride in Marysville	In progress	Anticipate sweeping once a year as recommended by the vendor	N/A
City of Olympia	Craig Tosomeen	Subsurface drainage enhancement to a gravel parking lot. Geoweb™ used to maintain the void space in the subsurface material, allowing drainage while providing structural support for heavy loads	Olympia High School	1996	No maintenance or monitoring is being performed	The parking lot has not subsided or failed
City of Olympia, Maintenance Department	Tom Khuen	Grasscrete™ pavers	Maintenance Building	1999	Used Weedeater™ 2 years after installation	Not happy because grass overgrowth is filling the voids and affecting infiltration

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Organization	Contact name	Project description	Project site	Year built	Maintenance	Results
Olympia	Chuck Dower	Eco-Stone pavers used on parking areas with low traffic	Martin Way Station, Safeway Parking lot, Cooper Pt Rd, Business on Evergreen Park Dr and Cooper Pt Rd	5-6 years old	Property owners responsible for maintenance, but no maintenance or testing has been observed	Construction cost has kept pavers from being used on a bigger scale, but existing projects support reduced runoff, and aesthetically they appear to be working well
Evergreen State College	Michel George	Redevelopment of parking lot that reorganizes parking lot space and lanes, implements planters and pervious pavement	Evergreen State College	N/A but in progress when article was written	N/A	N/A
King County	Bob Kelley	Soil amendment and revegetating landscaped areas with native plants	Novelty Hill Area of the Bear Creek Community	In progress	N/A	N/A
City of Bellingham	Renee LaCroix	Bioretention cell that treats runoff from a parking lot	Parking lot behind Bellingham City Hall	N/A	N/A	City staff report that water appears less turbid than before the rain garden was built
City of Bellingham	2020 Engineering, Inc.	Grass pavement system for parking area	Bayview Corner on Whidbey Island	N/A	N/A	The parking lot meets traditional traffic loading design standards. The grass parking replicates natural conditions for infiltration of stormwater runoff and eliminated the need for conventional detention/treatment systems

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4. Conclusion

Throughout Europe, Canada, and now the United States, low-impact development practices have been applied to reduce runoff channeled away from the site and to lower the imperviousness of developing areas, allowing for greater onsite retention and runoff treatment.

Bioretention cells, engineered landscapes/amended soils, green roofs, dispersion of runoff from impervious surfaces, and permeable pavement are popular techniques. These techniques have been implemented and proved successful at attenuating and treating offsite runoff in the Puget Sound region, designed to accommodate our regional climate and soil characteristics.

LID techniques have advantages over traditional stormwater management techniques in that they uniformly integrate stormwater controls throughout a site to create a landscape that mimics the natural hydrologic regime without relying on traditional end-of-pipe structural methods.

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Analysis and Recommendations for the Use of LID Techniques in Puget Sound

Produced through Funding from the Department of Ecology and Administered by the Puget Sound Action Team

PREPARED FOR: Puget Sound Action Team

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DATE: January 16, 2004

1. Introduction

The Puget Sound Action Team (PSAT) is interested in developing additional information on low-impact development (LID) practices for the Puget Sound region. PSAT contracted with CH2M HILL to develop this additional information in three primary phases: Phase 1, review of selected LID techniques; Phase 2, analyses and recommendations for the use of LID techniques in Puget Sound; and Phase 3, analysis and recommended changes to selected best management practices (BMPs) in the *Stormwater Management Manual for Western Washington* to include the benefits of LID techniques.

This project will produce three technical memoranda. They are:

1. Review of Low-Impact Development Techniques
2. Analysis and Recommendations for the use of LID Techniques in Puget Sound
3. Suggested Adaptations to BMPs in the Washington Stormwater Management Manual to Include Benefits of LID Techniques

This Technical Memorandum 2 covers the second phase of the project, Low Impact Development in the Puget Sound Region, analyses and recommendations for the use of LID techniques in Puget Sound.

2. Analysis of Low Impact Development Techniques

A series of scenarios was modeled to demonstrate the potential hydrologic effectiveness of a range of LID techniques in the Puget Sound region. The scenario modeling was based on the best available knowledge of LID techniques, but has been calibrated with measured data. The modeled LID scenarios are intended to provide a starting point for evaluating opportunities for LID in Puget Sound, but they do not represent all of the available LID techniques.

Following a review of the analysis methods and results, recommendations for use of selected LID techniques in Puget Sound are provided. General descriptions and design guidelines for each of the LID techniques included in the analysis are provided in Section 3.

LID Scenarios

Several combinations of LID techniques were modeled for three locations representing the different regions of Puget Sound:

- **Olympia –** Representative of the wetter southern parts of the Sound, including Thurston and Mason counties (with 50 inches + of annual precipitation).
- **SeaTac Airport –** Representative of Central Puget Sound, including King, Snohomish, and Pierce counties (with approximately 30 to 40 inches of annual precipitation); and
- **Port Angeles –** Representative of the drier northern parts of the Sound in San Juan, Island, and Jefferson counties (with <20 inches of annual precipitation);

For each of these locations, LID scenarios were modeled for a typical residential block and for a typical commercial lot, under two types of soil conditions that are representative of Hydrologic Soil Groups A and C (as defined by the Natural Resource Conservation Service).

Analysis of model results enabled LID techniques to be evaluated relative to the range of rainfall patterns, soil conditions, and land uses in the Puget Sound region. LID scenarios were compared with scenarios representing unmitigated development and natural forested conditions.

The modeled scenarios are shown in the table below (more detailed descriptions of the applied LID techniques are provided in Technical Memorandum 1). The remainder of this section describes the methodology and the results of LID scenario modeling. Section 3 below provides guidance for the implementation of the selected LID techniques.

Residential LID Applications

The following scenarios were modeled and compared for a typical 5-acre residential block with a total impervious area of about 47 percent (see Figure 1):

- **Unmitigated Residential Block –** All runoff from impervious area on lots and road rights-of-way is connected to a piped storm drainage system. All pervious surfaces are covered by "disturbed soils" (i.e., a relatively thin layer of turf placed on compacted soil).
- **LID Scenario 1: Soil Amendments and Bioretention –** The following LID techniques were applied on the residential block:
  - *On-lot Bioretention* - Rooftop runoff and on-lot pavement runoff are diverted into bioretention areas, which cover 5 percent of the lot area (e.g., 20-ft x 15-ft area on a typical 6,000 ft² lot). These bioretention areas have 24 inches of absorbent soil and up to 3 inches of surface ponding to retain stormwater and allow it to infiltrate into the surrounding native soil.

LID Scenarios Modeled

	Land Use							
Location and Rainfall	**Commercial Site LID Scenario 1**		**Commercial Site LID Scenario 2**		**Residential Block LID Scenario 1**		**Residential Block LID Scenario 2**	
South Puget Sound >50" rainfall	Bioretention and amended soils only		LID Scenario 1 plus pervious pavement		Bioretention, reduced impervious area and soil amendments		Scenario 1 plus permeable streets and green roofs	
Soil Type	A	C	A	C	A	C	A	C
Seattle 35-40" of rainfall	Bioretention and amended soils only		LID Scenario 1 plus pervious pavement		Bioretention, reduced impervious area and soil amendments		Scenario 1 plus permeable streets and green roofs	
Soil Type	A	C	A	C	A	C	A	C
North Puget Sound < 20" rainfall	Bioretention and amended soils only		LID Scenario 1 plus pervious pavement		Bioretention, reduced impervious area and soil amendments		Scenario 1 plus permeable streets and green roofs	
Soil Type	A	C	A	C	A	C	C	C
Notes: Unmitigated development and forested conditions were modeled for each rainfall, soil type, and land use.								

- *Bioretention Swales on Roads* - Runoff from paved areas within the road rights-of-way and overflow from on-lot bioretention areas is diverted into bioretention swales, which are applied along 45 percent of the main roads (both sides). The bioretention swales cover about 5 percent of the total right-of-way (ROW) area and have 24 inches of absorbent and 6 inches of surface ponding (on average). Overflow from bioretention swales is carried away by a piped storm sewer system (i.e., becomes surface runoff from the block).
- *Soil Amendments* – All remaining pervious space on lots and road rights-of-way is covered by 12" of vegetated absorbent soil.
- *Elimination of Unnecessary Pavement* - Some paved portions of the road shoulder are replaced with bioretention swales or absorbent soil (this reduced the total impervious percentage of the block from 47 percent to 44 percent).

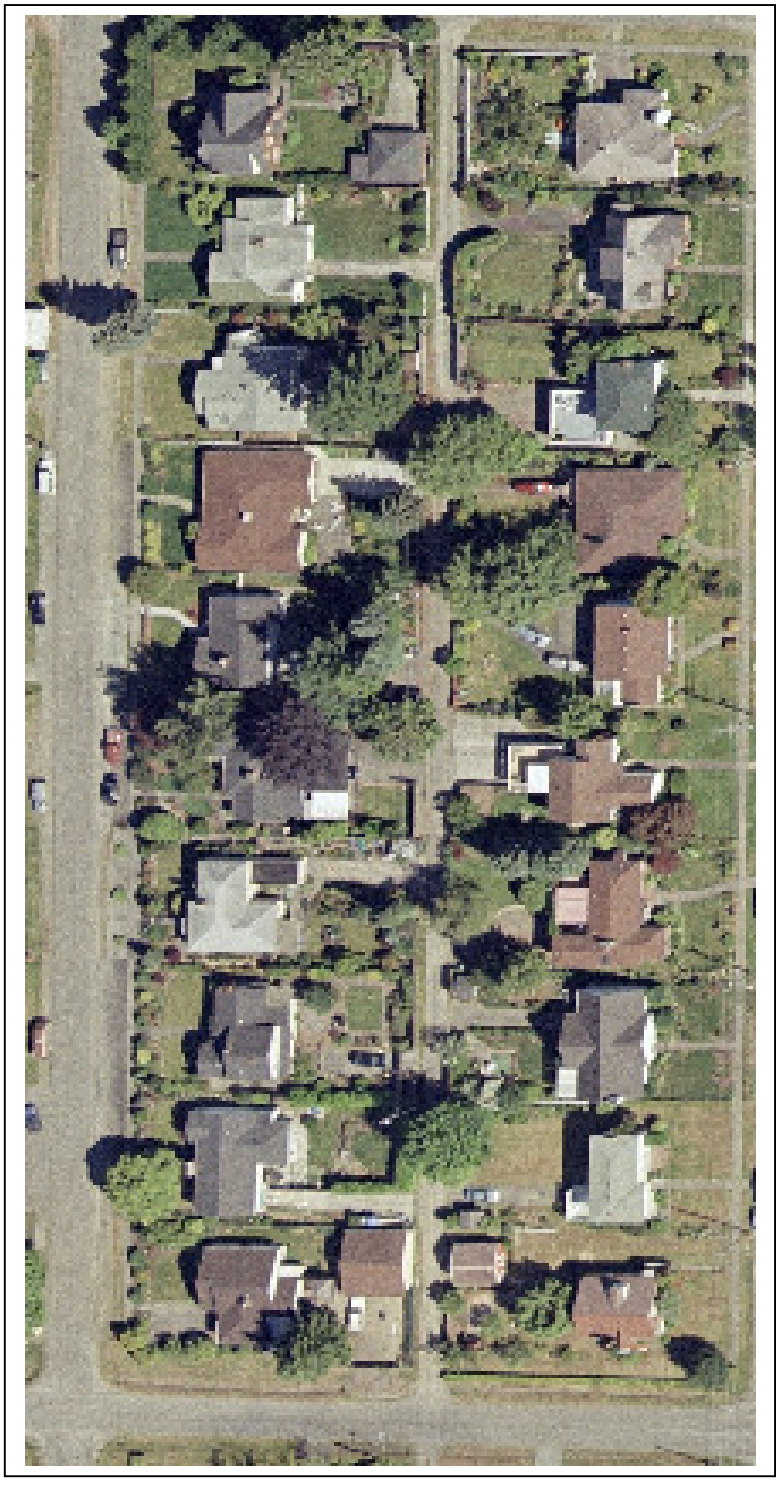


Figure 1 - Residential Prototype Block

- **LID Scenario 2: Soil Amendments, Bioretention, Pervious Paving and Green Roofs –** The following LID techniques are applied in addition to the techniques described above for Scenario 1:
  - *Pervious Paving* - All paved surfaces on lots and within road ROW are replaced by pervious paving, which is underlain by 12 inches of reservoir base course (available retention storage depth with 0.33 void space).
  - *Green Roofs* - All rooftops are covered by lightweight extensive green roofs, which consist of 4 inches of vegetated growing media.

For each of the scenarios described above, Figures 2a, b, and c show the percent of the total residential block area that is covered by various types of surfaces. Further details on modeling assumptions and the model layouts for each scenario are provided in Appendix A.

Commercial LID Applications

The following scenarios were modeled and compared for a typical 5 acre commercial lot with a total impervious area of 90 percent (35 percent rooftop and 55 percent parking lot):

- **Unmitigated Commercial Block –** All runoff from rooftop and parking lot area is connected to a piped storm drainage system. All pervious surfaces are covered by "disturbed soils" (i.e., a relatively thin layer of turf placed on compacted soil).
- **LID Scenario 1: Soil Amendments and Bioretention –** The following LID techniques are applied on the commercial lot:
  - *On-lot Bioretention* - Runoff from rooftop and parking lot is dispersed over a bioretention area, which covers 5 percent of the lot area (about 100 ft x 110 ft, or about half the commercial lot pervious space). This bioretention area has about 24 inches of absorbent soil and up to 6 inches of surface ponding to retain and infiltrate stormwater. Overflow from bioretention area is carried away by a piped storm sewer system (i.e., becomes surface runoff from the lot).
  - *Soil Amendments* – All remaining pervious space on the commercial lot is covered by 12 inches of vegetated absorbent soil.
- **LID Scenario 2: Soil Amendments, Bioretention, and Pervious Paving –** The following LID techniques are applied in addition to the techniques described above for Scenario 1:
  - *Pervious Paving* – 90 percent of the parking lot area (all except for loading bays) is replaced with pervious paving, underlain by 12 inches of reservoir base course (available retention storage depth with 0.33 void space). Runoff from the remaining impervious pavement flows onto the portion of the parking lot with pervious paving.

For each of the scenarios described above, Figures 3a, b and c show the percent of the total commercial site area that is covered by various types of surfaces. Further details on modeling assumptions and the model layouts for each scenario are provided in Appendix A.

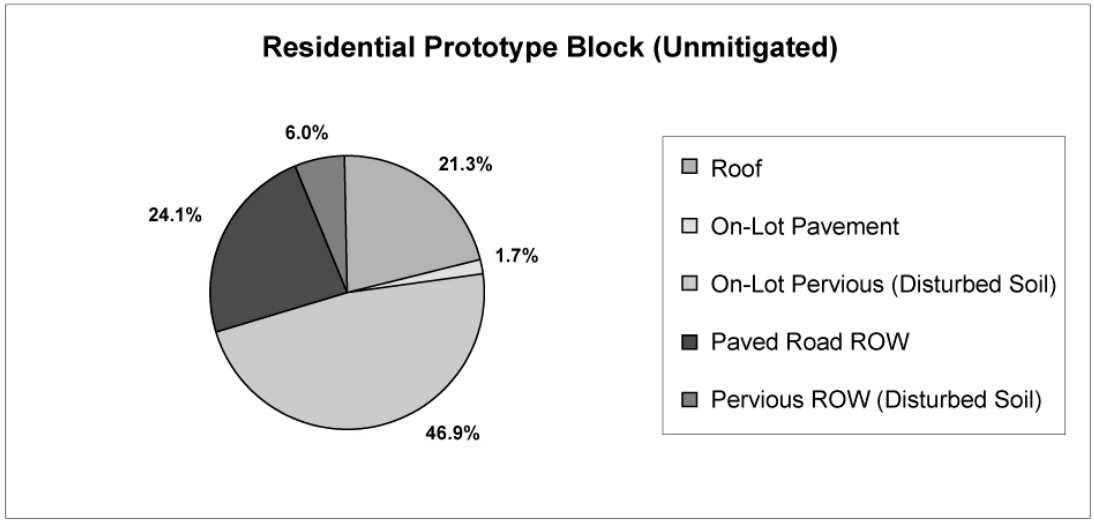


Figure 2a

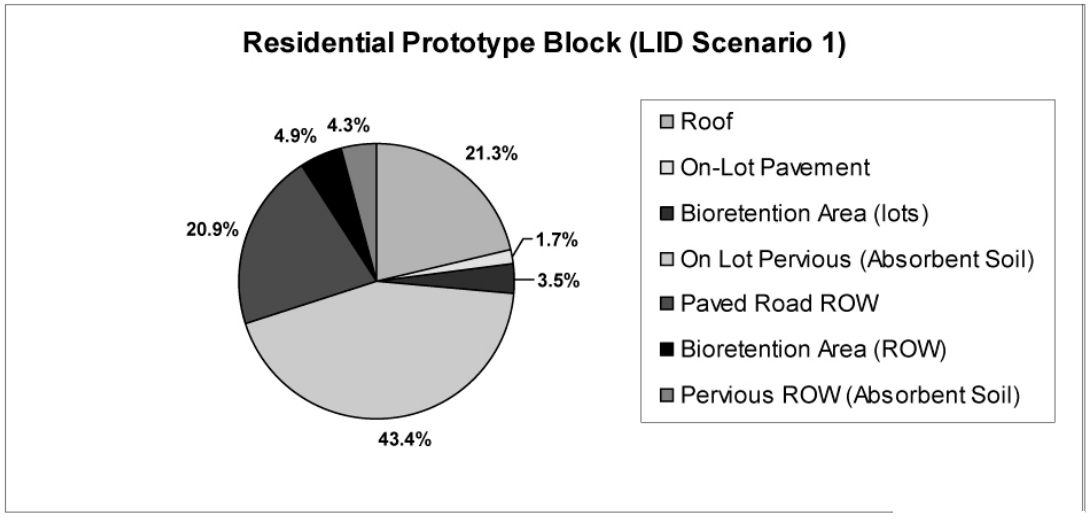


Figure 2b

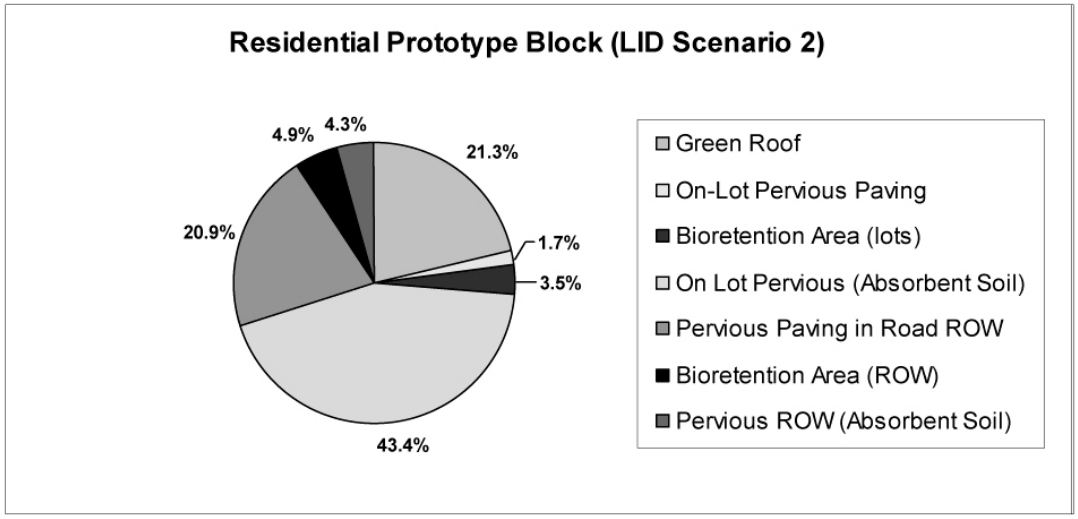


Figure 2c

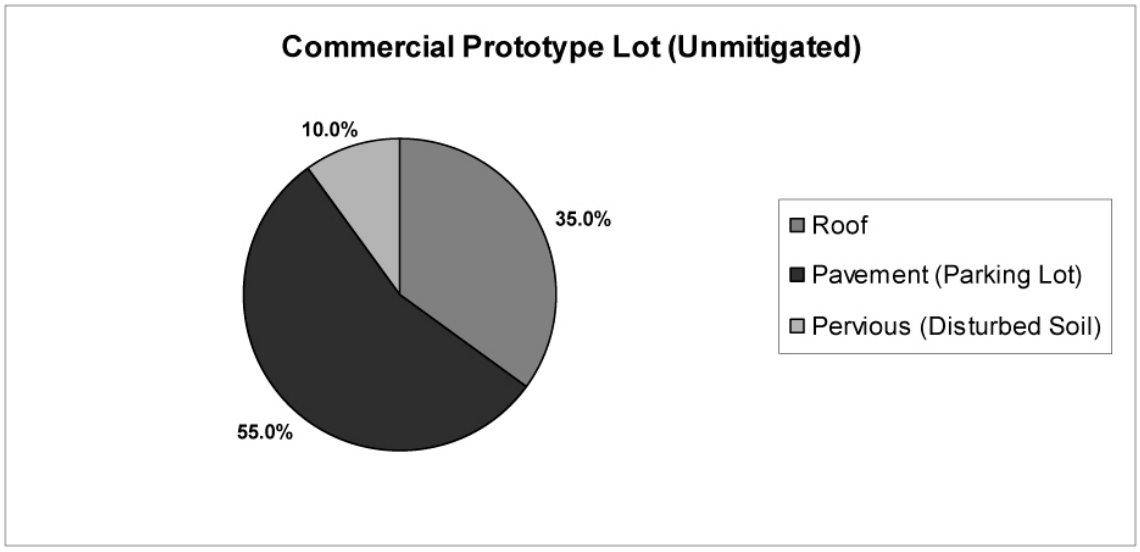


Figure 3a

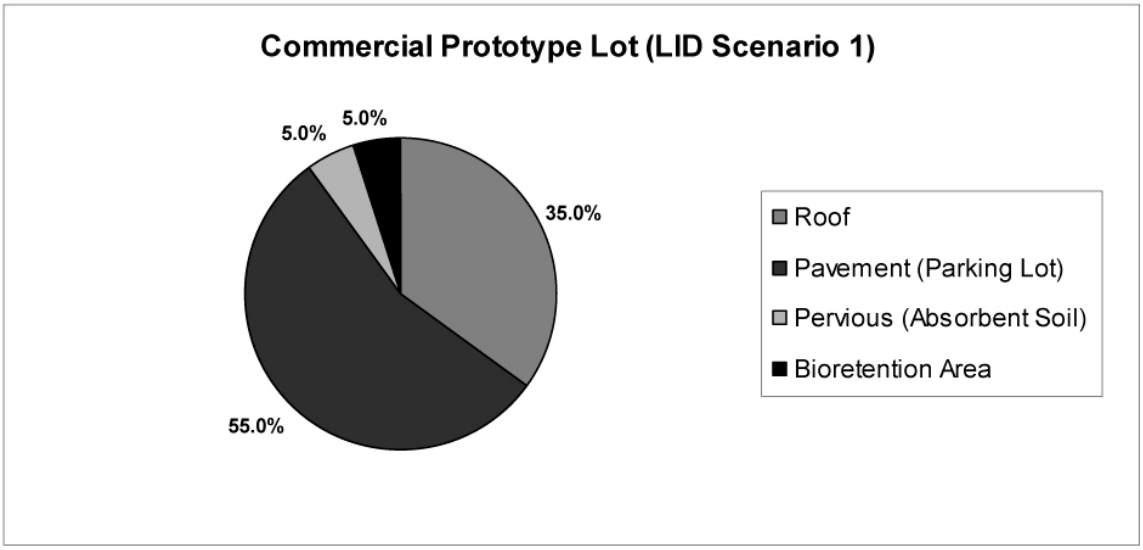


Figure 3b

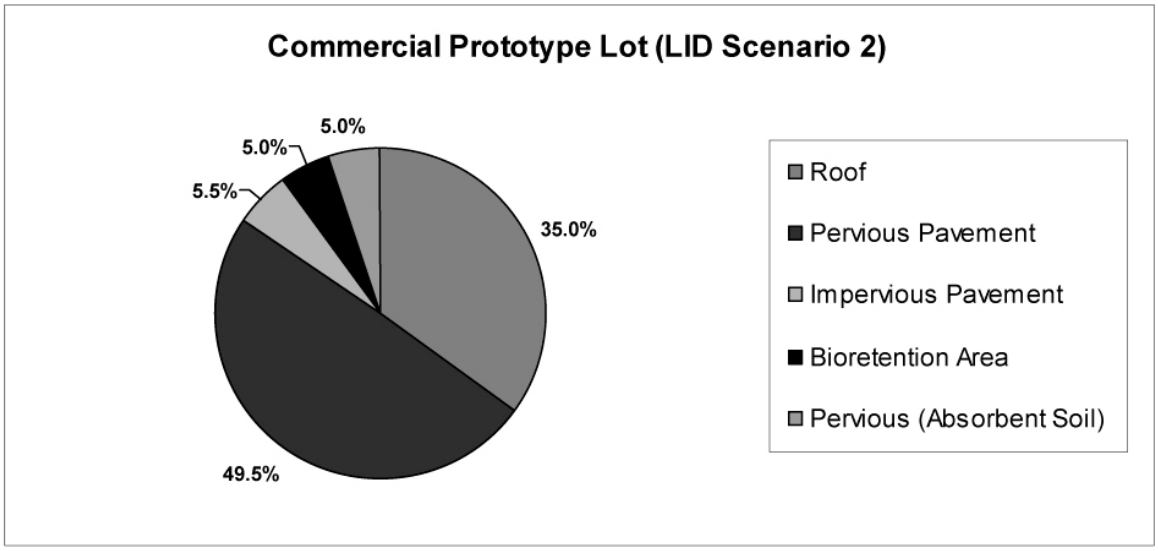


Figure 3c

The following section (Section 3) describes the applied LID techniques in more detail.

Modeling Summary

LIFE™ Overview

CH2M HILL's Low Impact Feasibility Evaluation (LIFE™) model was applied to test the performance of LID techniques for different land uses, rainfall patterns, and soil characteristics. LIFE™ is a hydrologic simulation tool that was developed to evaluate the performance of various LID techniques (e.g., bioretention, infiltration systems, rainwater capture/reuse systems, green roofs). It is well suited to site level analysis of spatially distributed stormwater source controls.

The LIFE™ model provides a continuous simulation of the runoff and infiltration from a development (or re-development) area, or from a watershed (or sub-catchment) with multiple land uses, given the following inputs:

- *Continuous rainfall data* (typically in time increments of one hour or less) and *evapotranspiration data* (daily), typically for a time period of one year or more. Evapotranspiration (ET) can also be calculated from temperature data.
- *Site design parameters and land cover characteristics* for each land use type being modeled (e.g., road width, rooftop coverage, surface parking coverage, population density).
- *Information on LID techniques* that are applied for each land use type, including:
  - Extent of source control application (e.g., percent of road and percent of building lots with certain types of source controls)
  - Source control design parameters (e.g., area and depth of infiltration facilities, soil depth for green roofs or absorbent landscaping, volume of rainwater re-use cisterns)
- *Soils information, including:*
  - Surface soil parameters (e.g., maximum water content, vegetation rooting depth)
  - Sub-surface soil parameters (e.g., saturated hydraulic conductivity)

Descriptions of the model inputs and assumptions used for this study are provided in the previous scenario descriptions and in Appendix A.

Hydrologic Performance Indicators

Changes in hydrology have been identified as the leading cause of channel instability and aquatic habitat degradation in the Puget Sound region. Therefore, the performance of the various LID scenario controls was evaluated relative to three indicators of hydrologic performance, which are discussed below.

- **Total Runoff Volume -** Total volume of surface runoff is a primary indicator of impacts on aquatic habitat. Under the natural forested state there is virtually no surface runoff – streams are fed by groundwater sources (interflow, aquifer outflow). Land development with conventional stormwater systems (ditches and pipes) produces surface runoff nearly every time it rains. The increased volume of surface runoff discharged to

watercourses results in ongoing erosion and habitat degradation. The ability of LID techniques to reduce runoff volume is a key indication of their stream protection value. Also, increased infiltration volume tends to improve stream baseflows.

For each LID scenario and unmitigated development scenario, water balance bar graphs were plotted to show the total volumes of surface runoff and infiltrated water over a 13-year modeled time period (1989 water year to 2002 water year). For comparison purposes, these water balance bar graphs are displayed in the results graphics below adjacent to bar graphs showing the total volume of rainfall on the 5-acre prototype sites over the same 13-year time period. The total runoff volume is displayed as a percentage of total rainfall volume on the water balance bar graphs for each scenario.

- **Flow Duration Curves –** These curves show the percentage of time that any given flow rate is exceeded. Flow duration curves for each LID scenario were compared with curves for natural forested conditions and for unmitigated development. The duration and magnitude of flows that exceed natural forested conditions is directly related to the level of stormwater-related impacts on stream stability and aquatic habitat. The ability of LID techniques to shift flow duration curves away from the traditional development curves towards the forested curves is a key indication of their effectiveness in maintaining pre-development hydrology and protecting aquatic habitat. Flow duration curves were generated using modeled flows from January 1, 1995, to the end of the 2002 water year. Flow duration curves were only provided for part of the modeled time period due to time constraints and the limitation of MS Excel™, which is currently used for graphing LIFE™ model outputs. The LIFE™ model functions for processing outputs and generating reports are currently being enhanced to allow larger databases.

- **Flow Hydrographs** – Modeled flow hydrographs are compared for a relatively large rainfall event that occurred in Puget Sound from March 16 to 20, 1997. At Olympia and SeaTac airports this was a prolonged storm with a return period of about 5 years. In Port Angeles this storm event was shorter duration (less total volume), but had a higher peak intensity. The ability of LID techniques to reduce the peak runoff rates resulting from this event is an indicator of potential benefits for both stream protection and flood risk reduction.

Performance Targets for Water Balance Management

Volume-based performance targets can provide useful benchmarks for assessing the potential value of various LID options. For example, the province of British Columbia has adopted a 10 percent runoff volume target (expressed as a percent of total rainfall volume).

Water Quality Benefits of LID

This analysis evaluates the potential hydrologic effectiveness of LID techniques (e.g., how well they reduce runoff volumes and rate). A quantitative evaluation of water quality benefits was not performed; however LID techniques that effectively improve hydrologic characteristics would also be expected to have significant benefits in terms of improving surface water quality.

LID techniques capture the first flush of pollutants that wash off from impervious surfaces. This is particularly important for roads and parking areas because pollutants from motor vehicles and road maintenance can accumulate on these surfaces.

Infiltration facilities are particularly beneficial in terms of improving water quality at the source. Absorption of stormwater runoff in the shallow soil zone filters out sediments and many pollutants, thus improving downstream water quality.

LID Analysis Results

This section summarizes the results of the scenario modeling, using the hydrologic performance indicators discussed previously.

Olympia Scenario Modeling Results

Based on the rainfall data provided by the National Climatic Data Center, the average annual rainfall measured at Olympia Airport for the modeled time period (1989 to 2002) was 45.4 inches. The Olympia rainfall data were scaled up by 10 percent in order to show the performance of the selected LID techniques with 50 inches of rainfall per year, which is closer to the average annual rainfall at this location reported by the National Weather Service. Each hourly rainfall value was scaled up by 10 percent, but rainfall durations were not extended.

Residential LID Applications (Olympia)

Figures 4a, b, and c show the hydrologic performance indicators (i.e., water balance summary graph, flow duration curves, example flow hydrograph) for the residential LID scenarios on Type A soils. Figures 5a, b, and c show the performance of residential LID scenarios on Type C soils.

For residential areas on Type A soils, site hydrology could be dramatically improved with only soil amendments and bioretention (i.e., LID scenario 1). Runoff volume could be reduced to about 1 percent of total rainfall, natural forested flow rates would only be exceeded about 0.06 percent of the time, and there would be no surface runoff during large, prolonged storm events, such as the one in March 1997.

With the application of additional LID techniques - pervious paving and green roofs (i.e., LID scenario 2) - the flow duration curve from the residential area could match the forested curve (see Figure 4b). However, this relatively small additional benefit may not be worth the additional cost in this case.

For residential areas on Type C soils, significant reductions in runoff volume could be achieved with only soil amendments and bioretention (runoff volume reduced to 6.7 percent of total rainfall), but flow rates would still exceed forested levels about 1 percent of the time (see Figure 5b) and there would still be significant surface runoff during large, prolonged rainfall events (see Figure 5c).

The addition of pervious paving and green roofs would improve runoff control performance during large storm events, bring the flow duration curve closer to the forested curve (forested flow rates exceeded about 0.2 percent of the time), and further reduce total runoff volumes (to about 1 percent of total rainfall).

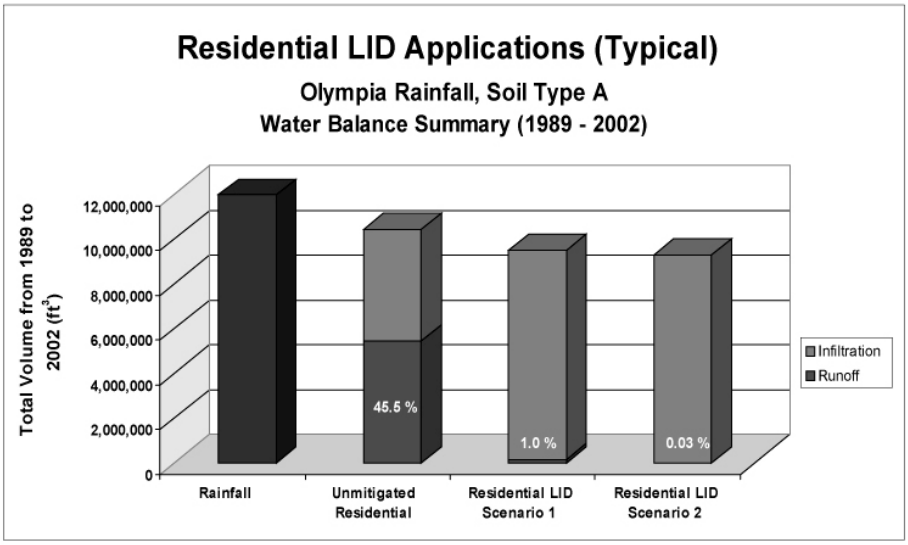


Figure 4a

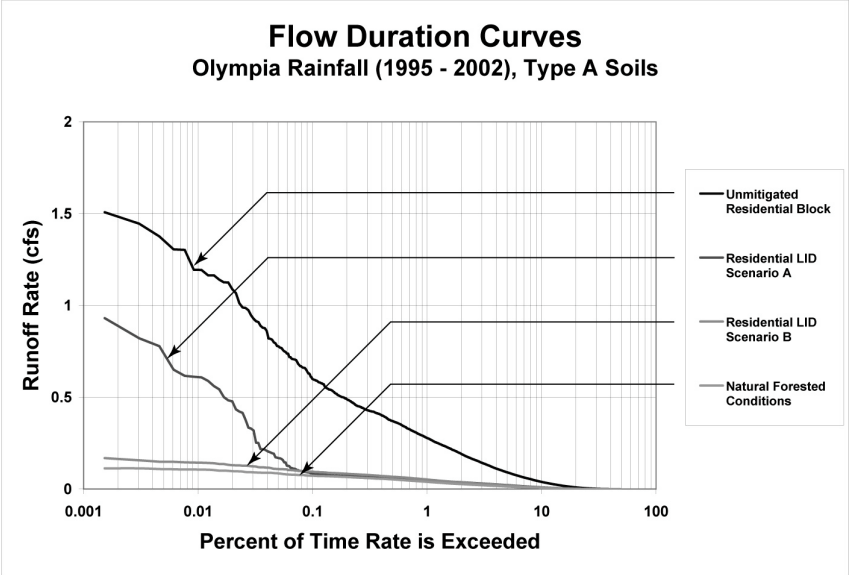


Figure 4b

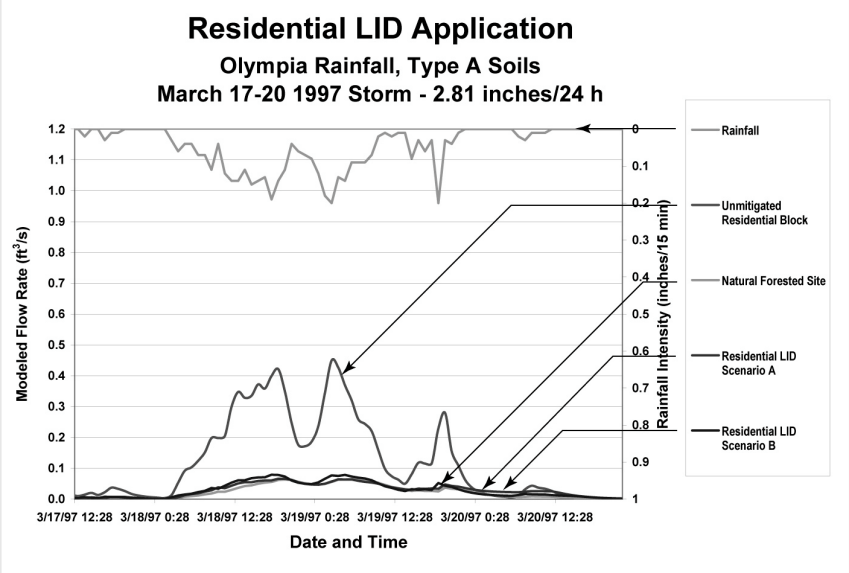


Figure 4c

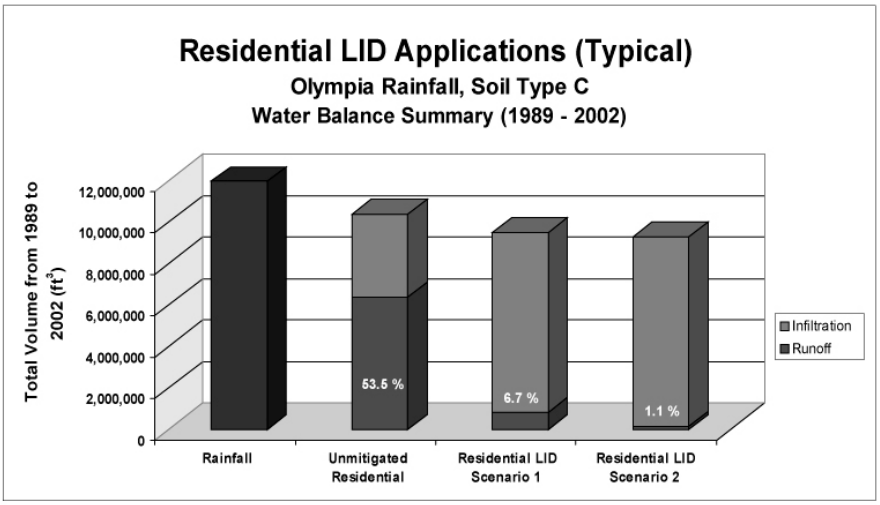


Figure 5a

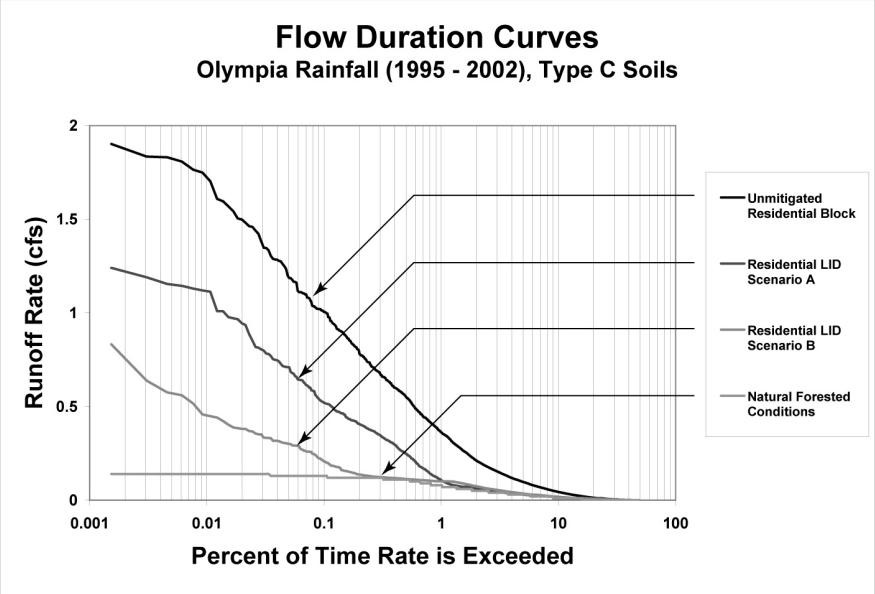


Figure 5b

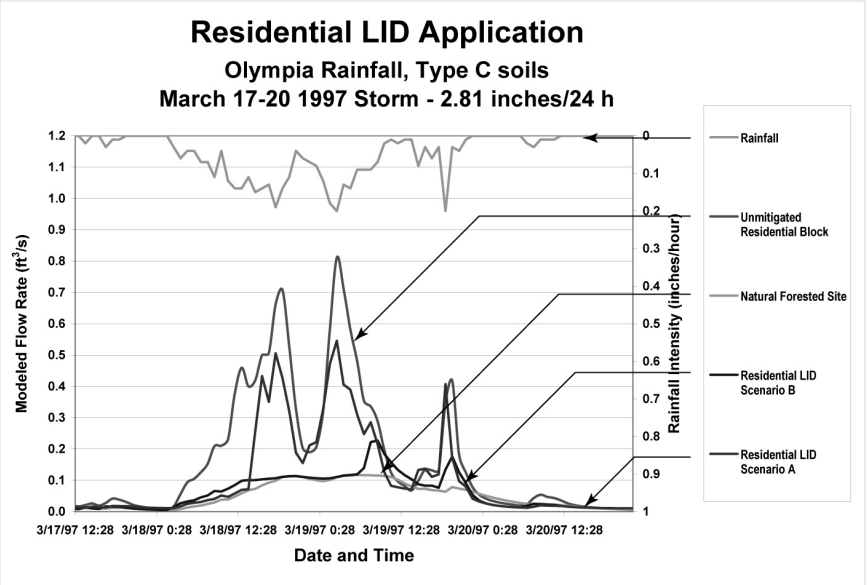


Figure 5c

Commercial LID Applications (Olympia)

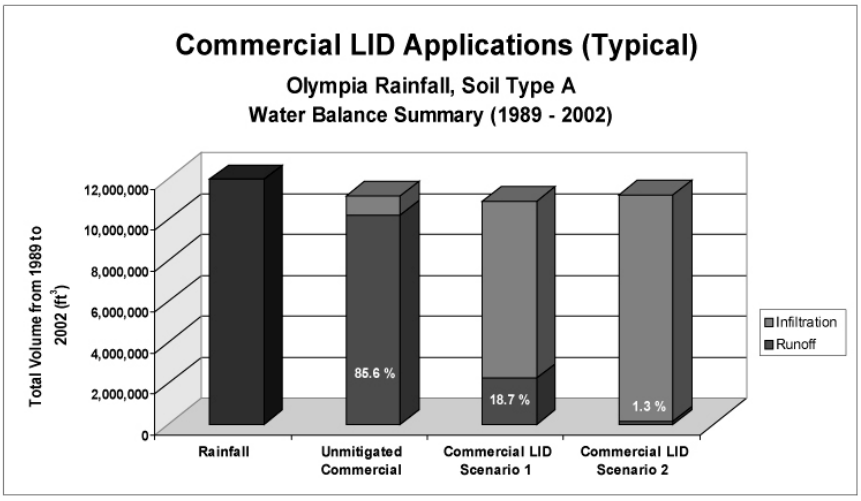
Figures 6a, b, and c show the hydrologic performance indicators for the commercial LID scenarios on Type A soils. Figures 7a, b, and c show the performance of commercial LID scenarios on Type C soils. The storm event used for hydrograph comparison purposes (March 1997) was a prolonged wet weather event at this location (maximum 24-hour rainfall of 2.81 inches).

For commercial areas on Type A soils, significant reductions in runoff volume could be achieved by applying soil amendments and bioretention (i.e., LID scenario 1) - from about 86 percent to 19 percent of total rainfall. However, there would be very little reduction in peak flow rates during large, prolonged storm events, and natural forested flow rates would be exceeded about 2 percent of the time (note that the flow duration curve approaches the curve for unmitigated development for the more extreme rainfall conditions). While this LID scenario would be fairly effective at managing the frequent small events, the bioretention facility would become overwhelmed during large storms due to the high levels of impervious area and relatively small amount of space available for infiltration.

The addition of pervious paving (i.e., LID scenario 2) would be required to achieve any significant reduction in peak flows from large storms, to achieve the runoff volume (runoff volume reduced to 1.3 percent of total rainfall), and to approach the natural forested flow duration curve (forested flow rates exceeded about 0.1 percent of the time).

For commercial areas on Type C soils, only the very small rainfall events could be effectively managed using only bioretention and soil amendments. Note that this still corresponds to nearly a 50 percent reduction in runoff volume (see Figure 7a) because the vast majority of rainfall events are very small.

Significant additional reductions in total runoff volume could be achieved with the addition of pervious paving (runoff volume reduced to 7.5 percent of total rainfall), but flow rates would still exceed forested levels about 2 percent of the time and there would be significant levels of surface runoff during a large, prolonged storm (although peak runoff rates would be reduced by about 50 percent).



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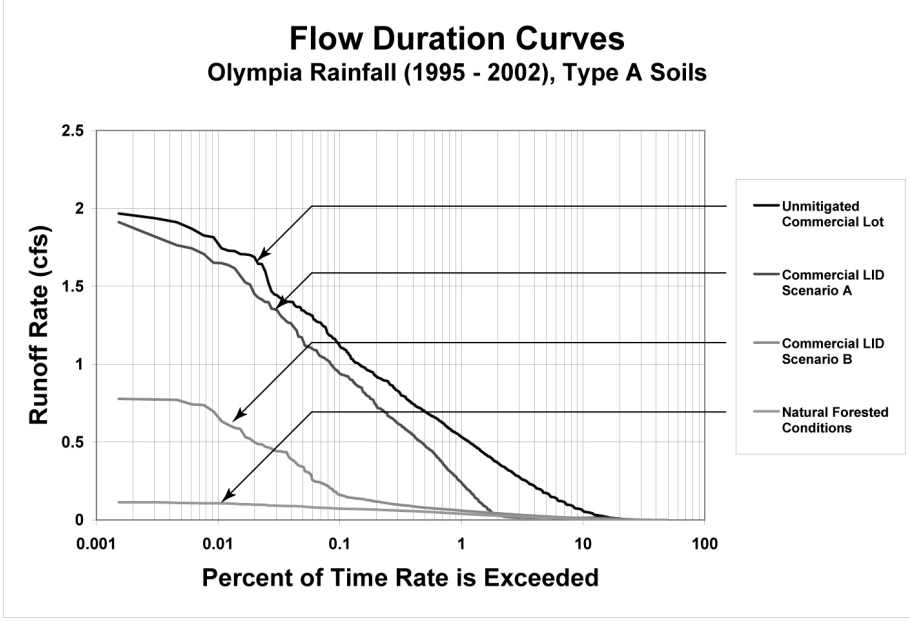
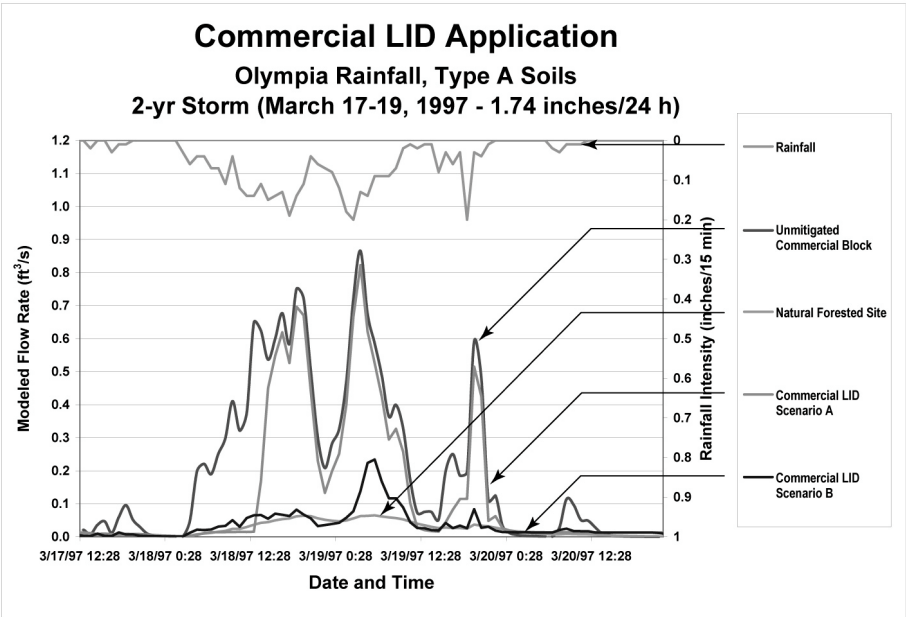


Figure 6b



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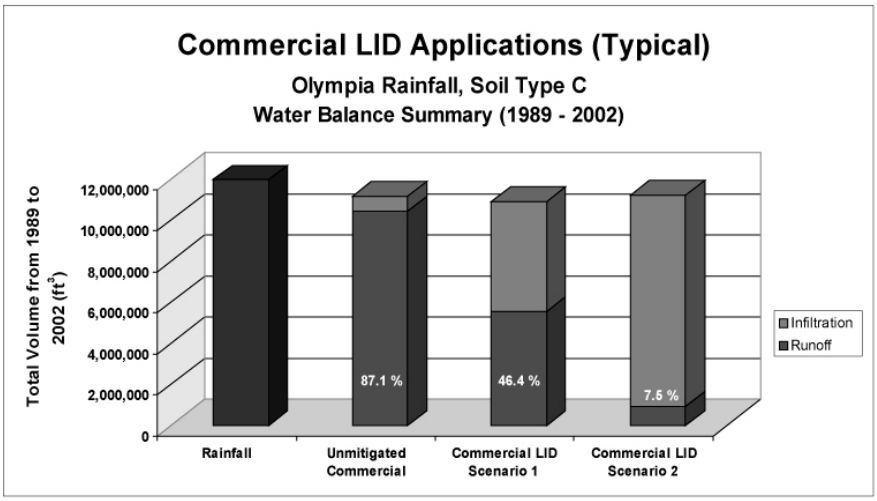

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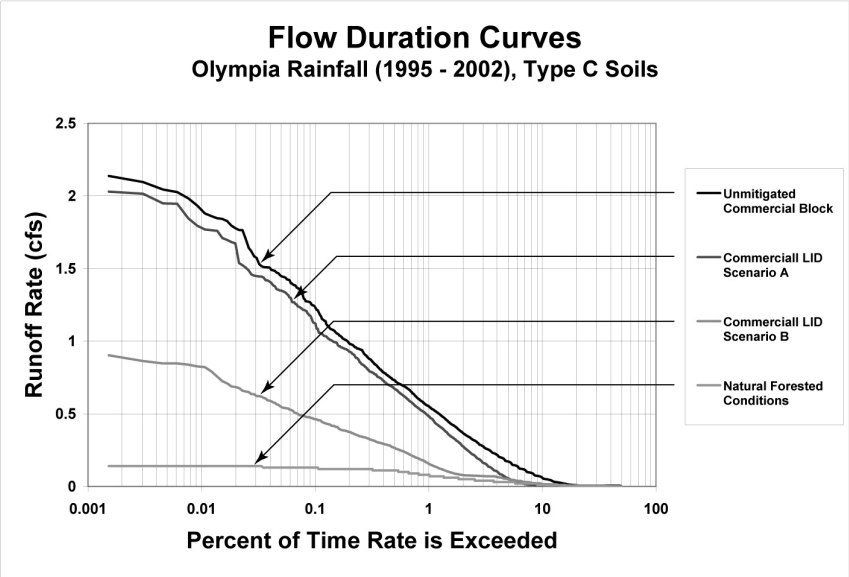


Figure 7b

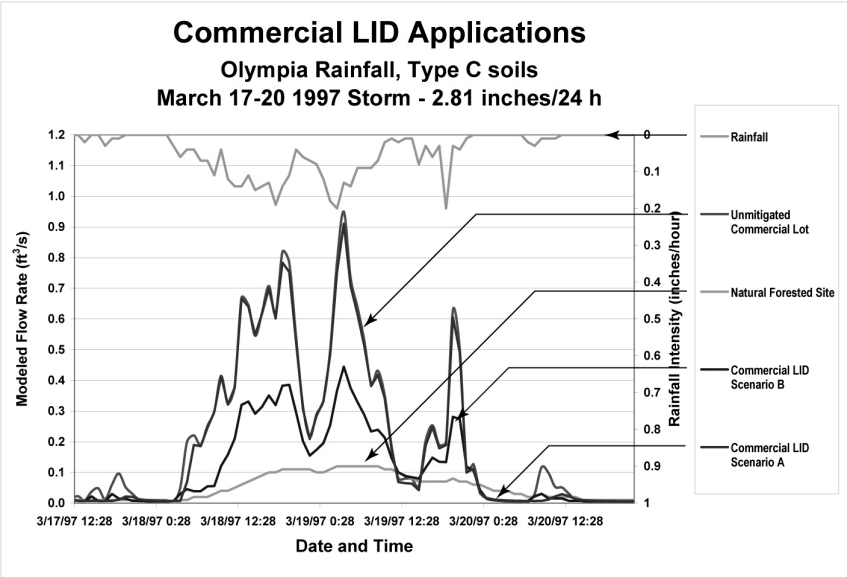


Figure 7c

SeaTac Scenario Modeling Results

The average annual rainfall measured at SeaTac airport for the modeled time period (1989 to 2002) was 37.9 inches. The storm event used for hydrograph comparison purposes (March 1997) was a prolonged wet-weather event at this location (maximum 24-hour rainfall of 2.34 inches).

Residential LID Applications (SeaTac)

Figures 8a, b, and c show the hydrologic performance indicators for the residential LID scenarios on Type A soils. Figures 9a, b, and c show the performance of residential LID scenarios on Type C soils.

For residential areas on Type A soils, site hydrology could be dramatically improved with only soil amendments and bioretention (i.e., LID scenario 1) – runoff volume could be reduced to about 0.3 percent of total rainfall, natural forested flow rates would be very rarely exceeded (only be exceeded about 0.02 percent of the time), and there would be no surface runoff during large, prolonged storm events.

With the application of additional LID techniques - pervious paving and green roofs (i.e., LID scenario 2) - the flow duration curve from the residential area could match the forested curve (see Figure 8b). However, the minor additional benefit would probably not be worth the additional cost in this case.

For residential areas on Type C soils, significant reductions in total runoff volume could be achieved using only soil amendments and bioretention (runoff volume reduced to 2.5 percent of total rainfall). Under this scenario, flow rates would exceed forested levels about 0.2 percent of the time, and the peak surface runoff rates during large, prolonged rainfall events would be reduced by about 50 percent (see Figure 9c).

The addition of pervious paving and green roofs would bring the flow duration curve much closer to the natural forested curve (forested flow rates only exceeded about 0.03 percent of the time), and eliminate surface runoff during large, prolonged rainfall events.

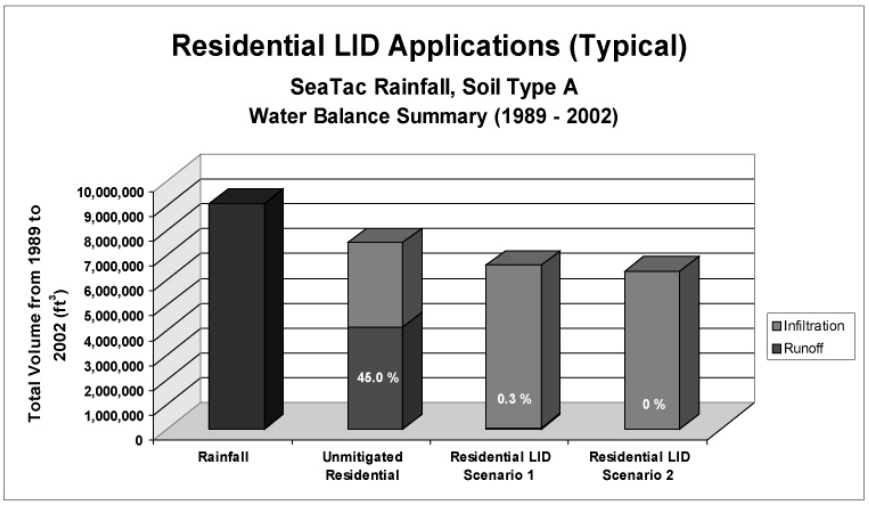
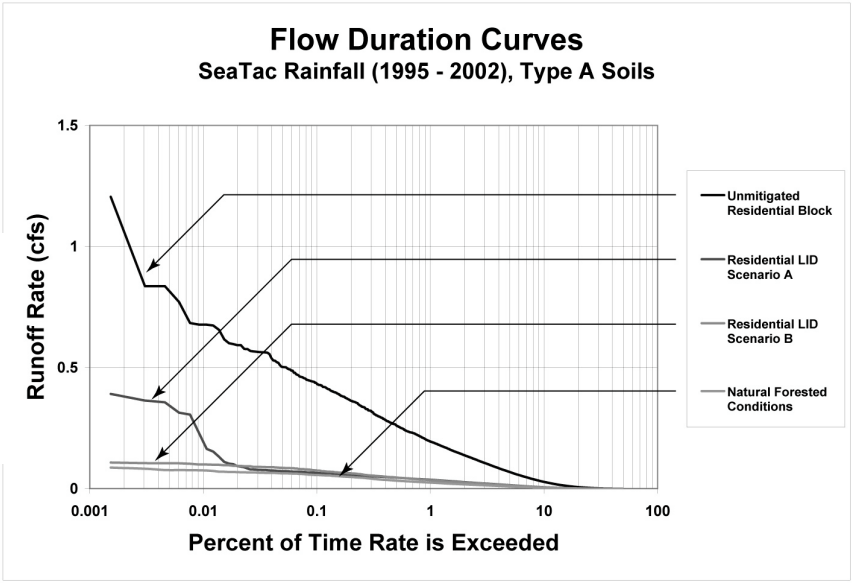


Figure 8a



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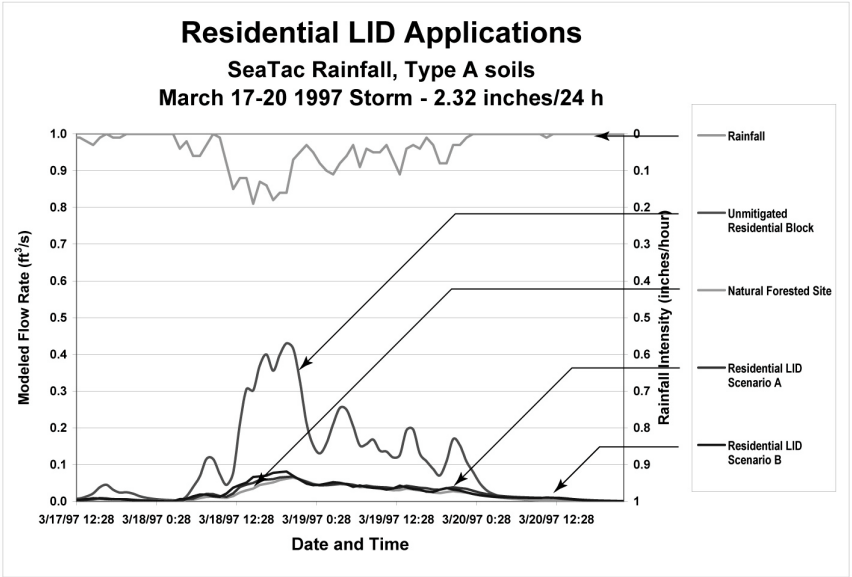


Figure 8c

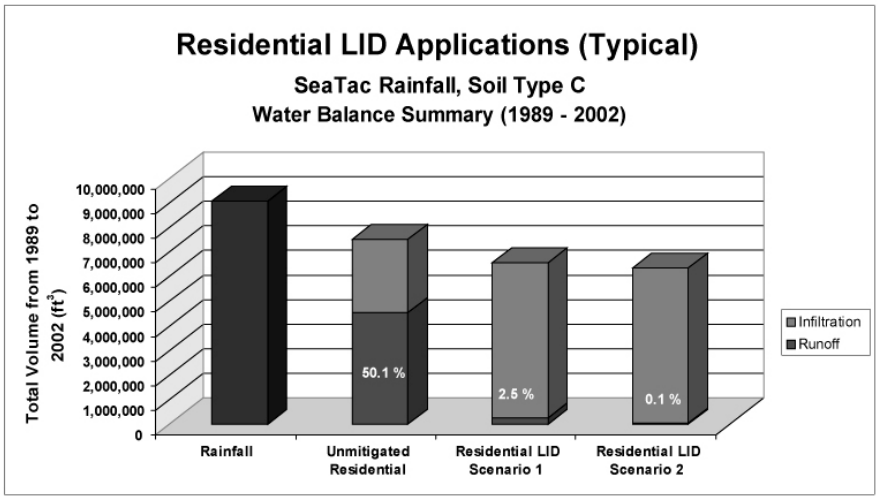


Figure 9a

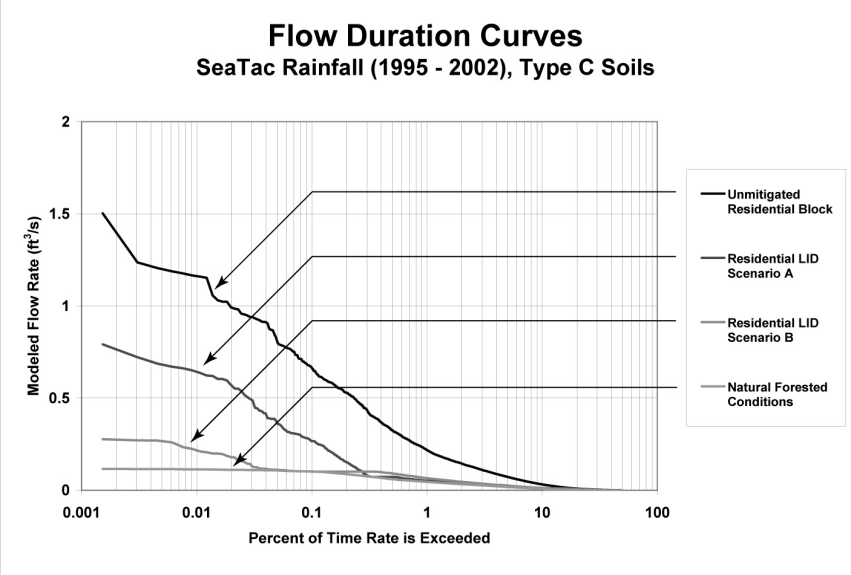


Figure 9b

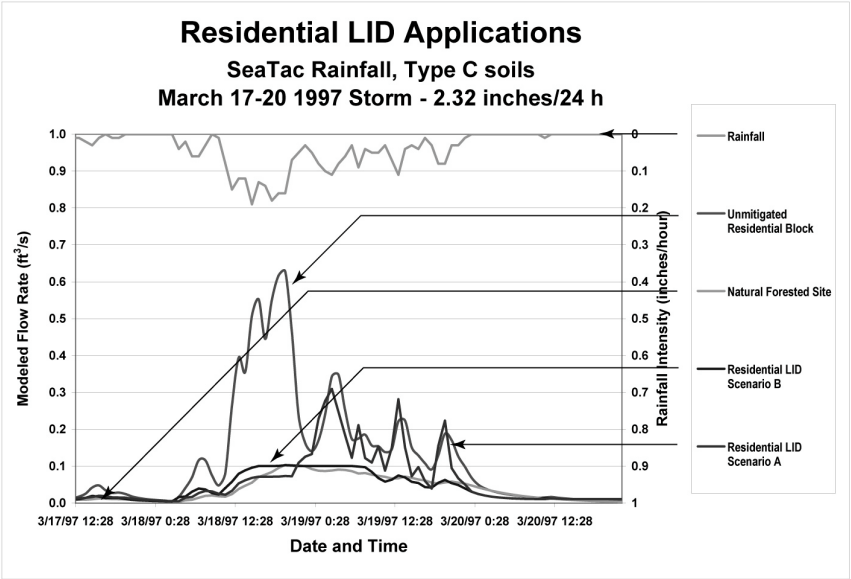


Figure 9c

Commercial LID Applications (SeaTac)

Figures 10a, b, and c show the hydrologic performance indicators for the commercial LID scenarios on Type A soils. Figures 11a, b, and c show the performance of commercial LID scenarios on Type C soils.

For commercial areas on Type A soils, application of soil amendments and bioretention (i.e., LID scenario 1) would come close to achieving the runoff volume target (runoff volume reduced to 10.9 percent of total rainfall). However, there would be very little reduction in peak flow rates during large, prolonged storm events (see Figure 10c). Natural forested flow rates would be exceeded less than 1 percent of the time, but the flow duration curve approaches the unmitigated development curve for the more extreme rainfall conditions (see Figure 10b). While this LID scenario would be effective at managing the frequent small events, the bioretention facility would become overwhelmed during large storms due to the high levels of impervious area and relatively small amount of space available for infiltration.

The addition of pervious paving (i.e., LID scenario 2) would eliminate surface runoff from large storms and bring the flow duration curve much closer to the natural forested curve (forested flow rates exceeded significantly about 0.03 percent of the time).

For commercial areas on Type C soils, only the small rainfall events could be effectively managed using only bioretention and soil amendments. This would still reduce total runoff volume by about 63 percent (see Figure 11a) because the small rainfall events make up the majority of the total rainfall volume.

The addition of pervious paving could significantly improve the level of reduction in runoff volume that can be achieved (runoff volume reduced to 3.1 percent of total rainfall). This would also reduce the duration of flow rates exceeding forested levels to about 0.5 percent of the time, and reduce peak runoff rates during large, prolonged storms by over 50 percent.

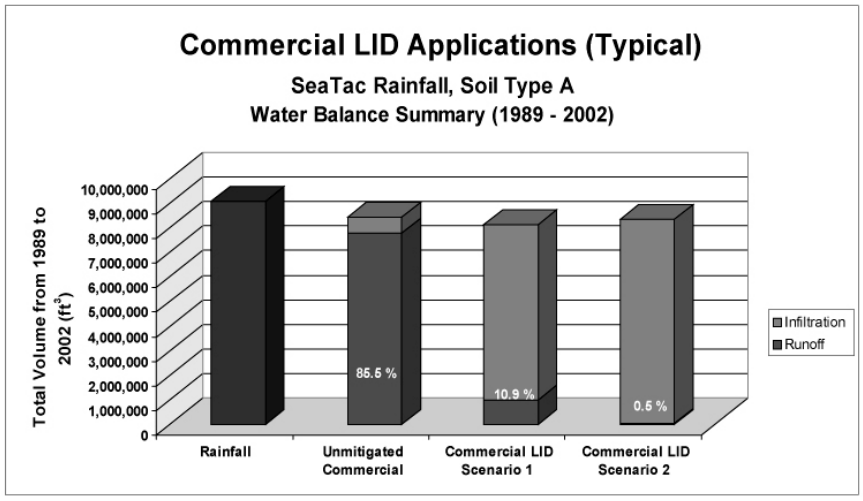


Figure 10a

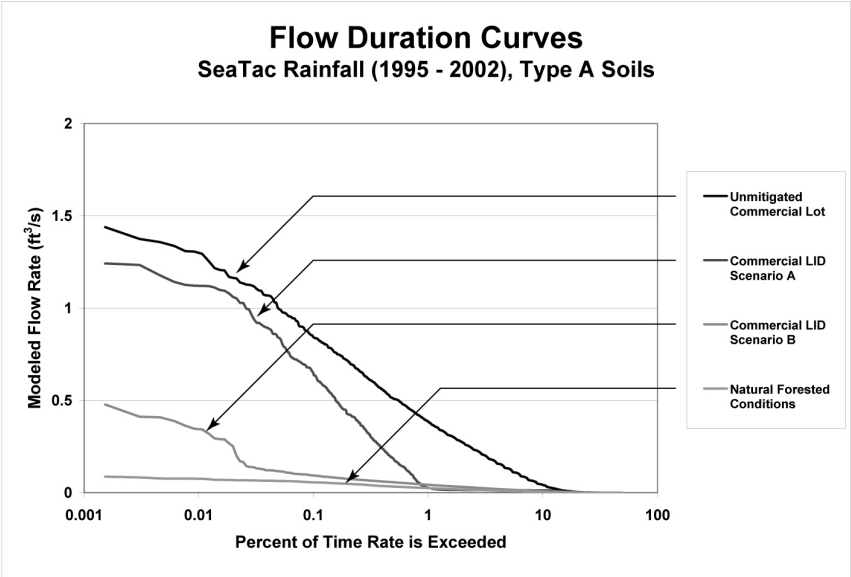
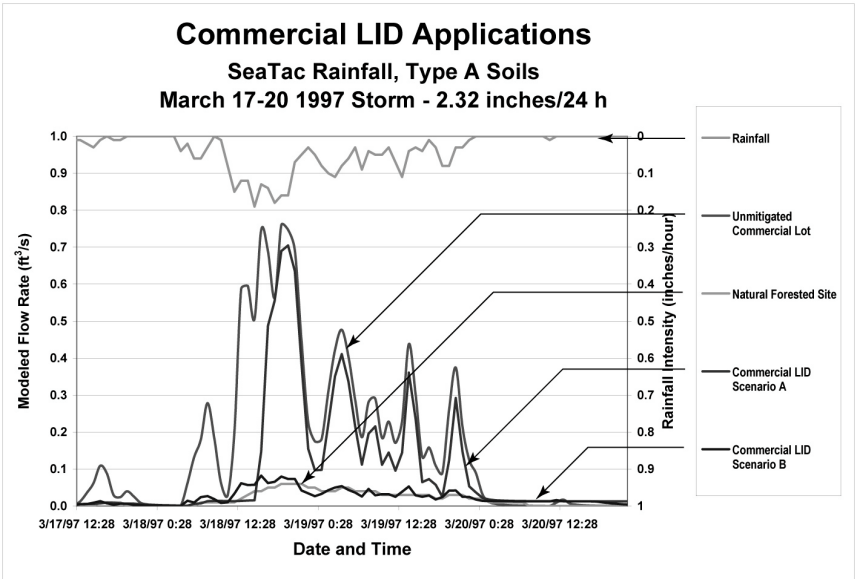


Figure 10b



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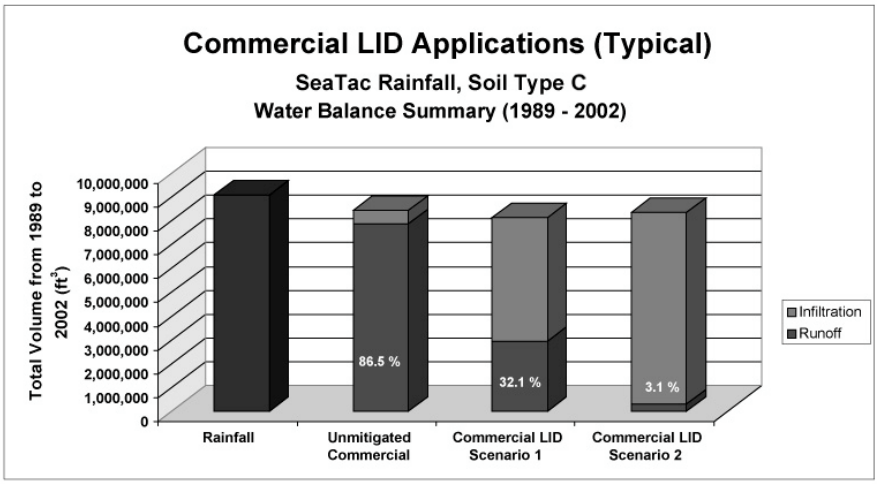


Figure 11a

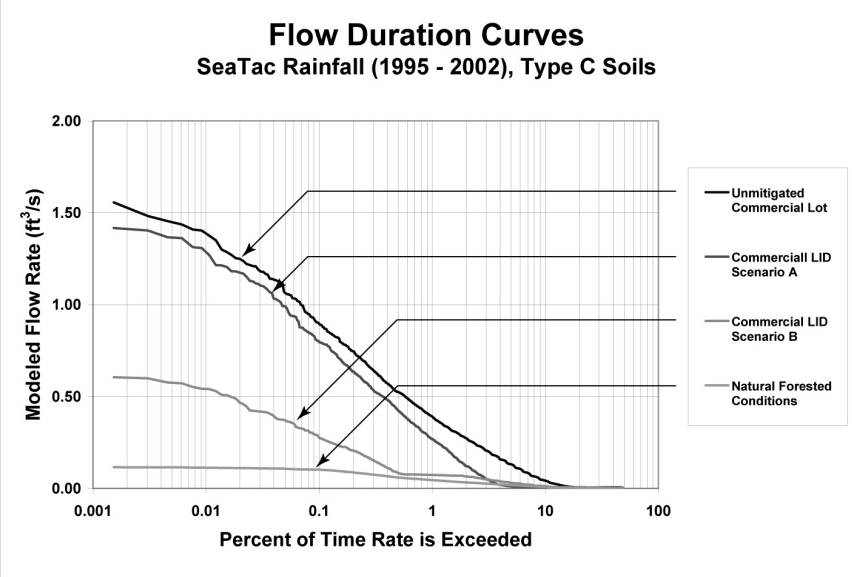


Figure 11b

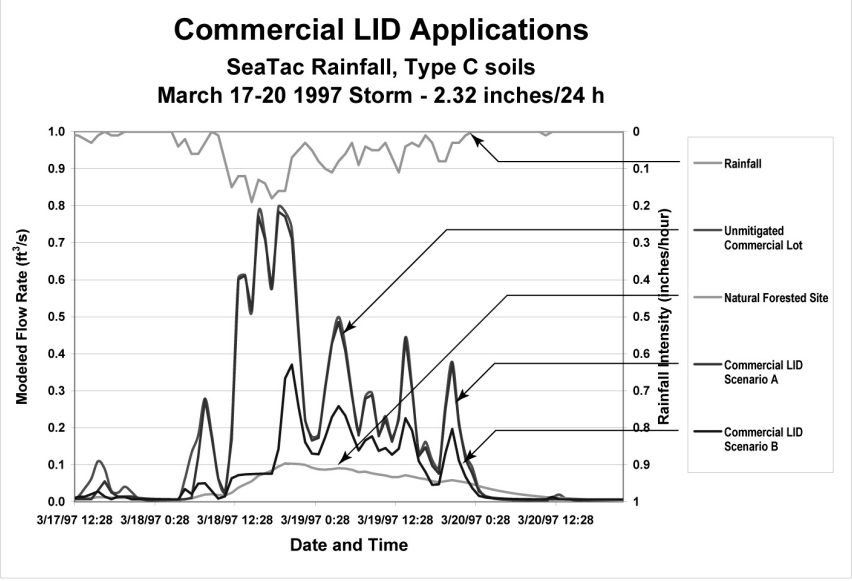


Figure 11c

Port Angeles Scenario Modeling Results

The average annual rainfall measured at the Port Angeles gauge for the modeled time period (1989 to 2002) was 16.6 inches, much less than Olympia or SeaTac. The March 1997 rainfall event that was used for comparison purposes was a shorter, more intense storm in Port Angeles (compared with the prolonged rainfall at the other locations).

Residential LID Applications (Port Angeles)

Figures 12a, b, and c show the hydrologic performance indicators for the residential LID scenarios on Type A soils. Figures 13a, b, and c show the performance of residential LID scenarios on Type C soils.

For residential areas on Type A soils, surface runoff could be virtually eliminated and the natural forested flow duration curve could be matched using only soil amendments and bioretention (i.e., LID scenario 1). Therefore, it would not make sense to spend additional money applying additional LID techniques.

For residential areas on Type C soils, soil amendments and bioretention could dramatically reduce runoff volume (to 0.9 percent of total rainfall), ensure that natural forested flow rates are very seldom exceeded (about 0.03 percent of the time), and eliminate surface runoff from high-intensity storms (see Figure 13c). Note that the peak runoff rates from traditional development tend to be very high during this type of storm event.

The addition of pervious paving and green roofs would virtually eliminate surface runoff and match the natural forested flow duration curve. However, the minor additional benefit may not be worth the additional cost in this case.

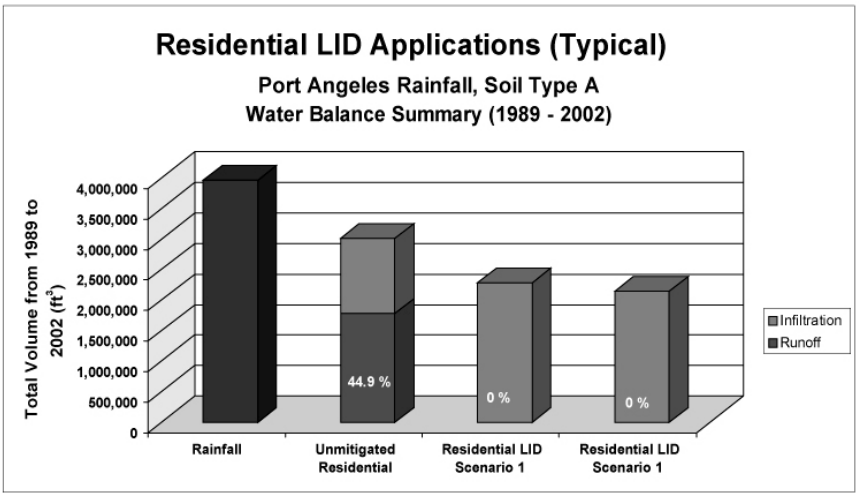


Figure 12a

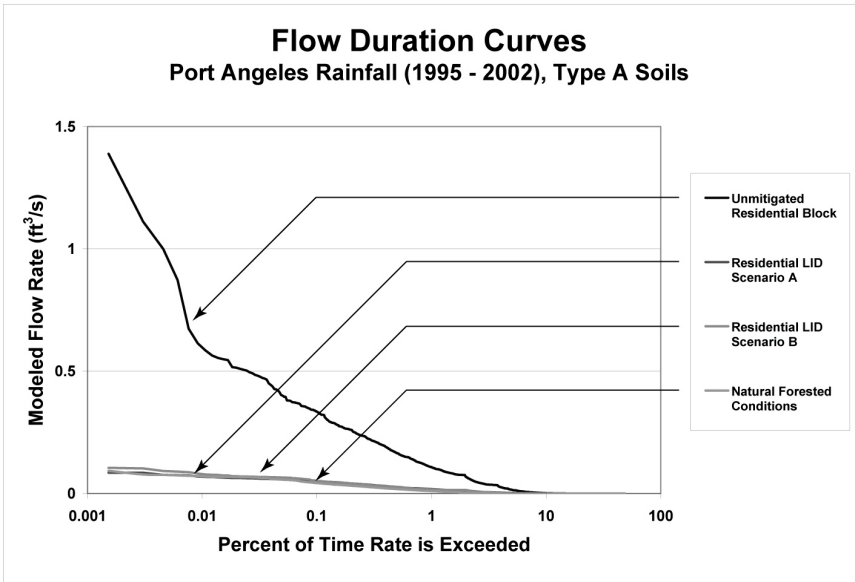
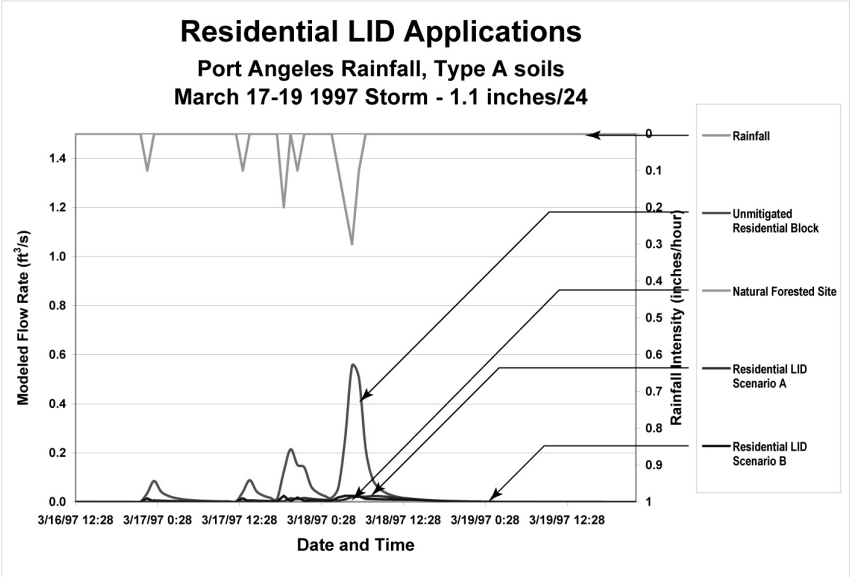


Figure 12b



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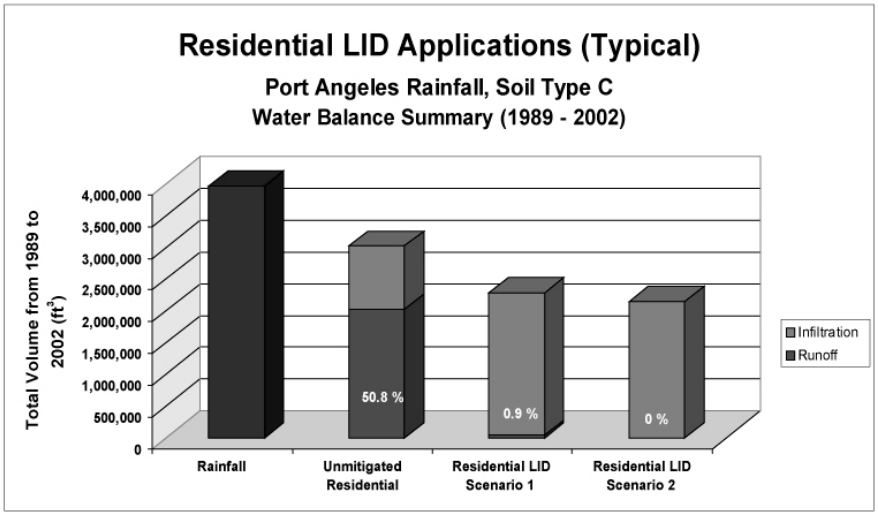

Figure 13a

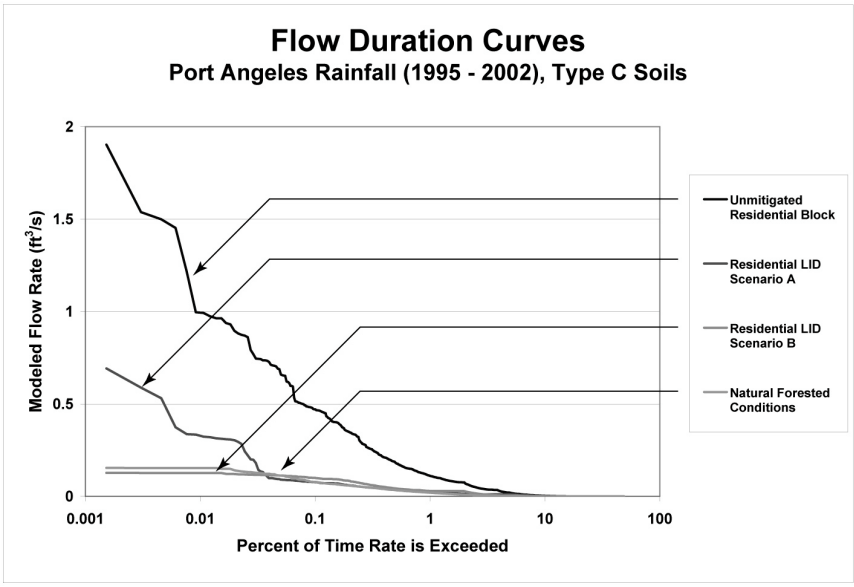

Figure 13b

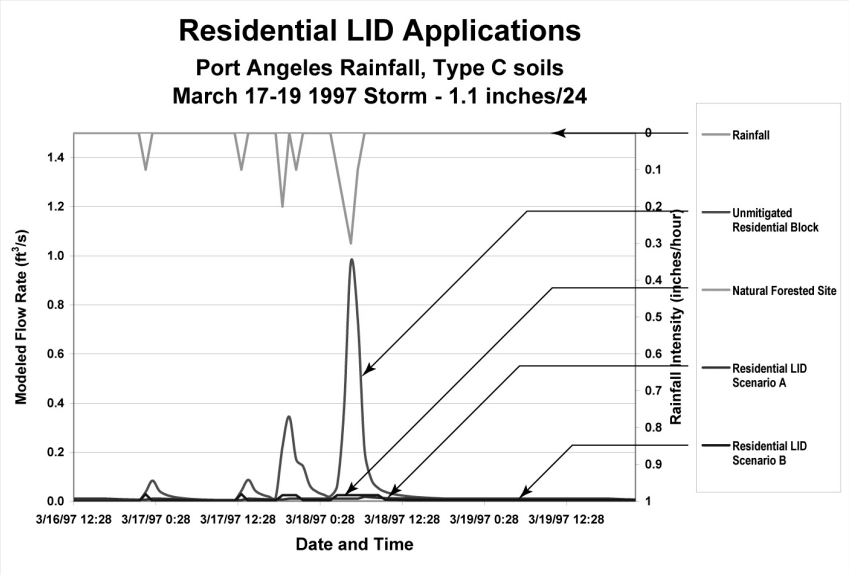

Figure 13c

Commercial LID Applications (Port Angeles)

Figures 14a, b, and c show the hydrologic performance indicators for the commercial LID scenarios on Type A soils. Figures 15a, b, and c show the performance of commercial LID scenarios on Type C soils.

For commercial areas on Type A soils, application of soil amendments and bioretention (i.e., LID scenario 1) could reduce total runoff volume to about target 7.7 percent of total rainfall (from the unmitigated level of 85.5 percent), and significantly reduce (but not eliminate) peak runoff rates during a high intensity storm. Under this LID scenario, natural forested flow rates would be exceeded about 0.3 percent of the time with the flow duration curve approaching the unmitigated development curve for the more extreme rainfall conditions (see Figure 14b).

The addition of pervious paving (i.e., LID scenario 2) would virtually eliminate surface runoff and match the flow duration curve for natural forested conditions.

For commercial areas on Type C soils, application of soil amendments and bioretention could achieve significant reductions in total runoff volume (from 86 percent to 24 percent of total rainfall) and peak runoff rates from high-intensity storms (from 1.3 to 0.5 ft^3/s during March 1997 storm). However, there would still be significant levels of surface runoff under this scenario.

Adding pervious paving would achieve a much greater level of reduction in total runoff volume (reduce runoff volume to 1.6 percent of total rainfall), and eliminate surface runoff during high-intensity storms. Flow rates would exceed natural forested levels less than 0.1 percent of the time under this LID scenario.

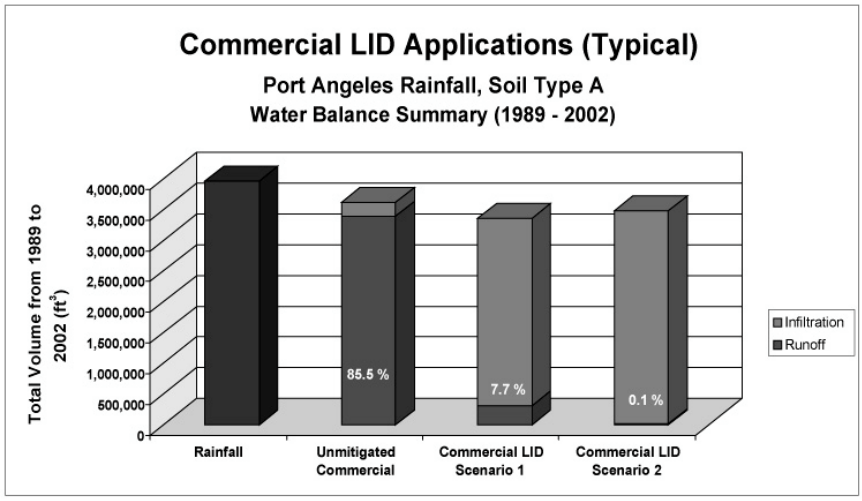

Figure 14a

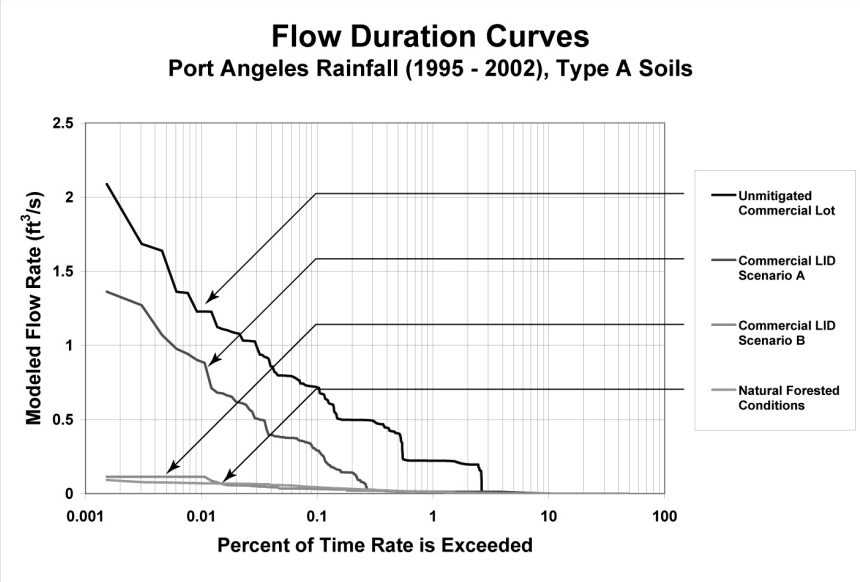

Figure 14b

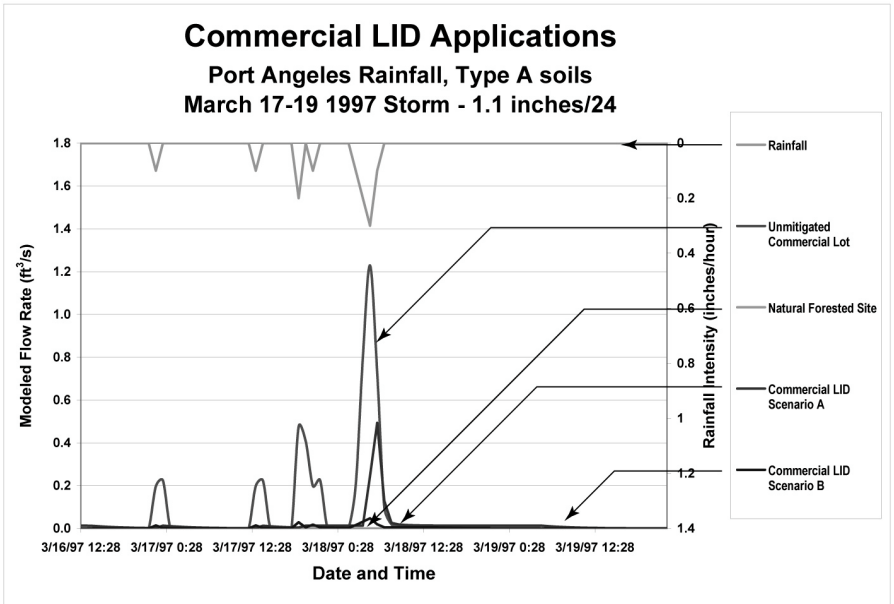

Figure 14c

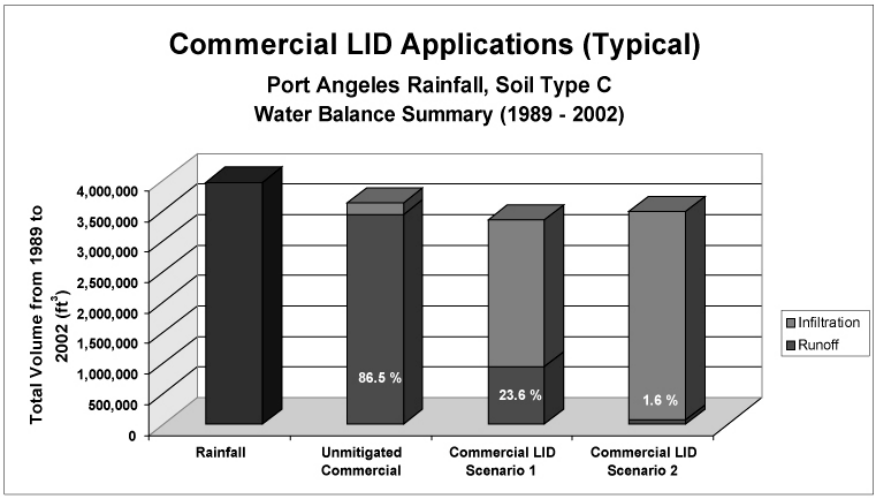

Figure 15a

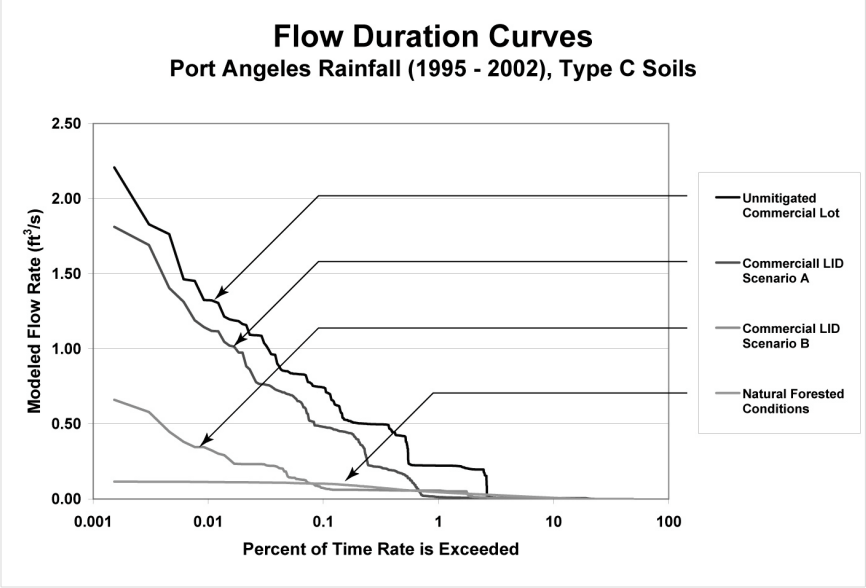

Figure 15b

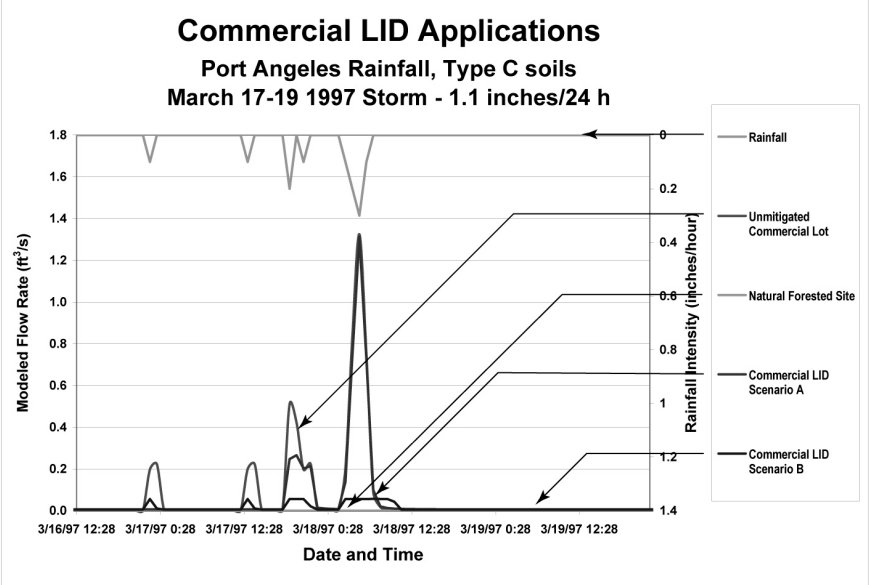

Figure 15c

Summary of Modeling Results

Total Runoff Volume

As discussed previously, total runoff volume is a key indicator of impacts on aquatic habitat. The following table summarizes the total runoff volume for each of the modeled scenarios, as a percentage of total rainfall volume.

Total Runoff Volume (as % of total rainfall) for Modeled Scenarios

	Soil Type A		Soil Type C	
Scenarios	Residential	Commercial	Residential	Commercial
Olympia				
Unmitigated	45.5	85.6	53.5	87.1
LID Scenario 1	1	18.7	6.7	46.4
LID Scenario 2	0.03	1.3	1.1	7.5
Sea Tac				
Unmitigated	45	85.5	50.1	86.5
LID Scenario 1	0.3	10.9	2.5	32.1
LID Scenario 2	0	0.5	0.1	3.1
Port Angeles				
Unmitigated	44.9	85.5	50.8	86.5
LID Scenario 1	0	7.7	0.9	23.6
LID Scenario 2	0	0.1	0	1.6

Flow Duration Curves

Comparing the flow duration curves for LID scenarios with curves for the natural forested condition and the unmitigated development condition is an effective means of analyzing to what extent the LID applications can help maintain predevelopment hydrology. The following table provides a summary of the percentage of time (from January 1, 1995, to September 30, 2002) when the flow from for the various development scenarios would be expected to exceed predevelopment (forested) flows.

Percent of Time that Flow Duration Curves for Modeled Development Scenarios Deviate from the Natural Forested Flow Duration Curves

	Soil Type A		Soil Type C	
Scenarios	Residential	Commercial	Residential	Commercial
Olympia				
Unmitigated	30	30	30	30
LID Scenario 1	0.1	2	1	10
LID Scenario 2	n/a	0.1	0.3	3
Sea Tac				
Unmitigated	30	30	30	30
LID Scenario 1	0.03	1	0.1	4
LID Scenario 2	n/a	0.04	0.04	0.7
Port Angeles				
Unmitigated	10	3	10	4
LID Scenario 1	n/a	0.4	0.05	0.7
LID Scenario 2	n/a	n/a	n/a	0.1

The "n/a" entry means that the flow duration curve for the depicted scenario does not vary from the natural forested condition (predevelopment) flow duration curve.

Key Conclusions from Scenario Modeling Results

The scenario modeling results show that the application of LID techniques could significantly reduce total runoff volume and peak runoff rates from residential and commercial developments throughout Puget Sound. These modeling results demonstrate that LID techniques can be very effective in maintaining natural flow regimes of streams in urbanizing watersheds and protecting aquatic habitat.

The effectiveness of LID techniques depends on land use, soil conditions, and local rainfall patterns. The scenario modeling results show that LID techniques tend to be more effective where:

- Impervious coverage is lower (greater runoff reduction achieved on residential sites than commercial sites).
- Soils have higher infiltration capacity (greater runoff reduction achieved for development sites on Type A soils than for those on Type C soils).
- Total annual rainfall is lower (greater runoff reduction achieved for sites in the drier areas of Puget Sound than for sites in Olympia and SeaTac areas).
- LID is applied more extensively (greater runoff reduction achieved for LID scenario 2 than for LID scenario 1).

Where conditions are most favorable, LID techniques alone may be able to achieve the flow control standard of the Western Washington stormwater manual. However, in most cases,

LID techniques cannot adequately control runoff from the most extreme rainfall/runoff situations. Therefore, a detention system would typically be necessary to meet the default flow control standard. The use of LID techniques may significantly reduce the size of stormwater detention facilities required.

In the drier areas of Puget Sound (Port Angeles):

- Residential developments may be able to achieve the flow control standard using only bioretention and soil amendments (LID Scenario 1), where soil conditions are good for infiltration (Type A soils). Where soils have less infiltration capacity (Type C soils), additional LID measures, such as pervious paving and green roofs (LID scenario 2) would likely be required to achieve the flow control standard.
- Commercial developments on Type A soils may be able to significantly reduce detention requirements using bioretention and soil amendments (LID Scenario 1), and potentially achieve compliance with flow control standards with the addition of pervious paving (LID Scenario 2). Commercial developments on Type C soils would require additional detention facilities, but detention requirements may be significantly reduced using LID techniques.

In the wetter areas of Puget Sound (Olympia, SeaTac):

- Residential developments on Type A soils may be able to achieve the flow control standard with more extensive application of LID techniques (LID Scenario 2), and significantly reduce detention requirements using only bioretention and soil amendments (LID Scenario 1). Residential development on Type C soils would require additional detention facilities, but detention requirements may be significantly reduced using LID techniques.
- For commercial developments on Type A soils, detention requirements may be significantly reduced using bioretention and pervious paving (LID Scenario 2). These LID techniques may also reduce detention requirements for commercial developments on Type C soils. Using only bioretention and amended soils (LID Scenario 1) would probably do little to reduce detention requirements for commercial developments on Type A or C soils.

Note that the LIFE™ model was used to demonstrate the relative potential benefits of various LID techniques, but has not been approved by the Washington State Department of Ecology as an alternative for sizing flow control facilities. Development projects should still use the WWHM or approved equivalent to estimate facility sizing. Guidance for how to estimate flow reduction benefits of LID approaches will be provided for these models.

3. Recommendations and Guidance on Selected LID Techniques in Puget Sound

Appropriate LID techniques for defined flow control and quality treatment criteria are subject to site constraints, which include: topography, drainage patterns, soils, ground cover, critical areas, adjacent areas, existing development, existing stormwater facilities, and on- and offsite utilities. It is unlikely that one LID technique will be sufficient to meet treatment and flow control criteria. However, as estimated by the LIFE™ model, combinations of LID techniques should allow significant reductions in the size of downstream facilities, and in a few cases, those facilities may even be eliminated. Data should be analyzed to determine site limitations, including areas with high potential for erosion and sediment deposition (based on soil properties, slope, etc.), and locations of sensitive and critical areas (e.g., vegetative buffers, wetlands, water quality sensitive areas, etc.). Site opportunities, such as natural groundwater recharge areas, should also be determined.

Infiltration in the Puget Sound region

Infiltration is the most preferred method of reducing and treating stormwater because it serves a dual purpose of pollutant removal (TSS, heavy metals, phosphates, hydrocarbons, bacteria) and aquifer recharge.

The storage capacity needed to retain impervious surface runoff and allow it to infiltrate can be provided in the following ways:

- In the void space of absorbent soil, sand, or gravel layers
- On the ground surface (i.e., ponding)
- In infiltration chambers
- In storage structures, such as cisterns. Runoff stored in structures must eventually be released to an infiltration area.

Note that the amount of area provided for infiltration tends to be a more important design parameter than storage volume.

There are two general categories of infiltration facilities:

- *Surface facilities* – Runoff is stored in a surface layer of absorbent soil, sand, or gravel, and/or on the ground surface in a ponding area. Surface facilities can be aesthetically landscaped and integrated into the design of open spaces (often called bioretention areas). This is the type of infiltration facility that was applied for the Puget Sound LID scenarios.
- *Sub-surface facilities* – Runoff is stored in sub-surface layers of gravel, sand, or drain rock and/or in infiltration chambers (e.g., inverted plastic half-pipes). Absorbent landscaping can be installed over the surface, and with proper engineering, pavement and light vehicle traffic may be allowed on the surface (e.g., a gravel soakaway layer under a driveway).

Infiltration facilities can also be a combination of the two types described above. For example, bioretention swales along roads may consist of an absorbent soil layer (surface swale) on top of a sub-surface infiltration trench (gravel layer).

Appropriate design of infiltration facilities should be selected based on site-specific characteristics and constraints.

General Design Guidelines for Infiltration Facilities

- Areas where large volumes of rainfall infiltrate under natural conditions (e.g., natural depressions with highly permeable soils) should be identified and preserved. Natural infiltration areas that directly feed stream baseflow (e.g., riparian corridors) are particularly important. Natural infiltration areas may be the best places to locate infiltration facilities.
- Site-specific percolation tests should be carried out (ideally under saturated soil conditions) to determine the hydraulic conductivity of soils on a development site, and to identify suitable infiltration areas. Percolation tests should be performed at the depth and location of proposed infiltration facilities.
- Infiltration facility sites should be protected from compaction and sedimentation during construction by pre-identifying and fencing or other means. Inadvertent compaction should be removed by ripping or scarifying the site prior to installation of infiltration facilities.
- Infiltration facilities should be placed over undisturbed or lightly compacted ground (about 80 percent modified proctor density) to maximize exfiltration of rainfall into the underlying subsoil.
- Adequate sediment and erosion control during construction is essential to prevent clogging of infiltration facilities and underlying soils.
- Pipes leading to infiltration facilities should be fitted with debris catchers and cleanouts to minimize the movement of sediment and debris into the facilities. This is particularly important for sub-surface infiltration facilities.
- Infiltration facilities should be designed to allow overflow to escape to downstream watercourses via a storm conveyance system or as overland flow.

There are nine site-suitability criteria for infiltration developed by Washington State Department of Ecology and sited in the *Stormwater Management Manual for Western Washington* (2001):

1. Setback criteria—drinking water wells, septic tanks or drainfields, springs used for public drinking water supplies, etc.
2. Groundwater protection areas—aquifer sensitive area, sole source aquifer, or wellhead protection zone, etc.
3. High vehicle traffic areas—pretreatment LID techniques (i.e., oil removal).
4. Soil infiltration rate/drawdown time—infiltration rates short-term and long-term: Infiltration needs to be less than 2.4 in/hr to a depth 2.5 times the

maximum design pond water depth or a minimum of 6 feet below the base of the infiltration facility to be considered water quality treatment. Comparable to soil hydrologic groups B and C.

5. Depth to bedrock, water table, or impermeable layer less than or equal to 5 feet above the seasonal high-water mark, bedrock (or hardpan), or other low-permeability layer.

6. Soil physical and chemical suitability for treatment—infiltration rate, cation exchange capacity, organic content, and depth of soil used for infiltration treatment (must be a minimum of 18 inches).

7. Seepage analysis and control—adverse effects caused by seepage zones on nearby building foundations, basements, roads, parking lots, or sloping sites.

8. Cold climate and impact of roadway deicers.

9. Verification testing of the completed facility.

The Washington State Department of Ecology uses the following recommended infiltration rates based on U.S. Department of Agriculture soil textural classifications.

Soil Textural Classifications

	Short-term Infiltration Rate (in/hr)	Correction Factor, CF	Estimated Long-Term (Design) Infiltration Rate (in/hr)
Clean sandy gravels and gravelly sands (i.e., 90% of the total soil sample is retained in the #10 sieve)	20	2	10
Sand	8	4	2
Loamy Sand	2	4	0.5
Sandy Loam	1	4	0.25
Loam	0.5	4	0.13

It is feasible to implement LID techniques that encompass retaining and infiltrating stormwater runoff on-site in the Puget Sound area. New analysis shows that there are more extensive areas of outwash soils in Seattle than previously believed, which supports infiltration as a viable option for low impact development (Booth, 2003).

Note that there are other LID options that would be appropriate in cases where the feasibility of infiltration is limited by factors such as shallow till or groundwater (e.g., green roofs, rainwater capture/reuse).

References

Booth, Derek. 2003. "What Does the Research Tell Us Is Achievable in Urban Streams?" Speech presented at NDS Workshop, Faculty Center, University of Washington, Seattle, Washington, May 2003.

Appendix A – LIFE™ Model Assumptions and Layout

Additional Description of LIFE™ Model Assumptions

This appendix discusses the LIFE™ model assumptions used in the scenarios described in Technical Memo #2. These scenarios are illustrated in Figures A-1 to A-6.

TABLE 1A
Assumed Properties of Various Surface Types for LIFE™ Model Scenarios on Type A Soils

Surface Type	Surface Saturated Hydraulic Conductivity[1] (in/hr)	Sub-surface Saturated Hydraulic Conductivity[1] (in/hr)	Maximum Water Content[2]	Field Capacity[3]	Wilting Point[4]	Soil Water Half-life[5] (hr)	Pan Evaporation Multiplier[6]	Surface Soil Depth[7] (in.)	Maximum Ponding Depth[8] (in.)
Disturbed Soil (unmitigated development)	0.4 - Type A 0.1 - Type C	0.4 - Type A 0.1 - Type C	0.4	0.22	0.08	2.5	0.75	4	0
Amended Soil (landscaped surfaces)	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	2	1	12	0
Bioretention Areas on Residential Lots	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	3	1	24	3
Bioretention Areas on Road ROW and Commercial Lots	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	3	1	24	6
Green Roof Growing Media	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	2	1	4	0
Natural Forested Areas	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	3	1	24	0

(1) Saturated hydraulic conductivity (SHC) is the maximum rate that water can move through the soil matrix under saturated conditions. The surface SHC governs the maximum rate that water can get into the soil matrix. The sub-surface SHC limits the rate that water can move out of surface soil layers, bioretention areas, or pervious paving into the underlying native soil.

(2) Maximum water content (MWC) is the water content (fraction of soil matrix total volume) of a completely saturated soil.

(3) Field capacity (FC) is the water content above which water starts to drain out of the soil under the force of gravity.

(4) Wilting point (WP) is the water content below which plants are generally unable to extract water from the soil.

(5) Soil water half-life is the time it would take for half the water to drain out of the soil matrix (if unrestricted by underlying native soil). In general, lower half-life values result in faster draining soil profiles.

(6) Pan evaporation multiplier is the multiplication factor for pan evaporation data to determine evapotranspiration losses during each time step (similar to a crop coefficient). The pan evaporation data was obtained from the climate station in Puyallup.

(7) Surface soil depth is the size of the surface soil 'reservoir', which is also assumed to be equivalent to vegetation rooting depth. For bioretention facilities or amended soils on landscaped areas, soil depth is a design parameter. For the pervious surfaces on unmitigated development, surface soil depth is an assumed value (shallower depth means that soils become saturated and generate surface runoff more frequently).

(8) Maximum ponding depth is average depth of water that can be retained on the soil surface. For bioretention facilities, surface runoff occurs when this ponding depth is exceeded, and for pervious surfaces runoff occurs at soil saturation (since ponding depth is 0).

Notes on Key Assumptions:

Long-Term Infiltration Rates - The sub-surface saturated hydraulic conductivity values govern the long-term infiltration rates. These values are assumed to be equivalent to typical Natural Resource Conservation Service (NRCS) guidelines for long-term infiltration rates of Hydrologic Soil Groups A and C (0.4 and 0.1 inches per hour).

Soil Storage Capacity – Soil depth is the assumed size of the soil 'reservoir'. The difference between maximum water content and field capacity is the soil storage capacity that can be infiltrated (20% of soil matrix volume for amended soil and 18% of the soil matrix volume for disturbed soil). The difference between field capacity and wilting point is the soil storage capacity that can be removed by evapotranspiration only (20% of soil matrix volume for amended soil, and 14% of the soil matrix volume for disturbed soil).

Fate of Infiltrated Water – The LIFE™ model tracks infiltration into the underlying native soil from all sources (pervious surfaces, bioretention areas, pervious paving). For modeled prototype sites on Type A soils, 10% of the infiltrated water is assumed to emerge as interflow (i.e., contributes to total flow from the site) under forested conditions, with slightly more emerging under developed conditions (12.5%) to account for more sub-surface channeling (e.g., along utility trenches). For modeled prototype sites on Type C soils, 20% of the infiltrated water is assumed to emerge as interflow under forested conditions and 25% under developed conditions. The infiltrated water that does not emerge as interflow is assumed to be "lost" to deep groundwater.

LIFE™ Model Screen Captures

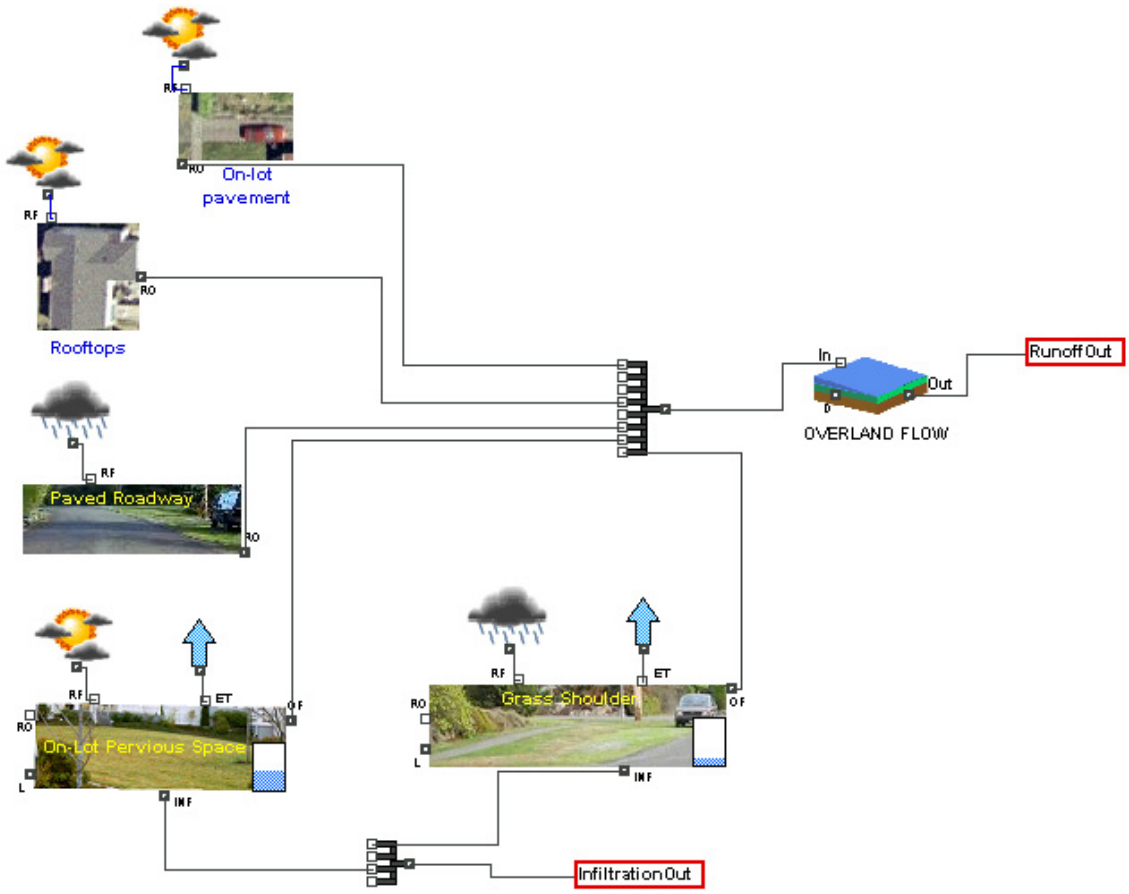

Figure A-1 Model Layout for Unmitigated Residential Block

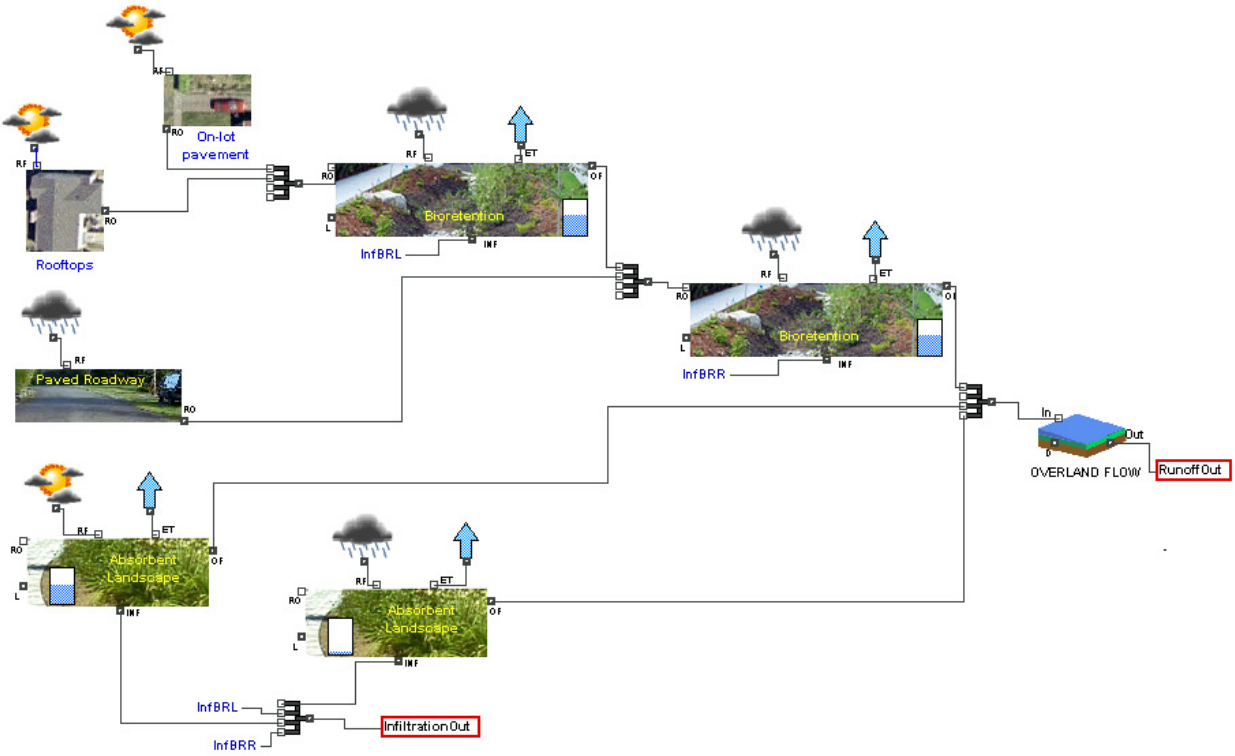

Figure A-2 Model Layout for Residential LID Scenario A

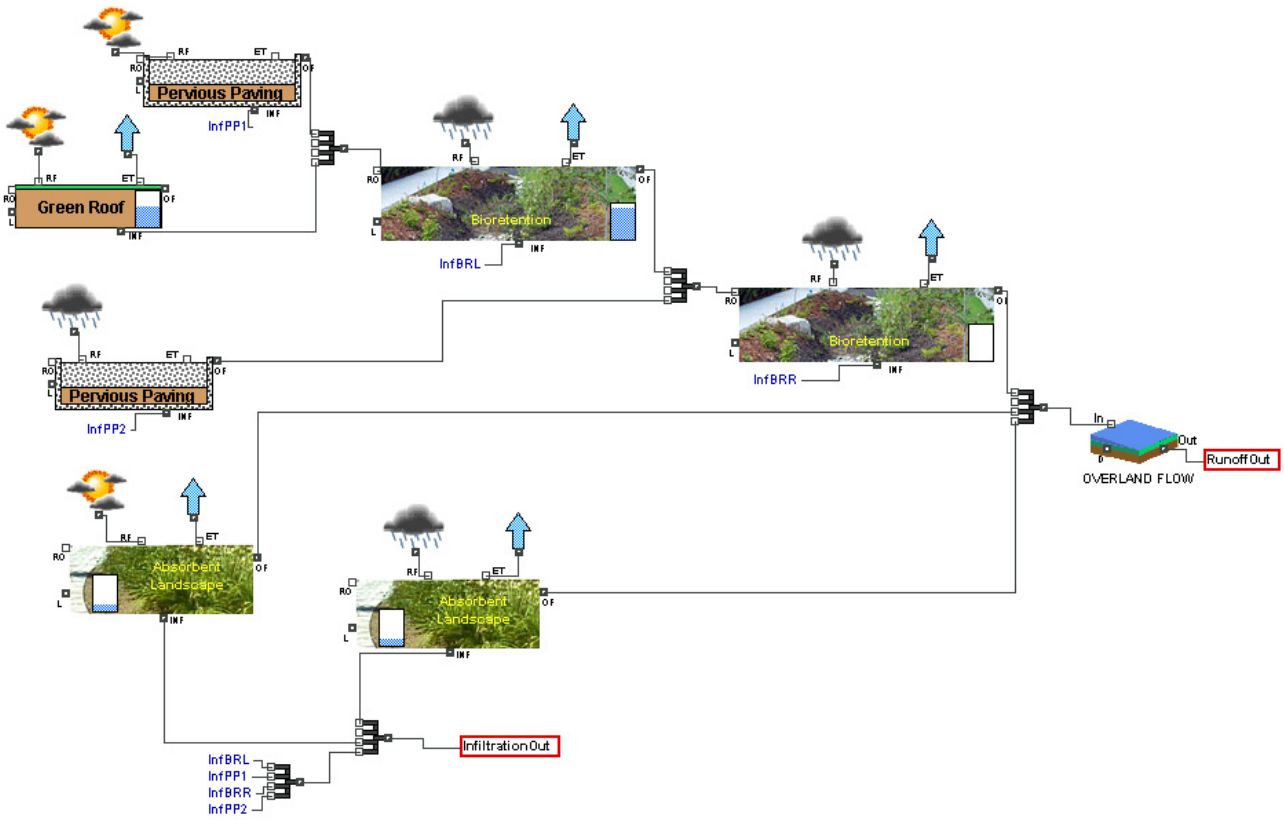

Figure A-3 Model Layout for Residential LID Scenario B

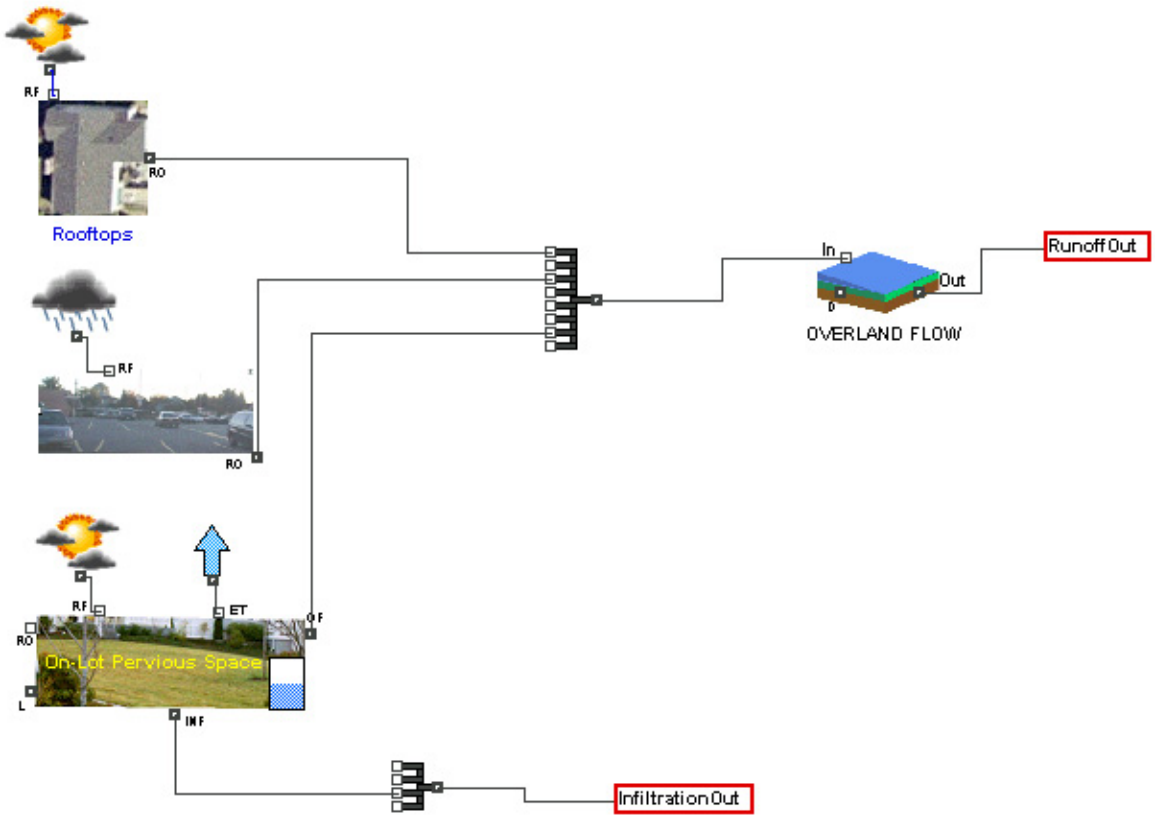

Figure A-4 Model Layout for Unmitigated Commercial Lot

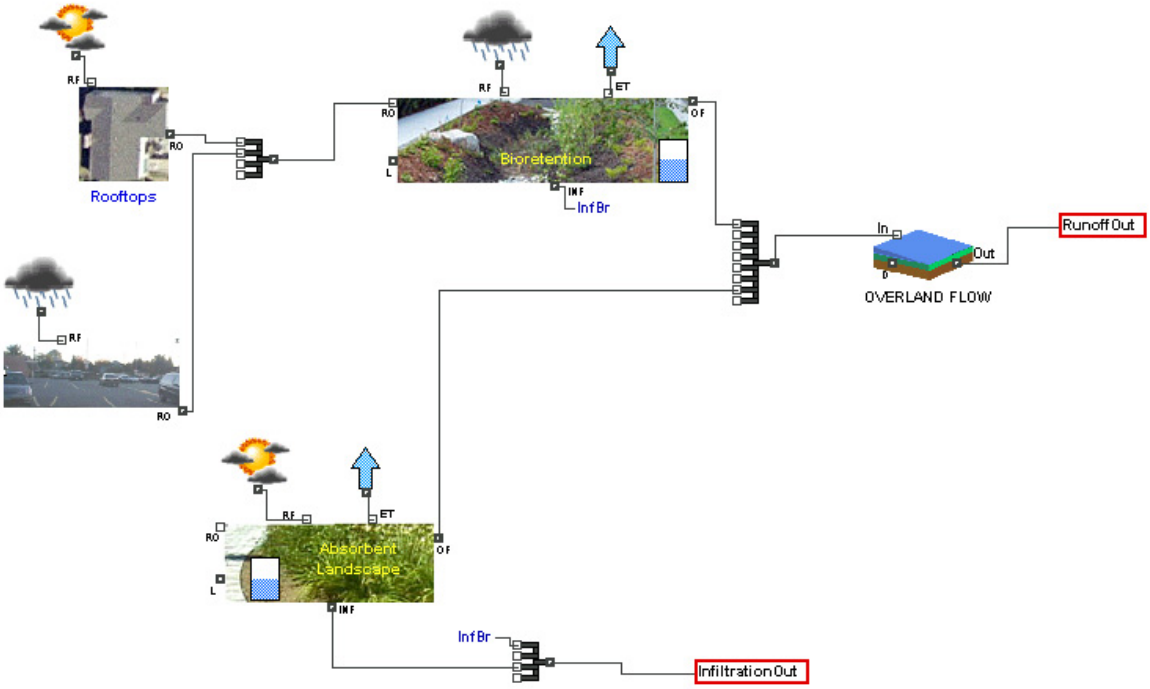

Figure A-5 Model Layout for Commercial LID Scenario A

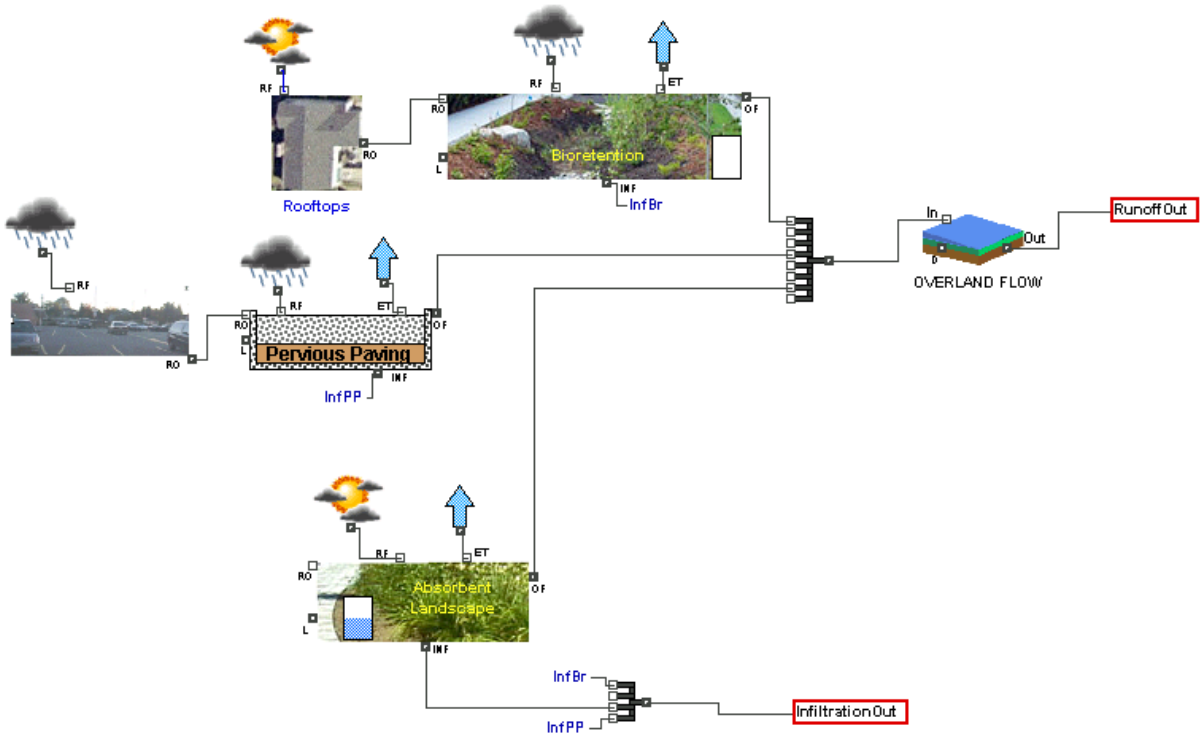

Figure A-6 Model Layout for Commercial LID Scenario B

Suggested Adaptations to BMPs in the Washington Stormwater Management Manual to Include Benefits of LID Techniques

Produced through Funding from the Department of Ecology and Administered by the Puget Sound Action Team

PREPARED FOR: Puget Sound Action Team
PREPARED BY: CH2M HILL
Bill Derry
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DATE: January 16, 2004

1. Introduction

The Puget Sound Action Team (PSAT) is interested in developing additional information on low-impact development (LID) practices for the Puget Sound region. PSAT contracted with CH2M HILL to develop this additional information in three primary phases: Phase 1, review of selected LID techniques; Phase 2, analyses and recommendations for the use of LID techniques in Puget Sound; and Phase 3, analysis and recommended changes to selected best management practices (BMPs) in the *Stormwater Management Manual for Western Washington* (Ecology, 2001) to include the benefits of LID techniques.

This project will produce three technical memoranda. They are:

1. Review of Low-Impact Development Techniques
2. Analysis and Recommendations for the use of LID Techniques in Puget Sound
3. Suggested Adaptations to BMPs in the Washington Stormwater Management Manual to Include Benefits of LID Techniques

This Technical Memorandum 3 covers the third phase of the project, Low-Impact Development in the Puget Sound Region, assessing selected best management practices in the stormwater manual and providing adaptations to these practices so that they include the benefits of LID techniques.

The stormwater manual provides technical standards and guidance on management measures to control the quantity and quality of stormwater runoff generated by new development and redevelopment. First issued in 1992, the manual was revised in 2001 to include improved knowledge of the impacts of stormwater runoff and the methods for controlling it. New research findings and changes in federal stormwater regulations and the Endangered Species Act call for significant changes in the way urban runoff is managed.

2. Analysis of Selected LID Techniques

Various LID practices were reviewed by CH2M HILL to provide current design recommendations for Washington State Department of Ecology to include in the stormwater management manual. Apart from the five selected LID practices discussed in Technical Memorandum 1 (bioretention cells, amended soils, green roofs, level spreaders, and pervious pavement), no other LID applications were discovered during this review that warranted development of recommendations.

Among the five selected LID practices, bioretention cells rank the highest of the LID techniques to implement because of their proven performance and broad potential application in the Puget Sound region. The question for bioretention cells is not if they will work, but how to design them according to site-specific conditions and contributing drainage area. Green roofs and pervious pavement have also proven to be effective LID practices at reducing stormwater runoff in Europe and on the East Coast, but may receive some resistance in the Puget Sound area due to the small number of existing local projects.

CH2M HILL recommends promoting these LID practices and monitoring projects to determine the extent that these practices can reduce stormwater runoff given local site characteristics.

Stormwater Manual Review and Recommendations for LID Techniques

The stormwater manual recognizes onsite stormwater management as a method to infiltrate, disperse, and retain stormwater runoff on a development site to the maximum extent practicable without causing flooding or erosion impacts. Volume V of the manual provides design guidance for runoff treatment BMPs, including the five selected LID practices, bioretention cells, amended soils, green roofs, dispersion of runoff, and pervious pavement. The current design standards in the manual for the five selected LID practices are very robust, so the following recommendations are intended to provide new design guidance that is not already included in the manual, LID design size criteria considerations, and future action that will promote awareness and use of these LID applications in the Puget Sound region.

Bioretention Cells

Bioretention cells are most effective when sized for the appropriate permeable soil depth and composition. There is a direct relationship between the depth of base material needed above till and the incoming water that is to be retained. SEA Streets, a very effective bioretention swale system in north Seattle, has varying permeable soil depths of 4 to 13 feet above the till. From this it can be assumed, at minimum, a 4-foot depth of permeable soil above till should be the design standard for bioretention cells. At this point there are not enough local case studies to derive a direct relationship between the depth of permeable base material above till and the storage volume needed. CH2M HILL recommends that

efforts be made to encourage implementation of bioretention cells, with follow-up monitoring, to derive this relationship.

The size of a bioretention cell can be determined by using the Western Washington Hydrology Model (WWHM) or an appropriately calibrated continuous simulation model based on the HSPF modeling software to estimate the volume of storage needed to retain and infiltate up to the 6-month, 24-hour storm event (see section 3 below for explanation of the 6-month, 24-hour design storm event). Storm events larger than this will presumably generate stormwater runoff and should be managed by traditional stormwater BMPs such as detention ponds, vaults, etc.

CH2M HILL has developed a simulation model called Low Impact Feasibility Evaluation (LIFE™). LIFE™ is a hydrologic simulation tool that was developed to evaluate the performance of various LID techniques (e.g., bioretention, infiltration systems, rainwater capture/reuse systems, and green roofs). It is well suited to site-level analysis of spatially distributed stormwater source controls (i.e., LID techniques). The LIFE™ model provides a continuous simulation of the runoff and infiltration from a development (or re-development) area or from a watershed (or sub-catchment) with multiple land uses. When calibrated to various site conditions within the Puget Sound region, it may also be an effective tool for sizing bioretention facilities, but it has not been reviewed or approved for this purpose by the Department of Ecology.

Bioretention cells should include the following design components:

1. **Pretreatment** to reduce runoff velocity and to filter particulate matter. Grass buffer strips or vegetated swales are commonly used as pretreatment devices.

2. **Ponding area** to store excess runoff and facilitate settling of particulate and evaporation of excess water. If topography allows, a wide depression providing surface storage and further settling of sediment prior to subsurface treatment should be incorporated. A maximum ponding depth of 6 inches is recommended. The maximum 6-inch ponding is recommended in soils with a minimum infiltration rate of 2 inches per hour. The maximum draw-down time for a ponded area is recommended to be 48 hours.

    - The width and depth of the bioretention area will vary with the space available and the volume needed for infiltration and detention. A 2:1 ratio of width to depth is recommended, but can be changed to accommodate site limitations.

    - Bioretention areas function best where soil infiltration is good (i.e., Types A and B [outwash] soils). Where infiltration is poorer (i.e., Type C [till] soils), bioretention is not recommended without using suitable supplemental storage such as additional gravel base, infiltration chambers, or downstream flow control.

    - Bioretention areas should not receive concentrated flow discharges.

    - The bottom of a storage layer should be 4 feet minimum above till and/or the seasonal high water table. Note that additional research or analysis is needed to verify this.

    - Forested areas should not be cleared to accommodate a bioretention area.

3. **Groundcover area** to provide biological uptake of pollutants and pathways for infiltration, evapotranspiration, erosion control, weed control, soil moisture retention, and plant material decomposition. Mulch should be a specified compost, fine ground bark, or stockpiled forest duff from the project site (Snohomish County, 2003). Three inches of mature mulch is recommended.

4. **Planting soil** to provide the area for stormwater storage and nutrient uptake by plants. Planting soil depth of 12 inches is recommended. This criterion can be met using onsite native topsoil, incorporating amendments into onsite soil, or importing blended topsoil (see section below on amended soils for further detail). The resulting soil should be amenable to the type of vegetation to be established. It should be clear that 12 inches of planting soil, with specifications listed below, is to support vigorous plant growth that intercepts the rainfall, returning much of it to the sky through evaporation and transpiration. An additional 3 feet of permeable soil is recommended for the storage capacity of the bioretention cell (see sand bed below).

   For water quality treatment, native soils with a long-term infiltration rate of at least 1 inch per hour are generally suitable for bioretention. Native soils in the filter layer with lower infiltration rates (i.e., SCS type B and C typical of the Northwest) should be amended with sand and compost to attain suitable filtration properties and a higher infiltration rate, or replaced completely with a specified bioretention soil mix.

   The bioretention soil compositions in the following table show the minimum infiltration rate of specified soil media. A minimum permeability (k) for the installed bioretention soil is specified as 3 inches per hour, and design values between 1 and 3 inches per hour should be considered reasonable based on expected long-term maintenance and loadings.

Bioretention Soil Composition

Medium	Composition of Medium in Filter Layer (%)	Minimum Infiltration Rate (inches/hour)
Sand	50-60	8
Topsoil	20-30	0.5
Compost	20-30	8
Total (Loamy Sand)	100	~5 (Use 2.5)

5. **Vegetation (plants)** to help in water removal through evapotranspiration and to help in pollutant removal through nutrient cycling (EPA, 2000). It is preferred that native vegetation be used where possible. Plants should be selected that can tolerate the hydrologic regime they will experience (i.e., wet and dry conditions). It is best to select a combination of trees, shrubs, and herbaceous materials. Trees that reach a diameter greater than 4 inches at 6 inches above the ground may be classified as a hazard in right-of-way areas and should not be used in the clear zone.

   The Broadview Green Grid list of plants below shows the plants used for the Broadview Green Grid project in northwest Seattle, Washington. Many of these plants are native to the Puget Sound region and are recommended for bioretention systems in this area.

Broadview Green Grid – List of Plants

Deciduous Trees
Flame Ash - 35 to 40' mature height / equal spread, small leaflets, reddish fall color.
Katsura Tree – 35 to 40' mature height / equal spread, yellow to orange fall color.
Norwegian Sunset Maple – 30-35' mature height, pyramidal form, orange fall color.
Pacific Sunset Maple – 25-30' mature height, round form, red fall color.
"Eddie's White Wonder" Dogwood – 25-30' mature height, pyramidal form, white flowers.
Galaxy Magnolia – 30' mature height, 15' spread, reddish purple flowers.
Autumn Brilliance Serviceberry – 20' mature height, 15' spread, white flowers, red fall color.
Ballerina Magnolia – 20' mature height, 20' spread, light pink to white flowers.
European Mountain Ash – 35' mature height, 25' spread, white flowers, red fruit, rust fall color.
Korean Mountain Ash – 40' mature height, 30' spread, white flowers, red fruit, orange to red fall color.
Purple-Leaf Hazelnut – 20' height, 15' spread, purple foliage spring through summer.

Evergreen Trees
Japanese Black Pine – 50+' mature height, 30+' spread, irregular form, slow grower.
Austrian Pine – 50+' mature height, 20+' spread, pyramidal form, fast grower.
Hinoki Cypress – 20+' mature height, 15+' spread, irregular sculptural form, very slow grower.

Deciduous (screening) Shrubs
Vine Maple – 15' mature height, 10-15' spread, multi-stemmed, orange to red fall color.
Diane Witchhazel – 10' mature height, 10' spread, red flower, orange-red fall color.
Belle Etoile Mock Orange – 6' mature height, 6' spread, white flowers.
Red-Flowering Currant – 6' mature height, 6' spread, pink to reddish flowers, fruit attracts birds.
Red-Twig Dogwood – 6' mature height, 8' spread, white flowers, ornamental red twigs
Yellow-Twig Dogwood – 6' mature height, 8' spread, white flowers, ornamental yellow twigs.
Oak-Leaf Hydrangea – 6' mature height, 6' spread, cream flowers, bronze to crimson fall color.
Blueberry – 6' mature height, 4' spread, edible fruit.
Salmonberry – 5' mature height, 4' spread, purple flowers, fruit attracts birds.
Wild Rose – 5' mature height, 4' spread, pink flowers, rose hips of visual interest.

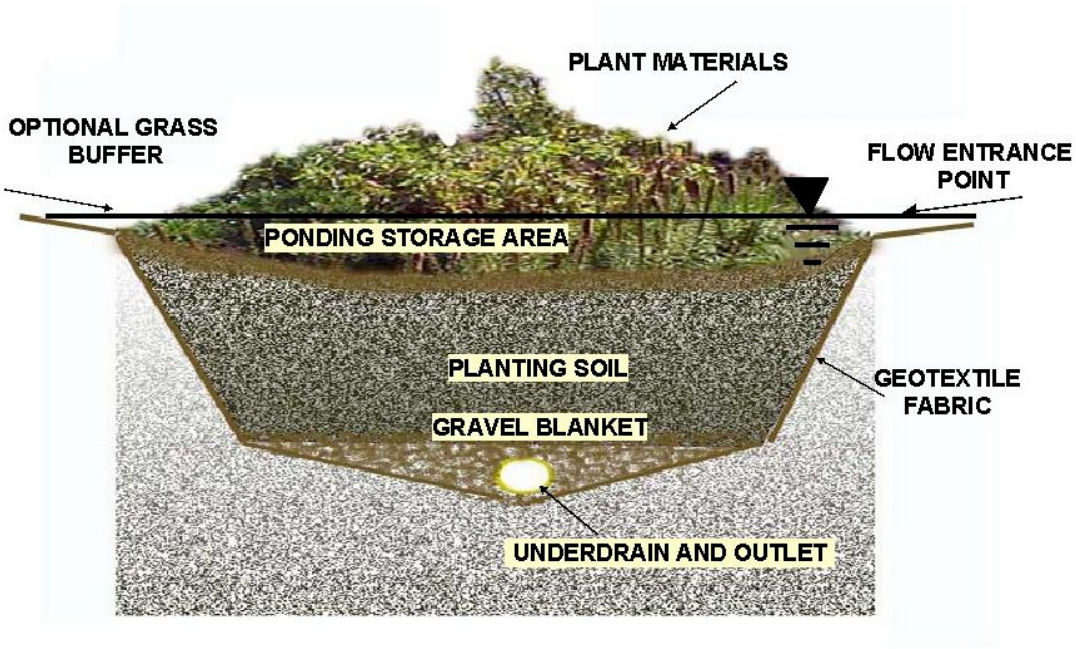
Evergreen (screening) Shrubs
Strawberry Tree – 8+'mature height, 8+' spread, cream flowers, non-edible fruit resembles a strawberry
Compact Strawberry Tree – 5' mature height, 5' spread, densely branched.
Evergreen Huckleberry – 5-8' mature height, 6' spread, white flowers, black berries.
PJM Rhododendron – 5' mature height. 5' spread, purple flowers, bronze fall color.

Deciduous (low growing) Shrubs
Pavement Rose – 2-4' mature height, 4-6' spread, profuse flowers of many colors bloom all summer.
Kelsey Dogwood – 2' mature height, 3' spread, light green summer foliage, fine-textured red twigs.
Snowberry – 3' mature height, 3' spread, ornamental white berries in winter.
Tangerine Potentialla – 2' mature height, 3' spread, yellow flowers with orange-red flush.
Isanti Dogwood – 3-4' mature height, 4-6' spread, like Red-Twig, above but lower growing.

Evergreen (low growing) Shrubs
Salal – 4' mature height, 4' spread, reliable native plant with cream flowers.
White Rockrose – 3-4' mature height, 4-5 foot spread, white flowers.
Creeping Mahonia – 2' mature height, 3-4' spread, reddish fall color can remain into the winter.
Lavender – 2-3' mature height, near equal spread, lavender-blue flower spikes, grayish foliage.

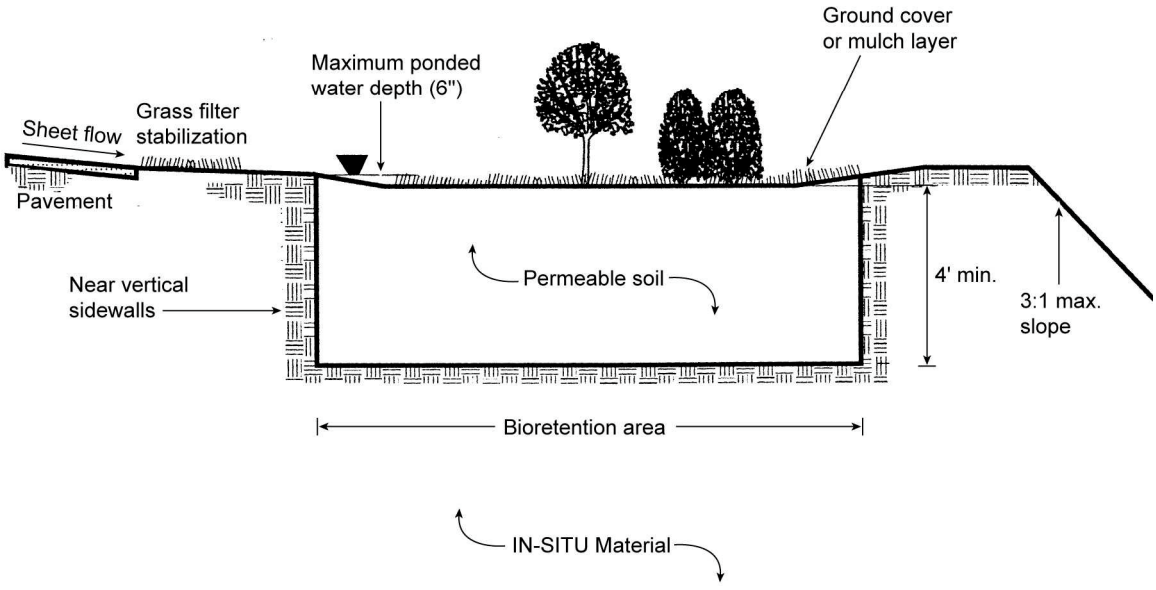
Perennials and Ferns
Swordfern – reliable, evergreen native fern.
Day Lily – 2-4' tall many colorful varieties blend well with native wetland plants.
Gladwin Iris – 1-2' tall with large ornamental seed capsules in the fall.
Douglasiana Iris – 1-2' tall native variety, with white, cream or lavender blooms.
Cranesbill – low perennial with blue to purple flowers.
Purple Palace Heuchera – large bronzy-purple leaves, delicate pink flower spikes
Coral Bells – large green leaves, delicate bright pink flower spikes
Sunrose – low-growing , multicolored, flowering perennial, grows well in full sun.
Gaura – fine-textured perennial with small pink flowers, blends well with native wetland plants.
Epimedium "Rose Queen" – large, evergreen leaves, small pink flowers
Lupine – 1-4' tall, blue-, purple- or red-blooming native plant.

6. **Sand bed** to provide aeration and drainage of the planting soil and assist in flushing pollutants from soil materials. The total depth of permeable soil should be 4 feet below the biofiltration cell. Either planting soil or sand can be used for permeable soil.



Typical bioretention facility with underdrain

Source: Prince George's County (MD) Department of Environmental Protection



Bioretention system cross-section

Source: Low Impact Development Center, Inc.

Amended Soils

The stormwater manual describes the benefits of preserving natural soil during and after construction. Naturally occurring (undisturbed) soil and vegetation provide the best means of stormwater infiltration and treatment. The manual endorses retaining or enhancing 65 percent or more of the development site's native cover and preserving wetland and stream corridors. Ideally, the preserved area should be located downslope from the building sites to allow stormwater runoff flow dispersion through duff, undisturbed soils, and native vegetation.

Establishing a minimum soil quality and depth is not the same as preservation of naturally occurring soil and vegetation. However, establishing a minimum soil quality and depth will provide improved onsite management of stormwater flow and water quality. There are many different soil "recipes" that produce healthy soil systems, and several have been applied in the Puget Sound region with good results. We do not have any specific recommendations for soil amendments.

The following subsections provide a summary of soil design criteria from various local sources in the Puget Sound region.

Organic Content

The quantity of compost to be incorporated into the native soil should be based on the organic content goal. Undisturbed sites in the Puget Sound Lowland area consist of up to 3.5 feet of forest duff soil. This native topsoil usually has an organic content from 4 to 6 percent, significantly higher than the average subsoil organic content of less than 1 percent (Chollak, 1998). The final organic content target of amended soil is between 8 and 13 percent by soil weight. The organic content of all existing subsoil exposed during site construction is expected to be less than 1 percent. As a rule of thumb, a 2-to-1 ratio of existing soil to compost, by loose volume, will achieve the desired organic level. To maximize the benefits of compost incorporation, a minimum of the top 6 inches of soil should be amended (Chollak, 1998).

Soil organic matter can be attained through numerous materials such as compost, composted woody material, biosolids, and forest product residuals. It is important that the materials used to meet the soil quality and depth BMP be appropriate and beneficial to the plant cover to be established. Likewise, it is important that imported topsoils improve soil conditions and do not have an excessive percent of clay fines (Snohomish County, 2003).

Topsoil Layer

The duff layer and native topsoil should be retained in an undisturbed state to the maximum extent practicable. When grading is required, the removed native soil should be relocated to other areas within the project site.

A topsoil layer should have a minimum organic matter content of 10 percent dry weight and a pH from 6.0 to 8.0 or matching the pH of the original undisturbed soil. The layer's minimum depth should be 8 inches except where tree roots limit the depth of incorporation of amendments needed to meet the criteria. Subsoils below the topsoil layer should be mixed with at least 4 inches of upper material to avoid stratified layers.

These criteria can be met by using onsite native topsoil, incorporating amendments into onsite soil, or importing blended topsoil. Imported topsoil should be limited to 25 percent fines passing through a 200 sieve. The resulting soil should be conducive to the type of vegetation to be established (Snohomish County, 2003).

Snohomish County BMP T.5.13 in the stormwater manual outlines the following soil specifications:

- 8-inch depth of soil with 10 percent organic content in planting beds and 5 percent organic content in turf areas.
- Compacted subsoils must be scarified at least 4 inches below the 8-inch-deep amended layer (for a finished uncompacted depth of 12 inches).
- Planting beds must be mulched with 2 inches of organic material/mulch.

In order to obtain the quality of compost and other materials used to meet organic content, the following criteria must be met (taken from the Snohomish County manual for identifying compost, topsoils, and other organic materials for amendment and mulch):

- Only Grade A Compost as defined by Washington State Department of Ecology Interim Compost Quality Guidelines ("composted materials" WAC Chapter 173-350 Section 220) or topsoil manufactured from these composts plus sand or sandy soil can be used to meet the organic content for the "pre-approved" amendment rates. Products must be identified on the Soil Management Plan form, and recent product test sheets provided showing that they meet additional requirements for organic matter content and carbon-to-nitrogen ratio.
- For custom calculated amendment rates, organic matter may be provided by Grade A Compost or other organic materials with a carbon-to-nitrogen ratio below 25:1. The carbon-to-nitrogen ratio may be as high as 35:1 for plants native to the Puget Sound Lowlands Region.
- Alternative organic materials may be used in lieu of the specified compost if they meet the criteria for carbon-to-nitrogen ratio, contaminants (as defined in WAS Chapter 173-350 Section 220/Interim Compost Quality Guidelines for Class A Compost), and when mixed with existing native soil can achieve a calculated organic content of 5 percent for turf areas or 10 percent for planting areas.

To achieve a target soil organic matter content, Equation 1 can be used to calculate compost application rates:

$$CR = D(X)\frac{SBD(SOM\% - FOM\%)}{SBD(SOM\% - FOM\%) - CBD(COM\% - FOM\%)} \qquad \text{Equation 1.}$$

where:

CR = Compost application rate (inches)
D = Depth of incorporation (inches)
SBD = Soil bulk density (lb/cubic yard dry weight)
SOM% = Initial soil organic matter (%)

FOM% = Final target soil organic matter (%)
CBD = Compost bulk density (lb/cubic yard dry weight)
COM% = Compost organic matter (%)

King County required Quadrant to use one of two guidelines when amending soils (Quadrant, 2000):

1. Washington State Department of Ecology's On-Site Residential Stormwater Management Alternatives, November 1995 Edition. If Quadrant uses this guideline, the soil-to-compost mix will have a ratio of 1 part compost to 2 parts soils. The topsoil product must be suitable for placement 12 inches deep in nonstructural fills and landscaped areas.

2. King County Executive Proposed Site Alterations Code Ordinance (not yet adopted by the King County Council). This ordinance calls for adding 9 inches of amended topsoil consisting of native soils mixed with organic matter (mixed at a content rate of 8 to 13 percent dry weight) over existing scarified till soils. (Although the ordinance calls for a depth of 9 inches of amended soils, if Quadrant chooses to use this guideline they must still amend soils to a depth of 12 inches, using the content rate spelled out in the ordinance.)

Macro- and Micronutrients

Nitrogen and sulfur are the most commonly deficient macronutrients in Puget Sound Lowland soils. Potassium, phosphorus, magnesium, and calcium levels are sometimes also insufficient for optimal vegetation growth. Micronutrients (the nutrients needed by vegetation in small quantities) will be supplied by the addition of compost, with the possible exception of boron (Chollak, 1998).

It is recommended that lime be added to soils with a pH below 6.0. Lime has the additional benefit of correcting calcium and magnesium shortages. Gypsum is used for three primary purposes in soil: adding calcium and sulfur without increasing the pH; displacing sodium ions in extremely salty soils; and binding clay particles to enhance the macropore abundance. Gypsum is not generally needed in the Puget Sound Lowland (Chollak, 1998).

Engineered Soil Mixes

The City of Seattle has constructed several projects using engineered soil mixes to help achieve stormwater detention goals. The projects are categorized as either "biological" planting strips or bioretention facilities. Amended soil is used with planting strips to detain and purify runoff. The following soil specifications are from Seattle's *Soil Strategies for Stormwater Goals*, provided to CH2M HILL by the City of Seattle (City of Seattle, 2003).

- The City's soil mix must include 25 percent Decomposed Organic Mulch (Seattle City Ordinance Section 9-14.4(8)) by volume (plus or minus 2.5 percent), and the remaining volume shall be aggregate with the following gradations:

Sieve Size	Percent Passing
3/4 inch	100
1/4 inch	30-60

Sieve Size	Percent Passing
U.S. No. 8	20-50
U.S. No. 50	3-12
U.S. No. 200	0-3

- Infiltration of planting soil mix shall have a minimum permeability rate of 3 inches per hour at field density.
- The soil and decomposed organic mulch components shall be combined to create a consistent, homogeneous mixture.
- The planting soil shall be evenly placed in 12 lifts not exceeding 12 inches and distributed in the trench such that the compaction does not exceed 80 percent of maximum dry density per American Society for Testing and Materials (ASTM) Standard D-698.
- Use of mechanical vibratory compaction is not permitted.

Three soil mixes were used for Seattle's SEA Streets project to meet different bioretention facility needs:

1. Planting Soil Type A, per the City's standard specifications, was used on all areas of the project outside of the swale and road shoulder areas.
2. Planting Soil B was used within the detention swale areas. The high percentage of compost in the soil mix is intended to create conditions favorable for wetland vegetation.
3. Roadside Planting Soil was used in the 2-foot road shoulder areas. This soil mix was designed to support occasional vehicular traffic with minimal rutting, while also supporting vegetation growth.

Planting Soil Type A is required to consist of approximately two-thirds soil and one-third Decomposed Organic Mulch (Seattle City Ordinance Section 9-14.4(8)) by volume, thoroughly mixed together. The soil is specified to be sandy loam or loamy sand consisting largely of sand, but with enough silt and clay present to give it a small amount of stability. Soil components must meet the following gradation requirements:

Sieve Size	Percent Passing
3/8	100
U.S. No. 35	85-100
U.S. No. 100	40-60
U.S. No. 270	10-30

Planting Soil Type B must consist of approximately 50 percent native soil and 50 percent Decomposed Organic Compost (Seattle City Ordinance Section 9-14.4(9)) by volume, thoroughly mixed together. Soil Type B is amended to create optimum conditions for plant establishment and early growth using materials such as calcium carbonate or dolomite lime,

ureaform or ureaformaldeyde, calcium nitrate, superphosphate, and sulfate of potash magnesium. The percentages of these materials are to be indicated from a soil test by an approved independent laboratory or as directed by the Engineer.

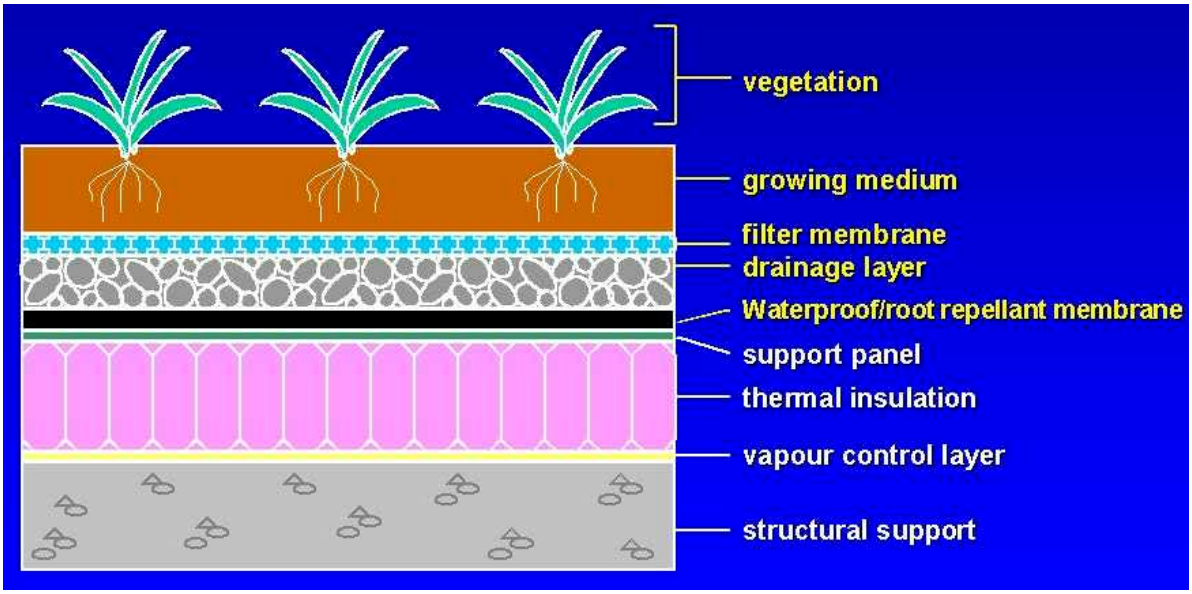
Roadside planting soil is Hendrikus Schraven Lawn Mix™ and is available from Hendrikus Schraven Landscape Construction and Design, Inc.

Decomposed Organic Mulch must consist entirely of recycled organic materials that have been sorted, ground, aerated, and aged for 1 year. The mulch must have a pH between 5.5 and 7.0 and a carbon-to-nitrogen ratio between 20:1 and 40:1, with maximum electrical conductivity of 3 ohms per centimeter.

Green Roofs

Vegetation on rooftops is a practical method of managing runoff in densely developed urban neighborhoods (Ecology, 2001). Ecology recognizes in the stormwater manual that green roof technologies are poorly understood in North America and the market remains immature, whereas green roofs are a well established practice in Europe.

A green roof is an extension of the existing roof that includes a special root-repelling membrane, a drainage system, a lightweight growing medium, and plants (Ecology, 2001). A typical green roof has a rubber or plastic waterproof liner laid over the traditional rooftop. Either above or below the waterproof layer is a layer of insulation such as perlite. Over or at the end of the insulation layer, a drainage layer may be added, depending on the pitch of the roof. Finally, a thin layer of soil mix is added and planted with grasses, ground-covers, or drought-tolerant plants (NEMO, 2003).



Typical cross section of a green roof

Source: NRDC, 2002

Major considerations in installing a green roof are the following:

- To reduce structural costs, a lightweight growing medium should be used rather than soil, except as topping layer on intensive systems greater than 18 inches deep. Clay and fine silt will cause many problems. Also organic content should be severely limited to limit unwanted biotic growth. Green roof media are mineral 'soils' with very few fines and perhaps 10 percent organic matter at most. Well tested guidelines for the physical properties of green roof soils have been published by FLL (the German green roof trade organization). The guidelines are available in English and cover all aspects of media development.
- The depth of the medium in relation to its absorbency may also be fine-tuned for structural load efficiency. The following are growing medium depth recommendations: single media – 2 to 4 inches; two-media systems – 4 to 18 inches; three-media systems – 18 to 36 inches. The performance of green roofs will vary tremendously depending on the physical properties of the media and the thickness of the green roof.
- Water storage in a plastic drainage layer or drain gravel layer under the growing medium can increase the effective retention capacity.
- Lightweight growing media can be subject to wind erosion when they dry out. Appropriate scheduling of soil placement and temporary protection of the soils until planted or watered should be arranged.
- Roof water should be kept separate from pavement runoff, which can be polluted with hydrocarbons and heavy metals. Whereas pavement runoff may require treatment, most green roof runoff is clean enough to be released directly to receiving waters.
- Proper waterproofing and flashing is essential.
- Most green roof systems include a root growth inhibitor to keep roots from invading the waterproof membrane area.
- The most successful green roof systems for the Puget Sound region use drought-tolerant grasses and sedum. Sedum is preferred for performance-oriented green roofs.
- Establishment watering may be required, using either standard surface watering devices or an automatic irrigation system. Watering requirements will vary, based on the green roof system chosen.

The following comments on greenroof performance in the Puget Sound area are from Charlie Miller of Roofscapes, Inc. (2003):

- Water quality removals of total nitrogen, total phosphorus, and other metals exceed 80 percent.
- Runoff peak rates are reduced for all but the largest storms.
- Runoff quantity benefits may vary in our region due to seasonal and temporal distribution of rainfall.

Green roof performance in the Puget Sound region has not been well established mainly because follow-up monitoring has not been well documented. We recommend promoting and monitoring green roofs to better define the quantity of reduced stormwater runoff and the overall benefits of using this LID approach in this region.

Dispersion of Runoff

Full dispersion of stormwater runoff is defined in the stormwater manual as runoff from impervious surfaces and cleared areas of development sites where at least 65 percent of the site is protected in a forest or native condition. Full dispersion mechanisms include:

- Roof downspouts BMPs
- Driveway dispersion BMPs
- Roadway dispersion BMPs
- Cleared area dispersion BMPs

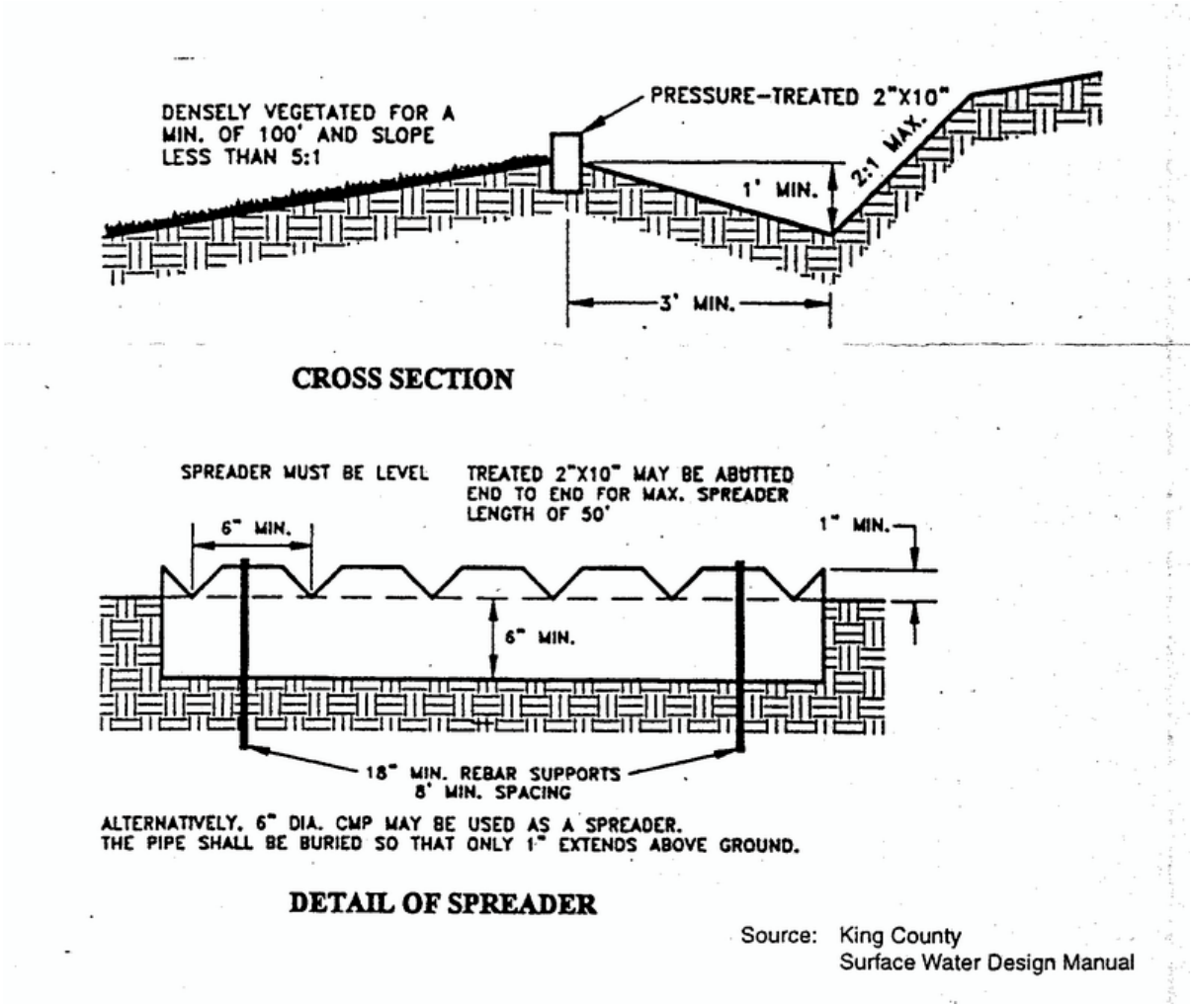
Level Spreaders

Another approach to dispersing runoff along pervious area is the use of level spreaders. A level spreader receives concentrated flow from channels, outlet structures, or other conveyance structures, and converts them to sheet flow. Although a level spreader by itself is not considered a pollutant reduction device, it improves the efficiency of other facilities, such as vegetated swales, filter strips, or infiltration devices, which are dependent on sheet flow to operate properly.

Typically, a level spreader consists of a depression in the soil surface that spreads the flow onto a flat area across a gentle slope. Level spreaders then release the stormwater flow onto level areas stabilized by vegetation to reduce speed and increase infiltration. The receiving area of the runoff conveyance outlet must be uniformly sloped and not susceptible to erosion. Particular care must be taken to construct the outlet lip completely level in a stable, undisturbed soil to avoid formation of rilling and channeling. Erosion-resistant matting can be used across the outlet lip, depending on expected flows (Prince George's County, 1999).

The length of the spreader depends upon the amount of water that flows through the conveyance. The depth of the level spreader should be 6 inches measured from the lip and must be uniform across the length of the measure. Level spreaders are generally used with filter strips. The depressions are seeded with vegetation. The grade of the channel for the last 15 feet before entering the level spreader must be less than or equal to 1 percent. The level lip of the spreader must be constructed at zero percent grade to ensure even spreading of storm runoff to produce sheet flow. The entrance to the spreader must be carefully graded to divert runoff directly into the zero-percent-graded channel. The level spreader must be constructed on undisturbed soils (not on fill), and the sheet flow must discharge onto undisturbed, stabilized areas. Stormwater must not be allowed to reconcentrate below the discharge point (Salt Lake County, 1999; and U. of Georgia, 2003).

The following level spreader design is from the King County Surface Water Design Manual.



Source: King County
Surface Water Design Manual

Pervious/Porous Pavement

The stormwater manual has an extensive section detailing the application, limitations, design considerations, general design criteria, and construction criteria for pervious pavement alternatives. The manual also provides construction criteria for a collection system underneath the pervious pavement, details about subgrade soils, geotextile and drain pipes, open-graded aggregate bases, stabilized bases, and paver installation.

At this time we have not found any significant additional design criteria in our extensive research to provide specific recommendations.

A point worth emphasizing (which the manual also emphasizes) is the importance of proper installation by qualified and experienced professionals for the success of this system.

In the manual, porous asphalt and porous concrete do not qualify for flow control credits; that is, they are not recognized as a long-term means of reducing stormwater runoff. It is recommended that credit for pervious pavement be a direct function of the underlying base material and the depth of that material. This could be a matrix, or a sliding scale, dependent on the native soil, or imported fill, and depth of this medium. The type of medium underneath the pervious pavement drives the infiltration rate potential of the system, and

the depth of the medium drives the stormwater runoff storage available with this system. Further study of the relationship between the depth and type of underlying base material will allow proper design for different site-specific conditions.

In Western Washington the Western Washington Hydrology Model (WWHM) or other acceptable continuous runoff simulation model can be used to size an infiltration basin. In this case, the bottom area of the "infiltration basin" will typically be the same as the area underlying the permeable surface.

Better Site Design Planning Principles

The manual also presents planning principles for better site design. The principles covered in the manual are in full agreement with current literature that has confirmed improved stormwater runoff control and water quality as a result of LID practices. The principles covered by the manual for better site design planning are the following:

- Define development envelope and protected areas
- Minimize directly connected impervious areas
- Maximize permeability
- Build narrower streets
- Maximize choices for mobility
- Use drainage as a design element

3. Further Recommendations for Discussion Regarding the Stormwater Manual

The stormwater manual design criteria for LID techniques, including the five selected for this review, are thorough and virtually up to date. Further investigation of the five selected techniques only provided newer design standards for green roofs. The benefits, and promotion of, low-impact development are stated clearly in the manual. At this point we recommend that the Washington State Department of Ecology, along with other local agencies and designers, address the following policy issues so that the Puget Sound region can enjoy the advantages of low-impact development.

What will promote the application of LID practices for agencies and developers?

We recommend that Ecology encourage the application of LID techniques through incentives. Measures such as cost-sharing and/or partnering with agencies/developers would increase interest in applying these techniques. Other incentives include expediting permit review and similar measures to move up the construction start date.

Currently, Ecology is sponsoring a committee that is reviewing the hydrologic benefits of various LID techniques and the potential credits allowed when these LID techniques are implemented. Further refinement with specific credits for specific LID techniques will provide great incentive for their application.

Should Ecology consider changing the design performance standards for BMPs?

Currently, the performance standard for BMPs is to match the peak and duration storm events from 50 percent of the 2-year to the 50-year. With this approach the stormwater runoff rate is managed but essentially all the runoff is allowed to leave a site and discharge into receiving waters downstream. There is some evidence that the increased frequent small storm discharges and increases in annual volume discharged may be as damaging as the infrequent peak events. A driving force that would promote LID application is to address the volume of runoff to retain on-site. We recommend that Ecology consider adding requirements that address the volume of annual runoff that should be retained on-site.

Should Ecology consider flexibility in the design performance standard for BMPs for built-out urban areas?

The LID approach to managing stormwater runoff focuses on retaining the smaller storm events onsite. Traditional BMPs focus on controlling the rate of runoff into receiving waters downstream. Ultimately, to improve stream conditions, both measures need to be addressed: retention onsite and controlled release rates. We suggest that Ecology consider the idea that in urban built-out redevelopment projects, peak-flow release rate requirements be flexible in exchange for on-site retention of the smaller storm events. The rationale is that urban built-out development sites have already caused severe scouring of local streams, often to the point that stream channels are eroded down to bedrock or a stable substrate. If complete retrofit or redevelopment of the watershed is unlikely over the next 50 years and

the streams are already degraded, is there a purpose in requiring the few redevelopment projects to control the peak runoff rate? Focusing on maintaining the smaller storm event runoff, which makes up the majority of stormwater runoff annual volume, is the first step in building up the stream channel. It would also provide hydrologic benefits on the site itself, and may be more beneficial.

Another issue is the design standard for sizing LID facilities in built-out urban watersheds. This question was addressed at a Natural Drainage System (NDS) workshop sponsored in Seattle by Seattle Public Utilities (SPU) in May 2003. SPU staff, CH2M HILL consultants, and University of Washington faculty leaders in stormwater management met to discuss the standardization of goals for managing runoff using LID techniques in urban retrofit situations. At the workshop it was recognized that, historically, the focus has been on managing less frequent but higher intensity peaks in terms of detention and flow control. This is important, but lower intensity, higher volume storms should be managed as well.

Professor Derek Booth, a workshop participant and Director of the Center for Urban Water Resources Management at the University of Washington, believes we currently have a backward approach - we determine a threshold peak runoff rate that should be controlled and then back-calculate the detention volume necessary to achieve that rate. In his opinion, the most effective means of managing stormwater runoff is to determine the volume of runoff that should be kept onsite, not in the streams. He also noted that the State of Maryland's stormwater manual focuses on controlling stormwater volume, not stormwater runoff rates, and believes that concentrating on managing stormwater volume versus peak flow will be a realistic approach to improving habitat restoration in our Puget Sound Lowland rivers. Although he does not believe that it is possible to restore a stream to its pre-development productivity, any incremental improvement is a step forward. Booth emphasized that we don't know the total benefit to the biological and hydrological system when focusing on one integrated part, but that less channel erosion will occur and water and habitat quality will improve when focusing on low intensity, higher volume storm events. (Booth, 2003)

Workshop participants suggested that the proposed design standard of LID techniques in urban retrofit situations retain and infiltrate the first 1 inch of precipitation. For the Seattle area, the 1-inch rainfall depth is approximately the 6-month, 24-hour storm event. This also represents approximately 90 percent of the annual rainfall. One of the questions at the workshop was "Will this standard reduce runoff by 90 percent?" The answer was "No one knows." Booth commented that people have spent lifetimes developing models to predict runoff given a specific storm event. Precipitation falling on land is dispersed in several ways. Less than 1 percent of the annual rainfall that falls on a forest runs off, but in an urban environment, a third or more of the annual rainfall may run off. The 10 percent of annual rainfall that comes in the most intense storms may represent a large portion of the annual runoff. Consequently, it is not scientifically sound to say that storm runoff will decrease by 90 percent if 90 percent of the rainfall is infiltrated. However, it is safe to say that whatever runoff there is, will be attenuated under LID systems (Booth, 2003).

Booth confirmed that the LID approach of retaining and infiltrating stormwater runoff onsite in the Puget Sound region is reasonable. Native western Washington forest soils have 50 percent porosity with a field capacity of 25 percent water storage, which supports infiltration as a realistic approach.

The consensus at the workshop was to design LID facilities for urban retrofit situations to retain and infiltrate the 6-month, 24-hour storm event (which corresponds to 1-inch precipitation) and engineer facilities to control or accommodate peak storm runoff rates for the larger storm events where feasible. However, Ed O'Brien, a workshop participant and a member of the Ecology Low Impact Development Credit Committee, made the following comment:

> The high infrequent flows need to be controlled in order to not perpetuate accelerated stream channel erosion. But that doesn't address the other changes in the natural hydrology that also cause loss of beneficial uses and habitat with smaller storm events. LID approaches such as Seattle's SEA Streets and Cascade Systems will help reduce the other hydrologic changes that influence stream health. Those LID approaches should have a spin-off benefit of reducing the size of facilities needed to achieve control of the high, infrequent flows that destabilize stream channels.

Various jurisdictions have set their own design storm goal using LID techniques. SPU designed the SEA Streets project (see Technical Memorandum 1) to retain the 2-year, 24-hour storm event. The WWHM model was used to calculate the storage volume necessary for the 2-year storm event. Swales were overexcavated by 1 foot, and the soil was amended with 30 percent compost and returned to the swales to produce sufficient storage.

Mark Blosser with the City of Olympia confirmed that, as Olympia moves to adopt the WWHM model, it will use it to estimate the storage volume required to match 50 percent of the 2- to 50-year storm event duration curve. The estimated storage volume is then divided between as many bioretention cells as are designed for the project. Mr. Blosser believes that Olympia is likely to include language requiring infiltration of 100 percent of summer storms where this is feasible and not risky (Blosser, 2003).

We believe further discussion of these issues is warranted.

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The Texas Manual on Rainwater Harvesting



Texas Water Development Board

Third Edition

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The Texas Manual on Rainwater Harvesting

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Chapter 1
Introduction

Rainwater harvesting is an ancient technique enjoying a revival in popularity due to the inherent quality of rainwater and interest in reducing consumption of treated water.

Rainwater is valued for its purity and softness. It has a nearly neutral pH, and is free from disinfection by-products, salts, minerals, and other natural and man-made contaminants. Plants thrive under irrigation with stored rainwater. Appliances last longer when free from the corrosive or scale effects of hard water. Users with potable systems prefer the superior taste and cleansing properties of rainwater.

Archeological evidence attests to the capture of rainwater as far back as 4,000 years ago, and the concept of rainwater harvesting in China may date back 6,000 years. Ruins of cisterns built as early as 2000 B.C. for storing runoff from hillsides for agricultural and domestic purposes are still standing in Israel (Gould and Nissen-Petersen, 1999).

Advantages and benefits of rainwater harvesting are numerous (Krishna, 2003).

- The water is free; the only cost is for collection and use.
- The end use of harvested water is located close to the source, eliminating the need for complex and costly distribution systems.
- Rainwater provides a water source when groundwater is unacceptable or unavailable, or it can augment limited groundwater supplies.
- The zero hardness of rainwater helps prevent scale on appliances, extending their use; rainwater eliminates the need for a water softener and the salts added during the softening process.
- Rainwater is sodium-free, important for persons on low-sodium diets.
- Rainwater is superior for landscape irrigation.
- Rainwater harvesting reduces flow to stormwater drains and also reduces non-point source pollution.
- Rainwater harvesting helps utilities reduce the summer demand peak and delay expansion of existing water treatment plants.
- Rainwater harvesting reduces consumers' utility bills.

Perhaps one of the most interesting aspects of rainwater harvesting is learning about the methods of capture, storage, and use of this natural resource at the place it occurs. This natural synergy excludes at least a portion of water use from the water distribution infrastructure: the centralized treatment facility, storage structures, pumps, mains, and laterals.

Rainwater harvesting also includes land-based systems with man-made landscape features to channel and concentrate rainwater in either storage basins or planted areas.

When assessing the health risks of drinking rainwater, consider the path taken by the raindrop through a watershed into a reservoir, through public drinking water treatment and distribution systems to the end user. Being the universal solvent, water absorbs contaminants and minerals on its

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travels to the reservoir. While in residence in the reservoir, the water can come in contact with all kinds of foreign materials: oil, animal wastes, chemical and pharmaceutical wastes, organic compounds, industrial outflows, and trash. It is the job of the water treatment plant to remove harmful contaminants and to kill pathogens. Unfortunately, when chlorine is used for disinfection, it also degrades into disinfection by-products, notably trihalomethanes, which may pose health risks. In contrast, the raindrop harvested on site will travel down a roof via a gutter to a storage tank. Before it can be used for drinking, it will be treated by a relatively simple process with equipment that occupies about 9 cubic feet of space.

Rainwater harvesting can reduce the volume of storm water, thereby lessening the impact on erosion and decreasing the load on storm sewers. Decreasing storm water volume also helps keep potential storm water pollutants, such as pesticides, fertilizers, and petroleum products, out of rivers and groundwater.

But along with the independence of rainwater harvesting systems comes the inherent responsibility of operation and maintenance. For all systems, this responsibility includes purging the first-flush system, regularly cleaning roof washers and tanks, maintaining pumps, and filtering water. For potable systems, responsibilities include all of the above, and the owner must replace cartridge filters and maintain disinfection equipment on schedule, arrange to have water tested, and monitor tank levels. Rainwater used for drinking should be tested, at a minimum, for pathogens.

Rainwater harvesting, in its essence, is the collection, conveyance, and storage of rainwater. The scope, method, technologies, system complexity, purpose, and end uses vary from rain barrels for garden irrigation in urban areas, to large-scale collection of rainwater for all domestic uses. Some examples are summarized below:

- For supplemental irrigation water, the Wells Branch Municipal Utility District in North Austin captures rainwater, along with air conditioning condensate, from a new 10,000-square-foot recreation center into a 37,000-gallon tank to serve as irrigation water for a 12-acre municipal park with soccer fields and offices.
- The Lady Bird Johnson Wildflower Research Center in Austin, Texas, harvests 300,000 gallons of rainwater annually from almost 19,000 square feet of roof collection area for irrigation of its native plant landscapes. A 6,000-gallon stone cistern and its arching stone aqueduct form the distinctive entry to the research center.
- The Advanced Micro Devices semiconductor fabrication plant in Austin, Texas, does not use utility-supplied water for irrigation, saving $1.5 million per year by relying on captured rainwater and collected groundwater.
- Reynolds Metals in Ingleside, Texas, uses stormwater captured in containment basins as process water in its metal-processing plant, greatly offsetting the volume of purchased water.
- The city of Columbia, Nuevo León, Mexico, is in the planning stages of developing rainwater as the basis for the city's water supply for new

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growth areas, with large industrial developments being plumbed for storage and catchment.

- On small volcanic or coral islands, rainwater harvesting is often the only option for public water supply, as watersheds are too small to create a major river, and groundwater is either nonexistent or contaminated with salt water. Bermuda, the U.S. Virgin Islands, and other Caribbean islands require cisterns to be included with all new construction.

In Central Texas, more than 400 full-scale rainwater harvesting systems have been installed by professional companies, and more than 6,000 rain barrels have been installed through the City of Austin's incentive program in the past decade. Countless "do-it-yourselfers" have installed systems over the same time period.

An estimated 100,000 residential rainwater harvesting systems are in use in the United States and its territories (Lye, 2002). More are being installed by the urban home gardener seeking healthier plants, the weekend cabin owner, and the homeowner intent upon the "green" building practices – all seeking a sustainable, high-quality water source. Rainwater harvesting is also recognized as an important water-conserving measure, and is best implemented in conjunction with other efficiency measures in and outside of the home.

Harvested rainwater may also help some Texas communities close the gap between supply and demand projected by the Texas Water Development Board (TWDB), as the state's population nearly doubles between 2000 and 2050 (Texas Water Development Board, 2002).

In fact, rainwater harvesting is encouraged by Austin and San Antonio water utilities as a means of conserving water. The State of Texas also offers financial incentives for rainwater harvesting systems. Senate Bill 2 of the 77th Legislature exempts rainwater harvesting equipment from sales tax, and allows local governments to exempt rainwater harvesting systems from ad valorem (property) taxes.

Rainwater harvesting systems can be as simple as a rain barrel for garden irrigation at the end of a downspout, or as complex as a domestic potable system or a multiple end-use system at a large corporate campus.

Rainwater harvesting is practical only when the volume and frequency of rainfall and size of the catchment surface can generate sufficient water for the intended purpose.

From a financial perspective, the installation and maintenance costs of a rainwater harvesting system for potable water cannot compete with water supplied by a central utility, but is often cost-competitive with installation of a well in rural settings.

With a very large catchment surface, such as that of big commercial building, the volume of rainwater, when captured and stored, can cost-effectively serve several end uses, such as landscape irrigation and toilet flushing.

Some commercial and industrial buildings augment rainwater with condensate from air conditioning systems. During hot, humid months, warm, moisture-laden air passing over the cooling coils of a residential air conditioner can produce 10 or more gallons per day of water. Industrial facilities produce thousands of gallons

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per day of condensate. An advantage of condensate capture is that its maximum production occurs during the hottest month of the year, when irrigation need is greatest. Most systems pipe condensate into the rainwater cistern for storage.

The depletion of groundwater sources, the poor quality of some groundwater, high tap fees for isolated properties, the flexibility of rainwater harvesting systems, and modern methods of treatment provide excellent reasons to harvest rainwater for domestic use.

The scope of this manual is to serve as a primer in the basics of residential and small-scale commercial rainwater harvesting systems design. It is intended to serve as a first step in thinking about options for implementing rainwater harvesting systems, as well as advantages and constraints.

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Chapter 2
Rainwater Harvesting System Components

Rainwater harvesting is the capture, diversion, and storage of rainwater for a number of different purposes including landscape irrigation, drinking and domestic use, aquifer recharge, and stormwater abatement.

In a residential or small-scale application, rainwater harvesting can be as simple as channeling rain running off an unguttered roof to a planted landscape area via contoured landscape. To prevent erosion on sloped surfaces, a bermed concave holding area down slope can store water for direct use by turfgrass or plants (Waterfall, 1998). More complex systems include gutters, pipes, storage tanks or cisterns, filtering, pump(s), and water treatment for potable use.

This chapter focuses on residential or small-scale commercial systems, for both irrigation and potable use.

The local health department and city building code officer should be consulted concerning safe, sanitary operations and construction of these systems.

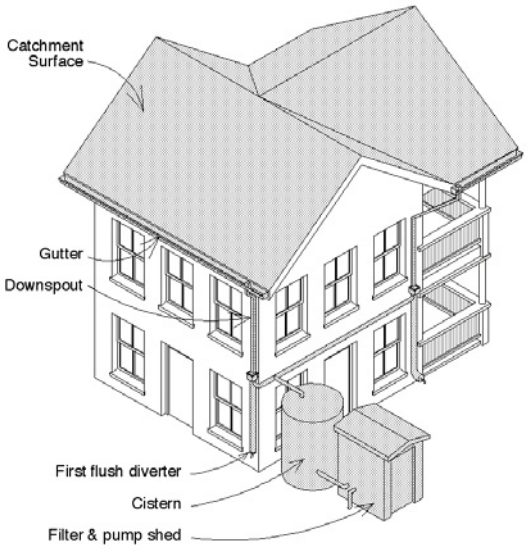

Figure 2-1. Typical rainwater harvesting installation

Basic Components

Regardless of the complexity of the system, the domestic rainwater harvesting system (Figure 2-1) comprises six basic components:

- Catchment surface: the collection surface from which rainfall runs off
- Gutters and downspouts: channel water from the roof to the tank
- Leaf screens, first-flush diverters, and roof washers: components which remove debris and dust from the captured rainwater before it goes to the tank
- One or more storage tanks, also called cisterns
- Delivery system: gravity-fed or pumped to the end use
- Treatment/purification: for potable systems, filters and other methods to make the water safe to drink

The Catchment Surface

The roof of a building or house is the obvious first choice for catchment. For additional capacity, an open-sided barn – called a rain barn or pole barn – can be built. Water tanks and other rainwater system equipment, such as pumps and filters, as well as vehicles, bicycles, and gardening tools, can be stored under the barn.

Water quality from different roof catchments is a function of the type of roof material, climatic conditions, and

the surrounding environment (Vasudevan, 2002).

Metal

The quantity of rainwater that can be collected from a roof is in part a function of the roof texture: the smoother the better. A commonly used roofing material for rainwater harvesting is sold under the trade name Galvalume®, a 55 percent aluminum/45 percent zinc alloy-coated sheet steel. Galvalume® is also available with a baked enamel coating, or it can be painted with epoxy paint.

Some caution should be exercised regarding roof components. Roofs with copper flashings can cause discoloration of porcelain fixtures.

Clay/concrete tile

Clay and concrete tiles are both porous. Easily available materials are suitable for potable or nonpotable systems, but may contribute to as much as a 10-percent loss due to texture, inefficient flow, or evaporation. To reduce water loss, tiles can be painted or coated with a sealant. There is some chance of toxins leaching from the tile sealant or paint, but this roof surface is safer when painted with a special sealant or paint to prevent bacterial growth on porous materials.

Composite or asphalt shingle

Due to leaching of toxins, composite shingles are not appropriate for potable systems, but can be used to collect water for irrigation. Composite roofs have an approximated 10-percent loss due to inefficient flow or evaporation (Radlet and Radlet, 2004).

Others

Wood shingle, tar, and gravel. These roofing materials are rare, and the water harvested is usually suitable only for irrigation due to leaching of compounds.

Slate. Slate's smoothness makes it ideal for a catchment surface for potable use, assuming no toxic sealant is used; however, cost considerations may preclude its use.

Gutters and Downspouts

Gutters are installed to capture rainwater running off the eaves of a building. Some gutter installers can provide continuous or seamless gutters.

For potable water systems, lead cannot be used as gutter solder, as is sometimes the case in older metal gutters. The slightly acidic quality of rain could dissolve lead and thus contaminate the water supply.

The most common materials for gutters and downspouts are half-round PVC, vinyl, pipe, seamless aluminum, and galvanized steel.

Seamless aluminum gutters are usually installed by professionals, and, therefore, are more expensive than other options.

Regardless of material, other necessary components in addition to the horizontal gutters are the drop outlet, which routes water from the gutters downward and at least two 45-degree elbows which allow the downspout pipe to snug to the side of the house. Additional components include the hardware, brackets, and straps to fasten the gutters and downspout to the fascia and the wall.

Gutter Sizing and Installation

When using the roof of a house as a catchment surface, it is important to consider that many roofs consist of one or more roof "valleys." A roof valley occurs where two roof planes meet. This is most common and easy to visualize

when considering a house plan with an "L" or "T" configuration. A roof valley concentrates rainfall runoff from two roof planes before the collected rain reaches a gutter. Depending on the size of roof areas terminating in a roof valley, the slope of the roofs, and the intensity of rainfall, the portion of gutter located where the valley water leaves the eave of the roof may not be able to capture all the water at that point, resulting in spillage or overrunning.

Besides the presence of one or more roof valleys, other factors that may result in overrunning of gutters include an inadequate number of downspouts, excessively long roof distances from ridge to eave, steep roof slopes, and inadequate gutter maintenance. Variables such as these make any gutter sizing rules of thumb difficult to apply. Consult you gutter supplier about your situation with special attention to determine where gutter overrunning areas may occur. At these points along an eave, apply strategies to minimize possible overrunning to improve catchment efficiency. Preventative strategies may include modifications to the size and configuration of gutters and addition of gutter boxes with downspouts and roof diverters near the eave edge.

Gutters should be installed with slope towards the downspout; also the outside face of the gutter should be lower than the inside face to encourage drainage away from the building wall.

Leaf Screens

To remove debris that gathers on the catchment surface, and ensure high quality water for either potable use or to work well without clogging irrigation emitters, a series of filters are necessary. Essentially, mesh screens remove debris both before and after the storage tank. The defense in keeping debris out of a rainwater harvesting system is some type of leaf screen along the gutter or in the downspout.

Depending upon the amount and type of tree litter and dust accumulation, the homeowner may have to experiment to find the method that works best. Leaf screens must be regularly cleaned to be effective. If not maintained, leaf screens can become clogged and prevent rainwater from flowing into a tank. Built-up debris can also harbor bacteria and the products of leaf decay.

Leaf guards are usually ¼-inch mesh screens in wire frames that fit along the length of the gutter. Leaf guards/screens are usually necessary only in locations with tree overhang. Guards with profiles conducive to allowing leaf litter to slide off are also available.

The **funnel-type downspout filter** is made of PVC or galvanized steel fitted with a stainless steel or brass screen. This type of filter offers the advantage of easy accessibility for cleaning. The funnel is cut into the downspout pipe at the same height or slightly higher than the highest water level in the storage tank.

Strainer baskets are spherical cage-like strainers that slip into the drop outlet of the downspout.

A cylinder of rolled screen inserted into the drop outlet serves as another method of filtering debris. The homeowner may need to experiment with various grid sizes, from insect screen to hardware cloth.

Filter socks of nylon mesh can be installed on the PVC pipe at the tank inflow.

First-Flush Diverters

A roof can be a natural collection surface for dust, leaves, blooms, twigs, insect bodies, animal feces, pesticides, and other airborne residues. The first-flush diverter routes the first flow of water from the catchment surface away from the storage tank. The flushed water can be routed to a planted area. While leaf screens remove the larger debris, such as leaves, twigs, and blooms that fall on the roof, the first-flush diverter gives the system a chance to rid itself of the smaller contaminants, such as dust, pollen, and bird and rodent feces.

The simplest first-flush diverter is a PVC standpipe (Figure 2-2). The standpipe fills with water first during a rainfall event; the balance of water is routed to the tank. The standpipe is drained continuously via a pinhole or by leaving the screw closure slightly loose. In any case, cleaning of the standpipe is accomplished by removing the PVC cover with a wrench and removing collected debris after each rainfall event.

There are several other types of first-flush diverters. The ball valve type consists of a floating ball that seals off the top of the diverter pipe (Figure 2-3) when the pipe files with water.

Opinions vary on the volume of rainwater to divert. The number of dry days, amount of debris, and roof surface are all variables to consider.

One rule of thumb for first-flush diversion is to divert a minimum of 10 gallons for every 1,000 square feet of collection surface. However, first-flush volumes vary with the amount of dust on the roof surface, which is a function of the number of dry days, the amount and type of debris, tree overhang, and season.

A preliminary study by Rain Water Harvesting and Waste Water Systems Pty Ltd., a rainwater harvesting component vendor in Australia, recommends that between 13 and 49 gallons be diverted per 1,000 square feet.

The primary reason for the wide variation in estimates is that there is no exact calculation to determine how much initial water needs to be diverted because there are many variables that would determine the effectiveness of washing the contaminants off the collection surface, just as there are many variables determining the make up of the contaminants themselves. For example, the slope and smoothness of the collection surface, the intensity of the rain event, the length of time between events (which adds to the amount of accumulated contaminants), and the nature of the contaminants themselves add to the difficulty of determining just how much rain should be diverted during first flush. In order to effectively wash a collection surface, a rain intensity of one-tenth of an inch of rain per hour is needed to wash a sloped roof. A flat or near-flat collection surface requires 0.18 inches of rain per hour for an effective washing of the surface.

The recommended diversion of first flush ranges from one to two gallons of first-flush diversion for each 100 square feet of collection area. If using a roof for a collection area that drains into gutters, calculate the amount of rainfall area that will be drained into every gutter feeding your system. Remember to calculate the horizontal equivalent of the “roof footprint” when calculating your catchment area. (Please refer to the Figure 4-1 in Chapter 4, Water Balance and System Sizing.) If a gutter receives the quantity of runoff that require multiple downspouts, first-flush

First-Flush Diverters

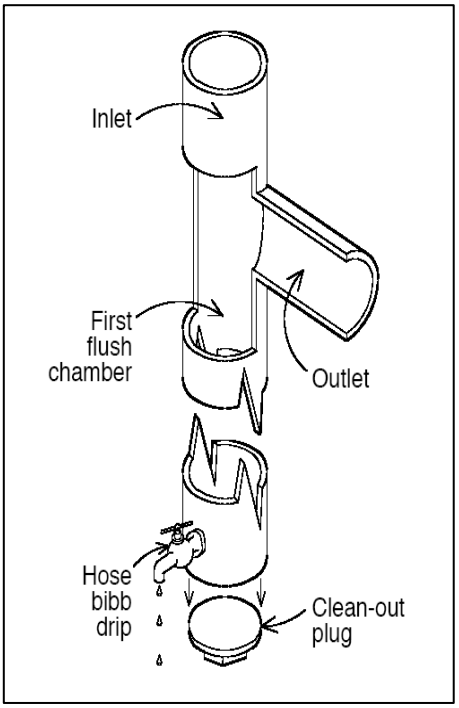

Figure 2-2. Standpipe first-flush diverter

Standpipe

The simplest first-flush diverter is a 6- or 8-inch PVC standpipe (Figure 2-2). The diverter fills with water first, backs up, and then allows water to flow into the main collection piping. These standpipes usually have a cleanout fitting at the bottom, and must be emptied and cleaned out after each rainfall event. The water from the standpipe may be routed to a planted area. A pinhole drilled at the bottom of the pipe or a hose bibb fixture left slightly open (shown) allows water to gradually leak out.

If you are using 3" diameter PVC or similar pipe, allow 33" length of pipe per gallon; 4" diameter pipe needs only 18" of length per gallon; and a little over 8" of 6" diameter pipe is needed to catch a gallon of water.

Standpipe with ball valve

The standpipe with ball valve is a variation of the standpipe filter. The cutaway drawing (Figure 2-3) shows the ball valve. As the chamber fills, the ball floats up and seals on the seat, trapping first-flush water and routing the balance of the water to the tank.

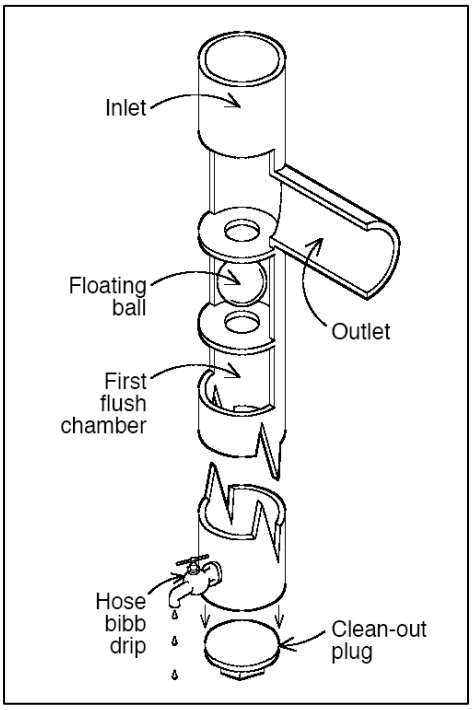

Figure 2-3. Standpipe with ball valve

diversion devices will be required for each downspout.

Roof Washers

The roof washer, placed just ahead of the storage tank, filters small debris for potable systems and also for systems using drip irrigation. Roof washers consist of a tank, usually between 30- and 50-gallon capacity, with leaf strainers and a filter (Figure 2-4). One commercially available roof washer has a 30-micron filter. (A micron, also called a micrometer, is one-millionth of a meter. A 30-micron filter has pores about one-third the diameter of a human hair.)

All roof washers must be cleaned. Without proper maintenance they not only become clogged and restrict the flow of rainwater, but may themselves become breeding grounds for pathogens.

The box roof washer (Figure 2-4) is a commercially available component consisting of a fiberglass box with one or two 30-micron canister filters (handling rainwater from 1,500- and 3,500-square-foot catchments, respectively). The box is placed atop a ladder-like stand beside the tank, from which the system owner accesses the box for cleaning via the ladder. In locations with limited drop, a filter with the canisters oriented horizontally is indicated, with the inlet and outlet of the filter being nearly parallel.

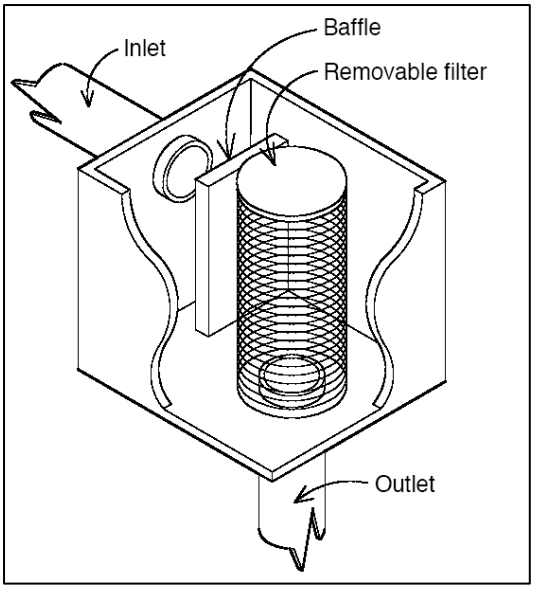

Figure 2-4. Box roof washer

Storage Tanks

The storage tank is the most expensive component of the rainwater harvesting system.

The size of storage tank or cistern is dictated by several variables: the rainwater supply (local precipitation), the demand, the projected length of dry spells without rain, the catchment surface area, aesthetics, personal preference, and budget.

A myriad of variations on storage tanks and cisterns have been used over the centuries and in different geographical regions: earthenware cisterns in pre-biblical times, large pottery containers in Africa, above-ground vinyl-lined swimming pools in Hawaii, concrete or brick cisterns in the central United States, and, common to old homesteads in Texas, galvanized steel tanks and attractive site-built stone-and-mortar cisterns.

For purposes of practicality, this manual will focus on the most common, easily installed, and readily available storage options in Texas, some still functional after a century of use.

Storage tank basics

- Storage tanks must be opaque, either upon purchase or painted later, to inhibit algae growth.

- For potable systems, storage tanks must never have been used to store toxic materials.
- Tanks must be covered and vents screened to discourage mosquito breeding.
- Tanks used for potable systems must be accessible for cleaning.

Storage tank siting

Tanks should be located as close to supply and demand points as possible to reduce the distance water is conveyed. Storage tanks should be protected from direct sunlight, if possible. To ease the load on the pump, tanks should be placed as high as practicable. Of course, the tank inlet must be lower than the lowest downspout from the catchment area. To compensate for friction losses in the trunk line, a difference of a couple of feet is preferable. When converting from well water, or if using a well backup, siting the tanks near the well house facilitates the use of existing plumbing.

Water runoff should not enter septic system drainfields, and any tank overflow and drainage should be routed so that it does not affect the foundation of the tanks or any other structures (Macomber, 2001).

Texas does not have specific rules concerning protection of rainwater systems from possible contamination sources; however, to ensure a safe water supply, underground tanks should be located at least 50 feet away from animal stables or above-ground application of treated wastewater. Also, runoff from tank overflow should not enter septic system drainfields. If supplemental hauled water might be needed, tank placement should also take into consideration accessibility by a water truck, preferably near a driveway or roadway.

Water weighs just over 8 pounds per gallon, so even a relatively small 1,500-gallon tank will weigh 12,400 pounds. A leaning tank may collapse; therefore, tanks should be placed on a stable, level pad. If the bed consists of a stable substrate, such as caliche, a load of sand or pea gravel covering the bed may be sufficient preparation. In some areas, sand or pea gravel over well-compacted soil may be sufficient for a small tank. Otherwise, a concrete pad should be constructed. When the condition of the soil is unknown, enlisting the services of a structural engineer may be in order to ensure the stability of the soil supporting the full cistern weight.

Another consideration is protecting the pad from being undermined by either normal erosion or from the tank overflow. The tank should be positioned such that runoff from other parts of the property or from the tank overflow will not undermine the pad. The pad or bed should be checked after intense rainfall events.

Fiberglass

Fiberglass tanks (Figure 2-5) are built in standard capacities from 50 gallons to 15,000 gallons and in both vertical



Figure 2-5. Two 10,000-gallon fiberglass tanks

cylinder and low-horizontal cylinder configurations.

Fiberglass tanks under 1,000 gallons are expensive for their capacity, so polypropylene might be preferred. Tanks for potable use should have a USDA-approved food-grade resin lining and the tank should be opaque to inhibit algae growth.

The durability of fiberglass tanks has been tested and proven, weathering the elements for years in Texas oil fields. They are easily repaired.

The fittings on fiberglass tanks are an integral part of the tank, eliminating the potential problem of leaking from an aftermarket fitting.

Polypropylene

Polypropylene tanks (Figure 2-6) are commonly sold at farm and ranch supply retailers for all manner of storage uses. Standard tanks must be installed above ground. For buried installation, specially reinforced tanks are necessary to withstand soil expansion and contraction. They are relatively inexpensive and durable, lightweight, and long lasting. Polypropylene tanks are available in capacities from 50 gallons to 10,000 gallons.



Figure 2-6. Low-profile 5,000-gallon polypropylene tanks

Polypropylene tanks do not retain paint well, so it is necessary to find off-the-shelf tanks manufactured with opaque plastic. The fittings of these tanks are aftermarket modifications. Although easy to plumb, the bulkhead fittings might be subject to leakage.

Wood

For aesthetic appeal, a wood tank (Figure 2-7) is often a highly desirable choice for urban and suburban rainwater harvesters.

Wood tanks, similar to wood water towers at railroad depots, were historically made of redwood. Modern wood tanks are usually of pine, cedar, or cypress wrapped with steel tension cables, and lined with plastic. For potable use, a food-grade liner must be used.



Figure 2-7. Installation of a 25,000-gallon Timbertank in Central Texas showing the aesthetic appeal of these wooden tanks

These tanks are available in capacities from 700 to 37,000 gallons, and are site-built by skilled technicians. They can be dismantled and reassembled at a different location.

Metal

Galvanized sheet metal tanks (Figure 2-8) are also an attractive option for the urban or suburban garden. They are available in sizes from 150 to 2,500 gallons, and are lightweight and easy to relocate. Tanks can be lined for potable use. Most tanks are corrugated galvanized steel dipped in hot zinc for corrosion resistance. They are lined with a food-grade liner, usually polyethylene or PVC, or coated on the inside with epoxy paint. The paint, which also extends the life of the metal, must be FDA- and NSF-approved for potability.



Figure 2-8. Galvanized sheet metal tanks are usually fitted with a food-grade plastic liner.

Concrete

Concrete tanks are either poured in place or prefabricated (Figure 2-9). They can be constructed above ground or below ground. Poured-in-place tanks can be integrated into new construction under a patio, or a basement, and their placement is considered permanent.

A type of concrete tank familiar to residents of the Texas Hill Country is constructed of stacked rings with sealant around the joints. Other types of prefabricated concrete tanks include new septic tanks, conduit stood on end, and concrete blocks. These tanks are fabricated off-site and dropped into place.

Concrete may be prone to cracking and leaking, especially in underground tanks in clay soil. Leaks can be easily repaired although the tank may need to be drained to make the repair. Involving the expertise of a structural engineer to determine the size and spacing of reinforcing steel to match the structural loads of a poured-in-place concrete cistern is highly recommended. A product that repairs leaks in concrete tanks, Xypex™, is now also available and approved for potable use.



Figure 2-9. Concrete tank fabricated from stacking rings of concrete

One possible advantage of concrete tanks is a desirable taste imparted to the water by calcium in the concrete being dissolved by the slightly acidic

rainwater. For potable systems, it is essential that the interior of the tank be plastered with a high-quality material approved for potable use.

Ferrocement

Ferrocement is a low-cost steel and mortar composite material. For purposes of this manual, Gunite™ and Shotcrete™ type will be classified as ferrocements. Both involve application of the concrete and mortar under pressure from a gun. Gunite, the dry-gun spray method in which the dry mortar is mixed with water at the nozzle, is familiar for its use in swimming pool construction. Shotcrete uses a similar application, but the mixture is a prepared slurry. Both methods are cost-effective for larger storage tanks. Tanks made of Gunite and Shotcrete consist of an armature made from a grid of steel reinforcing rods tied together with wire around which is placed a wire form with closely spaced layers of mesh, such as expanded metal lath. A concrete-sand-water mixture is applied over the form and allowed to cure. It is important to ensure that the ferrocement mix does not contain any toxic constituents. Some sources recommend painting above-ground tanks white to reflect the sun's rays, reduce evaporation, and keep the water cool.



Figure 2-10. Ferrocement tanks, such as this one, are built in place using a metal armature and a sprayed-on cement.

Ferrocement structures (Figure 2-10) have commonly been used for water storage construction in developing countries due to low cost and availability of materials. Small cracks and leaks can easily be repaired with a mixture of cement and water, which is applied where wet spots appear on the tank's exterior. Because walls can be as thin as 1 inch, a ferrocement tank uses less material than concrete tanks, and thus can be less expensive. As with poured-in-place concrete construction, assistance from a structural engineer is encouraged.

In-ground polypropylene

In-ground tanks are more costly to install for two reasons: the cost of excavation and the cost of a more heavily reinforced tank needed if the tank is to be buried more than 2-feet deep in well-drained soils. Burying a tank in clay is not recommended because of the expansion/contraction cycles of clay soil. For deeper installation, the walls of poly tanks must be manufactured thicker and sometimes an interior bracing structure must be added. Tanks are buried for aesthetic or space-saving reasons.

Table 2-1 provides some values to assist in planning an appropriate-sized pad and cistern to meet your water needs and your available space. Many owners of rainwater harvesting systems use multiple smaller tanks in sequence to meet their storage capacity needs. This has the advantage of allowing the owner to empty a tank in order to perform maintenance on one tank at a time without losing all water in storage.

A summary of cistern materials, their features, and some words of caution are provided in Table 2-2 to assist the prospective harvester in choosing the

appropriate cistern type. Prior to making your final selection, consulting with an architect, engineer, or professional rainwater installer is recommended to ensure the right choice for your situation.

Table 2-1. Round Cistern Capacity (Gallons)

Height (feet)	6-foot Diameter	12-foot Diameter	18-foot Diameter
6	1,269	5,076	11,421
8	1,692	6,768	15,227
10	2,115	8,460	19,034
12	2,538	10,152	22,841
14	2,961	11,844	26,648
16	3,384	13,535	30,455
18	3,807	15,227	34,262
20	4,230	16,919	38,069

Rain barrel

One of the simplest rainwater installations, and a practical choice for urban dwellers, is the 50- to 75-gallon drum used as a rain barrel for irrigation of plant beds. Some commercially available rain barrels are manufactured with overflow ports linking the primary barrel to a second barrel. A screen trap at the water entry point discourages mosquito breeding. A food-grade plastic barrel used for bulk liquid storage in restaurants and grocery stores can be fitted with a bulkhead fitting and spigot for garden watering. Other options include a submersible pump or jet pump.

Table 2-2. Cistern Types

MATERIAL	FEATURES	CAUTION
Plastics		
Trash cans (20-50 gallon)	commercially available; inexpensive	use only new cans
Fiberglass	commercially available; alterable and moveable	must be sited on smooth, solid, level footing
Polyethylene/polypropylene	commercially available; alterable and moveable	UV-degradable, must be painted or tinted
Metals		
Steel drums (55-gallon)	commercially available; alterable and moveable	verify prior to use for toxics; prone to corrosion an rust;
Galvanized steel tanks	commercially available; alterable and moveable	possibly corrosion and rust; must be lined for potable use
Concrete and Masonry		
Ferrocement	durable and immoveable	potential to crack and fail
Stone, concrete block	durable and immoveable	difficult to maintain
Monolithic/Poured-in-place	durable and immoveable	potential to crack
Wood		
Redwood, fir, cypress	attractive, durable, can be disassembled and moved	expensive

Adapted from *Texas Guide to Rainwater Harvesting, Second Edition*, Texas Water Development Board, 1997.

Pressure Tanks and Pumps

The laws of physics and the topography of most homesteads usually demand a pump and pressure tank between water storage and treatment, and the house or end use. Standard municipal water pressure is 40 pounds per square inch (psi) to 60 psi. Many home appliances – clothes washers, dishwashers, hot-water-on-demand water heaters – require 20–30 psi for proper operation. Even some drip irrigation system need 20 psi for proper irrigation. Water gains 1 psi of pressure for every 2.31 feet of vertical rise. So for gravity flow through a 1-inch pipe at 40 psi, the storage tanks would

have to be more than 90 feet above the house.

Since this elevation separation is rarely practical or even desirable, two ways to achieve proper household water pressure are (1) a pump, pressure tank, pressure switch, and check valve (familiar to well owners), or (2) an on-demand pump.

Pumps are designed to push water rather than to pull it. Therefore, the system should be designed with the pumps at the same level and as close to the storage tanks as possible.

Pump systems draw water from the storage tanks, pressurize it, and store it in a pressure tank until needed. The typical pump-and-pressure tank arrangement consists of a ¾- or 1-horsepower pump, usually a shallow well jet pump or a multistage centrifugal pump, the check valve, and pressure switch. A one-way check valve between the storage tank and the pump prevents pressurized water from being returned to the tank. The pressure switch regulates operation of the pressure tank. The pressure tank, with a typical capacity of 40 gallons, maintains pressure throughout the system. When the pressure tank reaches a preset threshold, the pressure switch cuts off power to the pump. When there is demand from the household, the pressure switch detects the drop in pressure in the tank and activates the pump, drawing more water into the pressure tank.

The cistern float filter (Figure 2-11) allows the pump to draw water from the storage tank from between 10 and 16 inches below the surface. Water at this level is cleaner and fresher than water closer to the bottom of the tank. The device has a 60-micron filter. An external suction pump, connected via a flexible hose, draws water through the filter.

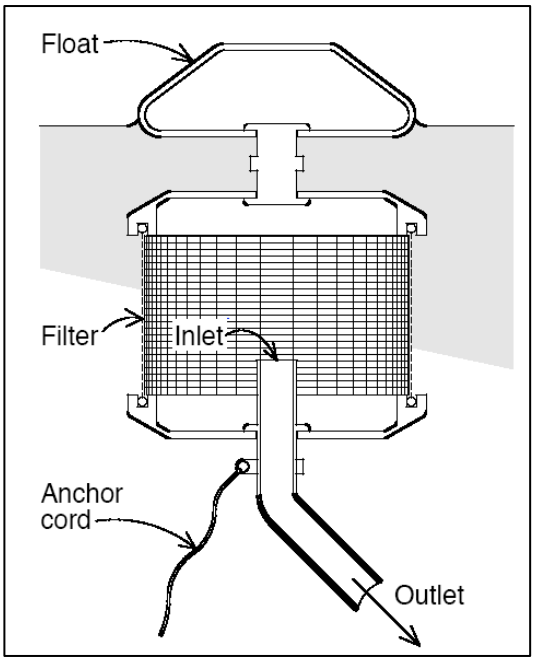

Figure 2-11. Cistern float filter

On-demand pump

The new on-demand pumps eliminate the need for a pressure tank. These pumps combine a pump, motor, controller, check valve, and pressure tank function all in one unit. They are self-priming and are built with a check valve incorporated into the suction port. Figure 2-12 shows a typical installation of an on-demand pump and a 5-micron fiber filter, 3-micron activated charcoal filter, and an ultraviolet lamp. Unlike conventional pumps, on-demand pumps are designed to activate in response to a demand, eliminating the need, cost, and space of a pressure tank. In addition, some on-demand pumps are specifically designed to be used with rainwater.

Treatment and Disinfection Equipment

For a nonpotable system used for hose irrigation, if tree overhang is present, leaf screens on gutters and a roof washer

diverting 10 gallons for every 1,000 square feet of roof is sufficient. If drip irrigation is planned, however, sediment filtration may be necessary to prevent clogging of emitters. As standards differ, the drip irrigation manufacturer or vendor should be contacted regarding filtering of water.

For potable water systems, treatment beyond the leaf screen and roof washer is necessary to remove sediment and disease-causing pathogens from stored water. Treatment generally consists of filtration and disinfection processes in series before distribution to ensure health and safety.

Cartridge Filters and Ultraviolet (UV) Light

The most popular disinfection array in Texas is two in-line sediment filters – the 5-micron fiber cartridge filter followed by the 3-micron activated charcoal cartridge filter – followed by ultraviolet light. This disinfection set-up is placed after the pressure tank or after the on-demand pump.

It is important to note that cartridge filters must be replaced regularly. Otherwise, the filters can actually harbor bacteria and their food supply. The 5-micron filter mechanically removes suspended particles and dust. The 3-micron filter mechanically traps microscopic particles while smaller organic molecules are absorbed by the activated surface. In theory, activated charcoal can absorb objectionable odors and tastes, and even some protozoa and cysts (Macomber, 2001).

Filters can be arrayed in parallel for greater water flow. In other words, two 5-micron fiber filters can be stacked in one large cartridge followed by two 3-micron activated charcoal filters in another cartridge. The ultraviolet (UV) light must be rated to accommodate the increased flow.



Figure 2-12. Typical treatment installation of an on-demand pump, 5-micron fiber filter, 3-micron activated charcoal filter, and an ultraviolet lamp (top).

NSF International (National Sanitation Foundation) is an independent testing and certification organization. Filter performance can be researched using a simple search feature by model or manufacturer on the NSF website. (See References.) It is best to purchase NSF-certified equipment.

Maintenance of the UV light involves cleaning of the quartz sleeve. Many UV lights are designed with an integral wiper unit. Manual cleaning of the sleeve is not recommended due to the possibility of breakage.

UV lamps are rated in gallons per minute. For single 5-micron and 3-micron in-line filters, a UV light rated at 12 gallons per minute is sufficient. For

filters in parallel installation, a UV light rated for a higher flow is needed. In-line flow restrictors can match flow to the UV light rating.

UV lights must be replaced after a maximum of 10,000 hours of operation. Some lights come with alarms warning of diminished intensity.

Ozone

Chemically, ozone is O_3: essentially a more reactive form of molecular oxygen made up of three atoms of oxygen. Ozone acts as a powerful oxidizing agent to reduce color, to eliminate foul odors, and to reduce total organic carbon in water. For disinfection purposes, an ozone generator forces ozone into storage tanks through rings or a diffuser stone. Ozone is unstable and reacts quickly to revert to O_2 and dissipates through the atmosphere within 15 minutes.

A rainwater harvesting system owner in Fort Worth uses an ozone generator to keep the water in his 25,000 gallons of storage "fresh" by circulating ozone through the five tanks at night. A standard sprinkler controller switches the ozone feed from tank to tank.

Membrane Filtration (Reverse Osmosis and Nanofiltration)

Membrane filtration, such as reverse osmosis and nanofiltration work by forcing water under high pressure through a semipermeable membrane to filter dissolved solids and salts, both of which are in very low concentrations in rainwater. Membrane processes, however, have been known empirically to produce "sweeter" water, perhaps by filtering out dissolved metals from plumbing.

A certain amount of feed water is lost in any membrane filtration process. Reject water, referred to as "brine," containing a concentrate of the contaminants filtered from the feed water, is discharged. The amount of reject water, however, is directly proportional to the purity of the feed water. Rainwater, as a purer water source to begin with, would generate less brine. Reverse osmosis membranes must be changed before they are fouled by contaminants.

Reverse osmosis (RO) equipment for household use is commercially available from home improvement stores such as Lowe's and Home Depot.

Chlorination

For those choosing to disinfect with chlorine, automatic self-dosing systems are available. A chlorine pump injects chlorine into the water as it enters the house. In this system, appropriate contact time is critical to kill bacteria. A practical chlorine contact time is usually from 2 minutes to 5 minutes with a free chlorine residual of 2 parts per million (ppm). The time length is based on water pH, temperature, and amount of bacteria. Contact time increases with pH and decreases with temperature. K values (contact times) are shown in Table 3-3.

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Chapter 3
Water Quality and Treatment

The raindrop as it falls from the cloud is soft, and is among the cleanest of water sources. Use of captured rainwater offers several advantages.

Rainwater is sodium-free, a benefit for persons on restricted sodium diets.

Irrigation with captured rainwater promotes healthy plant growth. Also, being soft water, rainwater extends the life of appliances as it does not form scale or mineral deposits.

The environment, the catchment surface, and the storage tanks affect the quality of harvested rainwater. With minimal treatment and adequate care of the system, however, rainfall can be used as potable water, as well as for irrigation.

The falling raindrop acquires slight acidity as it dissolves carbon dioxide and nitrogen. Contaminants captured by the rain from the catchment surface and storage tanks are of concern for those intending to use rainwater as their potable water source. The catchment area may have dust, dirt, fecal matter from birds and small animals, and plant debris such as leaves and twigs. Rainwater intended for domestic potable use must be treated using appropriate filtration and disinfection equipment, discussed in Chapter 2, Rainwater Harvesting System Components.

Total dissolved solids (TDS) in rainwater, originating from particulate matter suspended in the atmosphere, range from 2 milligrams per liter (mg/l or ppm)[1] to 20 mg/l across Texas, compared with municipal water TDS ranges of 100 ppm to more than 800 ppm.

The sodium content of some municipal water ranges from 10 parts per million (ppm) to as high as 250 ppm. Rainwater intended solely for outdoor irrigation may need no treatment at all except for a screen between the catchment surface and downspout to keep debris out of the tank, and, if the tank is to supply a drip irrigation system, a small-pore filter at the tank outlet to keep emitters from clogging.

Considerations for the Rainwater Harvesting System Owner

It is worth noting that owners of rainwater harvesting systems who supply all domestic needs essentially become owners of their "water supply systems," responsible for routine maintenance, including filter and lamp replacement, leak repair, monitoring of water quality, and system upgrades.

The rainwater harvesting system owner is responsible for both water supply and water quality. Maintenance of a rainwater harvesting system is an ongoing periodic duty, to include:

- monitoring tank levels,
- cleaning gutters and first-flush devices,
- repairing leaks,
- repairing and maintaining the system, and
- adopting efficient water use practices.

In addition, owners of potable systems must adopt a regimen of:

- changing out filters regularly,

[1] For dilute aqueous solutions mg/l is approximately equal to ppm because a liter of water weighs one kilogram.

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- maintaining disinfection equipment, such as cleaning and replacing ultraviolet lamps, and
- regularly testing water quality.

Water Quality Standards

No federal or state standards exist currently for harvested rainwater quality, although state standards may be developed in 2006.

The latest list of drinking water requirements can be found on the United States Environmental Protection Agency's website. (See References.) The next section discusses the potential vectors by which contaminants get into rainwater. For those intending to harvest rainwater for potable use, the microbiological contaminants *E. coli*, *Cryptosporidium*, *Giardia lamblia*, total coliforms, legionella, fecal coliforms, and viruses, are probably of greatest concern, and rainwater should be tested to ensure that none of them are found (Lye, 2002). County health department and city building code staff should also be consulted concerning safe, sanitary operations and construction of rainwater harvesting systems.

Factors Affecting Water Quality

pH (acidity/alkalinity)

As a raindrop falls and comes in contact with the atmosphere, it dissolves naturally occurring carbon dioxide to form a weak acid. The resultant pH is about 5.7, whereas a pH of 7.0 is neutral. (A slight buffering using 1 tablespoon of baking soda to 100 gallons of water in the tank will neutralize the acid, if desired. Also, a concrete storage tank will impart a slight alkalinity to the water.) While Northeast Texas tends to experience an even lower pH (more acidic) rainwater than in other parts of the state, acid rain is not considered a serious concern in Texas.

Particulate matter

Particulate matter refers to smoke, dust, and soot suspended in the air. Fine particulates can be emitted by industrial and residential combustion, vehicle exhaust, agricultural controlled burns, and sandstorms. As rainwater falls through the atmosphere, it can incorporate these contaminants.

Particulate matter is generally not a concern for rainwater harvesting in Texas. However, if you wish, geographic data on particulate matter can be accessed at the Air Quality Monitoring web page of the Texas Commission on Environmental Quality (TCEQ). (See References.)

Chemical compounds

Information on chemical constituents can also be found on the TCEQ Air Quality website. (See References.)

In agricultural areas, rainwater could have a higher concentration of nitrates due to fertilizer residue in the atmosphere (Thomas and Grenne, 1993). Pesticide residues from crop dusting in agricultural areas may also be present.

Also, dust derived from calcium-rich soils in Central and West Texas can add 1 mg/l to 2 mg/l of hardness to the water. Hard water has a high mineral content, usually consisting of calcium and magnesium in the form of carbonates.

In industrial areas, rainwater samples can have slightly higher values of suspended solids concentration and turbidity due to the greater amount of particulate matter in the air (Thomas and Grenne, 1993).

Catchment surface

When rainwater comes in contact with a catchment surface, it can wash bacteria, molds, algae, fecal matter, other organic matter, and/or dust into storage tanks. The longer the span of continuous number of dry days (days without rainfall), the more catchment debris is washed off the roof by a rainfall event (Thomas and Grenne, 1993; Vasudevan, 2002).

Tanks

The more filtering of rainwater prior to the storage tanks, the less sedimentation and introduction of organic matter will occur within the tanks. Gutter screens, first-flush diverters, roof washers, and other types of pre-tank filters are discussed in Chapter 2. Sedimentation reduces the capacity of tanks, and the breakdown of plant and animal matter may affect the color and taste of water, in addition to providing nutrients for microorganisms.

Most storage tanks are equipped with manholes to allow access for cleaning. Sediment and sludge can be pumped out or siphoned out using hose with an inverted funnel at one end without draining the tank annually.

Multiple linked tanks allow one tank to be taken off line for cleaning by closing the valve on the linking pipe between tanks.

Water Treatment

The cleanliness of the roof in a rainwater harvesting system most directly affects the quality of the captured water. The cleaner the roof, the less strain is placed on the treatment equipment. It is advisable that overhanging branches be cut away both to avoid tree litter and to deny access to the roof by rodents and lizards.

For potable systems, a plain galvanized roof or a metal roof with epoxy or latex paint is recommended. Composite or asphalt shingles are not advisable, as toxic components can be leached out by rainwater. See Chapter 2 for more information on roofing material.

To improve water quality, several treatment methods are discussed. It is the responsibility of the individual installer or homeowner to weigh the advantages and disadvantages of each method for appropriateness for the individual situation. A synopsis of treatment techniques is shown in Table 3-1. A discussion of the equipment is included in Chapter 2.

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Table 3-1. Treatment Techniques

METHOD	LOCATION	RESULT
Treatment		
Screening		
Leaf screens and strainers	gutters and downspouts	prevent leaves and other debris from entering tank
Settling		
Sedimentation	within tank	settles out particulate matter
Activated charcoal	before tap	removes chlorine*
Filtering		
Roof washer	before tank	eliminates suspended material
In-line/multi-cartridge	after pump	sieves sediment
Activated charcoal	after sediment filter	removes chlorine, improves taste
Slow sand	separate tank	traps particulate matter
Microbiological treatment /Disinfection		
Boiling/distilling	before use	kills microorganisms
Chemical treatments (Chlorine or Iodine)	within tank or at pump (liquid, tablet, or granular) before activated charcoal filter	kills microorganisms
Ultraviolet light	after activated charcoal filter, before tap	kills microorganisms
Ozonation	after activated charcoal filter, before tap	kills microorganisms
Nanofiltration	before use; polymer membrane (pores 10^{-3} to 10^{-6} inch)	removes molecules
Reverse osmosis	before use: polymer membrane (pores 10^{-9} inch)	removes ions (contaminants and microorganisms)
*Should be used if chlorine has been used as a disinfectant.		

Adapted from *Texas Guide to Rainwater Harvesting, Second Edition*, Texas Water Development Board, 1997.

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Chlorination

Chlorination is mentioned here more for its historical value than for practical application. Chlorine has been used to disinfect public drinking water since 1908, and it is still used extensively by rainwater harvesters in Hawaii, the U.S. Virgin Islands, and in older rainwater harvesting systems in Kentucky and Ohio. Chlorine must be present in a concentration of 1 ppm to achieve disinfection. Liquid chlorine, in the form of laundry bleach, usually has 6 percent available sodium hypochlorite. For disinfection purposes, 2 fluid ounces (¼ cup) must be added per 1,000 gallons of rainwater. Household bleach products, however, are not labeled for use in water treatment by the Food and Drug Administration. A purer form of chlorine, which comes in solid form for swimming pool disinfection, is calcium hypochlorite, usually with 75 percent available chlorine. At that strength, 0.85 ounces by weight in 1,000 gallons of water would result in a level of 1 ppm. In either case, it is a good idea to carefully dilute the chlorine source in a bucket of water, and then stir with a clean paddle to hasten mixing (Macomber, 2001). Chlorine contact times are show in Table 3-2.

The use of chlorine for disinfection presents a few drawbacks. Chlorine combines with decaying organic matter in water to form trihalomethanes. This disinfection by-product has been found to cause cancer in laboratory rats. Also, some users may find the taste and smell of chlorine objectionable. To address this concern, an activated carbon filter may be used to help remove chlorine.

Chlorine does not kill *Giardia* or *Cryptosporidium*, which are cysts protected by their outer shells. Persons with weakened or compromised immune systems are particularly susceptible to these maladies. To filter out *Giardia* and *Cryptosporidum* cysts, an absolute 1-micron filter, certified by the NSF, is needed (Macomber, 2001).

Table 3-2. Contact Time with Chlorine

Water pH	Water temperature		
	50 F or warmer	45 F	40 F or colder
	Contact time in minutes		
6.0	3	4	5
6.5	4	5	6
7.0	8	10	12
7.5	12	15	18
8.0	16	20	24

UV Light

UV light has been used in Europe for disinfection of water since the early 1900s, and its use has now become common practice in U.S. utilities. Bacteria, virus, and cysts are killed by exposure to UV light. The water must go

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through sediment filtration before the ultraviolet light treatment because pathogens can be shadowed from the UV light by suspended particles in the water. In water with very high bacterial counts, some bacteria will be shielded by the bodies of other bacteria cells.

UV lights are benign: they disinfect without leaving behind any disinfection by-products. They use minimal power for operation. One should follow manufacturer's recommendations for replacement of bulbs.

Testing

Harvested rainwater should be tested before drinking and periodically thereafter. Harvested rainwater should be tested both before and after treatment to ensure treatment is working. It is advisable to test water quarterly at a minimum, if used for drinking.

Harvested rainwater can be tested by a commercial analytical laboratory, the county health departments of many Texas counties, or the Texas Department of Health.

Before capturing rainwater samples for testing, contact the testing entity first to become informed of requirements for container type and cleanliness, sample volume, number of samples needed, and time constraints for return of the sample.

For instance, for total coliform testing, water must usually be captured in a sterile container issued by the testing entity and returned within a maximum of 30 to 36 hours. Testing for pH, performed by commercial analytical laboratories must be done on site; other tests are less time-critical.

A list of county health departments that will test for total and fecal coliform can be found on the Texas Department of State Health Services (TDSHS) website. (See References.) The testing fee is usually between $15 and $25. Homeowners should contact the health department prior to sample collection to procure a collection kit and to learn the proper methods for a grab sample or a faucet sample.

Texas Department of State Health Services will test for fecal coliforms for a fee of $20 per sample. (See References.) A collection kit can be ordered from TDSHS at (512) 458-7598.

Commercial laboratories are listed in telephone Yellow Pages under Laboratories–Analytical & Testing. For a fee, the lab will test water for pathogens. For an additional fee, labs will test for other contaminants, such as metals and pesticides.

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Chapter 4
Water Balance and System Sizing

The basic rule for sizing any rainwater harvesting system is that the volume of water that can be captured and stored (the supply) must equal or exceed the volume of water used (the demand).

The variables of rainfall and water demand determine the relationship between required catchment area and storage capacity. In some cases, it may be necessary to increase catchment surface area by addition of a rain barn or outbuilding to capture enough rainwater to meet demand. Cistern capacity must be sufficient to store enough water to see the system and its users through the longest expected interval without rain.

The following sections describe ways to determine the amount of rainfall, the estimated demand, and how much storage capacity is needed to provide an adequate water supply.

Intended End Use

The first decision in rainwater harvesting system design is the intended use of the water. If rainwater is to be used only for irrigation, a rough estimate of demand, supply, and storage capacity may be sufficient. On the other hand, if rainwater is intended to be the sole source of water for all indoor and outdoor domestic end uses, a more precise reckoning is necessary to ensure adequate supply.

How Much Water Can Be Captured?

In theory, approximately 0.62 gallons per square foot of collection surface per inch of rainfall can be collected. In practice, however, some rainwater is lost to first flush, evaporation, splash-out or overshoot from the gutters in hard rains, and possibly leaks. Rough collection surfaces are less efficient at conveying water, as water captured in pore spaces tends to be lost to evaporation.

Also impacting achievable efficiency is the inability of the system to capture all water during intense rainfall events. For instance, if the flow-through capacity of a filter-type roof washer is exceeded, spillage may occur. Additionally, after storage tanks are full, rainwater can be lost as overflow.

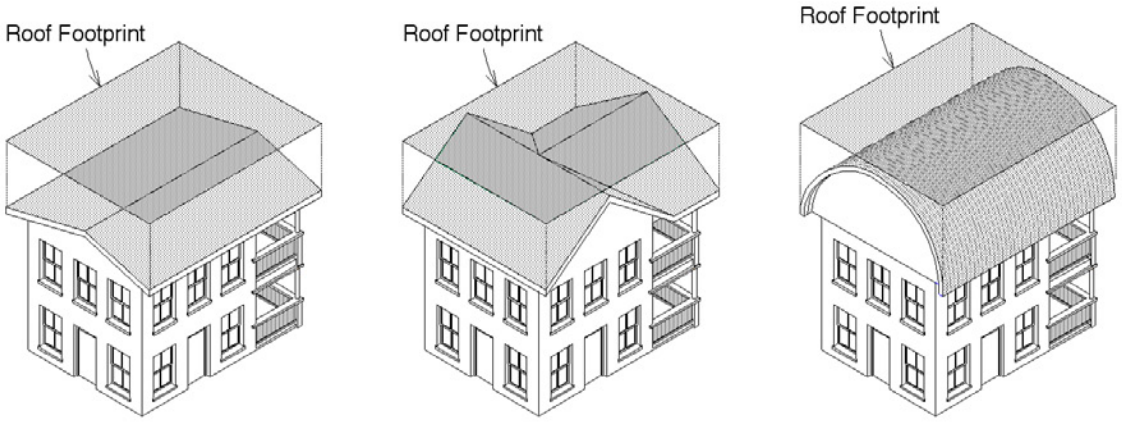

Figure 4-1. Catchment areas of three different roofs

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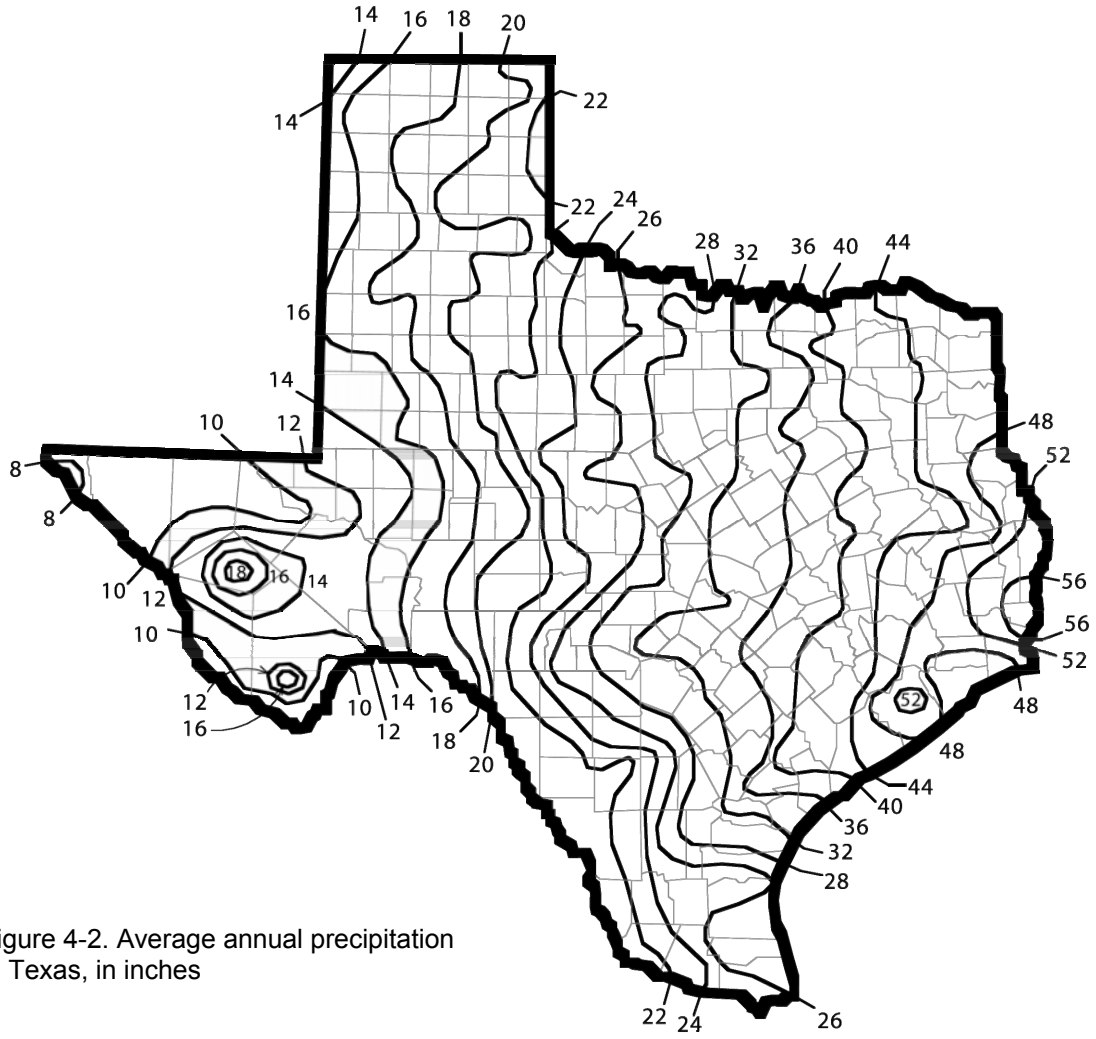

Figure 4-2. Average annual precipitation in Texas, in inches

For planning purposes, therefore, these inherent inefficiencies of the system need to be factored into the water supply calculation. Most installers assume an efficiency of 75 percent to 90 percent.

In most Texas locations, rainfall occurs seasonally, requiring a storage capacity sufficient to store water collected during rainy times to last through the dry spells. In West Texas, total annual rainfall might not be sufficient to allow a residence with a moderate-sized collection surface to capture sufficient water for all domestic use. Some residences might be constrained by the area of the collection surfaces or the volume of storage capacity that can be installed.

Collection Surface

The collection surface is the "footprint" of the roof (Figure 4-1). In other words, regardless of the pitch of the roof, the effective collection surface is the area covered by collection surface (length times width of the roof from eave to eave and front to rear). Obviously if only one side of the structure is guttered, only the area drained by the gutters is used in the calculation.

Rainfall Distribution

In Texas, average annual rainfall decreases roughly 1 inch every 15 miles,

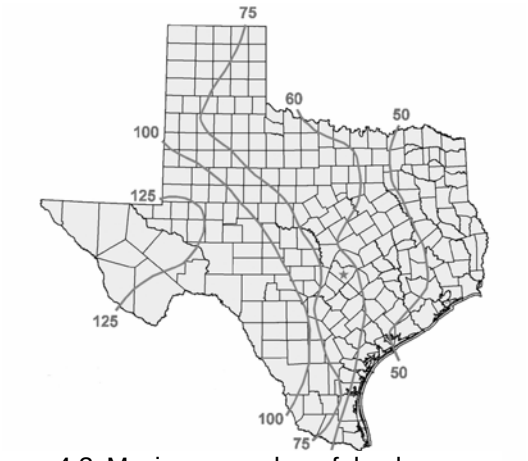

Figure 4-3. Maximum number of dry days (Krishna, 2003)

as you go from east to west (Figure 4-2), from 56 inches per year in Beaumont to less than 8 inches per year in El Paso. As one moves westward across the state, the prevalence and severity of droughts must also be considered.

To ensure a year-round water supply, the catchment area and storage capacity must be sized to meet water demand through the longest expected interval without rain. For instance, in West Texas, the historic longest span of continuous dry days has exceeded three months. For reference purposes, a contour map of historical maximum number of dry days in Texas is shown in Figure 4-3 (Krishna, 2003). If the rainwater harvesting system is intended to be the sole water source for a household, the designer must size the system to accommodate the longest anticipated time without rain, or otherwise plan for another water source, such as a well backup or hauled water.

Also, rainfall from high-intensity, short-duration rainfall events may be lost to overflow from storage tanks or splash-out from the gutters. Although these intense rainfall events are considered part of the cumulative annual rainfall, the total available volume of such an event is rarely captured.

Another consideration is that most rainfall occurs seasonally; annual rainfall is not evenly distributed throughout the 12 months of the year. The monthly distribution of rainfall is an important factor to consider for sizing a system. Monthly rainfall data for selected Texas cities is given in Appendix B.

Monthly Rainfall

Two different estimators of monthly rainfall are commonly used: average rainfall and median rainfall. Average annual rainfall is calculated by taking the sum of historical rainfall and dividing by the number of years of recorded data. This information is available from numerous public sources, including the National Climate Data Center website. (See References.) Median rainfall is the amount of rainfall that occurs in the midpoint of all historic rainfall totals for any given month. In other words, historically for the month in question, half of the time the rainfall was less than the median and half of the time rainfall was more than the median. Median values and average rainfall values for representative Texas cities are provided in Appendix B.

Median rainfall provides for a more conservative calculation of system sizing than average rainfall. The median value for rainfall is usually lower than the average value since large rainfall events tend to drive the average value higher. In other words, the sum of monthly medians is lower than the annual average due to the fact that the arithmetic average is skewed by high-intensity rainfall events. For planning purposes, median monthly rainfall can be used to estimate water availability to a

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reasonable degree of certainty (Krishna, 2001).

For example, in the sample calculations at the end of this chapter, the average annual rainfall for Dallas is about 35.0 inches, but the sum of the monthly medians is only 29.3 inches.

Calculating Storage Capacity

Once the median or average potential for rainfall capture is known from rainfall data and catchment area, it will be necessary to calculate storage capacity. The decision of whether rainwater will be used for irrigation, potable and domestic use, or both, will dictate water demand, and therefore, capacity.

A simple method of roughly estimating storage capacity popular among professional installers is to size the storage capacity to meet quarterly demand. The system is sized to meet estimated demand for a three-month period without rain. Annual estimated demand is divided by four to yield necessary storage capacity using this approach. This approach, however, may result in a more expensive system due to higher storage costs.

If a rainwater harvesting system is to be the sole water supply, overbuilding ensures a safety margin. As with many things in life, it helps to hope for the best but plan for the worst. Even when budget constraints may not allow the user to install as much storage capacity as a sizing method may indicate, it is important to provide for an area where additional tanks or cisterns can be installed at a later date when finances permit.

The Water Balance Method Using Monthly Demand and Supply

One method of determining the feasibility of a proposed system is the monthly water balance method. This method of calculation is similar to maintaining a monthly checkbook balance. Starting with an assumed volume of water already in the tanks, the volume captured each month is added to the previous balance and the demand is subtracted. The initial volume of water in the tanks would be provided by hauling or capturing water prior to withdrawing water from the system. An example is presented at the end of this chapter.

Data and calculations can be entered on an electronic spreadsheet to enable the user to compare different variables of catchment area and storage. It is suggested that homeowners experiment with different variables of storage capacity and, if applicable, catchment surface to find individual levels of comfort and affordability for catchment size and storage capacity.

As mentioned above:

- catchment area and rainfall determine supply, and
- demand dictates required storage capacity.

A commitment to conserving water with water-saving fixtures, appliances, practices indoors, and low-water-use landscaping outdoors is an essential component of any rainwater harvesting system design. Not only is conservation good stewardship of natural resources, it also reduces the costs for storage capacity and related system components.

If the amount of rainwater that can be captured – calculated from roof area and rainfall – is adequate or more than

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adequate to meet estimated demand, and meets the physical constraints of the building design, then storage capacity can be sized to meet estimated demand. If the monthly amount of water that can be captured, accounting for dry spells, is less than monthly estimated demand, then additional catchment area or supplemental supplies of water (such as groundwater from a well) will need to be considered.

In drier areas, no matter how large the storage capacity, catchment area may need to be increased with a rain barn or additional roof area to meet demand.

At the end of this chapter, an example of a water balance calculation is shown for the City of Dallas.

Estimating Demand

A water-conserving household will use between 25 and 50 gallons per person per day. (Note that total gallons per capita per day figures published for municipalities divide all the water distributed by the population, yielding a much larger amount per capita than actual domestic consumption.)

Households served previously by a water utility can read monthly demand from their meter or water bill to find monthly demand for purposes of building a new rainwater harvesting system. Divide the monthly total by the number of people in the house, and the days in the month to get a daily per capita demand number.

Water conservation is covered later in this chapter. Households solely dependent upon rainwater should adopt efficient water use practices both indoors and outdoors.

Estimating indoor water demand

Indoor water demand is largely unaffected by changes in weather, although changes in household occupancy rates depending upon seasons and ages of household members, more water use during the hot summer months, and very minor changes in consumption of water due to increases in temperature may be worth factoring in some instances. The results of a study of 1,200 single-family homes by the American Water Works Association (AWWA) in 1999 found that the average water conserving households used approximately 49.6 gallons per person per day (American Water Works Association, 1999).

Table 4-1 can be used to calculate indoor water demand. Many households use less than the average of 49.6 gallons per person found in the 1999 report by the AWWA, *Residential End Uses of Water*. The water volumes shown in the table assume a water-conserving household, with water-conserving fixtures and good practices, such as shutting off the water while brushing teeth or shaving. Overall demand in showers, baths, and faucet uses is a function of both time of use and rate of flow. Many people do not open the flow rate as high as it could be finding low or moderate flow rates more comfortable. In estimating demand, measuring flow rates and consumption in the household may be worth the effort to get more accurate estimates.

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Table 4-1. Estimating Indoor Daily Domestic Demand

	A. Water consumption using conserving fixtures	B. Assumptions from AWWA Residential End-Use Study	C. Adjustments to assumptions (adjust up or down according to actual use)	D. Number of persons in household	E. Household monthly demand A x (B or C)x D x 30
Toilets (use only appropriate type)					
ULFT	1.6 gal/flush	6 flushes/ person/day			
Dual Flush	1 gal/flush liquids 1.6 gal/flush solids	6 flushes/ person/day			
Baths & showers					
Showerhead	2.2 gal/min	5 minutes/ person/day			
Bath	50 gal/bath	NA			
Faucets (personal hygiene, cooking, and cleaning of surfaces)	2.2 gal/faucet/min	5 minutes/ person/day			
Appliances or uses which are measured on a per-use basis (not a per-person basis):					
Clothes washer Front-loading (horizontal-axis)	18–25 gal/load	2.6 loads/week			
Dishwasher	8 gal/cycle	0.7 cycles/day			
Miscellaneous other					
Total					

One can use Table 4-1 if the designer prefers to incorporate known or expected behavioral habits into the water demand estimates. The values in the first column are to be multiplied by variables reflecting your own household water use patterns. The average values in the second column are offered for information, but as with all averages, are subject to wide variation based upon actual circumstances. An example is dual flush toilets – multiply three flushes

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per day liquid only (1 gpf), and add three flushes per day for solids (1.6 gpf), (3x1) + (3x1.6) = 7.8 gallons multiplied by 3 persons = 23.4 gpd household demand x 30 days = 702 gallons per month. The authors recommend verifying any assumptions against the records of historical use from a municipal water bill if available.

Indoor water conservation

Indoor domestic water conservation can be achieved by a combination of fixtures, appliances, and water-conserving practices. The advantage of water-conserving appliances is that they require no change in household routine. Some water-conserving practices need user action, such as turning off the water while brushing teeth or shaving; washing vegetables in a pan rather than under a stream; washing only full loads of laundry and dishes; and keeping a pitcher of water in the refrigerator, rather than waiting for cold water to arrive from a faucet.

Water conservation appliances include:

- **Ultralow flush toilets (ULFTs)**. Since 1993, only ULFTs with 1.6 gallons per flush may be sold in the United States. Older toilets should be replaced with the more efficient models. Some of the ULFTs require special early closing flappers to maintain their low-flow rates, so care should be taken in purchasing the correct replacement flapper for leaking toilets. If purchasing a new toilet, those that do not use early closure flappers are recommended. Dual-flush toilets (using less volume for liquid wastes) are also a good choice for a water-wise household.
- **Faucet aerators and efficient showerheads**. These fixtures are designed to use 2.2 gallons per minute at 60 psi, or 2.5 gpm at 80 psi (Table 4-1). Studies have shown that most people feel comfortable at less than full flow rates, so using the new fixtures (which are the only ones sold in the United States since 1992) should provide you with an efficient and comfortable experience.
- **Hot water on demand**. These wall-mounted units heat water just prior to use, eliminating the waste of waiting for hot water from the water heater while cold water is allowed to flow down the drain. Hot water loop systems keep hot water continuously circulating to achieve the same goal, but can use more energy. Another on-demand unit heats water quickly only when activated by a pushbutton, rather than circulating water through a loop, saving both water and energy. A rebate from San Antonio Water System (SAWS) is available for installation of this type of on-demand circulation system.
- **Horizontal-axis (front-loading) clothes washers.** Because clothes are tumbled through a small volume of water in the bottom of the drum (rather than washed in a full tub of water), this appliance can save up to half the water of a traditional clothes washer. It is also as much as 42 percent more energy efficient. A list of front-loading, horizontal-axis clothes washers is maintained by the Consortium for Energy Efficiency online. (See References.) Several municipal utilities in Texas, including City of Austin, SAWS, and Bexar Met, offer rebates for the purchase of these energy- and water-efficient appliances.

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Estimating outdoor water demand

Outdoor water demand peaks in hot, dry summer. In fact, as much as 60 percent of municipal water demand in the summer is attributable to irrigation.

The water demands of a large turfgrass area almost always preclude the sole use of harvested rainwater for irrigation.

Many urban dwellers capture rainwater for irrigation of vegetable and ornamental gardens. Because it is free of salts and minerals, rainwater promotes healthy plant growth. In urban areas, rainwater harvesters may reduce their water bill by substituting harvested rainwater for municipal water for garden irrigation.

For both the health of landscape plants and water use-efficiency, the best way to water plants is according to their needs. For most plants adapted to Texas' climate, water stress is visually evident well before plant death. Signs of water stress include a gray blue tint to leaves, leaf rolling, and in the case of turfgrass, a footprint that does not spring back. Watering infrequently and deeply has been shown to promote plant health, waiting until plants need the water helps the water user to be sure that they are growing a healthy landscape.

For planning purposes, historical evapotranspiration can be used to project potential water demands. Evapotranspiration is the term for water use by plants, the combination of evaporation from the soil and transpiration from the plant leaves. An estimated value called potential evapotranspiration is available on the Texas Evapotranspiration website, or can be calculated from weather-related data. (See References.)

A recommended general reference for water-wise landscaping is *Xeriscape: Landscape Water Conservation*, publication B-1584, available online. (See References.) Other plant lists and resources are available at the Texas Master Gardeners' website. (See References.) Many municipal water utilities, including those in the cites of El Paso, Houston, Austin, San Antonio, and the Metroplex area have published water-wise landscaping information tailored to local climate and soil conditions

It is recommended that rainwater harvesting families install landscapes of native and adapted plants, and also ascribe to the seven principles of Xeriscaping. A water-wise landscape can be quite attractive, while conserving water and demanding less care than a garden of non-native or non-adapted plants.

Principles of Water-Wise Landscaping

1. Plan and design for water conservation.
2. Create practical turf areas.
3. Group plants of similar water needs together.
4. Use soil amendments like compost to allow the soil to retain more water.
5. Use mulches, especially in high and moderate watering zones, to lessen soil evaporation.
6. Irrigate efficiently by applying the right amount of water at the right time.
7. Maintain the landscape appropriately by fertilizing, mowing, and pruning.

References

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National Climate Data Center, www.ncdc.noaa.gov

Texas Evapotranspiration Network, texaset.tamu.edu

Texas Master Gardeners, aggiehorticulture.tamu.edu/mastergd/mg.html

Xeriscape: Landscape Water Conservation, publication B-1584, tcebookstore.org

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Rainwater Harvesting System Sizing
Sample Water Balance Calculations for Dallas, Texas

Two methods of determining system sizing are shown below. In the first example, monthly average rainfall data are used, and in the second example, monthly median rainfall data are used for calculations. Monthly rainfall data for several locations in Texas are provided in Appendix B.

Keep in mind that the basic monthly water balance calculation is
Water available (gallons) = Initial volume in storage (gallons) + gallons captured – gallons used.
In an especially wet month, gallons in storage + gallons captured may exceed storage capacity; storage capacity could become a limiting factor, or a slightly larger cistern may be considered.

Assumptions

- Demand of 3,000 gallons/month
- Collection efficiency of 85 percent
- 0.62 gallons per square foot of roof area per inch of rain
- 10,000-gallon storage capacity
- 1,000 gallons in storage on January 1 to start out. (The water may have been collected between the time of system completion and new home occupancy, or it may be hauled water; systems designed for irrigation use only should be completed in the fall to collect rainwater during the slow-/non-growth season.)
- Irrigation volume is estimated based upon a small ornamental landscape, and limited supplemental irrigation, since this example is used for potable supply.

Calculations using Monthly Average Rainfall Data

First calculate the number of gallons collected in January. Using the average value of 1.91 inches of rain for January in Dallas (from Appendix B), the number of gallons of rainwater that can be expected to be stored in January from a 2,500-square-foot roof assuming 85% collection efficiency is determined from the equation:

Rainfall (inches) x roof area x 0.62 gal/sq ft /in. rain x collection efficiency

In this example:

$1.97_{\text{in. rainfall}} \times 2{,}500_{\text{sq. ft. catchment}} \times 0.62_{\text{gallons/in. rain/sq. ft.}} \times 0.85_{\text{collection efficiency}} = 2{,}595 \text{ gallons}$

To calculate gallons in storage at the end of each month, add the volume of water already in storage (1,000 gallons in this example) to the gallons collected and subtract the monthly demand.

1,000 + 2,595 – 3,000 = 595 gallons available in storage at the end of January

This calculation is repeated for each month. To help you follow Table 4-2, please read below:

The value in Column E is added to Column F from preceding row and then A is subtracted. If calculated storage amount is zero or less, use zero for the next month. Rainfall exceeding storage capacity is ignored (water lost). The table shows that a collection surface of 2,500 square feet is adequate to meet expected demand (Column F should be more than zero at all times, if not the collection area needs to be increased or the monthly demand should be reduced).

Calculations using Monthly Median Rainfall Data

Table 4-3 shows the results of using monthly median rainfall (Column D), and performing the same calculations as before. Using monthly median rainfall data is a more conservative method, and is likely to provide a higher reliability than using average rainfall data for system sizing.

Homeowners can easily try different values for collection surface and storage capacity using an electronic spreadsheet, downloadable in Excel format from the Texas Water Development Board www.twdb.state.tx.us/assistance/conservation/alternative_technologies/rainwater_harvesting/rain.asp

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Table 4-2. Sample Water Balance Calculations for Dallas, Texas (Using Average Rainfall and a 2,500-square-foot collection surface)

Month	A. Water demand	B. Irrigation demand (watering by hose or bucket)	C. Total demand (gallons)	D. Average rainfall (inches)	E. Rainfall collected (gallons)	F. End-of-month storage (1,000 gal. to start)
January	3,000	0	3,000	1.97	2,596	595
February	3,000	0	3,000	2.40	3,162	757
March	3,000	150	3,150	2.91	3,834	1,441
April	3,000	150	3,150	3.81	5,020	3,311
May	3,000	150	3,150	5.01	6,601	6,762
June	3,000	150	3,150	3.12	4,111	7,723
July	3,000	150	3,150	2.04	2,688	7,261
August	3,000	150	3,150	2.07	2,727	6,838
September	3,000	150	3,150	2.67	3,518	7,206
October	3,000	150	3,150	3.76	4,954	9,010
November	3,000	0	3,000	2.70	3,557	9,567
December	3,000	0	3,000	2.64	3,478	10,000*

* Note that there were 44 gallons of overflow in December in this example. A 10,000-gallon cistern appears to be appropriate under the given assumptions.

Table 4-3. Sample Water Balance Calculations for Dallas, Texas (Using Median Rainfall and a 2,500-square-foot collection surface)

Month	A. Water demand	B. Irrigation demand (watering by hose or bucket)	C. Total demand (gallons)	D. Median rainfall	E. Rainfall collected	F. End-of-month storage (1,000 gal. to start)
January	3,000	0	3,000	1.80	2,372	372
February	3,000	0	3,000	2.11	2,780	151
March	3,000	150	3,150	2.36	3,109	111
April	3,000	150	3,150	2.98	3,926	887
May	3,000	150	3,150	4.27	5,626	3,363
June	3,000	150	3,150	2.85	3,755	3,968
July	3,000	150	3,150	1.60	2,108	2,926
August	3,000	150	3,150	1.74	2,292	2,068
September	3,000	150	3,150	2.50	3,294	2,212
October	3,000	150	3,150	2.94	3,873	2,935
November	3,000	0	3,000	2.00	2,635	2,570
December	3,000	0	3,000	2.10	2,767	2,337

This table shows that it is critical to start with an initial storage (1,000 gallons), otherwise the cistern may run out of water in February/March, under the given assumptions.

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The graph below (Figure 4-4) illustrates the information from Tables 4-2 and 4-3, previous page. The area under the curves represents the amount of water in storage at the end of each month. The assumptions from the example on the previous page are: a Dallas family of three using 33 gallons per person per day for indoor use, plus irrigation demand as shown in the examples, a collection efficiency of 85 percent, and a roof area of 2,500 square feet. The upper curve denotes water availability using average monthly rainfall data, and the lower curve is based on the monthly median rainfall. A 10,000-gallon cistern is planned in this example for storage of rainwater.

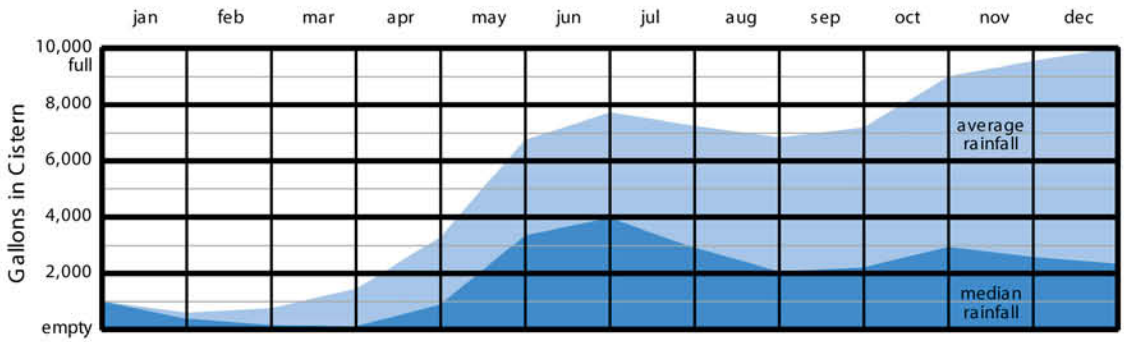

Figure 4-4. Volume of water in storage, using average rainfall data and median rainfall data for Dallas, Texas

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Chapter 5
Rainwater Harvesting Guidelines

No national standards exist for rainwater harvesting systems. As a result, efforts abound to give assistance to those considering using rainwater as a water supply at state and local levels. In Texas the voluntary approach has been the hallmark of water conservation efforts, and a Water Conservation Best Management Practices (BMP) Guide produced by the Texas Water Development Board (TWDB) in 2004 included a section on Rainwater Harvesting and Condensate Reuse for use by water providers. (See References.) Guidance in other parts of the country ranges from voluntary guidelines such as BMPs to codes and ordinances stipulating minimum standards for various aspects of rainwater harvesting. The wide variety in approaches is summarized in this chapter by sharing a few key examples of the initiatives that are available to assist the planner of a rainwater harvesting system.

RWH Best Management Practices

Water Conservation Implementation Task Force Guidelines. In 2003 a statewide Water Conservation Implementation Task Force was appointed by the TWDB under a legislative mandate to develop recommendations for water conservation for the state of Texas. Best management practices reached by a consensus of the Task Force address rainwater harvesting and air conditioner condensate in the Task Force Water Conservation Best Management Practices Guide (TWDB, 2004).

American Rainwater Catchment Systems Association. The American Rainwater Catchment Systems Association (ARCSA) is in the process of publishing guidelines for potable and nonpotable rainwater harvesting systems. The guidelines will be available on the ARCSA website at www.arcsa-usa.org.

Other Voluntary Guidelines

A number of University-level programs have published guidelines that are helpful to rainwater designers and planners. Included among them are Texas Cooperative Extension's guidelines and the University of Arizona's "Harvesting Rainwater for Landscape Use," both of which focus on capturing rainwater for outdoor irrigation. The University of Hawaii College of Tropical Agriculture and Human Resources in Hawaii produced "Guidelines on Rainwater Catchment Systems in Hawaii," which has information for people using rainwater for potable consumption. (See References.)

These guidelines for potable systems recommend that storage tanks be constructed of non-toxic material such as steel, fiberglass, redwood, or concrete. Liners used in storage tanks should be smooth and of food-grade material approved by the U.S. Food and Drug Administration (Macomber, 2001).

Building Codes

In addition to voluntary effort, some states and municipalities are choosing to establish rules. Ohio, Kentucky, Hawaii, Arizona, New Mexico, Washington, West Virginia, Texas, and the U.S. Virgin Islands are considering or have developed rules related to rainwater harvesting.

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Rules, ordinances, building codes, and homeowner association covenants nationwide run the gamut from requiring rainwater harvesting systems on new construction to prohibiting tanks as an eyesore.

In Texas, HB 645, passed by the 78th Legislature in 2003, prevents homeowners associations from implementing new covenants banning outdoor water-conserving measures such as composting, water-efficient landscapes, drip irrigation, and rainwater harvesting installations. The legislation allows homeowners associations to require screening or shielding to obscure view of the tanks.

The State of Ohio has the most extensive rules on rainwater harvesting in the United States, with code on cistern size and material, manhole openings, outlet drains, overflow pipes, fittings, couplings, and even roof washers. Ohio's rules also address disinfection of private water systems. (See References.)

Cistern Design, Construction, and Capacity

Cistern design is covered by rules in some states, often embedded in the rules for hauled water storage tanks. In Ohio, cisterns and stored water storage tanks must have a smooth interior surface, and concrete tanks must be constructed in accordance with ASTM C913, *Standard Specification for Precast Concrete Water and Wastewater Structures*. Plastic and fiberglass tank materials and all joints, connections, and sealant must meet NSF/ANSI Standard 61, *Drinking Water System Components*.

In the U.S. Virgin Islands, Bermuda, and other Caribbean islands (islands without large reservoirs or adequate groundwater reserves), all new construction and even building expansion must have a provision for a self-sustaining water supply system, either a well or a rainwater collection area and cistern.

The rules for private water systems in the U.S. Virgin Islands state that new cisterns must have a minimum capacity of 2,500 gallons per dwelling (Virgin Islands Code, Title 29, Public Planning and Development).

The U.S. Virgin Islands specifies that cisterns for hotels or multi-family dwellings have a minimum capacity of 10 gallons per square foot of roof area for buildings of one story, and 15 gallons per square foot of roof area for multi-story buildings, although the requirement is waived for buildings with access to centralized potable water systems.

The City of Portland, Oregon, requires a minimum cistern capacity of 1,500 gallons capable of being filled with harvested rainwater or municipal water, with a reduced pressure backflow prevention device and an air gap protecting the municipal supply from cross-connection (City of Portland, 2000).

Backflow Prevention and Dual-Use Systems

The option of "dual-supply" systems within a residence – potable harvested rainwater supplemented with water from a public water system with appropriate backflow prevention – is an option that might be explored for residences which cannot collect enough rainwater.

In most Texas locations, rainfall occurs seasonally, requiring a large storage capacity to hold enough water collected during rain events to last through the dry spells.

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Allowing for a connection to the public water supply system could serve to promote harvested rainwater as a supplemental water source to customers already connected to the public water supply infrastructure.

This "conjunctive" use would require an appropriate backflow prevention device to keep rainwater from entering the public water supply due to a drop in pressure in the utility's distribution system.

The City of Portland has approved supplemental use of public utility water at a residence since 1996. The code includes specific guidance for design and installation of the system. It also limits rainwater to nonpotable uses. The Portland Office of Planning and Development publishes a RWH Code Guide which includes FAQ and the relevant code sections (City of Portland, 2000).

The State of Washington Building Codes Council in 2002 developed guidelines for installation of rainwater harvesting systems at commercial facilities. They are similar to the City of Portland guidelines mentioned above, but require a larger cistern size, determined by the size of the catchment area, which is limited to roof areas. In 2003, the Washington State Legislature approved a 10 percent reduction in stormwater fees for any commercial facility that installed a rainwater harvesting system in compliance with the guidelines (Washington State Legislature, 2003).

Required Rainwater Harvesting Systems

Perhaps the most supportive ordinances are those requiring rainwater harvesting in new construction.

For instance, Santa Fe County, New Mexico, passed the precedent-setting regulation requiring rainwater harvesting systems on new residential or commercial structures of 2,500 square feet and larger. A bill requiring rainwater harvesting systems on all new construction narrowly missed passage in the New Mexico legislature (Darilek, 2004; Vitale, 2004)

The City of Tucson, Arizona, has instituted requirements for water harvesting in its land use code as a means of providing supplemental water for on-site irrigation. In fact, "storm water and runoff harvesting to supplement drip irrigation are required elements of the irrigation system for both new plantings and preserved vegetation" (City of Tucson Code, Chapter 23).

Water harvesting in Tucson is also intended to help in meeting code requirements for floodplain and erosion hazard management (City of Tucson Code, Chapter 26).

2005 Rainwater Harvesting Legislation

The Texas Legislature passed House Bill (HB) 2430 in May 2005, establishing a rainwater harvesting evaluation committee to recommend minimum water quality guidelines and standards for potable and nonpotable indoor uses of rainwater. The committee will also recommend treatment methods for indoor uses of rainwater, methods by which rainwater harvesting systems could be used in conjunction with existing municipal water systems, and ways in which that the state can further promote rainwater harvesting. The committee consists of representatives from the Texas Water Development Board, Texas Commission on

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Environmental Quality, Department of State Health Services, and the Texas Section of the American Water Works Association. The committee will provide its recommendations to the Legislature by December 2006.

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Chapter 6
Cost Estimation

Developing a budget for a rainwater harvesting system may be as simple as adding up the prices for each of the components and deciding what one can afford. For households without access to reliable groundwater or surface water, and too remotely located to hook up to the existing potable supply infrastructure, the information in this chapter will assist in determining how large a system can be installed for a set budget, and the range of costs for an ideal system. For some, the opportunity to provide for all or a portion of their water needs with rainwater is an exercise in comparing the costs with other options to determine which is most cost-effective. This chapter provides some information on cost ranges for standard components of rainwater systems for both potable use and for irrigation. It also has a brief section on comparing costs with other types of water supply.

The single largest expense is the storage tank, and the cost of the tank is based upon the size and the material. Table 6-1 shows a range of potential tank materials and costs per gallon of storage. The size of storage needed (see Chapter 4, Water Balance and System Sizing) and the intended end use of the water will dictate which of the materials are most appropriate. Costs range from a low of about $0.50 per gallon for large fiberglass tanks to up to $4.00 per gallon for welded steel tanks.

As tank sizes increase, unit costs per gallon of storage decreases.

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Table 6-1. Storage Tank

	Cost	Size	Comments
Fiberglass	$0.50–2.00/gallon	500–20,000 gallons	Can last for decades w/out deterioration; easily repaired; can be painted
Concrete	$0.30–1.25/gallon	Usually 10,000 gallons or more	Risks of cracks and leaks but these are easily repaired; immobile; smell and taste of water sometimes affected but the tank can be retrofitted with a plastic liner
Metal	$0.50–1.50/gallon	150–2,500 gallons	Lightweight and easily transported; rusting and leaching of zinc can pose a problem but this can be mitigated with a potable-approved liner
Polypropylene	$0.35–1.00/gallon	300–10,000 gallons	Durable and lightweight; black tanks result in warmer water if tank is exposed to sunlight; clear/translucent tanks foster algae growth
Wood	$2.00/gallon	700–50,000 gallons	Esthetically pleasing, sometimes preferable in public areas and residential neighborhoods
Polyethylene	$0.74–1.67/gallon	300–5,000 gallons	
Welded Steel	$0.80–$4.00/gallon	30,000–1 million gallons	
Rain Barrel	$100	55–100 gallons	Avoid barrels that contain toxic materials; add screens for mosquitoes

Gutters and downspouts (Table 6-2) are needed to collect the water and route it to the tank. Two types of gutters are available for the "do-it-yourselfers": vinyl and plastic, which are available for approximately the same cost. For those desiring professionally installed materials, costs range from $3.50 to $12 per foot of gutter, including materials and installation, in 2004.

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Table 6-2. Gutters

	Cost	Comments
Vinyl	$.30/foot	Easy to install and attach to PVC trunk lines
Plastic	$.30/foot	Leaking, warping and breaking are common problems
Aluminum	$3.50-6.25/foot	Must be professionally installed
Galvalume	$9-12/foot	Mixture of aluminum and galvanized steel; must be professionally installed

Some method of discarding the first flush of rain from the roof is necessary to remove debris. The simplest method is a vertical PVC standpipe, which fills with the first flush of water from the roof, then routes the balance of water to the tank.

The roof washer, placed just ahead of the storage tank, usually consists of a tank with leaf strainers and a filter. A commercially available model has a series of baffles and a 30-micron filter.

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Table 6-3. Roof Washers

	Cost	Maintenance	Comments
Box Washer	$400-800	Clean the filter after every substantial rain	Neglecting to clean the filter will result in restricted or blocked water flow and may become a source or contamination
Post Filtering w/ Sand Filter	$150-500	Occasionally backwash the filter	Susceptible to freezing; a larger filter is best
Smart-Valve Rainwater Diverter Kit	$50 for kit	Occasional cleaning	Device installed in a diversion pipe to make it self-flushing and prevent debris contamination; resets automatically

Roof washers consist of a tank, usually between 30- and 50-gallon capacity, with leaf strainers and a filter. A roof washer is a critical component of potable systems and is also needed to filter small particles to avoid clogging drip irrigation emitters. A wide range of equipment is available with different flow capacity and maintenance requirements. In Table 6-3 a list of different equipment used to intercept and pre-filter the water shows a range of costs from $50 to more than $800. It is important that the rainwater harvester pick a roof washer that is adequate for the size of collection area.

Table 6-4 shows the ranges for pump costs including pressure tanks. Demand-activated pumps such as Grundfos may not require a pressure tank, and can often provide enough water to meet a home's demand for instantaneous flow. Careful thought should be given to the possibility of multiple simultaneous demands upon the system in determining the appropriate size pump. The range for pump costs runs from $385 for the low-end tankless pump, to more than $1,000 for the combined price of a high-end pump and pressure tank.

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Table 6-4. Pumps and Pressure Tanks

	Cost	Comments
Grundfos MQ Water Supply System	$385-600	Does not require a separate pressure tank
Shallow Well Jet Pump or Multi-Stage Centrifugal Pump	$300-600	These require a separate pressure tank
Pressure Tank	$200-500	Galvanized tanks are cheaper than bladder tanks but often become waterlogged, and this will wear out the pump more rapidly

For those planning a potable system, or if a drip irrigation system is used, some sort of filtration is necessary. Rainwater harvesting suppliers can assist the end user in purchasing the right equipment for his/her needs and the expected demand.

It is important for the end user intending to use rainwater for potable supply to include disinfection among the water treatment components. The costs vary widely depending upon intended end-use, the desired water quality, and preferences of the user. As shown in Table 6-5, combined filtration/ disinfection costs can cost up to $1,000 or more. Chapter 2, Rainwater Harvesting System Components, will assist you in choosing the right filtration and/or disinfection equipment for your system.

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Table 6-5. Filtering/Disinfection

	Cost	Maintenance	Effectiveness	Comments
Cartridge Filter	$20-60	Filter must be changed regularly	Removes particles >3 microns	A disinfection treatment is also recommended
Reverse Osmosis Filter	$400-1500	Change filter when clogged (depends on the turbidity)	Removes particles >0.001 microns	A disinfection treatment is also recommended
UV Light Disinfection	$350-1000; $80 to replace UV bulb	Change UV bulb every 10,000 hours or 14 months; the protective cover must be cleaned regularly	Disinfects filtered water provided there are <1,000 coliforms per 100 milliliter	Water must be filtered prior to exposure for maximum effectiveness
Ozone Disinfection	$700-2600	Effectiveness must be monitored with frequent testing or an in-line monitor ($1,200 or more)	Less effective in high turbidity, can be improved with pre-filtering	Requires a pump to circulate the ozone molecules
Chlorine Disinfection	$1/month manual dose or a $600-$3000 automatic self-dosing system	Monthly dose applied manually	High turbidity requires a higher concentration or prolonged exposure but this can be mitigated by pre-filtering	Excessive chlorination may be linked to negative health impacts.

Operating Costs

There are also operating costs that should be considered as you prepare your budget. As with any water treatment system, the cleaner the water needs to be, the greater the effort required to maintain the system.

Fortunately, with filter cartridges, this just means regular replacement of the cartridges, and with the disinfection system, following the manufacturers' recommendations for regular maintenance. But proper operation and maintenance of the system does add to total costs.

Filter cartridges should be replaced per manufacturer's specifications, based upon the rate of water use.

Some of the operating costs and time expenditures necessary for system maintenance are regularly cleaning gutters and roof washers, checking the

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system for leaks by monitoring water levels, and paying close attention to water use rates to determine if an invisible leak has sprung. Although the "do-it-yourselfers" can handle all of these tasks with little added financial burden, the time for regular maintenance and operation must be set aside to operate a successful system.

Comparing to Other Sources of Water

In some areas of Texas the cost of drilling a well can be as high as $20,000 with no guarantee of hitting a reliable source of water. The deeper the well, the more expensive the effort will be. Also, well water can have very high TDS levels in some aquifers, resulting in "hard" water. Rainwater is naturally soft and has become a preferred option in some parts of rural central Texas with costs lower than or equal to those of drilling a well, and reliability high enough to justify reliance on weather patterns, rather than on an aquifer's water quality and quantity.

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Chapter 7
Financial and Other Incentives

Financial incentives and tax exemptions encourage the installation of rainwater harvesting systems. The Texas Legislature has passed bills, and some local taxing entities have adopted rules that provide tax exemptions for rainwater harvesting systems. A few public utilities have implemented rebate programs and rain barrel distribution events that encourage rainwater harvesting by residential, commercial, and industrial customers. In addition to financial incentives, performance contracting provisions in state code can be used to encourage installation of rainwater harvesting systems. This chapter includes a brief description of methods for determining the appropriate size of an incentive by local governments.

In addition to financial incentives, administrative contracting rules for state and local governments encourage the use of rainwater harvesting as an alternative water source in Texas.

Tax Exemptions

Property tax exemption for commercial installations (State-wide exemption)

A constitutional amendment passed as Proposition 2 by Texas voters in November 1993 exempted pollution control equipment, including water-conserving equipment at nonresidential buildings, from property taxes. Rainwater harvesting equipment at commercial installations is considered water-conserving equipment. The intent of this amendment to Article VIII of the Texas Constitution was to ensure that capital expenditures undertaken to comply with environmental rules and regulations did not raise a facility's property taxes, by adding Section 11.31 to Chapter 11, and Section 26.045 to Chapter 26 of the Texas Tax Code.

The Texas Commission on Environmental Quality (TCEQ) established procedures and mechanisms for use determination under Texas Administrative Code (TAC) Title 30, Chapter 17.

To qualify for the property tax exemption, (1) a facility must first receive a determination from the TCEQ that the property is used for pollution control purposes, and (2) the applicant then submits this use determination to the local tax appraisal district to obtain the property tax exemption.

The Application and Instructions for Use Determination for Pollution Control Property and Predetermined Equipment List, as well as instructions for applying for Property Tax Exemptions for Pollution Control Property, are downloadable from the TCEQ website. (See References.)

Property tax exemptions extended (State-wide)

Passed in 2001 by the 77th Texas Legislature, Senate Bill 2 amended Section 11.32 of the Texas Tax Code to allow taxing units of government the option to exempt from taxation all or part of the assessed value of the property on which water conservation modifications have been made. The taxing entity designates by ordinance or law the list of eligible water conservation initiatives, which may include rainwater harvesting systems.

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County property tax exemptions

Homeowners planning to install rainwater harvesting systems should check with their respective county appraisal districts for guidance on exemption from county property taxes. Links to some county appraisal districts, as well as the Office of the State Comptroller's Application for Water Conservation Initiatives Property Tax Exemption, can be found online. (See References.)

Hays County is one of the fastest-growing counties in Texas, and is also the county with the most rapidly increasing number of new rainwater harvesting installations in the state. Hays County encourages rainwater harvesting with a $100 rebate on the development application fee.

For rainwater harvesting systems serving as the sole source of water for a residence, Hays County grants a property tax exemption from county taxes for the value of the rainwater harvesting system. Guidelines for rainwater harvesting benefits and qualification can be found at the Hays County website. (See References.)

Homeowners in other parts of the state should consider approaching their local government to see if such a property tax exemption could be passed in their locale.

Sales Tax Exemption (State-wide)

Senate Bill 2 exempts rainwater harvesting equipment and supplies from sales tax. Senate Bill 2 amended Subchapter H of the Tax Code by adding Section 151.355, which states:

> "Water-related exemptions. The following are exempted from taxes imposed by this chapter: (1) rainwater harvesting equipment or supplies, water recycling and reuse equipment or supplies, or other equipment."

An application for sales tax exemption is included as Appendix D, or can be downloaded from the Office of the State Comptroller. (See References.)

Municipal Incentives

In addition to tax exemptions, two Texas cities offer financial incentives in the form of rebates and discounts to their customers who install rainwater harvesting and condensate recovery systems.

City of Austin Rainwater Harvesting Programs

The City of Austin Water Conservation Department promotes both residential and commercial/industrial rainwater harvesting. (See References.) The City of Austin sells 75-gallon polyethylene rain barrels to its customers below cost, at $60 each, up to four rain barrels per customer. City of Austin customers who purchase their own rain barrels are eligible for a $30 rebate.

Customers may also receive a rebate of up to $500 on the cost of installing a pre-approved rainwater harvesting system. The rebate application includes a formula to calculate optimum tank size and a list of area suppliers and installation contractors. (See References.)

Commercial entities may be eligible for as much as a $40,000 rebate against the cost of installing new equipment and processes to save water under the Commercial Incentive Program. (See References.)

New commercial or industrial sites that develop capacity to store sufficient water

on-site for landscape irrigation may be able to receive an exemption from installing an irrigation meter.

San Antonio Water System Large-Scale Retrofit

Rainwater harvesting projects are eligible for up to a 50-percent rebate under San Antonio Water System's (SAWS) Large-Scale Retrofit Rebate Program. (See References.) SAWS will rebate up to 50 percent of the installed cost of new water-saving equipment, including rainwater harvesting systems, to its commercial, industrial, and institutional customers. Rebates are calculated by multiplying acre-feet of water conserved by a set value of $200/acre-foot. Equipment and projects must remain in service for 10 years. The water savings project is sub-metered, and water use data before and after the retrofit are submitted to SAWS to determine if conservation goals are met. To qualify for the rebate, an engineering proposal and the results of a professional water audit showing expected savings are submitted.

The rebate shortens the return on investment period, giving an incentive to industry to undertake water-conserving projects.

Determining How Much of a Financial Incentive a Utility May Wish to Offer

To determine whether a municipal utility should consider offering a rebate or financial incentive to stimulate the use of rainwater harvesting, benefits and costs must be presented on an economic basis. This is most easily accomplished by condensing the factors into terms of dollars per acre-foot ($/AF) and comparing that to the cost of building a new water supply project. The spreadsheet included in the TWDB's Report No. 362, Water Conservation Best Management Practices Guide (p. 118 to 130), gives an example and the steps in calculating the net present value of conserved water.

This approach requires the utility to estimate the potential for water savings due to rainwater harvesting systems installed and the likely number of participants in a program.

Rainwater Harvesting at State Facilities

In 2003, the 78th Texas Legislature, second session, passed HB9, which encourages rainwater harvesting and water recycling at state facilities. The bill requires that the Texas Building and Procurement Commission appoint a task force charged with developing design recommendations to encourage rainwater harvesting and water recycling at state facilities built with appropriated money.

The intent of HB9 is to promote the conservation of energy and water at state buildings. The bill requires that before a state agency may use appropriated money to make a capital expenditure for a state building, the state agency must determine whether the expenditure could be financed with money generated by a utility cost-savings contract.

If it is determined to be not practicable to finance construction with utility cost savings, rainwater harvesting and water recycling are encouraged by HB9.

In addition the Texas Education Code (Section 61.0591) provides an incentive to institutes of higher education for achieving goals set by the Texas Higher Education Coordinating Board (THECB) including:

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> "energy conservation and water conservation, rainwater harvesting, and water reuse."

The code states that not less than 10 percent of THECB total base funding will be devoted to incentive funding.

Performance Contracting

Another means of encouraging the installation of water- or energy-efficient equipment is to pay for the equipment through the savings in utility bills. This method of financing water conservation has been used by commercial and industrial consumers, and is written into state code for government buildings in several locations.

The Texas Education Code (Chapter 44.901 and Chapter 51.927), the Texas Local Government Code (Chapter 302.004), and the State Government Code (Chapter 2166.406) allow public schools, institutes of higher education, state building facilities, and local governments to enter into performance contracts. Performance contracting allows a facility to finance water- and energy-saving retrofits with money saved by the reduced utility expenditures made possible by the retrofit. In other words, the water- and energy-conserving measures pay for themselves within the contracted period. More information on performance contracting can be found on the State Energy Conservation Office website. (See References.)

Following are descriptions of alternative water sources that are eligible for performance contracts:

> "landscaping measures that reduce watering demands and capture and hold applied water and rainfall, including: (a) landscape contouring, including the use of berms, swales, and terraces; and (b) the use of soil amendments that increase the water-holding capacity of the soil, including compost."
>
> "rainwater harvesting equipment and equipment to make use of water collected as part of a stormwater system installed for water quality control."
>
> "equipment needed to capture water from nonconventional, alternate sources, including air-conditioning condensate or graywater, for nonpotable uses, and metering equipment needed to segregate water use in order to identify water conservation opportunities or verify water savings."

Performance contracts serve as a win-win opportunity for school districts and institutes of higher education to effect improvements on facilities for water- and energy-conservation without incurring net construction costs.

The State Energy Conservation Office, in Suggested Water Efficiency Guidelines for Buildings and Equipment at Texas State Facilities, recommends that use of alterative water sources be explored for landscape irrigation use. (See References.) Suggested water sources include captured stormwater or rainwater, air-conditioner condensate, water from basement sump pump discharge, and other sources, in accordance with local plumbing codes.

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Appendix B
Rainfall Data

The following data are provided for representative Texas cities in various geographical areas to assist in assessing the optimal storage size for a particular rainwater harvesting system. Each rainwater harvesting system designer should assess the variables of water demand, rainfall, catchment surface area, storage capacity, and risk tolerance when designing a rainwater harvesting system, especially one intended to be the sole water source.

Abilene

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Maximum	4.35	3.60	5.16	6.80	13.17	9.60	7.52	8.18	11.03	10.68	4.60	6.28	
Median	0.81	0.73	0.90	1.88	2.47	2.30	1.69	1.62	2.25	2.09	0.94	0.77	
Average	1.00	1.05	1.17	2.05	3.22	2.90	2.03	2.40	2.71	2.56	1.24	1.03	
Average annual rainfall													**23.36**

Amarillo

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.00	0.00	0.00	0.04	0.01	0.10	0.28	0.03	0.00	0.00	0.00	
Maximum	2.33	1.83	4.01	5.84	9.81	10.73	7.59	7.55	5.02	6.34	2.26	4.52	
Median	0.33	0.42	0.58	0.86	2.45	3.08	2.59	2.79	1.61	0.97	0.43	0.35	
Average	0.52	0.55	0.93	1.18	2.67	3.40	2.80	2.93	1.84	1.44	0.59	0.53	
Average annual rainfall													**19.39**

Austin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	
Maximum	9.21	6.56	6.03	9.93	9.98	14.96	10.54	8.90	7.44	12.31	7.95	14.16	
Median	1.27	2.30	1.73	2.20	3.68	2.89	1.15	1.27	2.98	2.82	1.88	1.42	
Average	1.77	2.37	1.90	2.83	4.33	3.54	1.73	2.18	3.17	3.63	2.25	2.26	
Average annual rainfall													**31.96**

Brady

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.10	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Maximum	6.40	5.30	4.30	6.02	8.00	7.70	13.55	11.30	9.45	7.04	10.40	7.90	
Median	0.60	1.26	0.90	1.78	3.10	1.87	0.85	1.34	2.40	1.70	1.10	0.70	
Average	1.03	1.50	1.26	2.07	3.40	2.40	1.80	2.01	2.86	2.34	1.43	1.28	
Average annual rainfall													**23.38**

Brownsville

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.34	0.01	0.00	
Maximum	4.79	10.25	5.72	10.35	9.12	8.52	9.43	9.56	20.18	17.12	7.69	3.98	
Median	0.77	0.84	0.41	0.84	1.86	2.22	0.96	2.45	4.69	2.92	0.90	0.78	
Average	1.31	1.38	0.80	1.62	2.39	2.55	1.50	2.69	5.19	3.62	1.55	1.10	
Average annual rainfall													**25.70**

College Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.22	0.1	0.29	0.08	0.23	0.09	0	0	0.32	0	0.19	0.23	
Maximum	15.6	9.82	6.07	12.5	11.38	12.63	7.06	10.63	12.13	12.91	8.33	10.72	
Median	2.205	2.72	2.12	3.75	4.515	2.895	1.97	1.84	4.12	3.18	2.92	2.635	
Average	2.87	2.88	2.5	3.77	4.73	3.79	2.24	2.43	4.3	3.64	3.07	3.15	
Average annual rainfall													**38.75**

Corpus Christi

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.10	0.49	0.00	0.00	0.01	
Maximum	10.78	8.11	4.89	8.04	9.38	13.35	11.92	14.79	20.33	11.88	5.24	9.80	
Median	0.99	1.36	0.78	1.39	2.70	2.43	1.04	2.64	4.00	2.60	1.34	0.90	
Average	1.54	1.85	1.36	2.03	3.12	3.16	1.80	3.28	5.21	3.50	1.57	1.59	
Average annual rainfall													**30.00**

Dallas

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.13	
Maximum	8.46	7.60	8.70	15.40	13.74	10.30	7.34	5.12	10.67	14.00	7.54	8.90	
Median	1.80	2.11	2.36	2.98	4.27	2.85	1.60	1.74	2.50	2.94	2.00	2.10	
Average	1.97	2.40	2.91	3.81	5.01	3.12	2.04	2.07	2.67	3.76	2.70	2.64	
Average annual rainfall													**35.10**

El Paso

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	
Maximum	2.23	1.69	2.26	1.42	4.22	3.18	5.53	5.57	6.68	3.12	1.63	3.29	
Median	0.29	0.34	0.18	0.09	0.10	0.36	1.18	1.06	0.96	0.55	0.24	0.42	
Average	0.42	0.40	0.30	0.21	0.32	0.70	1.57	1.45	1.38	0.71	0.36	0.61	
Average annual rainfall													**8.43**

Houston

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.36	0.38	0.11	0.43	0.04	0.26	0.45	0.31	0.80	0.05	0.41	0.64	
Maximum	9.78	5.99	8.52	10.92	14.39	16.28	8.10	9.42	11.35	16.05	10.07	9.34	
Median	2.82	2.63	3.19	2.59	5.02	3.55	2.69	3.52	3.92	3.79	3.27	3.41	
Average	3.68	2.95	3.40	3.54	5.36	5.07	3.05	3.69	4.31	4.63	4.09	3.54	
Average annual rainfall													**48.45**

Lubbock

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Maximum	4.05	2.51	3.34	5.63	13.38	8.43	7.20	8.85	8.55	10.80	2.67	2.24	
Median	0.33	0.39	0.63	1.08	2.23	2.37	2.07	1.78	1.87	0.98	0.45	0.42	
Average	0.52	0.62	0.90	1.24	2.64	2.95	2.16	2.15	2.49	1.81	0.67	0.56	
Average annual rainfall													**18.49**

San Angelo

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.01	0.00	0.00	0.26	0.05	0.00	0.00	0.00	0.00	0.00	0.00	
Maximum	3.65	4.47	5.00	5.10	11.24	6.01	7.21	8.13	11.00	8.68	3.55	3.98	
Median	0.58	0.62	0.65	1.29	2.32	2.09	0.70	1.38	2.38	1.90	0.68	0.33	
Average	0.79	1.04	0.92	1.66	2.78	2.20	1.10	1.75	2.83	2.24	0.98	0.76	
Average annual rainfall													**19.12**

San Antonio

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.00	0.01	0.03	0.02	0.00	0.01	0.00	0.00	0.05	0.00	0.00	0.03	
Maximum	8.52	6.43	6.12	9.32	12.85	11.95	8.29	11.14	13.09	17.96	8.51	13.96	
Median	1.10	1.85	1.27	1.94	3.04	2.70	1.21	2.00	2.24	2.75	1.93	1.09	
Average	1.59	1.92	1.66	2.52	3.97	3.61	1.82	2.45	3.08	3.42	2.24	1.69	
Average annual rainfall													**29.96**

Waco

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	0.03	0.00	0.04	0.12	0.52	0.27	0.00	0.00	0.00	0.00	0.13	0.04	
Maximum	5.92	7.69	5.56	13.37	15.00	12.06	8.58	8.91	7.29	10.51	7.03	9.72	
Median	1.55	2.00	2.22	2.76	3.87	2.34	0.82	0.96	2.57	2.37	2.29	1.94	
Average	1.83	2.28	2.25	3.30	4.49	2.98	1.82	1.76	3.02	3.12	2.40	2.31	
Average annual rainfall													**31.68**

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Appendix C
Case Studies

Lady Bird Johnson Wildflower Center
Austin

4801 La Crosse Avenue
Austin, Texas 78739
(512) 292-4100
http://www.wildflower.org

Capacity: 70,000 gallons
Catchment area: 17,000 square feet
Demand: Gardens and landscaping



The entry cistern at the Lady Bird Johnson Wildflower Research Center is reminiscent of the stone-and-mortar cisterns used by Hill Country settlers. Water from a 1,200-square-foot roof area is conveyed to the entry cistern via an aqueduct.

Harvested rainwater from three separate catchment areas provides 10 to 15 percent of the garden and landscaping irrigation of the Lady Bird Johnson National Wildflower Research Center in Austin. An integral part of its architecture, the Center's rainwater harvesting system serves to not only conserve water, but also as a public education tool. The Center collects water from 17,000 square feet of roof space and can store more than 70,000 gallons in on-site cisterns.

One of the most prominent features of the center is the 43-foot native-stone-façade tower cistern, which is built around a 5,000-gallon storage tank. Metal rooftops totaling an area of 17,000 square feet drain into the tower cistern and two 25,000-gallon tanks collect a total of about 300,000 gallons in an average rainfall year. A pressurized distribution system delivers water from the large tanks to an irrigation system. The municipal water supply is linked to the systems with backflow prevention devices to prevent water contamination.

The 3,000-gallon entry cistern, fed by an elevated stone-faced aqueduct draining just less than 1,200 square feet of roof area, is reminiscent of rainwater cisterns used by original Hill Country settlers. The Little House cistern captures rainwater from a roof area of about 700 square feet in the Children’s Area.

In addition, the Wetland Pond, the Commons Well, and the Balcony Spring together collect 2,500 gallons per inch of rain from the roofs, although water from these features is not used for irrigation.

H-E-B
Austin

6900 Brodie Lane
(corner William Cannon Blvd. and Brodie Lane)
Austin, Texas 78745

Capacity:	28,000 gallons
Catchment area:	50,000 square feet
Demand:	Native and adapted plant landscape



The H-E-B at the corner of Brodie Lane and William Cannon Blvd. in south central Austin irrigates an adjacent landscape of water-thrifty plants with rainwater stored in four painted steel tanks totaling 28,000 gallons. A 24-inch-diameter pipe conveys water from the roof to the tanks.

Two 8,000-gallon and two 6,000-gallon painted steel tanks are fed from a 24-inch-diameter collection pipe draining the 50,000-square-foot roof. Using efficient drip irrigation, captured rainwater irrigates an adjacent water-thrifty landscape of native and adapted trees and ornamentals. Walkways and plant labels enhance the attractiveness of the site.

The four tanks are connected with 6-inch PVC pipes and valves, allowing a tank to be taken off-line to be drained and cleaned.

H-E-B, based in San Antonio, prides itself on environmental stewardship in the communities where its supermarkets conduct business. H-E-B saves 6.2 million gallons of water annually by recycling condensation from manufacturing steam equipment.



Tanks are linked with 6-inch PVC pipe. Valves allow taking one or more tank off-line for draining or cleaning.

Sunset Canyon Pottery
Dripping Springs

4002 E. Highway 290
Dripping Springs, Texas 78620
(512) 894-0938

Sunset Canyon Pottery supplies all its potable and pottery works water demand with water stored in a 46,000-gallon ferrocement tank. When visiting this site on private property, please first request permission from Sunset Canyon Pottery staff.

The ferrocement tank at Sunset Canyon Pottery supplies process water for pottery works, as well as potable water for the straw-bale studio and gift shop. The tank was constructed first by forming an armature of steel reinforcement bars, then spraying on a cement-like material similar to that used for in-ground swimming pools.

New Braunfels Municipal Utility District
New Braunfels

New Braunfels Utilities Service Center
355 FM 306
New Braunfels, Texas 78130

The New Braunfels Utilities Service Center, completed in 2004, captures rainwater in four 1,000-gallon plastic-lined galvanized steel tanks, one located at each building wing. Water is used to irrigate the landscape of native and adapted plants. The metal tanks form both a practical and aesthetic feature of the architecture of this public building.



Four lined, galvanized steel tanks will capture water for irrigation of native and adapted plants.

Hays County Cooperative Extension Office
San Marcos

1253 Civic Center Loop
San Marcos, Texas 78666
(512) 393-2120

Capacity:	750-gallon galvanized metal tank 1,600 polyethylene tank
Catchment area:	2,500 square feet
Demand:	Demonstration garden
Cost:	$1,125



As a demonstration project, a 750-gallon galvanized steel tank captures rainwater from the 5,000-square-foot roof of the Hays County Extension Office.

The Hays County Extension Office captures rainwater from half the roof area of its 5,000-square-foot building in two tanks: a 750-gallon galvanized steel tank and a 1,600-gallon black polypropylene tank using existing guttering and downspouts. Plans are in the works for water to be gravity-fed to an adjacent Master Gardener demonstration garden.

Edwards Aquifer Authority
San Antonio

1615 N. St. Mary's Street
San Antonio, TX 78215
(210) 222-2204

Capacity:	2,500 gallons
Catchment area:	1,135 square feet
Demand:	Landscaping

The Edwards Aquifer Authority collects rainwater from a catchment area of 1,135 square feet in two cisterns. Water is delivered through gravity flow into a 500-gallon polypropylene tank in the courtyard area. The second cistern, a 2,000-gallon ranch-style metal cistern, is located on the front lawn, visible from the street. Harvested rainwater is used to irrigate the 266-square-foot courtyard, and 2,700-square-foot lawn.



A 2,000-gallon, ranch-style metal cistern is one of two tanks that capture rainwater for landscaping at the Edwards Aquifer Authority building. (Photo courtesy: Lara Stuart)

J.M. Auld Lifetime Learning Center
Kerrville

1121 Second Street
Kerrville, Texas 72028
(830) 257-2218

Capacity:	6,600 gallons (Two 3,300-gallon stacked concrete ring tanks)
Catchment area:	5,000 square feet
Demand:	Adjacent gardens Pondless waterfall
Total Cost:	$10,500
Breakdown:	Two 3,300 concrete tanks, $4,766 Plumbing supplies, $520 Pump, pressure tank, switch, $1,535 Gutter work, $541 Electrical supplies, $160 Trencher rental, $175 In-kind labor, Kerrville ISD, $2,800



Stacked concrete ring 3,000-gallon tank at the Auld Center, Kerrville, showing first flush diverter and cistern.

The Auld Lifelong Learning Center of Kerrville Independent School District is a community education facility operated by Kerrville Independent School District. Installed in 2003, two 3,300-gallon stacked concrete-ring tanks collect rainwater from a 5,000-square-foot roof. Tanks are located at the back corners of the building, with a transverse 3-inch PVC pipe conveying the rainwater drained from the front half of the roof. Five-gallon first flush diverters at each corner capture the dust and debris of the initial runoff of each rainfall event.

Tanks are fitted with unique water-level sight gages. Vertical rods the same length as the tank height are suspended on floating platforms within the tank. The length of rod protruding from the tops of tanks indicates water level.

Captured rainwater will irrigate several adjacent themed gardens. In addition, a unique water feature, a recirculating waterfall, adds aesthetic interest.

Menard ISD Elementary School
Menard

200 Gay St.
Menard, Texas 76859

Container garden and landscape-plant irrigation

Capacity:	1,000-gallon green polyethylene tank
Catchment area:	600 square feet
Demand:	50 emitters: 20 landscape plants, 30 container garden emitters
Total cost:	$475
Breakdown:	Tank, $400 Connections and valves/roofwasher, $35 Black poly pipe and emitters, $40

The rainwater harvesting system serves multiple purposes of education, beauty, and habitat improvement at Menard Independent School District Elementary School. The wildscape provides the requirements of food, water, and shelter for native animals. The demonstration site aids in teaching students about healthful wildlife habitats and container and landscape gardening. The water features, gazebo, and rock walkway enhance the outdoor esthetics of the school. A backyard wildscape at Menard Elementary School demonstrates the requirements of food, water, and shelter for rangeland maintenance conducive to supporting wildlife. Using existing gutters and downspouts from the roof of Menard Elementary School, rainwater is diverted into two 1,000-gallon green polypropylene tanks. One tank supplies a birdbath made of rocks with natural cavities and a prefabricated pond. Both water features are supplied with water conveyed by gravity pressure through 3/4-inch PVC pipe and drip emitters. Native plants provide a food source and cover for wildlife.



Using existing gutters and downspouts, rainwater harvesting techniques were used to create a backyard wildscape. The principles of wildscape construction can be transferred to large wildlife management programs.



Menard Elementary School rainwater harvesting installation showing downspout, 1,000-gallon poly tank, and gazebo (left) surrounded by native and adapted landscape plants. In this very attractive installation, harvested rainwater (using existing gutter and downspouts) furnishes water not only to the landscape, but also to a watering pond, birdbath, and wildlife guzzler. (Photo courtesy: Billy Kniffen)

Walker County Cooperative Extension Office
Huntsville

102 Tam Road
Huntsville, Texas 77320
(936) 435-2426

Capacity:	550-gallon polyethylene tank
Catchment area:	1,500 square feet
Demand:	Master Gardener demonstration plot
Total cost:	Total: $230
Breakdown:	Used 550-gallon tank, $150 Plumbing supplies and fittings, $70 Glue, thinner, and paint, $10



Rainwater captured from the 1,500-square-foot roof of the Walker County Extension office is stored in a 550-gallon polypropylene tank, a type readily available at ranch supply retailers. The 10-gallon flush diverter is the vertical standpipe visible to the left of the tank. Captured rainwater irrigates an adjacent Master Gardener demonstration garden, foreground.

The Walker County Master Gardeners and staff of Texas Cooperative Extension, supervised by agricultural county agent Reginald Lepley, installed a rainwater harvesting system at the Walker County Extension office for a cost of less than $250. A used white 550-gallon polypropylene tank was thoroughly cleaned and pressure-washed, and painted with brown latex paint to discourage algae growth. Raising the tank on concrete blocks allows gravity flow to a 10-foot by 25-foot Master Gardener demonstration garden. A detailed parts list, instructions and tips for rainwater harvesting in general, and more information on this installation can be found at

urbantaex.tamu.edu/D9/Walker/AG/HomeHort/WCMG/hortdemo/Waterdemo/index

AMD/Spansion FAB25
Austin

5204 E. Ben White Blvd.
Austin, Texas 78741

Rainwater drained from the facility's roofs and groundwater from the building perimeter drains furnish all the water needed for landscape irrigation on AMD's Spansion site in east Austin. Water is collected and stored in a 10,000-gallon fiberglass tank, and then pressurized through the site irrigation loop using surplus pumps. The water savings has been verified at about 4.75 million gallons per year using online flow meters. In-house engineers designed the system and facilities tradespersons installed the tank, pump, piping, and electricity. The irrigation reclaim system has a three-year return on investment.

The plant also has segregated drains that allow the reuse and recycling of rinse water from the wafer manufacturing process for cooling tower and Ultra-pure treatment plant makeup drastically reducing city-supplied water. The water savings from the rinse water reuse system is approximately 210 million gallons per year and had a return on investment of less than one year.

J.J. Pickle Elementary School/St. John Community Center
Austin

Corner of Blessing and Wheatley Avenues
Austin, Texas

A model of sustainable design and building, the J.J. Pickle Elementary and St. John Community Center in northeast Austin is a joint project of Austin Independent School District and the City of Austin. Water from a portion of the 116,200-square-foot facility drains into three tanks, which provide cooling water to the air-conditioning system.

For energy savings, the classrooms, gym, dining area, and City library use sunlight rather than electric lights during the day. The complex opened in January 2002, with operational and maintenance cost savings of $100,000 expected each year.

The complex includes a public elementary school, shared gymnasium, a health center, public and school libraries, and a community policing office. The cost of construction is $13.6 million, with the AISD funding about $8.3 million and the City of Austin funding about $5.3 million. The money came from a 1996 School District bond election and a City 1998 bond package.





Water collected from the roof of the J.J. Pickle Elementary School and St. John Community Center is stored in three large tanks behind the building and used as cooling water for the complex's air-conditioning system.

Feather & Fur Animal Hospital
Austin

9125 Manchaca Road
Austin, Texas 78748

Captured water from the roof, parking lot, and condensate from the air conditioners is the sole source irrigation water for a 1-acre turf landscape at the Feather & Fur Animal Hospital in South Austin. Dr. Howard Blatt first explored ways to make use of an existing hand-dug 18,000-gallon underground cistern. The project has since been expanded to take advantage of other rainwater sources.



The Feather & Fur Animal Hospital in South Austin features a standing-seam metal roof for rainwater harvesting.

Rainwater collected from a standing-seam metal roof gravity flows into the cistern. Then water from the parking lot flows through a water quality pond with gabion for sedimentation and filtration treatment. From the pond, water flows via a 6-inch pipe to catch basin. A small sump pump empties to a 12,500-gallon fiberglass tank. Additionally, the primary condensation line from the air handlers also drains into the gutter and downspout system, which services the roof.

Pomerening/Dunford Residence
Bexar County

The Pomerening/Dunford family lives on the western edge of Bexar County and uses rainwater harvesting for all of their potable needs. The four-year-old installation features two 10,000-gallon cisterns that store captured water from a 2,400-square-foot collection area.



Two 10,000-gallon cisterns collect rainwater at the Pomerening/Dunford residence in Bexar County.

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Appendix D
Tax Exemption Application Form

Comptroller of Public Accounts 01-339(Back) (Rev. 6-04/5)

TEXAS SALES AND USE TAX EXEMPTION CERTIFICATION

Name of purchaser, firm or agency	
Address *(Street & number, P.O. Box or Route number)*	Phone *(Area code and number)*
City, State, ZIP code	

I, the purchaser named above, claim an exemption from payment of sales and use taxes (for the purchase of taxable items described below or on the attached order or invoice) from:

Seller: _____

Street address: _____ City, State, ZIP code: _____

Description of items to be purchased or on the attached order or invoice:

Purchaser claims this exemption for the following reason:

I understand that I will be liable for payment of sales or use taxes which may become due for failure to comply with the provisions of the Tax Code: Limited Sales, Excise, and Use Tax Act; Municipal Sales and Use Tax Act; Sales and Use Taxes for Special Purpose Taxing Authorities; County Sales and Use Tax Act; County Health Services Sales and Use Tax; The Texas Health and Safety Code; Special Provisions Relating to Hospital Districts, Emergency Services Districts, and Emergency Services Districts in counties with a population of 125,000 or less.

I understand that it is a criminal offense to give an exemption certificate to the seller for taxable items that I know, at the time of purchase, will be used in a manner other than that expressed in this certificate and, depending on the amount of tax evaded, the offense may range from a Class C misdemeanor to a felony of the second degree.

sign here ▶ Purchaser	Title	Date

NOTE: This certificate cannot be issued for the purchase, lease, or rental of a motor vehicle.
THIS CERTIFICATE DOES NOT REQUIRE A NUMBER TO BE VALID.
Sales and Use Tax "Exemption Numbers" or "Tax Exempt" Numbers do not exist.

This certificate should be furnished to the supplier. Do **not** send the completed certificate to the Comptroller of Public Accounts.

Better Site Design

I. An Introduction to Better Site Design

Few watershed management practices simultaneously reduce pollutant loads, conserve natural areas, save money, and increase property values. Indeed, if such "wonder practices" were ever developed, they would certainly spread quickly across the nation. As it turns out, these practices have existed for years. Collectively called "better site design," the techniques employ a variety of methods to reduce total paved area, distribute and diffuse stormwater, and conserve natural habitats. Despite their proven benefits and successful local application, better site design techniques often fail to earn the endorsement of local communities. In fact, many communities simply prohibit their use.

"Better site design" is a fundamentally different approach to residential and commercial development. It seeks to accomplish three goals at every development site: to reduce the amount of impervious cover, to increase natural lands set aside for conservation, and to use pervious areas for more effective stormwater treatment. To meet these goals, designers must scrutinize every aspect of a site plan—its streets, parking spaces, setbacks, lot sizes, driveways, and sidewalks— to see if any of these elements can be reduced in scale. At the same time, creative grading and drainage techniques reduce stormwater runoff and encourage more infiltration.

Why is it so difficult to implement better site design in so many communities? The primary reason is the outdated development rules that collectively govern the development process: a bewildering mix of subdivision codes, zoning regulations, parking and street standards, and drainage regulations that often work at cross-purposes with better site design. Few developers are willing to take risks to bend these rules with site plans that may take years to approve or that may never be approved at all.

In 1997, a national site planning roundtable was convened to address ways to encourage better site design techniques in more communities. The participants represented the diverse mix of organizations that affect the development process (listed in Table 1) and provided the technical and real world experience to make better site design happen. After two years of discussion, the roundtable endorsed 22 better site design techniques that offer specific guidance that can help achieve one of the basic better site design goals. These techniques are organized into three areas:

1. Residential Streets and Parking Lots
2. Lot Development
3. Conservation of Natural Areas

These techniques are not intended to be strict guidelines, and their actual application should be based on local conditions. The remainder of this article introduces each of the better site design techniques, describes some of the barriers to their wider use, and suggests ways to overcome these impediments.

Residential Streets and Parking Lots

As much as 65% of the total impervious cover in the landscape can be classified as "habitat for cars," which includes streets, parking lots, driveways, and other surfaces designed for the car. Consequently, 10 better site design techniques address ways to reduce car habitat in new developments.

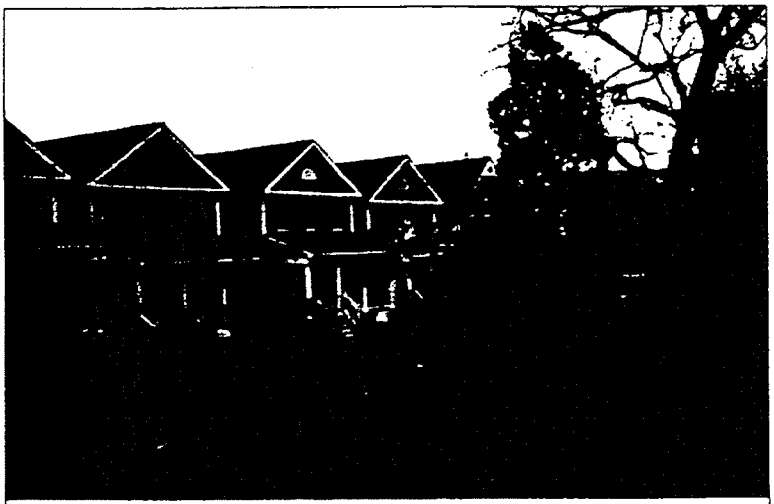

Figure 1: A Neotraditional Community in Gaithersburg, MD
Better site design techniques have been successfully applied in a growing number of communities like the Kentlands.

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Table 1: Organizations Represented at the National Site Planning Roundtable (Source: CWP,1998b)

The following organizations participated in a two-year long process to craft and refine the 22 model development principles. For a full look at the national consensus agreement, consult our web site at www.cwp.org.

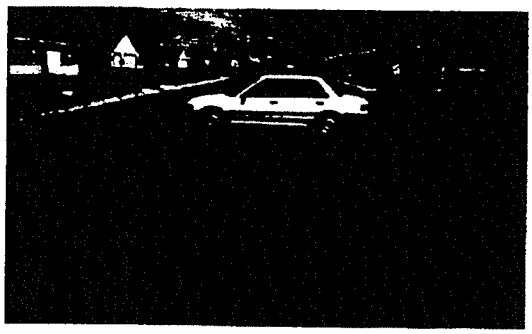
American Association of State Highway Transportation Officials
American Forest Association
American Institute of Architects
American Planning Association
American Public Works Association
American Rivers
American Society of Civil Engineers
American Society of Landscape Architects
Chesapeake Bay Program
Community Associations Inc.
The Conservation Fund
Office of Comprehensive Planning, County of Fairfax, VA
Howard Research and Development Corporation an affiliate of the Rouse Company
Institute of Transportation Engineers
International City/ County Management Association
Land Trust Alliance
Linowes & Blocher
Loiederman Associates, Inc.
Michael T. Rose Company
Montgomery County Council
Natelli Communities
National Association of Home Builders
National Realty Committee
Natural Resources Defense Council
Prince Georges County Department of Environmental Resources
U.S. EPA Office of Sustainable Ecosystems and Communities
U.S. Fire Administration
Urban Land Institute
Urban Wildlife Resources

Design residential streets for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency, maintenance, and service vehicle access. Street widths should be based on traffic volume.

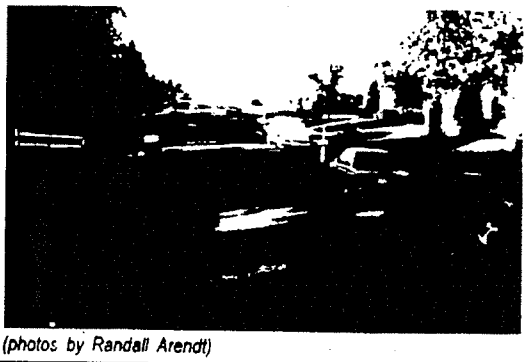
In some communities, residential streets can be 32, 36, and even 40 feet wide, despite the fact that they only serve a few dozen homes. These wide streets are the greatest source of impervious cover in most subdivisions. Wide residential streets are created by blanket applications of high volume and high speed design criteria, the perception that on-street parking is needed on both sides of the street, and the perception that they provide unobstructed access for emergency vehicles.

Communities have a significant opportunity to reduce impervious cover by revising their street standards to widths of smaller residential access streets. Residential streets widths should be designed to handle expected traffic volumes, provide adequate parking, and ensure access for service, maintenance, and emergency vehicles. Two strategies can help to narrow streets: using queuing streets (see Figure 2) and critically evaluating the need for on-street parking on both sides of the street. Several national engineering organizations have recommended residential streets as narrow as 22 feet in width (ASSHTO, 1994 and ASCE, 1990).

Conventional Street



Queuing Street



(photos by Randall Arendt)

Figure 2: Queuing Streets as a Technique for Minimizing Street Width
While traditional streets are composed of two travel lanes and parking on either side of the road, queuing streets have one designated travel lane and two queuing lanes that can be used for travel or parking.

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Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.

It stands to reason that a longer street network produces more impervious cover and greater development costs than a shorter one, yet most communities do not even consider whether a shorter street network can serve individual lots on residential streets. It is generally assumed that the cost of constructing roads is sufficient incentive to assure short street networks. Streets are designed to accommodate rapid, smooth traffic flow, and consequently, total street length is rarely the most important design consideration.

There is no one street layout guaranteed to minimize total street length in residential developments. Instead, site designers are encouraged to analyze different layouts to see if they can reduce street length.

Wherever possible, residential street right-of-way widths should reflect the minimum required to accommodate the travel-way, the sidewalk, and vegetated open channels. Utilities and storm drains should be located within the pavement section of the right-of-way wherever feasible.

In many communities, a single right-of-way width of 50 feet or more is applied to all residential street categories. While a wide right-of-way does not necessarily create more impervious cover, it requires more clearing and consumes land that could be used for achieving a more compact site design. By redesigning each of the main components of the right-of-way (ROW), the total width of the ROW can be sharply reduced. Techniques include reducing street width, narrowing sidewalks or restricting them to one side, narrowing the distance between street and sidewalk, and installing utilities beneath street pavement. Combined, these techniques narrow the ROW by 10 to 25 feet.

Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.

Many communities require the end of cul-de-sacs to be 50 to 60 feet in radius, creating large circles of needless impervious cover. There are several different options to reduce the impervious cover created by traditional cul-de-sacs. One option is to reduce the radius of the turnaround bulb. Several communities have implemented this successfully and the smaller radii can range from 33 to 45 feet. Since vehicles only use the outside of a cul-de-sac when turning, a second option is to create a pervious island in the middle of the cul-de-sac, creating a donut-like effect. A third option is to replace cul-de-sacs with loop roads and hammerheads (see Figure 3).

Engineering techniques have improved the performance of conventional roadside ditches.

Where density, topography, soils, and slope permit, vegetated open channels should be used in the street right-of-way to convey and treat stormwater runoff.

Communities often require that curbs and gutters be installed along residential streets, which quickly convey stormwater runoff and associated pollutant loads directly into the stream. In contrast, open channels can remove pollutants by infiltration and filtering, and are also often less expensive than curb and gutter systems.

New engineering techniques have greatly improved the performance of conventional roadside ditches, which have traditionally suffered from erosion, standing water and increased pavement maintenance. One alternative is dry swales, which are designed both to convey the 10 year storm and treat a water quality stream through a sandy loam filter along the roadway (see Figure 4).

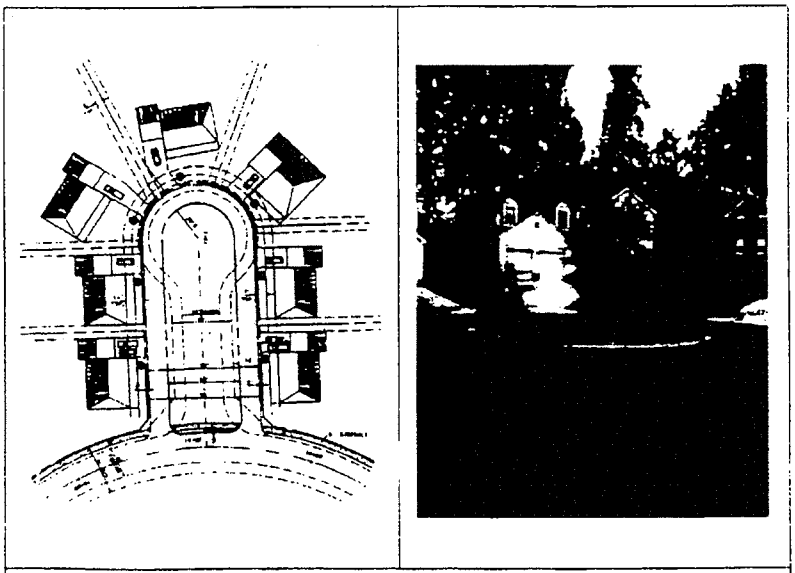

Figure 3: Two Alternatives to the Traditional Cul-de-Sac
A loop road or a pervious island in the middle are two alternatives that can significantly reduce impervious cover.

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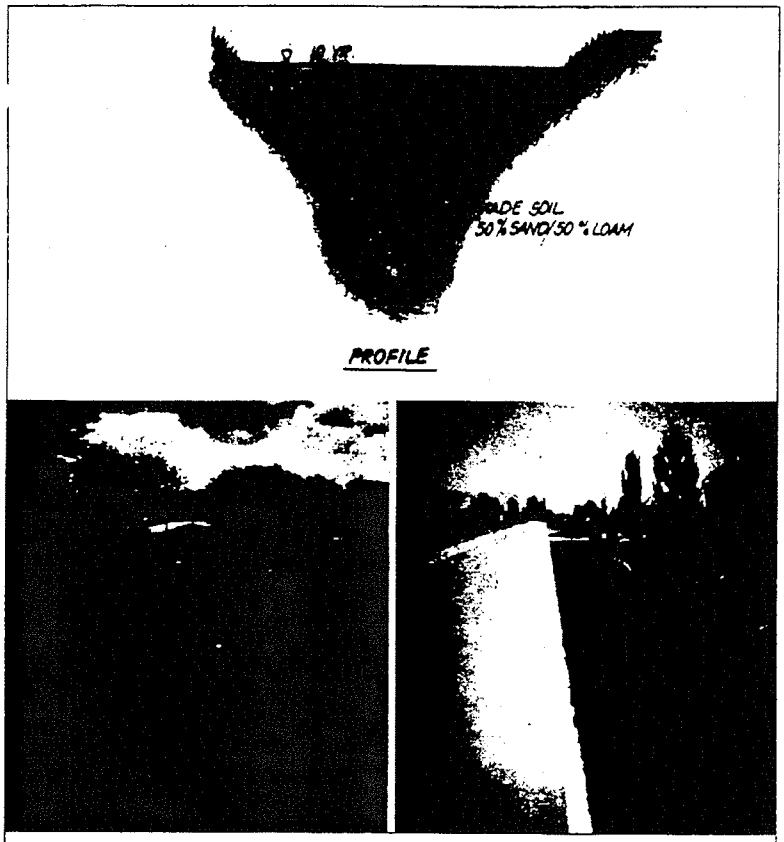

Figure 4: Profile and Two Examples of Open Vegetated Channels

Open vegetated channels allow for infiltration and treatment of stormwater on-site. A dry swale is typically designed to convey the 10 year storm, while treating smaller events with a subsurface composed of a sand and loam filler that treats the runoff before it enters a stream.

The required parking ratio governing a particular land use or activity should be enforced as both a maximum and a minimum in order to curb excess parking space construction. Existing parking ratios should be reviewed for conformance, taking into account local and national experience to see if lower ratios are warranted and feasible.

Many communities routinely build more parking spaces than are needed to meet actual parking demands. This is a result of using outdated or overly generous local parking codes to determine minimum parking ratios.

Communities should check their local codes to ensure that both a minimum and a maximum number of parking spaces are set for each building project (see Table 2 for recommended maximum parking spaces). By referring to national, regional and/or local studies, communities can evaluate their parking needs more accurately, thereby reducing the creation of unnecessary parking spaces. Even small reductions in parking can reduce construction and stormwater management costs. As it turns out, shrinking parking lots is critical in reducing the impact of commercial development (see next Feature Article).

Parking codes should be revised to lower parking requirements where mass transit is available or enforceable shared parking arrangements are made.

Despite the fact that parking lot size can shrink dramatically if credits for shared parking or mass transit are provided, only a handful of communities require or encourage developers to use these tools. Shared parking allows adjacent land uses to share parking lots if peak parking demands occur during different times of the week. Mass transit can reduce the number of vehicle trips, which translates directly into smaller parking lots.

Despite challenges, several communities have successfully provided parking credits for shared parking for reducing the total number of parking spaces created. One such example is Oakland, California, where a thorough study of short and long term parking demand was conducted. By taking an inventory of existing land uses, parking, and occupancy; and by considering vacancy factors, mass transit access, low auto ownership, and operations of special use facilities, the study concluded that parking rate for office space could be reduced from three spaces to 1.44 spaces per 1,000 gross square feet (ITE, 1995).

Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, and using pervious materials in the spillover parking areas where possible.

Reducing the size of parking stall dimensions represents another opportunity to reduce impervious cover. The length and often the width of a typical parking stall can often be reduced by a foot or more.

Table 2: Recommended Parking Demand Ratios for Selected Land Uses
(Source CWP 1998b)

Land Use	Better Site Design Parking Ratios
Single Family Homes	2 spaces or less per dwelling unit*
Professional Offices	3.0 spaces or less per 1000 ft²
Retail	4.0 to 4.5 spaces or less per 1000 ft²

* can be accommodated in driveway

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Parking codes can also be amended to require a fixed percentage of smaller stalls for compact cars. Lastly, while permeable parking surfaces can be more expensive to install and maintain, the use of these materials in the 10-20% of the lot that will be used for spillover parking can reduce stormwater treatment costs.

Provide meaningful incentives to encourage structured and shared parking to make it more economically viable.

The type of parking facility in a development site is usually determined by the cost of land balanced against the cost of constructing parking. In suburban and rural areas, the low cost of land makes surface parking more cost-effective than building a garage. In highly urban areas, garages may be a more economical option, since land costs are at a premium.

Vertical parking structures can significantly reduce impervious cover by reducing acreage converted to parking. However, given the economics of surface parking versus garages, it is unlikely that garages will become the norm without incentives. Incentives for defraying some of the costs of parking garages could include tax credits, stormwater waivers or bonuses for density, floor area or building height. A simple way to save on the cost of garages is to incorporate them below or on the first floor of buildings, thereby reducing the structural cost for parking.

Wherever possible, provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands.

Although parking lots are a significant source of stormwater pollution, many communities do not require developers to provide stormwater quality control. In other communities, opportunities to minimize and treat stormwater runoff at the parking lot are often overlooked. Parking lots can be made more attractive at the same time they treat stormwater. Bioretention areas, dry swales, perimeter sand filters, and filter strips are all effective at treating stormwater within the parking lot. Figure 5 provides a schematic diagram and example of a bioretention facility.

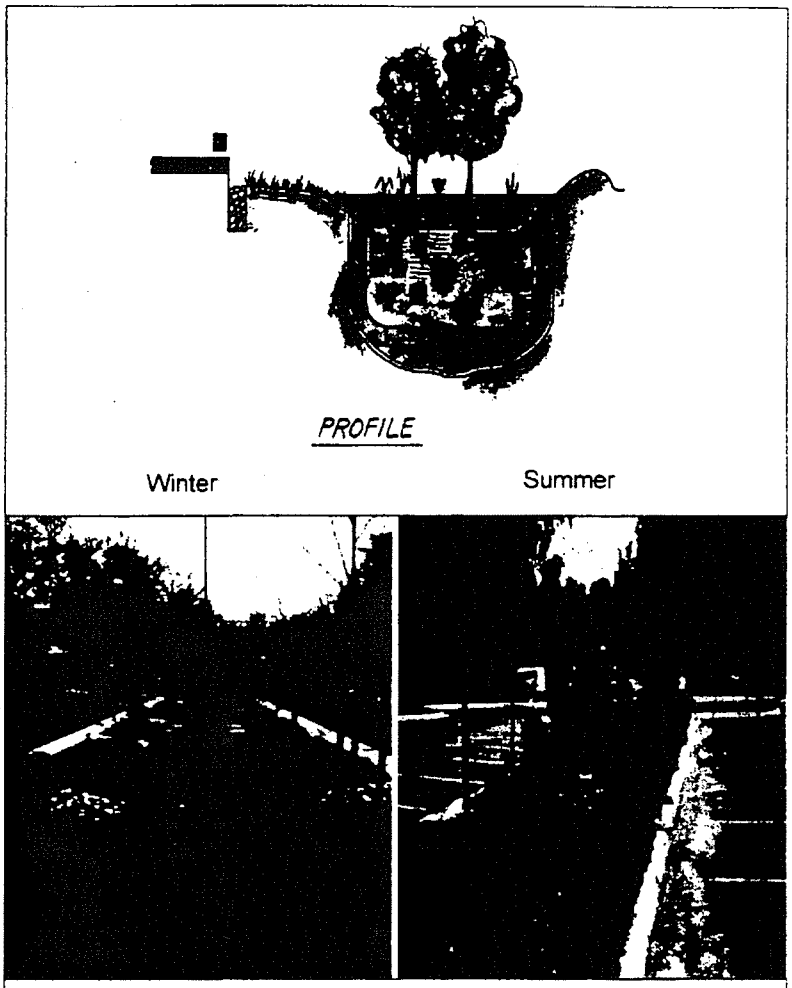

Figure 5: Profile of Parking Lot Bioretention Facilities
Bioretention areas can be designed for parking lots or on-site residential stormwater treatment, and can be an attractive landscaping feature in all seasons.

Lot Development

Many opportunities exist to reduce impervious cover in residential developments by modifying the shape, size, and layout of residential lots. Perhaps the greatest opportunity is to shift from conventional subdivisions to open space or cluster subdivisions.

Advocate open space design subdivisions incorporating smaller lot sizes to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space, and promote watershed protection.

Open space subdivisions cluster houses into a smaller portion of the development site, leaving more of the site as natural open space. Figure 6 illustrates the differences between a conventional and an open space subdivision. Open space subdivisions have been documented to reduce impervious cover, stormwater runoff, and construction costs (see the second feature article in this issue for more details). While open space subdivisions are not always feasible in dense residential zones (more than six dwelling units per acre), communities that can utilize this technique should consider making open space subdivisions a by-right development option.

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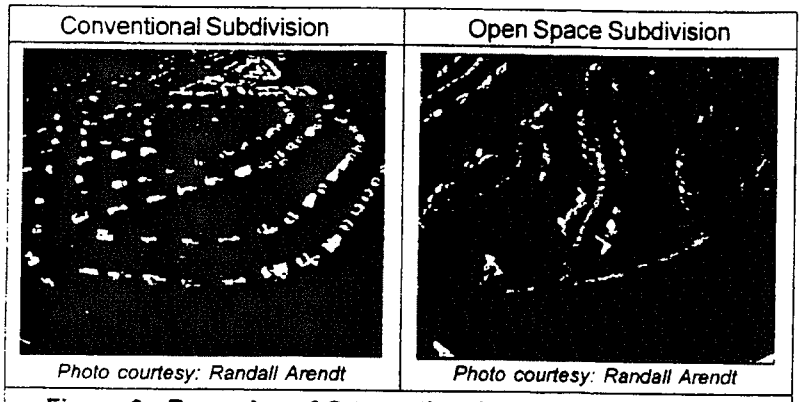

Figure 6: Examples of Conventional and Open Space Site Designs
Many conventional developments are designed using a cookie-cutter approach. Open space site designs preserve more of the existing vegetation and reduce the amount of land that is cleared and graded for individual lots.

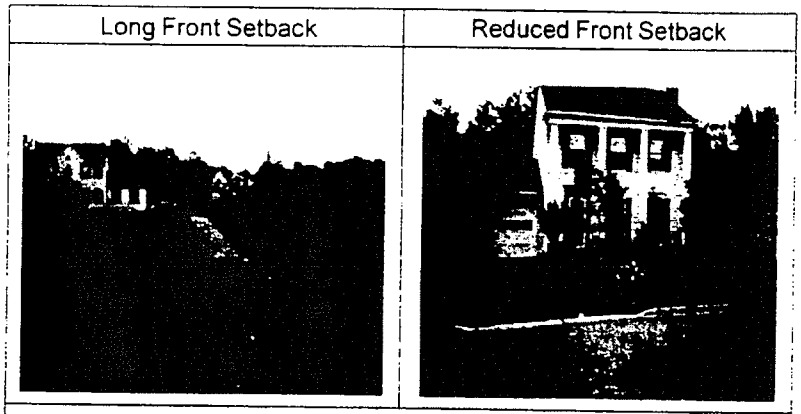

Figure 7: Examples of Long and Reduced Front Setbacks
Smaller front setbacks can reduce site impervious cover, but many current subdivision codes have strict requirements that govern setbacks.

Although open space subdivisions (also known as cluster design) have been advocated by planners for many years, they are often prohibited or severely restricted by local zoning regulations. In 95% of communities surveyed by Heraty (1992), clustering is a voluntary, rather than a mandatory, development option. In addition, open space subdivisions often require a special exception or zoning variance (i.e. they are not a by-right form of development) which requires more review time. Consequently, open space designs are not always widely exercised by developers.

Relax side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front setback requirements to minimize driveway lengths and reduce overall lot imperviousness.

Many current subdivision codes have very strict requirements that govern lot geometry, including setbacks and lot shape. These criteria constrain site planners from designing open space or cluster developments that can reduce impervious cover. Smaller front and side setbacks, often essential for open space designs, are typically not allowed or require a zoning variance that may be difficult to obtain.

Relaxing setback requirements allows developers to create attractive, compact lots that are marketable and livable (see Figure 7). For example, side yard setbacks can be as close as five feet from detached housing without specific fire protection measures. Often, fears about fire safety, noise, parking capacity and sight distance impairment are cited as impediments to shorter setbacks, but the reality is that these concerns can be overcome with careful design.

Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and providing common walkways linking pedestrian areas.

Most subdivision codes require sidewalks on both sides of residential streets, constructed of impervious concrete or asphalt, 4-6 feet wide, and 2-10 feet from the street. While these codes are intended to promote pedestrian safety, sidewalks should not be designed so rigidly. Instead, the general goal should be to improve pedestrian movement by diverting it away from street traffic. Often, a sidewalk on one side of the street is sufficient. In fact, in a study of pedestrian accidents associated with sidewalks, there was a negligible difference in accident rates when sidewalks were reported on just one side of the street versus sidewalks on both sides of the street (NHI, 1996).

Communities should also consider reducing the sidewalk width of sidewalks to 3-4 feet and placing them further from the street. Sidewalk design should emphasize the connections between neighborhoods, schools, and shops, instead of merely following the road layout (Figure 8). In addition, sidewalks should be graded to drain to front yards rather than the street. These alternatives reduce impervious cover and provide practical, safe, and attractive travel paths.

Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together.

Most local subdivision codes are not very explicit as to how driveways should be designed. Most simply require a standard apron to connect the street to the driveway but do not specify width or

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surface material for driveways. Typical residential driveways are 12 feet wide for one car driveways and 20 feet wide for two. Shared driveways are discouraged or prohibited by many communities.

Shared driveways can reduce impervious cover, and can work when maintenance agreements and easements can be enforced. By specifying narrower driveways, promoting permeable paving materials, and allowing two-track driveways or gravel and grass surfaces, communities can sharply reduce the typical 400 to 800 square feet of impervious cover created by each driveway (see Figure 9).

Clearly specify how community open space will be managed and designate a sustainable legal entity responsible for managing both natural and recreational open space.

Open space subdivisions encourage the preservation of common areas that must be effectively managed. Surveys of local open space regulations, however, revealed that open space was poorly defined in most communities (Heraty, 1992). Less than a third required that open space be consolidated. Only 10% required that a portion of open space be maintained as natural cover, and few specified which uses were allowed or excluded in the open space areas. Some communities are wary of open space because they feel that community associations may lack financial, legal, or technical resources to effectively maintain their common areas.

In reality, open space maintained in a natural condition costs up to five times less to maintain than lawns. Communities should explore more reliable methods to assure that responsibility is taken for open space management. Effective methods include creating a community association, or shifting responsibility to a land trust or park through a conservation easement.

Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas and avoid routing rooftop runoff to the roadway and the stormwater conveyance system.

Often, local codes discourage the storage and treatment of rooftop runoff on individual lots, thus bypassing opportunities to promote filtering or infiltration in the front or back yard. Most subdivision codes require that yards have a minimum slope to ensure drainage away from homes. The slope helps move runoff away from the home to prevent nuisance ponding, basement flooding, or ice formation on driveways or sidewalks. However, these concerns are only significant within 10 or 15 feet from the home foundation.

Sending rooftop runoff over a pervious surface before it reaches an impervious one can decrease the annual runoff volume from residential development sites by as much as 50%. Techniques to treat rooftop runoff in the yard include directing flow into small bioretention areas that encourage sheet flow across vegetated areas (see Figure 10) or infiltrate runoff in trenches, dry wells, or french drains.

Conservation of Natural Areas

Conservation of natural areas is integral to better site design, and the last six techniques deal with conserving and managing natural areas at the development site. These techniques include stream buffers, clearing and grading, tree conservation and stormwater treatment. To fully utilize these techniques, communities may need to offer developers both flexibility and incentives.

Create a variable width, naturally vegetated buffer system along all perennial streams that also encompasses critical environmental features such as the 100-year floodplain, steep slopes and freshwater wetlands.

This technique establishes a three-zone buffer system to protect streams, shorelines and wetlands at the development site (Figure 11). These three zones



Figure 8: Using Flexible Design Standards for Sidewalks
Creating sensible pathways can produce safe, pedestrian friendly communities.

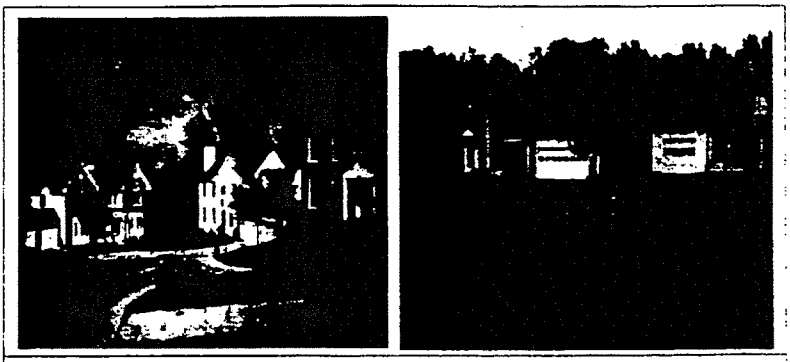

Figure 9: Examples of Different Types of Shared Driveways
Shared driveways can help reduce the amount of impervious cover created for parking.

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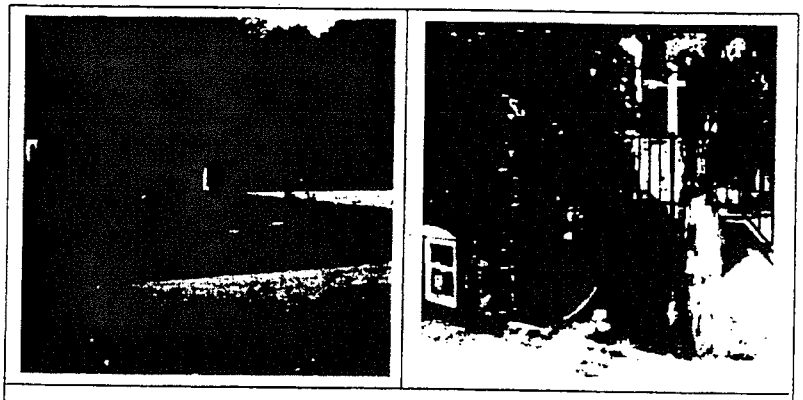

Figure 10: Alternative Runoff Management
Two alternatives for managing rooftop runoff are bioretention areas and rain barrels.

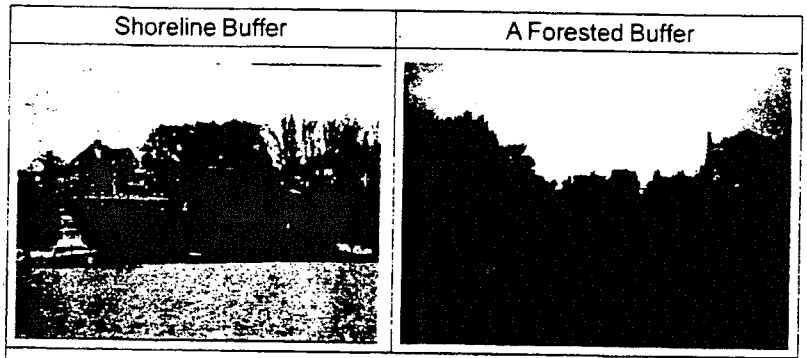

Figure 11: Development vs. Buffer
A buffer is more than a setback from the stream or shoreline. Native vegetation cover should be retained within part of the buffer to protect the water quality, treat stormwater, and enhance natural beauty.

are distinguished by the types of allowable uses unique to each zone. In addition, the buffer should incorporate the 100-year floodplain, steep slopes, and freshwater wetlands to fully protect the water quality of streams, help treat stormwater, and enhance the quality of life for residents (Schueler, 1995).

Buffers are noted for their economic benefits as well, including include increased property values, reduced flood damages, and sediment removal costs savings. A model stream buffer ordinance and regional samples can be downloaded from our website at www.cwp.org.

The riparian stream buffer should be preserved or restored with native vegetation. The buffer system should be maintained through the plan review delineation, construction, and post-development stages.

While establishing a buffer is paramount to better site design, assuring that the forest buffer is safeguarded from clear cutting is just as essential. Many communities have stream buffer ordinances, but a line drawn on a map is virtually invisible to contractors and landowners. Few communities require that buffer lines be marked. A strong buffer ordinance should outline the legal rights and responsibilities for management and maintenance during construction and for the long term. An effective buffer program should also indicate who is responsible for these issues and address measures to reestablish buffers using native vegetation. Figure 12 illustrates two techniques for preserving and maintaining natural areas and buffers.

Clearing and grading of forests and native vegetation at a site should be limited to the minimum amount needed to build lots, allow access, and provide fire protection. A fixed portion of any community open space should be managed as protected green space in a consolidated manner.

Most communities allow the entire development site to be cleared and graded, with a few exceptions in specially regulated areas such as jurisdictional wetlands, steep slopes, and floodplains. Since areas that are conserved in their natural state retain their natural hydrology and are not exposed to erosion during construction, it is desirable to conserve as much original soil at the site as possible. Clearing should be limited to the minimum area required for building footprints, construction access, and safety setbacks. Existing tools that could be adapted to limit clearing include erosion and sediment control ordinances, grading ordinances, forest conservation or tree protection ordinances, and open space development. One study has shown that providing grassed lots can add $750 to the value of a lot as compared to bare lots (Harbor and Herzog, 1999). For more information on clearing and grading, see Technical Notes 80, 81, 107 and 108.

Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and conserving native vegetation. Wherever practical, incorporate trees into community open space, street rights-of-way, parking lot islands, and other landscaped areas.

Few communities require that a percentage of trees and native vegetation be conserved during the development process. In fact, many communities promote the use of lawns instead of native vegetation. However, native trees, shrubs, and grasses contribute to the quality of the environment, create a sense of place, and increase property values. Tools that can be used for tree conservation include adopting forest conservation ordinances, encouraging open space design, planting street trees in the rights-of-way,

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adopting clearing and grading restrictions to preserve trees and native vegetation, and adding landscaping requirements for parking lots.

Incentives and flexibility should be encouraged to promote conservation of stream buffers, forests, meadows, and other areas of environmental value. In addition, off-site mitigation should be encouraged where it is consistent with locally adopted watershed plans.

A small number of communities require conservation of non-regulated areas such as stream buffers, forests, and meadows. Even fewer provide meaningful incentives for developers to conserve more natural areas than they are required to. To combat this problem, communities may want to offer increased flexibility and incentives to reward developers for conserving natural areas.

Methods to encourage conservation include by-right open space development, buffer flexibility, property tax credits, density bonuses, transferrable development rights, and providing credits for reduced stormwater management requirements. Stormwater credits exist for natural area conservation, disconnecting rooftop runoff, and routing sheetflow to buffers (MDE, 2000).

New stormwater outfalls should not discharge unmanaged stormwater into jurisdictional wetlands, sole-source aquifers, or sensitive areas.

Stormwater runoff generated from impervious cover can represent a significant threat to the quality of wetlands, surface water and groundwater. While many communities are beginning to require stormwater quality practices, they are often poorly matched to site conditions and watershed objectives.

Stormwater practices can be designed to be effective, attractive and relatively easy to maintain. A well-designed stormwater practice should add value to a community while meeting stormwater management objectives. For new criteria on the design of stormwater practices, refer to the Maryland Stormwater Manual available online: http://www.mde.state.md.us/ environment/wma/

Summary

For many communities, implementing better site design may require that development rules be changed, and this process is not an easy one. Advocates of better site design are likely to have to answer some difficult questions from fire chiefs, lawyers, traffic engineers, developers, and many others in the community. Will a proposed change make it more difficult to park? Lengthen response times for emergency vehicles? Increase risks to community residents and children? Progress toward better site design will require more local governments to examine their current practices in the context of a broad range of concerns, such as how the changes will affect development costs, local liability, property values, public safety, and a host of other factors.

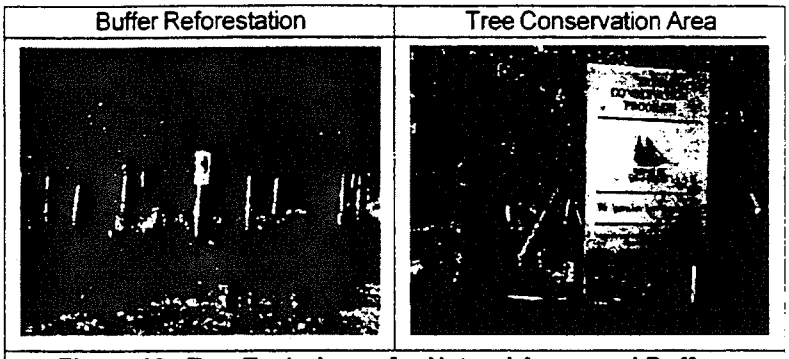

Figure 12: Two Techniques for Natural Areas and Buffers
Buffer reforestation and tree conservation are two important techniques for maintaining natural areas, including buffers. Buffer lines should be clearly marked to protect from clearing and grading both during and after construction.

Subsequent articles in this special issue of *Techniques* supply more background on the benefits of better site design and how it can be implemented in your community. In the next article, *The Benefits of Better Site Design in Residential Subdivisions*, we document how open space subdivisions can reduce runoff, pollutant export and development costs when compared to conventional subdivisions. The third article, *The Benefits of Better Site Design at Commercial Developments*, examines strategies to shrink the parking lots that comprise more than half of the area of new commercial developments and help mitigate the harmful impact parking lots have on the environment. The last article, *Changing Development Rules in Your Community*, describes a process for making better site design happen in your community. Finally, our *Resources* section profiles more than a dozen useful better site design references.

Better site design has considerable potential to reduce the environmental impacts of new development sites, and when adapted properly, of redevelopment sites as well. Better site design is a particularly useful strategy in watersheds where future development is projected to approach or slightly exceed impervious cover thresholds. It should be kept in mind, however, that better site design alone cannot adequately protect most watersheds. It must be combined and integrated with other watershed protection tools, such as watershed planning, land conservation,

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erosion and sediment control and the rest. These caveats notwithstanding, better site design is the one of the few watershed protection tools that simultaneously provides dividends for watershed advocates, developers and the community as a whole. Consequently, communities are encouraged to invest in the local site planning roundtable process that can make it happen. ***–HYK***

Better site design alone cannot adequately protect most watersheds.

Editor's Note: We are currently working on techniques for infill and redevelopment. Beginning later this year, we will begin a national roundtable consensus process focusing on topics, challenges, and concerns. Refer to our website (www.cwp.org) for updates on this project.

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Better Site Design

II. The Benefits of Better Site Design in Residential Subdivisions

Though they may not realize it, site planners have an excellent opportunity to reduce storm water runoff and pollutant export simply by changing the way they lay out new residential subdivisions. Planners that employ open space design techniques can collectively reduce the amount of impervious cover, increase the amount of natural land conserved, and improve the performance of stormwater treatment practices at new residential developments

Simply put, open space designs concentrate density on one portion of a site in order to conserve open space elsewhere by relaxing lot sizes, frontages, road sections, and other subdivision geometry. While site designs that employ these techniques go by many different names, such as clustering or conservation design, they all incorporate some or all of the following better site design techniques:

- Using narrower, shorter streets and rights-of-way
- Applying smaller lots and setbacks and narrow frontages to preserve significant open space
- Reducing the amount of site area devoted to residential lawns
- Spreading stormwater runoff over pervious surfaces
- Using open channels rather than curb and gutter
- Protecting stream buffers
- Enhancing the performance of septic systems, when applicable

In this article, we examine some of the benefits of employing better site design techniques as they apply to residential subdivisions. The analysis utilizes a simple spreadsheet computer model to compare actual residential sites constructed in the 1990s using conventional design techniques with the same sites "redesigned" utilizing better site design techniques. For each development scenario, site characteristics such as total impervious and vegetative cover, infrastructure quantities, and type of stormwater management practice are estimated.

The Simplified Urban Nutrient Output Model (SUNOM) was used to perform a comparative analysis for two subdivisions that span a wide range of residential density (see box on page 645). The first is a large-lot subdivision known as Duck Crossing, and the second is a medium-density subdivision known as Stonehill Estates. In each case, the model was used to simulate five different development scenarios:

- Pre-developed conditions
- Conventional design without stormwater practices
- Conventional design with stormwater practices
- Open space design without stormwater practices
- Open space design with stormwater practices

This article compares the hydrology, nutrient export, and development cost for these sites under both conventional and open space design, and with and without stormwater treatment. The article also summarizes other research on the benefits of open space design and discusses the implications it can have for the watershed manager.

Open space design concentrates density on one portion of a site in order to conserve open space elsewhere.



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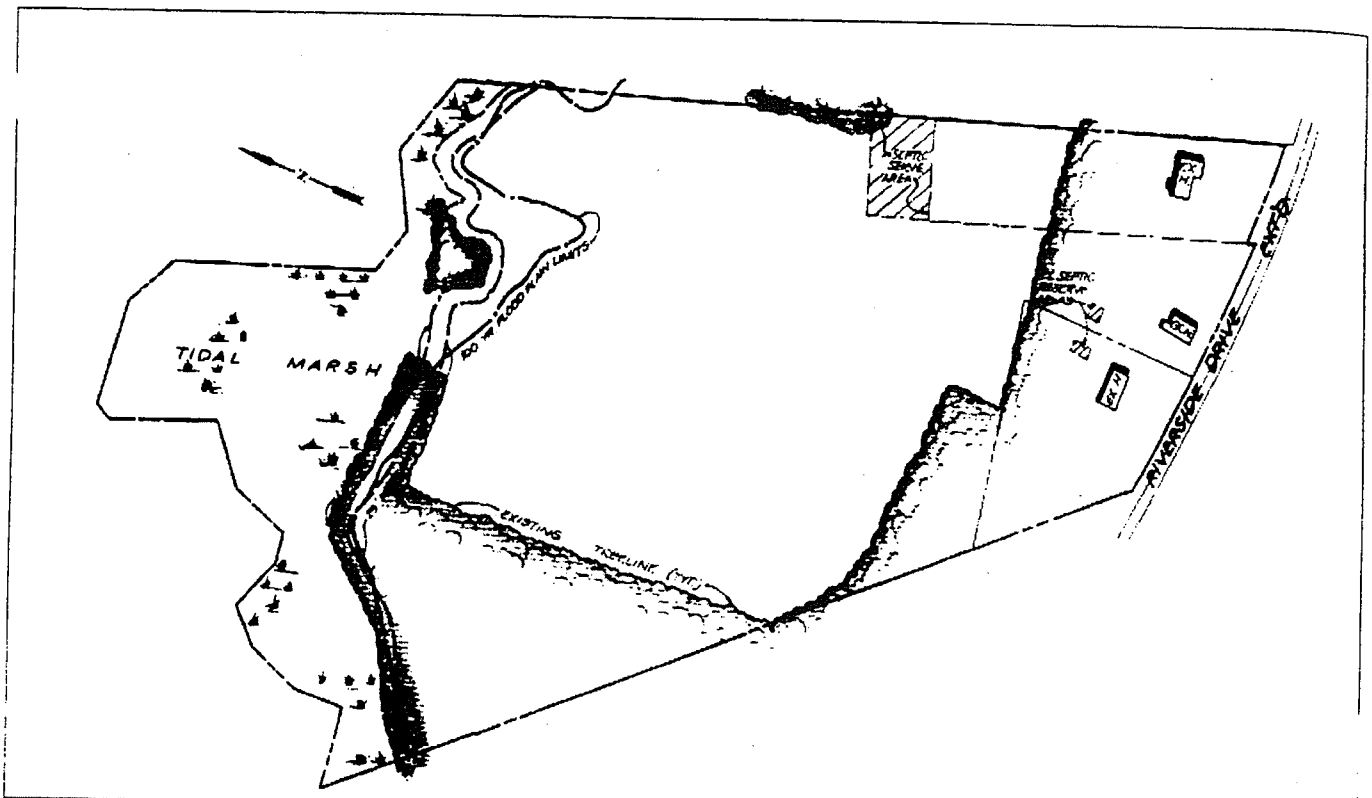

Figure 1: Predevelopment Conditions at the Duck Crossing Site

Duck Crossing - A Low-Density Residential Subdivision

Duck Crossing is a large-lot residential development located in Wicomico County on Maryland's Eastern Shore. Prior to development, the low gradient coastal plain site contained a mix of tidal and non-tidal wetlands, natural forest, and meadow (Figure 1). Its sandy soils were highly permeable (hydrologic soil group A). Three existing homes were located on the parcel, which relied on septic systems for on-site sewage disposal. The existing septic systems discharged a considerable nutrient load to shallow groundwater.

A conventional large-lot subdivision of eight single family homes was constructed on the 24-acre site in the early 1990s. The subdivision is reasonably typical of rural residential development along the Chesapeake Bay waterfront during this era (Figure 2). Each new lot ranged from three to five acres in size, and was set back several hundred feet from an access road. The access road was 30 feet wide and terminated in a large diameter cul-de-sac. Sidewalks were located on both sides of the street. Each lot was served by a conventional septic system with a primary and reserve field of about 10,000 square feet. Stormwater management consisted of curb and gutters that conveyed runoff into a storm drain system that, in turn, discharged to a small dry pond (designed for the water quality volume, only).

The entire site was privately owned, with the exception of the tidal marsh, which was protected under state and federal wetland laws and represented the only common open space on the site. As a result of construction, the existing meadow was entirely converted to lawn, and the impervious cover for the site increased to slightly over 8%.

Open Space Design for Duck Crossing

The critical ingredient of the open space redesign was a reduction in lot size from several acres to about 30,000 square feet. This enabled about 74% of the site to be protected and managed as common open space, which included most of the existing forest, wetlands and meadow (Figure 3). Consequently, only 19% of the site was managed as turf, nearly all of which was located on the private lots.

The open space redesign at Duck Crossing also incorporated a narrower access road (20 feet wide) along with shorter, shared driveways that served six of the eight lots. The road turnaround was designed as a loop rather than a cul-de-sac bulb. Also, a wood chip trail system was provided through the open space

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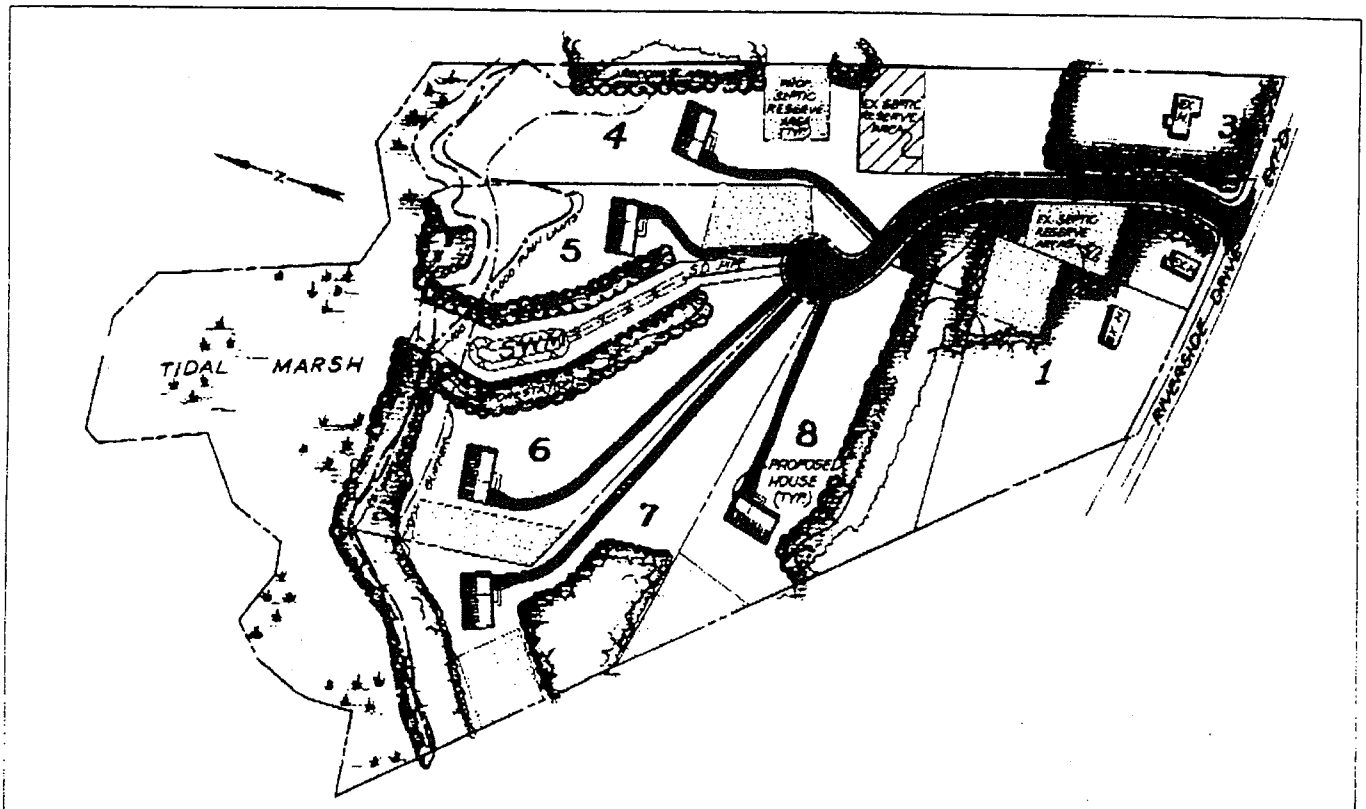

Figure 2: The Low-Density Conventional Subdivision Built at Duck Crossing (eight lots)

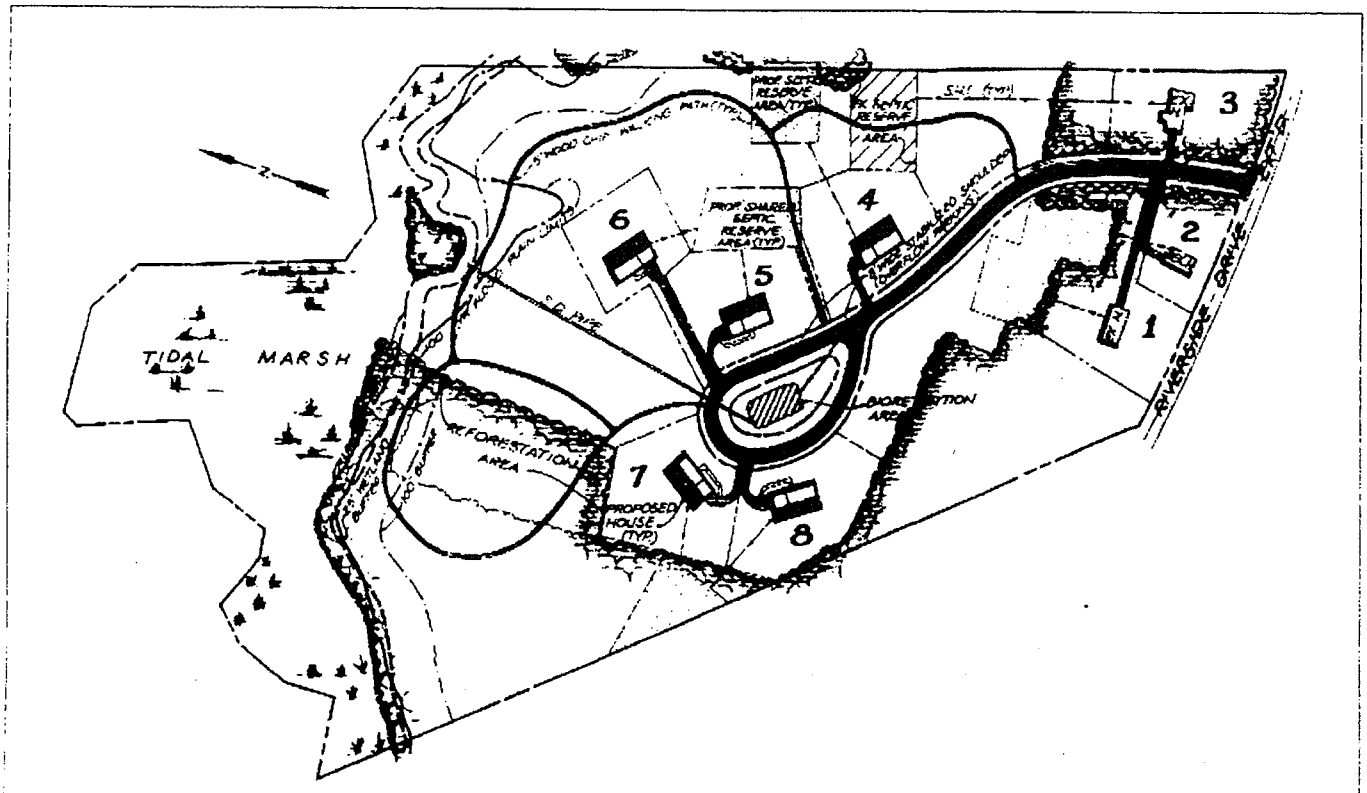

Figure 3: The Open Space Subdivision That Could Have Been Built at Duck Crossing (eight lots)

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instead of sidewalks along the road. Each home site was carefully located away from sensitive natural areas and the 100-year flood plain. Taken together, these better site design techniques reduced impervious cover for the site by about a third compared to the conventional design (from 8% to 5%).

The redesigned stormwater conveyance system utilized dry swales rather than a curb and gutter system, and featured the use of bioretention areas in the roadway loop to treat stormwater quality. This combination of stormwater practices provided greater pollutant removal through filtration and infiltration.

One of the most important objectives in the redesign strategy was to improve the location and performance of the septic systems that dispose of wastewater at the site. Home sites were oriented to be near soils that were most suitable for septic system treatment. In addition, six homes shared three common septic fields located within open space rather than on individual private lots. Lastly, given the permeability of the soils, advanced re-circulating sand filters were installed to provide better nutrient removal than could be achieved by conventional septic systems.

Comparative Hydrology for Duck Crossing

Given its low impervious cover and permeable soils, the water balance at Duck Crossing was dominated by infiltration, even after development. The comparative hydrology under the five development scenarios is presented in Table 1. As might be expected, the conventional design yielded the greatest volume of surface runoff and the least amount of infiltration. The open space design produced about 25% less annual surface runoff and 12% more infiltration than the conventional design, but did not come close to replicating pre-development conditions. The use of stormwater practices did not materially change the water balance under either the conventional or open space design at Duck Crossing (see Table 1).

The open space design sharply reduced nutrient export.

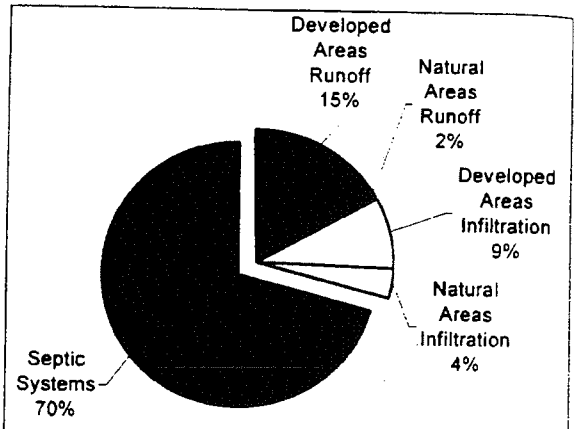

Figure 4: Nitrogen Load Distribution From the Conventional Design of Duck Crossing, Without Stormwater Practices

Comparative Nutrient Output at Duck Crossing

Nutrient export at Duck Crossing was dominated more by subsurface water movement than by surface runoff. Indeed, stormwater runoff seldom comprised more than 15% of the annual nitrogen or phosphorus load from this lightly developed site. The SUNOM model indicated that the major source of nutrients was subsurface discharges from septic systems, which typically accounted for 60 to 80% of the total load in every development scenario (see Figure 4).

The open space design sharply reduced nutrient export, primarily because re-circulating sand filters were used in the shared septic systems and helped to reduce (but not eliminate) subsurface nutrient discharge. The other elements of the open space design (reduced impervious cover, reduced lawn cover, and multiple stormwater practices) also helped to reduce nutrient export, but by a much smaller amount. The comparative nutrient export from each Duck Crossing development scenario is detailed in Figure 5.

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Table 1: Annual Water Budget of Duck Crossing

		Pre-Developed	Conventional Design	Open Space Design
Runoff (inches/year)	no practice	2.3	4.8	3.9
	practices	--	4.8	3.7
Infiltration (inches/year)	no practice	18.2	15.3	17.0
	practices	--	15.3	17.2

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Comparative Cost of Development

The cost to build infrastructure for the open space design was estimated to be 25% less than the conventional design at Duck Crossing, due primarily to the necessity for less road paving, sidewalks, and curbs and gutters. Even when higher costs were factored in for the more sophisticated stormwater and on-site wastewater treatment used in the open space design, the total cost was still 12% lower than the conventional design. In addition, the open space design had seven fewer acres that needed to be cleared and graded, or served by erosion and sediment controls, compared to the conventional design (these costs are not currently evaluated by the SUNOM model). Overall, the SUNOM model estimated that the conventional design at Duck Crossing had a total infrastructure cost of $143,600, compared to $126,400 for the open space design.

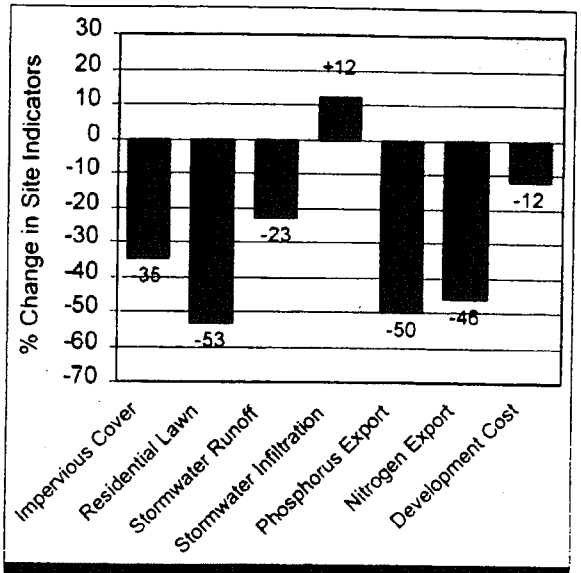
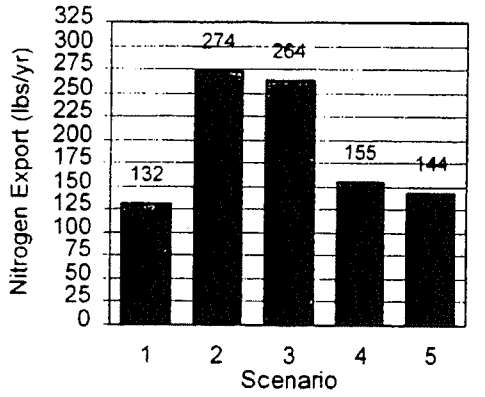
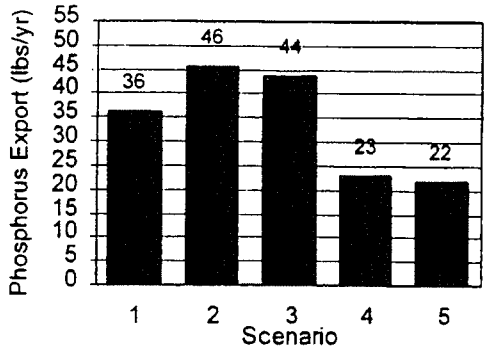


Figure 6: Percentage Change in Key Site Conditions From a Conventional Design to an Open Space Design, Both With Stormwater Practices





1 - Pre-Developed Conditions
2 - Conventional Design (no practices)
3 - Conventional Design (with practices)
4 - Open Space Design (no practices)
5 - Open Space Design (with practices)

Figure 5: Annual Nitrogen and Phosphorus Loads for Each Development Scenario at Duck Crossing

Summary

The comparative results for the Duck Crossing redesign analysis are summarized in Figure 6. The open space design increased natural area conservation and reduced impervious cover, stormwater runoff, nutrient export, and development costs compared to the conventional subdivision design.

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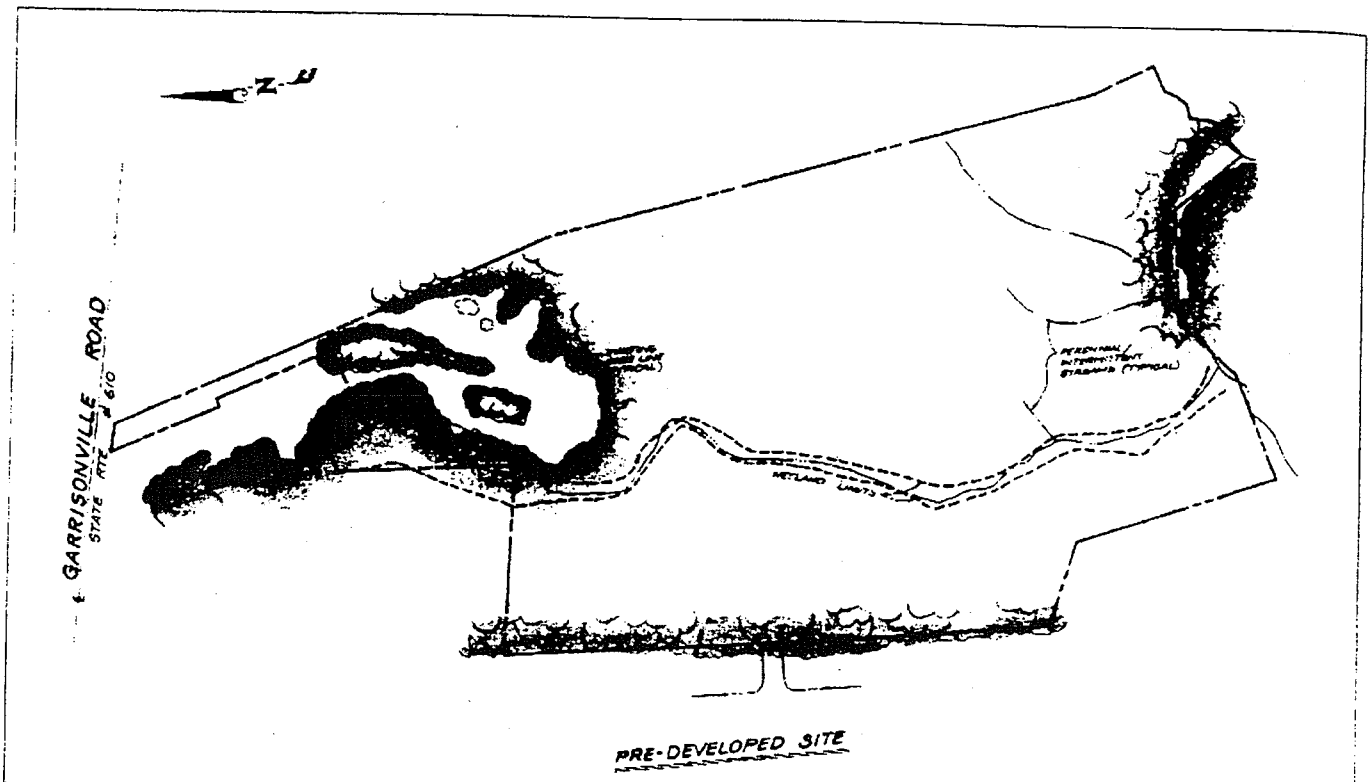

Figure 7: Predevelopment Conditions at the Stonehill Estates Site

Stonehill Estates - A Medium-Density Residential Subdivision

Stonehill Estates, located near Fredericksburg, Virginia, is situated in the rolling terrain of the Piedmont. The undeveloped parcel was 45 acres in size, nearly all of which was mature hardwood forest (Figure 7). An intermittent stream bisected the site, discharging into a perennial stream near the southern edge of the parcel. Roughly 3.6 acres of forested wetlands were found along the stream corridors, and an extensive floodplain was located along the perennial stream. Soils at the site were primarily silt loams and were moderately permeable (hydrologic soil groups C and D).

The site was highly attractive for development, given the excellent access provided by two existing roads, both of which had public water and sewer lines that could be easily tapped to serve the new subdivision. The conventional design was zoned for three dwelling units per acre. After unbuildable lands were excluded, the parcel yielded a total of 108 house lots, each of which was about 9,000 square feet in size (Figure 8). The subdivision design typifies medium-density residential subdivisions developed in the last two decades in the Mid-Atlantic region, where lots sizes were uniform in size and shape and homes were set back a generous and fixed distance from the street. The design utilized a mix of wide and moderate street sections (34 feet and 26 feet), and included six large diameter cul-de-sacs for turnarounds. Sidewalks were generally installed on both sides of the street.

The stormwater management system for the conventional design represents the typical "pipe and pond" approach utilized in many medium-density residential subdivisions. Street runoff was conveyed by curbs and gutters into a storm drain system that discharged into the intermittent stream channel, and then traveled downstream to a dry extended detention pond. The pond was primarily designed to control flooding, but also provided some limited removal of stormwater pollutants.

Interestingly, about 25% of the site was reserved as open space in the conventional design at Stonehill Estates. Nearly all of these lands were unbuildable because of environmental and site constraints (e.g., floodplains, steep slopes, wetlands, and stormwater facilities), and the resulting open space was highly fragmented. Even so, about a fourth of the forested wetlands were impacted by two roads crossing over the intermittent stream. Almost 90% of the original forest cover was cleared as a result of the conventional design, and was replaced by lawns and impervious cover. Overall, about 60% of the site was converted to lawns, and another 27% was converted to impervious cover.

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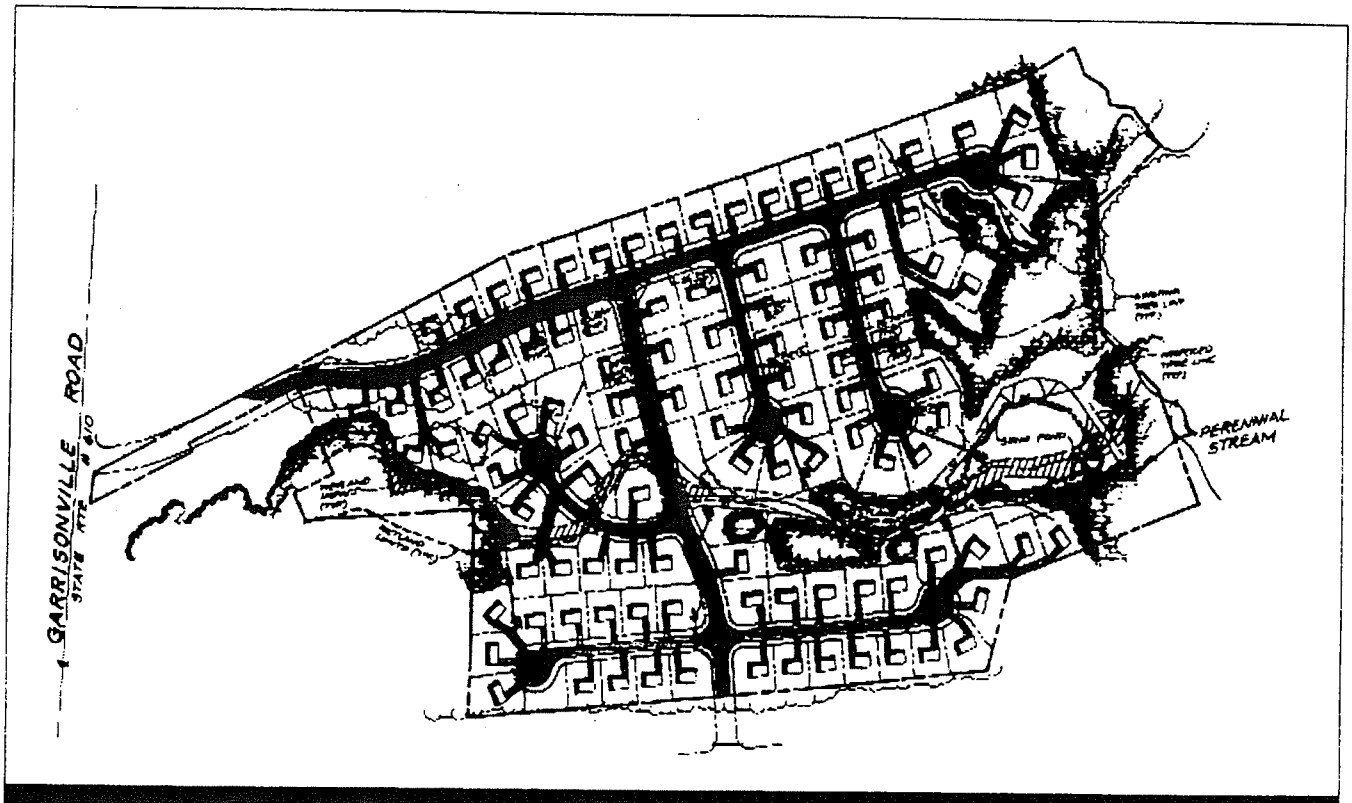

Figure 8: The Conventional Subdivision Design That Was Built at Stonehill Estates (108 lots)

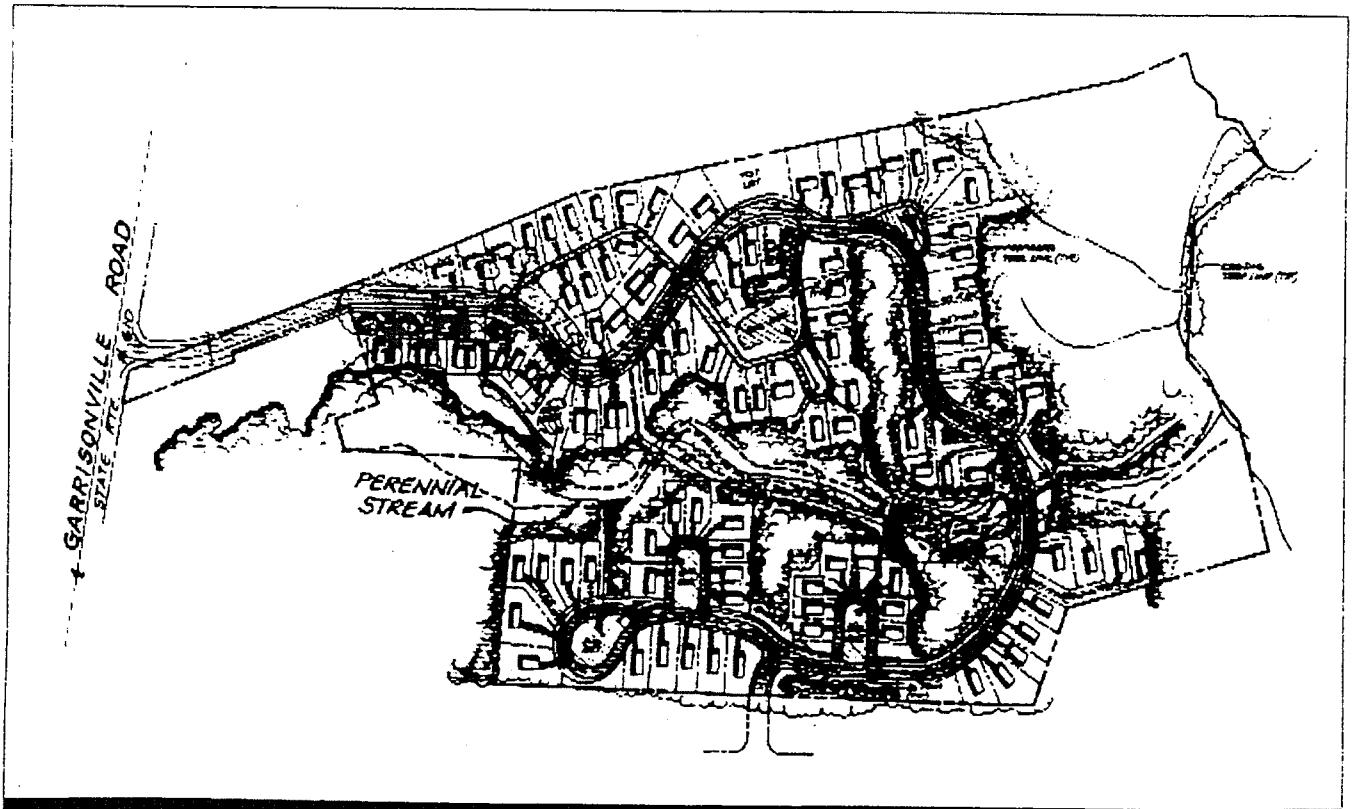

Figure 9: The Open Space Subdivision That Could Have Been Built at Stonehill Estates (108 lots)

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Open Space Design for Stonehill Estates

In the redesign analysis, Stonehill Estates was designed to incorporate many of the open space design techniques advocated by Arendt (1994). The resulting design retained the same number of lots as the conventional design, but had a much different layout (Figure 9). The average lot size declined from about 9,000 square feet in the conventional design to 6,300 square feet in the open space design. This reduced lot size allowed about 44% of the site to be protected as open space, most of which was managed as a single unit that included an extensive natural buffer along the perennial and intermittent stream corridor.

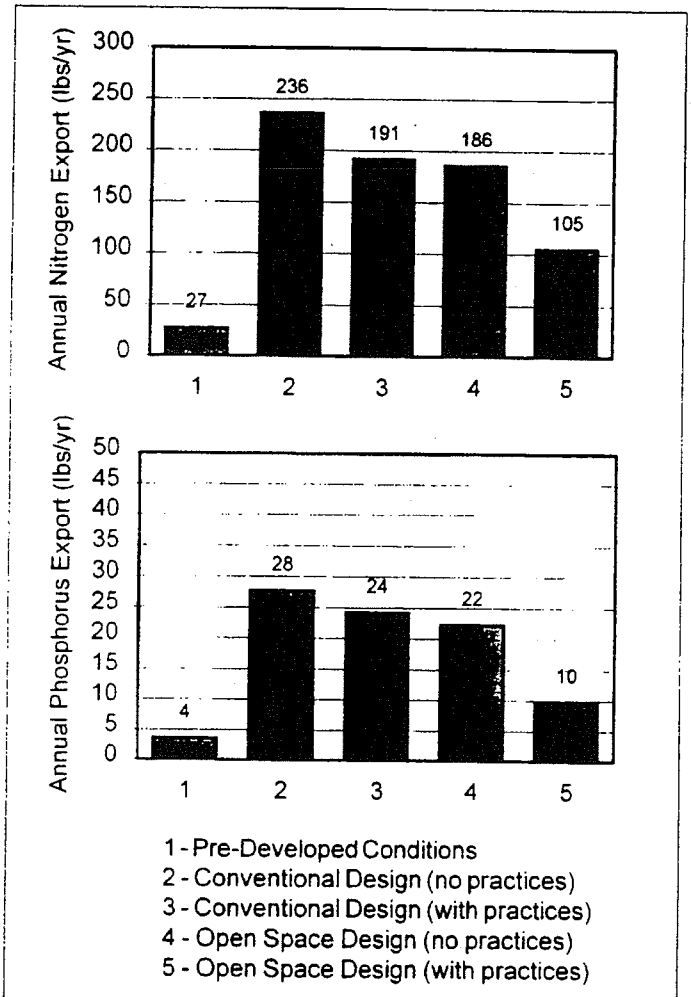

Figure 10: Annual Nitrogen and Phosphorus Loads for Each Stonehill Estates Development Scenario

The basic open space layout was augmented by several other better site design practices, including narrower streets, shorter driveways, and fewer sidewalks. Loop roads were used as an alternative to cul-de-sacs. In some portions of the site, irregularly shaped lots and shared driveways were used to reduce overall road length. Each individual lot was located adjacent to open space, so that the more compact open space lots would not feel as crowded. As a result of these techniques, the open space design for Stonehill Estates reduced impervious cover from 27% to 20%. In addition, lawn cover declined from 60% to 30% of the total site area.

The innovative stormwater collection system utilized dry swales rather than storm drains in gently sloping portions of the site. The dry swales and several bioretention areas located in loop turnarounds were used to initially treat stormwater quality. Each of these practices then discharged to a small micro-pool detention pond, whose embankment was created by the single road crossing over the intermittent stream.

Comparative Hydrology

Prior to its development, the highly wooded site produced very little surface runoff, but because of relatively tight soils, generated only a modest amount of infiltration. However, after the site was converted into the conventional subdivision, surface runoff increased by a factor of five, and infiltration was reduced by about 40% (Table 2). In contrast, the open space design worked to reduce stormwater runoff and increase stormwater infiltration compared to the conventional design, although it did not come close to replicating the original hydrology of the forested site (Table 2).

Table 2: Comparative Hydrology of Stonehill Estates

		Pre-Developed	Conventional Design	Open Space Design
Runoff (inches/year)	no practice	2.1	10.6	8.8
	practices	n/a	10.6	8.0
Infiltration (inches/year)	no practice	4.9	3.1	4.0
	practices	n/a	3.1	4.8

Comparative Nutrient Output

As might be expected, the conversion of the forest into a conventional subdivision greatly increased nutrient export from the site; the model indicated that annual phosphorus and nitrogen export would increase by a factor of seven and nine, respectively, after development (see Figure 10). Unlike Duck Crossing, nutrient export at Stonehill Estates was dominated by stormwater runoff after development. The SUNOM model indicated that stormwater runoff contributed about 94% of the annual nutrient export from the site,

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Table 3: Redesign Analyses Comparing Impervious Cover and Stormwater Runoff from Conventional and Open Space Subdivisions

Residential Subdivision	Original Zoning for Subdivision	Impervious Cover at the Site			Reduction in Stormwater Runoff (%)
		Conventional Design	Open Space Design	Net Change	
Remlik Hall [1]	5 acre lots	5.4 %	3.7%	- 31%	20%
Tharpe Knoll [2]	1 acre lots	13%	7%	- 46%	44%
Chapel Run [2]	½ acre lots	29%	17%	- 41%	31%
Pleasant Hill [2]	½ acre lots	26%	11%	- 58%	54%
Prairie Crossing [3]	½ to 1/3 acre lots	20%	18%	- 20%	66%
Buckingham Greene [2]	1/8 acre lots	23%	21%	- 7%	8%
Belle-Hall [4]	High Density	35%	20%	- 43%	31%

Sources: [1] Maurer, 1996; [2] DE DNREC, 1997; [3] Dreher, 1994; and [4] SCCCL, 1995.

with subsurface water movement adding only 6% to the total export. Nutrient loads were not greatly reduced by the dry extended detention pond installed at the conventional subdivision; the model indicated that nutrient export from the conventional design would still be six to seven times greater than the predevelopment condition even with this stormwater treatment practice.

In contrast, the open space design resulted in greater nutrient reduction (Figure 10). For example, the open space design scenario *without* stormwater practices produced a lower nutrient load than the conventional design scenario *with* stormwater practices. This was primarily due to lower impervious cover associated with the open space design. When the open space design was combined with more sophisticated stormwater practices (i.e., bioretention, dry swales and wet ponds), nutrient export was half that of the conventional design. It is interesting to note, however, that even when the most innovative site design and stormwater techniques were applied to the site, nutrient export was still three to four times greater than that produced by the forest prior to development.

Infrastructure Costs

The total cost to build infrastructure at Stonehill Estates was about 20% less for the open space design than for the conventional design. Considerable savings were realized in the form of less road paving and shorter lengths of sidewalks, water and sewer lines and curbs and gutters. The cost difference between the open space and conventional designs would have been greater were it not for the fact that higher costs were incurred for the more sophisticated stormwater practices used in the open space design. It was estimated that the infrastructure cost for the conventional design was $1.54 million, compared to $1.24 million for the open space design.

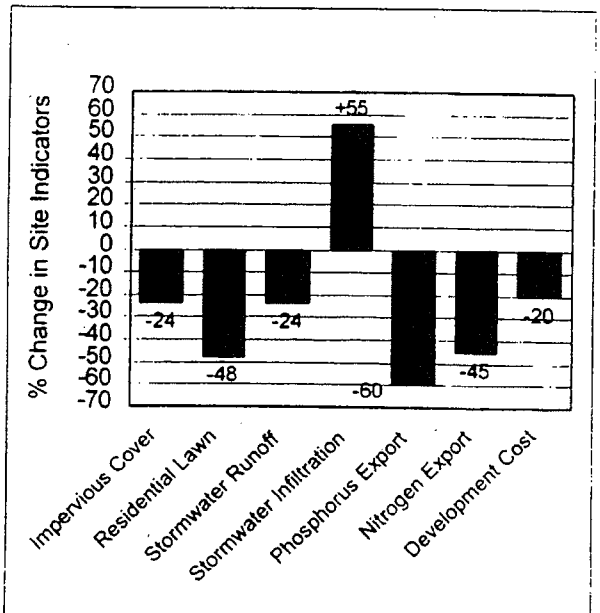

Figure 11: Change in Site From a Conventional Design to an Open Space Design, Both With Stormwater Practices

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Table 4: Projected Construction Cost Savings for Open Space Designs from Redesign Analyses

Residential Development	Construction Cost Savings	Notes
Remik Hall[1]	52%	Includes costs for engineering, road construction, and obtaining water and sewer permits
Tharpe Knoll[2]	56%	Includes roads and stormwater management
Chapel Run[2]	64%	Includes roads, stormwater management, and reforestation
Pleasant Hill[2]	43%	Includes roads, stormwater management, and reforestation
Buckingham Greene[2]	63%	Includes roads and stormwater management

Sources:[1] Maurer, 1996; [2] DE DNREC, 1997

Summary

The comparative results for the Stonehill Estates redesign analysis are summarized in Figure 11. The open space design reduced impervious cover, natural area conversion, stormwater runoff, nutrient export and development costs compared to the conventional subdivision design.

Other Redesign Research

Several other researchers have employed redesign comparisons to demonstrate the benefits of open space subdivisions, over a wide range of base lot sizes. The results are shown in Table 3. It should be recognized that each study used slightly different models and assumptions, and as such, strict comparisons should be avoided. The redesign comparisons clearly show that open space designs can sharply reduce impervious cover and stormwater runoff while accommodating the same number of dwelling units, at least to base lot sizes of an eighth of an acre. The reductions in impervious cover and runoff range from 7 to 65%. The ability of open space design to reduce impervious cover starts to diminish for residential zones that exceed densities of four dwelling units per acre.

Other studies reinforce the conclusion that open space designs are less expensive to build than conventional subdivisions.

These studies reinforce the conclusion that open space designs are usually less expensive to build than conventional subdivisions. The projected construction cost savings associated with open space designs ranged from 40 to 66% (Table 4). Most of the cost savings were due to reduced need for road building and stormwater conveyance. In another study, Liptan and Brown (1996) reported that open space design produced infrastructure construction costs savings of $800 per home in a California subdivision.

Numerous economic studies have shown that well-designed and marketed open space designs are very desirable to home buyers and very profitable for developers. Strong evidence indicates that open space subdivisions sell faster, produce better cashflow, yield a higher return on investment and appreciate faster than their traditional counterparts (Arendt *et al.*, 1994, Ewing, 1996, NAHB, 1997, ULI, 1988. CWP, 1998a, and Porter, 1988). While open space designs are often perceived as applying only to upscale and affluent consumers, several successful open space subdivisions have been built for moderate to lower income buyers. Both ULI (1988) and Ewing (1996) report that open space designs can be an effective tool to promote affordable housing within local communities.

The relatively high demand for open space designs reflects two important economic trends. The first trend is that the tastes and preferences of many new home buyers are gradually changing. Recent market surveys indicate that home buyers increasingly desire natural areas, smaller lawns, better pedestrian access, wildlife habitat and open space in the communities they choose to live in. The second trend is that open space developments that can provide these amenities seldom comprise more than 5% of the new housing offered in most communities. Consequently, there appears to be a large and relatively untapped potential demand for more open space developments. Other compelling benefits of open space design are detailed in CWP (1998a) and Schueler (1995).

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Table 5: Sample Evaluation Criteria for the Quantity and Quality of Open Space Development (Adapted from Conservation Fund, 1999)

Points Achieved by the Development	Percent of Open Space Achieved for Different Residential Zones				
	More than 4 units per acre	From 2 to 4 units per acre	From 1 to 2 units per acre	From 0.5 to 1 unit per acre	less than ½ unit per acre
-2	0 to 9%	less than 15%	15 to 24%	25 to 34%	less than 40%
-1	10 to 14%	15 to 24%	25 to 34%	35 to 49%	less than 50%
0	15 to 24%	25 to 34%	35 to 49%	50 to 59%	less than 60%
+1	25 to 30%	35 to 40%	50 to 55%	60 to 70%	less than 70%
+2	more than 30%	more than 40%	more than 55%	more than 70%	more than 80%

The total open space achieved by the site is computed using the following formula:

$$\frac{A(0.2) + B(0.2) + C(0.5) + D}{E} \times 100$$

A = open space acres in managed landscape
B = open space acres in annual crops
C = open space acres in perennial crops
D = open space acres in native vegetation
E = total undeveloped acres in open space

Evaluating the Quality of Individual Open Space Developments

In the real world, site designers must satisfy a wide range of economic objectives, and water quality or resource protection is usually not on the top of the list. It is certainly possible to design a lousy open space design, and communities should expect a wide range in the quality of open space designs they review. How can a community objectively evaluate the quality of individual open space design proposals, and differentiate poor or mediocre projects from the good and outstanding ones?

Nerenberg and Freil (1999) have recently developed a simple rating system to evaluate the quality of individual open space design proposals. The rating system, known as the Conservation Development Evaluation System (CeDES), was developed in consultation with a host of planning agencies and organizations. The CeDES employs 10 core criteria to test how well a proposed open space design reduces impervious cover, minimizes grading, prevents soil loss, reduces and treats stormwater, manages open space, protects sensitive areas, and conserves trees or native vegetation. Each of the 10 core criteria has a quantitative benchmark for comparison. An example of one benchmark that rates the quantity and quality of open space is provided in Table 5. A full description of the CeDES rating can be found in Conservation Fund (1999).

Based on the total score achieved under the 10 core criteria, an open space design project can earn anywhere from zero "oak leaves" up to four "oak leaves." The more oak leaves earned, the better the quality of the proposed project. Based on initial testing, the CeDES seems to do a good job of sorting the poor projects from the outstanding ones. While the CeDES is intended for use as a tool for local development review, it can also be used as a marketing tool to let home buyers know how green their new subdivision actually is.

Implications for the Watershed Manager

The redesign comparisons have several implications for the watershed manager. First, they offer compelling quantitative evidence that open space design can sharply reduce stormwater and nutrient export from new development, and as such, can serve as an effective tool for watershed protection. It is interesting to note that open space design, by itself, produced nutrient reductions roughly equivalent to those achieved by structural stormwater practices. In other words, nutrient export from open space designs *without* stormwater treatment was comparable to the conventional designs *with* stormwater treatment. When open space design were combined with effective stormwater treatment, nutrient loads were sharply reduced, but were still greater than pre-development conditions.

Despite its economic and environmental benefits, open space design is not a development option in many communities.

A second, more troubling implication is that it may well be impossible to achieve a strict goal of no increase in nutrient load for new development, even when the best site design and most sophisticated stormwater practices are applied. A handful of communities have adopted stormwater criteria that mandate that no

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net increase in phosphorus load occur as a result of development, but as the redesign comparisons in this article show, such criteria are not likely to be actually achieved. Thus, if nutrient loads are capped in a watershed, managers may need to remove pollutants at existing developments with stormwater retrofits in order to offset increases in nutrient loads produced by new development.

The redesign research also has some implications for watershed-based zoning. Quite simply, a shift from conventional to open space design can reduce the impervious cover of many residential zoning categories by as much as 30 to 40%. In some watersheds, an aggressive shift to open space design in new residential zones is an essential strategy to meet an impervious cover cap for protecting sensitive or impacted streams.

Another notable finding is that large lot subdivisions have the potential to generate the same unit area nutrient export as higher density subdivisions. The high nutrient loading from large lot developments in un-sewered areas is attributed to subsurface discharges from septic systems. From a nutrient management standpoint, it may be more cost effective to regulate septic system performance than stormwater performance in very low density residential subdivisions located on permeable soils.

Lastly, watershed managers have only a few tools at their disposal that offer developers a real chance to save money. The economic evidence clearly suggests that open space design is such a tool, and has potential to either reduce the cost of development, or at least offset the cost of other watershed protection measures. However, despite its economic and environmental benefits, open space design is not a development option in many communities, nor is it widely used by most developers even when available. Many communities will need to fundamentally change their local development rules in order to make open space design an attractive development option.

Site planning roundtables that involve the local players that shape new residential development, described later in this issue, are an effective way to bring this change about. The ultimate goal is to make open space design a "by-right" form of development, so that its design, review and approval are just as easy and certain as a conventional subdivision. Who knows, the day may come when a special exception or permit is needed to build a conventional subdivision. - ***JAZ***

Editor's Note: Some useful model ordinances for open space design can be found at www.cwp.org. Also, check the Resources section in this issue for some great references on how to make open space design work in your community.

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Description of the Simplified Urban Nutrient Output Model

The basic tool used in the redesign analysis was a spreadsheet model known as the Simplified Urban Nutrient Output Model (SUNOM). The SUNOM model computes the annual hydrologic budget, nutrient export and infrastructure cost for individual development sites, using simple input variables that can be easily derived or measured from any site engineering plan.

The first step in applying the SUNOM model is to measure the fraction of the site in each of six categories of surface cover: impervious surfaces, lawns, forests/wetlands, meadow, open water, and stormwater treatment areas. In the next step, the user measures key infrastructure variables from the site plan including the length of roads, sidewalks, water and sewer utilities, curb and gutter, and storm drain pipes (in some cases, widths or diameters are needed as well). Basic soil type data is then collected, in order to classify soils according to the hydrologic soil group(s) present on the pervious surfaces of the site. Lastly, basic data is assembled on the size and type of stormwater practices and septic systems, when present. Depending on the size and complexity of the plan, it typically takes about a day to derive all the necessary inputs to operate the model.

Estimating Hydrology for the Site

SUNOM operates based on a simplified water balance. Rainfall can take several different pathways once it reaches the ground surface. A fraction of the rainfall leaves the site directly as stormwater runoff, while the remainder infiltrates into the subsurface soils (storage in surface depressions or interception by the tree canopy interception is ignored in the model, since they are a small and often temporary component of the annual water balance). Once water infiltrates into the soil, much of it returns to the atmosphere through evapotranspiration. The remainder moves to shallow ground water, is transported as interflow, or recharges deeper groundwater. The SUNOM model does not differentiate between these three final destinations, but simply computes the total volume of subsurface infiltration. The water budget can be adjusted further if lawn irrigation or septic system effluent is expected to contribute "outside" water to the development site.

Surface runoff from all surfaces is calculated using a volumetric runoff coefficient that is closely related to impervious cover. Resulting runoff quantities are normalized to runoff inches over the entire site (Schueler, 1987). Surface runoff from natural cover and turf are computed assuming that these areas are one percent impervious (NVPDC, 1980), but these values can be changed to reflect the prevailing soil type or soil compaction (see Technical Note 107).

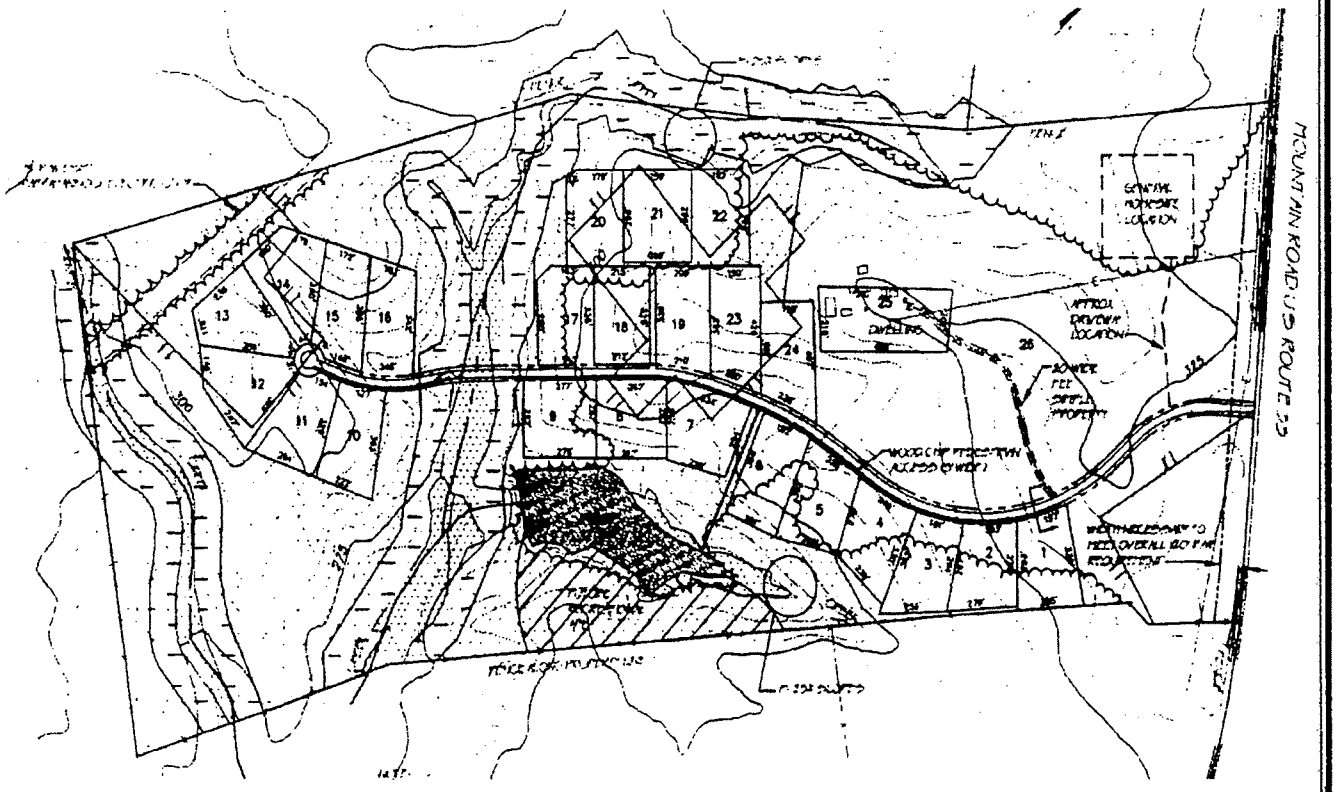

Figure 1: The SUNOM Model Operates Using Basic Site Variables That Can Be Easily Derived From Most Site Plan Submittals

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Estimating infiltration is a somewhat trickier affair. For the purposes of the model, total infiltration is defined as the sum of subsurface infiltration plus septic infiltration. Subsurface infiltration is estimated based on annual infiltration volume for the prevailing hydrologic soil group of the pervious area, which can be adjusted for soil compaction. The annual volume of subsurface infiltration is calculated without estimating its final destination (i.e., quick interflow, deep recharge, shallow groundwater). Once annual stormwater runoff and subsurface infiltration volumes are calculated, they can be checked against an annual evapotranspiration volume to ensure that the overall water balance is reasonable.

Annual septic system infiltration is calculated under the assumption that entire wastewater flow into a septic system infiltrates to the subsurface. The volume of this wastewater flow, in site-inches, is derived as a function of the number of individuals using each septic system multiplied by their per capita annual water use. Some stormwater practices can take surface runoff and convert it into subsurface infiltration. The model accounts for this by deducting the fraction of treated runoff volume that is infiltrated back into the soil from the annual stormwater runoff volume and adding it to the infiltration volume.

Calculation of Nutrient Loads

This module computes nutrient loads for each of the types of surface cover present at a site by multiplying its computed stormwater runoff and subsurface infiltration volume by a median nutrient concentration. For stormwater flows, the mean concentrations are derived based on national stormwater monitoring data or single land use or source area marketing data. Subsurface nutrient concentrations for natural areas are estimated based on measured baseflow concentrations from adjacent undeveloped receiving waters. Median nutrient concentrations from published sources were used to characterize the subsurface concentrations from turf areas. In the case of septic systems, typical per capita septic loads, along with septic efficiencies, were used to characterize this nutrient loading source.

The total annual nutrient load for a development site is then computed as the sum of the stormwater runoff load, and the subsurface infiltration load from natural areas, turf, and septic systems. Surface stormwater loads are adjusted to reflect pollutant reduction by stormwater practices if they are present. The spreadsheet contains typical nutrient removal rates for many common stormwater practices (see Technical Note 95). Subsurface infiltration loads can also be adjusted to reflect the use of innovative septic system technology with higher nutrient removal capability. Default data are provided in the SUNOM model for all nutrient concentration and removal parameters, but the user can also supply their own estimates if better local or regional data are available.

Development Cost

The SUNOM modules computes the cost of building the infrastructure to serve a new development. The module calculates these costs based on the dimensions of the infrastructure that are specified in the development plan, and supplied as model input (e.g., length and area of roads, length and diameter of pipe). These units of infrastructure are then multiplied by unit costs that were derived for the mid-Atlantic region. The SUNOM model can estimate the following component costs: paving for roads or parking lots, curb and gutter, sidewalks, stormwater conveyance, utilities, landscaping, reforestation, septic systems and other necessary elements for site construction. Stormwater treatment costs are calculated as a function of the volume of stormwater runoff treated by the practice using predictive equations developed by the Center (see Technical Note 90). At this time, the SUNOM model does not estimate engineering or permitting costs, nor does it itemize costs related to clearing, grading and erosion and sediment control, but these enhancements can be added by the user.

Appropriate Use of the SUNOM Model

The SUNOM model is basically a simple accounting tool to track the annual runoff, nutrient loads, and total infrastructure costs from four kinds of surface cover in a development plan. The model is most appropriately used as a tool to compare how these factors change in response to different development scenarios. These "redesign" scenarios help demonstrate the costs and benefits of better site design. As with any empirical model, it is very important to make sure that parameter values are sensible and regionally appropriate. The user should always check whether default infiltration rates, nutrient concentrations, removal rates and unit costs make sense given local conditions. The SUNOM model is intended to serve as a planning model rather than an engineering model. More detailed simulation models or monitoring may be required to give the precise and accurate predictions needed for actual engineering design at a given development site. More extensive documentation on the model is contained in Appendix A of CWP, 1998. We are continually improving the SUNOM model, and the most recent version, which utilizes a Microsoft Excel spreadsheet, is available through the Center at a nominal charge.

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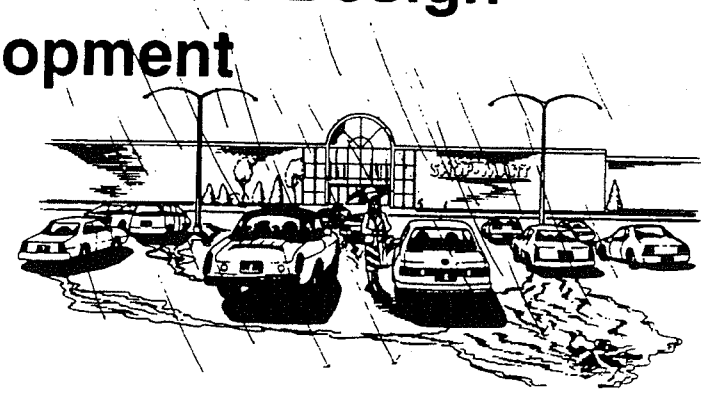
Better Site Design

III. The Benefits of Better Site Design in Commercial Development



Modern commercial development is dominated by the parking lot. Indeed, as much as half of the entire surface area of a typical office park or shopping center is devoted to parking. No one has ever stepped up to claim that they invented the parking lot, and their reluctance is understandable: the parking lot is a prime habitat for the car and not much else.

From an environmental standpoint, parking lots rank among the most harmful land uses in any watershed. Parking lots not only collect pollutants that are deposited from the atmosphere, but also accumulate pollutants that leak, drip or wear off cars. Researchers have found that parking lot runoff can have extremely high concentrations of nutrients, trace metals and hydrocarbons (see Technical Notes 15 and 105). Parking lots also influence the local air and stream temperatures. In the summer months, pavement temperatures can exceed 120 degrees Fahrenheit, which in turn increases local air temperatures five to 10 degrees compared to a shaded forest. Parking lots can also exacerbate smog problems, as parked cars emit greater levels of smog precursors under extreme heat island conditions (Scott *et al.*, 1999).

Perhaps the greatest environmental impact of parking lots is hydrological in nature. Simply put, there is no other kind of surface in a watershed that produces more runoff and delivers it faster than a parking lot. When this runoff is discharged into a headwater stream, its great erosive power steadily degrades the quality of downstream habitats, unless exceptionally sophisticated stormwater practices are installed.

Is it possible to design a better parking lot? At first glance, there seems to be little opportunity to incorporate better site design into parking lots. However, the better site design techniques described earlier in this issue suggest a key design strategy: *work to incrementally shrink the surface area of the parking lots and then use the space saved to integrate functional landscaping and better stormwater treatment within the parking lot.* Through a series of relatively minor design adjustments, it is possible to reduce the surface area of parking lots by 5-20%. These design adjustments include curbing excess parking, incrementally reducing parking demand ratios, providing credits for mass transit, shrinking stall sizes, narrowing drive aisles, and using grid pavers for spillover parking areas.

In this article, we examine some of the benefits of employing better site design as they apply to commercial development. As with the residential redesign, this analysis also uses the Simplified Urban Nutrient Output Model (SUNOM) to compare actual commercial development sites constructed in the 1990s with the same sites redesigned utilizing better site design techniques. The two commercial developments analyzed include a retail shopping center and a commercial office park.

Our fairly conservative approach to parking lot redesign is intended to reflect realistic opportunities in a suburban setting. For example, we did not utilize shared parking, porous pavement, or structured parking in any of the redesigns, although each of these techniques is very effective. Nor did we reduce the basic footprint or size of the buildings in either scenario, although smaller "boxes" may well have been more appropriate for the zoning. Instead, our basic approach was to make a series of relatively modest changes in parking lot design to shrink parking lot area, and then implement better landscaping and stormwater treatment measures within the saved space.

From an environmental standpoint, parking lots rank among the most harmful land uses in any watershed.

This article reports on the potential benefits of parking lot redesign in terms of reduced runoff, pollutant export and development costs. It also reviews the initial experience of communities that are experimenting with new and innovative parking lot designs, and concludes with some implications for both the engineer and watershed manager.

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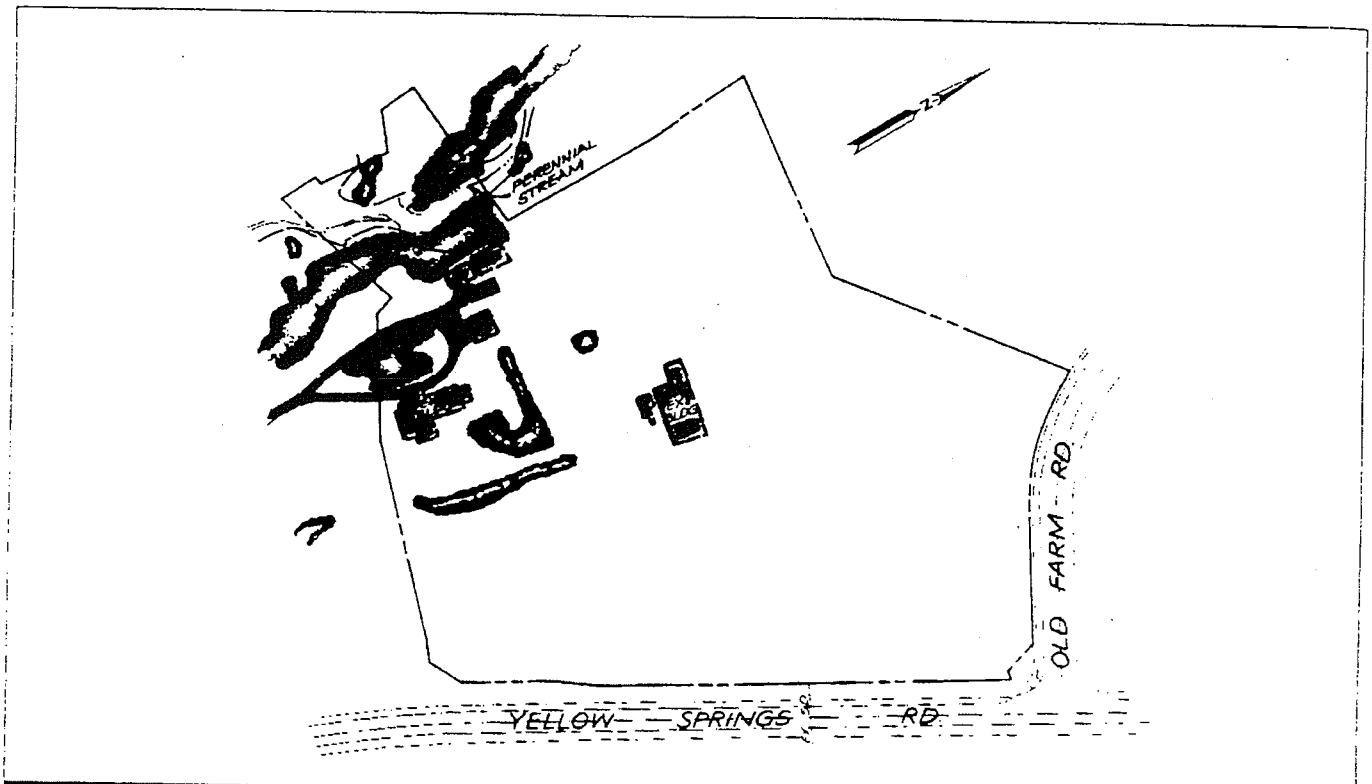

Figure 1: Predevelopment Conditions at the Old Farm Shopping Center Site

Redesign of the Old Farm Shopping Center

The undeveloped Old Farm shopping center, located in the City of Frederick, Maryland, was primarily meadow, with some shrubby forest and a few farm buildings. Bordered by two major arterial roads and served by existing public water and sewer, the site was a prime candidate for commercial development.

Construction of the shopping center site parcel commenced in 1992. The 9.3 acre site is a typical suburban "strip" shopping center with two large retail stores, other retail space, a gas station and a drive-in bank (Figure 2). In terms of surface cover, the shopping center devoted 50% of its total area for parking, as compared to 16% for the actual footprint of the retail buildings. Another 24% of the surface area was devoted to landscaping or stormwater treatment. Less than 10% natural cover was retained on the site, and part of the project encroached on the 100-year floodplain and the stream buffer. The entire site was mass graded during construction. The basic layout was designed to accommodate the car, with generous parking located in front of the stores. The parking lot design provided 5.2 full-size stalls per 1,000 square feet (sf) of retail space, which exceeded the already generous local parking requirement of five spaces per 1,000 sf. According to the most recent national parking research, only 4.0 to 4.5 spaces are needed to serve shopping centers (ULI, 1999).

The stormwater treatment system at Old Farm consisted of an infiltration basin located near the rear of the shopping center that captured runoff from about a third of the site, and three oil grit separators that provide some treatment for the remaining two-thirds of the site. After discharging from the oil/grit separators, runoff traveled through a series of storm drains that extended along the road and eventually discharged to the stream (albeit without detention of any kind). It should be noted that recent performance monitoring has shown that oil grit separators have little or no pollutant removal capability (see Technical Notes 101 and 104).

The Redesigned Old Farm Shopping Center

The Old Farm shopping center was redesigned using a "U-shaped" layout that maintained the same amount of gross floor area, but sharply reduced the site area devoted to parking (Figure 3). The new design reduced walking distances, encouraged pedestrian use, and created a more intimate shopping experience. Parking dropped from 50% of the total site area to 38%, primarily because the parking demand ratio was reduced from 5.2 spaces to 4.4 spaces per 1,000 sf of retail area.

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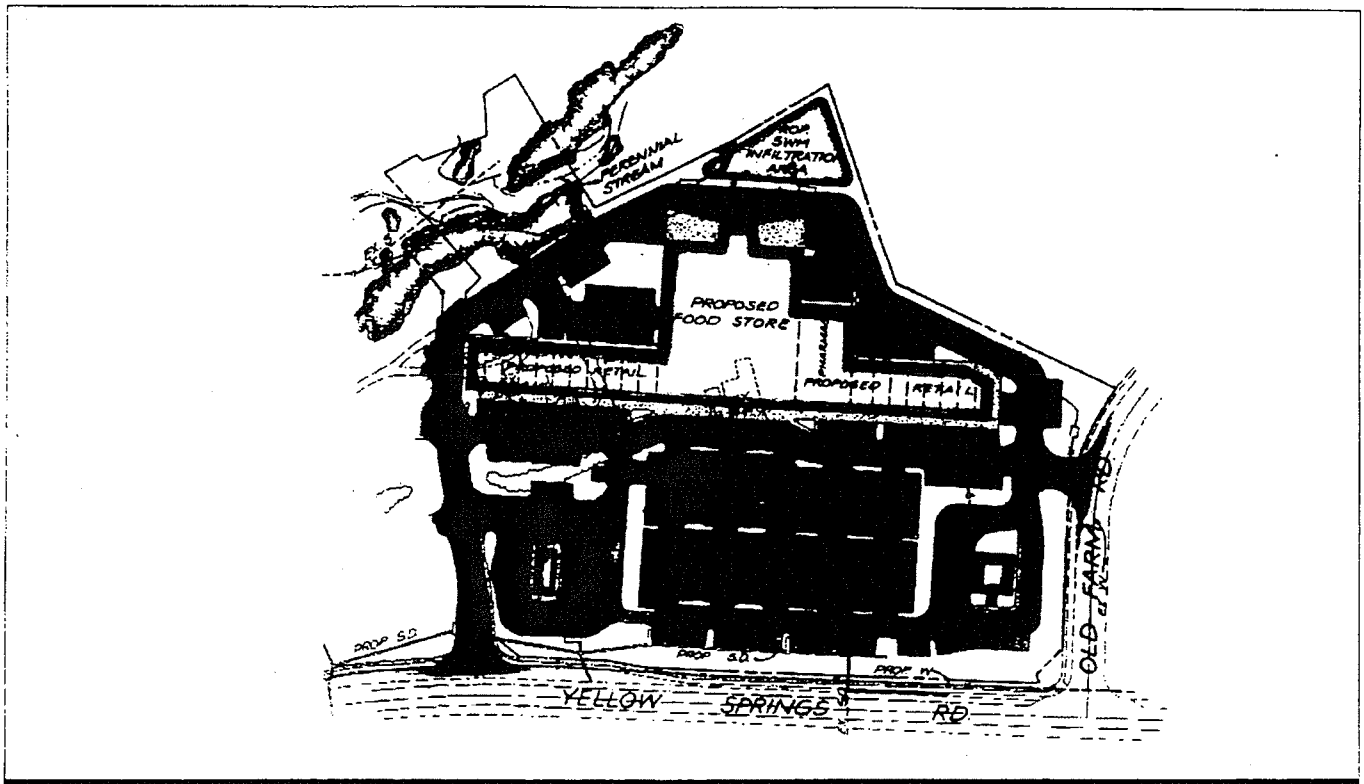

Figure 2: The Conventional Design of the Old Farm Shopping Center

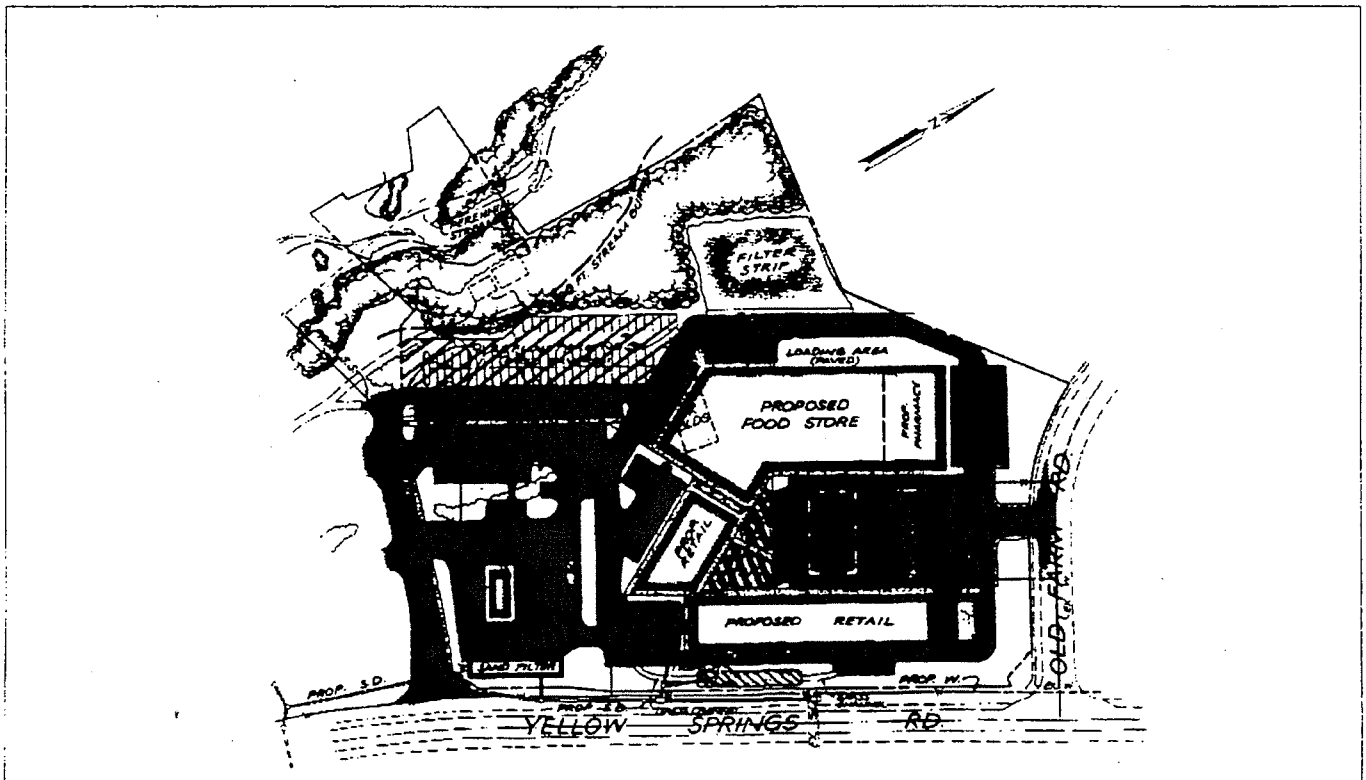

Figure 3: The Innovative Design of the Old Farm Shopping Center

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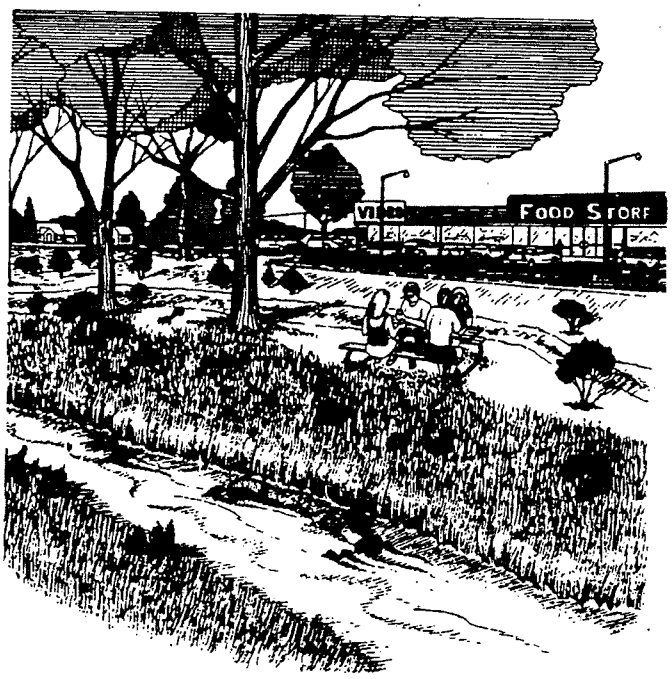
Table 1: Hydrology of the Old Farm Shopping Center Case Study

		Pre-Developed	Conventional Parking Lot	Innovative Parking Lot
Runoff (inches/yr)	no practice	2.6	24.5	20.6
	practices		18.1	15.1
Infiltration (inches/yr)	no practice	11.8	2.7	3.4
	Practices		9.1	8.9

The rationale for the lower parking demand was justified in two ways. First, no extra parking spaces were allowed beyond those required by the locality. Second, the existing parking demand ratio was reduced by about 15% to reflect actual parking demand more accurately. As a result, the total number of parking spaces dropped from 343 to 291. In addition, 17% of the parking stalls were designed for compact cars, which require slightly smaller stalls than standard full-sized spaces. Taken together, these changes eliminated slightly more than one acre of parking area, which provided enough space to design a more effective landscaping and stormwater treatment system.

Several parking lot islands were increased in size and converted into bioretention areas to treat stormwater. Other elements of the stormwater treatment system included a sand filter, an infiltration trench, and a filter strip. Furthermore, 25% of the entire parking area was designated for "spillover parking," and grid pavers were used rather than normal paving materials. The grid pavers helped store the first few tenths of an inch of rainfall that would have otherwise run off the parking lot (ICPI, 2000). Lastly, the redesign enabled reforestation and greater protection of the buffer along the stream that runs along the edge of the property. As a result, the proportion of natural cover at the site climbed from 7% to 19% as a result of the parking lot redesign.



Comparative Hydrology at the Old Farm Shopping Center

As expected, the construction of the original shopping center dramatically changed the hydrology of the site (Table 1). The increase in impervious cover from 1% to more than 70% increased annual runoff volume by a factor of nine. The infiltration basin used in the original design helped put some runoff back into the ground, but even so, annual runoff was seven times greater than the pre-development condition. The redesigned parking lot, by virtue of its lower impervious cover and improved stormwater practices, produced about 20% less runoff than the original design. Nevertheless, the stormwater practices at the redesigned parking lot were not able to match the pre-development hydrology.

Comparative Nutrient Output from the Old Farm Shopping Center

The conversion of the meadow into a shopping center greatly increased nutrient export from the site; the SUNOM model indicated that annual phosphorus and nitrogen export would increase tenfold as a result of the development (see Figure 4). Nutrient export from the shopping center was dominated by stormwater runoff, as the model indicated that stormwater runoff contributed about 95% of the annual nutrient export from the site. Nutrient loads were not greatly reduced by the infiltration basin or oil/grit separators that were installed at the conventional parking lot. Nutrient export was still projected to be eight to ten times higher than pre-development conditions, even after these stormwater treatment practices were installed.

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In contrast, the redesigned parking lot sharply reduced nutrient export (Figure 4). In fact, the redesigned parking lot *without* stormwater practices produced about the same nutrient load as the conventional parking lot *with* stormwater practices. This reduction was a direct result of the lower impervious cover associated with the redesigned parking lot. When the redesigned parking lot was combined with more sophisticated stormwater practices (i.e., bioretention, sand filter, infiltration trench and filter strip), the total nutrient export was half that of the conventional parking lot with stormwater practices. It is interesting to note, however, that this load was still about five times higher than that produced by the meadow prior to development.

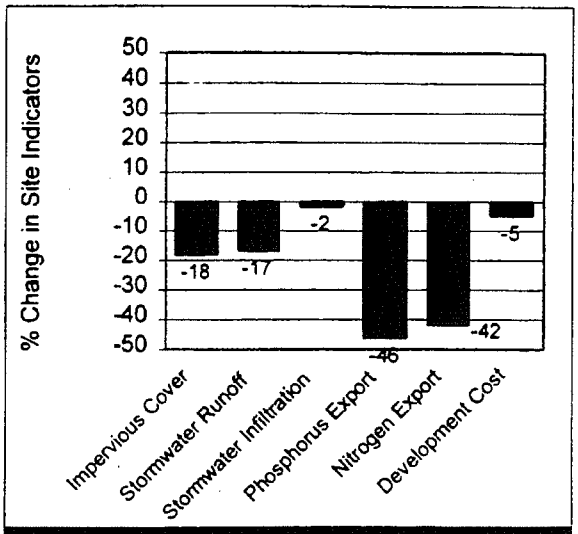

Figure 5: Percentage Change in Key Site Indicators From a Conventional Design of the Old Farm Shopping Center to an Innovative Design, Both With Stormwater Practices

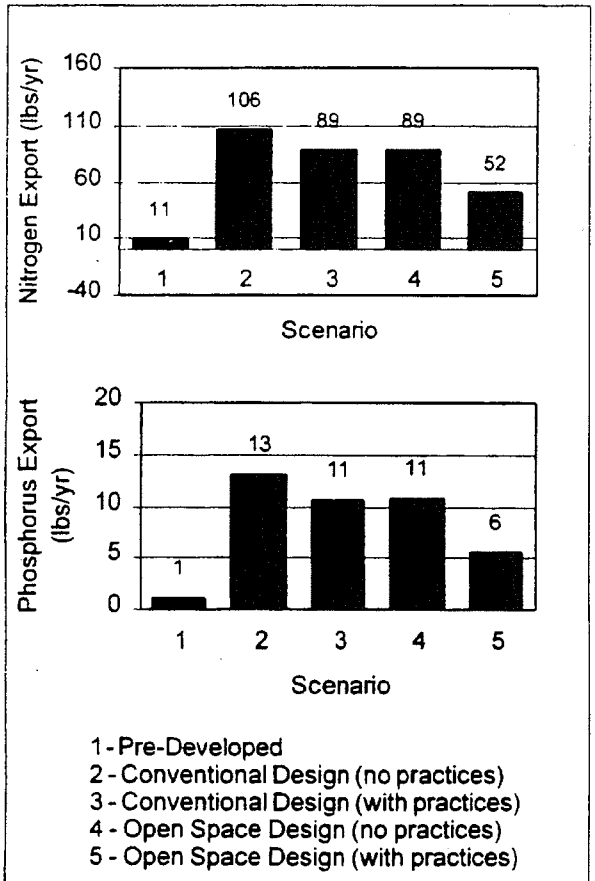

Figure 4: Annual Nitrogen and Phosphorus Export in Each Old Farm Shopping Center Development Scenario

Comparative Cost to Develop the Old Farm Shopping Center

The cost to develop the redesigned parking lot was marginally lower than the cost for the conventional parking lot — about 5%. Considerable cost savings were realized due to less paving, shorter sidewalks, and fewer curbs and gutters, but these savings were largely offset by added costs for improved stormwater practices, landscaping and grid pavers. Overall, the estimated cost to build the conventional parking lot was $782,500, compared to $746,270 for the redesigned parking lot. The extent of potential cost savings depends heavily on the level of sophistication of the original stormwater treatment system. In this case, the unsophisticated stormwater practices used in the conventional parking design were fairly inexpensive, but were also not effective in removing nutrients.

Summary

Figure 5 summarizes the redesign analysis of the Old Farm Shopping Center. The redesigned parking lot resulted in less impervious cover, stormwater runoff, and nutrient export for a slightly lower development cost than the conventional design.

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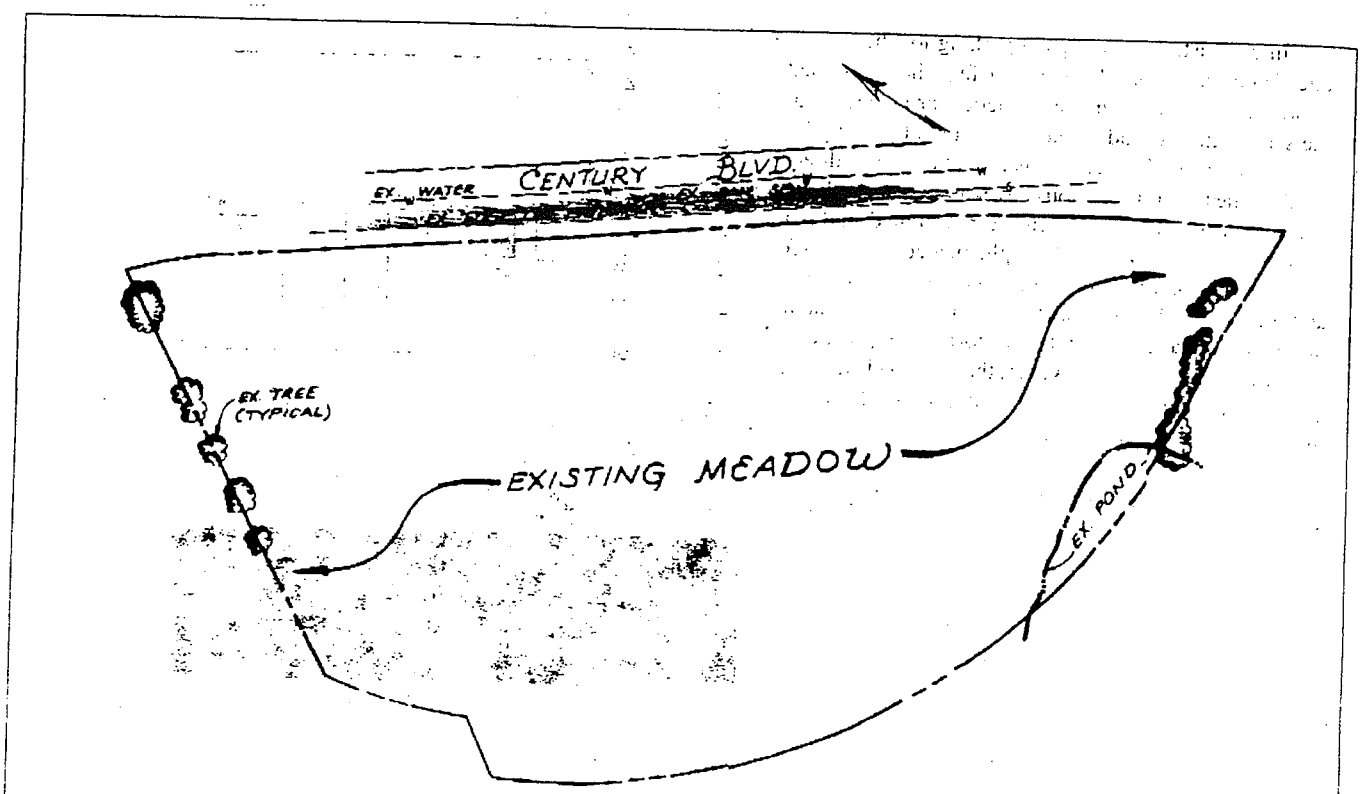

Figure 6: Predevelopment Conditions at the 270 Corporate Office Park Site

Redesigning the 270 Corporate Office Park

The second case study involved the redesign of a typical suburban office park. The 12.8 acre parcel is located in Germantown, Maryland in the mildly sloping terrain of the Piedmont (Figure 6). The existing cover at the site was almost entirely meadow, except for a few trees and an old farm pond that bisected the property boundary. No wetlands or other sensitive natural features were evident on the site. The site was zoned for office development, and existing infrastructure made it an attractive candidate for development. An existing network of public water and sewer, electric, gas, and other utilities ran along the frontage of a large arterial road.

The layout of the conventional suburban office park design is depicted in Figure 7. The project included a pair of five-story office buildings, surrounded by a sea of parking. Over half (52%) of the surface cover at the office park was devoted to parking, as compared to only 11% for actual footprint of the office building. Most of the remainder of the site was utilized for landscaping, stormwater treatment or turf. Only 2% of the natural cover was retained on the site, and nearly all of the parcel was mass graded during construction.

As with many suburban office parks, the location of the building and parking were primarily oriented toward the car. The parking lot was sized using a parking demand ratio of 3.1 spaces per 1,000 sf of building, which slightly exceeded the minimum parking requirements of the locality. As a result, the parking lot created room for 745 standard stalls, along with 33 larger stalls for vans and disabled access. The parking bays also featured roomy aisles between the stalls (24 feet wide). The design was intended to provide some amenities for the office workers, including a short path system between buildings, an ornamental stormwater pond, and some landscaping in required setbacks and parking islands.

The conventional design featured the classic "pipe and pond" approach to stormwater management. Parking lot runoff was initially collected by a curb and gutter system that sent runoff into underground storm drain pipes that, in turn, discharged into two very small wet ponds. Each pond served roughly half of the site and was expected to have a reasonably good capability to remove nutrients (see Technical Note 95).

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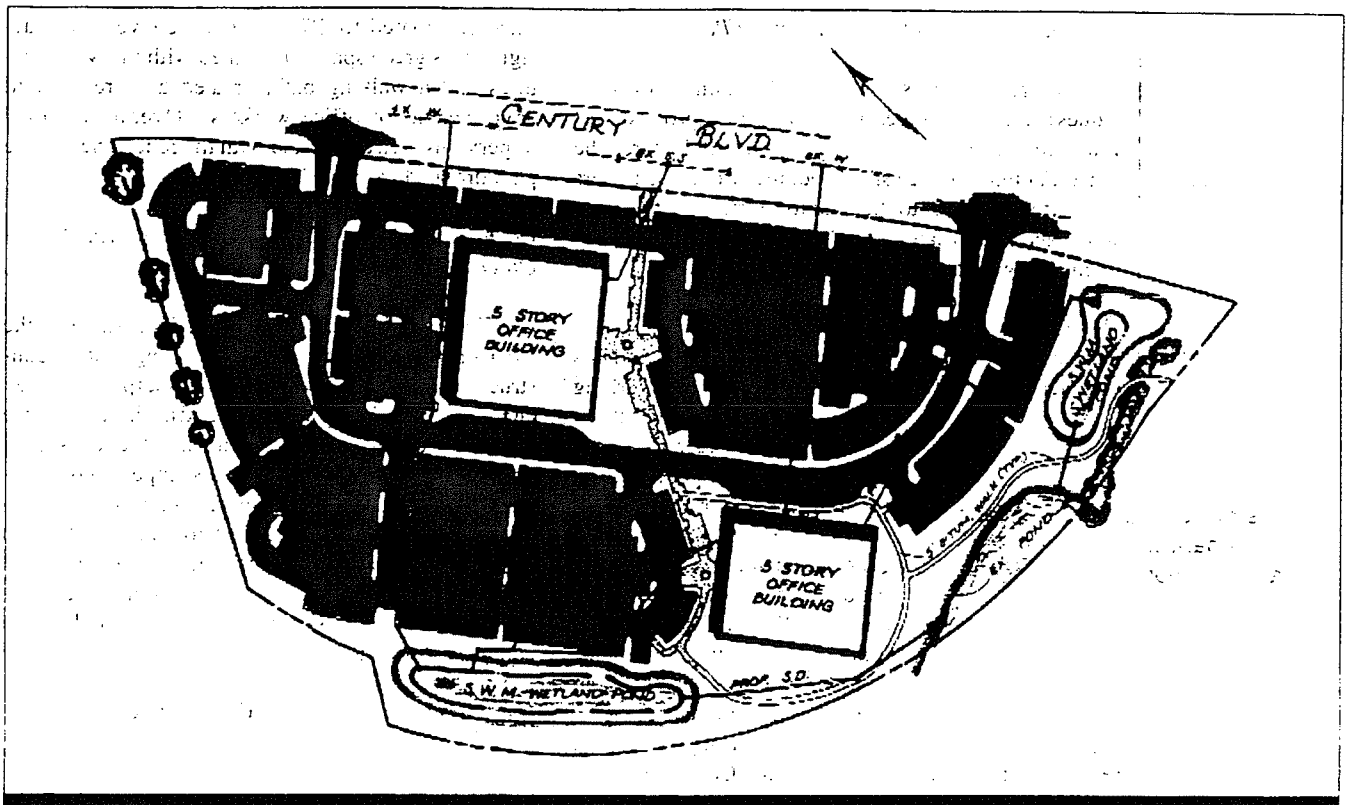

Figure 7: The Conventional Design of the 270 Corporate Office Park

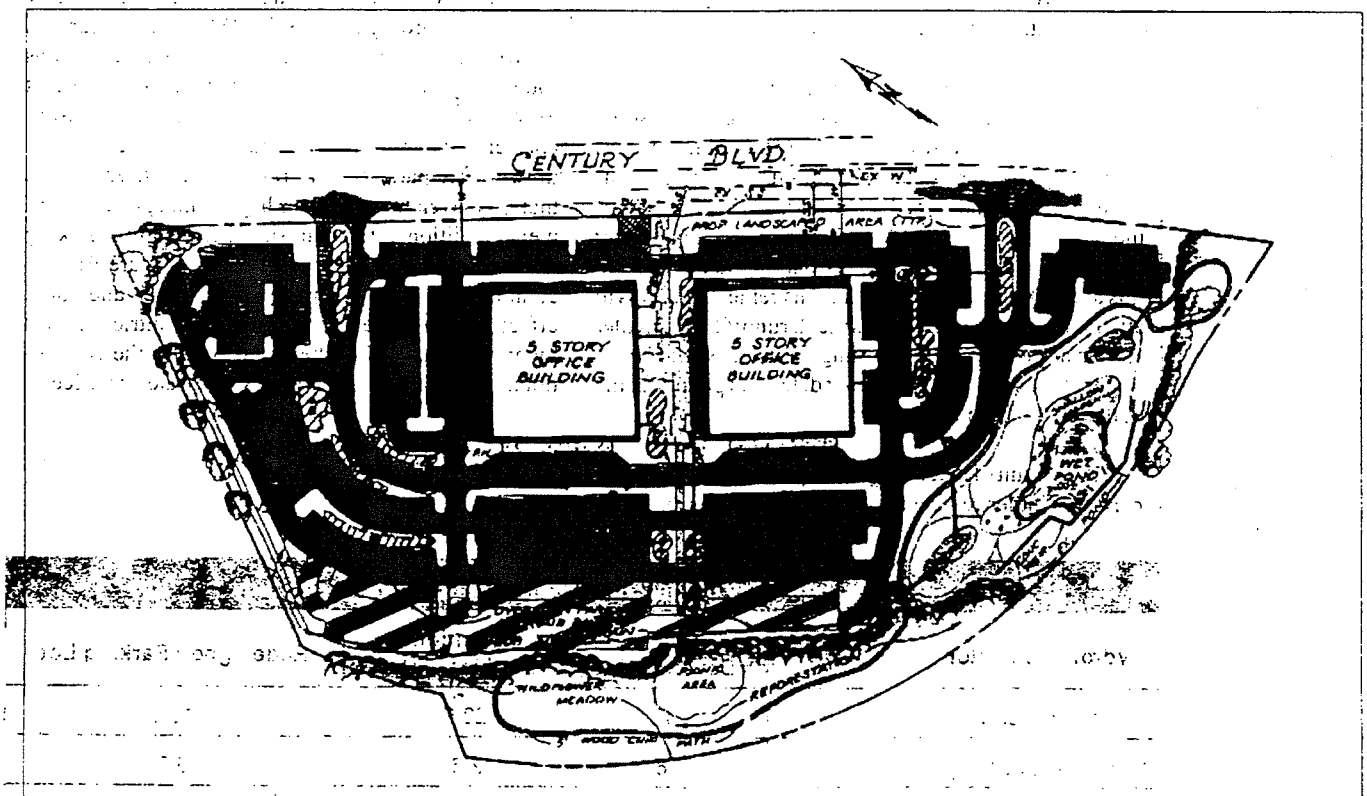

Figure 8: The Innovative Design of the 270 Corporate Office Park

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The Redesigned 270 Corporate Office Park

The redesigned site employed a number of techniques to minimize impervious cover and improve stormwater treatment (Figure 8). The office park featured the same amount of office space, but the two office towers were situated closer to the road to shorten utility extensions, and pedestrian access to a bus stop was provided to encourage the use of public transportation.

The key strategy employed in the redesign was to incrementally reduce the size of the parking lot, and this was achieved in five ways. First, no excess parking spaces were allowed over those required by the local parking demand ratio. Second, the local parking demand ratio was reduced by 8% to reflect actual parking demand. Third, the parking demand ratio was reduced by another 10% to reflect the proximity to the bus stop. Fourth, the size of approximately 20% of all parking stalls was downsized to accommodate compact cars. Lastly, drive aisles in many parking bays were reduced from 24 feet in width to 20 feet. Combined, these measures reduced the total parking lot area by nearly 30%, or about two acres. Once again, the savings in paving gave the designer more room to integrate landscaping with more effective stormwater treatment.

Construction of the conventional office park sharply increased annual runoff and decreased infiltration.

For example, larger landscaping islands were installed in the parking lot to plant shade trees, and some of these areas were also converted into bioretention areas to treat stormwater. A dry swale was used to treat stormwater within a landscaped setback area in another part of the site. About 15% of the lot was designated for spillover parking, and grid pavers were used to attenuate runoff in this area. The basic stormwater management goal was to attenuate, treat, or recharge as much runoff from smaller storms as possible in the parking lot itself. Runoff from larger storms was treated in a wet detention pond near the outlet of the property.

As a result of the redesign, roughly 14% of the office park was either retained in natural land cover or reforested (compared to 2% under the conventional design). This green space, combined with the water features and a walking path, created a more tranquil environment for office workers. Overall, the total impervious area associated with the redesigned office park dropped from 68% to 53%.

Comparative Hydrology for the 270 Corporate Center Office Park

The hydrological story was much the same for the 270 Corporate Center as for the shopping center. Construction of the conventional design sharply increased annual runoff volumes and decreased infiltration (Table 2). Runoff did not increase as much in the redesigned parking lot, primarily because its impervious cover was much lower. Annual runoff volumes were 21% lower in the redesigned parking lot compared to the conventional design, and infiltration volumes were 42% higher. Despite these improvements, the redesigned parking lot was unable to mimic the hydrologic conditions prior to development.

Nutrient Output at the 270 Corporate Center Office Park

As expected, the conversion of the meadow into an office park greatly increased nutrient export. Annual phosphorus and nitrogen export increased roughly ten-fold, according to the SUNOM model (Figure 9). As with the shopping center, stormwater runoff was found to generate about 95% of the annual nutrient export from the site. The two wet ponds were reasonably effective in removing nutrients at the conventional office park, but still resulted in nutrient export that was seven to eight times higher than pre-development conditions. In contrast, the redesigned parking lot sharply reduced nutrient export (Figure 9). The combination of lower impervious cover and more effective stormwater practices reduced nutrient export by about 40 to 50%, when compared to the conventional parking lot design *with* stormwater practices.

Table 2: Hydrology of the 270 Corporate Office Park Case Study

Hydrologic Factor	Pre-Developed	Conventional Parking Lot	Redesigned Parking Lot
Runoff (inches/yr)	2.7	23.8	18.9
Infiltration (inches/yr)	11.8	2.6	3.7

Note: no change in the annual volume of runoff or infiltration was calculated for the [illegible] practices installed at either the conventional or redesigned parking lot [illegible]

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Comparative Cost to Develop the 270 Corporate Office Park

The cost to develop the redesigned office park was approximately the same as the cost to develop the conventional office park, although the component costs were somewhat different. Less was spent on paving, sidewalks and utility pipes, but these savings were largely offset by higher costs for improved stormwater treatment practices, landscaping, grid pavers and curiously, curbs and gutters (the higher cost for this last item was due to the wider parking islands used for bioretention areas). Overall, the estimated cost to build the conventional parking lot was $948,900, compared to $921,200 for the redesigned parking lot.

Summary

The redesigned parking lot at the 270 Corporate Office Park resulted in less impervious cover, stormwater runoff, and nutrient export for about the same development cost as the conventional design. The results are summarized in Figure 10.

The Limits and Potential of Parking Lot Redesign

To our knowledge, no one has yet tried to quantify the potential economic and environmental benefits of better parking lot design at new commercial developments. This initial analysis provides compelling evidence that better site design is an important, if not indispensable, tool for managing the quantity and quality of stormwater runoff from parking lots.

In each of the case studies, the redesigned parking lot resulted in less impervious cover, stormwater runoff, and nutrient export for about the same or even slightly lower cost than the conventional design. Taken together, better site design techniques reduced impervious cover by at least 15% in each case. While this is an impressive reduction, about half of each site remained impervious after the redesign. Perhaps the most critical benefit of each redesign was that it created more room to locate more effective stormwater treatment practices. When smaller parking lots were combined with better stormwater practices, the resulting nutrient export was almost half that of a conventional parking lot.

In each case study, the critical ingredient was an incremental reduction in the local parking demand ratio. Without this capability to shrink the surface area devoted to parking, designers have little ability to devise the more sophisticated stormwater treatment and landscaping systems that can

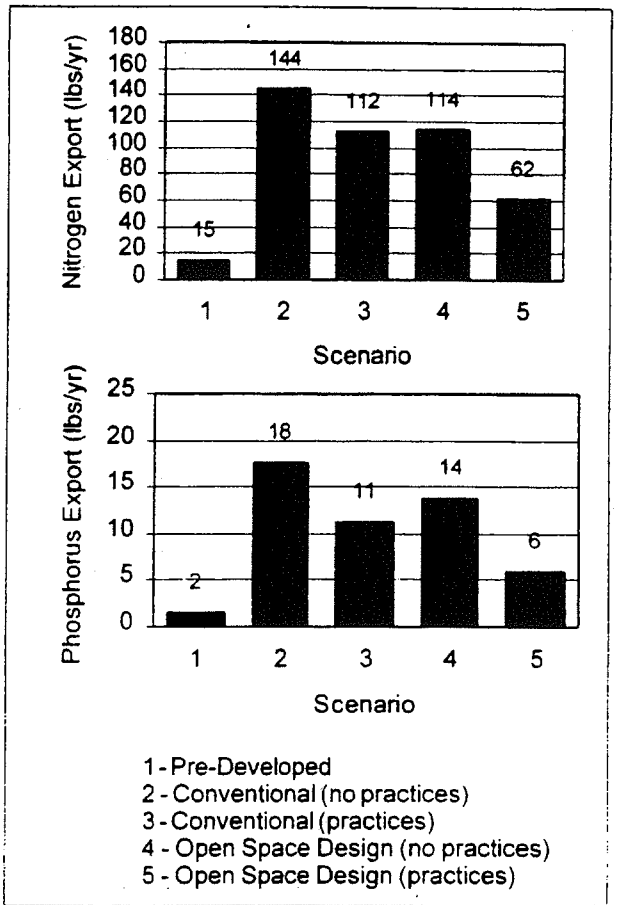

Figure 9: Annual Nitrogen and Phosphorus Load in Each 270 Corporate Office Park Development Scenario

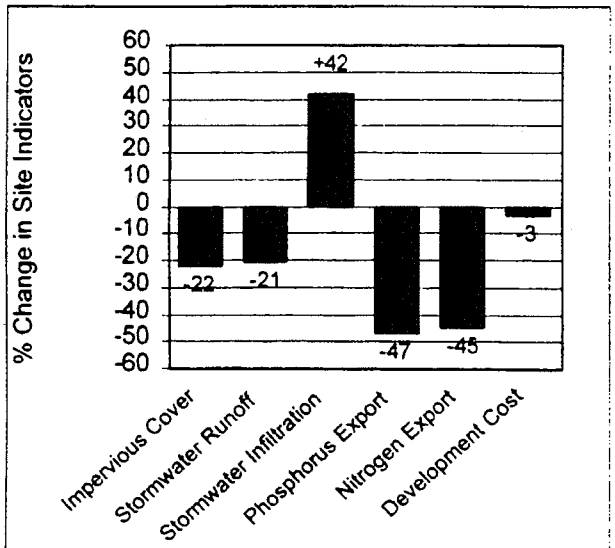

Figure 10: Percentage Change in Key Site Conditions from a Conventional Design to a Redesigned Parking lot at the 270 Corporate Office Park, Both With Stormwater Practices

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help mitigate the impact of the parking lot. Therefore, the first and most important step in implementing better site design for commercial developments *is to reduce local parking demand ratios, even if only by five or ten percent*. For many communities, however, this modest step may seem like a terrifying leap, possibly off a cliff.

Developers, bankers, retailers and drivers all have a shared interest in abundant and convenient parking, and it is hard to convince them that any attempt to downsize parking lots, however modest, will not work against this goal. This kind of thinking is quite understandable. Most people can easily recall the rare situation where parking was hard to find, but the more common situation where parking is plentiful generally escapes our everyday notice.

Small wonder, then, that so many communities are prone to inertia when it comes to changing parking codes. Perhaps the only way watershed advocates can overcome this inertia is to document the existence of excess parking capacity in each community. Indeed, it is a rather simple step for volunteers to count cars and photograph empty stalls during peak times at similar commercial land uses to demonstrate how generous local parking requirements actually are.

The most important step to implement better site design for commercial developments is to reduce local parking demand ratios.

A small but growing list of communities are now experimenting with their parking standards and parking lot designs, including cities like Scarborough, Ontario; Oakland, CA; Olympia, WA; Sacramento, CA; Bellevue, WA; Davis, CA and Prince George's County, MD. Each community has worked in different ways to redesign their parking lots, and many of their successful experiences are recounted in *Better Site Design: A Handbook for Changing Development Rules in Your Community* (CWP 1998a).

Given the prevalence of parking lots in our urban landscape and the environmental harm they cause, we need to fundamentally change the way that parking lots are sized and designed. The modest ideas presented in this article are merely an initial step in this direction. A wide range of professions collectively influence the form and function of parking lots, including engineers, hydrologists, landscape architects, urban foresters, soil scientists, developers, leasing agents, plan reviewers, transportation researchers and many, many others. Working together, these groups can move us closer toward the goal of a truly sustainable parking lot, i.e., one that not only provides car habitat, but also prevents damage to other habitats, as well. - *JAZ*

Editor's Note: Some useful benchmarks for testing how good your local parking codes can be found in the Codes and Ordinances Worksheet (see accompanying article).

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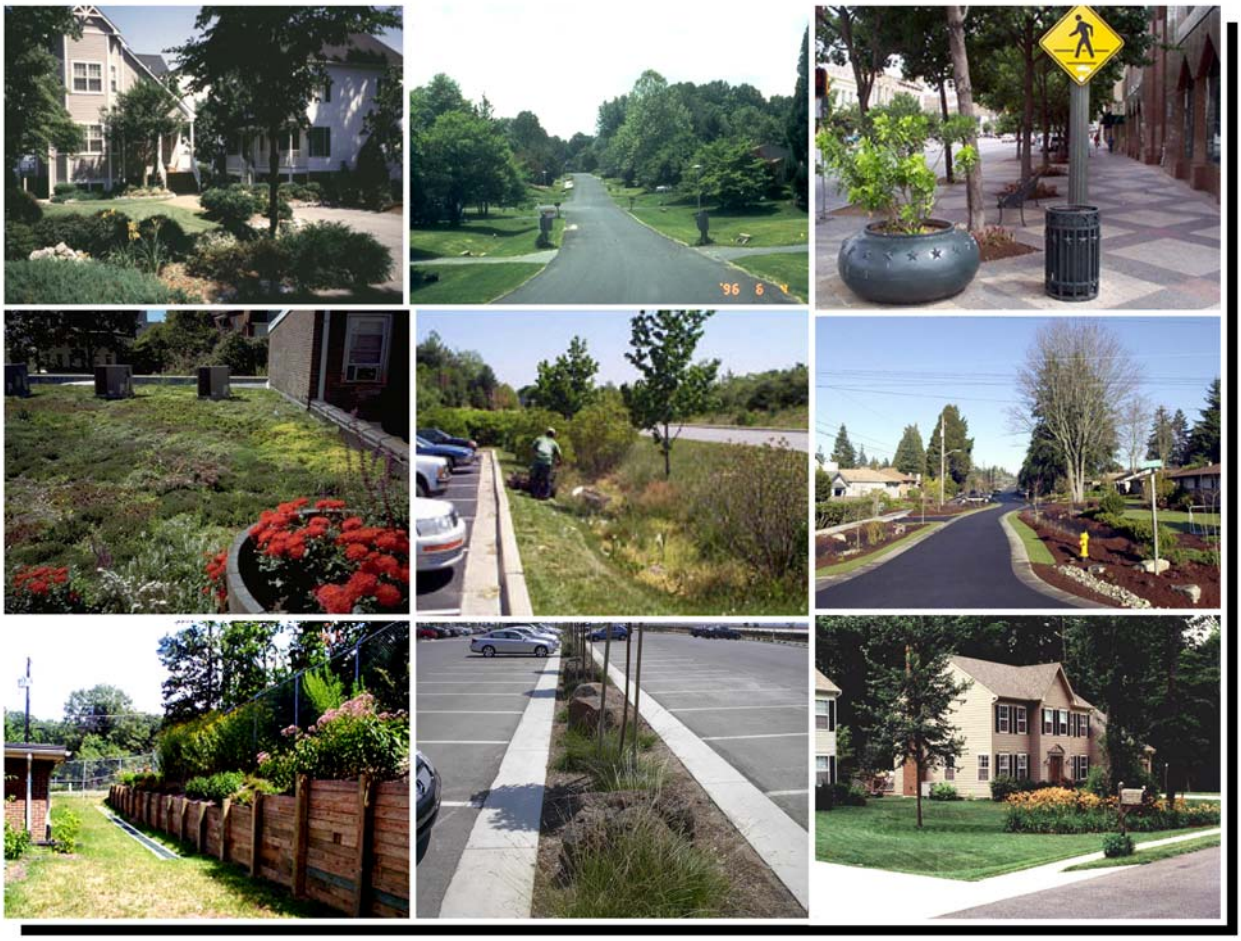
Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices



Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices

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FOREWORD

One of the most exciting new trends in water quality management today is the movement by many cities, counties, states, and private-sector developers toward the increased use of Low Impact Development (LID) to help protect and restore water quality. LID comprises a set of approaches and practices that are designed to reduce runoff of water and pollutants from the site at which they are generated. By means of infiltration, evapotranspiration, and reuse of rainwater, LID techniques manage water and water pollutants at the source and thereby prevent or reduce the impact of development on rivers, streams, lakes, coastal waters, and ground water.

Although the increase in application of these practices is growing rapidly, data regarding both the effectiveness of these practices and their costs remain limited. This document is focused on the latter issue, and the news is good. In the vast majority of cases, the U.S. Environmental Protection Agency (EPA) has found that implementing well-chosen LID practices saves money for developers, property owners, and communities while protecting and restoring water quality.

While this study focuses on the cost reductions and cost savings that are achievable through the use of LID practices, it is also the case that communities can experience many amenities and associated economic benefits that go beyond cost savings. These include enhanced property values, improved habitat, aesthetic amenities, and improved quality of life. This study does not monetize and consider these values in performing the cost calculations, but these economic benefits are real and significant. For that reason, EPA has included a discussion of these economic benefits in this document and provided references for interested readers to learn more about them.

Readers interested in increasing their knowledge about LID and Green Infrastructure, which encompasses LID along with other aspects of green development, should see www.epa.gov/npdes/greeninfrastructure and www.epa.gov/nps/lid. It is EPA's hope that as professionals and citizens continue to become more knowledgeable about the effectiveness and costs of LID, the use of LID practices will continue to increase at a rapid pace.

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EXECUTIVE SUMMARY

This report summarizes 17 case studies of developments that include Low Impact Development (LID) practices and concludes that applying LID techniques can reduce project costs and improve environmental performance. In most cases, LID practices were shown to be both fiscally and environmentally beneficial to communities. In a few cases, LID project costs were higher than those for conventional stormwater management practices. However, in the vast majority of cases, significant savings were realized due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Total capital cost savings ranged from 15 to 80 percent when LID methods were used, with a few exceptions in which LID project costs were higher than conventional stormwater management costs.

EPA has identified several additional areas that will require further study. First, in all cases, there were benefits that this study did not monetize and did not factor into the project's bottom line. These benefits include improved aesthetics, expanded recreational opportunities, increased property values due to the desirability of the lots and their proximity to open space, increased total number of units developed, increased marketing potential, and faster sales. Second, more research is also needed to quantify the environmental benefits that can be achieved through the use of LID techniques and the costs that can be avoided. Examples of environmental benefits include reduced runoff volumes and pollutant loadings to downstream waters, and reduced incidences of combined sewer overflows. Finally, more research is needed to monetize the cost reductions that can be achieved through improved environmental performance, reductions in long-term operation and maintenance costs, and/or reductions in the life cycle costs of replacing or rehabilitating infrastructure.

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INTRODUCTION

BACKGROUND

Most stormwater runoff is the result of the man-made hydrologic modifications that normally accompany development. The addition of impervious surfaces, soil compaction, and tree and vegetation removal result in alterations to the movement of water through the environment. As interception, evapotranspiration, and infiltration are reduced and precipitation is converted to overland flow, these modifications affect not only the characteristics of the developed site but also the watershed in which the development is located. Stormwater has been identified as one of the leading sources of pollution for all waterbody types in the United States. Furthermore, the impacts of stormwater pollution are not static; they usually increase with more development and urbanization.

Extensive development in the United States is a relatively recent phenomenon. For the past two decades, the rate of land development across the country has been twice the rate of population growth. Approximately 25 million acres were developed between 1982 and 1997, resulting in a 34 percent increase in the amount of developed land with only a 15 percent increase in population.[1,2] The 25 million acres developed during this 15-year period represent nearly 25 percent of the total amount of developed land in the contiguous states. The U.S. population is expected to increase by 22 percent from 2000 to 2025. If recent development trends continue, an additional 68 million acres of land will be developed during this 25-year period.[3]

Water quality protection strategies are often implemented at three scales: the region or large watershed area, the community or neighborhood, and the site or block. Different stormwater approaches are used at different scales to afford the greatest degree of protection to waterbodies because the influences of pollution are often found at all three scales. For example, decisions about where and how to grow are the first and perhaps most important decisions related to water quality. Growth and development can give a community the resources needed to revitalize a downtown, refurbish a main street, build new schools, and develop vibrant places to live, work, shop, and play. The environmental impacts of development, however, can pose challenges for communities striving to protect their natural resources. Development that uses land efficiently and protects undisturbed natural lands allows a community to grow and still protect its water resources.

Strategies related to these broad growth and development issues are often implemented at the regional or watershed scale. Once municipalities have determined where to grow and where to preserve, various stormwater management techniques are applied at the neighborhood or community level. These measures, such as road width requirements, often transcend specific development sites and can be applied throughout a neighborhood. Finally, site-specific stormwater strategies, such as rain gardens and infiltration areas, are incorporated within a particular development. Of course, some stormwater management strategies can be applied at several scales. For example, opportunities to maximize infiltration can occur at the neighborhood and site levels.

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Many smart growth approaches can decrease the overall amount of impervious cover associated with a development's footprint. These approaches include directing development to already degraded land; using narrower roads; designing smaller parking lots; integrating retail, commercial, and residential uses; and designing more compact residential lots. These development approaches, combined with other techniques aimed at reducing the impact of development, can offer communities superior stormwater management.

Stormwater management programs have struggled to provide adequate abatement and treatment of stormwater at the current levels of development. Future development will create even greater challenges for maintaining and improving water quality in the nation's waterbodies. The past few decades of stormwater management have resulted in the current convention of control-and-treatment strategies. They are largely engineered, end-of-pipe practices that have been focused on controlling peak flow rate and suspended solids concentrations. Conventional practices, however, fail to address the widespread and cumulative hydrologic modifications within the watershed that increase stormwater volumes and runoff rates and cause excessive erosion and stream channel degradation. Existing practices also fail to adequately treat for other pollutants of concern, such as nutrients, pathogens, and metals.

LOW IMPACT DEVELOPMENT

Low Impact Development (LID)[4] is a stormwater management strategy that has been adopted in many localities across the country in the past several years. It is a stormwater management approach and set of practices that can be used to reduce runoff and pollutant loadings by managing the runoff as close to its source(s) as possible. A set or system of small-scale practices, linked together on the site, is often used. LID approaches can be used to reduce the impacts of development and redevelopment activities on water resources. In the case of new development, LID is typically used to achieve or pursue the goal of maintaining or closely replicating the predevelopment hydrology of the site. In areas where development has already occurred, LID can be used as a retrofit practice to reduce runoff volumes, pollutant loadings, and the overall impacts of existing development on the affected receiving waters.

In general, implementing integrated LID practices can result in enhanced environmental performance while at the same time reducing development costs when compared to traditional stormwater management approaches. LID techniques promote the use of natural systems, which can effectively remove nutrients, pathogens, and metals from stormwater. Cost savings are typically seen in reduced infrastructure because the total volume of runoff to be managed is minimized through infiltration and evapotranspiration. By working to mimic the natural water cycle, LID practices protect downstream resources from adverse pollutant and hydrologic impacts that can degrade stream channels and harm aquatic life.

It is important to note that typical, real-world LID designs usually incorporate more than one type of practice or technique to provide integrated treatment of runoff from a site. For example, in lieu of a treatment pond serving a new subdivision, planners might incorporate a bioretention area in each yard, disconnect downspouts from driveway surfaces, remove curbs, and install grassed swales in common areas. Integrating small

practices throughout a site instead of using extended detention wet ponds to control runoff from a subdivision is the basis of the LID approach.

When conducting cost analyses of these practices, examples of projects where actual practice-by-practice costs were considered separately were found to be rare because material and labor costs are typically calculated for an entire site rather than for each element within a larger system. Similarly, it is difficult to calculate the economic benefits of individual LID practices on the basis of their effectiveness in reducing runoff volume and rates or in treating pollutants targeted for best management practice (BMP) performance monitoring.

The following is a summary of the different categories of LID practices, including a brief description and examples of each type of practice.

Conservation designs can be used to minimize the generation of runoff by preserving open space. Such designs can reduce the amount of impervious surface, which can cause increased runoff volumes. Open space can also be used to treat the increased runoff from the built environment through infiltration or evapotranspiration. For example, developers can use conservation designs to preserve important features on the site such as wetland and riparian areas, forested tracts, and areas of porous soils. Development plans that outline the smallest site disturbance area can minimize the stripping of topsoil and compaction of subsoil that result from grading and equipment use. By preserving natural areas and not clearing and grading the entire site for housing lots, less total runoff is generated on the development parcel. Such simplistic, nonstructural methods can reduce the need to build large structural runoff controls like retention ponds and stormwater conveyance systems and thereby decrease the overall infrastructure costs of the project. Reducing the total area of impervious surface by limiting road widths, parking area, and sidewalks can also reduce the volume of runoff that must be treated. Residential developments that incorporate conservation design principles also can benefit residents and their quality of life due to increased access and proximity to communal open space, a greater sense of community, and expanded recreational opportunities.

Examples of Conservation Design

- Cluster development
- Open space preservation
- Reduced pavement widths (streets, sidewalks)
- Shared driveways
- Reduced setbacks (shorter driveways)
- Site fingerprinting during construction

Infiltration practices are engineered structures or landscape features designed to capture and infiltrate runoff. They can be used to reduce both the volume of runoff discharged from the site and the infrastructure needed to convey, treat, or control runoff. Infiltration practices can also be used to recharge ground water. This benefit is especially important in areas where maintaining drinking water supplies and stream baseflow is of special concern because of limited precipitation or a high ratio of withdrawal to recharge rates. Infiltration of runoff can also help to maintain stream temperatures because the infiltrated water that moves laterally to replenish stream baseflow typically has a lower temperature than overland flows, which might be subject

Examples of Infiltration Practices

- Infiltration basins and trenches
- Porous pavement
- Disconnected downspouts
- Rain gardens and other vegetated treatment systems

to solar radiation. Another advantage of infiltration practices is that they can be integrated into landscape features in a site-dispersed manner. This feature can result in aesthetic benefits and, in some cases, recreational opportunities; for example, some infiltration areas can be used as playing fields during dry periods.

Runoff storage practices. Impervious surfaces are a central part of the built environment, but runoff from such surfaces can be captured and stored for reuse or gradually infiltrated, evaporated, or used to irrigate plants. Using runoff storage practices has several benefits. They can reduce the volume of runoff discharged to surface waters, lower the peak flow hydrograph to protect streams from the erosive forces of high flows, irrigate landscaping, and provide aesthetic benefits such as landscape islands, tree boxes, and rain gardens. Designers can take advantage of the void space beneath paved areas like parking lots and sidewalks to provide additional storage. For example, underground vaults can be used to store runoff in both urban and rural areas.

Examples of Runoff Storage Practices

- Parking lot, street, and sidewalk storage
- Rain barrels and cisterns
- Depressional storage in landscape islands and in tree, shrub, or turf depressions
- Green roofs

Runoff conveyance practices. Large storm events can make it difficult to retain all the runoff generated on-site by using infiltration and storage practices. In these situations, conveyance systems are typically used to route excess runoff through and off the site. In LID designs, conveyance systems can be used to slow flow velocities, lengthen the runoff time of concentration, and delay peak flows that are discharged off-site. LID conveyance practices can be used as an alternative to curb-and-gutter systems, and from a water quality perspective they have advantages over conventional approaches designed to rapidly convey runoff off-site and alleviate on-site flooding. LID conveyance practices often have rough surfaces, which slow runoff and increase evaporation and settling of solids. They are typically permeable and vegetated, which promotes infiltration, filtration, and some biological uptake of pollutants. LID conveyance practices also can perform functions similar to those of conventional curbs, channels, and gutters. For example, they can be used to reduce flooding around structures by routing runoff to landscaped areas for treatment, infiltration, and evapotranspiration.

Examples of Runoff Conveyance Practices

- Eliminating curbs and gutters
- Creating grassed swales and grass-lined channels
- Roughening surfaces
- Creating long flow paths over landscaped areas
- Installing smaller culverts, pipes, and inlets
- Creating terraces and check dams

Filtration practices are used to treat runoff by filtering it through media that are designed to capture pollutants through the processes of physical filtration of solids and/or cation exchange of dissolved pollutants. Filtration practices offer many of the same benefits as infiltration, such as reductions in the volume of runoff transported off-site, ground water recharge, increased stream baseflow, and reductions in thermal impacts to receiving waters. Filtration practices also have the added advantage of providing increased pollutant removal benefits. Although pollutant build-up and removal may be of concern, pollutants are typically captured in the upper soil horizon and can be removed by replacing the topsoil.

Examples of Filtration Practices

- Bioretention/rain gardens
- Vegetated swales
- Vegetated filter strips/buffers

Low impact landscaping. Selection and distribution of plants must be carefully planned when designing a functional landscape. Aesthetics are a primary concern, but it is also important to consider long-term maintenance goals to reduce inputs of labor, water, and chemicals. Properly preparing soils and selecting species adapted to the microclimates of a site greatly increases the success of plant establishment and growth, thereby stabilizing soils and allowing for biological uptake of pollutants. Dense, healthy plant growth offers such benefits as pest resistance (reducing the need for pesticides) and improved soil infiltration from root growth. Low impact landscaping can thus reduce impervious surfaces, improve infiltration potential, and improve the aesthetic quality of the site.

Examples of Low Impact Landscaping

- Planting native, drought-tolerant plants
- Converting turf areas to shrubs and trees
- Reforestation
- Encouraging longer grass length
- Planting wildflower meadows rather than turf along medians and in open space
- Amending soil to improve infiltration

EVALUATIONS OF BENEFITS AND COSTS

To date, the focus of traditional stormwater management programs has been concentrated largely on structural engineering solutions to manage the hydraulic consequences of the increased runoff that results from development. Because of this emphasis, stormwater management has been considered primarily an engineering endeavor. Economic analyses regarding the selection of solutions that are not entirely based on pipes and ponds have not been a significant factor in management decisions. Where costs have been considered, the focus has been primarily on determining capital costs for conventional infrastructure, as well as operation and maintenance costs in dollars per square foot or dollars per pound of pollutant removed.

Little attention has been given to the benefits that can be achieved through implementing LID practices. For example, communities rarely attempt to quantify and monetize the pollution prevention benefits and avoided treatment costs that might accrue from the use of conservation designs or LID techniques. To be more specific, the benefits of using LID practices to decrease the need for combined sewer overflow (CSO) storage and conveyance systems should be factored into the economic analyses. One of the major factors preventing LID practices from receiving equal consideration in the design or selection process is the difficulty of monetizing the environmental benefits of these practices. Without good data and relative certainty that these alternatives will work and not increase risk or cost, current standards of practice are difficult to change.

This report is an effort to compare the projected or known costs of LID practices with those of conventional development approaches. At this point, monetizing the economic and environmental benefits of LID strategies is much more difficult than monetizing traditional infrastructure costs or changes in property values due to improvements in existing utilities or transportation systems. Systems of practices must be analyzed to determine net performance and monetary benefits based on the capacity of the systems to both treat for pollutants and reduce impacts through pollution prevention. For example, benefits might come in the form of reduced stream channel degradation, avoided stream restoration costs, or reduced drinking water treatment costs.

One of the chief impediments to getting useful economic data to promote more widespread use of LID techniques is the lack of a uniform baseline with which to compare the costs and benefits of LID practices against the costs of conventional stormwater treatment and control. Analyzing benefits is further complicated in cases where the environmental performance of the conservation design or LID system exceeds that of the conventional runoff management system, because such benefits are not easily monetized. The discussion below is intended to provide a general discussion of the range of economic benefits that may be provided by LID practices in a range of appropriate circumstances.

OVERVIEW OF BENEFITS

The following is a brief discussion of some of the actual and assumed benefits of LID practices. Note that environmental and ancillary benefits typically are not measured as part of development projects, nor are they measured as part of pilot or demonstration projects, because they can be difficult to isolate and quantify. Many of the benefits described below are assumed on the basis of limited studies and anecdotal evidence.

The following discussion is organized into three categories: (1) environmental benefits, which include reductions in pollutants, protection of downstream water resources, ground water recharge, reductions in pollutant treatment costs, reductions in the frequency and severity of CSOs, and habitat improvements; (2) land value benefits, which include reductions in downstream flooding and property damage, increases in real estate value, increased parcel lot yield, increased aesthetic value, and improvement of quality of life by providing open space for recreation; and (3) compliance incentives.

Environmental Benefits

Pollution abatement. LID practices can reduce both the volume of runoff and the pollutant loadings discharged into receiving waters. LID practices result in pollutant removal through settling, filtration, adsorption, and biological uptake. Reductions in pollutant loadings to receiving waters, in turn, can improve habitat for aquatic and terrestrial wildlife and enhance recreational uses. Reducing pollutant loadings can also decrease stormwater and drinking water treatment costs by decreasing the need for regional stormwater management systems and expansions in drinking water treatment systems.

Protection of downstream water resources. The use of LID practices can help to prevent or reduce hydrologic impacts on receiving waters, reduce stream channel degradation from erosion and sedimentation, improve water quality, increase water supply, and enhance the recreational and aesthetic value of our natural resources. LID practices can be used to protect water resources that are downstream in the watershed. Other potential benefits include reduced incidence of illness from contact recreation activities such as swimming and wading, more robust and safer seafood supplies, and reduced medical treatment costs.

Ground water recharge. LID practices also can be used to infiltrate runoff to recharge ground water. Growing water shortages nationwide increasingly indicate the need for water resource management strategies designed to integrate stormwater, drinking water, and wastewater programs to maximize benefits and minimize costs. Development pressures typically result in increases in the amount of impervious surface and volume of runoff. Infiltration practices can be used to replenish ground water and increase stream baseflow. Adequate baseflow to streams during dry weather is important because low ground water levels can lead to greater fluctuations in stream depth, flows, and temperatures, all of which can be detrimental to aquatic life.

Water quality improvements/reduced treatment costs. It is almost always less expensive to keep water clean than it is to clean it up. The Trust for Public Land[5] noted Atlanta's tree cover has saved more than $883 million by preventing the need for stormwater retention facilities. A study of 27 water suppliers conducted by the Trust for Public Land and the American Water Works Association[6] found a direct relationship between forest cover in a watershed and water supply treatment costs. In other words, communities with higher percentages of forest cover had lower treatment costs. According to the study, approximately 50 to 55 percent of the variation in treatment costs can be explained by the percentage of forest cover in the source area. The researchers also found that for every 10 percent increase in forest cover in the source area, treatment and chemical costs decreased approximately 20 percent, up to about 60 percent forest cover.

Reduced incidence of CSOs. Many municipalities have problems with CSOs, especially in areas with aging infrastructure. Combined sewer systems discharge sanitary wastewater during storm events. LID techniques, by retaining and infiltrating runoff, reduce the frequency and amount of CSO discharges to receiving waters. Past management efforts typically have been concentrated on hard engineering approaches focused on treating the total volume of sanitary waste together with the runoff that is discharged to the combined system. Recently, communities like Portland (Oregon), Chicago, and Detroit have been experimenting with watershed approaches aimed at reducing the total volume of runoff generated that must be handled by the combined system. LID techniques have been the primary method with which they have experimented to reduce runoff. A Hudson Riverkeeper report concluded, based on a detailed technical analysis, that New York City could reduce its CSO's more cost-effectively with LID practices than with conventional, hard infrastructure CSO storage practices. [7]

Habitat improvements. Innovative stormwater management techniques like LID or conservation design can be used to improve natural resources and wildlife habitat, maintain or increase land value, or avoid expensive mitigation costs.

Land Value and Quality of Life Benefits

Reduced downstream flooding and property damage. LID practices can be used to reduce downstream flooding through the reduction of peak flows and the total amount or volume of runoff. Flood prevention reduces property damage and can reduce the initial capital costs and the operation and maintenance costs of stormwater infrastructure. Strategies designed to manage runoff on-site or as close as possible to its point of generation can reduce erosion and sediment transport as well as reduce flooding and downstream erosion. As a result, the costs for cleanups and streambank restoration can be reduced or avoided altogether. The use of LID techniques also can help protect or restore floodplains, which can be used as park space or wildlife habitat.[8]

Real estate value/property tax revenue. Homeowners and property owners are willing to pay a premium to be located next to or near aesthetically pleasing amenities like water features, open space, and trails. Some stormwater treatment systems can be beneficial to developers because they can serve as a "water" feature or other visual or recreational amenity that can be used to market the property. These designs should be visually attractive and safe for the residents and should be considered an integral part of planning the development. Various LID projects and smart growth studies have shown that people are willing to pay more for clustered homes than conventionally designed subdivisions. Clustered housing with open space appreciated at a higher rate than conventionally designed subdivisions. EPA's *Economic Benefits of Runoff Controls*[9] describes numerous examples where developers and subsequent homeowners have received premiums for proximity to attractive stormwater management practices.

Lot yield. LID practices typically do not require the large, contiguous areas of land that are usually necessary when traditional stormwater controls like ponds are used. In cases where LID practices are incorporated on individual house lots and along roadsides as part of the landscaping, land that would normally be dedicated for a stormwater pond or other large structural control can be developed with additional housing lots.

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Aesthetic value. LID techniques are usually attractive features because landscaping is an integral part of the designs. Designs that enhance a property's aesthetics using trees, shrubs, and flowering plants that complement other landscaping features can be selected. The use of these designs may increase property values or result in faster sale of the property due to the perceived value of the "extra" landscaping.

Public spaces/quality of life/public participation. Placing water quality practices on individual lots provides opportunities to involve homeowners in stormwater management and enhances public awareness of water quality issues. An American Lives, Inc., real estate study found that 77.7 percent of potential homeowners rated natural open space as "essential" or "very important" in planned communities.[10]

Compliance Incentives

Regulatory compliance credits. Many states recognize the positive benefits LID techniques offer, such as reduced wetland impacts. As a result, they might offer regulatory compliance credits, streamlined or simpler permit processes, and other incentives similar to those offered for other green practices. For example, in Maryland the volume required for the permanent pool of a wet pond can be reduced if rooftop runoff is infiltrated on-site using LID practices. This procedure allows rooftop area to be subtracted from the total impervious area, thereby reducing the required size of the permanent pool. In addition, a LID project can have less of an environmental impact than a conventional project, thus requiring smaller impact fees.

COST CONSIDERATIONS

Traditional approaches to stormwater management involve conveying runoff off-site to receiving waters, to a combined sewer system, or to a regional facility that treats runoff from multiple sites. These designs typically include hard infrastructure, such as curbs, gutters, and piping. LID-based designs, in contrast, are designed to use natural drainage features or engineered swales and vegetated contours for runoff conveyance and treatment. In terms of costs, LID techniques like conservation design can reduce the amount of materials needed for paving roads and driveways and for installing curbs and gutters. Conservation designs can be used to reduce the total amount of impervious surface, which results in reduced road and driveway lengths and reduced costs. Other LID techniques, such as grassed swales, can be used to infiltrate roadway runoff and eliminate or reduce the need for curbs and gutters, thereby reducing infrastructure costs. Also, by infiltrating or evaporating runoff, LID techniques can reduce the size and cost of flood-control structures. Note that more research is needed to determine the optimal combination of LID techniques and detention practices for flood control.

It must be stated that the use of LID techniques might not always result in lower project costs. The costs might be higher because of the costs of plant material, site preparation, soil amendments, underdrains and connections to municipal stormwater systems, and increased project management.

Another factor to consider when comparing costs between traditional and LID designs is the amount of land required to implement a management practice. Land must be set aside for both traditional stormwater management practices and LID practices, but the former require the use of land *in addition to* individual lots and other community areas, whereas bioretention areas and swales can be incorporated into the landscaping of yards, in rights-

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of-way along roadsides, and in or adjacent to parking lots. The land that would have been set aside for ponds or wetlands can in many cases be used for additional housing units, yielding greater profits.

Differences in maintenance requirements should also be considered when comparing costs. According to a 1999 EPA report, maintenance costs for retention basins and constructed wetlands were estimated at 3 to 6 percent of construction costs, whereas maintenance costs for swales and bioretention practices were estimated to be 5 to 7 percent of construction costs.[11] However, much of the maintenance for bioretention areas and swales can be accomplished as part of routine landscape maintenance and does not require specialized equipment. Wetland and pond maintenance, on the other hand, involves heavy equipment to remove accumulated sediment, oils, trash, and vegetation in forebays and open ponds.

Finally, in some circumstances LID practices can offset the costs associated with regulatory requirements for stormwater control. In urban redevelopment projects where land is not likely to be available for large stormwater management practices, developers can employ site-dispersed BMPs in sidewalk areas, in courtyards, on rooftops, in parking lots, and in other small outdoor spaces, thereby avoiding the fees that some municipalities charge when stormwater mitigation requirements cannot otherwise be met. In addition, stormwater utilities often provide credits for installing runoff management practices such as LID practices.[12]

CASE STUDIES

The case studies presented below are not an exhaustive list of LID projects nationwide. These examples were selected on the basis of the quantity and quality of economic data, quantifiable impacts, and types of LID practices used. Economic data are available for many other LID installations, but those installations often cannot be compared with conventional designs because of the unique nature of the design or the pilot status of the project. Table 1 presents a summary of the LID practices employed in each case study.

Table 1. Summary of LID Practices Employed in the Case Studies

Name	LID Techniques							
	Biore-tention	Cluster Building	Reduced Impervious Area	Swales	Permeable Pavement	Vegetated Landscaping	Wetlands	Green Roofs
2nd Avenue SEA Street	✓		✓	✓				
Auburn Hills	✓		✓	✓		✓	✓	
Bellingham Parking Lot Retrofits	✓							
Central Park Commercial Redesigns	✓			✓				
Crown Street	✓		✓	✓				
Gap Creek			✓			✓		
Garden Valley	✓	✓		✓	✓		✓	
Kensington Estates		✓	✓		✓	✓	✓	
Laurel Springs	✓	✓	✓	✓				
Mill Creek		✓	✓	✓				
Poplar Street Apartments	✓			✓			✓	
Portland Downspout Disconnection*			✓					
Prairie Crossing	✓		✓	✓		✓		
Prairie Glen	✓	✓	✓	✓		✓	✓	
Somerset	✓			✓				
Tellabs Corporate Campus	✓			✓		✓	✓	
Toronto Green Roofs								✓

*Although impervious area stays the same, the disconnection program reduces directly connected impervious area.

The case studies contain an analysis of development costs, which are summarized in Table 2. Note that some case study results do not lend themselves well to a traditional vs.

LID cost comparison and therefore are not included in Table 2 (as noted). *Conventional development cost* refers to costs incurred or estimated for a traditional stormwater management approach, whereas *LID cost* refers to costs incurred or estimated for using LID practices. *Cost difference* is the difference between the conventional development cost and the LID cost. *Percent difference* is the cost savings relative to the conventional development cost.

Table 2. Summary of Cost Comparisons Between Conventional and LID Approaches[a]

Project	Conventional Development Cost	LID Cost	Cost Difference[b]	Percent Difference[b]
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington Estates	$765,700	$1,502,900	–$737,200	-96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[c]	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

[a] The Central Park Commercial Redesigns, Crown Street, Poplar Street Apartments, Prairie Crossing, Portland Downspout Disconnection, and Toronto Green Roofs study results do not lend themselves to display in the format of this table.
[b] Negative values denote increased cost for the LID design over conventional development costs.
[c] Mill Creek costs are reported on a per-lot basis.

2ND AVENUE SEA STREET, SEATTLE, WASHINGTON



The 2nd Avenue Street Edge Alternative (SEA) Street project was a pilot project undertaken by Seattle Public Utilities to redesign an entire 660-foot block with a number of LID techniques. The goals were to reduce stormwater runoff and to provide a more "livable" community. Throughout the design and construction process, Seattle Public Utilities worked collaboratively with street residents to develop the final street design.[13]

The design reduced imperviousness, included retrofits of bioswales to treat and manage stormwater, and added 100 evergreen trees and 1,100 shrubs.[14] Conventional curbs and gutters were replaced with bioswales in the rights-of-way on both sides of the street, and the street width was reduced from 25 feet to 14 feet. The final constructed design reduced imperviousness by more than 18 percent. An estimate for the final total project cost was $651,548. A significant amount of community outreach was involved, which raised the level of community acceptance. Community input is important for any project, but because this was a pilot study, much more was spent on communication and redesign than what would be spent for a typical project.

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The costs for the LID retrofit were compared with the estimated costs of a conventional street retrofit (Table 3). Managing stormwater with LID techniques resulted in a cost savings of 29 percent. Also, the reduction in street width and sidewalks reduced paving costs by 49 percent.

Table 3. Cost Comparison for 2nd Avenue SEA Street [15]

Item	Conventional Development Cost	SEA Street Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$65,084	$88,173	–$23,089	–35%	–11%
Stormwater management	$372,988	$264,212	$108,776	29%	50%
Site paving and sidewalks	$287,646	$147,368	$140,278	49%	65%
Landscaping	$78,729	$113,034	–$34,305	–44%	–16%
Misc. (mobilization, etc.)	$64,356	$38,761	$25,595	40%	12%
Total	**$868,803**	**$651,548**	**$217,255**	**--**	**--**

* Negative values denote increased cost for the LID design over conventional development costs.

The avoided cost for stormwater infrastructure and reduced cost for site paving accounted for much of the overall cost savings. The nature of the design, which included extensive use of bioswales and vegetation, contributed to the increased cost for site preparation and landscaping. Several other SEA Street projects have been completed or are under way, and cost evaluations are expected to be favorable.

For this site, the environmental performance has been even more significant than the cost savings. Hydrologic monitoring of the project indicates a 99 percent reduction in total potential surface runoff, and runoff has not been recorded at the site since December 2002, a period that included the highest-ever 24-hour recorded rainfall at Seattle-Tacoma Airport.[16] The site is retaining more than the original design estimate of 0.75 inch of rain. A modeling analysis indicates that if a conventional curb-and-gutter system had been installed along 2nd Avenue instead of the SEA Street design, 98 times more stormwater would have been discharged from the site.[17]

AUBURN HILLS SUBDIVISION, SOUTHWESTERN WISCONSIN



Auburn Hills in southwestern Wisconsin is a residential subdivision developed with conservation design principles. Forty percent of the site is preserved as open space; this open space includes wetlands, green space and natural plantings, and walking trails. The subdivision was designed to include open swales and bioretention for stormwater management. To determine potential savings from using conservation design, the site construction costs were compared with the estimated cost of building the site as a conventional subdivision.[18] Reduced stormwater management costs accounted for approximately 56 percent of the total cost savings. A cost comparison is provided in Table 4. Other savings not shown in Table 4 were realized as a result of reduced sanitary sewer, water distribution, and utility construction costs.

Table 4. Cost Comparison for Auburn Hills Subdivision [19]

Item	Conventional Development Cost	Auburn Hills LID Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$699,250	$533,250	$166,000	24%	22%
Stormwater management	$664,276	$241,497	$422,779	64%	56%
Site paving and sidewalks	$771,859	$584,242	$187,617	24%	25%
Landscaping	$225,000	$240,000	–$15,000	-7%	-2%
Total	**$2,360,385**	**$1,598,989**	**$761,396**	**—**	**—**

* Negative values denote increased cost for the LID design over conventional development costs.

The clustered design used in the development protected open space and reduced clearing and grading costs. Costs for paving and sidewalks were also decreased because the cluster design reduced street length and width. Stormwater savings were realized primarily through the use of vegetated swales and bioswales. These LID practices provided stormwater conveyance and treatment and also lowered the cost of conventional stormwater infrastructure. The increase in landscaping costs resulted from additional open space present on-site compared to a conventional design, as well as increased street sweeping. Overall, the subdivision's conservation design retained more natural open space for the benefit and use of the homeowners and aided stormwater management by preserving some of the site's natural hydrology.[20]

BELLINGHAM, WASHINGTON, PARKING LOT RETROFITS



The City of Bellingham, Washington, retrofitted two parking lots—one at City Hall and the other at Bloedel Donovan Park—with rain gardens in lieu of installing underground vaults to manage stormwater.[21] At City Hall, 3 parking spaces out of a total of 60 were used for the rain garden installation. The Bloedel Donovan Park retrofit involved converting to a rain garden a 550-square-foot area near a catch basin. Both installations required excavation, geotextile fabric, drain rock, soil amendments, and native plants. Flows were directed to the rain gardens by curbs. An overflow system was installed to accommodate higher flows during heavy rains.

The City compared actual rain garden costs to estimates for conventional underground vaults based on construction costs for similar projects in the area ($12.00 per cubic foot of storage). Rain garden costs included labor, vehicle use/rental, and materials. Table 5 shows that the City Hall rain garden saved the City $22,000, or 80 percent, over the underground vault option; the Bloedel Donovan Park installation saved $40,000, or 76 percent.

Table 5. Cost Comparison for Bellingham's Parking Lot Rain Garden Retrofits[22]

Project	Conventional Vault Cost	Rain Garden Cost	Cost Savings	Percent Savings
City Hall	$27,600	$5,600	$22,000	80%
Bloedel Donovan Park	$52,800	$12,800	$40,000	76%

CENTRAL PARK COMMERCIAL REDESIGNS, FREDERICKSBURG, VA (A MODELING STUDY)



The Friends of the Rappahannock undertook a cost analysis involving the redesign of site plans for several stores in a large commercial development in the Fredericksburg, Virginia, area called Central Park.[23,24] Table 6 contains a side-by-side analysis of the cost additions and reductions for each site for scenarios where LID practices (bioretention areas and swales) were incorporated into the existing, traditional site designs. In five of the six examples, the costs for the LID redesigns were higher than those for the original designs, although they never exceeded $10,000, or 10 percent of the project. One example yielded a $5,694 savings. The fact that these projected costs for LID were comparable to the costs for traditional designs convinced the developer to begin incorporating LID practices into future design projects.[25]

Table 6. Site Information and Cost Additions/Reductions Using LID Versus Traditional Designs

Name	Total BMP Area (ft²)	Total Impervious Area Treated (ft²)	Percent of Impervious Area Treated	Cost Additions[a]	Cost Reductions[b]	Change in Cost After Redesign
Breezewood Station Alternative 1	4,800	64,165	98.4%	$36,696	$34,785	+ $1,911
Breezewood Station Alternative 2	3,500	38,775	59.5%	$24,449	$21,060	+ $3,389
Olive Garden	1,780	31,900	59.1%	$14,885	$11,065	+ $3,790
Kohl's, Best Buy, & Office Depot	14,400	354,238	56.3%	$89,433	$80,380	+ $9,053
First Virginia Bank	1,310	20,994	97.7%	$6,777	$1,148	+ $5,629
Chick-Fil-A[c]	1,326	28,908	82.2%	$6,846	$12,540	– $5,694

[a] Additional costs for curb, curb blocks, storm piping, inlets, underdrains, soil, mulch, and vegetation as a result of the redesign.
[b] Reduced cost for curb, storm piping, roof drain piping, and inlets as a result of the redesign.
[c] Cost reduction value includes the cost of a Stormceptor unit that is not needed as part of the redesign.

CROWN STREET, VANCOUVER, BRITISH COLUMBIA



In 1995 the Vancouver City Council adopted a Greenways program that is focused on introducing pedestrian-friendly green space into the City to connect trails, environmental areas, and urban space. As a part of this program, the City has adopted strategies to manage stormwater runoff from roadways. Two initiatives are discussed here.

The Crown Street redevelopment project, completed in 2005, retrofitted a 1,100-foot block of traditional curb-and-gutter street with a naturalized streetscape modeled after the Seattle SEA Street design. Several LID features were incorporated into the design. The total imperviousness of the street was decreased by reducing the street width from 28 feet to 21 feet with one-

way sections of the road narrowed to 10 feet. Roadside swales that use vegetation and structural grass (grass supported by a grid and soil structure that prevents soil compaction and root damage) were installed to collect and treat stormwater through infiltration.[26]

Modeling predicts that the redesigned street will retain 90 percent of the annual rainfall volume on-site; the remaining 10 percent of runoff will be treated by the system of vegetated swales before discharging.[27,28] The City chose to use the LID design because stormwater runoff from Crown Street flows into the last two salmon-bearing creeks in Vancouver.[29] Monitoring until 2010 will assess the quality of stormwater runoff and compare it with both the modeling projections and the runoff from a nearby curb-and-gutter street.

The cost of construction for the Crown Street redevelopment was $707,000. Of this, $311,000 was attributed to the cost of consultant fees and aesthetic design features, which were included in the project because it was the first of its kind in Vancouver. These added costs would not be a part of future projects. Discounting the extra costs, the $396,000 construction cost is 9 percent higher than the estimated $364,000 conventional curb-and-gutter design cost.[30] The City has concluded that retrofitting streets that have an existing conventional stormwater system with naturalized designs will cost marginally more than making curb-and-gutter improvements, but installing naturalized street designs in new developments will be less expensive than installing conventional drainage systems.[31,32]

One goal of Vancouver's Greenways program is to make transportation corridors more pedestrian-friendly. A method used to achieve this goal is to extend curbs at intersections out into the street to lessen the crossing distance and improve the line of sight for pedestrians. When this initiative began, the City relocated stormwater catch basins that would have been enclosed within the extended curb. Now, at certain intersections, the City uses the new space behind the curb to install "infiltration bulges" to collect and infiltrate roadway runoff. The infiltration bulges are constructed of permeable soils and vegetation. (The City of Portland, Oregon, has installed similar systems, which they call "vegetated curb extensions.") The catch basins are left in place, and any stormwater that does not infiltrate into the soil overflows into the storm drain system.[33]

The infiltration bulges have resulted in savings for the City. Because the stormwater infiltration bulges are installed in conjunction with planned roadway improvements, the only additional costs associated with the stormwater project are the costs of a steel curb insert to allow stormwater to enter the bulge and additional soil excavation costs. These additional costs are more than offset by the $2,400 to $4,000 cost that would have been required to relocate the catch basins. To date, the City has installed nine infiltration bulges, three of which are maintained by local volunteers as part of a Green Streets program in which local residents adopt city green space.[34]

GAP CREEK SUBDIVISION, SHERWOOD, ARKANSAS



Gap Creek's original subdivision plan was revised to include LID concepts. The revised design increased open space from the originally planned 1.5 acres to 23.5 acres. Natural drainage areas were preserved and buffered by greenbelts. Traffic-calming circles were used, allowing the developer to reduce street widths from 36 to 27 feet. In addition, trees were kept close to the curb line. These design techniques allowed the development of 17 additional lots.

The lots sold for $3,000 more and cost $4,800 less to develop than comparable conventional lots. A cost comparison is provided in Table 7. For the entire development, the combination of cost savings and lot premiums resulted in an additional profit to the developer of $2.2 million.[35,36]

Table 7. Cost Comparison for Gap Creek Subdivision[37]

Total Cost of Conventional Design	Gap Creek LID Cost	Cost Savings	Percent Savings	Savings per Lot
$4,620,600	$3,942,100	$678,500	15%	$4,800

GARDEN VALLEY, PIERCE COUNTY, WASHINGTON (A MODELING STUDY)



The Garden Valley subdivision is a 9.7-acre site in Pierce County, Washington. A large wetland on the eastern portion of the site and a 100-foot buffer account for 43 percent of the site area. Designers evaluated a scenario in which roadway widths were reduced and conventional stormwater management practices were replaced with swales, bioretention, and soil amendments. The use of these LID elements would have allowed the cost for stormwater management on the site to be reduced by 72 percent. A cost comparison is provided in Table 8.[38] Other costs expected with the LID design were a $900 initial cost for homeowner education with $170 required annually thereafter. Annual maintenance costs for the LID design (not included above) were expected to be $600 more than those for the conventional design, but a $3,000 annual savings in the stormwater utility bill was expected to more than offset higher maintenance costs.

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Table 8. Cost Comparison for Garden Valley Subdivision[39]

Item	Conventional Development Cost	Garden Valley LID Cost	Cost Savings*	Percent Savings*
Stormwater management	$214,000	$59,800	$154,200	72%
Site paving	$110,400	$200,900	–$90,500	–82%
Total	**$324,400**	**$260,700**	**$63,700**	**—**

* Negative values denote increased cost for the LID design over conventional development costs.

The design incorporated the use of narrower roadways coupled with Grasscrete parking along the roadside, which increased the overall site paving costs. However, this added cost was more than offset by the savings realized by employing LID for stormwater management. The LID practices were expected to increase infiltration and reduce stormwater discharge rates, which can improve the health and quality of receiving streams.

KENSINGTON ESTATES, PIERCE COUNTY, WASHINGTON (A MODELING STUDY)



A study was undertaken to evaluate the use of LID techniques at the Kensington Estates subdivision, a proposed 24-acre development consisting of single-family homes on 103 lots. The study assumed that conventional stormwater management practices would be replaced entirely by LID techniques, including reduced imperviousness, soil amendments, and bioretention areas. The design dictated that directly connected impervious areas on-site were to be minimized. Three wetlands and an open space tract would treat stormwater discharging from LID installations. Open space buffers were included in the design. The LID proposal also included rooftop rainwater collection systems on each house.[40,41]

The proposed LID design reduced effective impervious area from 30 percent in the conventional design to approximately 7 percent, and it was approximately twice as expensive as the traditional design. A cost comparison is provided in Table 9.

Table 9. Cost Comparison for Kensington Estates Subdivision[42]

Item	Conventional Development Cost	Kensington Estate LID Cost	Additional Cost
Stormwater management	$243,400	$925,400	$ 682,000
Site paving	$522,300	$577,500	$55,200
Total	**$765,700**	**$1,502,900**	**$737,200**

Although the study assumed that roadways in the LID design would be narrower than those in the conventional design, site paving costs increased because the LID design assumed that Grasscrete parking would be included along the roadside to allow infiltration. The use of Grasscrete increased the overall site paving costs.

The avoidance of conventional stormwater infrastructure with the use of LID afforded significant cost savings. The LID measures eliminated the need for a detention pond and made more lots available for development. The significant cost for the rooftop rainwater collection systems was assumed to be offset somewhat by savings on stormwater utility bills.[43]

The study also anticipated that the use of LID would reduce stormwater peak flow discharge rates and soil erosion. Furthermore, greater on-site infiltration increases ground water recharge, resulting in increased natural baseflows in streams and a reduction in dry channels. Proposed clustering of buildings would allow wetlands and open space to be preserved and create a more walkable community. The reduced road widths were anticipated to decrease traffic speeds and accident rates.

LAUREL SPRINGS SUBDIVISION, JACKSON, WISCONSIN



The Laurel Springs subdivision in Jackson, Wisconsin, is a residential subdivision that was developed as a conservation design community. The use of cluster design helped to preserve open space and minimize grading and paving. The use of bioretention and vegetated swales lowered the costs for stormwater management.

The costs of using conservation design to develop the subdivision were compared with the estimated cost of developing the site with conventional practices (Table 10).[44] The total savings realized with conservation design were just over $504,469, or approximately 30 percent of the estimated conventional construction cost. Savings from stormwater management accounted for 60 percent of the total cost savings. Other project savings were realized with reduced sanitary sewer, water distribution, and utility construction costs.

Table 10. Cost Comparison for Laurel Springs Subdivision[45]

Item	Conventional Development Cost	Laurel Springs LID Cost	Cost Savings	Percent Savings	Percent of Total Savings
Site preparation	$441,600	$342,000	$99,600	23%	20%
Stormwater management	$439,956	$136,797	$303,159	69%	60%
Site paving and sidewalks	$607,465	$515,755	$91,710	15%	18%
Landscaping	$165,000	$155,000	$10,000	6%	2%
Total	**$1,654,021**	**$1,149,552**	**$504,469**	—	—

In addition to preserving open space and reducing the overall amount of clearing and grading, the cluster design also reduced street lengths and widths, thereby lowering costs for paving and sidewalks. Vegetated swales and bioswales largely were used to replace conventional stormwater infrastructure and led to significant savings. Each of these factors helped to contribute to a more hydrologically functional site that reduced the total amount of stormwater volume and managed stormwater through natural processes.

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MILL CREEK SUBDIVISION, KANE COUNTY, ILLINOIS



The Mill Creek subdivision is a 1,500-acre, mixed-use community built as a conservation design development. Approximately 40 percent of the site is identified as open space; adjacent land use is mostly agricultural. The subdivision was built using cluster development. It uses open swales for stormwater conveyance and treatment, and it has a lower percentage of impervious surface than conventional developments. An economic analysis compared the development cost for 40 acres of Mill Creek with the development costs of 30 acres of a conventional development with similar building density and location.[46]

When compared with the conventional development, the conservation site design techniques used at Mill Creek saved approximately $3,411 per lot. Nearly 70 percent of these savings resulted from reduced costs for stormwater management, and 28 percent of the savings were found in reduced costs for site preparation. A cost comparison is provided in Table 11. Other savings not included in the table were realized with reduced construction costs for sanitary sewers and water distribution.

Table 11. Cost Comparison for Mill Creek Subdivision[47]

Item	Conventional Development Cost per Lot	Mill Creek LID Cost per Lot	Cost Savings per Lot	Percent Savings per Lot	Percent of Total Savings
Site preparation	$2,045	$1,086	$959	47%	28%
Stormwater management	$4,535	$2,204	$2,331	51%	68%
Site paving and sidewalks	$5,930	$5,809	$121	2%	4%
Total	**$12,510**	**$9,099**	**$3,411**	—	—

The use of cluster development and open space preservation on the site decreased site preparation costs. The majority of the cost savings were achieved by avoiding the removal and stockpiling of topsoil. In addition to cost savings from avoided soil disturbance, leaving soils intact also retains the hydrologic function of the soils and aids site stormwater management by reducing runoff volumes and improving water quality. The site's clustered design was also responsible for a decrease in costs for paving and sidewalks because the designers intentionally aimed to decrease total road length and width.

The designers used open swales as the primary means for stormwater conveyance. Coupled with other site techniques to reduce runoff volumes and discharge rates, significant savings in stormwater construction were avoided because of reduced storm sewer installation; sump pump connections; trench backfill; and catch basin, inlet, and cleanout installation.

In addition to the cost savings, the conservation design at Mill Creek had a positive effect on property values: lots adjacent to walking/biking trails include a $3,000 premium, and lots adjacent to or with views of open space include a $10,000 to $17,500 premium. The

600 acres of open space on the site include 127 acres of forest preserve with quality wetlands, 195 acres of public parks, and 15 miles of walking/biking trails.[48]

POPLAR STREET APARTMENTS, ABERDEEN, NORTH CAROLINA



The use of bioretention, topographical depressions, grass channels, swales, and stormwater basins at the 270-unit Poplar Street Apartment complex improved stormwater treatment and lowered construction costs. The design allowed almost all conventional underground storm drains to be eliminated from the design. The design features created longer flow paths, reduced runoff volume, and filtered pollutants from runoff. According to the U.S. Department of Housing and Urban Development, use of LID techniques resulted in a $175,000 savings (72 percent).[49]

PORTLAND DOWNSPOUT DISCONNECTION PROGRAM, PORTLAND, OREGON



The City of Portland, Oregon, implemented a Downspout Disconnection Program as part of its CSO elimination program. Every year, billions of gallons of stormwater mixed with sewage pour into the Willamette River and Columbia Slough through CSOs. When roof runoff flows into Portland's combined sewer system, it contributes to CSOs. The City has reduced the frequency of CSOs to the Columbia Slough and hopes to eliminate 94 percent of the overflows to the Willamette River by 2011.[50]

The Downspout Disconnection Program gives homeowners, neighborhood associations, and community groups the chance to work as partners with the Bureau of Environmental Services and the Office of Neighborhood Involvement to help reduce CSOs. Residents of selected neighborhoods disconnect their downspouts from the combined sewer system and allow their roof water to drain to gardens and lawns. Residents can do the work themselves and earn $53 per downspout, or they can have community groups and local contractors disconnect for them. Community groups earn $13 for each downspout they disconnect. (Materials are provided by the City.)

More than 44,000 homeowners have disconnected their downspouts, removing more than 1 billion gallons of stormwater per year from the combined sewer system. The City estimates that removing the 1 billion gallons will result in a $250 million reduction in construction costs for an underground pipe to store CSOs by reducing the capacity needed to handle the flows. The City has spent $8.5 million so far to implement this program and will continue to encourage more homeowners and businesses to disconnect their downspouts to achieve additional CSO and water quality benefits.

PRAIRIE CROSSING SUBDIVISION, GRAYSLAKE, ILLINOIS



The Prairie Crossing subdivision is a conservation development on 678 acres, of which 470 acres is open space. The site was developed as a mixed-use community with 362 residential units and 73 acres of commercial property, along with schools, a community center, biking trails, a lakefront beach, and a farm. The site uses bioretention cells and vegetated swales to manage stormwater.[51]

A cost analysis was performed to compare the actual construction costs of Prairie Crossing with the estimated costs of a conventional design on the site with the same layout. Cost savings with conservation design were realized primarily in four areas: stormwater management, curb and gutter installation, site paving, and sidewalk installation. The total savings were estimated to be almost $1.4 million, or nearly $4,000 per lot (Table 12). Savings from stormwater management accounted for approximately 15 percent of the total savings. The cost savings shown are relative to the estimated construction cost for the items in a conventional site design based on local codes and standards.

Table 12. Cost Comparison for Prairie Crossing Subdivision[52]

Item	Cost Savings	Percent Savings
Reduced Road Width	$178,000	13%
Stormwater Management	$210,000	15%
Decreased Sidewalks	$648,000	47%
Reduced Curb and Gutter	$339,000	25%
Total	**$1,375,000**	**—**

Reduced costs for sidewalks accounted for nearly half of the total cost savings. This savings is attributed in part to the use of alternative materials rather than concrete for walkways in some locations. In addition, the design and layout of the site, which retained a very high percentage of open space, contributed to the cost savings realized from reducing paving, the length and number of sidewalks, and curbs and gutters. The use of alternative street edges, vegetated swales, and bioretention and the preservation of natural areas all reduced the need for and cost of conventional stormwater infrastructure.[53] Benefits are associated with the mixed-use aspect of the development as well: residents can easily access schools, commercial areas, recreation, and other amenities with minimal travel. Proximity to these resources can reduce traffic congestion and transportation costs. Also, mixed-use developments can foster a greater sense of community and belonging than other types of development. All of these factors tend to improve quality of life.

PRAIRIE GLEN SUBDIVISION, GERMANTOWN, WISCONSIN



The Prairie Glen subdivision is nationally recognized for its conservation design approach. A significant portion of the site (59 percent) was preserved as open space. Wetlands were constructed to manage stormwater runoff, and the open space allowed the reintroduction of native plants and wildlife habitat. The site layout incorporated hiking trails, which were designed to allow the residents to have easy access to natural areas.[54]

To evaluate the cost benefits of Prairie Glen's design, the actual construction costs were compared with the estimated costs of developing the site conventionally. When compared with conventional design, the conservation design at Prairie Glen resulted in a savings of nearly $600,000. Savings for stormwater management accounted for 25 percent of the total savings. Table 13 provides a cost comparison. Other savings not included in the table were realized with reduced sanitary sewer, water distribution, and utility construction costs.

Table 13. Cost Comparison for Prairie Glen Subdivision[55]

Item	Conventional Development Cost	Prairie Glen LID Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$277,043	$188,785	$88,258	32%	22%
Stormwater management	$215,158	$114,364	$100,794	47%	25%
Site paving and sidewalks	$462,547	$242,707	$219,840	48%	54%
Landscaping	$50,100	$53,680	–$3,580	–7%	–1%
Total	**$1,004,848**	**$599,536**	**$405,312**	**—**	**—**

* Negative values denote increased cost for the LID design over conventional development costs.

The cluster design and preservation of a high percentage of open space resulted in a significant reduction in costs for paving and sidewalks. These reduced costs accounted for 54 percent of the cost savings for the overall site. Reduced costs for soil excavation and stockpiling were also realized. The use of open-channel drainage and bioretention minimized the need for conventional stormwater infrastructure and accounted for the bulk of the savings in stormwater management. Landscaping costs increased due to the added amount of open space on the site.

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SOMERSET SUBDIVISION, PRINCE GEORGE'S COUNTY, MARYLAND



The Somerset subdivision, outside Washington, D.C., is an 80-acre site consisting of nearly 200 homes. Approximately half of the development was built using LID techniques; the other half was conventionally built using curb-and-gutter design with detention ponds for stormwater management. Bioretention cells and vegetated swales were used in the LID portion of the site to replace conventional stormwater infrastructure. Sidewalks were also eliminated from the design. To address parking concerns, some compromises were made: because of local transportation department concern that roadside parking would damage the swales, roads were widened by 10 feet.[56] (Note that there are alternative strategies to avoid increasing impervious surface to accommodate parking, such as installing porous pavement parking lanes next to travel lanes.)

Most of the 0.25-acre lots have a 300- to 400-square-foot bioretention cell, also called a rain garden. The cost to install each cell was approximately $500—$150 for excavation and $350 for plants. The total cost of bioretention cell installation in the LID portion of the site was $100,000 (swale construction was an additional cost). The construction cost for the detention pond in the conventionally designed portion of the site was $400,000, excluding curbs, gutters, and sidewalks.[57,58] By eliminating the need for a stormwater pond, six additional lots could be included in the LID design. A comparison of the overall costs for the traditional and LID portions of the site is shown in Table 14.

Table 14. Cost Comparison for Somerset Subdivision

Conventional Development Cost	Somerset LID Cost	Cost Savings	Percent Savings	Savings per Lot
$2,456,843	$1,671,461	$785,382	32%	$4,000

In terms of environmental performance, the LID portion of the subdivision performed better than the conventional portion.[59] A paired watershed study compared the runoff between the two portions of the site, and monitoring indicated that the average annual runoff volume from the LID watershed was approximately 20 percent less than that from the conventional watershed. The number of runoff-producing rain events in the LID watershed also decreased by 20 percent. Concentrations of copper were 36 percent lower; lead, 21 percent lower; and zinc, 37 percent lower in LID watershed runoff than in conventional watershed runoff. The homeowners' response to the bioretention cells was positive; many perceived the management practices as a free landscaped area.

SARB_011084

TELLABS CORPORATE CAMPUS, NAPERVILLE, ILLINOIS



The Tellabs corporate campus is a 55-acre site with more than 330,000 square feet of office space. After reviewing preliminary planning materials that compared the costs of conventional and conservation design, the company chose to develop the site with conservation design approaches. Because the planning process included estimating costs for the two development approaches, this particular site provides good information on commercial/industrial use of LID.[60]

Development of the site included preserving trees and some of the site's natural features and topography. For stormwater management, the site uses bioswales, as well as other infiltration techniques, in parking lots and other locations. The use of LID techniques for stormwater management accounted for 14 percent of the total cost savings for the project. A cost comparison is provided in Table 15. Other cost savings not shown in Table 15 were realized with reduced construction contingency costs, although design contingency costs were higher.

Table 15. Cost Comparison for Tellabs Corporate Campus[61]

Item	Conventional Development Cost	Tellabs LID Cost	Cost Savings	Percent Savings	Percent of Total Savings
Site preparation	$2,178,500	$1,966,000	$212,500	10%	46%
Stormwater management	$480,910	$418,000	$62,910	13%	14%
Landscape development	$502,750	$316,650	$186,100	37%	40%
Total	**$3,162,160**	**$2,700,650**	**$461,510**	**—**	**—**

Savings in site preparation and landscaping had the greatest impact on costs. Because natural drainage pathways and topography were maintained to the greatest extent possible, grading and earthwork were minimized; 6 fewer acres were disturbed using the conservation design approach. Landscaping at the site maximized natural areas and restored native prairies and wetland areas. The naturalized landscape eliminated the need for irrigation systems and lowered maintenance costs when compared to turf grass, which requires mowing and regular care. In the end, the conservation approach preserved trees and open space and provided a half acre of wetland mitigation. The bioswales used for stormwater management complemented the naturalized areas and allowed the site to function as a whole; engineered stormwater techniques augmented the benefits of the native areas and wetlands.[62]

SARB_011085

TORONTO GREEN ROOFS, TORONTO, ONTARIO (A MODELING STUDY)



Toronto is home to more than 100 green roofs. To evaluate the benefits of greatly expanded use of green roofs in the city, a study was conducted using a geographic information system to model the effects of installing green roofs on all flat roofs larger than 3,750 square feet. (The model assumed that each green roof would cover at least 75 percent of the roof area.) If the modeling scenario were implemented, 12,000 acres of green roofs (8 percent of the City's land area) would be installed.[63] The study quantified five primary benefits from introducing the green roofs: (1) reduced stormwater flows into the separate storm sewer system, (2) reduced stormwater flows into the combined sewer system, (3) improved air quality, (4) mitigation of urban heat island effects, and (5) reduced energy consumption.[64]

The study predicted economic benefits of nearly $270 million in municipal capital cost savings and more than $30 million in annual savings. Of the total savings, more than $100 million was attributed to stormwater capital cost savings, $40 million to CSO capital cost savings, and nearly $650,000 to CSO annual cost savings. The cost of installing the green roofs would be largely borne by private building owners and developers; the cost to Toronto would consist of the cost of promoting and overseeing the program and would be minimal. Costs for green roof installations in Canada have averaged $6 to $7 per square foot. The smallest green roof included in the study, at 3,750 square feet, would cost between $22,000 and $27,000. The total cost to install 12,000 acres of green roofs would be $3 billion to $3.7 billion.[65,66] Although the modeled total costs exceed the monetized benefits, the costs would be spread across numerous private entities.

CONCLUSION

The 17 case studies presented in this report show that LID practices can reduce project costs and improve environmental performance. In most cases, the case studies indicate that the use of LID practices can be both fiscally and environmentally beneficial to communities. As with almost all such projects, site-specific factors influence project outcomes, but in general, for projects where open space was preserved and cluster development designs were employed, infrastructure costs were lower. In some cases, initial costs might be higher because of the cost of green roofs, increased site preparation costs, or more expensive landscaping practices and plant species. However, in the vast majority of cases, significant savings were realized during the development and construction phases of the projects due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Total capital cost savings ranged from 15 to 80 percent when LID methods were used, with a few exceptions in which LID project costs were higher than conventional stormwater management costs.

EPA has identified several additional areas that will require further study. First, in all the cases, there were benefits that this study did not monetize and factor into the project's bottom line. These benefits include improved aesthetics, expanded recreational opportunities, increased property values due to the desirability of the lots and their proximity to open space, increased number of total units developed, the value of increased marketing potential, and faster sales.

Second, more research is also needed to quantify the environmental benefits that can be achieved through the use of LID techniques and the costs that can be avoided by using these practices. For example, substantial downstream benefits can be realized through the reduction of the peak flows, discharge volumes, and pollutant loadings discharged from the site. Downstream benefits also might include reductions in flooding and channel degradation, costs for water quality improvements, costs of habitat restoration, costs of providing CSO abatement, property damage, drinking water treatment costs, costs of maintaining/dredging navigable waterways, and administrative costs for public outreach and involvement.

Finally, additional research is needed monetize the cost reductions that can be achieved through improved environmental performance, reductions in long-term operation and maintenance costs and/or reductions in the life cycle costs of replacing or rehabilitating infrastructure.

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identified practices seeks to maintain and use vegetation and open space, optimize natural hydrologic processes to reduce stormwater volumes and discharge rates, and use multiple treatment mechanisms to remove a large range of pollutants. In the context of this report, case studies ascribing to one of the above, or similar, labels were evaluated, and these terms are used interchangeably throughout the report.

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SARB_011090

Resolution of the California Ocean Protection Council Regarding Low Impact Development

May 15, 2008, as amended

WHEREAS, ocean water quality is critical to the health of marine and coastal ecosystems; and

WHEREAS, ongoing, traditional development of California's watersheds continues to replace natural landscapes with impervious surfaces; roads and parking lots make up about half of all impervious surfaces; and

WHEREAS, runoff from urbanized areas contains and transports pollutants – including trash, heavy metals, oil and grease, fertilizers, and pathogens – to the ocean; and

WHEREAS, these pollutants contribute to beach closures, harmful algal blooms and reduced fish populations; and

WHEREAS, increased runoff from urbanized landscapes also erodes stream banks and damages habitat for fish and a wide variety of plants and animals; and

WHEREAS, polluted runoff impacts California's $46 billion, tourist-oriented, ocean-dependent economy; and

WHEREAS, rainwater is a valuable resource which should be conserved; and

WHEREAS, the Clean Water Act and Porter-Cologne Water Quality Control Act require that California reduce stormwater pollutant discharges from municipal storm drains, new developments and redevelopments, construction sites, Caltrans facilities, and industrial facilities; the Porter-Cologne Act also requires a California Ocean Plan for water quality regulation of ocean water, and prohibits waste discharges to Areas of Special Biological Significance (ASBS) which comprise one-third of the State's coastline; and

WHEREAS, the California Coastal Act requires that development in the coastal zone maintain and, where feasible, restore the biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes; and

WHEREAS, Low Impact Development (LID) is a stormwater management strategy aimed at maintaining or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives and fulfill environmental regulatory requirements; LID employs a variety of natural and built features that reduce the rate of runoff, filter pollutants out of runoff, and facilitate the infiltration of water into the ground; and

WHEREAS, by reducing water pollution and increasing groundwater recharge, LID helps to improve the quality of receiving surface waters and stabilize the flow rates of nearby streams; and

WHEREAS, LID design detains, treats and infiltrates runoff by minimizing impervious area, using pervious pavements and green roofs, dispersing runoff to landscaped areas, and routing runoff to rain gardens, cisterns, swales, and other small-scale facilities distributed throughout a site; and

WHEREAS, LID designs can alternatively, or in conjunction with the techniques set forth above, capture, retain, and treat stormwater for onsite reuse, such as for irrigating landscaping; and

WHEREAS, a recent U.S. Environmental Protection Agency report concluded that LID drainage designs can cost 15% to 80% *less* than more conventional drainage designs; other studies have shown LID facilities are less expensive to maintain than conventional stormwater treatment facilities; and

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WHEREAS, LID has also been shown to help reduce the frequency of combined sewer overflows, which plague at least one major California coastal community; and

WHEREAS, other states and federal government departments, including the Department of Defense, have been leaders in advancing LID implementation faster than California; and

WHEREAS, Caltrans should continue its efforts to lead in innovative stormwater design approaches; and

WHEREAS, some local governments are concerned that they lack sufficient funds to maintain and improve existing drainage infrastructure and fully implement stormwater pollution prevention programs; and

WHEREAS, in 2005, the Local Government Commission adopted the Ahwahnee Water Principles for Resource-Efficient Land Use, which state in relevant part that "community design should be compact, mixed use, walkable, and transit-oriented so that automobile-generated urban runoff pollutants are minimized and the open lands that absorb water are preserved to the maximum extent possible" and that "impervious surfaces such as driveways, streets and parking lots should be minimized so that land is available to absorb stormwater, reduce polluted urban runoff, recharge groundwater, and reduce flooding"; and

WHEREAS, the California Ocean Protection Act mandates that the Ocean Protection Council (OPC) – made up of the Secretaries for the Resources Agency and Cal/EPA, the chair of the State Lands Commission, one designee each from the California Senate and Assembly, and two public members appointed by the Governor – coordinate and improve the protection of California's ocean and coastal resources; and the Governor's Ocean Action Plan calls for the OPC to play a leadership role in managing and protecting California's oceans, bays, estuaries, and coastal wetlands, including integration of coastal water quality programs to increase their effectiveness.

NOW, *THEREFORE*, the California Ocean Protection Council hereby:

RESOLVES to promote the policy that new developments and redevelopments should be designed consistent with LID principles so that stormwater pollution and the peaks and durations of runoff are significantly reduced and, in the case of a new development, substantially the same as before development occurred on the site; and

RESOLVES to promote the retrofit of existing impervious areas throughout California with LID in all appropriate circumstances, and to support the Ahwahnee Water Principles for Resource-Efficient Land Use as described above; and

FINDS that LID is a practicable and superior approach that new and redevelopment projects can implement to minimize and mitigate increases in runoff and runoff pollutants and the resulting impacts on downstream uses, coastal resources and communities; and

RESOLVES to distribute this resolution widely, sending it to mayors, boards of supervisors, and appropriate agency managers of all coastal cities and counties and to appropriate federal agencies including resource protection agencies, the Army Corps of Engineers and the Department of Defense; and

FURTHER RESOLVES to advance LID implementation in California using the following approaches:

1. State Leadership

a. *State Government Leadership on LID* – For all state-funded (including bond-funded) development projects greater than one acre, LID should be considered to be the best

available technology standard for reducing pollutants from stormwater discharges. All existing State facilities should consider retrofitting to meet LID objectives, whenever feasible. The California Environmental Protection Agency (Cal/EPA) and the California Resources Agency should assemble the relevant boards and departments within their agencies to develop a set of LID standards to be used in development projects built with state funds, including bond funds.

b. *Department of Transportation (Caltrans)* – Caltrans is encouraged to continue to develop details and specifications for permeable pavements and other LID features and to incorporate LID where feasible in projects Caltrans funds or oversees, including local assistance programs. Caltrans should consider allocating a percentage of project budgets to the implementation of stormwater controls, with LID features as the highest priority. Caltrans should evaluate and revise as necessary any design standards which unnecessarily inhibit implementation of LID, such as street widths, required pavement and other materials, curb designs, and minimum parking requirements.

c. *Office of Planning and Research* – The Office of Planning and Research (OPR) is encouraged to provide technical guidance to public agencies to promote the use of LID consistent with stormwater National Pollution Discharge Elimination System (NPDES) standards and criteria. The guidance should be provided through an OPR technical advisory and revisions to the OPR guidance for preparation of local general plans, as appropriate. OPR is also encouraged to work with the Resources Agency to develop proposals for future CEQA Guideline amendments that encourage consideration of LID in the CEQA review process.

d. *Building Standards Commission* – The Building Standards Commission is encouraged to incorporate LID objectives and methods, and to incorporate or reference applicable NPDES permit criteria for stormwater treatment, flow control and use of LID in ongoing development of its Green Building Standards.

e. *Department of Water Resources* – The Department of Water Resources (DWR) is encouraged to provide incentives for LID implementation and habitat protection goals in its integrated regional water management (IRWM) and stormwater flood management funding programs to encourage watershed resource protection. The OPC encourages DWR to adopt language to include the fostering of LID as a Program Priority in their draft IRWM guidelines.

2. State Regulatory Actions

a. *State Water Board LID Policy* – The State Water Board is encouraged to adopt a statewide policy for addressing all elements associated with changes in runoff due to hydromodification impacts, including those specifically related to urbanization. This policy would include direction on when and how to use LID to avoid, minimize and mitigate runoff so that downstream water bodies are protected.

b. *NPDES Permit Requirements* – When crafting stormwater NPDES permit requirements, the State Water Board and Regional Water Boards should ensure that LID designs are utilized as the primary approach to satisfying post-construction runoff control requirements and that LID designs can be utilized to control pollutants and the rate and volume of runoff.

c. *LID Performance Evaluation and Monitoring* – Together with the Coastal Commission, the State Water Board is encouraged to conduct ongoing evaluation of the effectiveness

of their regulatory programs that promote LID (and other, similar approaches) implementation in regulated new development and redevelopment projects.

3. Incentives, Technical Support, and Research

The OPC will consider the following approaches, proposed by stakeholders and participants in public workshops sponsored by the OPC, to promote LID and to leverage funding with other agencies.

a. *Local Streets and Drainage Retrofits* – Encourage local governments to retrofit existing streets, highways, municipal parking lots, public buildings, and drainage systems with LID where feasible. Promote and consider funding research and technology transfer related to the retrofit of local facilities, including demonstration projects with interpretive displays and technical documentation of results.

b. *Technical Assistance to Local Government* – Promote and consider funding technical assistance for local agency public works, planning and engineering management and staff in the use of LID.

c. *Research and Development of LID* – Promote and consider funding technical research for development of a LID design manual, including example designs and specifications for LID features, and post-construction evaluations of the effectiveness of constructed LID features in removing pollutants and controlling runoff flows.

d. *Updating Local Development Policies* –Assist and consider funding for local governments to update standard details and specifications and other development policies to promote LID and remove barriers to LID.

e. *Local Incentives* – Promote local programs that provide incentives, including reduction of stormwater utility fees, to encourage the use of cisterns, rain gardens, and other LID strategies to retain runoff and, where feasible, reuse runoff for irrigation.

f. *Incentives for Stormwater Recharge* – Encourage water agencies to offer economic incentives for new regional and sub-regional stormwater recharge projects similar to incentives currently provided for water conservation and water reuse.

-----Original Message-----
From: Strauss.Alexis@epamail.epa.gov [mailto:Strauss.Alexis@epamail.epa.gov]
Sent: Friday, January 25, 2008 9:09 AM
To: Beckman, David
Subject: Draft MS4 Permit for Southern Orange County

----- Forwarded by Alexis Strauss/R9/USEPA/US on 01/25/2008 09:08 AM -----

Eugene Bromley/R9/USEPA /US 01/24/2008 04:16 PM		To jhaas@waterboards.ca.gov cc Doug Eberhardt/R9/USEPA/US@EPA, John Kemmerer/R9/USEPA/US@EPA, Alexis Strauss/R9/USEPA/US@EPA, Laurie Kermish/R9/USEPA/US@EPA, John Tinger/R9/USEPA/US@EPA Subject Draft MS4 Permit for Southern Orange County

We have reviewed the latest draft MS4 permit for Southern Orange County (NPDES permit No. CAS0108740 public noticed on December 12, 2007) and we would like to offer the following comment regarding the Development Planning Component of the permit (Part D.1).

Presently the draft permit includes:

SUSMP requirements (Part D.1.d), but only for priority projects as defined in Part D.1.d.(1),
Site design BMP requirements for all projects where applicable and feasible (Part D.1.c.(2)), and
Low Impact Development (LID) requirements as a possible substitute for SUSMPs (Part D.1.d.(8)).

We recommend that the permit be revised to put more emphasis on LID. In April 2007, EPA entered into an agreement with several national organizations to promote green infrastructure (which is very similar to LID) to improve stormwater quality management for MS4s. In January 2008, EPA also published an action strategy for the new initiative

(available at http://cfpub.epa.gov/npdes/whatsnew.cfm?program_id=6) which encourages green infrastructure requirements in MS4 permits, and promises more guidance on this in the future.

Your Response to Comments II of December 12, 2007 (Comment #19) notes that site design BMPs are similar to LID, but apparently not quite the same since LID itself is included in a separate section of the permit (Part D.1.d.(8)) as a possible substitute for SUSMPs. To increase the emphasis on LID in the permit, we recommend that the permit include provisions similar to Part 5.E.III.2 of the August 28, 2007 draft MS4 permit for Ventura County (NPDES permit No. CAS004002), which specifically requires that LID be woven into the design of specified new development and redevelopment projects. We would recommend that the requirements apply to priority projects as defined in the Orange County permit, and also, at a minimum, all new projects disturbing one or more acres (like the draft Ventura County permit). EPA's Phase II stormwater regulations at 40 CFR 122.34(b)(5) require post-construction BMPs for all new developments and significant redevelopments disturbing one or more acres. As a Phase I permit, the requirements for Orange County should be no less stringent.

We also have concerns about the site design BMP requirements in the proposed permit (Part D.1.d.(4)). Part D.1.d.(4).(b).(ii) and (iii) have requirements for "a portion" of impervious areas, and walkways and trails, etc. The term "a portion" is vague and accordingly, we would recommend LID provisions similar to the draft Ventura County permit where more precise requirements would be developed.

We also have the following additional comments on the draft permit:

1) Page 37 (Part D.1.h.(4)) - we note that the studies upon which the future hydromodification criteria would be based have yet to be completed and are not available for public review at this time. To ensure adequate public participation, we would recommend that the RB solicit public comment on any modification of permit requirements based on the future studies.

2) Page 43 (Part D.2.d.(1)(c)) - the term "enhanced BMPs" for construction sites discharging into 303(d) waters is somewhat vague, and we believe the requirements should be clarified.

3) Page 49 (Part D.3.a.(3)) - with regards to requirements for pesticides and fertilizers, we recommend that you consider enhanced BMPs for waterbodies identified as impaired for these constituents (such as Aliso Creek, San Juan Creek). Similarly, for other waterbodies listed as impaired for other constituents, the permit should identify the waterbodies and prescribe enhanced BMPs for the constituents of concern.

Thank you for the opportunity to comment on the draft permit. I can be reached at (415) 972-3510.

A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption

Commissioned and Sponsored by:
California State Water Resources Control Board Stormwater Program
And
The Water Board Academy

Project Officer:
Greg Gearheart, P.E.

December 2007



Prepared by:
Low Impact Development Center
Beltsville, Maryland
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EXECUTIVE SUMMARY

Managing stormwater runoff has historically presented technical challenges because of its diffuse and episodic nature, the range of pollutants requiring treatment, and the volume of runoff resulting from changes in land cover. Complicating the technical challenges is a regulatory environment that has been based on presumptive minimum treatment standards and has not effectively promoted innovative treatment approaches. Recent research and pilot applications have demonstrated efficient approaches to control and treat stormwater runoff and have removed many of the technical barriers. However, regulatory and institutional barriers still exist and can prevent application of effective control programs.

This analysis reviewed the State of California's primary mechanisms of regulating stormwater runoff and considered how low impact development (LID) approaches could be used for compliance purposes. A review of the country's more progressive regulatory approaches is also included to illustrate requirements or incentives for LID or other innovative treatment programs. California has already made steps toward a regulatory system that encourages better treatment performance and the application of LID; the State Water Resources Control Board's recent emphasis on limiting hydromodification impacts (changes in a site's runoff and transport characteristics) from development will create the framework for broader adoption of LID. In addition, the Porter-Cologne Act (commonly referred to as the California Water Code) allows the Water Boards broad discretion to implement innovative natural resource protection programs because it allows the regulation of any activity or factor that affects water quality and is not narrowly focused on end-of-pipe treatment.[1]

INTRODUCTION

When the Clean Water Act (CWA) was amended in 1987, a federal mandate to manage and control stormwater was established.[2] The past 20 years have witnessed significant shifts in the science and regulatory environment of municipal and post-construction runoff control. The recent movement to address stormwater on a watershed basis by limiting hydromodification and the volume of discharges is a departure from the convention of peak flow limitation and flood control. Advances in understanding the relationship between hydromodification and stream health and the science to preserve or restore water quality have greatly outpaced the changes in the regulatory environment and institutional structures that influence stormwater programs, neither of which having ever fully matured to achieve water quality or environmental goals.

With the technical approach coming into focus, the regulatory system needed to foster and propel these new strategies has not yet been developed. The intent of regulatory compliance is not necessarily meeting resource objectives. Regulations often set a minimum benchmark of environmental effort and often are not or cannot be designed to fully achieve water quality objectives. Maximum extent practicable or water quality standards along with other programs and efforts are used to augment regulations to achieve the full desired environmental outcome. Designing regulations and integrating them with other programs to achieve desired outcomes and benefits is critical to improving stormwater management.

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[1] California Water Code sections 13000, 13050(i), 13140, 13142, 13241.
[2] 40 CFR 122.26

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Several states, including California, have begun to evaluate the regulatory changes that are required and the impacts that they will have on the success of their programs. This effort is one step in that process. This paper will focus on municipal and post-construction runoff and review the regulatory and institutional structure that influences stormwater control in California. It will also evaluate new programs and efforts aimed at improving stormwater management. Lastly it will evaluate policy and program options that could further advance the implementation of comprehensive water programs.

BACKGROUND

The diversity of climatic and geographic conditions within California has influenced the structure of the State's water agencies. The State Water Resources Control Board (SWRCB), created in 1967, has water allocation and water quality protection responsibilities. Nine Regional Water Quality Control Boards (RWQCBs), established along major watershed boundaries, have development and enforcement responsibilities of water quality objectives and implementation plans. The U.S. Environmental Protection Agency (EPA) has authorized the State to administer the National Pollutant Discharge Elimination System (NPDES) program, which uses statewide and regional programs to fulfill the mandated requirements. Municipal NPDES permits are issued by the Regional Boards.

The Porter-Cologne Water Quality Control Act, passed in 1969 and predating the CWA, is the main statute that governs water quality control in the state. Porter-Cologne subjects any activity or factor that affects water quality to regulation and covers point and non-point sources. By looking comprehensively at influences on water quality, not only are pollutant discharges subject to regulation, but also parameters such as flow or riparian or land use changes that can impose physical or temperature impacts.[3] Porter-Cologne applies to all waters of the state including wetlands and groundwater. It also establishes the tenant that waste discharges to state waters are a privilege and not a right.[4,5]

Through Porter-Cologne the SWRCB and RWQCBs are provided:[6]

1. Planning authority to designate beneficial uses of State waters, establish water quality objectives, and develop implementation programs to meet water quality objectives and designated uses.
2. Permitting authority.
3. Enforcement authority to ensure permit compliance.

---

[3] J. M. Gerstein, et al., *State and Federal Approach to Control of Nonpoint Sources of Pollution*, University of California Cooperative Extension, August 2005.

[4] State Water Resources Control Board, *Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program*, May 20, 2004.

[5] When the 1987 amendments to the CWA designated municipal stormwater runoff as a point source, regulation of stormwater came under the provisions of the National Pollutant Discharge Elimination System (NPDES) program. California, like other states, has a defined institutional and regulatory separation between municipal stormwater and other non-point sources that are influenced by Porter-Cologne.

[6] State Water Resources Control Board, *Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program*, May 20, 2004.

With this authority, the SWRCB is responsible for setting statewide policy and regulations, in addition to developing statewide water quality control plans. Based on the SWRCB policies, the nine RWQCBs develop individual water quality control plans, referred to as Basin Plans. Once developed, the basin plans must be approved by the SWRCB, the Office of Chief Council, and the U.S. EPA.[7] The coordinated efforts between the State and Regional Boards constitute the primary mechanism through which the State addresses point and nonpoint source pollution and implements its control program. The SWRCB also has the authority to adopt statewide water quality control plans, like the California Ocean Plan, the Plan for California's Nonpoint Source Pollution Control Program, and the California Thermal Plan. The Ocean Plan contains a prohibition of any discharge of waste (e.g., stormwater) to waters designated as Areas of Special Biological Significance (ASBS).

In addition to the framework above, a number of other regulatory agents and programs (e.g., the California Water Boards and CWA 401 Certification, the California Coastal Commission and the Coastal Zone Act Reauthorization Amendments) also directly impact stormwater discharges in the state. Although not discussed in detail, the requirements of these programs work in concert with the stormwater program and can lead to more stringent pollutant discharge limitations in runoff.

NPDES Permits

Construction General Permit

The SWRCB last issued statewide general NPDES stormwater permits for designated construction activities in 1999 (SWRCB Order 99-08-DWQ). This permit contains minimum requirements to control post-construction runoff. Page 79 of SWRCB Order 99-08-DWQ states:

> *10. Post-Construction Storm Water Management*
>
> *The SWPPP shall include descriptions of the BMPs to reduce pollutants in storm water discharges after all construction phases have been completed at the site (Post-Construction BMPs). Post-Construction BMPs include the minimization of land disturbance, the minimization of impervious surfaces, treatment of storm water runoff using infiltration, detention/retention, biofilter BMPs, use of efficient irrigation systems, ensuring that interior drains are not connected to a storm sewer system, and appropriately designed and constructed energy dissipation devices. These must be consistent with all local post-construction storm water management requirements, policies, and guidelines. The discharger must consider site-specific and seasonal conditions when designing the control practices. Operation and maintenance of control practices after construction is completed shall be addressed, including short-and long-term funding sources and the responsible party.*

[7] State Water Resources Control Board, *Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program*, May 20, 2004.

While this language describes LID techniques, there is no level of compliance specified. The standard for the Construction General Permit is Best Available Technology economically achievable/ Best Conventional pollutant control Technology (BAT/BCT).[8] However, since it is not easy to apply a technology standard to the practice of minimizing land disturbance, this permit language is difficult to enforce. Municipal permits have the standard of Maximum Extent Practicable (MEP) which lends itself more naturally to specifying and enforcing a level of compliance for low impact development.

In March 2007 the SWRCB released a preliminary draft NPDES stormwater permit for construction activities as part of the Reissuance process of SWRCB Order 99-08-DWQ. This preliminary draft permit contains much more specific requirements for post-construction stormwater runoff. If approved, the new permit would establish statewide post-construction runoff standards. This would significantly alter the existing framework that relies on the municipalities to address post-construction runoff and leaves the unincorporated areas of the State largely unaddressed. The draft permit requires mitigating hydromodification by maintaining pre-development hydrologic characteristics on a site.[9]

Municipal Phase I Permits

The Regional Boards are currently using their authority to issue municipal separate storm sewer system (MS4) permits to address post-construction runoff.[10] Each Regional Board issues individual MS4 NPDES stormwater permits to their qualifying or designated Phase I permittees. At a minimum these require the MS4 permittees to develop and implement plans such as Standard Urban Storm Water Mitigation Plans (SUSMPs) that address new development and redevelopment projects that disturb more than one acre.[11,12] For example, the SUSMPs in the Los Angeles Water Board jurisdiction establish which types of development will be required to implement stormwater controls and the control, pollutant removal, site design, and maintenance requirements. The Los Angeles County SUSMP stipulates the following runoff requirement:[13]

> *Post-development peak stormwater runoff discharge rates shall not exceed the estimated pre-development rate for developments where the increased peak stormwater discharge rate will result in increased potential for downstream erosion.*

This language, which is typical for many municipal stormwater permits in California and the country, establishes the regulated physical stormwater parameter as the *rate* of discharge. This definition is typically based on one or more single peak storm events rather than continual flow information from runoff events. The SUSMP regulatory construct is in line with the historical

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[8] State Water Resources Control Board, National Pollutant Discharge Elimination System General Permit for Storm Water Discharges Associated with Construction Activity, Water Quality Order 99-08-DWQ, p.1.

[9] State Water Resources Control Board, Draft National Pollutant Discharge Elimination General System General Permit Number CAR000002, Waste Discharge Requirements For Discharges Of Storm Water Runoff Associated With Construction Activity, March 2007.

[10] Personal communication, Eric Berntsen, State Water Resources Control Board, April 2007.

[11] Memo from the SWRCB Office of Chief Counsel on SWRCB Order WQ 2000-11: SUSMP, Craig M. Wilson, December 26, 2000.

[12] Los Angeles County Urban Runoff and Stormwater NPDES Permit, Standard Urban Stormwater Mitigation Plan, March 2000.

[13] Ibid.

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thinking about stormwater impacts that postulated that the velocity of stormwater was the main factor impacting receiving stream quality and channel impacts. This primary requirement along with site design and treatment requirements form the range of requirements necessary to be satisfied for new development and redevelopment.

Municipal Phase II Permit

The SWRCB adopted a statewide General Phase II MS4 Permit in April, 2003 (SWRCB Order No. 2003-0005-DWQ). The permit contains similar post-construction language to Phase I permits.

The Central Coast Water Board requires municipalities, via the General Phase II MS4 Permit, to minimize negative impacts on aquatic ecosystems and degradation of water quality to the maximum extent practicable by incorporating LID methodology into new and redevelopment ordinances and design standards, unless permittees can demonstrate that conventional BMPs are equally effective, or that conventional BMPs would result in a substantial cost savings while still adequately protecting water quality and reducing discharge volume. In order to justify using conventional BMPs based on cost, permittees must show that the cost of low impact development would be prohibitive because the "cost would exceed any benefit to be derived." (State Water Resources Control Board Order No. WQ 2000-11). The Central Coast Water Board has determined that conventional site layouts, construction methods, and stormwater conveyance systems with "end-of-pipe" basins and treatment systems that do not address the changes in volume and rates of storm water runoff and urban pollutants (including thermal pollution) do not meet MEP standards.[14]

HYDROMODIFICATION

Changes in land cover are the cause of hydromodification: changes in a site's runoff and transport characteristics. Impervious surfaces, compacted soils, deforestation, and topographic modifications alter the distribution and flow of water across a site. Infiltration, interception, and evapotranspiration are diminished and a greater percentage of precipitation is converted to overland flow. These changes impact the water balance on site, less water infiltrates and is available for groundwater recharge or shallow subsurface flows that constitute the base flows of receiving streams. In addition, the increased volume of overland flow imparts physical impacts on receiving streams and transports pollutants that have collected on impervious surfaces.[15]

The effects of hydromodification can be demonstrated on a hydrograph, a representation of a site's stormwater discharge with respect to time. The hydrograph in Figure 1 shows development's impact on a site's runoff. Individual points on the curve represent the rate of stormwater discharge at a given time. The graph shows that development and corresponding changes in land cover result in greater discharge rates, greater volume, and a shorter time to reach the maximum discharge rate (referred to as time of concentration, T_c). In a natural or pre-

[14] Central Coast Water Board Low Impact Development web page, How LID is currently required: http://www.waterboards.ca.gov/centralcoast/stormwater/low%20impact%20devel/lid_index.htm (accessed November 2007).

[15] U.S. EPA, *Protecting Water Quality from Urban Runoff*, Nonpoint Source Control Branch, EPA-841-F-03-003, February 2003.

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development condition the initial rainfall is absorbed by the soil and vegetation. Once these are saturated, or the initial losses are satisfied, runoff occurs. In the post-development condition there is generally a much shorter time before runoff begins because of connectivity of impervious and developed areas and the loss of vegetative cover.

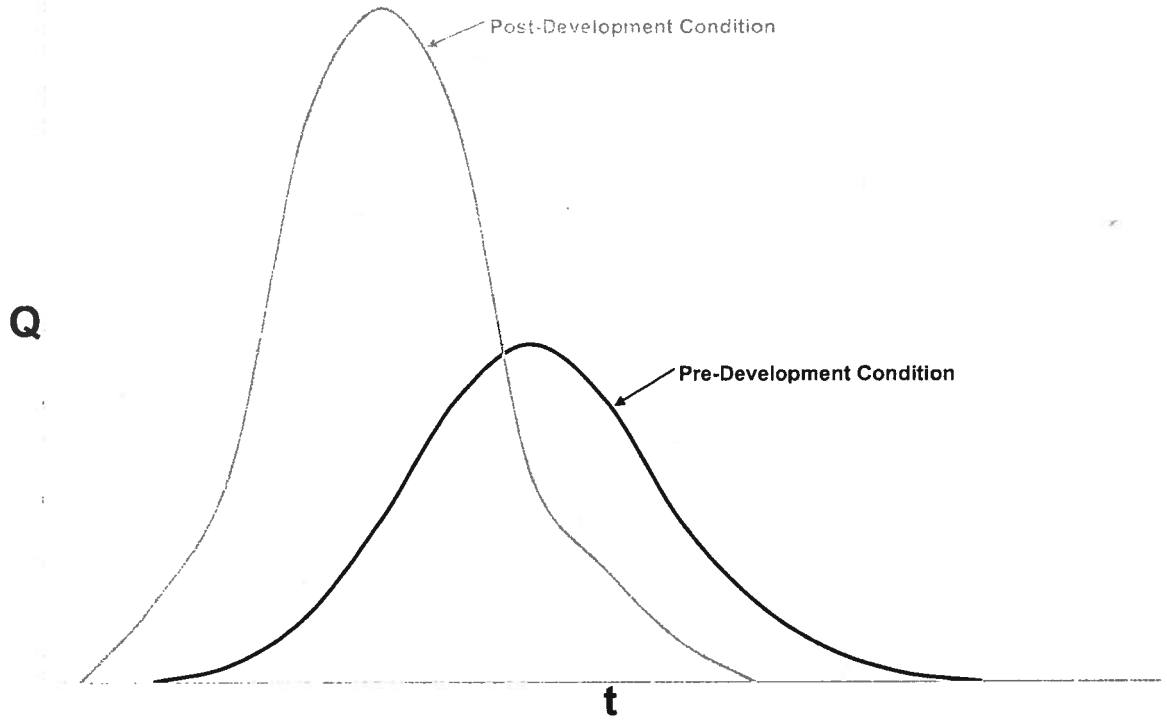

Figure 1. Hydrographs showing development's impact on runoff.
(Q = volumetric flow rate; t = time)

The area under the hydrographs represents the total volume of stormwater discharged. Along with the increased rate of discharge is an increased volume of discharge after development. The first analyses of these hydrograph impacts produced the consensus that the maximum rate of discharge was the critical parameter for protecting the integrity of receiving streams. The result of this concept was a regulatory structure, like those witnessed in many SUSMPs, that establishes requirements for the peak rate of discharge. Figure 2 shows how the post-development hydrograph responds to this type of regulatory structure.

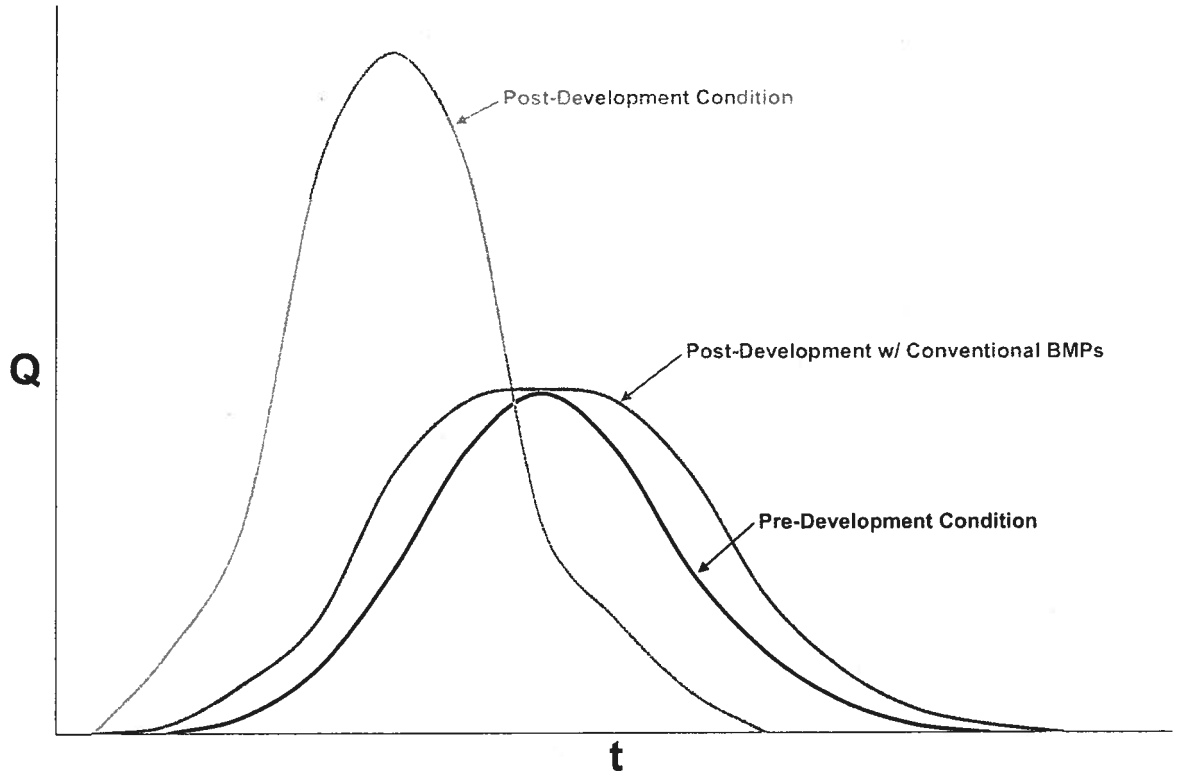

Figure 2. Post-development hydrograph response to conventional BMPs.
(Q = volumetric flow rate; t = time)

As Figure 2 illustrates, although the post-construction rate of stormwater discharge is equivalent to the pre-construction rate, it is sustained for a longer period of time and the total volume and energy of stormwater discharged, when compared to pre-development, is greater. This hydrograph response illustrates one reason why stormwater control efforts have been largely unsuccessful. Even when peak discharge rates are matched, the increased volume of stormwater delivers more energy and an increased amount of pollutants to the receiving stream when compared to pre-developed conditions. This result demonstrates the inefficiencies of the prevailing regulatory system and helps to predict that this type of framework will be unlikely to ultimately achieve water quality goals.

A regulatory system that attempts to address this deficiency and reduce the increase in the volume of stormwater discharge will propose a standard that stipulates that the rate of post-construction discharge will be equal not only to the pre-development peak rate, but also as every point-in-time along the hydrograph. This approach, a version of which is presented in the draft Construction stormwater NPDES permit, results in the hydrograph response represented in Figure 3.

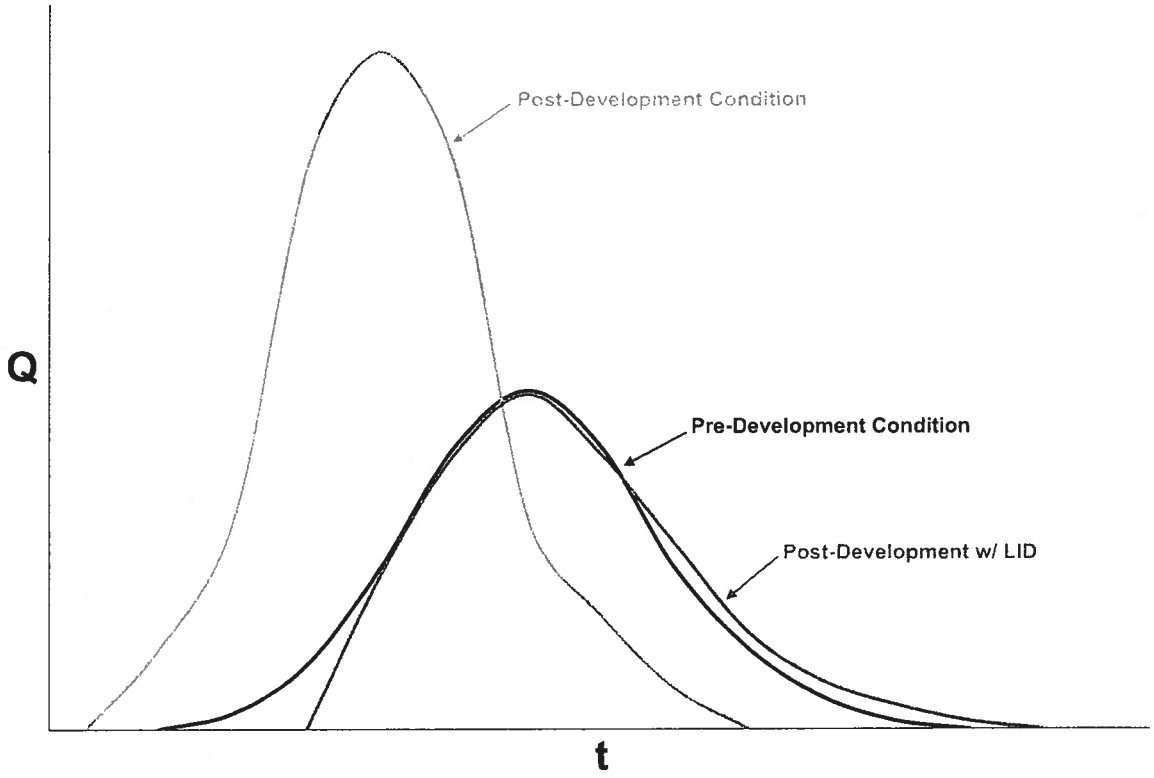

Figure 3. Post-development hydrograph response to LID controls.
(Q = volumetric flow rate; t = time)

Low Impact Development's Influence on Hydromodification

Traditionally, a wastewater collection and treatment system approach has been applied to stormwater management. End-of-pipe treatment and control technologies have been the predominate methods of stormwater control. However, this system of control essentially concedes the inevitability of hydromodification; that the only control options are those that deal with the consequences of development without addressing the root causes of the problem. To be fair, many stormwater management plans and manuals address site design, source control, and pollution prevention strategies. Mostly though, these are presented as "add-on" options that may be done above the standard end-of-pipe controls. The regulatory mandates still largely preserve the centralized collection and treatment system of control.

Over the past decade, LID has emerged as an alternative management approach. Rather than centralized, end-of-pipe controls, LID relies on an integrated system of decentralized, small-scale control measures. These measures range from site design practices to technology driven LID BMPs. The underlying principle of LID is that undeveloped land does not present a stormwater runoff or pollution problem. The evolved natural hydrology of any given site manages water in the most efficient manner. This most often translates to high rates of infiltration, vegetative interception, and evapotranspiration.

LID attempts to offset the inevitable consequences of development and changes in land cover by preserving or mimicking natural hydrology. It is a source control option that minimizes stormwater pollution by recognizing that the greatest efficiencies are gained by minimizing stormwater generation. This is a process that begins with functional conservation of watershed resources, reducing impacts of development, and then using innovative management practices to meet the stormwater objective; it is not the use of the management practices alone. Site preservation practices coupled with small-scale BMPs that rely on the environmental services of vegetation and soils or systems that mimic these services comprise the control approach of LID. These practices, taken in aggregate, limit the observed hydromodification on a developed site and present a more comprehensive and beneficial control approach.

Needing to be addressed, however, is the lag in broad LID implementation. Even though it has been demonstrated as an attractive strategy, its application is limited and has not yet been fully integrated. Several barriers have generally slowed and hampered greater LID adoption. Bureaucratic inertia involving the entrenchment of prevailing conventional practices, institutional structures, and regulatory shortfalls are the prime barriers preventing a broad shift in stormwater management philosophy. Of these, regulatory structure is the most critical barrier. If regulations are crafted appropriately and call for proper environmental performance, a significant catalyst for overcoming the other barriers will be created and facilitate further institutional changes.

To appropriately implement LID it is important to assess its role in water quality protection. LID is one part of a toolkit that can be used to better manage natural resources and limit the pollution delivered to waterways. It is not independent of watershed planning and to gain optimal benefits LID needs to be integrated with appropriate land use programs. LID by itself will not deliver the water quality outcomes desired; it does provide enhanced stormwater treatment and mitigate excess volume and flow rates. However, if not integrated in a comprehensive fashion, LID techniques can end up as a series of uncoordinated innovative BMPs that have limited water quality benefit.

The potential of LID is maximized when it is used in conjunction with other conservation and planning approaches. Programs like Smart Growth are the first step of the process. Before LID is used, decisions about where and how to develop within the watershed need to be evaluated to limit water quality impacts. Once these decisions are made, LID can then be used to mitigate the impacts of the development. Coordinating and integrating LID with Smart Growth and other innovative land use approaches will limit conversions in land cover, preserve natural watershed areas, and maximize the management of stormwater runoff. In urbanized areas, LID can be coordinated with green building and redevelopment efforts and it can be used to augment infrastructure projects by enhancing capacity. Retrofitting LID in urban locations provides opportunity to provide multiple environmental, social, and infrastructure benefits.

Regulatory Climate

Stormwater presents a significant challenge for establishing efficient and effective regulations. Its episodic and dynamic nature is the polar opposite of the largely predictable and constant nature of municipal and industrial wastewater discharges that have been such a large focus of the regulatory and permit efforts of the past decades. Incorporating stormwater into these programs

has been an institutional and technological challenge.[16] The resulting approach to stormwater control has been an adoption and reliance on minimum control measures that are implemented to demonstrate compliance with stormwater management plans. Discharge flow limitations and water quality criteria are often required and influence the selection of control measures. Even with the best efforts of these programs, water quality and use designations of waters nationwide are still well short of their intended goals.

The prevailing problem is that the current construct of many stormwater regulations do not require the use of the best available technologies and do not address hydromodification. This regulatory shortfall has hampered innovative applications of new technologies and an institutional shift in the practice of stormwater management. In California and other locations around the country, innovative practices are being adopted with increasing frequency. In certain instances innovation and implementation are outpacing regulatory programs and driving the revision of regulations; in others, innovative regulations have been adopted to establish environmental performance criteria that provide a significant incentive to adopt new control strategies. In either case, the resulting regulatory and incentive structures are informative for new program development.

A critical differentiation in regulatory application exists and will be presented in the examples in the following section. Minimizing and mitigating hydromodification is a critical performance criterion for Greenfield development. Undisturbed, Greenfield sites still possess natural hydrologic characteristics and attributes that can be used to inform appropriate control and mitigation strategies. Development or redevelopment of previously developed urban areas will require surrogate performance criteria. The natural hydrology of these areas has largely been lost due to the impacts of decades or centuries of urbanization. Linking performance criteria to hydrology in these areas is not as practical as Greenfield sites, but other approaches are used to approximate the desired outcomes of limited runoff volumes and pollutant loads.

POLICIES AND PROGRAMS

The following examples demonstrate how various jurisdictions have crafted their regulations to mitigate hydromodification or an increase in the volume of stormwater discharge.

- **401 Certifications**

  Section 401 of the CWA grants each state the right to ensure that the State's interests are protected concerning any federally permitted activity occurring in or adjacent to Waters of the State. In California, the Regional Water Quality Control Boards (Regional Boards) are the agency mandated to ensure protection of the State's waters. If a proposed project requires a U.S. Army Corps of Engineers CWA Section 404 permit, or involves dredge or fill activities that may result in a discharge to U.S. surface waters and/or "Waters of the State" the project proponent is required to obtain a Clean Water Act (CWA) Section 401 Water

[16] The NPDES program is not the only available avenue for regulating stormwater discharges. Other federal, state, and local water policies or programs offer significant opportunity for the development of comprehensive stormwater programs. In some cases, these provisions have influenced stormwater management, but municipal stormwater control is still largely driven by the NPDES program.

Quality Certification and/or Waste Discharge Requirements (Dredge/Fill Projects) from the Regional Board, verifying that the project activities will comply with state water quality standards.[17]

Section 401 gives the Regional Boards the authority to consider the impacts of the entire project and require mitigation for volume, velocity, and pollutant load of the discharge from new outfalls to surface waters. Some Regional Boards that have large areas not covered by Phase I or II Municipal permits, require low impact development and hydromodification mitigation consistent with municipal post-construction design standards.

- **404 Compliance**

Section 404 of the CWA regulates fill and disturbance of wetlands and waters of the United States. The US Corps of Engineers, Norfolk District, (which has permit review responsibilities) encourages 404 compliance with the use of LID principles. Projects applying for a permit are required to demonstrate that they have avoided and minimized impacts to jurisdictional areas to the maximum extent practicable. For unavoidable impacts, projects may be required to provide compensatory wetland mitigation. The Norfolk District office considers LID practices as partial mitigation, provided that there is no project-specific loss of wetland acreage.

This allowance is intended to minimize impacts that the Corps has witnessed to wetlands and streams that are associated with conventional stormwater management facilities. Therefore, the Corps allows consideration of LID BMPs (e.g., swales, bioretention facilities) as viable alternatives to in-channel or in-wetland stormwater basins. The initiative's goal is to reduce the number and size of conventional stormwater facilities impacting wetlands or waters of the U.S. In addition, the emphasis on LID design and BMPs is intended to ensure that the post-development and pre-development hydrographs are similar to reduce wetland impacts and maintain pre-development groundwater recharge.

- **Preliminary Draft California NPDES Construction General Permit for Stormwater Discharges**

The preliminary draft revised General Permit, released for comment in March 2007, included for the first time post-construction stormwater control performance standards.[18] Previously post-construction language was difficult to enforce as the standard of BAT/BCT was not easily applied to low impact development practices. If accepted, the draft permit will establish consistent state-wide post-construction standards that can be enhanced or augmented by the Regional Boards. The permit stipulates several performance standards for new development and redevelopment as identified below.

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[17] North Coast Water Board, 401 Certification web page: http://www.waterboards.ca.gov/northcoast/programs/wqwetcert.html, (accessed November 2007).

[18] State Water Resources Control Board, National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges - Associated Construction and Land Disturbance Activities, March 2, 2007.

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1. *The discharger shall, through the use of non-structural and structural measures, ensure that the post-development runoff volume approximates the pre-project runoff volume for areas covered with impervious surfaces...*
2. *For projects whose disturbed project area exceeds two acres, the discharger shall preserve the post-construction drainage divides for all drainage areas serving a first order stream or larger and ensure that post-project time of concentration is equal or greater than pre-project time of concentration.*
3. *For projects whose disturbed project area exceeds 50 acres, the discharger shall preserve pre-construction drainage patterns by distributing their non-structural and structural controls within all drainage areas serving first order streams or larger and ensuring that post-project time of concentration is equal to or greater than pre-project time of concentration.*

The regulatory approach of the draft permit is one of volume and time of concentration control. Pre-development site hydrology must be evaluated and guides post-construction performance objectives. The pre-development water balance must be approximated so that there is no increase in the volume of runoff that leaves the site. In addition, while the regulation expressly permits the use of both non-structural and structural controls, it is likely that achieving the hydrologic objectives of the standard will require a significant reliance on LID techniques.

- **Santa Clara Valley Hydromodification Management Plan**

The RWQCB, San Francisco Bay Region, requires stormwater programs to develop and implement hydromodification management plans (HMPs). The Santa Clara Valley Urban Runoff Pollution Prevention Program was the first permit to include the new HMP requirements.[19] The Program's hydromodification control standard requires that those who discharge stormwater manage increases in peak runoff flow and increased runoff volume where the increased volume or flow can cause erosion or siltation problems. The implemented HMP limits post-construction runoff to pre-construction rates and/or durations.[20]

Performance criteria to demonstrate compliance with the hydromodification control standard are also presented in the permit. The first of which is that the project shall use stormwater controls to maintain pre-construction stream erosion potential.[21] The second requires that post-construction stormwater discharge rates and flow durations be equivalent to pre-construction values for flows from 10% of the 2-year peak flow up to the full 10-year peak flow.[22]

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[19] Santa Clara Valley Urban Runoff Pollution Prevention Program, Hydromodification Management Plan – Final Report, April 21, 2005.
[20] Ibid.
[21] Erosion potential is a measure of how a site's runoff hydraulically impacts a receiving stream. Greater volumes of stormwater released at greater rates and for longer durations impart greater physical impacts on receiving streams.
[22] Santa Clara Valley Urban Runoff Pollution Prevention Program, Hydromodification Management Plan – Final Report, April 21, 2005.

Santa Clara's HMP is an interesting case because the language differs greatly from conventional stormwater control regulations. By requiring quantification of the erosion potential of a site, the HMP directly addresses both the rate and volume of discharge. This requirement, coupled with flow duration criteria for small storms up to the 10-year storm, will require sites to maintain the pre-development hydrograph for a large percentage of storm events post construction.

This regulatory construct is efficient for several reasons. A great majority of stormwater regulations contain requirements for peak control only. As discussed in the background of this report, controlling only that single parameter is not sufficient to adequately protect receiving stream water quality because increased stormwater volumes and extended durations contribute larger mass loads of pollutants and impart greater physical impacts. By establishing discharge performance criteria for the volume, rate, and duration, these standards are more protective and demonstrate the full complement of factors that require control to limit the physical impacts of stormwater discharges.

Also important is the range of storms for which the duration of discharge must be controlled. Stormwater regulations routinely pick two design storms (often the two and 10 year events) for which peak flow rate requirements are established. The consequence of this is that no control is provided for the most frequently occurring small storms that are less than the two year event. Research shows that post-construction discharges from these small, frequent storms have much greater physical impacts than originally thought. Along this same line is the ability to effectively manage dry flows which can constitute a significant portion of runoff and pollutant transport in many areas of California. The duration control criterion recognizes the impacts of these small storms and established performance criteria designed to mitigate these effects.

- **San Diego County Phase I MS4 Permit**

In January 2007, the San Diego Regional Water Quality Control Board reissued the Phase I Municipal Stormwater Permit for San Diego County.[23] The permit has specific requirements for the implementation of low impact development BMPs and a Hydromodification Management Plan. Not only does the permit specify that LID is required to meet MEP for retail gas outlets and heavy industry meeting certain criteria, but also the permit requires all new and redevelopment projects to implement LID BMPs where feasible.

Priority Development Projects, a subset of development projects with a particular potential threat to water quality, as specified in the permit, are required to implement LID in the following ways:

[23] California Regional Water Quality Control Board, San Diego Region, Order No. R9-2007-0001, NPDES NO. CAS0108758, Water Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer Systems Draining the Watersheds of the County of San Diego, the Incorporated Cities of San Diego County, the San Diego Unified Port District, and the San Diego County Regional Airport Authority.

1. Draining a portion of the site's impervious areas into pervious areas prior to discharge to the MS4.[24]
2. Properly designing and constructing the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas.
3. Constructing a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces.

Another set of LID BMP requirements apply to Priority Development Projects where feasible:

1. Conserve natural areas, including existing trees, other vegetation, and soils.
2. Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised.
3. Minimize the impervious footprint of the project.
4. Minimize soil compaction.
5. Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions).

Permittees are then given the responsibility of defining the applicability and feasibility of LID BMPs. They are required to establish minimum standards to maximize the use of LID practices and principles as a means of reducing stormwater runoff. This includes siting, design, and maintenance criteria for each LID BMP to ensure that they are constructed correctly and are effective at pollutant removal and/or runoff control. Additionally, prior to occupancy of a Priority Development Project, the LID BMPs must be inspected to verify compliance with specifications. Education concerning how to implement LID BMPs into the local regulatory programs and methods of minimizing impacts to receiving waters as a result of development is required for municipal personnel and development planning staff.

The permit's hydromodification requirements also apply to all Priority Development Projects. Each permittee must develop and apply criteria for priority projects so that runoff discharge rates, durations, and velocities are controlled to maintain or reduce downstream erosion conditions and protect stream habitat.

The Hydromodification Management Plan (HMP) must include:

1. A stability standard for channel segments which receive urban runoff discharges.
2. A range of runoff flows for which post-project runoff flow rates and durations shall not exceed pre-project runoff flow rates and durations.
3. Hydrologic control measures so that post-project runoff flow rates and durations do not exceed pre-project runoff flow rates and durations, and do not result in channel conditions which do not meet the channel standard.

[24] "Portion" corresponds with the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.

4. Other performance criteria (numeric or otherwise) as necessary to prevent urban runoff from increasing erosion of channel beds and banks, silt pollutant generation, or other impacts to beneficial uses and stream habitat due to increased erosive force.
5. A review of pertinent literature.
6. A protocol to evaluate potential hydrograph change impacts to downstream watercourses.
7. A description of how the HMP requirements will be incorporated into the local approval processes.
8. The identified range of runoff flows to be controlled expressed in terms of peak flow rates of rainfall events.
9. Criteria for selection and design of management practices and measures to control flow rates and durations and address potential hydromodification impacts.
10. Technical information supporting standards and criteria proposed.
11. A description of inspections and maintenance to be conducted for management practices and measures to control flow rates and durations and address potential hydromodification impacts.
12. A description of pre- and post-project monitoring and other program evaluations to be conducted to assess the effectiveness of implementation of the HMP.
13. Mechanisms for addressing cumulative impacts within a watershed on channel morphology.
14. Information on evaluation of channel form and condition, including slope, discharge, vegetation, underlying geology.

Until the HMP is completed, the permit requires that interim criteria for projects disturbing 50 acres or more be established and implemented. The interim hydromodification criteria must contain a range of runoff flow rates for which Priority Development Project post-project runoff flow rates and durations shall not exceed pre-project runoff flow rates and durations.

While the San Diego Permit requirements have not been in effect long enough to draw conclusions about its implementation success, the concepts of:

- Including both LID and hydromodification requirements to address both on-site and receiving water concerns;
- Requiring the permittees to clearly define BMP feasibility in an effort to ensure maximum implementation;
- Including an education component for municipal staff to aid program implementation and consistency;
- Requiring inspection of management measures to ensure proper construction and long-term effectiveness; and
- Including interim requirements to implement until the more detailed plans have been approved.

The permit language and concepts are robust and specifically delineate LID and performance criteria requirements that are likely to lead to enhanced water quality protection and improvement.

- **Ventura County Draft Phase I MS4 Permit**

The August 2007 draft of the Ventura County Municipal Stormwater Permit also includes LID and hydromodification requirements.[25] The New Development and Redevelopment Criteria specify that all new and redevelopment shall integrate low impact development principles into project design. Permittees have 365 days to develop an LID technical guidance document for planners and developers that includes objectives and specifications for the integration of LID strategies, including:

1. Site assessment;
2. Site planning and layout;
3. Vegetative protection, re-vegetation, and maintenance;
4. Techniques to minimize land disturbance;
5. Techniques to implement LID measures at various scales;
6. Integrated water resources management practices;
7. LID design and flow modeling guidance;
8. Hydrologic analysis; and
9. LID credits.

In addition, the permit requires an LID training program for builders, design professionals, regulators, resource agencies, and stakeholders that addresses the integration of LID at various scales.

The permit's hydromodification control criteria require all new and redevelopment projects to implement control measures that prevent down stream erosion by maintaining the project's pre-development stormwater runoff flow rates and durations. The permit requires that the Erosion Potential (E_p) in streams be maintained at a value of 1, unless an alternative value is shown to be protective. The permit specifies a preference for LID strategies.

The Southern California Storm Water Monitoring Coalition is currently developing a regional methodology to eliminate adverse impacts from urbanization. The objectives for the Hydromodification Control Study (HCS) are:

1. Establishment of a stream classification for Southern California streams.
2. Development of a deterministic or predictive relationship between changes in watershed impervious cover and stream-bed/stream bank enlargement.
3. Development of a numeric model to predict stream bed/stream bank enlargement and evaluate the effectiveness of mitigation strategies.

Until the HCS is completed, permittees are required to implement the following interim hydromodification criteria:

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[25] California Regional Water Quality Control Board, Los Angeles Region, Waste Discharge Requirements for Storm Water (Wet Weather) and Non-Storm Water (Dry Weather) Discharges from the Municipal Separate Storm Sewer Systems within the Ventura County Watershed Protection District, County of Ventura and the Incorporated Cities therein, August 28, 2007.

1. Projects disturbing land area of less than fifty acres must implement hydromodification controls such that the 2-year 24-hour storm event post-development hydrograph peak flow and volume will match within one percent of the 2-year 24-hour storm event pre-development peak flow and volume hydrograph.
2. Projects disturbing land areas of fifty acres or greater shall develop and implement a Hydromodification Analysis Study that demonstrates that post-development conditions are not expected to alter the duration of sediment transporting flows in receiving waters. The HAS must demonstrate that the selected hydromodification control BMPs will maintain an E_p value of 1 unless an alternative value can be shown to be protective.

Once the HCS is completed, permittees must develop Hydromodification Control Plans (HCPs) that are watershed specific and identify:

1. Stream classifications;
2. Flow rate and duration control methods;
3. Sub-watershed mitigation strategies; and
4. Stream restoration measures which will maintain the stream and tributary E_p at 1 unless an alternative value can be shown to be protective.

In addition, the HCP must contain the following elements:

1. Hydromodification management standards;
2. Natural drainage areas and hydromodification management control areas;
3. New development and redevelopment projects subject to the HCP;
4. Description of authorized hydromodification management control BMPs;
5. Hydromodification management control BMP design criteria;
6. For flow duration control methods, the range of flows to control for, and goodness of fit criteria;
7. Allowable low critical flow, Q_c, which initiates sediment transport;
8. Description of the approved hydromodification model;
9. Any alternate hydromodification management model and design;
10. Stream restoration measures design criteria;
11. Monitoring and effectiveness assessment; and
12. Record keeping.

The permit requires that verification of maintenance provisions be provided for the hydromodification controls for all new and redevelopment projects and that LID and hydromodification measures be inspected to ensure proper installation prior to the issuance of occupancy certificates. The permit also specifies that the permittee implement a tracking system, and an inspection and enforcement program for new and redevelopment post-construction stormwater BMPs.

While this permit is still in draft form and has not yet been adopted, it has a broad scope of requirements. The permit requires:

- An LID Technical Guidance document;
- An LID training program;
- A Hydromodification Control Plan;
- Interim hydromodification criteria;
- Verification of maintenance provisions for hydromodification controls;
- A tracking, inspection, and enforcement program for post-construction stormwater BMPs; and
- Inspection of LID and hydromodification measures prior to the issuance of occupancy certificates.

This permit does not allow for a feasibility assessment for its LID requirements. It requires that all new and redevelopment projects integrate LID principles into project design and that the permittee develop a LID Technical Guidance document that includes the specifications for the integration of LID strategies.

- **New Jersey Stormwater Management Rules**

New Jersey's new stormwater requirements adopted in 2004 contain specific criteria for infiltration and the rate and volume of discharge.[26] The state establishes groundwater recharge requirements with the following performance standards.

1. *...that the site and its stormwater management measures maintain 100 percent of the average pre-construction groundwater recharge volume for the site; OR*
2. *...that the increase of stormwater runoff volume from pre-construction to post-construction for the two-year storm is infiltrated.*

The recharge provisions contain exemptions for the defined "urban redevelopment area," hot spots, and industrial stormwater exposed to source material.[27] These provisions are complemented by runoff quantity requirements.

1. *...that post-construction runoff hydrographs for the two, 10, and 100-year storm events do not exceed, at any point in time, the pre-construction runoff hydrographs for the same storm events; OR*
2. *...that there is no increase, as compared to the pre-construction condition, in the peak runoff rates of stormwater leaving the site for the two, 10, and 100-year storm events and that the increased volume or change in timing of stormwater runoff will not increase flood damage...; OR*
3. *...that the post-construction peak runoff rates for the two, 10, and 100-year storm events are 50, 75, and 80 percent, respectively, of the pre-construction peak runoff rates...*

In addition to the hydrologic performance standards, water quality standards requiring 80% total suspended solids (TSS) removal for the water quality design storm of 1.25 inches in two hours is also required. The New Jersey standards took important steps forward with their primary hydrologic requirements. Maintaining groundwater recharge rates or infiltrating the

[26] "Stormwater Management Rule," *New Jersey Register*, N.J.A.C., Vol. 7, No. 8 (February 2, 2004).
[27] Ibid.

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post-construction volume increase for the two year storm addresses one of the significant impacts of development – lost infiltration and groundwater recharge. Establishing these requirements will help to maintain pre-development water balance on the site.

Most importantly the primary runoff volume language requiring the post-construction hydrograph to match the pre-development hydrograph at each and every point does not allow an increase in the volume of stormwater discharged. This is not only an environmentally protective standard, but it would necessarily encourage wide adoption of non-structural controls and LID.

- **Portland Stormwater Requirements**

Portland's stormwater requirements are a good example of urban standards. Hydrology is not as much of a driving factor with urbanized areas as natural hydrology has been greatly altered and is likely not replicable in many instances because of factors such as existing utilities, density, soil compaction, fill materials, and existing historical contamination. Portland also has a combined sewer system and has a great interest in reducing stormwater inflow into the system.

The city's code requires on-site stormwater management for new development and redevelopment, and encourages the use of green infrastructure techniques to meet this objective.[28] In addition, new city-owned buildings are required to have a green roof covering 70% of the roof area. As an incentive for other buildings, a zoning bonus that allows additional square footage is available for those that install a green roof. The city will also allow up to a 35% discount in the stormwater utility for properties with on-site stormwater management.[29] This provides an incentive for existing properties to retrofit with on-site controls.

These are some of the most progressive urban stormwater standards in the country. They establish defined performance criteria based upon retention of stormwater and are a departure from many urban models whose aim is to provide water quality treatment for the first-flush of stormwater. Existing urban areas are often confronted by infrastructure capacity and maintenance concerns in addition to water quality requirements. Limiting the volume of stormwater discharged is a critical factor in addressing these issues. By also encouraging the use of green infrastructure, Portland is adopting a policy that will yield multiple environmental benefits in additional to providing stormwater retention.

- **Seattle Green Factor**

Adopted in January 2007, the Green Factor is an alternative approach for urban stormwater control. The Green Factor is a landscaping requirement in neighborhood business districts that stipulates that 30% of a site must be vegetated. This system encourages multiple layers of visible plantings and plantings in the public rights-of-way adjacent to the properties. The

[28] Portland City Code Chapter 17.38, Policy Framework, Appeals, and Update Process.
[29] C. Kloss and C. Calarusse, *Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows*, Natural Resources Defense Council, June 2006.

system is flexible and weights different landscaping practices according to their effectiveness. The square footage of each practice is multiplied by its green factor and then aggregated with the score of each additional practice to satisfy the requirements. For example, asphalt and concrete have a green factor of 0, permeable pavements 0.6, and green roofs 0.7. Bonuses are also provided for utilizing rain water harvesting and low water-use plants.[30]

This regulatory construct is interesting because it is not stormwater specific, nor does it contain specific discharge performance requirements. However, because of the practices selected for green factors and the benefits gained by adding vegetation and other green infrastructure practices, this policy will beneficially impact the volume of stormwater runoff. It is similar to the Green Area Ratio program in Berlin, Germany that has been a catalyst for encouraging green roof installation and the preservation or creation of other green spaces. The downside to this approach is that stormwater benefit may not be as great as stormwater specific performance requirements because of the flexibility in selecting green options. However, this is a progressive, multi-benefit/multi-pollutant policy approach.

This approach also provides an opportunity to assess appropriate amounts of vegetative cover in urban areas and the benefits gained from a comprehensive greening program. Analysis of this program can determine the environmental benefits with respect to the urban aesthetics desired. In addition, this type of system lends itself to a trading scheme where vegetative cover percentages can be increased in one area to offset a lack elsewhere or to provide enhanced performance in a critical or sensitive area.

- **Washington D.C. Anacostia Redevelopment Standards**

The area along the Anacostia River in Washington, DC (hereafter, the District) is slated for major redevelopment in the coming years. The Anacostia is one of the most polluted rivers in the country with a significant amount of this pollution contributed by stormwater runoff and combined sewer overflows. The District realized that the redevelopment presented an opportunity to revitalize a historically neglected portion of the city and established social, economic, and environmental benchmarks for the development area.

A comprehensive set of environmental standards was developed that included provisions for: (1) integrated environmental design; (2) stormwater; (3) green building; and (4) site planning and preservation. Like Portland's standards, natural hydrology is not as much a consideration as stormwater volume retention to limit discharges from the MS4 system and combined sewer overflows. The stormwater standards adopted serve as another example of an innovative urban application.

The stormwater control requirements stipulate on-site retention of the first inch of rainfall for new development and redevelopment and water quality treatment for up to the two-year storm volume along with a stated preference for vegetated controls. Where it is not technically feasible for on-site retention of stormwater, an off-set provision allows developers to provide off-site mitigation for 1½ times the volume that could not be provided

[30] Seattle Municipal Code, SMC 23.47A, Council Bill Number: 115746, Ordinance Number: 122311.

for the developed area or to pay into a dedicated stormwater fund for twice the cost of an equivalent volume reduction.[31] The off-set provision was modeled after other environmental off-set provisions and intended to provide an incentive to maximize on-site treatment.

These standards are considered some of the most progressive in the country. The driving focus was to significantly decrease stormwater inflow into the collection system and provide enhanced water quality treatment for any discharge while also supporting a green building and sustainability focus within the city. The stormwater standards were used as a platform to provide not only advanced stormwater control, but also encourage the integration of green space throughout an urban redevelopment to gain the associated social, economic, and multi-media environmental benefits.

- **Maryland Stormwater Act of 2007**

The Maryland Stormwater Act was passed by the General Assembly in April 2007 and signed into law by the Governor. The new act stipulates that Environmental Site Design (ESD) using LID practices is the preferred stormwater control method in the State and must be utilized as the first control option for new development projects.[32] Only after the developer or designer can demonstrate that they have used ESD to the maximum extent practicable are they permitted to use conventional stormwater controls.

This is more of a command-and-control regulatory construct mandating the use of a particular stormwater control system. However, because of the expansive list of LID BMPs and techniques, there is a great deal of flexibility built into the regulation. It also provides alternative options when site constraints may limit ESD's ability to achieve the stormwater management requirements. A significant benefit of this new policy is the understood preference for a new stormwater control regime based on LID principles that signals a departure from the standard methods of stormwater control.

An additional benefit of the new legislation is that it moves the State program to a more performance based system of stormwater management. Moving away from minimum treatment standards for selecting end-of-pipe BMPs and towards a system of integrated site design principles begins to allow the regulatory system to address overall site performance and function.

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[31] Anacostia Waterfront Corporation, *Final Environmental Standards*, June 1, 2007.

[32] *Maryland Stormwater Management Act of 2007,* Senate Bill 784 / House Bill 786, (available at http://mlis.state.md.us/2007RS/billfile/sb0784.htm).

CONCLUSIONS AND RECOMMENDATIONS

The State of California has a well developed institutional framework that can aid the development of a comprehensive LID program. Many steps already taken by the State have established the necessary performance criteria needed for broader LID adoption. The draft general Construction permit establishes volume limitations for post-construction runoff rather than the traditional approach of limiting flow rate. Preserving pre-construction runoff volumes will require the use of site design approaches and LID that will limit stormwater generation and maximize natural hydrologic processes for treatment.

In addition, the San Francisco Region's requirement for hydromodification plans places the emphasis on in-stream impacts of stormwater runoff and the need to develop programs that effectively manage the increased volume and flow that contribute to these impacts. The critical link in both of these approaches is that they require stormwater volume to be limited. Establishing a performance criterion for volume will more than likely require LID or other similar approaches that limit the conversion of precipitation to runoff.

Importantly, the institutional structure within the State can function to efficiently promote the adoption of innovative control approaches. The coordinated efforts of the State Board establishing broad policy approaches and the Regional Boards setting additional requirements within their watersheds when needed allows for alternative and evolving regulatory approaches, as highlighted by the examples above. Critical to this is the authority granted by the Porter-Cologne Act to regulate any activity or factor that impacts water quality. This stipulation gives the State broad authority to assess the cause of stormwater runoff and pollution and develop strategies to mitigate the originating cause. This condition exceeds that of many states that are limited by choice or statute to manage stormwater as a waste product while giving limited attention to the upstream factors that affect runoff. The planning and permitting authority that exists in the State and Regional Boards allows for the development of comprehensive control requirements that maximize vegetation, natural systems, and LID.

Important to the successful application of LID, is evaluating how it will be used for new development and redevelopment or urban retrofit. The pre-draft of the Reissuance of the Statewide construction general permit and the hydromodification management plans apply to new development and redevelopment and assess pre-development hydrologic conditions. Matching pre-development hydrologic conditions is a fair method in Greenfield development and redevelopment situations where determinations of pre-development conditions can be made and will help to decrease the pollution impact of new development across the state.

However, existing development exerts a tremendous pollution impact largely due to the resulting, developed landscape and its associated runoff characteristics. Addressing it by matching pre-development hydrology may not always be possible because many urban areas lack land for stormwater control and natural hydrology has been altered so significantly. In these instances, the urban stormwater regulations in Portland and Washington, D.C. that require volume retention can serve as appropriate models. These regulations do not focus on the natural function of a site, but rather attempt to limit runoff as a means of pollution prevention and enhancing infrastructure capacity. The desired outcome is the same as the hydromodification

approaches, but the assessment and control requirements are structured differently to account for urban conditions.

The important concept across all of these approaches is that the regulations established a performance requirement to limit the volume of stormwater discharges. The fact that volume is the critical regulatory requirement instead of maximum flow rate leads to greater adoption of LID and vegetated systems. The City of Salinas and the Central Coast Regional Water Quality Control Board found that ordinances that only encourage LID adoption had little voluntary implementation, but ordinances that require LID have resulted in more widespread implementation.[33]

Regulations can address new development or redevelopment but LID retrofits are also a critical need on existing development to mitigate existing stormwater pollution. Appropriately structured incentive programs can encourage LID adoption outside of a regulatory structure and reduce stormwater volume. Portland uses the potential for a discount from its stormwater utility fee to create an incentive for existing properties to retrofit to on-site stormwater controls. The recurring financial benefits that can be gained from a one-time capital investment and limited maintenance requirements can entice owners to adopt on-site practices that otherwise may not have.

Utility fees or other dedicated funding can serve multiple purposes. Portland's utility fee funds its program and provides an incentive for volume reductions. The off-set fee that is permissible in the Anacostia portion of Washington creates a revenue stream that the city can use for installations within right-of-ways or city owned property. To be effective for both purposes, a fee must be structured and valued to provide sufficient programmatic funding and allow for a fee discount sufficient to create an incentive. Washington's preference is for on-site controls, so the required off-set fee is based upon twice the cost to manage the volume of stormwater to encourage the maximization of on-site options.

LID is also a complement to other land use planning or environmental programs. The water quality benefits of Smart Growth programs can be enhanced by using LID. LID can also be used within the Leadership in Energy and Environmental Design (LEED®) system to gain points for environmentally sensitive design. Many LID practices provide benefits like energy conservation or other site design benefits in addition to stormwater control that can contribute to the overall LEED® rating of a project.

The State and Regional Boards have begun to implement policies that will encourage LID practices. These policies will likely lead to broader implementation of distributed, on-site stormwater techniques. Other policy options that have been adopted in other jurisdictions have the potential to augment California's existing efforts and develop a more robust regulatory system. The institutional framework within the State allows for regulatory innovation and should provide the necessary platform for a water resources program that fully incorporates LID.

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[33] Chris Conway, et al., *Technical Memorandum to the Central Coast Regional Water Quality Control Board and the City of Salinas – Model Low Impact Development (LID) Ordinance for Salinas and the Central Coast*, Kennedy/Jenks Consultants, January 22, 2007.

Pennsylvania Stormwater Best Management Practices Manual

Chapter 3

Stormwater Management Principles and Recommended Control Guidelines



363-0300-002 / December 30, 2006

Chapter 3 Stormwater Management Principles and Recommended Control Guidelines

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3.1 Introduction

This Chapter provides guidance for municipalities striving to improve their stormwater management programs. It presents stormwater management principles and recommends site control guidelines to address volume, water quality and flow rate. These guidelines can serve as the basis for municipal stormwater regulation. Pennsylvania laws and regulations do not directly manage stormwater at the state level, although some state level management occurs through the Stormwater Management Act and the NPDES permitting program. All municipalities, regardless of their specific setting, are encouraged to enact the most comprehensive stormwater management ordinances possible. They should also work with their watershed neighbors to integrate their individual municipal actions within the watershed as a whole.

The guidelines established in this chapter reflect the ten basic principles of stormwater management presented in the forward. The principles are listed below once more to emphasize their fundamental importance as the foundation for the control guidelines that will follow.

1. Managing stormwater as a resource;
2. Preserving and utilizing existing natural features and systems;
3. Managing stormwater as close to the source as possible;
4. Sustaining the hydrologic balance of surface and ground water;
5. Disconnecting, decentralizing and distributing sources and discharges;
6. Slowing runoff down, and not speeding it up;
7. Preventing potential water quality and quantity problems;
8. Minimizing problems that cannot be avoided;
9. Integrating stormwater management into the initial site design process; and
10. Inspecting and maintaining all BMPs.

3.2 Recommended Site Control Guidelines

Site control guidelines are designed to meet water volume and water quality requirements and to follow the ten principles previously listed. The control guidelines presented in this Chapter are comprehensive are consistent with the Pennsylvania Comprehensive Stormwater Management Policy, and are recommended to restore natural hydrology including velocity, current, cross-section, runoff volume, infiltration volume, and aquifer recharge volume. Following the guidelines will help sustain stream base flow and prevent increased frequency of damaging bank full flows. The guidelines also will help prevent increases in peak runoff rates for larger events (2-year through 100-year) on both a site-by-site and watershed basis. When applicable, Act 167 watershed plans may require additional rate controls to reduce cumulative flooding impacts downstream.

The site control guidelines are:

- **Effective** — The morphologic impacts on streams from increased volumes of runoff during smaller storms are prevented. The guidelines will be effective on a site-by-site basis, as well as on a broader watershed-wide scale;

- **Proportional** — The stormwater controls will produce approximately the same post-development stormwater discharge for all types of development in almost any location;

- **Equitable** — The requirements are based on project characteristics rather than project location so that physically similar projects will have similar storm water controls;

- **Flexible** — The diversity among Pennsylvania's 2,566 municipalities is accommodated by the guidelines. This diversity in physical conditions presents a major challenge that requires flexibility to achieve a uniform stormwater management program across the state.

3.3 Recommended Volume Control Guidelines

Regardless of where land development occurs, the impervious surfaces, the changes in vegetation, and the soil compaction associated with that development result in significant increases in runoff volume. When the balance of a developed site is cleared of existing vegetation, graded, and re-compacted, it produces an increase in runoff volume. While traditionally, if the original vegetation were replaced with natural vegetation, the runoff characteristics would be considered to be equivalent to the original natural vegetation. The disturbance and the compaction destroy the permeability of the natural soil.

The relative increase in runoff volume varies with event magnitude (return period). For example, the two-year rainfall of 3.27 inches/24 hours (SE PA) will result in an increase in runoff volume of 2.6 inches from every square foot of impervious surface placed on well-drained HSG B soil in woodland cover (Figure 3-1). For larger events, as the total rainfall increases, the net runoff also increases, but less than proportionately. For example, total rainfall for the 100-year storm is twice the rainfall for the 2-year storm (7.5 inches vs. 3.27 inches); however, the increase in runoff for the 100-year storm is only 1.7 inches more than the runoff for the 2-year storm (4.3 – 2.6 inches). This pattern holds true throughout the state.

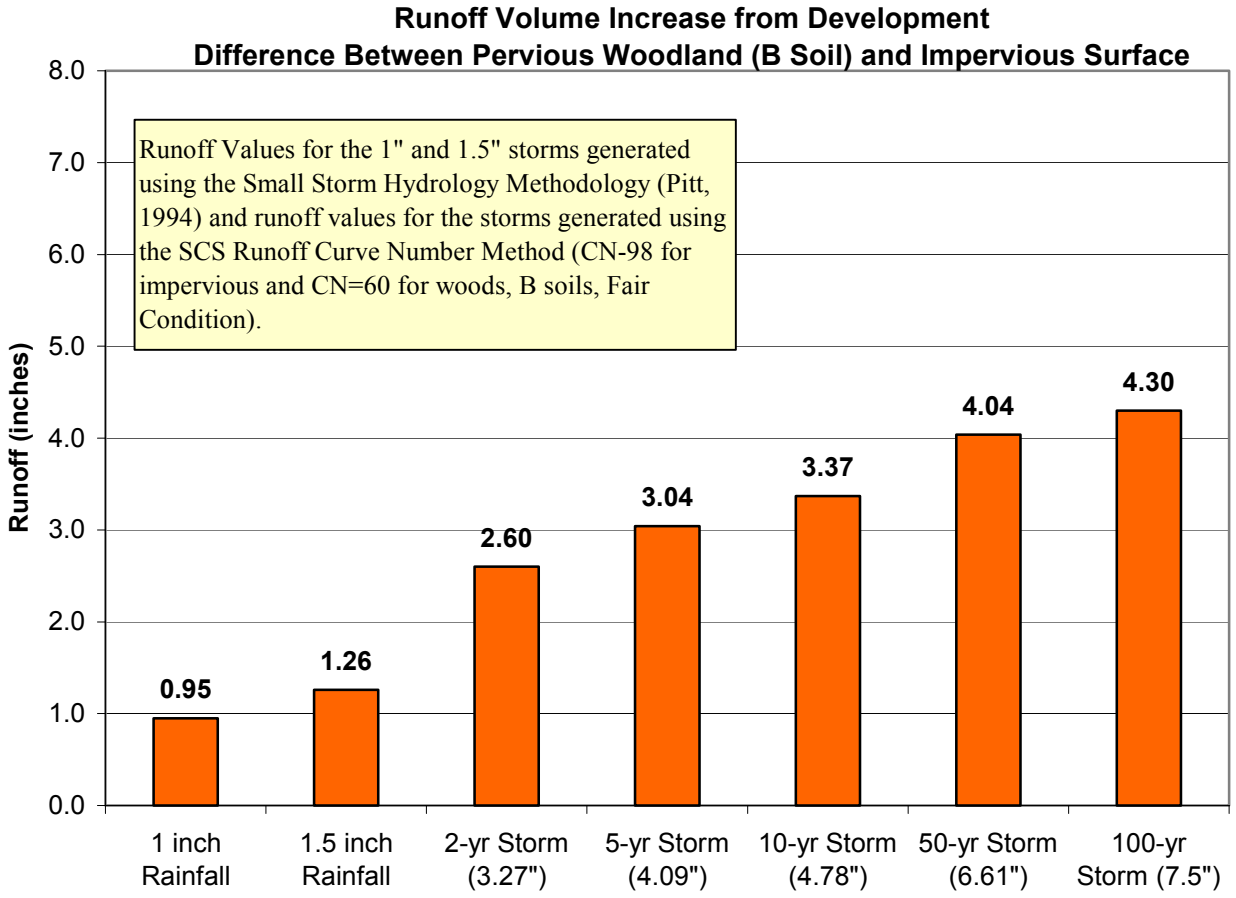

Figure 3-1. **Runoff Volume Increase from Impervious Surfaces - B Soils.**

For a specific site, the net increase in runoff volume during a given storm depends on both the pre-development permeability of the natural soil and the vegetative cover. Poorly drained soils result in a smaller increase of runoff volume because the volume of pre-development runoff is already high. Therefore, the amount of runoff resulting from development does not represent a large net increase. Using the same rainfall values, Figure 3-2 illustrates that the two-year rainfall of 3.27 inches/24 hours produces an increase of only 2.01 inches on a HSG C soil, while the better drained (B) soil in Figure 3-1 produces a 2.60-inch runoff volume increase. Thus a volume control guideline must be based on the net change in runoff volume for a given frequency rainfall to be equitable throughout the state on any given development site.

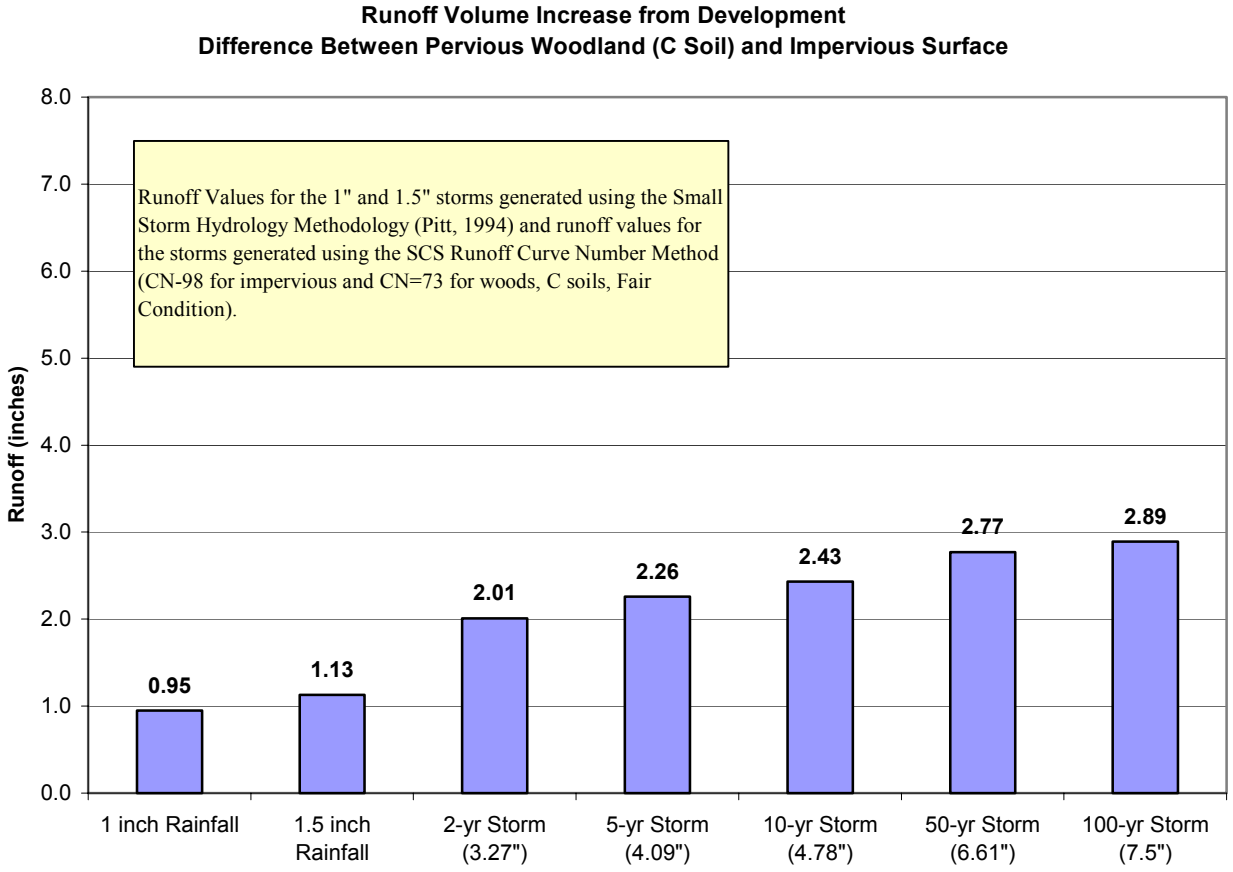

***Figure 3-2*. Runoff Volume Increase from Impervious Surfaces - C Soils**

Consideration of a volume control guideline has focused on providing stream channel protection and water quality protection from the frequent rainfalls that comprise a major portion of runoff events in any part of the state. On the basis of these factors, the 2-year event has been chosen as the stormwater management design storm for Volume Control Guideline 1.

Regardless of the volume reduction goal desired, it is considered unreasonable to design any stormwater BMP for greater than a 2-year event. The increase in runoff volume from the 100-year rainfall after site development is so large that it is impractical to require management of the total increase in volume. During such extreme events, the runoff simply overwhelms the natural and human-made conveyance elements of pipes and stream channels. In practice, a BMP sized for the increase in the 100-year runoff volume would be empty most of the time and would have a 1% probability of functioning at capacity in any one year. Of course, large storms need to be managed in terms of flooding and peak rate control, to the extent practicable.

3.3.1 Volume Control Criteria

A volume control guideline is essential to mitigate the consequences of increased runoff. To do this, the volume reduction BMP must:

1. Protect stream channel morphology;
2. Maintain groundwater recharge;
3. Prevent downstream increases in flooding; and
4. Replicate the natural hydrology on site before development to the greatest extent possible.

Protect Stream Channel Morphology: Increased volume of runoff results in an increase in the frequency of bank full or near bank full flow conditions in stream channels. The increased presence of high flow conditions in riparian sections has a detrimental effect on stream shaping, including stream channel and overall stream morphology. Stream bank erosion is greatly accelerated. As banks are eroded and undercut and as stream channels are gouged and straightened; meanders, pools, riffles, and other essential elements of habitat are lost or diminished. Research has demonstrated that bank-full stream flow typically occurs between the 1-year and the 2-year storm event (often around the 1.5-year storm). Urbanization can cause the natural bankfull stream flows to occur far more often. Strategies employed by the CG's include a combination of volume reduction and extended detention to reduce the bankfull flow occurances.

Maintain Groundwater Recharge: Over 80 percent of the annual precipitation infiltrates into the soil mantle in Pennsylvania's watersheds under natural conditions. More than half of this is taken up by vegetation and transpired. Part of this infiltrated water moves down gradient to emerge as springs and seeps, feeding local wetlands and surface streams. The rest enters deep groundwater aquifers that supply drinking water wells. Without groundwater recharge, surface stream flows and supplies of groundwater for wells will diminish or disappear during drought periods. Certain land areas recharge more groundwater than others; therefore, protecting the critical recharge areas is important in maintaining the water cycle's balance. In round numbers, an estimate of the annual water balance is: surface water runoff, 20%; evapotranspiration (ET), 45%; groundwater recharge, 35%.

Prevent Downstream Increases in Runoff Volume and Flooding: Although site-based rate control measures may help protect the area immediately downstream from a development site, the increased volume of runoff and the prolonged duration of runoff from multiple development sites can increase peak flow rates and duration of flooding from runoff caused by relatively small rain events. Replicating pre-development runoff volumes for small storms will usually substantially reduce the problem of frequent flooding that plague many communities. Although control of runoff volumes from small storms almost always helps to reduce flooding during large storms, additional measures are necessary to provide adequate relief from the serious flooding that occurs during such events.

Replicate the Surface Water Hydrology On-site Before Development: The objective for stormwater management is to develop a program that replicates the natural hydrologic conditions of watersheds to the maximum extent practicable. However, the very process of clearing the existing vegetation from the site removes the single largest component of the natural hydrologic regime, evapotranspiration (ET). Unless the ET component is replaced, the runoff increase will be substantial. Several of the BMPs described in this manual, such as infiltration, tree planting, vegetated roof systems and rain gardens, can help replace a portion of the ET function.

3.3.2 Volume Control Alternatives

While the volume control guideline alternatives are quite specific concerning the volume of runoff to be controlled from a development site, they do not specify the methods by which this can be accomplished. The selection of a BMP, or combination of BMPs, is left to the design process. But in all instances, minimizing the volume increase from existing and future development is the goal. The BMPs

described in this manual place emphasis on infiltration of precipitation as an important solution; however, three methods are provided to reduce the volume of runoff from land development:

1. Infiltration;
2. Capture and Reuse; and
3. Vegetation systems that provide ET, returning rainfall to the atmosphere.

It is anticipated that many of the stormwater management systems used in Pennsylvania will include one or more of these methods, depending on specific site conditions that constrain stormwater management opportunities**.** Inherent in these guidelines is the assumption that all soils allow some infiltration. Where this is not possible, a vegetated roof, or bioretention combined with capture-and-reuse systems, or other forms of runoff volume control will be necessary to achieve the required capture and removal volumes.

For Regulated Activities equal or less than one acre that do not require design of stormwater storage facilities, the applicant may select either Control Guideline 1 or Control Guideline 2 on the basis of economic considerations, applicability and limitations of the analytic procedures and other factors. Control Guideline 1 may require more complex and detailed analyses while providing a greater opportunity to select stormwater controls that require fewer resources to construct and operate. For all Regulated Activities larger than one acre and for all projects that require design of stormwater storage facilities, Control Guideline 2 may not be used.

3.3.3 Volume Control Guideline 1

The Control Guideline 1 is applicable to any size of the Regulated Activity. Use of Control Guideline 1 (CG-1) is recommended where site conditions offer the opportunity to reduce the increase in runoff volume as follows:

Do not increase the post-development total runoff volume for all storms equal to or less than the 2-year/24-hour event.

Existing (pre-development) non-forested pervious areas must be considered meadow (good condition) or its equivalent.

Twenty (20) percent of existing impervious area, when present, shall be considered meadow (good condition) in the model for existing conditions for redevelopment.

The scientific basis for Volume Control Guideline 1 is as follows:

- The 2-year event provides stream channel protection and water quality protection for the relatively frequent runoff events across the state;
- Volume reduction BMPs based on this standard will provide a storage capacity to help reduce the increase in peak flow rates for larger runoff events;
- In a natural stream system in Mid-Atlantic States, the bank full stream flow occurs with a period of approximately 1.5 years. If the runoff volume from storms less than the 2-year event are not increased, the fluvial impacts on streams will be reduced;
- The 2-year storm is well defined and data are readily accessible for use in stormwater management calculations.

3.3.4 Volume Control Guideline 2

Control Guideline 2 (CG-2) is independent of site constraints and should be used if CG-1 is not followed. This method is not applicable to Regulated Activities greater than one (1) acre or for projects that require design of stormwater storage facilities. For new impervious surfaces:

> **Stormwater facilities shall be sized to capture at least the first two inches (2") of runoff from all contributing impervious surfaces.**
>
> **At least the first one inch (1.0") of runoff from new impervious surfaces shall be permanently removed from the runoff flow — i.e. it shall not be released into the surface Waters of this Commonwealth. Removal options include reuse, evaporation, transpiration, and infiltration.**
>
> **Wherever possible, infiltration facilities should be designed to accommodate infiltration of the entire permanently removed runoff; however, in all cases at least the first one-half inch (0.5") of the permanently removed runoff should be infiltrated.**

The scientific basis for Volume Control Guideline 2 is as follows:

- Groundwater recharge will be maintained;
- The permanently removed volume will reduce the runoff;
- The combined permanently removed volume and extended detention volume will provide water quality protection by:
  - Capture / treatment of 95+/-% of the yearly water budget, and a higher volume of pollutants (first flush);
  - Capture / treatment of 99+/-% of the yearly storm events from paved areas. Example: for over 50 years of data on the Brandywine, 2.6 storms per year on average exceed 2";
- Volume reduction BMPs based on this standard will provide a storage capacity to reduce the increase in peak flow rates;
- In many of Pennsylvania's natural streams, the bank full stream flow occurs with a period of approximately 1.5 years. The combination of volume reduction and extended detention will reduce the depth and frequency of flows for all events less than the 2-year event, therefore, the fluvial impacts on streams will be reduced.

3.3.5 Retention and Detention Considerations

Infiltration areas should be spread out and located in the sections of the site that are most suitable for infiltration.

In all cases, retention and detention facilities should be designed to completely drain water quality volumes including both the permanently removed volume and the extended detention volume over a period of time not less than 24 hours and not more than 72 hours from the end of the design storm.

3.4 Recommended Peak Rate Control Guideline

Peak rate control for large storms, up to the 100-year event, is essential to protect against immediate downstream erosion and flooding. Most designs achieve peak rate control through the use of detention structures. Peak rate control can also be integrated into volume control BMPs in ways that eliminate the need for additional peak rate control detention systems. Non-Structural BMPs also can contribute to rate control, as discussed in Chapters 5 and 8.

The recommended control guideline for peak rate control is:

Do not increase the peak rate of discharge for the 1-year through 100-year events (at minimum); as necessary, provide additional peak rate control as required by applicable and approved Act 167 plans.

Where Act 167 plans apply, hydrologic modeling may have been performed to provide the basis for establishing more stringent release rate controls on sub-districts within the watershed. As volume reduction BMPs are incorporated into stormwater management on a watershed basis, release rate values will require re-evaluation. Use of the control guidelines will reduce or perhaps even eliminate the increase in peak rate and runoff volume for some storms.

3.5 Recommended Water Quality Control Guideline

The volume control achieved through applying CG-1 and CG-2 may also remove a major fraction of particulate associated pollutants from impervious surfaces during most storms. Pervious surfaces such as “lawnscapes” subject to continuing fertilization may generate NPS pollutants throughout a major storm, as may stream banks subjected to severe flows. While infiltration BMPs and landscape BMPs are very effective in NPS reduction, if the volume control measures simply overflow during severe storms then they will not achieve the control anticipated. Solutes will continue to be transported in runoff throughout the storm, regardless of magnitude.

CG-1 will provide water quality control and stream channel protection as well as flood control protection for most storms if the BMPs drain reasonably well and are adequately sized and distributed. CG-2 will not fully mitigate the peak rate for larger storms, and will require the addition of secondary BMPs for peak rate control. These secondary BMPs could also provide water quality control. In the event that this secondary BMP is added to assure rate mitigation during severe storms, the incorporation of vegetation could provide effective water quality controls.

The recommended control guideline for *total water quality control* is:

> Achieve an 85 percent reduction in post-development particulate associated pollutant load (as represented by Total Suspended Solids), an 85 percent reduction in post-development total phosphorus loads, and a 50 percent reduction in post-development solute loads (as represented by NO3-N), all based on post-development land use.

The recommended water quality control guideline is a set of performance-based goals. The guideline does not represent specific effluent limitations but presents composite efficiency expectations that can be used to select appropriate BMPs.

These reductions may be estimated based on the pollutant load for each land use type and the pollutant removal effectiveness of the proposed BMPs, as shown in Chapters 5 and 6 and discussed in Chapter 8. The inclusion of total phosphorus as a parameter is in recognition of the fact that much of

the phosphorus in transit with stormwater is attached to the small (colloidal) particles, which are not subject to gravity settlement in conventional detention structures, except over extended periods. With infiltration or vegetative treatment, however, the removal of both suspended solids and total phosphorus should be very high.

New impervious surfaces, such as rooftops, that produce relatively little additional pollutants can be left out of the water quality impact site evaluation under most circumstances. Rainfall has some latent concentration of nitrate (1 to 2 mg/l) as the result of air pollution, but it would be unreasonable to require the removal of this pollutant load from stormwater runoff. The control of nitrate from new development should focus on reduction of fertilizer applications rather than removal from runoff.

When the proposed development plan for a site is measured by type of surface (roof, parking lot, driveway, lawn, etc.), an estimate of potential pollutant load can be made based on the volume of runoff from those surfaces, with a flow-weighted pollutant concentration applied. The total potential non-point source load can then be estimated for the parcel, and the various BMPs, both Structural and Non-Structural, can be considered for their effectiveness. This method is described in detail in Chapter 8. In general, the Non-Structural BMPs are most beneficial for the reduction of solutes, with Structural BMPs most useful for particulate reduction. Because soluble pollutants are extremely difficult to remove, prevention or reduction on the land surface, as achieved through Non-Structural BMPs described in Chapter 5, are the most effective methods for reducing them.

3.6 Stormwater Standards for Special Management Areas

CG-1 and CG-2 may require modification, on a case-by-case basis, before they are applied to Special Management Areas around the Commonwealth. Special Areas include highways and roads, existing urban or developed sites, contaminated or brownfield sites, sites situated in karst topography, sites located in public water supply protection areas, sites situated in High Quality or Exceptional Value watersheds, sites situated on old mining lands, etc. These are areas where BMP application of any type may be limited. Stormwater management for these Special Management Areas is discussed in more detail in Chapter 7.

DRAFT

State of West Virginia
Department of Environmental Protection
Division of Water and Waste Management
601 57th Street, SE
Charleston, WV 25304-2345

General
National Pollution Discharge Elimination System
Water Pollution Control Permit

Permit No.: WV0116025

Subject: Stormwater Discharges From small Municipal Separate Storm Sewer Systems

Issue Date:

Effective Date:

Expiration Date:

Supersedes: WV/NPDES General Water Pollution Control Permit No. WV0116025, issued March 7, 2003

To Whom It May Concern:

This is to certify that operators of small municipal separate storm sewer systems (MS4s) located in the State of West Virginia who have satisfied the registration requirements and agreeing to be regulated under the terms and conditions of this general permit are hereby granted coverage under the General WV/NPDES Water Pollution Control Permit to discharge stormwater into waters of the State.

All operators of regulated small municipal separate storm sewer systems are required to apply for and obtain coverage in accordance with this permit, unless waived in accordance with CFR § 122.32(a).

This permit is subject to the following terms and conditions:

The information submitted on and with the site registration application form, once approved, will hereby be known as the stormwater management program (SWMP). The information submitted on and with the site registration application, also known as the SWMP, once approved, will hereby be made terms and conditions of the permit with like effect as if all such information were set forth herein, and other conditions set forth in Parts I, II, III, IV, Appendices A through D and the SWMP approval letter.

The validity of this permit is contingent upon the payment of the applicable annual permit fee, as

required by Chapter 22, Article 11, Section 10 of the Code of West Virginia.

Part I

Coverage under this General Permit

A. Permit Area

1. This permit covers all areas of the State of West Virginia.

B. Eligibility

1. Jurisdictions including, but not limited to; municipalities, counties, transportation facilities, Federal and State owned prison systems, and universities that are located within the boundaries of a Bureau of the Census defined "Urbanized Area" (UA) based on the latest decennial census.

2. Municipalities that are designated by the Division of Water and Waste Management (DWWM) under 40 CFR 122.32(a)(2). Designation criteria are included in Appendix D of this general permit.

C. This permit authorizes the following non-stormwater discharges provided they have been determined not to be substantial contributors of pollutants to a particular small MS4 applying for coverage under this permit. However, the DWWM recommends that your stormwater management program include public education and outreach activities directed at reducing these discharges even if they are not substantial contributors of pollutants to your system.

1. Uncontaminated water line flushing
2. Landscape irrigation,
3. Diverted stream flows,
4. Uncontaminated ground water infiltration (as defined at 40 CFR 35.2005(20)),
5. Uncontaminated pumped groundwater,
6. Discharges from potable water sources,
7. Foundation drains,
8. Air conditioning condensate,
9. Irrigation water,
10. Springs,
11. Water from crawl space pumps,
12. Footing drains,
13. Lawn watering runoff,
14. Water from individual residential car washing,
15. Flows from riparian habitats and wetlands,
16. Residual street wash water,
17. Discharges or flows from fire fighting activities, and
18. A discharge authorized by a separate National Pollutant Discharge Elimination System (NPDES) permit.

D. This permit does not relieve entities that cause illicit discharges, including spills, of oil or hazardous substances, from responsibilities and liabilities under State and Federal law and regulations pertaining to those discharges.

E. This permit does not authorize a violation of West Virginia State Water Quality Standards (Title 47 CSR Series 2) and West Virginia Ground Water Quality Standards (Title 47 CSR Series 58).

Part II

Notice of Intent (NOI) and Stormwater Management Program (SWMP) Applications

A. Applications

Within thirty (30) days of the effective date of this permit, all operators of small MS4s shall submit a Notice of Intent (NOI) on the form provided in Appendix A of this permit.

Within six months of the effective date of this permit, all operators of regulated small MS4s shall submit a stormwater management program (SWMP) to the DWWM. A SWMP can be submitted on the form provided by DWWM, or in a prescribed manner acceptable to the DWWM that contains all necessary components.

NOIs and SWMPs shall be submitted to:

WVDEP - Division of Water and Waste Management
MS4 / NPDES Stormwater Permitting
601 57th Street, SE
Charleston, WV 25304

B. Requirements of SWMP

1. The permittee must develop a stormwater management program designed to reduce the discharge of pollutants from your small municipal separate storm sewer system to the maximum extent practicable (MEP), to protect water quality, and satisfy the appropriate requirements of the Clean Water Act.

2. The permittee shall, to the maximum extent practicable, use known, available, and reasonable methods of prevention, control and treatment to prevent and control stormwater pollution from entering waters of the State of West Virginia.

3. In order to meet public notice requirements of NPDES permits, the permittee shall make available to the public, in accordance with Code of State Regulations; Title 47, Series 10, Section 12, the opportunity to comment on MS4 stormwater management programs.

4. The SWMP must include the minimum control measures described in Section C of this part along with measurable goals and milestones as appropriate for each measure and justifications for each milestone. Information about developing measureable goals can be found on the USEPAs website: http://cfpub.epa.gov/npdes/stormwater/measurablegoals/part3.cfm

5. Subject to the five-year limitation noted below in this paragraph, extension of milestones will be granted for good cause shown. Failure to implement effective best management practices (BMPs) is not good cause to extend milestones.

6. The SWMP must also provide details on how you will implement and enforce the program. The terms and conditions of this permit and the permittees SWMP must be fully

implemented, except where noted, within five years of the effective date of this permit.

7. The SWMP shall include an ongoing program for gathering, tracking, maintaining, and using information to evaluate the stormwater management program development, implementation and permit compliance.

8. If the permittees small MS4 discharges into waters listed on the Clean Water Act Section 303(d) list of impaired waters or waters with an approved Total Maximum Daily Load (TMDL), the SWMP must document how the proposed BMP's will control the discharge of the pollutants of concern, as described in Part III.D. Permittees discharging to waters with an approved TMDL shall meet the applicable wasteload allocations of that TMDL.

9. An annual report prescribed in Part IV.D of this permit shall be submitted to DWWM each year on the anniversary of the SWMP approval.

C. Stormwater Management Program for small MS4s

a. Requirements

1. Permittees implementing BMPs specific to their current SWMP shall continue to do so until such time as their SWMP with new and updated BMPs is approved. However, permittees should begin implementation of the terms and conditions of this permit as soon as this permit becomes effective, as full implementation is required within five years.

2. a. Coordination among entities covered under the small MS4 general permit may be necessary to comply with certain conditions of the SWMP. The SWMP shall include, when applicable, coordination mechanisms among entities covered under the small MS4 general permit to encourage coordinated stormwater related policies, programs and projects within adjoining or shared areas. Entities covered under the small MS4 permit include, municipalities, transportation agencies, universities, colleges, hospitals, prisons, and military bases.

   b. Coordination mechanisms shall specify roles and responsibilities for the control of stormwater and its associated pollutants between physically interconnected MS4s covered by the small MS4 general permit.

   c. Coordination mechanisms shall coordinate stormwater management activities for shared water bodies among permittees with the goal of avoiding conflicting plans, policies and regulations.

   d. The SWMP shall include coordination mechanisms among departments within each permittee to address and eliminate barriers to compliance with the terms of this permit.

b. Minimum Control Measures

The SWMP shall include all components described in Part II, Sections B and C. In accordance with 40 CFR 122.35(a), a small MS4 may rely on another entity to implement one or more of the

components in this section. If the permittee is relying on another entity to implement any component of the SWMP, that entity must be fully disclosed in the SWMP.

1. **Public Education and Outreach**

The SWMP shall include an education program aimed at residents, businesses, industries, elected officials, policy makers, planning staff and other employees of the permittee. The goal of the education program is to reduce or eliminate behaviors and practices that cause or contribute to adverse stormwater impacts. An education program may be developed locally or regionally.

The minimum performance measures are:

a. The permittee shall continue to implement their education and outreach program for the area served by the MS4 that was established during the previous permit cycle. The outreach program shall be designed to achieve measurable improvements in the target audience's understanding of stormwater pollution and steps they can take to reduce their impacts. Newly permitted MS4s shall *begin* implementation of the requirements contained in Part II.C.1. within six months of the approval of their SWMP.

Education and outreach efforts shall be prioritized to target the following audiences and subject areas:

i. General public

- General impacts of stormwater flows into surface waters.
- Impacts from impervious surfaces.
- Source control BMPs and environmental stewardship actions and opportunities in the areas of pet waste, vehicle maintenance, landscaping, and rain water reuse.

ii. General public, businesses, including home-based and mobile businesses

- BMPs for use and storage of automotive chemicals, hazardous cleaning supplies, carwash soaps and other hazardous materials.
- Impacts of illicit discharges and how to report them.

iii. Homeowners, landscapers and property managers

- Yard care techniques that protect water quality.
- BMPs for use and storage of pesticides and fertilizers.
- BMPs for carpet cleaning and auto repair and maintenance.
- Runoff Reduction techniques, including site design, pervious paving, retention of forests and mature trees.
- Stormwater pond maintenance.

iv. Engineers, contractors, developers, review staff and land use planners

- Technical standards for construction site sediment and erosion control.
- Runoff Reduction techniques, including site design, pervious pavement, alternative parking lot design, retention of forests and mature trees.
- Stormwater treatment and flow control BMPs.
- Impacts of increased stormwater flows into receiving water bodies.

b. Each permittee shall measure the understanding and adoption of the targeted behaviors among the targeted audiences. The resulting measurements shall be used to direct education and outreach resources most effectively, as well as to evaluate changes in adoption of the targeted behaviors.

c. Each permittee shall track and maintain records of public education and outreach activities.

2. **Public Involvement and Participation**

The SWMP shall include ongoing opportunities for public involvement through advisory councils, watershed associations and/or committees, participation in developing rate structures, stewardship programs, environmental activities or other similar activities. The permittee shall facilitate opportunities for direct action, educational, and volunteer programs such as riparian planting, volunteer monitoring programs, storm drain marking or stream clean up programs. Each permittee shall comply with any applicable State and local public notice requirements when developing their SWMP.

The minimum performance measures are:

a. No later than six months from the effective date of this permit, all permittees shall create opportunities for the public to participate in the decision making processes involving the development, implementation and update of the permittees SWMP. Each permittee shall develop and implement a process for consideration of public comments on their SWMP.

b. No later than six months from the effective date of this permit, all permittees shall establish a method of routine communication to groups such as watershed associations and environmental organizations that are located in the same watershed/s as the permittee, or organizations that conduct environmental stewardship projects located in the same watershed/s or in close proximity to the permittee. This is to make these groups aware of opportunities for their direct involvement and assistance in stormwater activities that are in their watershed.

c. Each permittee shall make their SWMP and their annual report required under this permit available to the public when requested. The current SWMP and the latest annual report shall be posted on the permittees website. To comply with the posting requirement, a permittee that does not maintain a website may submit the updated SWMP and annual report in electronic format to the DWWM for electronic distribution when it is requested.

3. **Illicit Discharge Detection and Elimination**

The SWMP shall include an ongoing program to detect and remove illicit connections, discharges as defined in 40 CFR 122.26(b)(2), and improper disposal, including any spills not under the purview of another responding authority, into the municipal separate storm sewers owned or operated by the permittee. Newly permitted MS4s shall *begin* implementation of the requirements contained in Part II.C.3 of this permit within one year of the approval of their SWMP.

The minimum performance measures are:

a. The Permittees existing municipal storm sewer system map/s that were created during the first permit cycle shall be updated on an annual basis and shall include the following information:

i. The location of all known storm sewer outfalls, receiving waters and structural stormwater BMPs owned, operated or maintained by the permittee. The location and type of all other stormwater conveyances located within the boundaries of the permittees MS4 watershed. The permittee may opt to include land use on the map also. In the process of updating the map, when stormwater outfalls become known, they are to be added to the permittees map.

ii. An update of known connections to the municipal separate storm sewer authorized or allowed by the permittee after the effective date of this permit.

iii. Geographic areas that discharge stormwater into the permittees MS4, which may not be located within the municipal boundary.

iv. Each permittee shall submit this map, or updated map to DWWM with the third year annual report. The map shall be a scale of 1" = 500 ft. and on pages sized 24"x36" or 22"x36" and folded to 8 x 11 inches.

b. Each permittee shall implement a program or system to review and update their Illicit Discharge Detection and Elimination (IDDE) Ordinance or other regulatory mechanism to effectively prohibit and eliminate non-stormwater, illegal discharges, and/or dumping into the permittees municipal separate storm sewer system to the regulatory extent allowable under State and Local law. The ordinance or other regulatory mechanism shall be reviewed on an annual basis and updated when necessary. The IDDE program shall be adequately funded to fulfill the general permit requirements.

i. The regulatory mechanism does not need to prohibit the following categories of non-stormwater discharges, unless they are identified to be significant sources of pollutants to waters of the State:

- Diverted stream flows,
- Rising ground waters,
- Uncontaminated ground water infiltration (as defined at 40 CFR 35.2005(20)),
- Uncontaminated pumped groundwater,
- Foundation drains,
- Air conditioning condensation,
- Irrigation water from agricultural sources
- Springs,
- Water from crawl space sump pumps,
- Footing drains,
- Flows from riparian habitats and wetlands,
- Non-stormwater discharges covered by another NPDES permit,
- Discharges or flows from emergency fire fighting activities,

ii. The regulatory mechanism shall prohibit the following categories of non-stormwater discharges *unless* the stated conditions are met:

- Discharges from potable water sources, including water line flushing, hyperchlorinated water line flushing, fire hydrant system flushing, and pipeline hydrostatic test water. For planned discharges to the MS4, the discharge shall be dechlorinated to a concentration of 0.1ppm or less, pH adjusted, if necessary, and

volumetrically and velocity controlled to prevent resuspension of sediments in the MS4.

- Discharges from lawn watering and other irrigation runoff. These shall be minimized through; at a minimum, public education activities described in Part II, Section C.1. of this permit.

- Street, parking lot and sidewalk wash water, water used to control dust, and routine external building wash down, that does not use detergents. The permittee shall reduce these discharges through; at a minimum, public education activities described in Part II, Section C.1. of this permit. To avoid washing pollutants into the MS4, permittees must minimize the amount of street wash and dust control water used. At active construction sites, street sweeping must be performed prior to washing the street.

iii. The permittees SWMP shall, at a minimum, address each category in ii above in accordance with the conditions stated therein.

iv. The SWMP shall further address any category of discharges in i or ii above if the discharges are identified as significant sources of pollutants to waters of the State.

v. The ordinance or other regulatory mechanism shall include escalating enforcement procedures and actions.

vi. The permittee shall develop an enforcement strategy and implement the enforcement provisions of the ordinance or other regulatory mechanism.

c. Each permittee shall continue to assess, update and implement their ongoing program to detect and address non-stormwater discharges, spills, illicit connections and illegal dumping into the permittees MS4. New permittees shall develop the aforementioned program. This program shall include:

i. Procedures for locating priority areas likely to have illicit discharges, including at a minimum, evaluating land uses associated with business/industrial activities present; areas where complaints have been registered in the past; and areas with storage of large quantities of materials that could result in spills.

ii. Field assessment activities, including visual inspection of priority outfalls identified in i, above, during dry weather and for the purposes of verifying outfall locations, identifying previously unknown outfalls, and detecting illicit discharges.

- Receiving waters shall be prioritized for visual inspection no later than three years from the effective date of this permit, including a field assessment of at least two water bodies. At a minimum, one field assessment shall be made each year thereafter.

- Screening for illicit connections shall be conducted consistent with: Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments, Center for Watershed Protection, October 2004, or another methodology of comparable effectiveness.

iii. Procedures for characterizing the nature of, and potential public or environmental threat posed by, any illicit discharges found by or reported to the Permittee. Procedures shall include detailed instructions for evaluating whether the discharge must be immediately contained and steps to contain the discharge.

Compliance with this provision shall be achieved by investigating within seven days, any complaints, reports or monitoring information that indicates a potential illicit discharge, spill, or illegal dumping, and immediately investigating problems and violations determined to be emergencies or otherwise judged to be urgent or severe. In some instances, when imminent water quality impairments are deemed severe or urgent, the first step to take is to refer the incident to WVDEP.

iv. Procedures for tracing the source of an illicit discharge; including visual inspections, and when necessary, opening manholes, using mobile cameras, collecting and analyzing water samples, and/or other detailed inspection procedures.

v. Procedures for removing the source of the discharge; including notification of appropriate authorities; notification of the property owner; assistance for eliminating the discharge, if necessary; follow-up inspections; and escalating enforcement and legal actions if the discharge is not eliminated.

Compliance with this provision shall be achieved by initiating an investigation within fifteen (15) days of a report or discovery of a suspected illicit connection to determine the source of the connection, the nature and volume of discharge through the connection, and the party responsible for the connection. Upon confirmation of the illicit nature of a storm drain connection, termination of the connection shall be verified within ninety (90) days, using enforcement authority as needed.

d. Permittees shall inform public employees, businesses, and the general public of hazards associated with illegal discharges and improper disposal of waste.

i. Distribute appropriate information to target audiences pursuant to Part II, Section C.1. of this permit.

ii. Publicly list and publicize a hotline or other local telephone number for public reporting of spills and other illicit discharges. Keep a record of calls received and follow-up actions taken in accordance with Part II, Section C.3. of this permit; include a summary in the annual report.

e. Permittees shall adopt and implement procedures for program evaluation and assessment, including tracking the number and type of spills or illicit discharges identified, inspections made; and any feedback received from public education efforts. A summary of this information shall be included in the Permittees annual report.

f. Each permittee shall provide appropriate training for municipal staff on the identification and reporting of illicit discharges into MS4s.

i. Permittees shall ensure that all municipal field staff who are responsible for identification, investigation, termination, cleanup, and reporting illicit discharges, including spills, improper disposal and illicit connections are trained to conduct

these activities. Follow up training shall be provided on an annual basis to address changes in procedures, techniques or requirements. Permittees shall document and maintain records of the training provided and the staff trained.

ii. Permittees shall develop and implement an ongoing training program shall be for all municipal staff, which, as part of their normal job responsibilities, might come into contact with or otherwise observe an illicit discharge or illicit connection to the storm sewer system. Employees shall be trained on the identification of an illicit discharge/connection, and on the proper procedures for reporting and responding to the illicit discharge/connection. Follow up training shall be provided on an annual basis to strengthen knowledge of illicit discharges/connections and to address changes in procedures, techniques or requirements. Permittees shall document and maintain records of the training provided and the staff trained.

4. Controlling Runoff from Construction Sites

The SWMP shall include an ongoing program to assess, implement, and enforce the existing program to reduce pollutants in stormwater runoff to your small MS4 from construction site activities that result in a land disturbance of one acre or greater. Reduction of stormwater discharges from construction activity disturbing less than one acre must be included in your program if that construction activity is part of a larger common plan of development or sale that will disturb one acre or more. Permittee may opt to include in this program construction sites that are less than one acre. Newly permitted MS4s shall *begin* implementation of the requirements contained in Part II.C.4 of this permit within one year of the approval of their SWMP.

The minimum performance measures are:

a. Permittees shall implement a program or system to review and update their ordinance or other regulatory mechanism that addresses stormwater runoff from construction sites one acre or greater. Newly permitted MS4s that do not yet have an ordinance in place shall begin development an ordinance or other regulatory mechanism within twelve months of the effective date of this permit. The ordinance or other enforceable mechanism shall include, at a minimum:

i. Implementation of erosion and sediment control BMPs at regulated construction sites. Sediment and erosion control BMPs shall be consistent with the BMPs contained in West Virginia's Erosion and Sediment Control Best Management Practices Manual and/or other State manuals, as appropriate, listed in Appendix E.

ii. Requirements for construction site operators to implement appropriate erosion and sediment control BMPs. More stringent requirements may be used, and certain requirements may be tailored to local circumstances through the use of basin or watershed plans or other similar water quality and quantity planning efforts. Such local requirements shall provide equal protection of receiving waters and equal levels of pollutant control to those provided by DWWM WV/NPDES stormwater permits.

iii. Requirements for construction site operators to control waste such as discarded building materials, concrete truck washout, chemicals, litter, and sanitary waste at the construction site that may cause adverse impacts to water quality.

iv. Requirements for demonstration that registration under the WV/NPDES construction stormwater general permit has been obtained for those sites one acre and greater. Provided that the DWWM has not approved the permittee as a 'Qualifying Local Program' in which coverage under WV/NPDES construction stormwater permit will be issued by the permittee and not by the DWWM.

v. Establishment of authority for site plan review, which incorporate consideration of potential water quality impacts and review of individual pre-construction site plans to ensure consistency with local and State sediment and erosion control requirements.

vi. Establishment of authority for receipt and consideration of comments and information submitted by the public.

vii. Establishment of authority for site inspections and enforcement of control measures including steps to identify priority sites for inspection and enforcement based on the nature of the construction activity, topography, and the characteristics of soils and receiving water quality.

viii. Adequate funding for site inspections and enforcement of control measures.

ix. Measures to provide educational and training measures for construction site operators, including requiring a stormwater pollution prevention plan for construction sites within your jurisdiction.

b. The program shall include a permitting and/or approval process with plan review, inspection and enforcement capability, for both private sector and public sector construction sites. At a minimum, the construction site runoff program shall be applied to all sites that disturb a land area of one acre or greater, including projects less than one acre that are part of a larger common plan of development. For newly permitted MS4s the permitting and/or approval process shall be in place no later than two years from the approval date of their SWMP. In addition to an Ordinance described in Part II, Section C.4.a, the following elements shall be incorporated into this program:

i. Procedures to incorporate plan review of new and redevelopment projects with the planning and approval process of these same projects with other municipal departments within the permittees MS4.

ii. Procedures for routine inspections of permitted construction sites during construction to verify proper installation and maintenance of required erosion and sediment controls. Enforcement shall be conducted as necessary based on the inspection.

iii. Development of an enforcement strategy to respond to issues of non-compliance.

iv. Procedures for providing educational and training measures for construction site operators and the permittees inspectors.

v. Development of an application process whereby the construction site operator will describe the sediment and erosion control measures to be taken on the site. This application process can include submittal of the stormwater pollution prevention plan that was used to obtain registration under DWWM WV/NPDES construction

stormwater permit. The application shall include a listing of all water bodies into which the construction site will discharge and whether or not they are on the 303(d) list for impaired waters.

vi. Development of procedures for keeping records of all regulated construction activities within your MS4, inspection reports, warning letters, and any other enforcement documentation. A summary of inspection and enforcement activities that are conducted shall be included in the annual report.

5. **Controlling Runoff from New Development and Redevelopment**

The SWMP shall include an ongoing program to develop, assess, implement, and enforce their ~~a~~ program to reduce pollutants in stormwater runoff to your small MS4 from new development and redevelopment activities. This program shall be applied to all sites that disturb a land area one acre or greater, including projects less than one acre that are part of a larger common plan of development or sale. The program shall apply to private sector and public sector development, including roads. The program must ensure that controls are in place that will increase groundwater recharge of stormwater runoff where and when possible, and would protect water quality and reduce the discharge of pollutants. Except where otherwise stated, newly permitted MS4s shall *begin* implementation of the requirements contained in Part II.C.4 of this permit within two years after the approval date of their SWMP.

The program shall include the following measures:

a. Long-term Stormwater Controls

The permittee shall protect the physical, chemical and biological integrity of receiving waters, and their designated uses, from the impacts of stormwater discharges through the implementation of watershed protection elements and site and neighborhood design elements. The purpose of *watershed protection* elements is to manage the impacts of stormwater on receiving waters that occur because of regional or watershed-scale management decisions. The primary purpose of *site and neighborhood design* elements is to manage the impacts of stormwater on receiving waters that occur because of site and neighborhood design management decisions. The technical principles of these management practices have many complementary similarities, and must be implemented in tandem.

All elements and standards are required, and must be described in the stormwater management program plan.

i. Watershed Protection

The permittee shall incorporate watershed protection elements into the subdivision ordinance or equivalent document. In addition, the permittee shall incorporate watershed protection elements into all relevant policy and/or planning documents as they come up for regular review. If a relevant planning document is not scheduled for review during the term of this permit, the permittee must identify the elements that cannot be implemented until that document is revised, and provide the DWWM a schedule for incorporation and implementation that cannot exceed seven years from the effective date of this permit. Planning documents include, but are not limited to; comprehensive or master plans, subdivision ordinances, general land use plan, zoning code,

transportation master plan, specific area plans, such as sector plan, site area plans, corridor plans, or unified development ordinances.

A. *Watershed protection elements.* As relevant, policy and/or planning documents must include the following, except where noted:

(1) Minimize the amount of impervious surfaces (roads, parking lots, roofs, etc.) within each watershed, by minimizing the creation, extension and widening of parking lots, roads and associated development.

(2) Preserve, protect, create and restore ecologically sensitive areas that provide water quality benefits and serve critical watershed functions. These areas may include, but are not limited to; riparian corridors, headwaters, floodplains and wetlands.

(3) Implement stormwater management practices that prevent or reduce thermal impacts to streams, including requiring vegetated buffers along waterways, and disconnecting discharges to surface waters from impervious surfaces such as parking lots.

(4) Seek to avoid or prevent hydromodification of streams and other water bodies caused by development, including roads, highways, and bridges.

(5) Implement standards to protect trees, and other vegetation with important evapotranspirative qualities.

(6) Implement policies to protect native soils, prevent topsoil stripping, and prevent compaction of soils.

B. *Measurable Goals.* For each of the six watershed elements in i.A, the permittee shall develop quantifiable objectives that include a time frame for achieving them. Short-term objectives (less than five years) and long-term objectives (greater than five years) are appropriate for many of these elements.

C. *Reporting.* Annual reports must include status of implementation of these elements with respect to incorporation into relevant documents and implementation via relevant policies. Reports should include proposed time frames, changes and measurable goals.

ii. Site and Neighborhood Design

The permittee shall develop a program to protect water resources by requiring all new and redevelopment projects to control stormwater discharge rates, volumes, velocities, durations and temperatures. These standards shall apply at a minimum to all new development and redevelopment disturbing one acre or greater, including projects less than one acre that are part of a larger common plan of development or sale. The permittee shall *begin* implementation of the requirements contained in Part II.C.5.a.ii [other than Part II.C.5.a.ii.A(3) and Part II.C.5.a.ii.A.(4)] within four years after the approval of the SWMP.

A. *Performance Standards.* The permittee must implement and enforce via ordinance and/or other enforceable mechanism(s) the following requirements for new and redevelopment:

1. Site design standards for all new and redevelopment that require, in combination or alone, management measures that keep and manage on site the first one inch of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation. Runoff volume reduction can be achieved by canopy interception, soil amendments, evaporation, rainfall harvesting, engineered infiltration, extended filtration and/or evapotranspiration and any combination of the aforementioned practices. This first one inch of rainfall must be 100% managed with no discharge to surface waters, except when the permittee chooses to implement the conditions in paragraph 4 below. This can be achieved through on site utilization of practices to include dry swales, bioretention, rain tanks and cisterns, soil amendments, roof top disconnections, permeable pavement, porous concrete, permeable pavers, reforestation, grass channels, green roofs and other practices that alone or combined will capture the first one inch of rainfall runoff volume. An Underground Injection Control permit may be required when certain conditions are met.

2. The following additional water quality requirements, as applicable:

   i. A project with reasonable potential for pollutant loading(s) must provide water quality treatment for associated pollutants (e.g., petroleum hydrocarbons at a vehicle fueling facility) before infiltration.

   ii. A project with reasonable potential for pollutant loading(s) that cannot implement adequate preventive or water quality treatment measures to ensure compliance with groundwater and/or surface water quality standards, must properly convey stormwater to a NPDES-permitted wastewater treatment facility or via a licensed waste hauler to a permitted treatment and disposal facility.

   iii. A project that discharges or proposes to discharge to any surface water or ground water that is used as a source of drinking water must comply with all applicable requirements relating to source water protection.

3. When considered at the watershed scale, certain types of development can either reduce existing impervious surfaces, or at least create less 'accessory' impervious. Incentive standards may be applied to these types of projects. A reduction of 0.1 inches from the one inch infiltration/evapotranspiration/reuse standard may be applied to any of the following types of development. Reductions are additive such that a maximum reduction of 0.5 inch is possible for a project that meets all five criteria.

   a) Redevelopment
   b) Brownfield redevelopment
   c) High density (>7 units per acre)
   d) Vertical Density, (Floor to Area Ratio (FAR) of 2 or >18 units per acre)
   e) Mixed use and Transit Oriented Development (within ½ mile of transit)

4. For projects that cannot meet 100% of the infiltration/evapotranspiration/reuse requirement on-site, two alternatives are available: off-site mitigation and payment in lieu. If these alternatives are chosen, then the permittee must develop and fairly apply criteria for determining the circumstances under which these alternatives will be available. A determination that standards cannot be met on site may not be based solely on the difficulty or cost of implementing measures, but must include multiple criteria

that would rule out an adequate combination of the practices set forth in section 1, above, such as: too small a lot outside of the building footprint to create the necessary infiltrative capacity even with amended soils; a site use that is inconsistent with capture and reuse of stormwater; too much shade or other physical conditions that preclude adequate use of plants.

These alternatives are only available, in combination or alone, for up to 0.4 inches of the original obligation at a 1:1.5 ratio, i.e., mitigation or payment in lieu must be for 1.5 times the amount of stormwater not managed on site. For either of these options to be available, the permittee must create an inventory of appropriate mitigation projects, and develop appropriate institutional standards and management systems to value, evaluate and track transactions.

i. *Off-site mitigation.* Infiltration/evapotranspiration/reuse measures may be implemented at another location in the same sewershed/watershed as the original project, approved by the permittee. The permittee shall identify priority areas within the sewershed/watershed in which mitigation projects can be completed. Mitigation must be for retrofit or redevelopment projects, and cannot be applied to new development.

ii. *Payment in lieu.* Payment in lieu may be made to the permittee, who will apply the funds to a public stormwater project. MS4s shall maintain a publicly accessible database of approved in lieu projects.

5. When public (local or otherwise) streets or parking lots are repaired, modified or reconstructed opportunities to improve stormwater management using canopy interception, soil amendments, evaporation, rainfall harvesting, engineered infiltration, extended filtration and/or evapotranspiration and/or any combination of the aforementioned practices shall be included in the design work. These requirements apply only to projects begun after the effective date of this permit.

B. *Plan Review, Approval and Enforcement*. To ensure that all new development and redevelopment projects conform to the standards stipulated in Part II, Section C.5.ii, the permittee shall develop project review, approval and enforcement procedures. The review, approval and enforcement procedures shall apply at a minimum to all new development and redevelopment disturbing greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, and shall include:

(1) Requirements to submit for review and approval a pre-application concept plan that describes how the performance standards will be met. A pre-application meeting attended by a project land owner or developer, the project design engineer, and municipal planning staff to discuss conceptual designs may also meet this requirement.

(2) Development of procedures for the site plan review and approval process(es) that include inter-departmental consultations, as needed, and a required re-approval process when changes to an approved plan are desired.

(3) A requirement for submittal of ‘as-built’ certifications within 90 days of completion of a project.

(4) A post-construction verification process to ensure that stormwater standards are being met, that includes enforceable procedures for bringing noncompliant projects into compliance.

(5) A description of a program to educate both internal staff and external project proponents of the requirements of Part II, Section C.5 of this permit.

C. *Maintenance Agreements*. The permittee shall require that all development subject to the requirements of Part II, Section C.5.ii. of this permit develop a maintenance agreement and maintenance plan for approved stormwater management practices. The permittee shall require that property owners or operators provide verification of maintenance for the approved stormwater management practices. These agreements shall allow the permittee, or its designee, to conduct inspections of the stormwater management practices and also account for transfer of responsibility in leases and/or deed transfers. The agreement shall also allow the permittee, or its designee, to perform necessary maintenance or corrective actions neglected by the property owner/operator, and bill or recoup costs from the property owner/operator when the owner/operator has not performed the necessary maintenance within thirty (30) days of notification by the permittee or its designee. Verification shall include one or more of the following as applicable:

(1) The owner/developer's signed statement accepting responsibility for maintenance until the maintenance responsibility is legally transferred to another party; and/or

(2) Written conditions in the sales or lease agreement that require the recipient to assume responsibility for maintenance; and/or

(3) Written conditions in project conditions, covenants and restrictions for residential properties assigning maintenance responsibilities to a home owner’s association, or other appropriate group, for maintenance of structural and treatment control stormwater management practices; and/or

(4) Any other legally enforceable agreement that assigns permanent responsibility for maintenance of structural or treatment control stormwater management practices.

D. *Inventory and Tracking of Management Practices*. The permittee shall develop a system designed to track stormwater management practices deployed at new development and redevelopment projects. Tracking of stormwater management practices shall begin during the plan review and approval process with a database or geographic information system (GIS). The database or tracking system shall include information on both public and private sector projects that are within the jurisdiction of the permittee. In addition to the standard information collected for all projects (such as project name, owner, location, start/end date, etc.), the tracking system shall also include:

1. Source control stormwater management practices (type, number, design or performance specifications)

2. Treatment control stormwater management practices (type, number, design or performance specifications)

3. Latitude and longitude coordinates of stormwater BMP controls using a global positioning system

4. Digital photographs of stormwater management practice controls

5. Maintenance requirements of stormwater management practices (frequency of required maintenance and inspections)

6. Inspection information (date, findings, follow up activities, compliance status)

E. *Stormwater BMP Inspections*. In order to ensure that all stormwater BMPs are operating correctly and are properly maintained, the permittee shall, at a minimum:

1. Develop an inspection calendar for stormwater BMPs. Inspections should be performed so that all stormwater BMP's are inspected at least once during the permit cycle.

2. Complete inspection reports shall include:

i. Facility type,
ii. Inspection date,
iii. Name and signature of inspector,
iv. GIS location and nearest street address,
v. Management practice ownership information (name, address, phone number, fax, and email),
vi. A description of the stormwater BMP condition including the quality of: vegetation and soils; inlet and outlet channels and structures; embankments, slopes, and safety benches; spillways, weirs, and other control structures; and sediment and debris accumulation in storage and forebay areas as well as in and around inlet and outlet structures,
vii. Photographic documentation of all critical stormwater BMP components, and
viii. Specific maintenance items or violations that need to be corrected by the stormwater BMP owner along with deadlines and reinspection dates.

3. Ensure that stormwater BMPs are maintained. The permittee shall promptly notify the stormwater BMP owner or operator of any deficiencies discovered during a maintenance inspection. The owner must correct the deficiency within thirty (30) days of the notice. The permittee must conduct subsequent inspection to ensure completion of all required repairs. If repairs are not made, the permittee shall enforce its correction orders and, if need be, perform the necessary work and assess against the owner the costs incurred for repairs.

F. *Reporting*. The permittee shall demonstrate compliance with the requirements for post-construction controls by summarizing the following in the Annual Report:

(1) A description of how the permittees legal authority addresses the watershed protection elements in Part II, Section C.5.

(2) A summary of the number and types of projects that the permittee reviewed for new and development considerations.

(3) A summary of the number and types of stormwater BMPs approved in new and redevelopment projects, including the number of approved projects that qualified for each of the incentives described in Part II, Section C.5.a.ii.A.3, and that qualified for each of the alternatives described in Part II, Section C.5.a.ii.A.4.

(4) A summary of the number and types of maintenance agreements approved.

(5) A summary of stormwater BMP maintenance inspections conducted by the permittee, including a summary of the number requiring maintenance or repair, the number brought into compliance within stipulated time-frame, and the number of enforcement actions taken.

(6) A summary of any evaluation data collected for long-term stormwater controls, including water quality information, stormwater BMP performance, and model results.

b. Assessments

The permittee shall conduct the following assessment to provide a foundation for program improvements to be implemented during the next permit term.

1. Street/Parking Design Assessment.

Permittee shall submit to DWWM a report assessing current street design guidelines and parking requirements that affect the creation of impervious cover, with the third year annual report. The assessment shall include recommendations and proposed schedules for incorporating policies and standards into relevant documents and procedures to minimize impervious cover attributable to parking and street designs. The local planning commission and the local transportation commission should be involved in the assessment.

6. **<u>Pollution Prevention & Good Housekeeping for Municipal Operations</u>**

Each permittee shall continue to implement their operations and maintenance (O&M) program that includes a training component and has the ultimate goal of preventing or reducing polluted runoff from municipal operations. Newly permitted MS4s shall have one year from the approval date of their SWMP to *begin* implementation of the requirements contained in Part II.C.6 of this permit.

The minimum performance measures are:

a. Develop and implement an operation and maintenance program that incorporates good housekeeping components at all municipal facilities, including but not limited to; municipal waste water treatment facility, potable drinking water facility, municipal fleet operations, maintenance garages, parks and recreation, street and infrastructure maintenance, and grounds maintenance operations.

i. Each permittee shall develop and establish maintenance standards at all municipal facilities that will help protect the physical, chemical and biological integrity of receiving waters.

ii. Each permittee shall establish an inspection schedule in which to perform inspections to determine if maintenance standards are being met. Inspections shall be performed no less than once per calendar year.

iii. Each permittee shall develop procedures for record keeping and tracking inspections and maintenance at all municipal facilities.

b. Establish and implement policies and procedures to reduce the discharge of pollutants in stormwater runoff from all lands owned or maintained by the permittee and subject to this permit, including but not limited to: parks, open space, road right-of-way, maintenance yards, water/sewer infrastructure and stormwater treatment and flow practices. These policies and procedures shall address, but are not limited to:

i. Application of fertilizer, pesticides, and herbicides including the development of nutrient management and integrated pest management plans.

ii. Sediment and erosion control.

iii. Landscape maintenance and vegetation disposal.

iv. Trash management.

v. Building exterior cleaning and maintenance.

c. Using training materials that are available from WVDEP, USEPA or other organizations, develop and implement an on-going training program for employees of the permittee whose construction, operations or maintenance job functions may impact stormwater quality. The training program shall include, but is not limited to those employees who work in the following areas:

- Street/sewer and right-of-way construction and maintenance,
- Water and sewer departments,
- Parks and recreation department,
- Municipal water treatment and waste water treatment,
- Fleet maintenance,
- Fire departments,
- Building maintenance and janitorial,
- Garage and mechanic crew,
- Contractors and subcontractors who may be contracted to work in the above described areas,
- Personnel responsible for answering questions about the permittees stormwater program, this includes persons who may take phone calls about the program,
- Any other department of the permittee that may impact stormwater runoff

i. The training program shall address the importance of protecting water quality, the requirements of this permit, operation and maintenance standards, inspection procedures, selecting appropriate BMPs, ways to perform their job activities to prevent or minimize impacts to water quality, and procedures for reporting water quality concerns, including potential illicit discharges. Follow-up and refresher training shall be provided at a minimum of once every twelve months, and shall include any changes in procedures, techniques or requirements. Permittees shall document and maintain records of training provided.

d. **Industrial Stormwater coverage for Municipal Operations**

Each permittee that owns or operates a publicly owned treatment works, including sanitary boards, maintenance garages and/or any other industrial activity must obtain coverage for their stormwater

discharges, unless coverage is already granted under DWWM WV/NPDES General Permit for Storm Water Discharges associated with Industrial activity, or an individual WV/NPDES permit.

The following monitoring requirements apply:

Pollutants of Concern	Cut-off Concentration	Measurement Frequency
BOD-5	30 mg/l	Once/Six months
COD	120 mg/l	Once/Six months
TSS	100 mg/l	Once/Six months
Ammonia Nitrogen	4 mg/l	Once/Six months
Oil & Grease	15 mg/l	Once/Six months
pH	6.0 – 9.00 s.u.	Once/Six months

Permittees that receive discharges into their small MS4 from their sewage treatment works must, in addition to the above listed monitoring requirements, also meet the following monitoring requirements for those discharges:

Pollutants of Concern	Cut-off Concentration	Measurement Frequency
Fecal Coliform, General	400 counts/100 ml	Once/Six months

Samples shall be collected once every six months, during the spring and fall seasons. Monitoring results shall be submitted to the DWWM with the annual report.

Stormwater samples shall be collected during the "first flush" of rainfall runoff, at least twenty minutes, but not more than fifty minutes after rainfall of at least 0.5 inches has begun, preceded by a period of dry weather of at least 48 hours.

Part III. Special Conditions

A. Sharing Responsibility

If you are relying on another MS4 regulated under the stormwater regulations to satisfy one or more of your permit obligations, you must note that fact in your stormwater management program. This other entity must, in fact, implement the control measure(s); the measure of component thereof, must be at least as stringent as the corresponding WV/NPDES permit requirement; and the other entity must agree to implement the control measure on your behalf. This agreement between the two or more parties must be documented in writing in the stormwater management plan and be retained by the permittee for the duration of this permit, including any automatic extensions of the permit term.

B. Discharge Compliance with Water Quality Standards

This general permit requires, at a minimum, that permittees develop, implement and enforce a stormwater management program designed to reduce the discharge of pollutants to the maximum extent practicable, to protect water quality, and satisfy the appropriate requirements of the Clean Water Act. If stormwater discharges have a reasonable potential to cause or contribute to violations

of water quality standards in the receiving water, additional controls are required. Full implementation of selected BMPs, using known, available, and reasonable methods of prevention, control and treatment to prevent and control stormwater pollution from entering waters of the State of West Virginia is considered an acceptable effort to reduce pollutants from the municipal storm drain system to the maximum extent practicable.

C. Requiring an Individual Permit

The DWWM may require any person authorized by this permit to apply for and/or obtain an individual WV/NPDES permit. Where the DWWM requires application for an individual WV/NPDES permit, the DWWM will notify the permittee in writing that a permit application is required. This notification shall include a brief statement of the reasons for this decision, an application form and a statement setting a deadline for the permittee to file the application.

D. Discharge to Impaired Waters

1. **303(d) Listed Waters**:

This permit does not authorize new sources or new discharges of pollutants of concern to impaired waters unless consistent an approved Total Maximum Daily Load (TMDL) and applicable state law. Impaired waters are those that do not meet applicable water quality standards. Impaired waters are identified on the West Virginia, Section 303(d) list until a TMDL is developed and approved by USEPA. Pollutants of concern are those pollutants for which the water body is listed as impaired. A list of impaired water bodies in West Virginia can be found at: http://www.wvdep.org/item.cfm?ssid=11&ss1id=720

a. MS4s that discharge into a receiving water which has been listed on the West Virginia Section 303(d) list of impaired waters, and with discharges that contain the pollutant(s) for which the water body is impaired, must document in the SWMP how the BMPs will control the discharge of the pollutant(s) of concern, and must ensure that there will be no increase of the pollutants of concern.

b. If a TMDL is approved during this permit cycle by USEPA for any waterbody into which an MS4 discharges, the MS4 must review the applicable TMDL to see if it includes requirements for control of stormwater discharges. Within six (6) months of the TMDL approval, the MS4 must modify its stormwater management program to include best management practices specifically targeted to achieve the wasteload allocations prescribed by the TMDL. The MS4 must include a monitoring component in the SWMP to assess the effectiveness of the BMPs in achieving the wasteload allocations. Monitoring shall be specifically for the pollutants of concern and be of sufficient frequency to determine if the stormwater BMPs are adequate to meet wasteload allocations. Monitoring can entail a number of activities from outfall monitoring to in-stream monitoring to modeling. For more information see the USEPA/State guidance titled: *Evaluating the effectiveness of municipal stormwater programs* and *Understanding Impaired Waters and Total Maximum Daily Load (TMDL) Requirements for Municipal Stormwater Programs.* Both of these guidance documents can be found on WVDEP's website: http://www2.wvdep.org/dwwm/stormwater/MS4_docs.htm

After monitoring results are carefully considered, the permittee shall ascertain if the SWMP and the mix of BMPs need to be modified to comply with wasteload allocations.

2. **Discharging into Waters with Approved TMDLs**

If a MS4 discharges into a water body with an approved TMDL, and the TMDL contains requirements for control of pollutants from the MS4 stormwater discharges, then the SWMP must include BMPs specifically targeted to achieve the wasteload allocations prescribed by the TMDL. A monitoring component to assess the effectiveness of the BMPs in achieving the wasteload allocations must also be included in the SWMP. Monitoring shall be specifically for the pollutants of concern and be of sufficient frequency to determine if the stormwater BMPs are sufficient to meet wasteload allocations. Monitoring shall be specifically for the pollutants of concern and be of sufficient frequency to determine if the stormwater BMPs are adequate to meet wasteload allocations. Monitoring can entail a number of activities from outfall monitoring to in-stream monitoring to modeling. For more information see the USEPA/State guidance titled: *Evaluating the effectiveness of municipal stormwater programs* and *Understanding Impaired Waters and Total Maximum Daily Load (TMDL) Requirements for Municipal Stormwater Programs.* Both of these guidance documents can be found on WVDEP's website: http://www2.wvdep.org/dwwm/stormwater/MS4_docs.htm

After monitoring results are carefully considered, the permittee shall ascertain if the SWMP and the mix of BMPs need to be modified to comply with wasteload allocations.

E. Endangered and Threatened Species

If a MS4 discharges to a stream where federally endangered or threatened species or its habitat are present, the applicant shall contact the US Fish and Wildlife Service to insure that requirements of the Federal Endangered Species Act are met.

Part IV. Monitoring, Recordkeeping, Reporting and Program Review

A. Evaluating the Stormwater Management Program

MS4s shall evaluate the effectiveness of their stormwater management programs and BMPs implemented to comply with this general permit. The permittee shall use a sufficient number of known, available, and reasonable methods necessary to evaluate the effectiveness of the SWMP. This information shall be submitted in the annual report in accordance with Part IV, Section D. For more information about evaluating your stormwater management program see the USEPA/States guidance titled: *Evaluating the effectiveness of municipal stormwater programs.* This guidance document can be found on WVDEP's website: http://www2.wvdep.org/dwwm/stormwater/MS4_docs.htm

B. Stormwater Monitoring

The permittee shall monitor stormwater from a minimum of one outfall that is representative of the stormwater discharge from the MS4. A representative outfall is one located in the most densely populated section of the MS4. The permittee shall, at a minimum, monitor one outfall for the following parameters:

Parameter	EPA Method No.	Method Detection Limit (mg/l)
Total Kjeldahl Nitrogen	351.4	0.03
Nitrate Nitrogen	300.0	0.002
Nitrite Nitrogen	300.0	0.004
Total Phosphorous	365.4	0.01

The DWWM recognizes there is not an EPA approved method to directly test for Total Nitrogen. The Total Nitrogen value to be reported on the permittees Discharge Monitoring Reports' (DMRs) shall be the sum of the following parameters; Total Kjeldahl Nitrogen, Nitrate, and Nitrite.

If all three constituents of total nitrogen are not detected at its method detection limit (MDL), the permittee shall sum the actual MDLs for each constituent and report the result as less than the calculation.

When calculating the sum of the constituents for total nitrogen, the permittee shall use actual analytical results when these results are greater than or equal to the MDL for a particular constituent and should use zero (0) for a constituent if one or two of the constituents are less than the MDL.

Effluent monitoring for the above pollutants shall be conducted using the most sensitive methods and detection levels commercially available and economically feasible. The methods and detection levels in the table above are recommended to be used unless the permittee desires to use an EPA Approved Method with a lower detection level.

Stormwater samples shall be collected once every six months, during the spring and fall seasons.

Stormwater samples shall be collected during the "first flush" of rainfall runoff, at least twenty minutes, but not more than fifty minutes after rainfall of at least 0.5 inches has begun, preceded by a period of dry weather of at least 48 hours.

C. Recordkeeping and Public Availability of SWMP and Annual Report

The permittee shall keep records under this general permit for at least three years after termination of this general permit. Records shall be submitted to the DWWM only when permittees are specifically asked to do so.

The permittee shall make their SWMP and their annual report available to the public at reasonable times during regular business hours. In addition, the SWMP and the annual report shall be posted on the permittees website. If the permittee does not maintain or utilize a website, an electronic copy of the SWMP and annual report shall be submitted to DWWM for distribution when it is requested.

D. Reporting

Annually, the permittee shall submit a report to the DWWM. The report shall include:

1. A description of the activities undertaken and implemented for each of the minimum control measures;

2. An explanation of how the permittee measured the effectiveness of each of the activities

implemented;

3. The status of compliance with each of the BMPs that were specified in the permittees stormwater management program;

4. An assessment of the progress toward achieving the identified measurable goals for each of the minimum control measures;

5. Results of information collected and analyzed, including monitoring data, during the annual reporting period;

6. A summary of the stormwater activities the permittee plans to undertake during the next annual reporting period;

7. A change in any identified measurable goals that apply to the minimum control measures;

8. A description of the status of the street and parking design assessment;

9. A description of the coordination efforts with other MS4's, County Governments, colleges, universities, correctional facilities, prisons, and any other entity regarding the implementation of the minimum control measures including the status of any memorandum of understanding (MOU) or other agreement executed between the permittee/s and any other entity;

10. A summary of construction site inspections and enforcement activities as described in Part II, Section C.4.b.vi.;

11. A summary of post construction controls as described in Part II, Section C.5.a.ii.F., and Part II, Section C.5.a.i.C.,

12. A description of specific BMPs *that were implemented* in order to reduce pollutants of concern in impaired receiving waters and waters in which a TMDL has been developed, and

13. A fiscal analysis of capital and operating expenditures to implement the minimum control measures. The fiscal analysis shall include only those expenditures by the locality seeking coverage under this general permit and not those for minimum control measures implemented by other entities.

E. Program Review

In order to assess the effectiveness of the permittees NPDES program for eliminating non-storm water discharges and reducing the discharge of pollutants to the maximum extent possible, the DWWM will review program implementation and annual reports. Additional periodic evaluations may be conducted to determine compliance with permit conditions.

The permittee must comply with all terms and conditions of this permit. Permit noncompliance constitutes a violation of the federal Clean Water Act (CWA) and State Act, Chapter 22, Article 11 &

Article 12 and is grounds for enforcement action; for permit modification, suspension or revocation.

Failure to comply with the terms and conditions of this permit, with the plans and specifications submitted with the site registration application, the most currently approved SWMP, and the appropriate appendices shall constitute grounds for the revocation or suspension of this permit and for the invocation of all the enforcement procedures set forth in Chapter 22, Article 11 of the Code of West Virginia.

This permit is issued in accordance with the provisions of Chapter 22, Article 11 of the Code of West Virginia

BY: _____
Director

Appendix A

WV/NPDES GENERAL PERMIT NUMBER WV0116025

SMALL MUNICIPAL SEPARATE STORM SEWER SYSTEMS

NOTICE OF INTENT (NOI)

1. MS4 Operator Information:

Name of city, county, storm water utility district or other jurisdiction that operates a Phase II MS4:

_____

Contact Person: _____ Telephone: _____

E-mail address of contact person: _____

Address: _____

City: _____ State:_____ Zip Code: _____

2. Receiving stream(s): _____

3. Fee - $17.50 per acre of area served by the MS4. Maximum fee is $1750.00

Amount enclosed: _____

NOTE:

The Notice of Intent provides MS4 entities initial coverage under the WV/NPDES MS4 General Permit. This permit requires the permittee to submit their Stormwater Management Program within six months of the issuance date of the General Permit.

I CERTIFY UNDER PENALTY OF LAW THAT I HAVE PERSONALLY EXAMINED AND AM FAMILIAR WITH THE INFORMATION SUBMITTED ON THIS FORM. I AM ALSO AWARE THAT THE STORMWATER MANAGEMENT PROGRAM/SITE REGISTRATION APPLICATION MUST BE SUBMITTED WITHIN SIX MONTHS OF THE ISSUANCE DATE OF THE GENERAL PERMIT NO. WV0116025.

I AM AWARE THAT THERE ARE SIGNIFICANT PENALTIES FOR SUBMITTING FALSE INFORMATION, INCLUDING THE POSSIBILITY OF FINE AND IMPRISONMENT.

OFFICIAL SIGNATURE _____ DATE _____

PRINT NAME _____

Return To: WVDEP - DWWM
MS4/NPDES
601 57th Street, SE
Charleston, WV 25304

Appendix B

Definitions

Accessory Impervious Surfaces means those additional impervious surfaces that are created to service new development; including roads, shopping centers, office parks and parking lots.

Best Management Practices (BMP's) means schedules of activities, prohibitions of practices, maintenance procedures, policies, and other management practices to prevent or reduce the pollution of waters of the State of West Virginia. BMP's also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, waste disposal or drainage from material storage. BMP's can include structural as well as non-structural practices.

Bioretention is the water quality and water quantity stormwater management practice using the chemical, biological and physical properties of plants, microbes and soils for the removal of pollution from stormwater runoff.

Canopy Interception is the interception of precipitation, by leaves and branches of trees and vegetation that does not reach the soil.

Clean Water Act (CWA) means Public Law 92-500, as amended by Public Law 95-217, Public Law 97-117 and Public Law 95-576; U.S.C. 1251 et seq.

Common Plan of Development is a contiguous construction project where multiple separate and distinct construction activities may be taking place at different times on different schedules but under one plan. The "plan" is broadly defined as any announcement or piece of documentation or physical demarcation indicating construction activities may occur on a specific plot; included in this definition are most subdivisions and industrial parks.

Cut off concentration is a concentration at which stormwater could potentially impair, or contribute to impairing water quality.

Director means the Director of the Division of Water and Waste Management, West Virginia Department of Environmental Protection, or his/her designated representative.

Engineered Infiltration is an underground device or system designed to accept stormwater and slowly exfiltrates it into the underlying soil. This device or system is designed based on soil tests that define the infiltration rate.

Evaporation means rainfall that is changed or converted into a vapor.

Evapotranspiration means the sum of evaporation and transpiration of water from the earth's surface to the atmosphere. It includes evaporation of liquid or solid water plus the transpiration from plants.

Extended Filtration is a structural stormwater device which filters stormwater runoff through a soil media and collects it an underdrain which slowly releases it after the storm is over.

Hydromodification means the alteration of the natural flow of water through a landscape, and often takes the form of channel straightening, widening, deepening, or relocating existing, natural stream channels. It can also involve excavation of borrow pits or canals, building of levees, streambank

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erosion, or other conditions or practices that change the depth, width or location of waterways. Hydromodification usually results in water quality and habitat impacts.

Illicit Discharge means any non-permitted discharge to a regulated small MS4 or to waters of the State of West Virginia that does not consist entirely of stormwater or authorized non-stormwater discharges covered under a NPDES permit.

Infiltration is the process by which stormwater penetrates into soil.

Land Use means the way in which land is used, especially in farming and municipal planning.

Maintenance Agreement means a formal agreement or contract between a local government and a property owner designed to guarantee that specific maintenance functions are performed.

Municipal Field Staff means employees of the municipality and its departments that spend a portion of their employment in the marketplace, outside of the company office.

Municipal Separate Storm Sewer System (MS4) means conveyances for stormwater, including, but not limited to, roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, human made channels or storm drains owned or operated by any municipality, sewer or sewage board, State agency or Federal agency or other public entity that discharges directly to surface waters of the State of West Virginia.

Municipal Staff means employees of the municipality and its departments.

Notice of Intent (NOI) means a notification of intent to seek coverage under this general permit, to discharge stormwater into waters of the State of West Virginia.

NPDES means National Pollutant Discharge Elimination System, a provision of the Clean Water Act which prohibits the discharge of pollutants into waters of the United States. This federally mandated permit program is used for regulating point source discharges.

Outfall means the point source where the MS4 discharges from a pipe, ditch or other discreet conveyance directly or indirectly to water of the State of West Virginia, or to another MS4.

Planning documents are documents a municipality or jurisdiction uses for planning. They include, but are not limited to; comprehensive or master plans, subdivision ordinances, general land use plan, zoning code, transportation master plan, specific area plans, such as sector plan, site area plans, corridor plans, or unified development ordinances.

Pollutants of Concern are those pollutants which cause a water body to be placed on the Section 303(d) list of impaired waters.

Qualifying Local Program means a WVDEP formally recognized state, municipal or county program that meets or exceeds the provisions of WV DEP stormwater construction program in accordance with 40 CFR 122.44(s).

Rainfall and Rainwater Harvesting is the collection, conveyance, and storage of rainwater. The scope, method, technologies, system complexity, purpose, and end uses vary from rain barrels for garden irrigation in urban areas, to large-scale collection of rainwater for all domestic uses.

Runoff Reduction Techniques means the collective assortment of stormwater practices that reduce the volume of stormwater from discharging off site.

Secretary means the Secretary of the West Virginia Department of Environmental Protection, or his/her designated representative.

Site Registration Application means the forms designed by the Director for the purpose of obtaining coverage under the small MS4 general permit. The information contained on the site registration application once approved becomes the "stormwater management program" for the permittee.

Soil amendments are components added to in situ or native soils to increase the spacing between soil particles so that the soil can absorb and hold more moisture. The amendment of soils changes various other physical, chemical and biological characteristics so that the soils become more effective in maintaining water quality.

Source control stormwater management means practices that control stormwater *before* pollutants have been introduced into stormwater.

Stormwater Pollution Prevention Plan (SWPPP) means the erosion and sediment control plan for a construction site.

Stormwater Management Practice means practices that manage stormwater, including structural and vegetative components of a stormwater system.

Total Maximum Daily Load (TMDL): A calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. A TMDL is the sum of individual wasteload allocations for point sources (WLA), load allocations for nonpoint sources and natural background (LA), and must consider seasonal variation and include a margin of safety. The TMDL comes in the form of a technical document or plan. (40 CFR 130.2 and 130.7)

Treatment control stormwater management means practices that 'treat' stormwater after pollutants have been incorporated into the stormwater.

Wasteload allocation (WLA): The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Water Quality Treatment means any passive or active process that removes pollutants from stormwater, and/or prevents pollutants from encountering stormwater.

Water Resources, 'Water' or 'Waters' means any and all water on or beneath the surface of the ground, whether percolating, standing, diffused or flowing, wholly or partially within this state, or bordering this state and within its jurisdiction, and includes, without limiting the generality of the foregoing, natural or artificial lakes, rivers, streams, creeks, branches, brooks, ponds (except farm ponds, industrial settling basins and ponds and water treatment facilities), impounding reservoirs, springs, wells, watercourses and wetlands.

Appendix C

I. MANAGEMENT CONDITIONS:

1. Duty to Comply
a) The permittee must comply with all conditions of this permit. Permit noncompliance constitutes a violation of the CWA and State Act and is grounds for enforcement action; for permit modification, revocation and reissuance, suspension or revocation; or for denial of a permit renewal application.
b) The permittee shall comply with all effluent standards or prohibitions established under Section 307(a) of the CWA for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.

2. Duty to Reapply
If the permittee wishes to continue an activity regulated by this permit after the expiration date of this permit, the permittee must apply for a new permit at least 180 days prior to expiration of the permit.

3. Duty to Mitigate
The permittee shall take all reasonable steps to minimize or prevent any discharge in violation of this permit, which has a reasonable likelihood of adversely affecting human health or the environment.

4. Permit Actions
This permit may be modified, revoked and reissued, suspended, or revoked for cause. The filing of a request by the permittee for permit modification, revocation and reissuance, or revocation, or a notification of planned changes or anticipated noncompliance, does not stay any permit condition.

5. Property Rights
This permit does not convey any property rights of any sort or any exclusive privilege.

6. Signatory Requirements
All applications, reports, or information submitted to the Chief shall be signed and certified as required in Title 47, Series 10 , Section 4.6 of the West Virginia Legislative Rules.

7. Transfers
This permit is not transferable to any person except after notice to the Chief. The Chief may require modification or revocation and reissuance of the permit to change the name of the permittee and incorporate such other requirements as may be necessary. .

8. Duty to Provide Information
The permittee shall furnish to the Chief, within a reasonable specified time, any information which the Chief may request to determine whether cause exists for modifying, revoking and reissuing, suspending, or revoking this permit, or to determine compliance with this permit. The permittee shall also furnish to the Chief, upon request, copies of records required to be kept by this permit.

9. Other Information
Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application or in any report to the Chief, it shall promptly submit such facts or information.

10. Inspection and Entry
The permittee shall allow the Chief, or an authorized representative, upon the presentation of credentials and other documents as may be required by law, to:
a) Enter upon the permittee's premises in which an effluent source or activity is located, or where records must be kept under the conditions of this permit;
b) Have access to and copy at reasonable times, any records that must be kept under the conditions of this permit;
c) Inspect at reasonable times any facilities, equipment (including monitoring and control equipment), practices, or operations regulated or required under this permit; and
d) Sample or monitor at reasonable times, for the purposes of assuring permit compliance or as otherwise authorized by the State Act, any substances or parameters at any location.

11. Permit Modification
This permit may be modified, suspended, or revoked in whole or in part during its term in accordance with the provisions of Chapter 22-11-12 of the Code of West Virginia.

12. Water Quality
The effluent or effluents covered by this permit are to be of such quality so as not to cause violation of applicable water quality standards adopted by the Environmental Quality Board.

13. Outlet Markers
A permanent marker at the establishment shall be posted in accordance with Title 47, Series 11, Section 9 of the West Virginia Legislative Rules.

14. Liabilities
a) Any person who violates a permit condition implementing sections 301, 302, 306, 307, 308, 318, or 405 of the Clean Water Act is subject to a civil penalty not to exceed $10,000 per day of such violation. Any person who willfully or negligently violates permit conditions implementing sections 301, 302, 306, 307, or 308 of the Clean Water Act is subject to a fine of not less than $2,500 nor more than $25,000 per day of violation, or by imprisonment for not more than 1 year, or both.
b) Any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.
c) Any person who knowingly makes any false statement, representation, or certification in any record or other document submitted or required to be maintained under this permit, including monitoring reports or reports of compliance or noncompliance shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.
d) Nothing in I.14 a), b), and c) shall be construed to limit or prohibit any other authority the Chief may have under the State Water Pollution Control Act, Chapter 22, Article 11.

II. OPERATION AND MAINTENANCE:

1. Proper Operation and Maintenance
The permittee shall at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the permittee to achieve compliance with the conditions of this permit. Proper operation and maintenance also includes adequate laboratory controls, and appropriate quality assurance procedures. Unless otherwise required by Federal or State law, this provision requires the operation of back-up auxiliary facilities or similar systems which are installed by the permittee only when the operation is necessary to achieve compliance with the conditions of the permit. For domestic waste treatment facilities, waste treatment operators as classified by the WV Bureau of Public Health Laws, W. Va. Code Chapter 16-1, will be required except that in circumstances where the domestic waste treatment facility is receiving any type of industrial waste, the Chief may require a more highly skilled operator.

2. Need to Halt or Reduce Activity Not a Defense
It shall not be a defense for a permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of the permit.

3. Bypass
a) Definitions
(1) "Bypass" means the intentional diversion of waste streams from any portion of a treatment facility; and
(2) "Severe property damage" means substantial physical damage to property, damage to the treatment facilities which causes them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.
b) Bypass not exceeding limitations. The permittee may allow any bypass to occur which does not cause effluent limitations to be exceeded, but only if it also is for essential maintenance to assure efficient operation. These bypasses are not subject to the provision of II.3.c) and II.3.d) of this permit.
c) (1) If the permittee knows in advance of the need for a bypass, it shall submit prior notice, if possible at least ten (10) days before the date of the bypass;
(2) If the permittee does not know in advance of the need for bypass, notice shall be submitted as required in IV.2.b) of this permit.
d) Prohibition of bypass
(1) Bypass is permitted only under the following conditions, and the Chief may take enforcement action against a permittee for a bypass, unless;
(A) Bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;
(B) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if adequate backup equipment should have been installed in the exercise of reasonable engineering judgement to prevent a bypass which occurred during normal periods of equipment downtime or preventative maintenance; and
(C) The permittee submitted notices as required under II.3.c) of this permit.
(2) The Chief may approve an anticipated bypass, after considering its adverse effects, if the Chief determines that it will meet the three conditions listed in II.3.d.(1) of this permit.

4. Upset
a) Definition. "Upset" means an exceptional incident in which there is unintentional and temporary noncompliance with technology-based permit effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventative maintenance, or careless or improper operation.

b) Effect of an upset. An upset constitutes an affirmative defense to an action brought for noncompliance with such technology-based permit effluent limitation if the requirements of II.4.c) are met. No determination made during administrative review of claims that noncompliance was caused by upset, and before an action for noncompliance, is final administrative action subject to judicial review.

c) Conditions necessary for a demonstration of upset. A permittee who wishes to establish the affirmative defense of upset shall demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:
(1) An upset occurred and that the permittee can identify the cause(s) of the upset;
(2) The permitted facility was at the time being properly operated;
(3) The permittee submitted notice of the upset as required in IV.2.b) of this permit.
(4) The permittee complied with any remedial measures required under I.3. of this permit.

d) Burden of proof. In any enforcement proceeding the permittee seeking to establish the occurrence of an upset has the burden of proof.

5. Removed Substances
Where removed substances are not otherwise covered by the terms and conditions of this permit or other existing permit by the Chief, any solids, sludges, filter backwash or other pollutants (removed in the course of treatment or control of wastewaters) and which are intended for disposal within the State, shall be disposed of only in a manner and at a site subject to the approval by the Chief. If such substances are intended for disposal outside the State or for reuse, i.e., as a material used for making another product, which in turn has another use, the permittee shall notify the Chief in writing of the proposed disposal or use of such substances, the identity of the prospective disposer or users, and the intended place of disposal or use, as appropriate.

III. MONITORING AND REPORTING

1. Representative Sampling
Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity.

2. Reporting
a) Permittee shall submit, according to the enclosed format, a Discharge Monitoring Report (DMR) indicating in terms of concentration, and/or quantities, the values of the constituents listed in Part A analytically determined to be in the plant effluent(s). DMR submissions shall be made in accordance with the terms contained in Section C of this permit.
b) Enter reported average and maximum values under "Quantity" and "Concentration" in the units specified for each parameter, as appropriate.
c) Specify the number of analyzed samples that exceed the allowable permit conditions in the columns labeled "N.E." (i.e., number exceeding).
d) Specify frequency of analysis for each parameter as number of analyses/specified period (e.g.,3/month is equivalent to 3 analyses performed every calendar month). If continuous, enter "Cont.". The frequency listed on format is the minimum required.

3. Test Procedures
Samples shall be taken, preserved and analyzed in accordance with the latest edition of 40 CFR Part 136, unless other test procedures have been specified elsewhere in this permit.

4. Recording of Results
For each measurement or sample taken pursuant to the permit, the permittee shall record the following information.
a) The date, exact place, and time of sampling or measurement;
b) The date(s) analyses were performed;
c) The individual(s) who performed the sampling or measurement;
d) The individual(s) who performed the analyses; if a commercial laboratory is used, the name and address of the laboratory;
e) The analytical techniques or methods used, and
f) The results of such analyses. Information not required by the DMR form is not to be submitted to this agency, but is to be retained as required in III.6.

5. Additional Monitoring by Permittee
If the permittee monitors any pollutant at any monitoring point specified in this permit more frequently than required by this permit, using approved test procedures or others as specified in this permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the Discharge Monitoring Report Form. Such increased frequency shall also be indicated. Calculations for all limitations which require averaging of measurements shall utilize an arithmetic mean unless otherwise specified in the permit.

6. Records Retention
The permittee shall retain records of all monitoring information, including all calibration and maintenance records and all original chart recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for the permit, for a period of at least three (3) years from the date of the sample, measurement, report or application. This period may be extended by request of the Chief at any time.

7. Definitions
a) "Daily discharge" means the discharge of a pollutant measured during a calendar day or within any specified period that reasonably represents the calendar day for purposes of sampling. For pollutants with limitations expressed in units of mass, the daily discharge is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurement, the daily discharge is calculated as the average measurement of the pollutant over the day.
b) "Average monthly discharge limitation" means the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.
c) "Maximum daily discharge limitation" means the highest allowable daily discharge.
d) "Composite Sample" is a combination of individual samples obtained at regular intervals over a time period. Either the volume of each individual sample is proportional to discharge flow rates or the sampling interval (for constant volume samples) is proportional to the flow rates over the time period used to produce the composite. The maximum time period between individual samples shall be two hours.
e) "Grab Sample" is an individual sample collected in less than 15 minutes.
f) "is" = immersion stabilization - a calibrated device is immersed in the effluent stream until the reading is stabilized.
g) The "daily average temperature" means the arithmetic average of temperature measurements made on an hourly basis, or the mean value plot of the record of a continuous automated temperature recording instrument, either during a calendar month, or during the operating month if flows are of shorter duration.
h) The "daily maximum temperature" means the highest arithmetic average of the temperatures observed for any two (2) consecutive hours during a 24 hour day, or during the operating day if flows are of shorter duration.
i) The "daily average fecal coliform" bacteria is the geometric average of all samples collected during the month.
j) "Measured Flow" means any method of liquid volume measurement, the accuracy of which has been previously demonstrated in engineering practice, or which a relationship to absolute volume has been obtained.
k) "Estimate" means to be based on a technical evaluation of the sources contributing to the discharge including, but not limited to pump capabilities, water meters and batch discharge volumes.
l) "Non-contact cooling water" means the water that is contained in a leak-free system, i.e., no contact with any gas, liquid, or solid other than the container for transport; the water shall have no net poundage addition of any pollutant over intake water levels, exclusive of approved anti-fouling agents.

IV. OTHER REPORTING

1. Reporting Spills and Accidental Discharges
Nothing in this permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities or penalties established pursuant to Title 47, Series 11, Section 2 of the West Virginia Legislative Rules promulgated pursuant to Chapter 22, Article 11.

Attached is a copy of the West Virginia Spill Alert System for use in complying with Title 47, Series 11, Section 2 of the Legislative rules as they pertain to the reporting of spills and accidental discharges.

2. Immediate Reporting
a) The permittee shall report any noncompliance which may endanger health or the environment immediately after becoming aware of the circumstances by using the Agency's designated spill alert telephone number. A written submission shall be provided within five (5) days of the time the permittee becomes aware of the circumstances. The written submission shall contain a description of the noncompliance and its cause; the period of noncompliance, including exact dates and times, and if the noncompliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent recurrence of the noncompliance.
b) The following shall also be reported immediately:
(1) Any unanticipated bypass which exceeds any effluent limitation in the permit;
(2) Any upset which exceeds any effluent limitation in the permit; and
(3) Violation of a maximum daily discharge limitation for any of the pollutants listed by the Chief in the permit to be reported immediately. This list shall include any toxic pollutant or hazardous substance, or any pollutant specifically identified as the method to control a toxic pollutant or hazardous substance.
c) The Chief may waive the written report on a case-by-case basis if the oral report has been received in accordance with the above.
d) Compliance with the requirements of IV.2 of this section shall not relieve a person of compliance with Title 47, Series 11, Section 2.

3. Reporting Requirements
a) Planned changes. The permittee shall give notice to the Chief of any planned physical alterations or additions to the permitted facility which may affect the nature or quantity of the discharge. Notice is required when:
(1) The alteration or addition to a permitted facility may meet one of the criteria for determining whether a facility is a new source in Section 13.7.b of Series 10, Title 47; or
(2) The alteration or addition could significantly change the nature or increase the quantity of pollutants discharged. This notification applies to pollutants which are subject neither to effluent limitations in the permit, nor to notification requirements under IV.2 of this section.
b) Anticipated noncompliance. The permittee shall give advance notice to the Chief of any planned changes in the permitted facility or activity which many result in noncompliance with permit requirements.
c) In addition to the above reporting requirements, all existing manufacturing, commercial, and silvicultural discharges must notify the Chief in writing as soon as they know or have reason to believe:
(1) That any activity has occurred or will occur which would result in the discharge, on a routine or frequent basis, or any toxic pollutant which is not limited in the permit, if that discharge will exceed the highest of the following "notification levels":
(A) One hundred micrograms per liter (100 ug/l);
(B) Two hundred micrograms per liter (200 ug/l) for acrolein and acrylonitrile; five hundred micrograms per liter (500 ug/l) for 2,4-dinitro phenol; and for 2-methyl 4,6-dinitrophenol; and one milligram per liter (1 mg/l) for antimony;
(C) Five (5) times the maximum concentration value reported for that pollutant in the permit application in accordance with Section 4.4.b.9 of Series10, Title 47.
(D) The level established by the Chief in accordance with Section 6.3.g of Series 10, Title 47;
(2) That any activity has occurred or will occur which would result in any discharge (on a non-routine or infrequent basis) of a toxic which is not limited in the permit, if that discharge will exceed the highest of the following "notification levels":
(A) Five hundred micrograms per liter (500 ug/l);
(B) One milligram per liter (1 mg/l) for antimony;
(C) Ten (10) times the maximum concentration value reported for that pollutant in the permit application in accordance with Section 4.4.b.7 of Series 10, Title 47;
(D) The level established by the Chief in accordance with Section 6.3.g of Series 10, Title 47.
(3) That they have begun or expect to begin to use or manufacture as an intermediate or final product or by-product of any toxic pollutant which was not reported in the permit application under Section 4.4.b.9 of Series 10, Title 47 and which will result in the discharge on a routine or frequent basis of that toxic pollutant at levels which exceed five times the detection limit for that pollutant under approved analytical procedure.
(4) That they have begun or expect to begin to use or manufacture as an intermediate or final product or by-product of any toxic pollutant which was not reported in the permit application under Section 4.4.b.9 of Series 10, Title 47 and which will result in the discharge on a non-routine or infrequent basis of that toxic pollutant at levels which exceed ten times the detection limit for that pollutant under approved analytical procedure.

4. Other Noncompliance
The permittee shall report all instances of noncompliance not reported under the above paragraphs at the time monitoring reports are submitted. The reports shall contain the information listed in IV.2.a). Should other applicable noncompliance reporting be required, these terms and conditions will be found in Section C of this permit.

Appendix D

Designation Criteria for small MS4s with a population greater than 1,000.

The DWWM will use the following designation criteria to evaluate and determine if the subject MS4s require permit coverage:

1. Discharge to sensitive waters

2. High growth or growth potential

3. High population density

4. Contiguity to an urbanized area

5. Significant contributor of pollutants to waters of the State

6. Ineffective protection of water quality by other programs

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Appendix E

Sediment and Erosion Control BMP manuals:

1. West Virginia BMP manual; http://www.wvdep.org/dwwm/stormwater/BMP/index.html

2. Maryland Soil Erosion and Sediment Control BMP manual; http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/erosionsedimentcontrol/standards.asp

3. Virginia Erosion and Sediment Control Handbook; http://www.dcr.virginia.gov/soil_&_water/e&s-ftp.shtml

4. USEPA has a listing of available state stormwater manuals here; http://yosemite.epa.gov/R10/WATER.NSF/0/17090627a929f2a488256bdc007d8dee?OpenDocument

5. West Virginia Department of Transportation, Division of Highways, Erosion and Sediment Control Manual, March 1, 2003. http://www.wvdot.com/engineering/TOC_engineering.htm

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SECTION

1.3

UNIFIED STORMWATER SIZING CRITERIA

1.3.1 Overview

This section presents an integrated approach for meeting the stormwater runoff quality and quantity management requirements in the minimum standards for development (see Section 1.2) by addressing the key adverse impacts of stormwater runoff from a development site. The purpose is to provide a framework for designing a stormwater management system to:

- Remove stormwater runoff pollutants and improve water quality (Minimum Standard #2);
- Prevent downstream streambank and channel erosion (Minimum Standard #3);
- Reduce downstream overbank flooding (Minimum Standard #4); and
- Safely pass or reduce the runoff from extreme storm events (Minimum Standard #5).

For these objectives, an integrated set of engineering criteria, known as the *Unified Stormwater Sizing Criteria*, have been developed which are used to size and design structural stormwater controls. Table 1.3.1-1 below briefly summarizes the criteria.

Table 1.3.1-1 Summary of the Statewide Stormwater Sizing Criteria for Stormwater Control and Mitigation

Sizing Criteria	Description
Water Quality	Treat the runoff from 85% of the storms that occur in an average year. For Georgia, this equates to providing water quality treatment for the runoff resulting from a rainfall depth of 1.2 inches. Reduce average annual post-development total suspended solids loadings by 80%.
Channel Protection	Provide extended detention of the 1-year storm event released over a period of 24 hours to reduce bankfull flows and protect downstream channels from erosive velocities and unstable conditions.
Overbank Flood Protection	Provide peak discharge control of the 25-year storm event such that the post-development peak rate does not exceed the predevelopment rate to reduce overbank flooding.
Extreme Flood Protection	Evaluate the effects of the 100-year storm on the stormwater management system, adjacent property, and downstream facilities and property. Manage the impacts of the extreme storm event through detention controls and/or floodplain management.

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Each of the unified stormwater sizing criteria are intended to be used in conjunction with the others to address the overall stormwater impacts from a development site. When used as a set, the unified criteria control the entire range of hydrologic events, from the smallest runoff producing rainfalls to the 100-year storm.

Figure 1.3.1-1 graphically illustrates the relative volume requirements of each of the unified stormwater sizing criteria as well as demonstrates that the criteria are "stacked" upon one another, i.e., the extreme flood protection volume requirement also contains the overbank flood protection volume, the channel protection volume and the water quality treatment volume. Figure 1.3.1-2 shows how these volumes would be stacked in a typical stormwater wet pond designed to handle all four criteria.

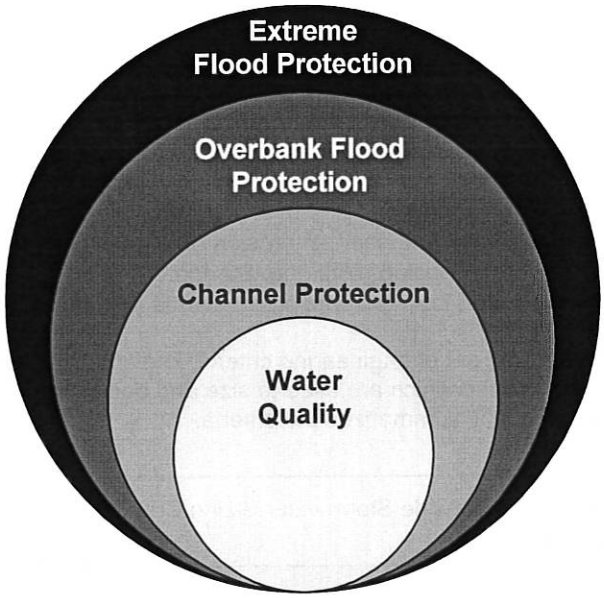

Figure 1.3.1-1 Representation of the Unified Stormwater Sizing Criteria

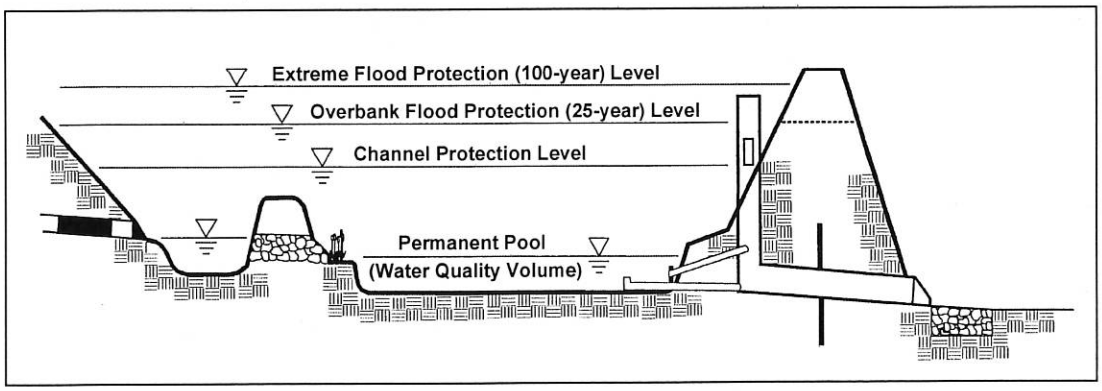

Figure 1.3.1-2 Unified Sizing Criteria Water Surface Elevations in a Stormwater (Wet) Pond

The following pages describe the four sizing criteria in detail and present guidance on how to properly compute and apply the required storage volumes.

1.3.2 Description of Unified Stormwater Sizing Criteria

1.3.2.1 Water Quality (WQ_v)

The Water Quality sizing criterion, denoted WQ_v, specifies a treatment volume required to remove a significant percentage of the total pollution load inherent in stormwater runoff by intercepting and treating the 85th percentile storm event, which is equal to 1.2 inches (i.e., all the runoff from 85% of the storms that occur on average during the course of a year and a portion of the runoff from all storms greater than 1.2 inches). The Water Quality Volume is a runoff volume that is directly related to the amount of impervious cover at a site.

In numerical terms, it is equivalent to a rainfall depth of 1.2 inches multiplied by the volumetric runoff coefficient (R_v) and the site area, and is calculated using the formula below:

$$WQ_V = \frac{1.2 R_V A}{12}$$

where: WQ_v = water quality volume (in acre-feet)
R_v = 0.05 + 0.009(I) where I is percent impervious cover
A = site area in acres

Discussion

Hydrologic studies show that small-sized, frequently occurring storms account for the majority of rainfall events that generate stormwater runoff. Consequently, the runoff from these storms also accounts for a major portion of the annual pollutant loadings. Therefore, by treating these frequently occurring smaller rainfall events and a portion of the stormwater runoff from larger events, it is possible to effectively mitigate the water quality impacts from a developed area.

A water quality treatment volume (WQ_v) is specified to size structural control facilities to treat these small storms up to a maximum runoff depth and the "first flush" of all larger storm events. For Georgia, this maximum depth was determined to be the runoff generated from the 85th percentile storm event (i.e., the storm event that is greater than 85% of the storms that occur within an average year). The 85th percentile volume was considered the point of optimization between pollutant removal ability and cost-effectiveness. Capturing and treating a larger percentage of the annual stormwater runoff would provide only a small increase in additional pollutant removal, but would considerably increase the required size (and cost) of the structural stormwater controls.

A value of 1.2 inches for the 85th percentile storm was derived from a rainfall analysis for 12 locations across the state of Georgia and is an average value chosen for the entire state. Thus, the statewide water quality treatment volume is equal to the runoff from the first 1.2 inches of rainfall. A stormwater management system designed for the WQ_v will treat the runoff from all storm events of 1.2 inches or less, as well as the first 1.2 inches of runoff for all larger storm events.

The volumetric runoff coefficient (R_v) was derived from a regression analysis performed on rainfall runoff volume data from a number of cities nationwide and is a shortcut method considered adequate for runoff volume calculation for the type of small storms normally considered in stormwater quality calculations. Figure 1.3.2-1 shows a plot of the Water Quality Volume versus impervious area percentage.

TSS Reduction Goal

This Manual follows the philosophy of removing pollutants to the "maximum extent practicable" through the use of a percentage removal performance goal. The approach taken in this Manual is to require treatment of the WQ_v from a site to reduce post-development total suspended solids (TSS) loadings by 80%, as measured on an average annual basis. This performance goal is based upon U.S. EPA guidance and has been adopted nationwide by many local and statewide agencies.

TSS was chosen as the representative stormwater pollutant for measuring treatment effectiveness for several reasons:

1. The use of TSS as an "indicator" pollutant is well established.
2. Sediment and turbidity, as well as other pollutants of concern that adhere to suspended solids, are a major source of water quality impairment due to urban development in Georgia watersheds.
3. A large fraction of many other pollutants of concern are either removed along with TSS, or at rates proportional to the TSS removal.
4. The 80% TSS removal level is reasonably attainable using well-designed structural stormwater controls (for typical ranges of TSS concentration found in stormwater runoff).

TSS is a good indicator for many stormwater pollutants. However, the removal performance for pollutants that are soluble or that cannot be removed by settling will vary depending on the structural control practice. For pollutants of specific concern, individual analyses of specific pollutant sources and the appropriate removal mechanisms should be performed.

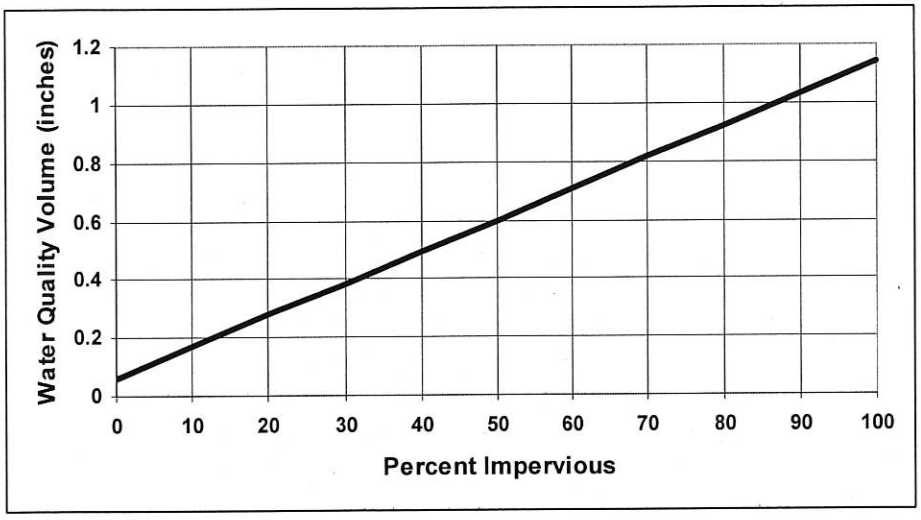

Figure 1.3.2-1 Water Quality Volume versus Percent Impervious Area

Determining the Water Quality Volume (WQ_v)

- *Measuring Impervious Area*: The area of impervious cover can be taken directly off a set of plans or appropriate mapping. Where this is impractical, NRCS TR-55 land use/impervious cover relationships can be used to estimate impervious cover. I is expressed as a percent value not a fraction (e.g., I = 30 for 30% impervious cover)
- *Multiple Drainage Areas*: When a development project contains or is divided into multiple drainage areas, WQ_v should be calculated and addressed separately for each drainage area.
- *Off-site Drainage Areas:* Off-site existing impervious areas may be excluded from the calculation of the WQ_v volume.
- *Credits for Site Design Practices*: The use of certain better site design practices may allow the WQ_v volume to be reduced through the subtraction of a site design "credit." These site design credits are described in Section 1.4.
- *Determining the Peak Discharge for the Water Quality Storm:* When designing off-line structural control facilities, the peak discharge of the water quality storm (Q_{wq}) can be determined using the method provided in Section 2.1.
- *Extended Detention of the Water Quality Volume:* The water quality treatment requirement can be met by providing a 24-hour drawdown of a portion of WQ_v in a stormwater pond or wetland

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system (as described in Chapter 3). Referred to as water quality ED (extended detention), it is different than providing extended detention of the 1-year storm for the channel protection volume (CP_v). The ED portion of the WQv may be included when routing the CP_v.

- WQ_v can be expressed in cubic feet by multiplying by 43,560.
- WQ_v can also be expressed in watershed-inches by removing the area (A) and the "12" in the denominator.

1.3.2.2 Channel Protection (CP_v)

The Channel Protection sizing criterion specifies that 24 hours of extended detention be provided for runoff generated by the 1-year, 24-hour rainfall event to protect downstream channels. The required volume needed for 1-year extended detention, denoted CP_v, is roughly equivalent to the required volume needed for peak discharge control of the 5- to 10-year storm.

- CP_v control is not required for post-development discharges less than 2.0 cfs.
- The use of nonstructural site design practices that reduce the total amount of runoff will also reduce the channel protection volume by a proportional amount.
- The channel protection criteria may be waived by a local jurisdiction for sites that discharge directly into larger streams, rivers, wetlands, lakes, estuaries, or tidal waters where the reduction in the smaller flows will not have an impact on streambank or channel integrity.

Discussion

The increase in the frequency and duration of bankfull flow conditions in stream channels due to urban development is the primary cause of streambank erosion and the widening and downcutting of stream channels. Therefore, channel erosion downstream of a development site can be significantly reduced by storing and releasing stormwater runoff from the channel-forming runoff events (which corresponds approximately to the 1-year storm event) in a gradual manner to ensure that critical erosive velocities and flow volumes are not exceeded.

Determining the Channel Protection Volume (CP_v)

- *CP_v Calculation Methods:* Several methods can be used to calculate the CP_v storage volume required for a site. Subsection 2.1.5.8 in Chapter 2 and Appendix D-1 illustrate the recommended average outflow method for volume calculation.
- *Hydrograph Generation:* The SCS TR-55 hydrograph methods provided in Section 2.1 can be used to compute the runoff hydrograph for the 1-year, 24-hour storm.
- *Rainfall Depths:* The rainfall depth of the 1-year, 24-hour storm will vary depending on location and can be determined from rainfall tables included in Appendix A for various locations across Georgia.
- *Multiple Drainage Areas*: When a development project contains or is divided into multiple drainage areas, CP_v may be distributed proportionally to each drainage area.
- *Off-site Drainage Areas:* Off-site drainage areas should be modeled as "present condition" for the 1-year storm event. If there are adequate upstream channel protection controls, then the off-site area can be modeled as "forested" or "natural" condition. A structural stormwater control located "on-line" will need to safely bypass any off-site flows.
- *Routing/Storage Requirements:* The required storage volume for the CP_v may be provided above the WQ_v storage in stormwater ponds and wetlands with appropriate hydraulic control structures for each storage requirement.
- *Control Orifices*: Orifice diameters for CP_v control of less than 3 inches are not recommended without adequate clogging protection (see Section 2.3).

1.3.2.3 Overbank Flood Protection (Q_{p25})

The Overbank Flood Protection criterion specifies that the post-development 25-year, 24-hour storm peak discharge rate, denoted Q_{p25}, not exceed the pre-development (or undisturbed natural conditions) discharge rate. This is achieved through detention of runoff from the 25-year event.

- Smaller storm events (e.g., 2-year and 10-year) are effectively controlled through the combination of the extended detention for the 1-year event (channel protection CP_v control) and the control of Q_{p25} for overbank channel protection.
- Larger storms (> 25-year) are partially attenuated through the control of Q_{p25}.
- The use of nonstructural site design practices that reduce the total amount of runoff will also reduce Q_{p25} by a proportional amount.

Control of Q_{p25} is not intended to serve as a stand-alone design standard, but is intended to be used in conjunction with the channel protection AND extreme flood protection criteria. If detention is designed for only the 25-year storm, smaller runoff events will simply pass through the outlet structure with little attenuation. If the channel protection criterion is not used, then for overbank flood protection, peak flow attenuation of the 2-year (Q_{p2}) through the 25-year (Q_{p25}) return frequency storm events must be provided.

Discussion

The purpose of overbank flood protection is to prevent an increase in the frequency and magnitude of damaging out-of-bank flooding (i.e., flow events that exceed the capacity of the channel and enter the floodplain). It is intended to protect downstream properties from flooding at middle-frequency storm events.

This criterion may be adjusted by a local jurisdiction for areas where all downstream conveyances are designed to handle runoff from the full buildout 25-year storm, or where it can be demonstrated that no downstream flooding will occur as a result of a proposed development (see 2.1.9). In this case, the overbank flood protection criterion may be waived by a local jurisdiction in lieu of provision of safe and effective conveyance to a major river system, lake, wetland, estuary, or tidal waters that have capacity to handle flow increases at the 25-year level.

Determining the Overbank Flood Protection Volume (Q_{p25})

- *Peak-Discharge and Hydrograph Generation:* The SCS TR-55 or USGS hydrograph methods provided in Section 2.1 can be used to compute the peak discharge rate and runoff for the 25-year, 24-hour storm.
- *Rainfall Depths:* The rainfall depth of the 25-year, 24-hour storm will vary depending on location and can be determined from rainfall tables included in Appendix A for various locations across Georgia.
- *Off-site Drainage Areas:* Off-site drainage areas should be modeled as "present condition" for the 25-year storm event and do not need to be included in Q_{p25} estimates, but can be routed through a structural stormwater control.
- *Downstream Analysis:* Downstream areas should be checked to ensure there is no peak flow increase above pre-development conditions to the point where the site area is 10% of the total drainage to that point.

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1.3.2.4 Extreme Flood Protection (Q_f)

The Extreme Flood Protection criterion specifies that all stormwater management facilities be designed to safely handle the runoff from the 100-year, 24-hour return frequency storm event, denoted Q_f. This is accomplished either by:

(1) Controlling Q_f through on-site or regional structural stormwater controls to maintain the existing 100-year floodplain. This is done where residences or other structures have already been constructed within the 100-year floodplain fringe area; or
(2) By sizing the on-site conveyance system to safely pass Q_f and allowing it to discharge into a receiving water whose protected full buildout floodplain is sufficiently sized to account for extreme flow increases without causing damage.

Local flood protection (levees, floodwalls, floodproofing, etc.) and/or channel enlargements may be substituted as appropriate, as long as adequate conveyance and structural safety is ensured through the measure used, and stream environmental integrity is adequately maintained.

Discussion

The intent of the extreme flood protection is to prevent flood damage from infrequent but large storm events, maintain the boundaries of the mapped 100-year floodplain, and protect the physical integrity of the structural stormwater controls as well as downstream stormwater and flood control facilities.

It is recommended that Q_f be used in the routing of runoff through the drainage system and stormwater management facilities to determine the effects on the facilities, adjacent property, and downstream. Emergency spillways of structural stormwater controls should be designed appropriately to safely pass the resulting flows.

Determining the Extreme Flood Protection Criteria (Q_{p25})

- *Peak-Discharge and Hydrograph Generation:* The SCS TR-55 or USGS hydrograph methods provided in Section 2.1 can be used to compute the peak discharge rate and runoff for the 100-year, 24-hour storm.
- *Rainfall Depths:* The rainfall depth of the 100-year, 24-hour storm will vary depending on location and can be determined from rainfall tables included in Appendix A for various locations across Georgia.
- *Off-site Drainage Areas:* Off-site drainage areas should be modeled as "full buildout condition" for the 100-year storm event to ensure safe passage of future flows.
- *Downstream Analysis:* If Q_f is being detained, downstream areas should be checked to ensure there is no peak flow increase above pre-development conditions to the point where the site area is 10% of the total drainage to that point.

1.3.3 Meeting the Unified Stormwater Sizing Criteria Requirements

1.3.3.1 Introduction

There are two primary approaches for managing stormwater runoff and addressing the unified stormwater sizing criteria requirements on a development site:

- **The use of better site design practices to reduce the amount of stormwater runoff and pollutants generated and/or provide for natural treatment and control of runoff; and**
- **The use of structural stormwater controls to provide treatment and control of stormwater runoff**

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This subsection introduces both of these approaches. Stormwater better site practices are discussed in-depth in Section 1.4, while structural stormwater controls are covered in Chapter 3.

1.3.3.2 Site Design as the First Step in Addressing Unified Stormwater Sizing Criteria Requirements

Using the site design process to reduce stormwater runoff and pollutants should always be the first consideration of the site designer and engineer in the planning of the stormwater management system for a development.

Through the use of a combination of approaches collectively known as *stormwater better site design* practices and techniques, it is possible to reduce the amount of runoff and pollutants that are generated, as well as provide for at least some nonstructural on-site treatment and control of runoff. Better site design concepts can be viewed as both water quantity and water quality management tools and can reduce the size and cost of required structural stormwater controls—sometimes eliminating the need for them entirely. The site design approach can result in a more natural and cost-effective stormwater management system that better mimics the natural hydrologic conditions of the site, has a lower maintenance burden and provides for more sustainability.

Better site design includes:

- Conserving natural features and resources
- Using lower impact site design techniques
- Reducing impervious cover
- Utilizing natural features for stormwater management

For each of the above categories, there are a number of practices and techniques that aim to reduce the impact of urban development and stormwater runoff from the site. These better site design practices are described in detail in Section 1.4.

For several of the better site design practices, there is a direct economic benefit to their implementation for both stormwater quality and quantity through the application of site design "credits." In terms of the unified stormwater sizing criteria, Table 1.3.3-1 shows how the use of nonstructural site design practices can provide a reduction in the amount of stormwater runoff that is required to be treated and/or controlled through the application of site design credits.

Table 1.3.3-1 Reductions or "Credits" to the Unified Stormwater Sizing Criteria through the Use of Better Site Design Practices

Sizing Criteria	Potential Benefits of the Use of Better Site Design Practices
Water Quality (WQ_v)	• Better site design practices that reduce the total amount of runoff will also reduce WQ_v by a proportional amount. • Certain site design practices will allow for a further reduction to the Water Quality Volume. The site design credits are discussed in Section 1.4.
Channel Protection, Overbank Flood Protection, and Extreme Flood Protection (CP_v, Q_{p25}, Q_f)	• The use of better site design practices that reduce the total amount of runoff will also reduce CP_v, Q_{p25}, and Q_f by a proportional amount. • Floodplain preservation may allow waiving of overbank flood and/or extreme flood protection requirements.

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1.3.3.3 Recommended Structural Stormwater Control Practices

Structural stormwater controls (sometimes referred to as *structural best management practices* or *BMPs*) are constructed stormwater management facilities designed to treat stormwater runoff and/or mitigate the effects of increased stormwater runoff peak rate, volume, and velocity due to urbanization.

This Manual recommends a number of structural stormwater controls for meeting unified stormwater sizing criteria. The recommended controls are divided into three categories: *general application*, *limited application*, and *detention* structural controls.

General Application Controls

General application structural controls are recommended for use with a wide variety of land uses and development types. These structural controls have a demonstrated ability to effectively treat the Water Quality Volume (WQ_v) and are presumed to be able to remove 80% of the total annual average TSS load in typical post-development urban runoff when designed, constructed and maintained in accordance with recommended specifications. Several of the general application structural controls can also be designed to provide water quantity control; i.e., downstream channel protection (CP_v), overbank flood protection (Q_{p25}) and/or extreme flood protection (Q_f). General application controls are the recommended stormwater management facilities for a site wherever feasible and practical.

There are six types of general application controls, which are summarized below. Detailed descriptions of each structural control along with design criteria and procedures are provided in Section 3.2.

Stormwater Ponds

Stormwater ponds are constructed stormwater retention basins that have a permanent pool (or micropool) of water. Runoff from each rain event is detained and treated in the pool. Pond design variants include:

- Wet Pond
- Wet Extended Detention Pond
- Micropool Extended Detention Pond
- Multiple Pond Systems

Stormwater Wetlands

Stormwater wetlands are constructed wetland systems used for stormwater management. Stormwater wetlands consist of a combination of shallow marsh areas, open water and semi-wet areas above the permanent water surface. Wetland design variants include:

- Shallow Wetland
- Extended Detention Shallow Wetland
- Pond/Wetland Systems
- Pocket Wetland

Bioretention Areas

Bioretention areas are shallow stormwater basins or landscaped areas that utilize engineered soils and vegetation to capture and treat stormwater runoff. Runoff may be returned to the conveyance system, or allowed to fully or partially exfiltrate into the soil.

Sand Filters

Sand filters are multi-chamber structures designed to treat stormwater runoff through filtration, using a sand bed as the primary filter media. Filtered runoff may be returned to the conveyance system, or allowed to fully or partially exfiltrate into the soil. The two sand filter design variants are:

- Surface Sand Filter
- Perimeter Sand Filter

Infiltration Trenches

An infiltration trench is an excavated trench filled with stone aggregate used to capture and allow infiltration of stormwater runoff into the surrounding soils from the bottom and sides of the trench.

Enhanced Swales

Enhanced swales are vegetated open channels that are explicitly designed and constructed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other means. The two types of enhanced swales are:

- Dry Swale
- Wet Swale/Wetland Channel

Limited Application Controls

Limited application structural controls are those that are recommended only for limited use or for special site or design conditions. Generally, these practices: (1) cannot alone achieve the 80% TSS removal target, (2) are intended to address hotspot or specific land use constraints or conditions, and/or (3) may have high or special maintenance requirements that may preclude their use. Limited application controls are typically used for *water quality treatment only*. Some of these controls can be used as a pretreatment measure or in series with other structural controls to meet pollutant removal goals. Limited application structural controls should be considered primarily for commercial, industrial or institutional developments.

The following limited application controls are provided for consideration in this Manual. Each is discussed in detail with appropriate application guidance in Section 3.3.

Biofilters

- Filter Strip
- Grass Channel

Filtering Practices

- Organic Filter
- Underground Sand Filter

Wetland Systems

- Submerged Gravel Wetland

Hydrodynamic Devices

- Gravity (Oil-Grit) Separator

Porous Surfaces

- Modular Porous Paver Systems
- Porous Concrete

Chemical Treatment

- Alum Treatment System

Proprietary Systems

- Commercial Stormwater Controls

Detention Controls

Detention structural controls provide only water quantity control (CP_v, Q_{p25}, and/or Q_f), and are typically used downstream of a general application or limited application structural control. Types of detention controls include:

- Dry Detention and Dry Extended Detention Basins
- Multi-purpose Detention Areas
- Underground Detention

A detailed discussion of each of the detention controls, as well as design criteria and procedures can be found in Section 3.4.

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1.3.3.4 Using Structural Stormwater Controls to Meet Unified Stormwater Sizing Criteria Requirements

Structural stormwater controls should be considered after all reasonable attempts have been made to minimize stormwater runoff and maximize its control and treatment through the better site design methods. Once the need for structural controls has been established, one or more appropriate controls will need to be selected to handle the stormwater runoff storage and treatment requirements calculated using the unified stormwater sizing criteria. Guidance for choosing the appropriate structural stormwater control(s) for a site is provided in Section 3.1.

Table 1.3.3-2 summarizes the stormwater management suitability of the various structural controls in addressing the unified stormwater sizing criteria. Given that many structural controls cannot meet all of the sizing criteria, typically two or more controls are used in series to form what is known as a stormwater "treatment train." Section 3.1 provides guidance on the use of a treatment train as well as calculating the pollutant removal efficiency for structural controls in series.

Table 1.3.3-2 Suitability of Structural Stormwater Controls to Meet Unified Stormwater Sizing Criteria

Structural Stormwater Control	Water Quality Volume (WQ_v)	Channel Protection (CP_v)	Overbank Flood Protection (Q_{p25})	Extreme Flood Protection (Q_f)
General Application				
Stormwater Ponds	✓	✓	✓	✓
Stormwater Wetlands	✓	✓	✓	✓
Bioretention Areas	✓	✪	●	●
Sand Filters	✓	✪	●	●
Infiltration Trenches	✓	✪	●	●
Enhanced Swales	✓	✪	✪	●
Limited Application				
Biofilters	O	●	●	●
Filtering Practices	✓	●	●	●
Wetland Systems	✓	●	●	●
Hydrodynamic Devices	O	●	●	●
Porous Surfaces	✓	✪	●	●
Chemical Treatment	✓	●	●	●
Proprietary Systems	*	*	*	*
Detention Controls	●	✓	✓	✓

✓ = Able to meet stormwater sizing criterion (for water quality, this control is presumed to meet the 80% TSS reduction goal when sized to treat the WQ_v and designed, constructed and maintained properly)

O = Typically provides partial treatment of WQ_v. May be used in pretreatment and as part of a "treatment train"

✪ = Can be incorporated into the structural control in certain situations

● = Not typically able or used to meet stormwater sizing criterion

* = The application and performance of specific commercial devices and systems must be provided by the manufacturer and should be verified by independent third-party sources and data

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1.3.3.5 Typical Steps in Addressing the Unified Stormwater Sizing Criteria

Each development site is unique in how stormwater management objectives are met. The type of development, physical site conditions, location in the watershed, and other factors determine how the minimum stormwater management standards and unified stormwater sizing criteria are addressed.

Figure 1.3.3-1 provides a flowchart for the typical steps in stormwater management system design using the unified stormwater sizing criteria. This is a subset of the stormwater site planning process detailed in Section 1.5.

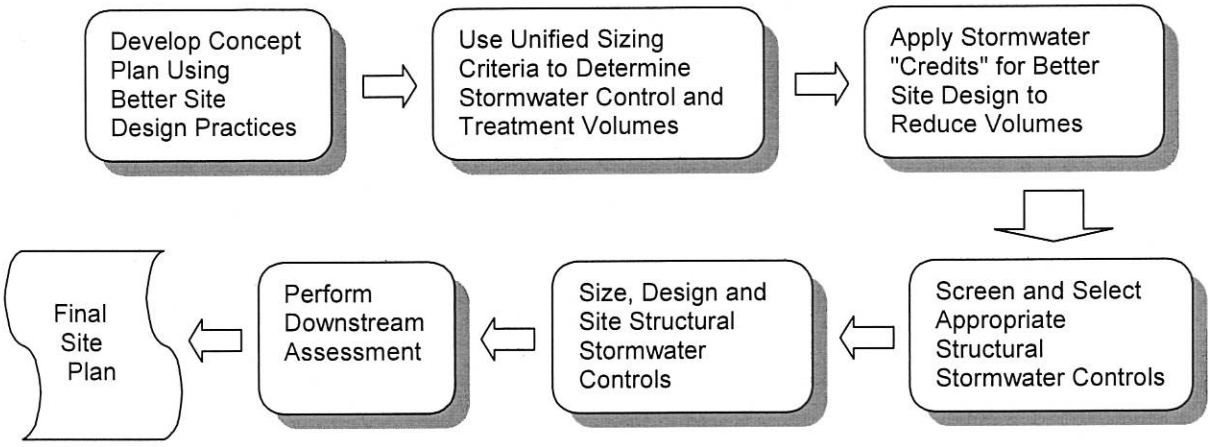

Figure 1.3.3-1 Typical Stormwater Management System Design Process

SARB_011181

Linda S. Adams
Agency Secretary

California Regional Water Quality Control Board

Central Coast Region

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Governor

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February 15, 2008

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Notification to Traditional, Small MS4s on Process for Enrolling under the State's General NPDES Permit for Storm Water Discharges

Introduction

As Executive Officer of the Regional Water Quality Control Board, Central Coast Region (Water Board), I am writing to notify you of the Water Board's revised process for enrolling traditional, small Municipal Separate Storm Sewer Systems (MS4s) under the State's General Permit No. CAS000004 (General Permit). Water Board staff have identified you as an entity that owns or operates an MS4, so you must enroll in the General Permit and develop and implement a Storm Water Management Program (SWMP). This letter describes the SWMP approval process and our expectations regarding the content of your SWMP to comply with the General Permit, and provides you with the schedule Water Board staff intend to follow for review of your SWMP and enrollment of your MS4 under the General Permit. Staff will communicate further with you as your enrollment cycles begin, to establish specific schedules for the five phases leading to enrollment.

Water Board staff will evaluate your SWMP for compliance with the General Permit requirements, including the Maximum Extent Practicable standard, and as appropriate will approve the SWMP and enroll you in the General Permit. If requested, Water Board staff will schedule a public hearing before the Central Coast Water Board for consideration of an individual SWMP.

The Water Board's revised enrollment process is a fundamental shift from the way we have reviewed and approved SWMPs to date. The revised enrollment process eliminates the multiple SWMP review/edit iterations and negotiations that characterized our previous approach. For SWMPs that do not meet the schedule and content described here for General Permit compliance, staff will draft specific resolutions or individual permits for Water Board consideration that will protect water quality, beneficial uses, and the biological and physical integrity of watersheds.

Enrollment Process and Schedule

Water Board staff grouped the 24 remaining un-enrolled traditional MS4s into eight enrollment cycles (Table 1). Each cycle spans a period of 33 to 38 weeks and concludes, on the projected date, with Water Board approval of individual SWMPs and enrollment of the MS4s under the General Permit.

Each enrollment cycle includes five time-limited phases requiring specific actions by both Water Board staff and the MS4 (Table 2). The precise timing and duration of each phase is subject to

change; Water Board staff will develop specific schedules at the commencement of each enrollment cycle.

Table 1: Enrollment Cycles for Attachment 1 and 2 MS4s

Cycle	MS4 Group	Group Members	Projected Start Date for Enrollment Cycle	Projected Executive Officer SWMP Approval	Projected Board SWMP Approval [1]
1	Santa Maria/Lompoc	Santa Maria Lompoc	Jan. 22, 2008	July 28, 2008	Sept. 5, 2008 San Luis Obispo
2	Coastal Santa Barbara County	Goleta Carpinteria Santa Barbara UC Santa Barbara	Jan. 29, 2008	September 2, 2008	Oct. 17, 2008 Santa Barbara
3	Santa Cruz Mountains and Coast	Santa Cruz County Capitola Soquel Aptos Ben Lomond Boulder Creek Live Oak Felton Coralitos Watsonville City of Santa Cruz Scotts Valley UC Santa Cruz	Mid February 2008	October 20, 2008	Dec. 5, 2008 San Luis Obispo
4	Coastal San Luis Obispo County	Arroyo Grande Grover Beach Pismo Beach Oceano Morro Bay Baywood – Los Osos	Mid April 2008	January 2009	2009 – 1st Quarter San Luis Obispo
5	Upper Salinas	King City Templeton Atascadero	Early June 2008	February 2009	2009 – 1st Quarter Salinas
6	City of San Luis Obispo	City of San Luis Obispo	Early September 2008	April 2009	2009 – 2nd Quarter San Luis Obispo
7	Upper Pajaro	Gilroy San Martin Santa Clara	Early November 2008	August 2009	2009 – 3rd Quarter Watsonville
8	Santa Ynez	Buellton Solvang Vandenberg AFB	Mid November 2008	August 2009	2009 – 3rd Quarter San Luis Obispo

1. Board approval only required if a hearing is requested by stakeholder

Table 2: Phases of MS4 Enrollment Cycle

	Duration (weeks)
Phase I: Water Board Staff Assessment of Water Quality Challenges	
Water Board staff: Assess available water quality information Accept input from stakeholders on water quality conditions Prepare and transmit to MS4 staff a statement of current knowledge of water quality challenges that must be addressed by SWMP	3 – 4
Phase II: Water Board Staff SWMP Review	
Water Board staff: Review SWMP and "red-lines" text Send red-lined SWMP and letter explaining requirements to MS4	3 – 4
Phase III: MS4 SWMP Redraft	
MS4 staff re-draft SWMP and post for Public Review	6
Phase IV: Water Board Staff Final Review and Posting of SWMP	
Water Board staff review SWMP	2 – 4
Water Board staff post SWMP and table of required revisions for Public Review	8
Water Board staff respond to public comment and EO approves SWMP	3 – 4
Phase V: Water Board Action (if hearing requested)	
Water Board staff prepare Staff Report with recommendation and resolution for SWMP approval	2
Water Board Staff: Post Staff Report with Board Agenda for Public Review Respond to additional public comment Prepares Presentation for Hearing Conduct internal review up to Board Meeting	6
Total	**33 to 38**

Communication

Clear and open communication between Water Board staff, MS4 staff, and stakeholders is vital to the success of this enrollment process. Also, the Phase II General Permit requires public participation as a component of developing and implementing successful stormwater management programs for MS4s. To comply with the General Permit, you must verify that you have achieved broad and timely distribution of announcements of scoping meetings, draft stormwater program documents, and local agency actions on stormwater program activities when you submit your SWMP for Water Board staff review.

Water Board staff are committed to ensuring that the enrollment process proceeds with open communication. Staff will employ a list-serve (email notification) for notifying all interested parties of important milestones in each enrollment cycle. Water Board staff will also maintain an MS4 enrollment tracking webpage where staff will post relevant documents and indicate the status of each MS4 in the enrollment process. Additionally, an individual Water Board staff person will be assigned to each enrollment cycle. We request that you also identify an individual to serve as point of contact representing your MS4 with whom we will communicate during the enrollment process. You must identify your point of contact when Water Board staff contact you to initiate your enrollment cycle.

Central Coast Water Board Expected SWMP Content

The federal Clean Water Act (CWA) provides that National Pollutant Discharge Elimination System (NPDES) permits for MS4s must require municipalities to reduce pollutants in their stormwater discharges to the Maximum Extent Practicable (MEP) (CWA §402(p)(3)(B)). The California Water Boards have established the meaning and application of this standard through several adopted stormwater permits (the MEP standard is the same for Phase I and Phase II municipalities)[1]. The Water Board implements the General Permit to be consistent with its Water Quality Control Plan (Basin Plan) to ensure protection of water quality, beneficial uses, and the biological and physical integrity of watersheds according to the issues in the Regions.

Your SWMP must include an array of Best Management Practices (BMPs), including the six Minimum Control Measures listed in the General Permit, to achieve the following conditions:

I. Maximize infiltration of clean stormwater, and minimize runoff volume and rate
II. Protect riparian areas, wetlands, and their buffer zones
III. Minimize pollutant loading; and
IV. Provide long-term watershed protection

I. Maximize Infiltration of clean stormwater, and minimize runoff volume and rate.
Water Board staff expect your SWMP to present a schedule for development and adoption of control standards for hydromodification. For SWMP adoption, staff will recommend to the Water Board the following interim requirements, which would apply until such time that you develop acceptable control standards for hydromodification:

- For new and re-development projects, Effective Impervious Area[2] shall be maintained at less than five percent (5%) of total project area.
- For new and redevelopment projects that create and/or replace 5,000 square feet or more of impervious surface, the post-construction runoff hydrographs shall match within one percent (1%) the pre-construction[3] runoff hydrographs, for a range of events with return periods from 1-year to 10-years.
- For projects whose disturbed project area exceeds two acres, preserve the pre-construction drainage density (miles of stream length per square mile of watershed) for all drainage areas serving a first order stream[4] or larger, and ensure that post-project time of concentration is equal or greater than pre-project time of concentration.

These interim requirements must be implemented for all applicable projects subject to your discretionary approvals within six (6) months of your enrollment in the Phase II permit. Your schedule for development and adoption of your own control standards for hydromodification must include:

- Numeric criteria for controlling stormwater runoff volume and rates from new and redevelopment.

[1] Several stormwater permits adopted by different Regional Boards have been legally challenged. All have been upheld by the State Water Resources Control Board and the courts. The Water Boards have broad authority to regulate stormwater and land use activities that result in discharges to waters of the State. Urbanization is one the most important land use activities affecting water quality, beneficial uses, and the physical and biological integrity of watersheds in the Central Coast Region.

[2] Effective Impervious Area is that portion of the impervious area that drains directly to a receiving surface waterbody via a hardened storm drain conveyance without first draining to a pervious area. In other words, impervious surfaces tributary to pervious areas are not considered Effective Impervious Area.

[3] Pre-construction condition is defined as undeveloped soil type and vegetation.

[4] A first order stream is defined as a stream with no tributaries.

- Numeric criteria for stream stability required to protect downstream beneficial uses and prevent physical changes to downstream stream channels that would adversely affect the physical structure, biologic condition, and water quality of streams.
- Specific applicability criteria, land disturbance acreage thresholds, and exemptions.
- Performance criteria for control BMPs and an inspection program to ensure proper long term functioning over.
- Education requirements for appropriate municipal staff on hydromodification and Low Impact Development.

You must include an effective strategy to control hydromodification, or Water Board staff will recommend to the Water Board requirements in the resolution approving your SWMP and enrolling you in the Phase II permit.

II. Protect riparian areas, wetlands, and their buffer zones:
Your SWMP must include BMPs and/or other control measures to establish and maintain a minimum 30-foot buffer zone for riparian areas and wetlands[5]. The buffer zone is a protective area that is undisturbed to the maximum extent practicable. Your SWMP must include consideration and prioritization of local conditions, such as habitat degradation, water quality, and land management practices, and apply more substantial buffer zones where necessary to protect riparian areas and wetlands.

You must include an effective strategy to adopt and implement protection of riparian areas, wetlands, and their buffer zones, or Water Board staff will recommend to the Water Board requirements in the resolution approving your SWMP and enrolling you in the Phase II permit.

III. Minimize pollutant loading
Your SWMP must include BMPs and/or other control measures to minimize pollutant loading, including volume- and/or flow-based treatment criteria. Your SWMP must include consideration and prioritization of local conditions, such as existing pollutant loading, water quality, 303(d) listed impaired waters, pollutants of concern, habitat degradation, and land management practices, and apply more stringent control measures where necessary to minimize pollutant loading.

You must include an effective strategy to reduce pollutant loading, or Water Board staff will recommend to the Water Board requirements in the resolution approving your SWMP and enrolling you in the Phase II permit.

IV. Provide long-term watershed protection
You must include in your SWMP a strategy to develop watershed based hydromodification management plans. These plans should incorporate Low Impact Development strategies with the goal of Post Construction Storm Water Management to achieve an Effective Impervious Area of no more than three to ten percent (3 – 10%) of watershed area within your jurisdiction, depending on local conditions.

The requirements listed above are often characterized as hydromodification controls, or Low Impact Development. These terms are related and their meanings overlap. These requirements are necessary to ensure protection of water quality, beneficial uses, and the biological and physical integrity of watersheds and aquatic habitat. You can reference information on hydromodification controls and Low Impact Development principles on the Central Coast Water Board's website:

[5] The Central Coast Water Quality Control Plan (Basin Plan) requires protection of riparian and wetland habitat and their buffer zones (Basin Plan, Section V.G. 4).

http://www.waterboards.ca.gov/centralcoast/stormwater/low%20impact%20devel/lid_index.htm.

Evaluation of Program Effectiveness and Progress toward Water Quality Goals

Because MEP is a dynamic performance standard which evolves over time as stormwater management knowledge increases, MS4 managers must continually assess and modify their programs to incorporate improvements in control measures and BMPs to achieve MEP. Therefore, your SWMP should contain a detailed plan for evaluating its effectiveness and progress toward complying with the General Permit. Your SWMP must also explain how you will communicate evaluation results with stakeholders. Your evaluation plan should include quantifiable measures for evaluating the effectiveness of the program and be based on the following objectives:

- Assess compliance with requirements of the General Permit , including:
  - Inspection Programs
  - Construction Site Controls
  - Elimination of unlawful discharges
  - New development and redevelopment requirements
- Verify that BMPs are being implemented (e.g., all new applicable developments meet hydromodification control requirements described above and as further described in your SWMP);
- Assess the chemical, physical, and biological impacts on beneficial uses caused by pollutants of concern in stormwater discharges;
- Characterize watersheds and stormwater discharges;
- Identify sources of pollutants; and
- Evaluate long-term trends in receiving water quality.

Conclusion

Please become familiar with the schedule for the enrollment cycle for your MS4, and the steps in the enrollment process. When Water Board staff contact you to initiate your enrollment cycle, please provide us with contact information for the individual that will be representing your MS4.

Please begin updating or preparing your SWMP to include the following as explained in this letter:

- Hydromodification controls for new and redevelopment;
- Protection of riparian and wetland habitat and their buffer zones;
- Minimization of pollutant loading;
- Provision of long-term watershed protection; and
- Evaluation of program effectiveness.

Your SWMP must be specific and must include: well-defined BMPs and other actions that you will implement, schedules, measurable goals, and measures to determine the effectiveness of your program. If your SWMP is not comprehensive or lacks specificity, I will not approve it, and Water Board staff will draft a resolution or an individual permit for consideration by the Water Board at a hearing.

I am clarifying the Water Board's revised enrollment process and SWMP content and requirements to speed up approval of SWMPs for MS4s in the Central Coast Region that will protect water quality, beneficial uses, and the biological and physical integrity of watersheds. I am also committing staff time to regulate MS4s and provide technical and financial assistance to municipalities for stormwater management programs.

The Proposition 84 Storm Water Grant Program funds may be used to provide matching grants to local public agencies for the reduction and prevention of stormwater pollution of rivers, lakes, and streams. A total of approximately $82 million will be available for matching grants. A scoping meeting to answer questions and to solicit input will be held at our office in San Luis Obispo on Monday, March 3, 2008, from 1:00 – 4:00 PM. For more information on the Proposition 84 Storm Water Grant Program and workshops, visit the State Water Board's website at: http://www.waterboards.ca.gov/funding/prop84.html.

I anticipate you will have questions about this letter and the expected content of your SWMP. Please contact us. Our lead staff for this enrollment process is **Dominic Roques**, **droques@waterboards.ca.gov** or at **(805) 542-4780.**

Sincerely,

Roger W. Briggs
Executive Officer

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INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES ("LID") FOR VENTURA COUNTY

Richard R. Horner[†]

ABSTRACT

The Clean Water Act NPDES permit that regulates municipal separate storm sewer systems (MS4s) in Ventura County, California will be reissued in 2007. The draft permit includes provisions for requiring the use of low impact development practices (LID) for certain kinds of development and redevelopment projects. Using six representative development project case studies, the author investigated the practicability and relative benefits of the permit's LID requirements. The results showed that (1) LID site design and source control techniques are more effective than conventional best management practices (BMPs) in reducing runoff rates; (2) Effective Impervious Area (EIA) can practicably be capped at three percent, a standard more protective than that proposed in the draft permit; and (3) in five out of six case studies, LID methods would reduce site runoff volume and pollutant loading to zero in typical rainfall scenarios.

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INTRODUCTION

The Assessment in Relation to Municipal Permit Conditions

This purpose of this study is to investigate the relative water quality and water reuse benefits of three levels of storm water treatment best management practices (BMPs): (1) basic "treat-and-release" BMPs (e.g., drain inlet filters, CDS units), (2) commonly used BMPs that expose runoff to soils and vegetation (extended-detention basins and biofiltration swales and filter strips), and (3) low-impact development (LID) practices. The factors considered in the investigation are runoff volume, pollutant loading, and the availability of water for infiltration or other reuse. In order to assess the differential impact of storm water reduction approaches on these factors, this study examines six case studies typical of development covered by the Ventura County Municipal Separate Storm Sewer System Permit.

Low-impact development methods reduce storm runoff and its contaminants by decreasing their generation at sources, infiltrating into the soil or evaporating storm flows before they can enter surface receiving waters, and treating flow remaining on the surface through contact with vegetation and soil, or a combination of these strategies. Soil-based LID practices often use soil enhancements such as compost, and thus improve upon the performance of more traditional basins and biofilters. For the study's purposes, verification of the practicability and utility of LID practices was based on a modified version of the Planning and Land Development Program (Part 4, section E) in the Draft Ventura County Municipal Separate Storm Sewer System Permit ("Draft Permit"). The Draft Permit requires that Effective Impervious Area (EIA) of certain types of new development and redevelopment projects be limited to five percent of

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total development project area. EIA is defined as hardened surface hydrologically connected via sheet flow or a discrete hardened conveyance to a drainage system or receiving water body. (Draft Permit p. 50) The study modified this requirement to three percent, as a way to test both the feasibility of meeting the higher, five percent standard in the draft permit and because as the lower, three percent EIA is essential to protect the Ventura County aquatic environment (see Attachment A).

The Draft Permit further requires minimizing the overall percentage of impervious surfaces in new development and redevelopment projects to support storm water infiltration. The Draft Permit also directs an integrated approach to minimizing and mitigating storm water pollution, using a suite of strategies including source control, LID, and treatment control BMPs. (Draft Permit p. 50) It is noted in this section of the document that impervious surfaces can be rendered "ineffective" if runoff is dispersed through properly designed vegetated swales. In testing the practicability of the draft permit's requirements and a three percent EIA standard, this study broadened this approach to encompass not only vegetated swales (channels for conveyance at some depth and velocity) but also vegetated filter strips (surfaces for conveyance in thin sheet flow) and bioretention areas (shallow basins with a range of vegetation types in which runoff infiltrates through soil either to groundwater or a subdrain for eventual surface discharge). The Draft Permit's stipulation of "properly designed" facilities was interpreted to entail, among other requirements, either determination that existing site soils can support runoff reduction through infiltration or that soils will be amended using accepted LID techniques to attain this objective. Finally, the study further broadened implementation options to include water harvesting (collection and storage for use in, for example, irrigation or gray water systems), roof downspout infiltration trenches, and porous pavements.

The Draft permit was interpreted to require management of EIA, other impervious area (what might be termed Not-Connected Impervious Area, NCIA), and pervious areas as follows:

- Runoff from EIA is subject to treatment control and the Draft Permit's Hydromodification Mitigation Control requirements before discharge.

- NCIA must be drained onto a properly designed vegetated surface or its runoff managed by one of the other options discussed in the preceding paragraph. To the extent NCIA runoff is not eliminated prior to discharge from the site in one of these ways, it is subject to treatment control and the Draft Permit's Hydromodification Mitigation Control requirements before discharge.

- Runoff from pervious areas is subject to treatment control and the Draft Permit's Hydromodification Mitigation Control requirements before discharge. This provision applies to pervious areas that both do and do not receive drainage from NCIA.

Where treatment control BMPs are required to manage runoff from the site, the Draft Permit's Volumetric or Hydrodynamic (Flow Based) Treatment Control design bases were assumed to apply. The former basis applies to storage-type BMPs, like ponds, and requires capturing and treating either the runoff volume from the 85th percentile 24-hour rainfall event for the location, the volume of annual runoff to achieve 80 percent or more volume treatment, or the volume of runoff produced from a 0.75 inch storm event. The calculations in this analysis used the 0.75-inch quantity. The Hydrodynamic basis applies to flow-through BMPs, like swales, and requires treating the runoff flow rate produced from a rain event equal to at least 0.2 inches per hour intensity (or one of two other approximately equivalent options).

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Scope of the Assessment

With respect to each of the six development case studies, three assessments were undertaken: a baseline scenario incorporating no storm water management controls; a second scenario employing conventional BMPs; and a third development scenario employing LID storm water management strategies.

To establish a baseline for each case study, annual storm water runoff volumes were estimated, as well as concentrations and mass loadings of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). These baseline estimates were based on the anticipated land use and cover with no storm water management efforts.

Two sets of calculations were then conducted using the parameters defined for the six case studies.

The first group of calculations estimated the extent to which basic BMPs reduce runoff volumes and pollutant concentrations and loadings, and what impact, if any, such BMPs have on recharge rates or water retention on-site.

The second group of calculations estimated the extent to which commonly used soil-based BMPs and LID site design strategies ameliorate runoff volumes and pollutant concentrations and loadings, and the effect such techniques have on recharge rates. When evaluating LID strategies, it was presumed that EIA would be limited to three percent and runoff from EIA, NCIA, and pervious areas would be managed as indicated above. The assessment of basins, biofiltration, and low-impact design practices analyzed the expected infiltration capacity of the case study sites. It also considered related LID techniques and practices, such as source reduction strategies, that could work in concert with infiltration to serve the goals of: (1) preventing increase in annual runoff volume from the pre- to the post-developed state, (2) preventing increase in annual pollutant mass loadings between the two development states, and (3) avoiding exceedances of California Toxics Rule (CTR) acute saltwater criteria for copper and zinc.

The results of this analysis show that:

- Developments implementing no post-construction BMPs result in storm water runoff volume and pollutant loading that are substantially increased, and recharge rates that are substantially decreased, compared to pre-development conditions.

- Developments implementing basic post-construction treatment BMPs achieve reduced pollutant loading compared to developments with no BMPs, but storm water runoff volume and recharge rates are similar to developments with no BMPs.

- Developments implementing traditional basins and biofilters, and even more so low-impact post-construction BMPs, achieve significant reduction of pollutant loading and runoff volume as well as greatly enhanced recharge rates compared to both developments with no BMPs and developments with basic treatment BMPs.

- Typical development categories, ranging from single family residential to large commercial, can feasibly implement low-impact post-construction BMPs designed in compliance with the draft permit's requirements, as modified to include a lower, three percent EIA requirement.

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This report covers the methods employed in the investigation, data sources, and references for both. It then presents the results, discusses their consequences, draws conclusions, and makes recommendations relative to the feasibility of utilizing low-impact development practices in Ventura County developments.

CASE STUDIES

Six case studies were selected to represent a range of urban development types considered to be representative of coastal Southern California, including Ventura County. These case studies involved: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), an office building (OFF), a relatively large (1000 homes) single-family residential development (Lg-SFR) and a sizeable commercial retail installation (COMM).[1]

Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. Code requirements vary by jurisdiction, with the tendency now to drop below the traditional 200 sq ft average. About 180 sq ft is common, but various standards for full- and compact-car spaces, and for the mix of the two, can raise or lower the average.[2] The 176 sq ft size is considered to be a reasonable value for conventional practice.

Roadways and walkways assume a wide variety of patterns. Exclusive of the two SFR cases, simple, square parking lots with roadways around the four sides and square buildings with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively.

Single-family residences were assumed each to have a driveway 20 ft wide and 30 ft long. It was further assumed that each would have a sidewalk along the front of the lot, which was calculated to be 5749 sq ft in area. Assuming a square lot, the front dimension would be 76 ft. A 40-ft walkway was included within the property. Sidewalks and walkways were taken to be 4 ft wide.

Exclusive of the COMM case, the total area for all of these impervious features was subtracted from the total site area to estimate the pervious area, which was assumed to have conventional landscaping cover (grass, small herbaceous decorative plants, bushes, and a few trees). For the COMM scenario, the hypothetical total impervious cover was enlarged by 10 percent to represent the landscaping, on the belief that a typical retail commercial establishment would typically be mostly impervious.

Table 1 (page 5) summarizes the characteristics of the six case studies. The table also provides the recorded or estimated areas in each land use and cover type.

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[1] Building permit records from the City of San Marcos in San Diego County provided data on total site areas for the first four case studies, including numbers of buildings, building footprint areas (including porch and garage for Sm-SFR), and numbers of parking spaces associated with the development projects. While the building permit records made no reference to features such as roadways, walkways, and landscaping normally associated with development projects, these features were taken into account in the case studies using assumptions described herein. Larger developments were not represented in the sampling of building permits from the San Marcos database. To take larger development projects into account in the subsequent analysis, the two larger scale case studies were hypothesized. The Lg-SFR scenario scaled up all land use estimates from the Sm-SFR case in the ratio of 1000:23. The hypothetical COMM scenario consisted of a building with a 2-acre footprint and 500 parking spaces. As with the smaller-scale cases, these hypothetical developments were assumed to have roadways, walkways, and landscaping, as described herein.

[2] J. Gibbons, *Parking Lots*, NONPOINT EDUCATION FOR MUNICIPAL OFFICERS, Technical Paper No. 5 (1999) (http://nemo.uconn.edu/tools/publications/tech_papers/tech_paper_5.pdf).

Table 1. Case Study Characteristics and Land Use and Land Cover Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
No. buildings	11	23	1	1	1000	1
Total area (ft^2)	476,982	132,227	33,669	92,612	5,749,000	226,529
Roof area (ft^2)	184,338	34,949	3,220	7,500	1,519,522	87,120
No. parking spaces	438	-	33	37	-	500
Parking area (ft^2)	77,088	-	5808	6512	-	88,000
Access road area (ft^2)	22,212	-	6097	6456	-	23,732
Walkway area (ft^2)	33,960	10,656	1362	2078	463,289	7,084
Driveway area (ft^2)	-	13,800	-	-	600,000	-
Landscape area (ft^2)	159,384	72,822	17,182	70,066	3,166,190	20,594

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential;
REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

METHODS OF ANALYSIS

Annual Storm Water Runoff Volumes

Annual surface runoff volumes produced were estimated for both pre- and post-development conditions for each case study site. Runoff volume was computed as the product of annual precipitation, contributing drainage area, and a runoff coefficient (ratio of runoff produced to rainfall received). For impervious areas the following equation was used:

$$C = (0.009)\,I + 0.05$$

where I is the impervious percentage. This equation was derived by Schueler (1987) from Nationwide Urban Runoff Program data (U.S. Environmental Protection Agency 1983). With I = 100 percent for fully impervious surfaces, C is 0.95.

The basis for pervious area runoff coefficients was the Natural Resource Conservation Service's (NRCS) Urban Hydrology for Small Watersheds (NRCS 1986, as revised from the original 1975 edition). This model estimates storm event runoff as a function of precipitation and a variable representing land cover and soil, termed the curve number (CN). Larger events are forecast to produce a greater amount of runoff in relation to amount of rainfall because they more fully saturate the soil. Therefore, use of the model to estimate annual runoff requires selecting some event or group of events to represent the year. A 0.75-inch rainfall event was used in the analysis here for the relative comparison between pre- and post-development and applied to deriving a runoff coefficient for annual estimates, recognizing that smaller storms would produce less and larger storms more runoff.

To select CN for the pre-development case, an analysis performed in the area of the Cedar Fire in San Diego County was used in which CN was determined before and after the 2003 fire.[3] In the San Diego analysis, CN = 83 was estimated for the pre-existing land cover, which was generally chaparral, a vegetative cover also typical of Ventura County. As indicated below, soils are also similar in Ventura and San Diego Counties, making the parameter selection reasonable for use in both locations. For post-development landscaping, CN = 86 was selected based on tabulated data in NRCS (1986) and professional judgment.

Pre- and post-development runoff quantities were computed with these CN values and the 0.75-inch rainfall, and then divided by the rainfall to obtain runoff coefficients. The results were 0.07

[3] American Forests, *San Diego Urban Ecosystem Analysis After the Cedar Fire* (Feb. 3, 2006) (http://www.ufei.org/files/pubs/SanDiegoUrbanEcosystemAnalysis-PostCedarFire.pdf).

and 0.12, respectively. Finally, total annual runoff volumes were estimated based on an average annual precipitation in the City of Ventura of 14.71 inches.[4]

Storm Water Runoff Pollutant Discharges

Annual pollutant mass discharges were estimated as the product of annual runoff volumes produced by the various land use and cover types and pollutant concentrations typical of those areas. Again, the 0.75-inch precipitation event was used as a basis for volumes. Storm water pollutant data have typically been measured and reported for general land use types (e.g., single-family residential, commercial). However, an investigation of low-impact development practices of the type this study sought to conduct demands data on specific land coverages. The literature offers few data on this basis. Those available and used herein were assembled by a consultant to the City of Seattle for a project in which the author participated. They appear in Attachment B (Herrera Environmental Consultants, Inc. undated).

Pollutant concentrations expected to occur typically in the mixed runoff from the several land use and cover types making up a development were estimated by mass balance; i.e., the concentrations from the different areas of the sites were combined in proportion to their contribution to the total runoff.

The Effect of Conventional Treatment BMPs on Runoff Volume, Pollutant Discharges, and Recharge Rates

The first question in analyzing how BMPs reduce runoff volumes and pollutant discharges was, What BMPs are being employed in Ventura County developments under the permit now in force? This permit is open-ended and provides regulated entities with a large number of choices and few fixed requirements. These options presumably include manufactured BMPs, such as drain inlet inserts (DIIs) and continuous deflective separation (CDS) units. Developments may also select such non-proprietary devices as extended-detention basins (EDBs) and biofiltration swales and filter strips. EDBs hold water for two to three days for solids settlement before releasing whatever does not infiltrate or evaporate. Biofiltration treats runoff through various processes mediated by vegetation and soil. In a swale, runoff flows at some depth in a channel, whereas a filter strip is a broad surface over which water sheet flows. Each of these BMP types was applied to each case study, although it is not clear that these BMPs, in actuality, have been implemented consistently within Ventura County to date.

The principal basis for the analysis of BMP performance was the California Department of Transportation's (CalTrans, 2004) BMP Retrofit Pilot Program, performed in San Diego and Los Angeles Counties. One important result of the program was that BMPs with a natural surface infiltrate and evaporate (probably, mostly infiltrate) a substantial amount of runoff, even if conditions do not appear to be favorable for an infiltration basin. On average, the EDBs, swales, and filter strips lost 40, 50 and 30 percent, respectively, of the entering flow before the discharge point. DIIs and CDS units do not contact runoff with a natural surface, and therefore do not reduce runoff volume.

The CalTrans program further determined that BMP effluent concentrations were usually a function of the influent concentrations, and equations were developed for the functional

[4] Ventura County Watershed Protection District (http://www.vcwatershed.org/fws/specialmedia.htm). The City of Ventura is considered to be representative of most of the developed and developing areas in Ventura County. However, there is some variation around the county, with the maximum precipitation registered at Ojai (annual average 21.32 inches). Ojai is about 15 miles inland and lies at elevation 745 ft at the foot of the Topatopa Mountains, the orographic effect of which influences its meteorology. Ojai's higher rainfall was taken into account in the calculations, and the report notes the few instances where it affected the conclusions.

relationships in these cases. BMPs generally reduced influent concentrations proportionately more when they were high. In relatively few situations influent concentrations were constant at an "irreducible minimum" level regardless of inflow concentrations.

In analyzing the effects of BMPs on the case study runoff, the first step was to reduce the runoff volumes estimated with no BMPs by the fractions observed to be lost in the pilot study. The next task was estimating the effluent concentrations from the relationships in the CalTrans report. The final step was calculating discharge pollutant loadings as the product of the reduced volumes and predicted effluent concentrations. As before, typical pollutant concentrations in the mixed runoff were established by mass balance.

Estimating Infiltration Capacity of the Case Study Sites

Infiltrating sufficient runoff to maintain pre-development hydrologic characteristics and prevent pollutant transport is the most effective way to protect surface receiving waters. Successfully applying infiltration requires soils and hydrogeological conditions that will pass water sufficiently rapidly to avoid overly-lengthy ponding, while not allowing percolating water to reach ground-water before the soil column captures pollutants.

The study assumed that infiltration would occur in surface facilities and not in below-ground trenches. The use of trenches is certainly possible, and was judged to be an approved BMP by CalTrans after the pilot study. However, the intent of this investigation was to determine the ability of pervious areas to manage the site runoff. This was accomplished by determining the infiltration capability of the pervious areas in their original condition for each development case study, and further assessing the pervious areas' infiltration capabilities if soils were modified according to low impact development practices.

The chief basis for this aspect of the work was an assessment of infiltration capacity and benefits for Los Angeles' San Fernando Valley (Chralowicz et al. 2001). The Chralowicz study posited providing 0.1-0.5 acre for infiltration basins to serve each 5 acres of contributing drainage area. At 2-3 ft deep, it was estimated that such basins could infiltrate 0.90-1.87 acre-ft/year of runoff in San Fernando Valley conditions. Soils there are generally various loam textures with infiltration rates of approximately 0.5-2.0 inches/hour. The most prominent soils in Ventura County, at least relatively near the coast, are loams, sandy loams, loamy sands, and silty clay loams, thus making the conclusions of the San Fernando Valley study applicable for these purposes.[5] This information was used to estimate how much of each case study site's annual runoff would be infiltratable, and if the pervious portion would provide sufficient area for infiltration. For instance, if sufficient area were available, the infiltration configuration would not have to be in basin form but could be shallower and larger in surface area. This study's analyses assumed the use of bioretention areas rather than traditional infiltration basins.

Volume and Pollutant Source Reduction Strategies

As mentioned above, the essence of low-impact development is reducing runoff problems before they can develop, at their sources, or exploiting the infiltration and treatment abilities of soils and vegetation. If a site's existing infiltration and treatment capabilities are inadequate to preserve pre-development hydrology and prevent runoff from causing or contributing to violations of water quality standards, then LID-based source reduction strategies can be implemented, infiltration and treatment capabilities can be upgraded, or both.

[5] Cabrillo Port Liquefied Natural Gas Deepwater Port Draft EIS/EIR (Oct. 2004) (http://www.cabrilloport.ene.com/files/eiseir/4.05%20%20-Agriculture%20and%20Soils.pdf).

Source reduction can be accomplished through various LID techniques. Soil can be upgraded to store runoff until it can infiltrate, evaporate, or transpire from plants through compost addition. Soil amendment, as this practice is known, is a standard LID technique.

Upgraded soils are used in bioretention cells that hold runoff and effect its transfer to the subsurface zone. This standard LID tool can be used where sufficient space is available. This study analyzed whether the six development case study sites would have sufficient space to effectively reduce runoff using bioretention cells, assuming the soils and vegetation could be amended and enhanced where necessary.

Conventional pavements can be converted to porous asphalt or concrete or replaced with concrete or plastic unit pavers or grid systems. For such approaches to be most effective, the soils must be capable of infiltrating the runoff passing through, and may require renovation.

Source reduction can be enhanced by the LID practice of water harvesting, in which water from impervious surfaces is captured and stored for reuse in irrigation or gray water systems. For example, runoff from roofs and parking lots can be harvested, with the former being somewhat easier because of the possibility of avoiding pumping to use the water and fewer pollutants. Harvesting is a standard technique for Leadership in Energy and Environmental Design (LEED) buildings.[6] Many successful systems of this type are in operation, such as the Natural Resources Defense Council offices (Santa Monica, CA), the King County Administration Building (Seattle, WA), and two buildings on the Portland State University campus (Portland, OR). This investigation examined how water harvesting could contribute to storm water management for case study sites where infiltration capacity, available space, or both appeared to be limited.

RESULTS OF THE ANALYSIS

1. "Base Case" Analysis: Development without Storm Water Controls

Comparison of Pre- and Post-Development Runoff Volumes

Table 2 (page 9) presents a comparison between the estimated runoff volumes generated by the respective case study sites in the pre- and post-development conditions, assuming implementation of no storm water controls on the developed sites. On sites dominated by impervious land cover, most of the infiltration that would recharge groundwater in the undeveloped state is expected to be lost to surface runoff after development. This greatly increased surface flow would raise peak flow rates and volumes in receiving water courses, raise flooding risk, and transport pollutants. Only the office building, the plan for which retained substantial pervious area, would lose less than half of the site's pre-development recharge.

[6] New Buildings Institute, Inc., *Advanced Buildings* (2005) (http://www.poweryourdesign.com/LEEDGuide.pdf).

Table 2. Pre- and Post-Development without BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater

Annual Volume (acre-ft)	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Precipitation[b]	13.4	3.72	0.95	2.60	162	6.37
Pre-development runoff[c]	0.94	0.26	0.07	0.18	11	0.45
Pre-development recharge[d]	12.5	3.46	0.88	2.42	150	5.92
Post-development impervious runoff[c]	8.48	1.59	0.44	0.60	69	5.50
Post-development pervious runoff[c]	0.54	0.25	0.06	0.24	11	0.07
Post-development total runoff[c]	9.02	1.83	0.50	0.84	80	5.57
Post-development recharge[d]	4.39	1.88	0.45	1.76	82	0.80
Post-development recharge loss (% of pre-development recharge)	8.08 (65%)	1.57 (46%)	0.43 (49%)	0.66 (27%)	68 (45%)	5.12 (86%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential;
COMM—retail commercial
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Pollutant Concentrations and Loadings

Table 3 presents the pollutant concentrations from the literature and loadings calculated as described for the various land use and cover types represented by the case studies. Landscaped areas are expected to release the highest TSS concentration, although relatively low TSS mass loading because of the low runoff coefficient. The highest copper concentrations and loadings are expected from parking lots. Roofs, especially commercial roofs, top the list for both zinc concentrations and loadings. Landscaping would issue by far the highest phosphorus, although access roads and driveways would contribute the highest mass loadings.

Table 3. Pollutant Concentrations and Loadings for Case Study Land Use and Cover Types

Land Use	Concentrations				Loadings			
	TSS (mg/L)	TCu (mg/L)	TZn (mg/L)	TP (mg/L)	Lbs. TSS/ acre-year	Lbs. TCu/ acre-year	Lbs. TZn/ acre-year	Lbs. TP/ acre-year
Residential roof	25	0.013	0.159	0.11	79	0.041	0.503	0.348
Commercial roof	18	0.014	0.281	0.14	57	0.044	0.889	0.443
Access road/driveway	120	0.022	0.118	0.66	380	0.070	0.373	2.088
Parking	75	0.036	0.097	0.14	237	0.114	0.307	0.443
Walkway	25	0.013	0.059	0.11	79	0.041	0.187	0.348
Landscaping	213	0.013	0.059	2.04	85	0.005	0.024	0.815

The CTR acute criteria for copper and zinc are 0.0048 mg/L and 0.090 mg/L, respectively. Table 3 shows that all developed land uses are expected to discharge copper above the criterion, based on the mass balance calculations using concentrations from Table 3. Any surface release from the case study sites would violate the criterion at the point of discharge, although dilution by the receiving water would lower the concentration below the criterion at some point. Even if copper mass loadings are reduced by BMPs, any surface discharge would exceed the criterion initially, but it would be easier to dilute below that level. In contrast, runoff from some land covers would not violate the acute zinc criterion. Because of this difference, the evaluation considered whether or not the zinc criterion would be exceeded in each analysis, whereas there was no point in this analysis for copper. There are no equivalent water quality

criteria for TSS and TP; hence, their concentrations were not further analyzed in the different scenarios.

Table 4 shows the overall loadings, as well as zinc concentrations, expected to be delivered from the case study developments should they not be fitted with any BMPs. As Table 4 shows, all cases are forecast to exceed the 0.090 mg/L acute zinc criterion, and the retail commercial development does so by a wide margin. Because of its size, the large residential development dominates the mass loading emissions.

Table 4. Case Study Pollutant Concentration and Loading Estimates without BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.175
Lbs. TSS/year	1321	345	125	242	15016	853
Lbs. TCu/year	0.46	0.074	0.032	0.045	3.21	0.37
Lbs. TZn/year	3.09	0.607	0.174	0.301	26.4	2.64
Lbs. TP/year	6.58	2.39	0.72	1.78	104	3.36

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

2. "Conventional BMP" Analysis: Effect of Basic Treatment BMPs

Effect of Basic Treatment BMPs on Post-Development Runoff Volumes

The current permit allows regulated parties to select from a range of BMPs in order to treat or infiltrate a given quantity of annual rainfall. The range includes drain inlet inserts, CDS units, and other manufactured BMPs, detention vaults, and sand filters, all of which isolate runoff from the soil; as well as basins and biofiltration BMPs built in soil and generally having vegetation. Treatment BMPs that do not permit any runoff contact with soils discharge as much storm water runoff as equivalent sites with no BMPs, and hence yield zero savings in recharge. As mentioned above, the CalTrans (2004) study found that BMPs with a natural surface can reduce runoff by substantial margins (30-50 percent for extended-detention basins and biofiltration).

With such a wide range of BMPs in use, runoff reduction ranging from 0 to 50 percent, and a lack of clearly ascertainable requirements, it is not possible to make a single estimate of how much recharge savings are afforded by maximal implementation of the current permit. We made the following assumptions regarding implementation of BMPs. Assuming natural-surface BMPs perform at the average of the three types tested by CalTrans (2004), i.e., 40 percent runoff reduction, the estimate can be bounded as shown in Table 5 (page 11). The table demonstrates that allowing free choice of BMPs without regard to their ability to direct water into the ground forfeits substantial groundwater recharge benefits when hardened-surface BMPs are selected. Use of soil-based conventional BMPs could cut recharge losses from half or e more of the full potential to about one-quarter to one-third or less, except with the highly impervious commercial development. This analysis shows the wisdom of draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way. But as subsequent analyses showed, soil amendment can gain considerably greater benefits.

Table 5. Pre- and Post-Development with Conventional BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater

Annual Volume (acre-ft)	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Precipitation[b]	13.4	3.72	0.95	2.60	162	6.37
Pre-development runoff[c]	0.94	0.26	0.07	0.18	11	0.45
Pre-development recharge	12.5	3.46	0.88	2.42	150	5.92
Post-development impervious runoff[c, d]	5.09-8.48	0.95-1.59	0.26-0.44	0.36-0.60	41-69	3.30-5.50
Post-development pervious runoff[c, d]	0.32-0.54	0.15-0.25	0.04-0.06	0.14-0.24	6.6-11	0.04-0.07
Post-development total runoff[c, d]	5.41-9.02	1.10-1.83	0.30-0.50	0.50-0.84	48-80	3.34-5.57
Post-development recharge[d, e]	4.39-7.99	1.88-2.62	0.45-0.65	1.76-2.10	82-114	0.80-3.03
Post-development recharge loss (% of pre-development recharge) [d, e]	4.51-8.08 (36-65%)	0.84-1.57 (24-46%)	0.23-0.43 (26-49%)	0.32-0.66 (13-27%)	36-68 (24-45%)	2.89-5.12 (49-86%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial. Ranges represent 40 percent runoff volume reduction, with full site coverage by BMPs having a natural surface, to no reduction, with BMPs isolating runoff from soil.
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Ranging from the quantity with hardened bed BMPs to the quantity with soil-based BMPs
[e] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Effect of Basic Treatment BMPs on Pollutant Discharges

Table 6 (page 12) presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from four types of conventional treatment BMPs. The manufactured CDS BMPs in this table, which do not expose runoff to soil or vegetation, are not expected to drop any of the concentrations sufficiently to meet the acute zinc criterion at the discharge point. The loading reduction results show the CDS units always performing below 50 percent reduction for all pollutants analyzed, and most often in the vicinity of 20 percent, with zero copper reduction.

When treated with swales or filter strips, effluents from each development case study site are expected to fall below the CTR acute zinc criterion. All but the large commercial site would meet the criterion with EDB treatment. These natural-surface BMPs, if fully implemented and well maintained, are predicted to prevent the majority of the pollutant masses generated on most of the development sites from reaching a receiving water. Only total phosphorus reduction falls below 50 percent for two case studies. Otherwise, mass loading reductions range from about 60 to above 80 percent for the EDB, swale, and filter strip. This data indicates that draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way, pays water quality as well as hydrologic dividends.

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Table 6. Pollutant Concentration and Loading Reduction Estimates with Conventional BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Effluent Concentrations:						
CDS TZn (mg/L)[a]	0.095	0.095	0.098	0.102	0.095	0.131
EDB TZn (mg/L)[a]	0.085	0.086	0.084	0.084	0.086	0.098
Swale TZn (mg/L)	0.055	0.054	0.055	0.056	0.054	0.068
Filter strip TZn (mg/L)	0.039	0.039	0.039	0.041	0.039	0.048
Loading Reductions:						
CDS TSS loading reduction	15.7%	19.9%	22.0%	24.0%	19.9%	16.9%
CDS TCu loading reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CDS TZn loading reduction	22.7%	22.4%	22.9%	23.1%	22.4%	25.1%
CDS TP loading reduction	30.6%	41.5%	40.7%	45.9%	41.5%	20.3%
EDB TSS loading reduction	68.1%	73.7%	79.0%	81.1%	73.7%	71.7%
EDB TCu loading reduction	61.9%	55.7%	66.2%	63.0%	55.7%	66.8%
EDB TZn loading reduction	59.7%	59.6%	60.4%	61.9%	59.6%	66.6%
EDB TP loading reduction	61.9%	69.7%	69.1%	72.9%	69.7%	54.5%
Swale TSS loading reduction	68.8%	71.1%	73.1%	73.9%	71.1%	69.4%
Swale TCu loading reduction	72.5%	68.5%	78.2%	73.3%	68.5%	75.8%
Swale TZn loading reduction	78.4%	78.1%	84.3%	78.8%	78.1%	80.7%
Swale TP loading reduction	66.3%	70.7%	67.2%	76.2%	70.7%	55.0%
Filter strip TSS loading reduction	69.9%	75.4%	80.6%	82.6%	75.4%	72.3%
Filter strip TCu loading reduction	74.4%	69.1%	78.2%	75.4%	69.1%	78.7%
Filter strip TZn loading reduction	78.3%	77.9%	78.4%	78.7%	77.9%	80.9%
Filter strip TP loading reduction	48.4%	53.1%	63.7%	59.8%	53.1%	34.6%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial; CDS— continuous deflective separation unit; EDB—extended-detention basin

3. LID Analysis: Development According to Modified Draft Permit Provisions

(a) Hydrologic Analysis

The LID analysis was first performed according to the Draft Permit provisions under the Planning and Land Development Program (Part 4, section E). In this analysis, however, EIA was limited to three instead of five percent, under the reasoning presented in Attachment A. All runoff from NCIA was assumed to drain to vegetated surfaces, as provided in the Draft Permit.

One goal of this exercise was to identify methods that reduce runoff production in the first place. It was hypothesized that implementation of source reduction techniques could allow all of the case study sites to infiltrate substantial proportions of the developed site runoff, advancing the hydromodification mitigation objective of the Draft Permit. When runoff is dispersed into the soil instead of being rapidly collected and conveyed away, it recharges groundwater, supplementing a resource that maintains dry season stream flow and wetlands. An increased water balance can be tapped by humans for potable, irrigation, and process water supply. Additionally, runoff volume reduction would commensurately decrease pollutant mass loadings.

Accordingly, the analysis considered the practicability of more than one scenario by which the draft permit's terms could be met, as modified to reflect three percent EIA. In one option, all roof runoff is harvested and stored for some beneficial use. A second option disperses runoff into the soil via roof downspout infiltration trenches. The former option is probably best suited to cases like the large commercial and office buildings, while distribution in the soil would fit best with residences and relatively small commercial developments. The analysis was repeated with the assumptions of harvesting OFF and COMM roof runoff for some beneficial use and dispersing roof runoff from the remaining four cases in roof downspout infiltration systems.

Expected Infiltration Capacities of the Case Study Sites

The first inquiry on this subject sought to determine how much of the total annual runoff each property is expected to infiltrate. This assessment tested the feasibility of draining all but three percent of impervious area to pervious land on the sites. Based on the findings of Chralowicz et al. (2001), it was assumed that an infiltration zone of 0.1-0.5 acres in area and 2-3 ft deep would serve a drainage catchment area in the size range 0-5 acres and infiltrate 0.9-1.9 acre-ft/year. The conclusions of Chralowicz et al. (2001) were extrapolated to conservatively assume that 0.5 acre would be required to serve each additional five acres of catchment, and would infiltrate an incremental 1.4 acre-ft/year (the midpoint of the 0.9-1.9 acre-ft/year range). According to these assumptions, the following schedule of estimates applies:

Pervious Area Available for Infiltration	Catchment Served acres	Infiltration Capacity
0.5 acres	0-5 acres	1.4 acre-ft/year
1.0 acres	5-10 acres	2.8 acre-ft/year
1.5 acres	10-15 acres	4.2 acre-ft/year
(Etc.)	...	...

As a formula, infiltration capacity ≈ 2.8 x available pervious area. To apply the formula conservatively, the available area was reduced to the next lower 0.5-acre increment before multiplying by 2.8.

As shown in Table 7, five of the six sites have adequate or greater capacity to infiltrate the full annual runoff volume from NCIA and pervious areas where EIA is limited to three percent of the total site area (four at the higher Ojai rainfall). Indeed, five of the six development types have sufficient pervious area to infiltrate *all* runoff, including runoff from EIA areas. With the most representative rainfall, only the large commercial development, with little available pervious area, falls short of the needed capacity to infiltrate all rainfall, but it still has the capacity to meet the terms of the draft permit, as modified for this analysis. These results are based on infiltrating in the native soils with no soil amendment. For any development project at which infiltration-oriented BMPs are considered, it is important that infiltration potential be carefully assessed using site-specific soils and hydrogeologic data. In the event such an investigation reveals a marginal condition (e.g., hydraulic conductivity, spacing to groundwater) for infiltration basins, soils could be enhanced to produce bioretention zones to assist infiltration. Notably, the four case studies with far greater than necessary infiltration capacity would offer substantial flexibility in designing infiltration, allowing ponding at less than 2-3 ft depth.

Table 7. Infiltration and Runoff Volume With 3 Percent EIA and All NCIA Draining to Pervious Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
EIA runoff (acre-ft/year)	0.38	0.11	0.03	0.07	4.6	0.18
NCIA + pervious area runoff (acre-ft/year)	**8.63**	**1.73**	**0.47**	**0.76**	**75.0**	**5.39**
Total runoff (acre-ft/year)	9.01	1.84	0.50	0.83	79.6	5.57
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.47
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**1.4**
Infiltration capacity [c]	> 100%[d]	> 100%	> 100%	> 100%	> 100%	~26% [d]

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Compare runoff production from NCIA + pervious area (**row 3**) with estimated infiltration capacity (**row 6**)
[d] At Ojai rainfall levels, capacity would be ~78 percent at the MFR site and ~18 percent at the COMM site.

As Table 7 shows, five of the six case study sites have the capacity to infiltrate *all* runoff produced onsite by draining impervious surfaces to pervious areas. Even runoff from the area assumed to be EIA could be infiltrated in most cases based on the amount of pervious area available in typical development projects. By showing that it is possible under normal site conditions and using native soils to retain *all* runoff in typical developments, these results demonstrate that a three percent EIA requirement, which would not demand that all runoff be retained, is feasible and practicable.

Additional Source Reduction Capabilities of the Case Study Sites: Water Harvesting Example

Infiltration is one of a wide variety of LID-based source reduction techniques. Where site conditions such as soil quality or available area limit a site's infiltration capacity, other source LID measures can enhance a site's runoff retention capability. For example, soil amendment, which improves infiltration, is a standard LID technique. Water harvesting is another. Such practices can also be used where infiltration capacity is adequate, but the developer desires greater flexibility for land use on-site. Table 8 shows the added implementation flexibility created by subtracting roof runoff by harvesting it or efficiently directing it into the soil through downspout dispersion systems, further demonstrating the feasibility of meeting the draft permit's proposed requirements, as modified to include a three percent EIA standard.

Table 8. Infiltration and Runoff Volume Reduction Analysis Including Roof Runoff Harvesting or Disposal in Infiltration Trenches (Assuming 3 Percent EIA and All NCIA Draining to Pervious Areas)

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
EIA runoff (acre-ft/year)	0.38	0.11	0.03	0.07	4.6	0.18
Roof runoff (acre-ft/year)	4.92	0.93	0.09	0.20	41	2.33
Other NCIA + pervious area runoff (acre-ft/year)	**3.71**	**0.79**	**0.39**	**0.56**	**35**	**3.06**
Total runoff (acre-ft/year)	9.01	1.84	0.50	0.83	79.6	5.57
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.47
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**1.4**
Infiltration capacity [c]	> 100%	> 100%	> 100%	> 100%	> 100%	~45% [d]

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Comparison of runoff production from NCIA + pervious area (**row 3**) with estimated infiltration capacity (**row 6**)
[d] If the higher rainfall at Ojai is assumed, capacity would be ~32 percent of the amount needed for the COMM case.

Effect of Full LID Approach on Recharge

Table 9 (page 15) shows the recharge benefits of preventing roofs from generating runoff and infiltrating as much as possible of the runoff from the remainder of the case study sites. The data show that LID methods offer significant benefits relative to the baseline (no storm water controls) in all cases. These benefits are particularly impressive in developments with relatively high site imperviousness, such as in the MFR and COMM cases. In the latter case the full LID approach (excluding the common and effective practice of soil amendment) would cut loss of the potential water resource represented by recharge and harvesting from 86 to 37 percent.

Table 9. Comparison of Water Captured Annually (in acre-ft) from Development Sites for Beneficial Use With a Full LID Approach Compared to Development With No BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Pre-development recharge[b] (acre-ft)	12.5	3.46	0.88	2.42	150	5.92
No BMPs:						
post-development recharge [b] (acre-ft)	4.39	1.88	0.45	1.76	82	0.80
post-development runoff (acre-ft)	8.08	1.57	0.43	0.66	68	5.12
post-development % recharge lost	65%	46%	49%	27%	45%	86%
Full LID approach:						
post-development runoff capture (acre-ft)[c]	12.5	3.46	0.88	2.42	150	3.73
post-development runoff (acre-ft)	0	0	0	0	0	2.19
post-development % recharge lost	0%	0%	0%	0%	0%	37%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial
[b] Quantity of water infiltrating the soil; the difference between precipitation and runoff
[c] Water either entirely infiltrated in BMPs and recharged to groundwater or partially harvested from roofs and partially infiltrated in BMPs. For the first five case studies, EIA was not distinguished from the remainder of the development, because these sites have the potential to capture all runoff.

(b) Water Quality Analysis

As outlined above, it was assumed that EIA discharges, as well as runoff from all pervious surfaces, are subject to treatment control. For purposes of the analysis, treatment control was assumed to be provided by conventional sand filtration. This choice is appropriate for study purposes for two reasons. First, sand filters can be installed below grade, and land above can be put to other uses. Under the Draft Permit's approach, pervious area should be reserved for receiving NCIA drainage, and using sand filters would not draw land away from that service or other site uses. A second reason for the choice is that sand filter performance data equivalent to the data used in analyzing other conventional BMPs are available from the CalTrans (2004) work. Sand filters may or may not expose water to soil, depending on whether or not they have a hard bed. This analysis assumed a hard bed, meaning that no infiltration would occur and thus there would be no additional recharge in sand filters. Performance would be even better than shown in the analytical results if sand filters were built in earth.

Pollutant Discharge Reduction Through LID Techniques

The preceding analyses demonstrated that each of the six case studies could feasibly comply with the draft permit's requirements, as modified to include a more protective three percent EIA standard. Moreover, for five of the six case studies, *all* storm water discharges could be eliminated at least under most meteorological conditions by dispersing runoff from impervious surfaces to pervious areas. Therefore, pollutant additions to receiving waters would also be eliminated. This demonstrates not only that a lower EIA (three percent) is a feasible and practicable approach to maintaining the natural hydrology of land being developed, as discussed above, but that a lower EIA is a feasible and practicable way to eliminate the discharge of pollutants that could cause or contribute to violations of water quality standards.

While the high proportion of impervious area present on the large commercial site relative to pervious area would not allow eliminating all discharge, harvesting roof water and draining NCIA to properly-prepared pervious area would substantially decrease the volume discharged. Deployment of treatment control BMPs (e.g. sand filter treatment) could cut contaminant discharges from pollutants in the remaining volume of runoff to low levels.

Table 10 presents the pollutant reductions from the untreated case achievable through the complete LID approach described above in comparison to conventional treatments (from Table 6). Assuming EIA still discharges through sand filters, pollutant loadings from the untreated condition are expected to decrease by more than 96 percent for all but the COMM case. In that challenging case loadings would still fall by at least 89 percent for TSS and the metals and by 83 percent for total phosphorus, assuming City of Ventura rainfall levels, and slightly less assuming the higher Ojai rainfall levels. Thus, the Draft Permit's basic premise of disconnecting most impervious area, supplemented by specially managing roof water, is shown by both water quality and hydrologic results to be feasible and to afford broad and significant environmental benefits.

Table 10. Pollutant Loading Reduction Estimates With a Full LID Approach Relative to Conventional BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Conventional TSS loading reduction[b]	15.7-69.9%	19.9-75.4%	22.0-80.6%	24.0-82.6%	19.9-75.4%	16.9-72.3%
Conventional TCu loading reduction[b]	0.0-74.4%	0.0-69.1%	0.0-78.2%	0.0-75.4%	0.0-69.1%	0.0-78.7%
Conventional TZn loading reduction[b]	22.7-78.4%	22.4-78.1%	22.9-84.3%	23.1-78.8%	22.4-78.1%	25.1-80.9%
Conventional TP loading reduction[b]	30.6-66.3%	41.5-70.7%	40.7-69.1%	45.9-76.2%	41.5-70.7%	20.3-55.0%
LID TSS loading reduction[c]	99.4%	99.3%	99.5%	99.4%	99.3%	89.0% [d]
LID TCu loading reduction[c]	98.1%	96.7%	98.0%	96.2%	96.7%	90.6% [d]
LID TZn loading reduction[c]	99.1%	98.8%	98.9%	98.3%	98.8%	94.8% [d]
LID TP loading reduction[c]	98.1%	98.6%	98.8%	98.7%	98.6%	83.1%[d]

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial; CDS— continuous deflective separation unit; EDB—extended-detention basin; NCIA—not connected impervious area; EIA—effective (connected) impervious area

[b] Range from Table 6 represented by treatment by CDS unit, EDB, biofiltration swale, or biofiltration strip

[c] Based on directing roof runoff to downspout infiltration trenches (MFR, Sm-SFR, REST, and Lg-SFR) or harvesting it (OFF and COMM), draining other NCIA to pervious areas, and treating EIA with sand filters

[d] If the higher rainfall at Ojai is assumed, reduction estimates for TSS, TCu, TZn, and TP would be 84.0, 86.3, 92.5, and 75.5 percent, respectively.

SUMMARY AND CONCLUSIONS

This paper demonstrated that common Ventura County area residential and commercial development types subject to the Municipal NPDES Permit are likely, without storm water management, to reduce groundwater recharge from the predevelopment state by approximately half in most cases to a much higher fraction with a large ratio of impervious to pervious area. With no treatment, runoff from these developments is expected to exceed CTR acute copper and zinc criteria at the point of discharge and to deliver large pollutant mass loadings to receiving waters.

Conventional soil-based BMP solutions that promote and are component parts of low-impact development approaches, by contrast, regain about 30-50 percent of the recharge lost in development without storm water management, although commercially-manufactured filtration and hydrodynamic BMPs for storm water management give no benefits in this area. It is expected the soil-based BMPs generally would release effluent that meets the acute zinc criterion at the point of discharge, although it would still exceed the copper limit. Excepting phosphorus, it was found that these BMPs would capture and prevent the movement to receiving waters of the majority of the pollutant loadings considered in the analysis.

It was found that a three percent Effective Impervious Area standard can be met in typical developments, and that by draining all site runoff to pervious areas, runoff can be eliminated entirely in most development types. This result was reached assuming the use of native soils. Soil enhancement (typically, with compost) can further advance infiltration. Draining impervious surfaces onto the loam soils typical of Ventura County, in connection with limiting directly connected impervious area to three percent of the site total area, should eliminate storm runoff from some development types and greatly reduce it from more highly impervious types. Adding roof runoff elimination to the LID approach (by harvesting or directing it to downspout infiltration trenches) should eliminate runoff from all but mostly impervious developments. Even in the development scenario involving the highest relative proportion of impervious surface, losses of rainfall capture for beneficial uses could be reduced from more than 85 to less than 40 percent, and pollutant mass loadings would fall by 83-95 percent from the untreated scenario when draining to pervious areas was supplemented with water harvesting. These results demonstrate the basic soundness of the Draft Permit's concept to limit directly connected impervious area and drain the remainder over pervious surfaces.

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ATTACHMENT A

JUSTIFICATION OF PROPOSED EFFECTIVE IMPERVIOUS AREA LIMITATION

Summary

The literature shows that adverse impacts to the physical habitat and biological integrity of receiving waters occur as a result of the conversion of natural areas to impervious cover. These effects are observed at the lowest levels of impervious cover in associated catchments (two to three percent) and are pronounced by the point that impervious cover reaches five percent. To protect biological productivity, physical habitat, and other beneficial uses, effective impervious area should be capped at no more than three percent.

I. Impacts to physical habitat of California receiving waters observed at three percent impervious cover

Stein *et al*.[7] note that while studies from parts of the country with climates more humid than California's indicate that physical degradation of stream channels can initially be detected when watershed impervious cover approaches 10%, biological effects, which may be more difficult to detect, may occur at lower levels (CWP 2003).[8] Recent studies from both northern and southern California indicate that intermittent and ephemeral streams in California are more susceptible to the effects of hydromodification than streams from other regions of the US, with stream degradation being recognized when the associated catchment's impervious cover is as little as 3-5% (Coleman *et al*. 2005).[9] Furthermore, supplemental landscape irrigation in semi-arid regions, like California, can substantially increase the frequency of erosive flows (AQUA TERRA Consultants 2004).[10]

Coleman, *et al*.[3] report that the ephemeral/intermittent streams in southern California (northwestern Los Angeles County through southern Ventura County to central Orange County) appear to be more sensitive to changes in percent impervious cover than streams in other areas. Stream channel response can be represented using an *enlargement curve*, which relates the percent of impervious cover to a change in cross-sectional area. The data for southern California streams forms a relationship very similar in shape to the enlargement curves developed for other North American streams. However, the curve for southern California streams is above the general curve for streams in other climates. This suggests that a specific enlargement ratio is produced at a lower value of impervious surface area in southern California than in other parts of North America. Specifically, the estimated threshold of response is approximately 2-3% impervious cover, as compared to 7-10% for other portions of the U.S. It is important to note that this conclusion applies specifically to streams with a catchment drainage area less than 5 square miles.

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[7] Stein, E.D., S. Zaleski, (2005) *Managing Runoff to Protect Natural Streams: The Latest Developments on Investigation and Management of Hydromodification in California*. (Proceedings of a Special Technical Workshop Co-sponsored by California Stormwater Quality Association (CASQA), Stormwater Monitoring Coalition (SMC), University of Southern California Sea Grant (USC Sea Grant), Technical Report #475).

[8] Center for Watershed Protection (CWP), (2003) *Impacts of Impervious Cover on Aquatic Systems*. Ellicott City, MD.

[9] Coleman, D., C. MacRae, and E.D. Stein, (2005) *Effect of Increases in Peak Flows and Imperviousness on the Morphology of Southern California Streams.* Southern California Coastal Water Research Project Technical Report #450, Westminster, CA.

[10] AQUA TERRA Consultants, (2004) *Urbanization and Channel Stability Assessment in the Arroyo Simi Watershed of Ventura County CA*. FINAL REPORT. Prepared for Ventura County Watershed Protection Division, Ventura CA.

This study concludes that disconnecting impervious areas from the drainage network and adjacent impervious areas is a key approach to protecting channel stability. Utilizing this strategy can make it practical to keep the effective impervious cover (*i.e*. the amount hydrologically connected to the stream) equal to or less than the identified threshold of 2-3%.

II. Impacts to biological integrity of receiving waters observed with any conversion from natural to impervious surface

Two separate studies conducted by Horner *et al*.[11,12] in the Puget Sound region (Washington State), Montgomery County, Maryland, and Austin, Texas built a database totaling more than 650 reaches on low-order streams in watersheds ranging from no urbanization and relatively little human influence (the reference state, representing "best attainable" conditions) to highly urban (>60 percent total impervious area, "TIA"). Biological health was assessed according to the benthic index of biotic integrity (B-IBI) and, in Puget Sound, the ratio of young-of-the-year coho salmon (*Oncorhynchus kisutch*), a relatively stress-intolerant fish, to cutthroat trout (*Oncorhynchus clarki*), a more stress-tolerant species. The following discussion summarizes the results and conclusions of these two studies.

There is no single cause for the decline of water resource conditions in urbanizing watersheds. Instead, it is the cumulative effects of multiple stressors that are responsible for degraded aquatic habitat and water quality. Imperviousness, while not a perfect yardstick, appears to be a useful predictor of ecological condition. However, a range of stream conditions can be associated with any given level of imperviousness. In general, only streams that retain a significant proportion of their natural vegetative land-cover and have very low levels of watershed imperviousness appear to retain their natural ecological integrity. It is this change in watershed land-cover that is largely responsible for the shift in hydrologic regime from a sub-surface flow dominated system to one dominated by surface runoff.

While the decline in ecological integrity is relatively continuous and is consistent for all parameters, the impact on physical conditions appears to be more pronounced earlier in the urbanization process than chemical degradation. It is generally acknowledged, based on field research and hydrologic modeling, that it is the shift in hydrologic conditions that is the driving force behind physical changes in urban stream-wetland ecosystems.

Multiple scales of impact operate within urbanizing watersheds: landscape-level impacts, including the loss of natural forest cover and the increase in impervious surface area throughout the watershed; riparian corridor-specific impacts such as encroachment, fragmentation, and loss of native vegetation; and local impacts such as water diversions, exotic vegetation, stream channelization, streambank hardening, culvert installation, and pollution from the widespread use of pesticides and herbicides. All of these stressors contribute to the overall cumulative impact.

The researchers found that there is no clear threshold of urbanization below which there exists a "no-effect" condition. Instead, there appears to be a relatively continuous decline in almost all measures of water quality or ecological integrity. Losses of integrity occur from the lowest levels of TIA and are already pronounced by the point that TIA reaches 5 percent.

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[11] Horner, R. R., C. W. May, (2002) *The Limitations of Mitigation-Based Stormwater Management in the Pacific Northwest and the Potential of a Conservation Strategy based on Low-Impact Development Principles*. (Proceedings of the American Society of Engineers Stormwater Conference, Portland, OR).

[12] Horner, R.R., E. H. Livingston, C. W. May, J. Maxted, (2006) *BMPs, Impervious Cover, and Biological Integrity of Small Streams*. (Proceedings of the Eighth Biennial Stormwater Research and Watershed Management Conference, Tampa, FL).

Similarly, the Alliance for the Chesapeake Bay[13] reports that small-watershed studies by the Maryland Department of Natural Resources Biological Stream Survey have shown that some sensitive species are affected by even low amounts of impervious cover. In one study, no brook trout were observed in any stream whose watershed had more than 2 percent impervious cover, and brook trout were rare in any watershed with more than 0.5 percent impervious cover.

III. Ventura County's watersheds include biologically-significant water bodies

The literature discussed above is relevant to the watersheds of Ventura County, which contain rivers and streams that currently or historically support a variety of beneficial uses that may be impaired by water quality degradation and stream hydromodification as a result of storm water runoff from impervious land cover. Unlike some Southern California watersheds, Ventura County still has many natural stream systems with a high degree of natural functionality.

For instance, the Ventura River watershed in northwestern Ventura County "supports a large number of sensitive aquatic species,"[14] including steelhead trout, a federally-listed endangered species. Although "local populations of steelhead and rainbow trout have nearly been eliminated along the Ventura River" itself, the California Department of Fish and Game has "recognized the potential for the restoration of the estuary and enhancement of steelhead populations in the Ventura River."[15] Steelhead may also be present in tributaries such as San Antonio Creek.[16] Thriving rainbow trout populations exist in tributaries of the Ventura River including Matilija Creek and Coyote Creek.[17] The Ventura River either does or is projected to support the following beneficial uses: warm freshwater habitat; cold freshwater habitat; wildlife habitat; rare, threatened, or endangered species; migration of aquatic organisms; and spawning and reproduction.[18] Furthermore, the Ventura River Estuary also supports commercial fishing, shellfish harvesting, and wetland habitat.[19] The Ventura River receives municipal storm drain discharges from Ojai, San Buenaventura, and unincorporated areas of Ventura County.[20]

The Santa Clara River watershed in northern Ventura County "is the largest river system in southern California that remains in a relatively natural state."[21] Sespe Creek is one of the Santa Clara's largest tributaries, and "supports significant steelhead spawning and rearing habitat."[22] Other creeks in the Santa Clara River watershed that support steelhead are Piru Creek and Santa Paula Creek. Sespe Creek and the Santa Clara River also provide spawning habitat for the Pacific lamprey. Rainbow trout populations exist in tributaries of the Santa Clara River including Sespe Creek.[23] The creeks and the Santa Clara river do or are projected to support the following beneficial uses: warm freshwater habitat; cold freshwater habitat; wildlife habitat; preservation of biological habitats rare, threatened, or endangered species; migration of aquatic organisms; and spawning and reproduction.[24] Los Padres National Forest covers much of the Santa Clara River watershed, but increasing development in floodplain areas has been

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[13] Karl Blankenship, BAY JOURNAL,"It's a hard road ahead for meeting new sprawl goal: States will try to control growth of impervious" (July/August 2004), at http://www.bayjournal.com/article.cfm?article=66.
[14] Los Angeles Region Water Quality Control Plan (1994) p. 1-18 ("Basin Plan").
[15] Basin Plan, p. 1-16; Ventura County Environmental & Energy Resources Division, "Endangered Steelhead Trout in Ventura County: Past, Present, and Future," available at http://www.wasteless.org/Eye_articles/steelhead.htm.
[16] Ventura County Environmental & Energy Resources Division, "Steelhead Spawning in Ventura County," (2005), available at http://www.wasteless.org/Eye_articles/steehead2005.html.
[17] Ventura County Environmental & Energy Resources Division, "Endangered Steelhead Trout in Ventura County: Past, Present, and Future," available at http://www.wasteless.org/Eye_articles/steelhead.htm.
[18] Basin Plan, Table 2-1.
[19] Basin Plan, Table 2-4.
[20] Ventura County Watershed Protection District, *Report of Waste Discharge* (January 2005) at p. 3.
[21] Basin Plan, p. 1-16.
[22] Basin Plan, p. 1-16.
[23] Ventura County Environmental & Energy Resources Division, "Endangered Steelhead Trout in Ventura County: Past, Present, and Future," available at http://www.wasteless.org/Eye_articles/steelhead.htm.
[24] Basin Plan, Table 2-1.

identified as a threat to the river system's water quality.[25] Furthermore, the Santa Clara estuary supports the additional beneficial uses of shellfish harvesting and wetlands habitat.[26] The Santa Clara River receives municipal storm drain discharges from Fillmore, Oxnard, San Buenaventura, Santa Paula, and unincorporated areas of Ventura County.[27]

The Calleguas Creek watershed "empties into Mugu Lagoon, one of southern California's few remaining large wetlands."[28] It supports or is projected to support the following beneficial uses: estuarine habitat; marine habitat; wildlife habitat; preservation of biological habitats; rare, threatened, or endangered species; migration of aquatic organisms; spawning and reproduction; shellfish harvesting; and wetlands habitat.[29] Historically, Calleguas Creek drained largely agricultural areas. But this watershed has been under increasing pressure from sedimentation due to increased surface flow from municipal discharges and urban wastewaters, among other sources.[30] Increasing residential developments on steep slopes has been identified as a substantial contributing factor to the problem of accelerated erosion in the watershed (and sedimentation in the Lagoon). Calleguas Creek receives municipal storm drain discharges from Camarillo, Moorpark, Simi Valley, Thousand Oaks, and unincorporated areas of Ventura County.[31]

Ventura County's coastal streams also support a variety of beneficial uses:[32]

- Little Sycamore Canyon Creek in southern Ventura County (warm freshwater habitat; wildlife habitat; rare, threatened or endangered species; and spawning and reproduction);
- Lake Casitas tributaries (warm freshwater habitat; cold freshwater habitat; wildlife habitat; rare, threatened or endangered species; spawning and reproduction; and wetland habitat);
- Javon Canyon and Padre Juan Canyon (warm freshwater habitat; cold freshwater habitat; wildlife habitat; and spawning and reproduction); and
- Los Sauces Creek in northern Ventura County (warm freshwater habitat; cold freshwater habitat; wildlife habitat; migration of aquatic species; and spawning and reproduction).

IV. Conclusion

In order to protect the biological habitat, physical integrity, and other beneficial uses of the water bodies in Ventura County, effective impervious area should be capped at no more than three percent.

[25] Basin Plan, pp. 1-16, 1-18.
[26] Basin Plan, Table 2-4.
[27] Ventura County Watershed Protection District, *Report of Waste Discharge* (January 2005) at p. 3.
[28] Basin Plan, p. 1-18.
[29] Basin Plan, Table 2-1.
[30] Basin Plan, pp. 1-16, 1-18.
[31] Ventura County Watershed Protection District, *Report of Waste Discharge* (January 2005) at p. 3.
[32] Basin Plan, Table 2-1.

ATTACHMENT B

POLLUTANT CONCENTRATIONS FOR URBAN SOURCE AREAS (HERRERA ENVIRONMENTAL CONSULTANTS, INC. UNDATED)

Source Area	Study	Location	Sample Size (n)	TSS (mg/L)	TCu (ug/L)	TPb (ug/L)	TZn (ug/L)	TP (mg/L)	Notes
Roofs									
Residential	Steuer, et al. 1997	MI	12	36	7	25	201	0.06	2
Residential	Bannerman, et al. 1993	WI	~48	27	15	21	149	0.15	3
Residential	Waschbusch, et al. 2000	WI	25	15	n.a.	n.a.	n.a.	0.07	3
Residential	FAR 2003	NY		*19*	*20*	*21*	*312*	*0.11*	4
Residential	Gromaire, et al. 2001	France		*29*	*37*	*493*	*3422*	*n.a.*	5
Representative Residential Roof Values				**25**	**13**	**22**	**159**	**0.11**	
Commercial	Steuer, et al. 1997	MI	12	24	20	48	215	0.09	2
Commercial	Bannerman, et al. 1993	WI	~16	15	9	9	330	0.20	3
Commercial	Waschbusch, et al. 2000	WI	25	18	n.a.	n.a.	n.a.	0.13	3
Representative Commercial Roof Values				**18**	**14**	**26**	**281**	**0.14**	
Parking Areas									
Res. Driveways	Steuer, et al. 1997	MI	12	157	34	52	148	0.35	2
Res. Driveways	Bannerman, et al. 1993	WI	~32	173	17	17	107	1.16	3
Res. Driveways	Waschbusch, et al. 2000	WI	25	34	n.a.	n.a.	n.a.	0.18	3
Driveway	FAR 2003	NY		*173*	*17*		*107*	*0.56*	4
Representative Residential Driveway Values				**120**	**22**	**27**	**118**	**0.66**	
Comm./ Inst. Park. Areas	Pitt, et al. 1995	AL	16	110	116	46	110	n.a.	1
Comm. Park. Areas	Steuer, et al. 1997	MI	12	110	22	40	178	0.2	2
Com. Park. Lot	Bannerman, et al. 1993	WI	5	58	15	22	178	0.19	3
Parking Lot	Waschbusch, et al. 2000	WI	25	51	n.a.	n.a.	n.a.	0.1	3
Parking Lot	Tiefenthaler, et al. 2001	CA	5	36	28	45	293	n.a.	6
Loading Docks	Pitt, et al. 1995	AL	3	40	22	55	55	n.a.	1
Highway Rest Areas	CalTrans 2003	CA	53	*63*	*16*	*8*	*142*	*0.47*	7
Park and Ride Facilities	CalTrans 2003	CA	179	*69*	*17*	*10*	*154*	*0.33*	7
Comm./ Res. Parking	FAR 2003	NY		*27*	*51*	*28*	*139*	*0.15*	4
Representative Parking Area/Lot Values				**75**	**36**	**26**	**97**	**0.14**	

Landscaping/Lawns									
Landscaped Areas	Pitt, et al. 1995	AL	6	33	81	24	230	n.a.	1
Landscaping	FAR 2003	NY		*37*	*94*	*29*	*263*	n.a.	4
Representative Landscaping Values				**33**	**81**	**24**	**230**	**n.a.**	
Lawns - Residential	Steuer, et al. 1997	MI	12	262	n.a.	n.a.	n.a.	2.33	2
Lawns - Residential	Bannerman, et al. 1993	WI	~30	397	13	n.a.	59	2.67	3
Lawns	Waschbusch, et al. 2000	WI	25	59	n.a.	n.a.	n.a.	0.79	3
Lawns	Waschbusch, et al. 2000	WI	25	122	n.a.	n.a.	n.a.	1.61	3
Lawns - Fertilized	USGS 2002	WI	58	n.a.	n.a.	n.a.	n.a.	2.57	3
Lawns - Non-P Fertilized	USGS 2002	WI	38	n.a.	n.a.	n.a.	n.a.	1.89	3
Lawns - Unfertilized	USGS 2002	WI	19	n.a.	n.a.	n.a.	n.a.	1.73	3
Lawns	FAR 2003	NY	3	*602*	*17*	*17*	*50*	*2.1*	4
Representative Lawn Values				**213**	**13**	**n.a.**	**59**	**2.04**	

Notes:

Representative values are weighted means of collected data. Italicized values were omitted from these calculations.

1 - Grab samples from residential, commercial/institutional, and industrial rooftops. Values represent mean of DETECTED concentrations

2 - Flow-weighted composite samples, geometric mean concentrations

3 - Geometric mean concentrations

4 - Citation appears to be erroneous - original source of data is unknown. Not used to calculate representative value

5 - Median concentrations. Not used to calculate representative values due to site location and variation from other values.

6 - Mean concentrations from simulated rainfall study

7 - Mean concentrations. Not used to calculate representative values due to transportation nature of land use.

INITIAL INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES ("LID") FOR THE SAN FRANCISCO BAY AREA

Richard R. Horner†

ABSTRACT

The Clean Water Act NPDES permit that regulates municipal separate storm sewer systems (MS4s) in the San Francisco Bay Area, California will be reissued in 2007. The draft permit includes general provisions related to low impact development practices (LID) for certain kinds of development and redevelopment projects. Using six representative development project case studies, based on California building records, the author investigated the practicability and relative benefits of LID options for the majority of the region having soils potentially suitable for infiltration either in their natural state or after amendment using well recognized LID techniques. The results showed that (1) LID site design and source control techniques are more effective than conventional best management practices (BMPs) in reducing runoff rates; and (2) in each of the case studies, LID methods would reduce site runoff volume and pollutant loading to zero in typical rainfall scenarios.

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INTRODUCTION

The Assessment in Relation to Municipal Permit Conditions

This purpose of this study is to investigate the relative water quality and water reuse benefits of three levels of storm water treatment best management practices (BMPs): (1) basic "treat-and-release" BMPs (e.g., drain inlet filters, CDS units), (2) commonly used BMPs that expose runoff to soils and vegetation (extended-detention basins and biofiltration swales and filter strips), and (3) low impact development (LID) practices. The factors considered in the investigation are runoff volume, pollutant loading, and the availability of water for infiltration or other reuse. In order to assess the differential impact of storm water reduction approaches on these factors, this study examines six case studies typical of development covered by the proposed Municipal Regional Urban Runoff Phase I NPDES Stormwater Permit (MRP).

This report covers locations in the Bay Area most amenable to soil infiltration of stormwater runoff, those areas having soils in Natural Resources Conservation Service (NRCS) Hydrologic Soil Groups A, B, or C as classified by the Natural Resources Conservation Service (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). Depending on site-specific conditions, A and B soils would generally effectively infiltrate water without modification, whereas C soils could require organic amendments according to now standard LID methods. This report does not cover locations with group D soils, which are generally not amenable to infiltration, again depending on the specific conditions on-site. A subsequent report will examine options in these locations, which include other LID techniques (e.g., roof runoff harvesting for irrigation or gray water supply) and state-of-the-art conventional stormwater

SARB_011213

management practices. A minority but still substantial fraction of the Bay Area has group D soils (39.3, 68.0, 18.3, and 50.1 percent of the mapped areas of Alameda, Contra Costa, San Mateo, and Santa Clara Counties, respectively). Regarding any mapped soil type, it is important to keep in mind that soils vary considerably within small distances. Characteristics at specific locations can deviate greatly from those of the major mapped unit, making infiltration potential either more or less than may be expected from the mapping.

Low impact development methods reduce storm runoff and its contaminants by decreasing their generation at sources, infiltrating into the soil or evaporating storm flows before they can enter surface receiving waters, and treating flow remaining on the surface through contact with vegetation and soil, or a combination of these strategies. Soil-based LID practices often use soil enhancements such as compost, and thus improve upon the performance of more traditional basins and biofilters. The study encompassed vegetated swales (channels for conveyance at some depth and velocity), vegetated filter strips (surfaces for conveyance in thin sheet flow), and bioretention areas (shallow basins with a range of vegetation types in which runoff infiltrates through soil either to groundwater or a subdrain for eventual surface discharge). Application of these practices in a low impact site design mode requires either determination that existing site soils can support runoff reduction through infiltration or that soils will be amended using accepted LID techniques to attain this objective. Finally, the study further broadened implementation options to include water harvesting (collection and storage for use in, for example, irrigation or gray water systems), roof downspout infiltration trenches, and porous pavements.

The investigation also considered whether typical development patterns and local conditions in the Bay Area would enable LID implementation as required by a new standard proposed for the 2007 Ventura County Municipal Storm Water Permit. This standard requires management of effective impervious area (EIA), limiting it to 5%, as well as other impervious area (what might be termed Not-Connected Impervious Area, NCIA), and pervious areas.

Where treatment control BMPs are required to manage runoff from a site, Volume or Flow Hydraulic Design Bases commonly used in California were assumed to apply. The former basis applies to storage-type BMPs, like ponds, and requires capturing and treating either the runoff volume from the 85th percentile, 24-hour rainfall event for the location or the volume of annual runoff to achieve 80 percent or more volume treatment. The calculations in this analysis used the 85th percentile 24-hour rainfall event basis. The Flow basis applies to flow-through BMPs, like swales, and requires treating the runoff flow rate produced from a rain event equal to at least 0.2 inches per hour intensity (or one of two other approximately equivalent options).

Scope of the Assessment

With respect to each of the six development case studies, three assessments were undertaken: a baseline scenario incorporating no stormwater management controls; a second scenario employing conventional BMPs; and a third development scenario employing LID stormwater management strategies.

To establish a baseline for each case study, annual stormwater runoff volumes were estimated, as well as concentrations and mass loadings of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). These baseline estimates were based on the anticipated land use and cover with no stormwater management efforts.

Two sets of calculations were then conducted using the parameters defined for the six case studies. The first group of calculations estimated the extent to which basic BMPs reduce runoff volumes and pollutant concentrations and loadings, and what impact, if any, such BMPs have on recharge rates or water retention on-site.

The second group of calculations estimated the extent to which commonly used soil-based BMPs and LID site design strategies ameliorate runoff volumes and pollutant concentrations and loadings, and the effect such techniques have on recharge rates. When evaluating LID strategies in the context of the EIA concept employed in the draft Ventura County MS4 permit, it was presumed that EIA would be limited to three percent. It was also assumed that pervious surfaces on a site receiving runoff from other areas on the site would be sized and prepared to manage (through infiltration or storage) the volume directed there in addition to precipitation falling directly on those areas. The assessment of basins, biofiltration, and low impact design practices analyzed the expected infiltration capacity of the case study sites. It also considered related LID techniques and practices, such as source reduction strategies, that could work in concert with infiltration to serve the goals of: (1) preventing increase in annual runoff volume from the pre- to the post-developed state, (2) preventing increase in annual pollutant mass loadings between the two development states, and (3) avoiding exceedances of the Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan) criteria for copper and zinc.

The results of this analysis show that:

- A full-range of typical development categories common in the Bay Area, from single family residential to restaurants, housing developments, and commercial uses like office buildings, can feasibly implement standard LID techniques to achieve no stormwater discharge during rain events equal to, and in some cases greater than, design storm conditions. This conclusion is based on an analysis that used actual building records in California and annual rainfall records in two rainfall zones in the Bay Area to show that site conditions support this level of performance. In addition, site conditions typical at a wide range of development projects are more than sufficient to attain compliance with a three percent EIA limit, as is being contemplated in other MS4 re-issuance proceedings in California presently.

- Developments implementing no post-construction BMPs result in storm water runoff volume and pollutant loading that are substantially increased, and recharge rates that are substantially decreased, compared to pre-development conditions.

- Developments implementing basic post-construction treatment BMPs achieve reduced pollutant loading compared to developments with no BMPs, but stormwater runoff volume and recharge rates are similar to developments with no BMPs.

- Developments implementing traditional basins and biofilters, and even more so low impact post-construction BMPs, achieve significant reduction of pollutant loading and runoff volume as well as greatly enhanced recharge rates compared to both developments with no BMPs and developments with basic treatment BMPs.

This report covers the methods employed in the investigation, data sources, and references for both. It then presents the results, discusses their consequences, draws conclusions, and makes recommendations relative to the feasibility of utilizing low-impact development practices in Bay Area developments.

CASE STUDIES

Six case studies were selected to represent a range of urban development types considered to be representative of the Bay Area. These case studies involved: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), an office building (OFF), a relatively large (1000 homes) single-family residential development (Lg-SFR), and a single home (SINGLE).[1]

Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. Code requirements vary by jurisdiction, with the tendency now to drop below the traditional 200 sq ft average. About 180 sq ft is common, but various standards for full- and compact-car spaces, and for the mix of the two, can raise or lower the average.[2] The 176 sq ft size is considered to be a reasonable value for conventional practice.

Roadways and walkways assume a wide variety of patterns. Exclusive of the two SFR cases, simple, square parking lots with roadways around the four sides and square buildings with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively.

Single-family residences were assumed each to have a driveway 20 ft wide and 30 ft long. It was further assumed that each would have a sidewalk along the front of the lot, which was calculated to be 5749 sq ft in area. Assuming a square lot, the front dimension would be 76 ft. A 40-ft walkway was included within the property. Sidewalks and walkways were taken to be 4 ft wide. For each case study the total area for all of these impervious features was subtracted from the total site area to estimate the pervious area, which was assumed to have conventional landscaping cover (grass, small herbaceous decorative plants, bushes, and a few trees).

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[1] Building permit records from the City of San Marcos in San Diego County provided data on total site areas for the first four case studies, including numbers of buildings, building footprint areas (including porch and garage for Sm-SFR), and numbers of parking spaces associated with the development projects. While the building permit records made no reference to features such as roadways, walkways, and landscaping normally associated with development projects, these features were taken into account in the case studies using assumptions described herein. Larger developments and redevelopment were not represented in the sampling of building permits from the San Marcos database. To take these types of projects into account in the subsequent analysis, the Lg-SFR scenario scaled up all land use estimates from the Sm-SFR case in the ratio of 1000:23. The single home case (SINGLE) was derived from Bay Area records obtained at http://www.ppic.org/content/other/706EHEP_web_only_appendix.pdf, which showed 8000 ft^2 as a rough average for a single home lot in the region. As with the other cases, these hypothetical developments were assumed to have roadways, walkways, and landscaping, as described herein.

[2] J. Gibbons, *Parking Lots*, NONPOINT EDUCATION FOR MUNICIPAL OFFICERS, Technical Paper No. 5 (1999) (http://nemo.uconn.edu/tools/publications/tech_papers/tech_paper_5.pdf).

Table 1 summarizes the characteristics of the six case studies. The table also provides the recorded or estimated areas in each land use and cover type.

Table 1. Case Study Characteristics and Land Use and Land Cover Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
No. buildings	11	23	1	1	1000	1
Total area (ft^2)	476,982	132,227	33,669	92,612	5,749,000	8,000
Roof area (ft^2)	184,338	34,949	3,220	7,500	1,519,522	2114
No. parking spaces	438	-	33	37	-	-
Parking area (ft^2)	77,088	-	5808	6512	-	-
Access road area (ft^2)	22,212	-	6097	6456	-	-
Walkway area (ft^2)	33,960	10,656	1362	2078	463,289	518
Driveway area (ft^2)	-	13,800	-	-	600,000	835
Landscape area (ft^2)	159,384	72,822	17,182	70,066	3,166,190	4533

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home

METHODS OF ANALYSIS

Annual Stormwater Runoff Volumes

Annual surface runoff volumes produced were estimated for both pre- and post-development conditions for each case study site. Runoff volume was computed as the product of annual precipitation, contributing drainage area, and a runoff coefficient (ratio of runoff produced to rainfall received). For impervious areas the following equation was used:

$$C = (0.009)\, I + 0.05$$

where I is the impervious percentage. This equation was derived by Schueler (1987) from Nationwide Urban Runoff Program data (U.S. Environmental Protection Agency 1983). With I = 100 percent for fully impervious surfaces, C is 0.95.

The basis for pervious area runoff coefficients was the Natural Resource Conservation Service's (NRCS) Urban Hydrology for Small Watersheds (NRCS 1986, as revised from the original 1975 edition). This model estimates storm event runoff as a function of precipitation and a variable representing land cover and soil, termed the curve number (CN). Larger events are forecast to produce a greater amount of runoff in relation to amount of rainfall because they more fully saturate the soil. Therefore, use of the model to estimate annual runoff requires selecting some event or group of events to represent the year. The 85th percentile, 24-hour rainfall event was used in the analysis here for the relative comparison between pre- and post-development and applied to deriving a runoff coefficient for annual estimates, recognizing that smaller storms would produce less and larger storms more runoff.

A memorandum titled Rainfall Data Analysis and Guidance for Sizing Treatment BMPs (http://www.cccleanwater.org/construction/Publications/CCCWPBasinSizingMemoFINAL_4-20-05.pdf) prepared for the Contra Costa Clean Water Program demonstrated a linear relationship between unit basin storage volume for 80 percent capture (which is related to the 85th

percentile event) and mean annual precipitation. Rainfall for Bay Area 85th percentile, 24-hour events could thus be determined from locations where events have been established in direct proportion to mean annual rainfall.

In order to obtain appropriate regional estimates of annual precipitation, rainfall records were obtained from a number of sites in the four counties, plus the city of Vallejo, covered by the permit.[3] The mean annual range is from 13.73 to 24.30 inches, with quantities close to either 14 or 20 inches predominating. The study was performed for both of these rainfall totals. These figures were used in conjunction with 85th percentile, 24-hour event amounts of 0.75 for Los Angeles and 0.92 for Santa Rosa (http://ci.santa-rosa.ca.us/pworks/other/SW/SRSWManualFinalDraft.pdf), respectively, and mean annual totals of 12 and 31 inches for the respective cities to estimate 85 percentile, 24-hour event quantities of 0.77 and 0.82 inch for the 14 and 20-inch Bay Area rainfall zones, respectively.

Pre- and post-development runoff quantities were computed with selected CN values and the 0.77- and 0.82-inch rainfalls. The CN choices based on tabulated data in NRCS (1986) and professional judgment were 83 before development and 86 after land modification. Estimate runoff amounts were then divided by the rainfall totals to obtain runoff coefficients. The results were about the same for the two rainfall zones at 0.07 and 0.12 before and after development, respectively. Finally, total annual runoff volumes were estimated based on the two average annual precipitation figures.

Stormwater Runoff Pollutant Discharges

Annual pollutant mass discharges were estimated as the product of annual runoff volumes produced by the various land use and cover types and pollutant concentrations typical of those areas. Again, the 0.75-inch precipitation event was used as a basis for volumes. Stormwater pollutant data have typically been measured and reported for general land use types (e.g., single-family residential, commercial). However, an investigation of low impact development practices of the type this study sought to conduct demands data on specific land coverages. The literature offers few data on this basis. Those available and used herein were assembled by a consultant to the City of Seattle for a project in which the author participated. They appear in Attachment A (Herrera Environmental Consultants, Inc. undated).

Pollutant concentrations expected to occur typically in the mixed runoff from the several land use and cover types making up a development were estimated by mass balance; i.e., the concentrations from the different areas of the sites were combined in proportion to their contribution to the total runoff.

The Effect of Conventional Treatment BMPs on Runoff Volume, Pollutant Discharges, and Recharge Rates

The first question in analyzing how BMPs reduce runoff volumes and pollutant discharges was, What BMPs are being employed in Bay Area developments under the permit now in force? These county permits provide regulated entities with a large number of choices and few fixed requirements regarding the selection of stormwater BMPs. (See Contra Costa County NPDES Municipal Stormwater Permit, Order No. 99-058; see also Santa Clara County NPDES Municipal Stormwater Permit, Order No. 01-024, at C.3.a.). Clean Water Program Available options presumably include manufactured BMPs, such as drain inlet inserts (DIIs) and continuous deflective separation (CDS) units. Developments may also select such non-

[3] http://www.census.gov/stab/ccdb/cit7140a.txt, http://www.acwd.org/dms_docs/76d0b026b60d97830492079a48b1cb88.pdf, http://www.ci.berkely.ca.us/aboutberkeley/weather.html, http://www.usbr.gov/dataweb/dams/ca10168.htm, http://www.redwoodcity.org/about/weather.html.

proprietary devices as extended-detention basins (EDBs) and biofiltration swales and filter strips. EDBs hold water for two to three days for solids settlement before releasing whatever does not infiltrate or evaporate. Biofiltration treats runoff through various processes mediated by vegetation and soil. In a swale, runoff flows at some depth in a channel, whereas a filter strip is a broad surface over which water sheet flows. Each of these BMP types was applied to each case study, although it is not clear that these BMPs, in actuality, have been implemented consistently within the Bay Area to date.

The principal basis for the analysis of BMP performance was the California Department of Transportation's (CalTrans, 2004) BMP Retrofit Pilot Program, performed in San Diego and Los Angeles Counties. One important result of the program was that BMPs with a natural surface infiltrate and evaporate (probably, mostly infiltrate) a substantial amount of runoff, even if conditions do not appear to be favorable for an infiltration basin. On average, the EDBs, swales, and filter strips lost 40, 50 and 30 percent, respectively, of the entering flow before the discharge point. DIIs and CDS units do not contact runoff with a natural surface, and therefore do not reduce runoff volume.

The CalTrans program further determined that BMP effluent concentrations were usually a function of the influent concentrations, and equations were developed for the functional relationships in these cases. BMPs generally reduced influent concentrations proportionately more when they were high. In relatively few situations influent concentrations were constant at an "irreducible minimum" level regardless of inflow concentrations.

In analyzing the effects of BMPs on the case study runoff, the first step was to reduce the runoff volumes estimated with no BMPs by the fractions observed to be lost in the pilot study. The next task was estimating the effluent concentrations from the relationships in the CalTrans report. The final step was calculating discharge pollutant loadings as the product of the reduced volumes and predicted effluent concentrations. As before, typical pollutant concentrations in the mixed runoff were established by mass balance.

Estimating Infiltration Capacity of the Case Study Sites

Infiltrating sufficient runoff to maintain pre-development hydrologic characteristics and prevent pollutant transport is the most effective way to protect surface receiving waters. Successfully applying infiltration requires soils and hydrogeological conditions that will pass water sufficiently rapidly to avoid overly-lengthy ponding, while not allowing percolating water to reach ground-water before the soil column captures pollutants.

The study assumed that infiltration would occur in surface facilities and not in below-ground trenches. The use of trenches is certainly possible, and was judged to be an approved BMP by CalTrans after the pilot study. However, the intent of this investigation was to determine the ability of pervious areas to manage the site runoff. This was accomplished by determining the infiltration capability of the pervious areas in their original condition for each development case study, and further assessing the pervious areas' infiltration capabilities if soils were modified according to low impact development practices.

The chief basis for this aspect of the work was an assessment of infiltration capacity and benefits for Los Angeles' San Fernando Valley (Chralowicz et al. 2001). The Chralowicz study posited providing 0.1-0.5 acre for infiltration basins to serve each 5 acres of contributing drainage area. At 2-3 ft deep, it was estimated that such basins could infiltrate 0.90-1.87 acre-ft/year of runoff in San Fernando Valley conditions. Soils there are generally various loam textures with infiltration rates of approximately 0.5-2.0 inches/hour. Loams are also common formations in the portion of the Bay Area covered by this report, those areas with Hydrologic

Soil Groups A, B, and C,[4] thus making the conclusions of the San Fernando Valley study applicable for these purposes. This information was used to estimate how much of each case study site's annual runoff would be infiltratable, and if the pervious portion would provide sufficient area for infiltration. For instance, if sufficient area were available, the infiltration configuration would not have to be in basin form but could be shallower and larger in surface area. This study's analyses assumed the use of bioretention areas rather than traditional infiltration basins.

Volume and Pollutant Source Reduction Strategies

As mentioned above, the essence of low impact development is reducing runoff problems before they can develop, at their sources, or exploiting the infiltration and treatment abilities of soils and vegetation. If a site's existing infiltration and treatment capabilities are inadequate to preserve pre-development hydrology and prevent runoff from causing or contributing to violations of water quality standards, then LID-based source reduction strategies can be implemented, infiltration and treatment capabilities can be upgraded, or both.

Source reduction can be accomplished through various LID techniques. Soil can be upgraded to store runoff until it can infiltrate, evaporate, or transpire from plants through compost addition. Soil amendment, as this practice is known, is a standard LID technique.

Upgraded soils are used in bioretention cells that hold runoff and effect its transfer to the subsurface zone. This standard LID tool can be used where sufficient space is available. This study analyzed whether the six development case study sites would have sufficient space to effectively reduce runoff using bioretention cells, assuming the soils and vegetation could be amended and enhanced where necessary.

Conventional pavements can be converted to porous asphalt or concrete or replaced with concrete or plastic unit pavers or grid systems. For such approaches to be most effective, the soils must be capable of infiltrating the runoff passing through, and may require renovation.

Source reduction can be enhanced by the LID practice of water harvesting, in which water from impervious surfaces is captured and stored for reuse in irrigation or gray water systems. For example, runoff from roofs and parking lots can be harvested, with the former being somewhat easier because of the possibility of avoiding pumping to use the water and fewer pollutants. Harvesting is a standard technique for Leadership in Energy and Environmental Design (LEED) buildings.[5] Many successful systems of this type are in operation, such as the Natural Resources Defense Council office (Santa Monica, CA), the King County Administration Building (Seattle, WA), and two buildings on the Portland State University campus (Portland, OR). This investigation examined how water harvesting could contribute to stormwater management for case study sites where infiltration capacity, available space, or both appeared to be limited.

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[4] http://gis.ca.gov/catalog/BrowseCatalog.epl?id=108, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

[5] New Buildings Institute, Inc., *Advanced Buildings* (2005) (http://www.poweryourdesign.com/LEEDGuide.pdf).

RESULTS OF THE ANALYSIS

1. "Base Case" Analysis: Development without Stormwater Controls

Comparison of Pre- and Post-Development Runoff Volumes

Table 2 presents a comparison between the estimated runoff volumes generated by the respective case study sites in the pre- and post-development conditions, assuming implementation of no stormwater controls on the developed sites. On sites dominated by impervious land cover, most of the infiltration that would recharge groundwater in the undeveloped state is expected to be lost to surface runoff after development. This greatly increased surface flow would raise peak flow rates and volumes in receiving water courses, raise flooding risk, and transport pollutants. Only the office building, the plan for which retained substantial pervious area, would lose less than 40 percent of the site's pre-development recharge.

Table 2. Pre- and Post-Development without BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater (annual volume in acre-ft)

Distribution	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Precipitation[b]	12.8	3.54	0.90	2.47	154	0.21
Pre-development runoff[c]	0.89	0.25	0.07	0.17	10	0.02
Pre-development recharge[d]	11.9	3.29	0.83	2.30	144	0.19
Post-development impervious runoff[c]	8.07	1.51	0.42	0.57	66	0.09
Post-development pervious runoff[c]	0.51	0.24	0.06	0.23	10	0.01
Post-development total runoff[c]	8.58	1.75	0.48	0.80	76	0.10
Post-development recharge[d]	4.22	1.79	0.42	1.67	78	0.11
Post-development recharge loss (% of pre-development)	7.68 (65%)	1.50 (46%)	0.41 (49%)	0.65 (27%)	66 (45%)	0.08 (41%)
20 Inches/Year Rainfall:						
Precipitation[b]	18.2	5.06	1.29	3.54	220	0.30
Pre-development runoff[c]	1.28	0.35	0.10	0.24	15	0.03
Pre-development recharge[d]	16.9	4.71	1.19	3.30	205	0.27
Post-development impervious runoff[c]	11.5	2.16	0.60	0.82	94	0.13
Post-development pervious runoff[c]	0.73	0.34	0.08	0.33	15	0.01
Post-development total runoff[c]	12.2	2.50	0.68	1.15	109	0.14
Post-development recharge[d]	6.0	2.56	0.61	2.39	111	0.16
Post-development recharge loss (% of pre-development)	10.9 (65%)	2.15 (46%)	0.58 (49%)	0.91 (27%)	94 (45%)	0.11 (41%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Pollutant Concentrations and Loadings

Table 3 presents the pollutant concentrations from the literature and loadings calculated as described for the various land use and cover types represented by the case studies. Landscaped areas are expected to release the highest TSS concentration, although relatively low TSS mass loading because of the low runoff coefficient. The highest copper concentrations and loadings are expected from parking lots. Roofs, especially commercial roofs, top the list for both zinc concentrations and loadings. Landscaping would issue by far the highest phosphorus, although access roads and driveways would contribute the highest mass loadings. With expected concentrations being equal in the two rainfall zones, mass loadings in the 20 inches/year zone would be higher than those in the 14 inches/year zone in the same proportion as the ratio of rainfall quantities.

Table 3. Pollutant Concentrations and Loadings for Case Study Land Use and Cover Types

Land Use	Concentrations				Loadings			
	TSS (mg/L)	TCu (mg/L)	TZn (mg/L)	TP (mg/L)	Lbs. TSS/ acre-year	Lbs. TCu/ acre-year	Lbs. TZn/ acre-year	Lbs. TP/ acre-year
14 Inches/Year Rainfall:								
Residential roof	25	0.013	0.159	0.11	75	0.039	0.477	0.330
Commercial roof	18	0.014	0.281	0.14	54	0.042	0.844	0.420
Access road/driveway	120	0.022	0.118	0.66	360	0.066	0.354	1.981
Parking	75	0.036	0.097	0.14	225	0.108	0.291	0.420
Walkway	25	0.013	0.059	0.11	75	0.039	0.177	0.330
Landscaping	213	0.013	0.059	2.04	81	0.005	0.022	0.774
20 Inches/Year Rainfall:								
Residential roof	25	0.013	0.159	0.11	107	0.056	0.683	0.472
Commercial roof	18	0.014	0.281	0.14	77	0.060	1.207	0.601
Access road/driveway	120	0.022	0.118	0.66	515	0.094	0.507	2.834
Parking	75	0.036	0.097	0.14	322	0.155	0.417	0.601
Walkway	25	0.013	0.059	0.11	107	0.056	0.253	0.472
Landscaping	213	0.013	0.059	2.04	135	0.008	0.037	1.291

The Basin Plan freshwater acute criteria for copper and zinc are 0.013 mg/L and 0.120 mg/L, respectively (http://www.swrcb.ca.gov/rwqcb2/basinplan/web/BP_CH3.html). All developed land uses are expected to discharge copper at or above the criterion, based on the mass balance calculations using concentrations from Table 3. Any surface release from the case study sites would just meet or violate the criterion at the point of discharge, although dilution by the receiving water would lower the concentration below the criterion at some point. Even if copper mass loadings are reduced by BMPs, any surface discharge would equal or exceed the criterion initially, but it would be easier to dilute below that level. In contrast, runoff from land covers other than roofs would not violate the acute zinc criterion. Because of this difference, the evaluation considered whether or not the zinc criterion would be exceeded in each analysis, whereas there was no point in this analysis for copper. There are no equivalent water quality criteria for TSS and TP; hence, their concentrations were not further analyzed in the different scenarios.

Table 4 shows the overall loadings, as well as zinc concentrations, expected to be delivered from the case study developments should they not be fitted with any BMPs. As Table 4 shows, all cases are forecast to exceed the 0.120 mg/L acute zinc criterion. Because of its size, the large residential development dominates the mass loading emissions.

Table 4. Case Study Pollutant Concentration and Loading Estimates without BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/ Year Rainfall:						
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.121
Lbs. TSS/year	1254	328	119	230	14249	20
Lbs. TCu/year	0:44	0.070	0.030	0.043	3.04	0.004
Lbs. TZn/year	2.94	0.576	0.165	0.286	25.04	0.034
Lbs. TP/year	6.24	2.27	0.68	1.69	98.55	0.14
20 Inches/ Year Rainfall:						
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.121
Lbs. TSS/year	1864	501	180	360	21781	30
Lbs. TCu/year	0.63	0.102	0.043	0.063	4.44	0.006
Lbs. TZn/year	4.22	0.833	0.238	0.417	36.2	0.050
Lbs. TP/year	9.60	3.55	1.05	2.71	154	0.22

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home

2. *"Conventional BMP" Analysis: Effect of Basic Treatment BMPs*

Effect of Basic Treatment BMPs on Post-Development Runoff Volumes

The current set of regional permits allows regulated parties to select from a range of BMPs in order to treat or infiltrate a given quantity of annual rainfall. The administrative draft of the proposed MRP is also non-specific regarding the role of LID in satisfying permit conditions. The range of BMPs includes drain inlet inserts, CDS units, and other manufactured BMPs, detention vaults, and sand filters, all of which isolate runoff from the soil; as well as basins and biofiltration BMPs built in soil and generally having vegetation. Treatment BMPs that do not permit any runoff contact with soils discharge as much stormwater runoff as equivalent sites with no BMPs, and hence yield zero savings in recharge. As mentioned above, the CalTrans (2004) study found that BMPs with a natural surface can reduce runoff by substantial margins (30-50 percent for extended-detention basins and biofiltration).

With such a wide range of BMPs in use, runoff reduction ranging from 0 to 50 percent, and a lack of clearly ascertainable requirements, it is not possible to make a single estimate of how much recharge savings are afforded by maximal implementation of the current permits or the Municipal Regional Permit (MRP), if issued as now proposed. We made the following assumptions regarding implementation of BMPs. Assuming natural-surface BMPs perform at the average of the three types tested by CalTrans (2004), i.e., 40 percent runoff reduction, the estimate can be bounded as shown in Table 5. The table demonstrates that allowing free choice of BMPs without regard to their ability to direct water into the ground forfeits substantial groundwater recharge benefits when hardened-surface BMPs are selected. Use of soil-based conventional BMPs could cut recharge losses from half or more of the full potential to about one-quarter to one-third or less, except with the highly impervious commercial development. This analysis shows the wisdom of draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way. But as subsequent analyses showed, soil amendment can gain considerably greater benefits.

Table 5. Pre- and Post-Development with Conventional BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater (annual volume in acre-ft)

Distribution	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Precipitation[b]	12.8	3.54	0.90	2.47	154	0.21
Pre-development runoff[c]	0.89	0.25	0.07	0.17	10	0.02
Pre-development recharge[d]	11.9	3.29	0.83	2.30	144	0.19
Post-development impervious runoff[e]	4.84-8.07	0.90-1.51	0.25-0.42	0.34-0.57	39-66	0.05-0.09
Post-development pervious runoff[e]	0.30-0.51	0.14-0.24	0.04-0.06	0.13-0.23	6.3-10	0.006-0.01
Post-development total runoff[e]	5.15-8.58	1.05-1.75	0.29-0.48	0.48-0.80	46-76	0.06-0.10
Post-development recharge[d, e]	4.22-7.60	1.79-2.49	0.42-0.62	1.67-2.00	78-108	0.11-0.15
Post-development recharge loss (% of pre-development)[e]	4.29-7.68 (36-65%)	0.80-1.50 (24-46%)	0.80-0.41 (26-49%)	0.30-0.65 (13-27%)	34-66 (24-45%)	0.05-0.08 (24-41%)
20 Inches/Year Rainfall:						
Precipitation[b]	18.2	5.06	1.29	3.54	220	0.30
Pre-development runoff[c]	1.28	0.35	0.10	0.24	15	0.03
Pre-development recharge[d]	16.9	4.71	1.19	3.30	205	0.27
Post-development impervious runoff[e]	6.92-11.5	1.29-2.16	0.35-0.60	0.49-0.82	56-94	0.08-0.13
Post-development pervious runoff[e]	0.44-0.73	0.20-0.34	0.05-0.08	0.19-0.33	9.0-15	0.006-0.01
Post-development total runoff[e]	7.36-12.2	1.50-2.50	0.41-0.68	0.68-1.15	65-109	0.08-0.14
Post-development recharge[d, e]	6.0-10.8	2.56-3.56	0.61-0.88	2.39-2.86	111-155	0.16-0.22
Post-development recharge loss (% of pre-development)[e]	6.1-10.9 (36-65%)	1.14-2.15 (24-46%)	0.31-0.58 (26-49%)	0.44-0.91 (13-27%)	49-94 (24-45%)	0.07-0.11 (24-41%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home. Ranges represent 40 percent runoff volume reduction, with full site coverage by BMPs having a natural surface, to no reduction, with BMPs isolating runoff from soil.

[b] Volume of precipitation on total project area

[c] Quantity of water discharged from the site on the surface

[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff [e] Ranging from the quantity with hardened bed BMPs to the quantity with soil-based BMPs

Effect of Basic Treatment BMPs on Pollutant Discharges

Table 6 presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from four types of conventional treatment BMPs. The loading reduction results show the CDS units always performing below 50 percent reduction for all pollutants analyzed, and most often in the vicinity of 20 percent, with zero copper reduction.

Table 6. Pollutant Concentration and Mass Loading Reduction Estimates with Conventional BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Effluent Concentrations:						
CDS TZn (mg/L)[a]	0.095	0.095	0.098	0.102	0.095	0.094
EDB TZn (mg/L)[a]	0.085	0.086	0.084	0.084	0.086	0.084
Swale TZn (mg/L)	0.055	0.054	0.055	0.056	0.054	0.053
Filter strip TZn (mg/L)	0.039	0.039	0.039	0.041	0.039	0.038
Mass Loading Reductions—14 Inches/Year Rainfall:						
CDS TSS reduction	15.7%	19.9%	22.0%	24.0%	19.9%	20.2%
CDS TCu reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CDS TZn reduction	22.7%	22.4%	22.9%	23.1%	22.4%	22.5%
CDS TP reduction	30.6%	41.5%	40.7%	45.9%	41.5%	42.0%
EDB TSS reduction	68.1%	73.7%	79.0%	81.1%	73.7%	74.3%
EDB TCu reduction	61.9%	55.7%	66.2%	63.0%	55.7%	55.8%
EDB TZn reduction	59.7%	59.6%	60.4%	61.9%	59.6%	59.8%
EDB TP reduction	61.9%	69.7%	69.1%	72.9%	69.7%	70.1%
Swale TSS reduction	68.8%	71.1%	73.1%	73.9%	71.1%	71.3%
Swale TCu reduction	72.5%	68.5%	78.2%	73.3%	68.5%	68.5%
Swale TZn reduction	78.4%	78.1%	84.3%	78.8%	78.1%	78.2%
Swale TP reduction	66.3%	70.7%	67.2%	76.2%	70.7%	71.1%
Filter strip TSS reduction	69.9%	75.4%	80.6%	82.6%	75.4%	76.0%
Filter strip TCu reduction	74.4%	69.1%	78.2%	75.4%	69.1%	69.1%
Filter strip TZn reduction	78.3%	77.9%	78.4%	78.7%	77.9%	78.1%
Filter strip TP reduction	48.4%	53.1%	63.7%	59.8%	53.1%	53.5%

Table 6 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Mass Loading Reductions—20 Inches/Year Rainfall:						
CDS TSS reduction	18.8%	25.0%	26.3%	30.5%	25.0%	25.4%
CDS TCu reduction	0.7%	1.9%	1.1%	3.0%	1.9%	2.0%
CDS TZn reduction	23.1%	23.3%	23.6%	24.7%	23.3%	23.4%
CDS TP reduction	35.4%	46.6%	44.8%	51.8%	46.6%	47.1%
EDB TSS reduction	68.8%	74.6%	79.6%	81.6%	74.6%	75.1%
EDB TCu reduction	61.8%	55.6%	66.0%	62.7%	55.6%	55.7%
EDB TZn reduction	59.6%	59.3%	60.2%	61.5%	59.3%	59.6%
EDB TP reduction	63.0%	70.4%	69.7%	73.4%	70.4%	70.7%
Swale TSS reduction	69.1%	71.4%	73.6%	74.1%	71.4%	71.6%
Swale TCu reduction	72.5%	68.4%	77.9%	73.1%	68.4%	68.5%
Swale TZn reduction	78.3%	78.0%	84.1%	78.6%	78.0%	78.1%
Swale TP reduction	67.6%	71.9%	68.2%	77.1%	71.9%	72.3%
Filter strip TSS reduction	70.6%	76.3%	81.2%	83.1%	76.3%	76.8%
Filter strip TCu reduction	74.4%	69.0%	78.0%	75.1%	69.0%	69.1%
Filter strip TZn reduction	78.2%	77.8%	78.3%	78.5%	77.8%	77.9%
Filter strip TP reduction	49.9%	54.6%	66.3%	61.0%	54.6%	55.0%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home; CDS— continuous deflective separation unit; EDB—extended-detention basin

When treated with extended-detention basins, swales, or filter strips, effluents from each development case study site are expected to fall below the Basin Plan acute zinc criterion. These natural-surface BMPs, if fully implemented and well maintained, are predicted to prevent the pollutant masses generated on the six case study development sites from reaching a receiving water in both rainfall zones, which do not differ appreciably. Only total phosphorus reduction falls below 50 percent for three case studies. Otherwise, mass loading reductions range from about 60 to above 80 percent for the EDB, swale, and filter strip. These data indicate that draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way, pays water quality as well as hydrologic dividends.

3. LID Analysis

(a) Hydrologic Analysis

The LID analysis repeats the analysis above, focusing here on the performance of LID techniques in reducing or eliminating runoff from the six development case studies. In addition to assessing the total runoff that would be expected, the analysis also considered whether LID techniques would be sufficient to attain compliance with a performance standard being

considered by the Los Angeles Regional Water Quality Control Board for Ventura County, California. This standard limits EIA (Effective Impervious Area) to five percent (but our analysis further assumed EIA would be ultimately reduced to three percent). All runoff from NCIA (Not-Connected Impervious Area) was assumed to drain to vegetated surfaces.

One goal of this exercise was to identify methods that reduce runoff production in the first place. It was hypothesized that implementation of source reduction techniques could allow all of the case study sites to infiltrate substantial proportions, or all, of the developed site runoff, advancing the hydromodification mitigation objective of the Draft Permit. When runoff is dispersed into the soil instead of being rapidly collected and conveyed away, it recharges groundwater, supplementing a resource that maintains dry season stream flow and wetlands. An increased water balance can be tapped by humans for potable, irrigation, and process water supply. Additionally, runoff volume reduction would commensurately decrease pollutant mass loadings.

Accordingly, the analysis considered the practicability of more than one scenario. In one option, all roof runoff is harvested and stored for some beneficial use. A second option disperses runoff into the soil via roof downspout infiltration trenches. The former option is probably best suited to cases like large commercial and office buildings, while distribution in the soil would fit best with residences and relatively small commercial developments. The analysis was repeated with the assumptions of harvesting OFF roof runoff for some beneficial use and dispersing roof runoff from the remaining four cases in roof downspout infiltration systems.

Expected Infiltration Capacities of the Case Study Sites

The first inquiry on this subject sought to determine how much of the total annual runoff each property is expected to infiltrate, since infiltration is a basic (although not exclusive) LID technique. Based on the findings of Chralowicz et al. (2001), it was assumed that an infiltration zone of 0.1-0.5 acres in area and 2-3 ft deep would serve a drainage catchment area in the size range 0-5 acres and infiltrate 0.9-1.9 acre-ft/year. The conclusions of Chralowicz et al. (2001) were extrapolated to conservatively assume that 0.5 acre would be required to serve each additional five acres of catchment, and would infiltrate an incremental 1.4 acre-ft/year (the midpoint of the 0.9-1.9 acre-ft/year range). According to these assumptions, the following schedule of estimates applies:

Pervious Area Available for Infiltration	Catchment Served acres	Infiltration Capacity
0.5 acres	0-5 acres	1.4 acre-ft/year
1.0 acres	5-10 acres	2.8 acre-ft/year
1.5 acres	10-15 acres	4.2 acre-ft/year
(Etc.)	...	...

As a formula, infiltration capacity ≈ 2.8 x available pervious area. To apply the formula conservatively, the available area was reduced to the next lower 0.5-acre increment before multiplying by 2.8.

As shown in Table 7, in both rainfall zones all six of the sites have adequate or greater capacity to infiltrate the full annual runoff volume expected from NCIA and pervious areas where EIA is limited to three percent of the total site area. Indeed, five of the six development types have sufficient pervious area to infiltrate *all* runoff, including runoff from EIA areas. These results are based on infiltrating in the native soils with no soil amendment. For any development project at which infiltration-oriented BMPs are considered, it is important that infiltration potential be carefully assessed using site-specific soils and hydrogeologic data. In the event such an investigation reveals a marginal condition (e.g., hydraulic conductivity, spacing to groundwater) for infiltration basins, soils could be enhanced to produce bioretention zones to assist infiltration. Notably, the five case studies with far greater than necessary infiltration capacity would offer substantial flexibility in designing infiltration, allowing ponding at less than 2-3 ft depth.

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Table 7. Infiltration and Runoff Volume (With 3 Percent EIA and All NCIA Draining to Pervious Areas)

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.36	0.10	0.03	0.07	4.4	0.01
NCIA + pervious area runoff (acre-ft/year)	**8.20**	**1.64**	**0.45**	**0.73**	**71.3**	**0.08**
Total runoff (acre-ft/year)	8.56	1.74	0.48	0.80	75.7	0.09
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration potential[c]	>100%	>100%	>100%	>100%	>100%	>100%
20 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.52	0.14	0.04	0.10	6.2	0.01
NCIA + pervious area runoff (acre-ft/year)	**11.7**	**2.34**	**0.64**	**1.04**	**101.7**	**0.14**
Total runoff (acre-ft/year)	12.2	2.48	0.68	1.14	108.0	0.15
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration potential[c]	84%	>100%	>100%	>100%	>100%	>100%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Compare runoff production from NCIA + pervious area (**row 3**) with estimated infiltration capacity (**row 6**)

As Table 7 shows, each of the six case study sites have the capacity to infiltrate *all* or substantially all of the runoff produced onsite annually by draining impervious surfaces to pervious areas on native soils or, in some soil regimes, soils amended with organic matter. If these sites were designed as envisioned in this analysis, no runoff discharge is expected in storms as large as, and probably larger than, the design storm event—using infiltration only. Discharge would be anticipated only with exceptionally intense, large, or prolonged rainfall that saturates the ground at a faster rate than water can infiltrate or evaporate. Even runoff from the area assumed to be EIA could be infiltrated in most cases based on the amount of pervious area available in typical development projects. Therefore, this analysis shows that the EIA performance standard being considered for Ventura County, California, or one more stringent, can be met readily in development projects occurring on A, B, and C soils in the San Francisco Bay Area.

Additional Source Reduction Capabilities of the Case Study Sites: Water Harvesting Example

As noted, infiltration is one of a wide variety of LID-based source reduction techniques. Where site conditions such as soil quality or available area limit a site's infiltration capacity, other source LID measures can enhance a site's runoff retention capability. For example, soil amendment, which improves infiltration, is a standard LID technique. Water harvesting is another. Such practices can also be used where infiltration capacity is adequate, but the developer desires greater flexibility for land use on-site. Table 8 shows the added LID implementation flexibility created by subtracting roof runoff by harvesting it or efficiently directing it into the soil through downspout dispersion systems, further demonstrating the feasibility and robust performance of LID options for reducing or eliminating runoff in most expected conditions. Specifically, all development types studied could readily infiltrate and/or retain all expected annual precipitation.

Table 8. Infiltration and Runoff Volume Reduction Analysis Including Roof Runoff Harvesting or Disposal in Infiltration Trenches (Assuming 3 Percent EIA and All NCIA Draining to Pervious Areas)

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.36	0.10	0.03	0.07	4.4	0.01
Roof runoff (acre-ft/year)	4.68	0.89	0.08	0.19	38.5	0.05
Other NCIA + pervious area runoff (acre-ft/year)	**3.52**	**0.75**	**0.37**	**0.54**	**32.7**	**0.04**
Total runoff (acre-ft/year)	8.56	1.74	0.48	0.80	75.6	0.10
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration capacity[c]	>100%	>100%	>100%	>100%	>100%	>100%
20 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.52	0.14	0.04	0.10	6.2	0.01
Roof runoff (acre-ft/year)	6.67	1.27	0.12	0.28	55.1	0.08
Other NCIA + pervious area runoff (acre-ft/year)	**5.03**	**1.07**	**0.52**	**0.76**	**46.7**	**0.06**
Total runoff (acre-ft/year)	12.2	2.48	0.68	1.14	108.0	0.15
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10

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Table 8 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration capacity[c]	>100%	>100%	>100%	>100%	>100%	>100%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Comparison of runoff production from NCIA + pervious area (**row 3**) with estimated infiltration capacity (**row 6**)

Effect of Full LID Approach on Recharge

Table 9 shows the recharge benefits of preventing roofs from generating runoff and infiltrating as much as possible of the runoff from the remainder of the case study sites. The data show that LID methods offer significant benefits relative to the baseline (no stormwater controls) in all cases. These benefits are particularly impressive in developments with relatively high site imperviousness, such as in the MFR case.

Table 9. Comparison of Water Captured Annually (in acre-ft) from Development Sites for Beneficial Use with a Full LID Approach Compared to Development With No BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Pre-development recharge[b] (acre-ft)	11.9	3.29	0.83	2.30	144	0.19
No BMPs—						
Post-development recharge[b] (acre-ft)	4.22	1.79	0.42	1.67	78	0.11
Post-development recharge lost (acre-ft)	7.68	1.50	0.41	0.65	66	0.08
Post-development % recharge lost	65%	46%	49%	27%	45%	41%
Full LID approach—						
Post-development runoff capture (acre-ft)[c]	11.9	3.29	0.83	2.30	144	0.19
Post-development recharge lost (acre-ft)	0	0	0	0	0	0
Post-development % recharge lost	0%	0%	0%	0%	0%	0%

Table 9 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
20 Inches/Year Rainfall:						
Pre-development recharge[b] (acre-ft)	16.9	4.71	1.19	3.30	205	0.27
No BMPs—						
Post-development recharge[b] (acre-ft)	6.0	2.56	0.61	2.39	111	0.16
Post-development recharge lost (acre-ft)	10.9	2.15	0.58	0.91	94	0.11
Post-development % recharge lost	65%	46%	49%	27%	45%	41%
Full LID approach—						
Post-development runoff capture (acre-ft)[c]	16.9	4.71	1.19	3.30	205	0.27
Post-development recharge lost (acre-ft)	0	0	0	0	0	0
Post-development % recharge lost	0%	0%	0%	0%	0%	0%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—Single family home
[b] Quantity of water infiltrating the soil; the difference between precipitation and runoff
[c] Water either entirely infiltrated in BMPs and recharged to groundwater or partially harvested from roofs and partially infiltrated in BMPs. EIA was not distinguished from the remainder of the development, because these sites have the potential to capture all runoff.

(b) Water Quality Analysis

It was assumed that any site discharges would be subject to treatment control. For purposes of the analysis, treatment control was assumed to be provided by conventional sand filtration. This choice is appropriate for study purposes for two reasons. First, sand filters can be installed below grade, and land above can be put to other uses. Pervious area should be reserved for receiving NCIA drainage, and using sand filters would not draw land away from that service or other site uses. A second reason for the choice is that sand filter performance data equivalent to the data used in analyzing other conventional BMPs are available from the CalTrans (2004) work. Sand filters may or may not expose water to soil, depending on whether or not they have a hard bed. This analysis assumed a hard bed, meaning that no infiltration would occur and thus there would be no additional recharge in sand filters. Performance would be even better than shown in the analytical results if sand filters were built in earth.

Pollutant Discharge Reduction Through LID Techniques

The preceding analyses demonstrated that in each of the six case studies, *all* stormwater discharges could be eliminated at least under most meteorological conditions by dispersing runoff from impervious surfaces to pervious areas. Therefore, pollutant additions to receiving waters would also be eliminated.

SUMMARY AND CONCLUSIONS

This paper demonstrated that common Bay Area residential and commercial development types subject to the Municipal NPDES Permit are likely, without stormwater management, to reduce groundwater recharge from the pre-development state by approximately half in most cases to a much higher fraction with a large ratio of impervious to pervious area. With no treatment, runoff from these developments is expected to exceed Basin Plan acute copper and zinc criteria at the point of discharge and to deliver large pollutant mass loadings to receiving waters.

Conventional soil-based BMP solutions that promote and are component parts of low impact development approaches, by contrast, regain about 30-50 percent of the recharge lost in development without stormwater management in Bay Area locations having NRCS Hydrologic Soil Groups A, B, and C. It is expected the soil-based BMPs generally would release effluent that meets the acute zinc criterion at the point of discharge, although it would still exceed or just barely meet the copper limit. Excepting phosphorus, it was found that these BMPs would capture and prevent the movement to receiving waters of the majority of the pollutant loadings considered in the analysis.

It was found that by draining all site runoff to pervious areas with A, B, or C soil types, runoff can be eliminated entirely in most development categories. It follows that a three percent Effective Impervious Area standard can be met in typical developments, as well. This result was reached assuming the use of native soils or well recognized soil enhancement techniques (typically, with compost). Draining impervious surfaces onto these soils, in connection with limiting directly connected impervious area to three percent of the site total area, should eliminate storm runoff from some development types and greatly reduce it from more highly impervious types. Adding roof runoff elimination to the LID approach (by harvesting or directing it to downspout infiltration trenches) provides an additional tool, increasing flexibility and confidence that no discharge in most meteorological conditions is a feasible performance expectation. Even in the development scenarios involving the highest relative proportion of impervious surface, losses of rainfall capture for beneficial uses could be reduced from the untreated scenario when draining to pervious areas was supplemented with water harvesting. These results demonstrate the basic soundness of the concept of using LID techniques to reduce stormwater pollution in the Bay Area, and further show that limiting directly connected impervious area and draining the remainder over pervious surfaces, as contemplated by some Regional Water Boards in California, is also feasible.

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ATTACHMENT A

POLLUTANT CONCENTRATIONS FOR URBAN SOURCE AREAS (HERRERA ENVIRONMENTAL CONSULTANTS, INC. UNDATED)

Source Area	Study	Location	Sample Size (n)	TSS (mg/L)	TCu (ug/L)	TPb (ug/L)	TZn (ug/L)	TP (mg/L)	Notes
Roofs									
Residential	Steuer, et al. 1997	MI	12	36	7	25	201	0.06	2
Residential	Bannerman, et al. 1993	WI	~48	27	15	21	149	0.15	3
Residential	Waschbusch, et al. 2000	WI	25	15	n.a.	n.a.	n.a.	0.07	3
Residential	FAR 2003	NY		*19*	*20*	*21*	*312*	*0.11*	4
Residential	Gromaire, et al. 2001	France		*29*	*37*	*493*	*3422*	*n.a.*	5
Representative Residential Roof Values				**25**	**13**	**22**	**159**	**0.11**	
Commercial	Steuer, et al. 1997	MI	12	24	20	48	215	0.09	2
Commercial	Bannerman, et al. 1993	WI	~16	15	9	9	330	0.20	3
Commercial	Waschbusch, et al. 2000	WI	25	18	n.a.	n.a.	n.a.	0.13	3
Representative Commercial Roof Values				**18**	**14**	**26**	**281**	**0.14**	
Parking Areas									
Res. Driveways	Steuer, et al. 1997	MI	12	157	34	52	148	0.35	2
Res. Driveways	Bannerman, et al. 1993	WI	~32	173	17	17	107	1.16	3
Res. Driveways	Waschbusch, et al. 2000	WI	25	34	n.a.	n.a.	n.a.	0.18	3
Driveway	FAR 2003	NY		*173*	*17*		*107*	*0.56*	4
Representative Residential Driveway Values				**120**	**22**	**27**	**118**	**0.66**	
Comm./ Inst. Park. Areas	Pitt, et al. 1995	AL	16	110	116	46	110	n.a.	1
Comm. Park. Areas	Steuer, et al. 1997	MI	12	110	22	40	178	0.2	2
Com. Park. Lot	Bannerman, et al. 1993	WI	5	58	15	22	178	0.19	3
Parking Lot	Waschbusch, et al. 2000	WI	25	51	n.a.	n.a.	n.a.	0.1	3
Parking Lot	Tiefenthaler, et al. 2001	CA	5	36	28	45	293	n.a.	6
Loading Docks	Pitt, et al. 1995	AL	3	40	22	55	55	n.a.	1
Highway Rest Areas	CalTrans 2003	CA	53	*63*	*16*	*8*	*142*	*0.47*	7
Park and Ride Facilities	CalTrans 2003	CA	179	*69*	*17*	*10*	*154*	*0.33*	7
Comm./ Res. Parking	FAR 2003	NY		*27*	*51*	*28*	*139*	*0.15*	4
Representative Parking Area/Lot Values				**75**	**36**	**26**	**97**	**0.14**	

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Landscaping/Lawns									
Landscaped Areas	Pitt, et al. 1995	AL	6	33	81	24	230	n.a.	1
Landscaping	FAR 2003	NY		*37*	*94*	*29*	*263*	n.a.	4
Representative Landscaping Values				**33**	**81**	**24**	**230**	**n.a.**	
Lawns - Residential	Steuer, et al. 1997	MI	12	262	n.a.	n.a.	n.a.	2.33	2
Lawns - Residential	Bannerman, et al. 1993	WI	~30	397	13	n.a.	59	2.67	3
Lawns	Waschbusch, et al. 2000	WI	25	59	n.a.	n.a.	n.a.	0.79	3
Lawns	Waschbusch, et al. 2000	WI	25	122	n.a.	n.a.	n.a.	1.61	3
Lawns - Fertilized	USGS 2002	WI	58	n.a.	n.a.	n.a.	n.a.	2.57	3
Lawns - Non-P Fertilized	USGS 2002	WI	38	n.a.	n.a.	n.a.	n.a.	1.89	3
Lawns - Unfertilized	USGS 2002	WI	19	n.a.	n.a.	n.a.	n.a.	1.73	3
Lawns	FAR 2003	NY	3	*602*	*17*	*17*	*50*	*2.1*	4
Representative Lawn Values				**213**	**13**	**n.a.**	**59**	**2.04**	

Notes:

Representative values are weighted means of collected data. Italicized values were omitted from these calculations.

1 - Grab samples from residential, commercial/institutional, and industrial rooftops. Values represent mean of DETECTED concentrations

2 - Flow-weighted composite samples, geometric mean concentrations

3 - Geometric mean concentrations

4 - Citation appears to be erroneous - original source of data is unknown. Not used to calculate representative value

5 - Median concentrations. Not used to calculate representative values due to site location and variation from other values.

6 - Mean concentrations from simulated rainfall study

7 - Mean concentrations. Not used to calculate representative values due to transportation nature of land use.

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INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES ("LID") FOR THE SAN DIEGO REGION

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INTRODUCTION

This purpose of this study is to investigate the relative impact of three levels of storm water treatment best management practices (BMPs) on certain water quality and water reuse factors: basic "treat-and-release" BMPs (e.g., drain inlet filters, CDS units), commonly used BMPs that expose runoff to soils and vegetation (extended-detention basins and biofiltration swales and filter strips), and low-impact design (LID) practices. Low-impact methods reduce storm runoff and its contaminants by decreasing their generation at sources, infiltrating into the soil or evaporating storm flows before they can enter surface receiving waters, treating flow remaining on the surface through contact with vegetation and soil, or a combination of these strategies. Soil-based LID practices often use soil enhancements such as compost, and thus improve upon the performance of more traditional basins and biofilters. The factors considered in the investigation are runoff volume, pollutant loading, and the availability of water for infiltration or other reuse. In order to assess the differential impact of storm water reduction approaches on these factors, this study examines six case studies typical of development in the San Diego region that would require Standard Urban Stormwater Management Plans (SUSMPs).

With respect to each of the six development models, three assessments were undertaken. To establish a baseline, for each case study annual storm water runoff volumes were estimated, as well as concentrations and mass loadings of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). These baseline estimates were based on the anticipated land use and cover with no storm water management efforts.

Two sets of calculations were then conducted using the parameters defined for the six case studies. The first group of calculations estimated the extent to which the basic BMPs reduce runoff volumes and pollutant concentrations and loadings, and what impact, if any, such BMPs have on recharge rates or water retention on-site. The second group of calculations estimated the extent to which commonly used soil-based BMPs and low-impact site design strategies ameliorate runoff volumes and pollutant concentrations and loadings, and the effect such techniques have on recharge rates.

The assessment of basins, biofiltration, and low-impact design practices analyzed the expected infiltration capacity of the case study sites. It also considered related LID techniques and practices, such as source reduction strategies, that work in concert with infiltration to serve the goals of: (1) preventing increase in annual runoff volume from the pre- to the post-developed state, (2) preventing increase in annual pollutant mass loadings between the two development states, and (3) avoiding exceedences of California Toxics Rule (CTR) acute saltwater criteria for copper and zinc.

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The results of this analysis show that in developments implementing no post-construction BMPs, storm water runoff volume and pollutant loading are substantially increased and recharge rates are substantially decreased compared to pre-development conditions. Second, developments implementing basic post-construction treatment BMPs achieve reduced pollutant loading compared to developments with no BMPs, but storm water runoff volume and recharge rates are similar to developments with no BMPs. Third, developments implementing traditional basins and biofilters, and even more so low-impact post-construction BMPs, achieve significant reduction of pollutant loading and runoff volume as well as greatly enhanced recharge rates compared to both developments with no BMPs and developments with basic treatment BMPs.

This report covers the methods employed in the investigation, data sources, and references for both. It then presents the results, discusses their consequences, and draws conclusions, and makes recommendations relative to utilizing low-impact site design practices in SUSMPs.

CASE STUDIES

Four case studies were derived directly from building permit records for development projects in the City of San Marcos: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), and an office building (OFF). The records provided data on total site areas, numbers of buildings, building footprint areas (including porch and garage for Sm-SFR), and numbers of parking spaces associated with the development projects. While the building permit records made no reference to features such as roadways, walkways, and landscaping normally associated with development projects, these features were taken into account in the case studies through some reasonable assumptions, as detailed below. Larger developments were not represented in the sampling of building permits from the San Marcos database. To take larger development projects into account in the subsequent analysis, two larger scale case studies were hypothesized: a relatively large single-family residential development (Lg-SFR) and a sizeable commercial retail installation (COMM). The Lg-SFR scenario assumed 1000 homes, and scaled up all land use estimates from the Sm-SFR case in the ratio of 1000:23. The hypothetical COMM scenario consisted of a building with a 2-acre footprint and 500 parking spaces. As with the smaller-scale cases, these hypothetical developments were assumed to have roadways, walkways, and landscaping, which were also handled as follows.

Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. Code requirements vary by jurisdiction, with the tendency now to drop below the traditional 200 sq ft average. About 180 sq ft is common, but various standards for full- and compact-car spaces, and for the mix of the two, can raise or lower the average (http://nemo.uconn.edu/publications/tech_papers/tech_paper_5.pdf). The 176 sq ft size is considered to be a reasonable value for conventional practice.

Roadways and walkways assume a wide variety of patterns, of course. Exclusive of the two SFR cases, simple, square parking lots with roadways around the four sides and square buildings with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively.

Single-family residences were assumed each to have a driveway 20 ft wide and 30 ft long. It was further assumed that each would have a sidewalk along the front of the lot, which was calculated to be 5749 sq ft in area. Assuming a square lot, the front dimension would be 76 ft. A 40-ft walkway was included within the property. Sidewalks and walkways were taken to be 4 ft wide.

Exclusive of the COMM case, the total area for all of these impervious features was subtracted from the total site area to estimate the pervious area, which was assumed to have conventional landscaping cover (grass, small herbaceous decorative plants, bushes, and a few trees). For the hypothetical COMM scenario, the hypothetical total impervious cover was enlarged by 10 percent to represent the landscaping, on the belief that a typical retail commercial establishment would typically be mostly impervious.

Table 1 summarizes the characteristics of the six case studies. The table also provides the recorded or estimated areas in each land use and cover type.

Table 1. Case Study Characteristics and Land Use and Land Cover Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
San Marcos permit nos.	24718	30315-30337	31515	35339	Hypoth.	Hypoth.
San Marcos permit date	3/5/04	3/5/04	3/11/04	5/16/06	-	-
No. of buildings	11	23	1	1	1000	1
Total area (ft^2)	476982	132227	33669	92612	5749000	226529
Roof area (ft^2)	184338	34949	3220	7500	1519522	87120
Parking spaces	438	-	33	37	-	500
Parking area (ft^2)	77088	-	5808	6512	-	88000
Access road area (ft^2)	22212	-	6097	6456	-	23732
Walkway area (ft^2)	33960	10656	1362	2078	463289	7084
Driveway area (ft^2)	-	13800	-	-	600000	-
Landscape area (ft^2)	159384	72822	17182	70066	3166190	20594

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

METHODS OF ANALYSIS

Annual Storm Water Runoff Volumes

For each case study site the annual surface runoff volumes produced were estimated for both pre- and post-development conditions. Runoff volume was computed as the product of annual precipitation, contributing drainage area, and a runoff coefficient (ratio of runoff produced to rainfall received). For impervious areas the following equation was used: $C = 0.009\ I + 0.05$, where I is the impervious percentage. This equation was derived by Schueler (1987) from Nationwide Urban Runoff Program data (U.S. Environmental Protection Agency 1983). With I = 100 percent for fully impervious surfaces, C is 0.95.

The basis for pervious area runoff coefficients was the Natural Resource Conservation Service's (NRCS) Urban Hydrology for Small Watersheds (NRCS 1986, as revised from the original 1975 edition). This model estimates storm event runoff as a function of precipitation and a variable representing land cover and soil, termed the curve number (CN). Larger events are forecast to produce a greater amount of runoff in relation to amount of rainfall because they more fully saturate the soil. Therefore, use of the model to estimate annual runoff requires selecting some event or group of events to represent the year. Jurisdictions under the San Diego municipal storm water permit generally perform water quality analyses with respect to the 85th percentile rainfall quantity (the 85th percentile rainfall is the amount exceeding the precipitation in 85 percent of all events over time). That event was used in the analysis here for the relative comparison between pre- and post-development and applied to deriving a runoff coefficient for annual estimates, recognizing that smaller storms would produce less and larger storms more runoff. This meteorological statistic for San Marcos is 0.75 inch of rainfall (http://www.co.san-diego.ca.us/dpw/watersheds/pubs/susmp_85precip.pdf).

To select CN for the pre-development case, an analysis performed in the area of the Cedar Fire in San Diego was used in which CN was determined before and after the 2003 fire (http://www.ufei.org/files/pubs/SanDiegoUrbanEcosystemAnalysis-PostCedarFire.pdf). Here, CN = 83 was estimated for the pre-existing land cover, which was generally chaparral. For post-development landscaping, CN = 86 was selected based on tabulated data in NRCS (1986) and professional judgment.

Pre- and post-development runoff quantities were computed with these CN values and the 85th percentile rainfall, and then divided by the rainfall to obtain runoff coefficients. The results were 0.07 and 0.12, respectively. Finally, total annual runoff volumes were estimated based on an average annual precipitation of 10.26 inches (http://www.wrcc.dri.edu/cgi-bin/cliMONtpre.pl?casand).

Storm Water Runoff Pollutant Discharges

Annual pollutant mass discharges were estimated as the product of annual runoff volumes produced by the various land use and cover types and pollutant concentrations typical of those areas. Again, the 85th percentile precipitation event was used as a basis for volumes. Storm water pollutant data have typically been measured and reported for general land use types (e.g., single-family residential, commercial). However, an investigation of low-impact site design of the type this study sought to conduct demands data on specific land coverages. The literature offers few data on this basis. Those available and used herein were assembled by a consultant to the City of Seattle for a project in which the author participated. They appear in Attachment A (Herrera Environmental Consultants, Inc. undated).

Pollutant concentrations expected to occur typically in the mixed runoff from the several land use and cover types making up a development were estimated by mass balance; i.e., the concentrations from the different areas of the sites were combined in proportion to their contribution to the total runoff.

The Effect of Conventional Treatment BMPs on Runoff Volume, Pollutant Discharges, and Recharge Rates

The first question in analyzing how BMPs reduce runoff volumes and pollutant discharges was, What BMPs are being employed in San Diego SUSMPs? The currently applicable SUSMP program associated with the San Diego County MS4 permit provides regulated entities with a large number of choices. These options include manufactured BMPs, such as drain inlet inserts (DIIs) and continuous deflective separation (CDS) units. Developments may also select such non-proprietary devices as extended-detention basins (EDBs) and biofiltration swales and filter strips. EDBs hold water for two to three days for solids settlement before releasing whatever does not infiltrate or evaporate. Biofiltration treats runoff through various processes mediated by vegetation and soil. In a swale, runoff flows at some depth in a channel, whereas a filter strip is a broad surface over which water sheet flows. Each of these BMP types was applied to each case study.

The principal basis for the analysis of BMP performance was the California Department of Transportation's BMP Retrofit Pilot Program (Caltrans, 2004), performed in San Diego and Los Angeles Counties. One important result of the program was that BMPs with a natural surface infiltrate and evaporate (probably, mostly infiltrate) a substantial amount of runoff, even if conditions do not appear to be favorable for an infiltration basin. On average, the EDBs, swales, and filter strips respectively lost 40, 50 and 30 percent of the entering flow before the discharge point. DIIs and CDS units do not contact runoff with a natural surface, and therefore do not reduce runoff volume.

The Caltrans program further determined that BMP effluent concentrations were usually a function of the influent concentrations and developed equations for the functional relationships in these cases. BMPs generally reduced influent concentrations proportionately more when they were high. In a relatively few situations influent concentrations were constant at an "irreducible minimum" level regardless of inflow concentrations.

In analyzing the effects of BMPs on the case study sites' runoff, the first step was to reduce the runoff volumes estimated with no BMPs by the fractions observed to be lost in the pilot study. The next task was estimating the effluent concentrations from the relationships in the Caltrans report. The final step was calculating discharge pollutant loadings as the product of the reduced volumes and predicted effluent concentrations. As before, typical pollutant concentrations in the mixed runoff were established by mass balance.

Estimating Infiltration Capacity of the Case Study Sites

Infiltrating sufficient runoff to maintain pre-development hydrologic characteristics and prevent pollutant transport is the most effective way to protect surface receiving waters. Successfully applying infiltration requires soils and hydrogeological conditions that will pass water sufficiently rapidly to avoid overly lengthy ponding, while not allowing percolating water to reach groundwater before the soil column captures pollutants.

The study assumed that infiltration would occur in surface facilities and not in below-ground trenches. The use of trenches is certainly possible, and was judged to be an approved BMP by Caltrans after the pilot study. However, the intent of the investigation was to determine the ability of pervious areas to manage the site runoff. It determined what contribution these areas could make in their original condition, and then assessed how they could serve further if soils were modified using a low-impact site design technique.

The chief basis for this aspect of the work was an assessment of infiltration capacity and benefits for Los Angeles' San Fernando Valley (Chralowicz et al. 2001). The Chralowicz study posited providing 0.1-0.5 acre for infiltration basins to serve 5 acres of contributing drainage area. At 2-3 ft deep, it was estimated that such basins could infiltrate 0.90-1.87 acre-ft/year of runoff in San Fernando Valley conditions. Soils there are generally various loam textures with infiltration rates of approximately 0.5-2.0 inches/hour. Soils are similar in the San Marcos area (http://websoilsurvey.nrcs.usda.gov/app), thus making the conclusions of this study applicable for these purposes. This information was used to estimate how much of each case study site's annual runoff would be infiltratable and if the pervious portion would provide sufficient area.

Volume and Pollutant Source Reduction Strategies

As pointed out earlier, the essence of low-impact site design is reducing runoff problems before they can develop, at their sources, or exploiting the infiltration and treatment abilities of soils and vegetation. If these abilities are not adequate to preserve pre-development hydrology and prevent runoff from causing or contributing to violations of water quality standards, then the choice is to practice source reduction, upgrade infiltration and treatment capabilities, or both.

Soils can be upgraded to store runoff until it can infiltrate, evaporate, or transpire from plants through compost addition, a standard low-impact site design technique. Bioretention cells with these upgraded soils can be built to hold runoff and effect its

transfer to the subsurface zone, another standard low-impact tool. Of course, the space needed must be available to do so. This phase of the analysis determined for the case study sites if that space would indeed be available, assuming the soils and vegetation could be built up to use it effectively.

Source reduction can be accomplished through low-impact site design in various ways. Conventional pavements can be converted to porous asphalt or concrete or replaced with concrete or plastic unit pavers or grid systems. Of course, the soils must be capable of infiltrating the runoff passing through and may require renovation of the same type as discussed for bioretention. Water can also be "harvested," that is, captured and stored for reuse in irrigation or gray water systems. Many successful systems of this type are in operation, for example Natural Resources Defense Council offices, Santa Monica, CA; King County Administration Building, Seattle, WA; two buildings on the Portland State University campus, Portland, OR. Harvesting is a standard technique for Leadership in Energy and Environmental Design (LEED) buildings (http://www.poweryourdesign.com/LEEDGuide.pdf). Runoff from roofs and parking lots can be harvested, with the former being somewhat easier because of the possibility of avoiding pumping to use the water and fewer pollutants. The investigation concluded by determining how harvesting could contribute to storm water management for case study sites where infiltration capacity, available space, or both appeared to be limited.

RESULTS OF THE ANALYSIS

1. "Base Case" Analysis: Development Without Traditional BMP or LID Approaches

Comparison of Pre- and Post-Development Runoff Volumes

Table 2 presents a comparison between the estimated runoff volumes generated by the respective case study sites in the pre- and post-development conditions, assuming implementation of no BMPs on the developed sites. On sites dominated by impervious land cover, most of the infiltration that would recharge groundwater in the undeveloped state is expected to be lost to surface runoff after development. This greatly increased surface flow would raise peak flow rates and volumes in receiving water courses, raise flooding risk, and transport pollutants. Only the office building, the plan for which retained substantial pervious area, would not lose half or more of the pre-development recharge.

Table 2. Pre- and Post-Development Without BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater

Annual Volume (acre-ft)	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Precipitation[b]	9.35	2.59	0.66	1.82	113	4.44
Pre-development runoff[c]	0.65	0.18	0.05	0.13	8	0.31
Pre-development recharge[d]	8.69	2.41	0.61	1.69	105	4.13
Post-development impervious runoff[c]	5.91	1.11	0.31	0.42	48	3.83
Post-development pervious runoff[c]	0.37	0.17	0.04	0.16	7	0.05
Post-development total runoff[c]	6.29	1.28	0.35	0.58	56	3.88
Post-development recharge[d]	3.06	1.31	0.31	1.23	57	0.56
Post-development recharge loss (% of pre-development recharge)	5.63 (65%)	1.10 (46%)	0.30 (49%)	0.46 (27%)	48 (46%)	3.57 (86%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Pollutant Concentrations and Loadings

Table 3 presents the pollutant concentrations from the literature and loadings calculated as described for the various land use and cover types represented by the case studies. Landscaped areas are expected to release the highest TSS concentration, although relatively low TSS mass loading because of the low runoff coefficient. The highest copper concentrations and loadings are expected from parking lots. Roofs, especially commercial roofs, top the list for both zinc concentrations and loadings. Landscaping would issue by far the highest phosphorus, although access roads and driveways would contribute the highest mass loadings.

Table 3. Pollutant Concentration and Loading for Case Study Land Use and Cover Types

	Concentrations					Loadings		
Land Use	TSS (mg/L)	TCu (mg/L)	TZn (mg/L)	TP (mg/L)	Lbs. TSS/ acre-year	Lbs. TCu/ acre-year	Lbs. TZn/ acre-year	Lbs. TP/ acre-year
Residential roof	25	0.013	0.159	0.11	55	0.029	0.350	0.242
Commercial roof	18	0.014	0.281	0.14	40	0.031	0.619	0.309
Access road/driveway	120	0.022	0.118	0.66	264	0.048	0.260	1.455
Parking	75	0.036	0.097	0.14	165	0.079	0.214	0.309
Walkway	25	0.013	0.059	0.11	55	0.029	0.130	0.242
Landscaping	213	0.013	0.059	2.04	59	0.004	0.016	0.568

The CTR acute criteria for copper and zinc are 0.0048 mg/L and 0.090 mg/L, respectively. It may be seen in Table 3 that all developed land uses are expected to discharge copper above the criterion, based on the mass balance calculations using concentrations from Table 3. Any surface release from the case study sites would violate the criterion at the point of discharge, although dilution by the receiving water would lower the concentration below the criterion at some point. Even if copper mass loadings are reduced by BMPs, any surface discharge would exceed the criterion initially, but it would be easier to dilute below that level. In contrast, runoff from some land covers would not violate the acute zinc criterion. Because of this difference, the evaluation considered whether or not the zinc criterion would be exceeded in each analysis, whereas there was no point in this analysis for copper. There are no equivalent water quality criteria for TSS and TP; hence, their concentrations were not further analyzed in the different scenarios.

Table 4 follows with the overall loadings, as well as zinc concentrations, expected to be delivered from the case study developments should they not be fitted with any BMPs. As Table 4 shows, all cases are forecast to exceed the 0.090 mg/L acute zinc criterion, and the retail commercial development does so by a wide margin. Because of its size, the large residential development dominates the mass loading emissions.

Table 4. Case Study Pollutant Concentration and Loading Estimates Without BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.175
Lbs. TSS/year	920	241	87	169	10461	594
Lbs. TCu/year	0.32	0.051	0.022	0.032	2.24	0.25
Lbs. TZn/year	2.16	0.423	0.121	0.210	18.38	1.84
Lbs. TP/year	4.58	1.66	0.50	1.24	72.35	2.34

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

2. "Traditional SUSMP" Analysis: Effects of Basic Treatment BMPs

Post-Development Runoff Volumes

The current SUSMP program permits regulated parties to select from a range of BMPs in order to treat or infiltrate a given quantity of annual rainfall. According to Regional Board staff and third party reviews of the program (Tetra Tech, Inc. 2005), a wide variety of BMPs are selected. Many projects rely on drain inlet inserts, CDS units, and similar manufactured BMPs. Regulated entities currently can select these or other "treat-and-release" techniques in order to satisfy the current San Diego County MS4 Permit. As a category, such treatment BMPs do not permit any collected runoff contact with soils. Therefore, they discharge as much storm water runoff as equivalent sites with no BMPs, and afford zero savings in recharge.

Effects of BMPs on Pollutant Discharges

Table 5 presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from four types of conventional treatment BMPs. The "basic" BMPs in this table, the CDS units, are not expected to drop any of the concentrations sufficiently to meet the acute zinc criterion at the discharge point. The loading reduction results show the CDS unit always performing below 50 percent and most often in the vicinity of 20 percent, with zero copper reduction.

The Caltrans study (2004) produced less data on drain inlet insert performance. These devices were found to reduce pollutant mass loadings by the following amounts (average of the performance of two models): TSS—8.5 percent, TCu—1.0 percent, and TZn—1.5 percent.

3. LID Analysis: Relative Effect of Conventional Soil-Based BMPs and Low-Impact Development Approaches

Annual surface runoff and recharge predicted to occur with the three soil-based BMP types commonly employed in California were estimated. An assumption was full service of all portions of the case study sites with one of these practices. Although the analysis assumed use of one or another of the BMP types throughout each site, a project designer could elect to use more than one BMP to serve different portions. Table 6 gives the estimates, along with the savings in recharge afforded by the LID site design techniques relative to a condition with no BMPs. The percentages of savings exactly reflect the degree of infiltration observed in the Caltrans pilot study: 40, 50, and 30 percent, respectively, for EDBs, swales, and filter strips.

Table 5. Case Study Pollutant Concentration and Loading Estimates With BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Effluent Concentrations:						
CDS TZn (mg/L)[a]	0.095	0.095	0.098	0.102	0.095	0.131
EDB TZn (mg/L)[a]	0.085	0.086	0.084	0.084	0.086	0.098
Swale TZn (mg/L)	0.055	0.054	0.055	0.056	0.054	0.068
Filter strip TZn (mg/L)	0.039	0.039	0.039	0.041	0.039	0.048
Loading Reductions:						
CDS TSS loading reduction	15.7%	19.9%	22.0%	24.0%	19.9%	16.9%
CDS TCu loading reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CDS TZn loading reduction	22.7%	22.4%	22.9%	23.1%	22.4%	25.1%
CDS TP loading reduction	30.6%	41.5%	40.7%	45.9%	41.5%	20.3%
EDB TSS loading reduction	68.1%	73.7%	79.0%	81.1%	73.7%	71.7%
EDB TCu loading reduction	61.9%	55.7%	66.2%	63.0%	55.7%	66.8%
EDB TZn loading reduction	59.7%	59.6%	60.4%	61.9%	59.6%	66.6%
EDB TP loading reduction	61.9%	69.7%	69.1%	72.9%	69.7%	54.5%
Swale TSS loading reduction	68.8%	71.1%	73.1%	73.9%	71.1%	69.4%
Swale TCu loading reduction	72.5%	68.5%	78.2%	73.3%	68.5%	75.8%
Swale TZn loading reduction	78.4%	78.1%	84.3%	78.8%	78.1%	80.7%
Swale TP loading reduction	66.3%	70.7%	67.2%	76.2%	70.7%	55.0%
Filter strip TSS loading reduction	69.9%	75.4%	80.6%	82.6%	75.4%	72.3%
Filter strip TCu loading reduction	74.4%	69.1%	78.2%	75.4%	69.1%	78.7%
Filter strip TZn loading reduction	78.3%	77.9%	78.4%	78.7%	77.9%	80.9%
Filter strip TP loading reduction	48.4%	53.1%	63.7%	59.8%	53.1%	34.6%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial
CDS— continuous deflective separation unit; EDB—extended-detention basin

Effects of BMPs on Pollutant Discharges

Table 5 presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from the EDBs, swales, and filter strips. Effluents from each case study site are expected to fall below the CTR acute zinc criterion if treated with swales or filter strips. All but the large commercial site would meet the criterion with EDB treatment. These infiltration-oriented BMPs, swales, filters, and EDBs, if fully implemented and well maintained, are predicted to prevent the majority of the pollutant masses generated on most of the development sites from reaching a receiving water. Only total phosphorus reduction falls below 50 percent for two case studies. Mass loading reductions range above 80 percent for the EDB, swale, and filter strip.

Table 6. Distribution of Surface Runoff Versus Recharge to Groundwater With BMPs

Annual Volume (acre-ft)	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Total runoff with EDBs[a, b]	3.77	0.77	0.21	0.35	33	2.33
Recharge with EDBs[c]	5.58	1.83	0.45	1.46	79	2.11
Recharge savings with EDBs[d]	2.52	0.51	0.14	0.23	22	1.55
Total runoff with swales[b]	3.14	0.64	0.17	0.29	28	1.94
Recharge with swales[c]	6.20	1.95	0.49	1.52	85	2.50
Recharge savings with swales[d]	3.14	0.64	0.17	0.29	28	1.94
Total runoff with filter strips[b]	4.40	0.89	0.24	0.41	39	2.72
Recharge with filter strips[c]	4.95	1.70	0.42	1.41	74	1.72
Recharge savings with filter strips[d]	1.89	0.38	0.10	0.18	17	1.16

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial; EDBs—extended-detention basins
[b] Quantity of water discharged from the site on the surface
[c] Quantity of water infiltrating the soil; the difference between precipitation and runoff
[d] Difference between recharge with and without BMP (the latter from Table 2)

Expected Infiltration Capacities of the Case Study Sites

Table 7 summarizes the results of the infiltration analysis. The first inquiry on this subject sought to determine how much of the total annual runoff each property is expected to infiltrate. Based on the findings of Chralowicz et al. (2001), it was assumed that a site in the size range 0-5 acres could infiltrate 0.9-1.9 acre-ft/year with an infiltration device of feasible size, one in the range 5-10 acres could recharge 1.8-3.8 acre-ft/year, etc. As shown in the table, three of the six sites should be able to infiltrate the full annual runoff volume. The remainder could recharge to the ground about half or somewhat more of the annual production. These figures pertain to infiltrating in the native soils, with no soil improvements through composting such as often performed in low-impact site design.

Next, it was sought to determine whether the sites, as planned, have sufficient pervious area for surface infiltration facilities. Again, the results of Chralowicz et al. (2001) were used, and it was assumed that infiltration would take 0.1-0.5 acres on a site of 0-5 acres total area, 0.2-1.0 acres on a 5-10 acre property, etc. A site low in the range would likely need a smaller infiltration area than one higher in the size range. Five of the six case study sites clearly have more pervious area than required for infiltration facilities. The commercial retail development was the only development project that came close to lacking sufficient pervious area.

Table 7. Summary of Infiltration Analysis

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Total annual runoff (acre-ft)	6.29	1.28	0.35	0.58	56	3.88
Project area (acres)	11.0	3.0	0.8	2.1	132	5.2
Infiltration capacity (acre-ft)	2.7-5.7	0.9-1.9	0.9-1.9	0.9-1.9	24-51	1.8-3.8
Infiltration assessment	~Half+	All	All	All	~Half+	~Half+
Infiltration area needed (acres)	0.3-1.5	0.1-0.5	0.1-0.5	0.1-0.5	2.7-14	0.2-1.0
Pervious area available (acres)	3.7	1.7	0.4	1.6	72.7	0.5
Adequate area?	Yes	Yes	Yes	Yes	Yes	Maybe

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

As Table 7 shows, the case study sites offer considerable promise to manage storm water by infiltration. For any development project at which infiltration-oriented BMPs are

considered, it is important that infiltration potential be carefully assessed using site-specific soils and hydrogeologic data. In the event such an investigation reveals a marginal condition (e.g., hydraulic conductivity, spacing to groundwater) for infiltration basins, soils could be enhanced to produce bioretention zones to assist infiltration.

Volume and Pollutant Source Reduction Through Low-Impact Site Design

The preceding analysis showed that half the sites potentially could infiltrate all runoff produced in an average year, and also have the land to do so. The other three could recharge half or more of the runoff, and at least two have adequate land. One goal of this exercise was to identify alternatives that would reduce runoff production in the first place. It was hypothesized that implementation of source reduction techniques could allow all of the case study sites to infiltrate all of the remaining runoff. Additionally, runoff volume reduction would commensurately decrease pollutant mass loadings.

This analysis considered scenarios in which all roof runoff is either harvested and stored for some beneficial use or is spread over lawns or into the soil via roof downspout infiltration trenches. The former option is probably best suited to cases like the retail and office buildings, while distribution on or in the soil would fit best with residences and relatively small commercial developments like the restaurant. Table 8 shows the consequences of preventing roofs from generating runoff.

With the subtraction of roof runoff, all sites have the capacity to infiltrate all of the annual runoff volume. Comparison of the third and last rows of the table indicates the significant role of roof runoff, especially in the residential cases. With roof runoff included, the only case that was doubtful in having enough pervious area for full infiltration was the commercial case study site. Harvesting runoff from its 2-acre roof brings it into the situation of having sufficient land. These results show that a combination of roof runoff source reduction and land treatment of the remaining runoff for maximum infiltration appears to be an entirely feasible plan to manage storm water from a range of typical San Diego area developments.

Table 8. Summary of Roof Runoff Source Reduction Analysis

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Annual impervious (minus roof) runoff (acre-ft)	2.48	0.46	0.25	0.28	19.8	2.21
Annual pervious runoff (acre-ft)	0.37	0.17	0.04	0.16	7.5	0.05
Total annual runoff (minus roof) (acre-ft)	2.85	0.63	0.29	0.44	27.3	2.26
Project area (acres)	11.0	3.04	0.77	2.13	132	5.20
Infiltration capacity (acre-ft)	2.7-5.7	0.9-1.9	0.9-1.9	0.9-1.9	24-51	1.8-3.8
Infiltration assessment	All	All	All	All	All	All
Total annual runoff (with roof) (acre-ft)	6.29	1.28	0.35	0.58	56	3.88

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

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Table 9 summarizes the water retention and reuse benefits of the full LID approach involving infiltration by design, supplemented by harvesting from roofs in the MFR, Lg-SFR, and COMM cases. Infiltration contributes to the groundwater resource, while harvesting captures water for use in such applications as irrigation and gray water distribution systems. LID methods offer significant benefits relative to no BMPs in all cases. These benefits are particularly impressive with relatively high site imperviousness, such as in the MFR and COMM cases.

Table 9. Comparison of Water Captured Annually (in acre-ft) from Development Sites for Beneficial Use With a Full LID Approach Compared to Development Without Any BMPs

Water Capture	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Without BMPs[b]	3.06	1.31	0.31	1.23	57	0.56
With full LID approach[c]	9.35	2.59	0.66	1.82	113	4.44
LID benefit[d]	6.29	1.28	0.35	0.58	56	3.88

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial
[b] Water incidentally infiltrated on pervious areas remaining on the development site and recharged to groundwater
[c] Water either entirely infiltrated in BMPs and recharged to groundwater or partially harvested from roofs and partially infiltrated in BMPs
[d] Water capture for which LID approaches are directly responsible; the difference between capture with the full LID approach and without BMPs

SUMMARY AND CONCLUSIONS

This paper demonstrated that common San Diego area residential and commercial development types subject to SUSMPs are likely, without storm water management, to reduce groundwater recharge from the predevelopment state by approximately half in most cases to a much higher fraction with a large ratio of impervious to pervious area. With no treatment, runoff from these developments is expected to exceed CTR acute copper and zinc criteria at the point of discharge and to deliver large pollutant mass loadings to receiving waters.

Many San Diego SUSMP projects have been getting mostly traditional commercially manufactured filtration and hydrodynamic BMPs for storm water management. Such BMPs are included in the SUSMP menu of options currently, and they do have some beneficial impact on runoff quality compared to development without BMPs. However, they are not optimal solutions. These devices do not stem the loss of groundwater recharge, still allow zinc as well as copper water quality criteria violations from all development types analyzed, and capture relatively small fractions of the pollutant mass loadings produced in urban areas.

Conventional soil-based BMP solutions that promote and are component parts of low-impact development approaches, by contrast, regain 30-50 percent of the recharge lost in development without storm water management. It is expected they generally would release effluent that meets the acute zinc criterion at the point of discharge, although it would still exceed the copper limit. Excepting phosphorus, it was found that these BMPs would capture and prevent the movement to receiving waters of the majority of the pollutant loadings considered in the analysis.

It was found that the loam soils typical of the San Marcos area, where the case studies were set, should infiltrate at least half of all the runoff produced in an average year, and all of it for some development types and site designs. Soil enhancement (typically, with

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compost) can advance infiltration and lower its risk of failure. Using additive LID approaches, including specifically subtracting the roof runoff by harvesting it for reuse or distributing it in the soil with infiltration trenches, reduces overall runoff sufficiently to conclude that all development examples assessed could infiltrate their surface runoff production.

RECOMMENDATIONS

Low-impact site design techniques emphasize runoff volume and pollutant reduction at their sources and management of runoff and pollutants through vegetation and soil treatment. This type of treatment can infiltrate and evaporate much or even all of the runoff produced in design events. This report shows low-impact site design techniques to be capable of regaining the groundwater recharge lost in development to a greater extent than conventional BMPs. At the same time LID techniques substantially preserve pre-development hydrologic conditions and prevent most or all pollutant transport to receiving waters.

SARB_011249

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ATTACHMENT A

Pollutant Concentrations for Urban Source Areas (Herrera Environmental Consultants, Inc. undated)

Source Area	Study	Location	Sample Size (n)	TSS (mg/L)	TCu (ug/L)	TPb (ug/L)	TZn (ug/L)	TP (mg/L)	Notes
Roofs									
Residential	Steuer, et al. 1997	MI	12	36	7	25	201	0.06	2
Residential	Bannerman, et al. 1993	WI	~48	27	15	21	149	0.15	3
Residential	Waschbusch, et al. 2000	WI	25	15	n.a.	n.a.	n.a.	0.07	3
Residential	FAR 2003	NY		*19*	*20*	*21*	*312*	*0.11*	4
Residential	Gromaire, et al. 2001	France		*29*	*37*	*493*	*3422*	*n.a.*	5
Representative Residential Roof Values				**25**	**13**	**22**	**159**	**0.11**	
Commercial	Steuer, et al. 1997	MI	12	24	20	48	215	0.09	2
Commercial	Bannerman, et al. 1993	WI	~16	15	9	9	330	0.20	3
Commercial	Waschbusch, et al. 2000	WI	25	18	n.a.	n.a.	n.a.	0.13	3
Representative Commercial Roof Values				**18**	**14**	**26**	**281**	**0.14**	
Parking Areas									
Res. Driveways	Steuer, et al. 1997	MI	12	157	34	52	148	0.35	2
Res. Driveways	Bannerman, et al. 1993	WI	~32	173	17	17	107	1.16	3
Res. Driveways	Waschbusch, et al. 2000	WI	25	34	n.a.	n.a.	n.a.	0.18	3
Driveway	FAR 2003	NY		*173*	*17*		*107*	*0.56*	4
Representative Residential Driveway Values				**120**	**22**	**27**	**118**	**0.66**	
Comm./ Inst. Park. Areas	Pitt, et al. 1995	AL	16	110	116	46	110	n.a.	1
Comm. Park. Areas	Steuer, et al. 1997	MI	12	110	22	40	178	0.2	2
Com. Park. Lot	Bannerman, et al. 1993	WI	5	58	15	22	178	0.19	3
Parking Lot	Waschbusch, et al. 2000	WI	25	51	n.a.	n.a.	n.a.	0.1	3
Parking Lot	Tiefenthaler, et al. 2001	CA	5	36	28	45	293	n.a.	6
Loading Docks	Pitt, et al. 1995	AL	3	40	22	55	55	n.a.	1
Highway Rest Areas	CalTrans 2003	CA	53	*63*	*16*	*8*	*142*	*0.47*	7
Park and Ride Facilities	CalTrans 2003	CA	179	*69*	*17*	*10*	*154*	*0.33*	7

Comm./ Res. Parking	FAR 2003	NY		*27*	*51*	*28*	*139*	*0.15*	4
Representative Parking Area/Lot Values				**75**	**36**	**26**	**97**	**0.14**	
Landscaping/Lawns									
Landscaped Areas	Pitt, et al. 1995	AL	6	33	81	24	230	n.a.	1
Landscaping	FAR 2003	NY		*37*	*94*	*29*	*263*	n.a.	4
Representative Landscaping Values				**33**	**81**	**24**	**230**	**n.a.**	
Lawns - Residential	Steuer, et al. 1997	MI	12	262	n.a.	n.a.	n.a.	2.33	2
Lawns - Residential	Bannerman, et al. 1993	WI	~30	397	13	n.a.	59	2.67	3
Lawns	Waschbusch, et al. 2000	WI	25	59	n.a.	n.a.	n.a.	0.79	3
Lawns	Waschbusch, et al. 2000	WI	25	122	n.a.	n.a.	n.a.	1.61	3
Lawns - Fertilized	USGS 2002	WI	58	n.a.	n.a.	n.a.	n.a.	2.57	3
Lawns - Non-P Fertilized	USGS 2002	WI	38	n.a.	n.a.	n.a.	n.a.	1.89	3
Lawns - Unfertilized	USGS 2002	WI	19	n.a.	n.a.	n.a.	n.a.	1.73	3
Lawns	FAR 2003	NY	3	*602*	*17*	*17*	*50*	*2.1*	4
Representative Lawn Values				**213**	**13**	**n.a.**	**59**	**2.04**	

Notes:

Representative values are weighted means of collected data. Italicized values were omitted from these calculations.

1 - Grab samples from residential, commercial/institutional, and industrial rooftops. Values represent mean of DETECTED concentrations

2 - Flow-weighted composite samples, geometric mean concentrations

3 - Geometric mean concentrations

4 - Citation appears to be erroneous - original source of data is unknown. Not used to calculate representative value

5 - Median concentrations. Not used to calculate representative values due to site location and variation from other values.

6 - Mean concentrations from simulated rainfall study

7 - Mean concentrations. Not used to calculate representative values due to transportation nature of land use.

SUPPLEMENTARY INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES ("LID") FOR THE SAN FRANCISCO BAY AREA

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ABSTRACT

The Clean Water Act NPDES permit that regulates municipal separate storm sewer systems (MS4s) in the San Francisco Bay Area, California will be reissued in 2007. The draft permit includes general provisions related to low impact development practices (LID) for certain kinds of development and redevelopment projects. Using eight representative development project case studies, based on California building records, the author investigated the practicability and relative benefits of LID options for the portion of the region having soils potentially limiting to infiltration. The principal LID option applicable in this situation is roof runoff harvesting, supplement by dispersion of the roof water in single-home sites. Other site runoff would be treated by conventional stormwater best management practices (BMPs), as specified in the permit. The results showed that effectively managing roof runoff and treating the remainder with conventional BMPS can: (1) reduce annual runoff volumes by almost half to more than 3/4, depending on land use characteristics, with much of the water saved available for a beneficial use; and (2) decrease mass loadings of pollutants to receiving waters by 63 to over 90 percent, depending on pollutant and land use.

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INTRODUCTION

Background

A report titled Initial Investigation of the Feasibility and Benefits of Low-Impact Development Practices ("LID") for the San Francisco Bay Area used six representative development project case studies, based on California building records, to investigate the practicability and relative benefits of LID options for the majority of the region having soils potentially suitable for infiltration either in their natural state or after amendment using well recognized LID techniques. The results demonstrated that: (1) LID site design and source control techniques are more effective than conventional best management practices (BMPs) in reducing runoff rates; and (2) in each of the case studies, LID methods would reduce site runoff volume and pollutant loading to zero in typical rainfall scenarios.

For a broad regional assessment of relatively large scale use of soil-based, infiltrative LID practices, the initial report covered areas having soils in Natural Resources Conservation Service (NRCS) Hydrologic Soil Groups A, B, or C as classified by the Natural Resources Conservation Service (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). Depending on site-specific conditions, A and B soils would generally effectively infiltrate water without modification, whereas C soils could require organic amendments according to now standard LID methods. This supplementary report covers locations with group D soils, which are generally not amenable to infiltration, again depending on the specific conditions on-site. A minority but still substantial fraction of the Bay Area has group D soils (39.3, 68.0, 18.3, and 50.1 percent of the mapped areas of Alameda, Contra Costa, San Mateo, and Santa Clara Counties, respectively). Regarding any mapped soil type, it is important to keep in mind that soils vary considerably within small distances. Characteristics at specific locations can deviate greatly from

those of the major mapped unit, making infiltration potential either more or less than may be expected from the mapping. The soil survey data are regarded as appropriate for use in broad-scale assessments such as underlie this and the initial report, but once site-specific implementation begins, it is important to verify site conditions.

General Assessment Methods

The assessment for group D soils reported herein emphasizes the use of LID practices appropriate in areas with relatively restrictive soils to the greatest possible extent, supplemented by conventional stormwater management practices implemented at fully practicable, high levels of effectiveness. The assessment was performed in a manner analogous to the analysis for the other soil groups and as described in the initial report. To recap briefly, with respect to each of several development case studies, three assessments were undertaken: a baseline scenario incorporating no stormwater management controls; a second scenario employing conventional BMPs; and a third development scenario employing LID stormwater management strategies. In each assessment, annual stormwater runoff volumes were estimated, as well as concentrations and mass loadings (the products of concentrations times flow volumes) of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). The results of the second and third assessments were expressed in terms of the extent to which the management practices would reduce pollutant concentrations and loadings and runoff volumes, converting stormwater discharge a potential beneficial use (direct consumption or, in the case of group A, B, C soil areas, groundwater recharge).

Six case studies were selected to represent a range of urban development types considered to be representative of the Bay Area. These case studies involved: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), an office building (OFF), a relatively large (1000 homes) single-family residential development (Lg-SFR), and a single home (SINGLE). The land cover types for these various land uses were derived from building permit and other public records from the Bay Area or elsewhere in California.

Adaptation of Methods for Areas with Group D Soils

A key LID technique in a setting with soils relatively restrictive to infiltration is water harvesting, which can be applied at larger scales in commercial and light industrial developments and at smaller residential scales using cisterns or rain barrels. Harvesting has been successful in reducing runoff discharged to the storm drain system and conserving water in applications at all scales. For example, in downtown Seattle the King County Government Center collects enough roof runoff to supply over 60 percent of the toilet flushing and plant irrigation water requirements, saving approximately 1.4 million gallons of potable water per year (http://www.psat.wa.gov/Publications/LID_studies/rooftop_rainwater.htm, http://dnr.metrokc.gov/dnrp/ksc_tour/features/features.htm). A much smaller public building in Seattle, the Carkeek Environmental Learning Center, drains roof runoff into a 3500-gallon cistern to supply toilets (http://www.harvesth2o.com/seattle.shtml). Collecting drainage from individual dwellings for household use is a standard technique around the world, particularly in areas deficient in rainfall and without affordable alternative sources.

An additional general category of LID practices for poorly infiltrating locations, applicable especially at single homes and other relatively small-scale developments, is runoff dispersion for storage in vegetation and soil until evapotranspiration and some infiltration occurs. Section C.3.c of the California Regional Water Quality Control Board San Francisco Bay Region "Administrative Draft" NPDES Municipal Regional Stormwater Permit (“the Permit”) requires all single-family home projects that create and/or replace 5,000 square feet or more of impervious surface to implement one or more stormwater lot-scale BMPs from a selection of: (1) diverting roof runoff to vegetated areas; (2) directing paved surface runoff flow to vegetated areas; and/or (3) installing driveways, patios, and walkways with pervious material such as pervious concrete or pavers. Another way of distributing and dissipating roof runoff used successfully in varied soils in the state of Washington is the downspout dispersion system, consisting of a splash block or gravel-filled trench serving to spread roof runoff over a vegetated area (Washington Department of Ecology 2005 [Volume III, Section 3.1.2]).

The basis of the group D soils assessment was harvesting roof runoff to the maximum possible degree, supplemented in smaller-scale developments by runoff dispersion methods. The report asserts that, through these LID BMPs, it is practicable to prevent the entrance of any roof runoff into the municipal storm drain system in any soils setting in the Bay Area. In group D soils, infiltration likely cannot be relied upon to reduce runoff from other portions of developments, such as walkways, driveways, parking lots, access roads, and landscaping. Some water loss would undoubtedly occur, especially through evapotranspiration and at least some infiltration of runoff generated on or directed to landscaping. The analysis presented in this report does not take account of these losses and hence is somewhat conservative in estimating benefits.

As required by the Permit, any runoff not attenuated by harvest, evapotranspiration, or infiltration would be subject to quantity and quality controls. The analysis assumes that extended-detention basins (EDBs) with water residence times up to 72 hours would provide this control. EDBs are one of several general-purpose, conventional stormwater BMPs available for this service, others being wet ponds, constructed wetlands, sand or other media filters, and biofiltration swales and filter strips. The California Department of Transportation (Caltrans, 2004) tested the performance of all of these practices in its BMP Retrofit Pilot Program, conducted in San Diego and Los Angeles Counties. The initial report investigating LID for A, B, and C soils presented estimates of benefits for EDBs, swales, and filter strips, along with continuous deflective separation (CDS) units, a practice that effectively captures only large particulate pollutants. For brevity, this follow-up report focuses on just EDBs as the supplement to LID. In performance, EDBs tend to fall between swales and filter strips for total suspended solids, slightly lower than the other two BMP types for metals, and either between the two or comparable to swales for total phosphorus.

These practices were applied to the same six case studies used in the initial analysis and described in Table 1 of the first report. Two additional case studies were defined for the assessment reported here: a sizeable commercial retail installation (COMM) and an urban redevelopment (REDEV). The hypothetical COMM scenario consists of a building with a 2-acre footprint and 500 parking spaces. Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. A simple, square parking lot with roadways around the four sides and a square building with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively. The REDEV case was taken from an actual project in Berkeley involving a remodel of an existing structure, built originally as a corner grocery store with apartments above and a large side yard, and the addition of a new building on the same site to create a nine-unit, mixed-use, urban infill project. Table 1 summarizes the characteristics of these two case studies. The table also provides the recorded or estimated areas in each land use and cover type.

Table 1. Characteristics and Land Use and Land Cover Areas of Added Case Studies

	COMM[a]	REDEV[a]
No. buildings	1	1
Total area (ft^2)	226,529	5,451
Roof area (ft^2)	87,120	3,435
No. parking spaces	500	2 uncovered
Parking area (ft^2)	88,000	316 uncovered
Access road area (ft^2)	23,732	-
Walkway area (ft^2)	7,084	350
Driveway area (ft^2)	-	650
Landscape area (ft^2)	20,594	700

[a] COMM—retail commercial; REDEV—commercial/residential infill

The assessment for group D soils employed the same methods as the earlier analysis to estimate annual stormwater runoff volumes and pollutant discharges. Please refer to the initial report for details on those

methods. The Natural Resource Conservation Service (NRCS, 1986) methodology cited in that report was applied to estimate that infiltration in group D soils would be roughly 60 percent of the amount through landscaping or the bed of a conventional BMP in C soils, which were the basis for establishing runoff coefficients in the first analysis. While that initial analysis was performed for both 14- and 20-inch average annual runoff zones, typical of different Bay Area locations, this supplementary work covered only the former condition. This simplification was made in the interest of brevity in this report, given that the first analysis showed almost no difference in conclusions between the two situations.

RESULTS OF THE ANALYSIS

Table 2 provides a comprehensive summary of the results. Rows shaded in gray compare runoff and pollutant discharges with and without treatment by CDS units, which can capture relatively large solids but have no mechanisms for dissolved substances and the finer particles. Having no soil contact and very limited residence time for evaporation, this BMP cannot reduce runoff volume at all. It can achieve some substantial reductions in TSS and TP for land uses relatively high in landscaped area but little removal of metals, especially copper.

The blue-shaded rows show the performance of conventional EDBs. In the group D soils considered in this analysis, they were estimated to reduce annual runoff volumes by 13-23 percent, the higher values for land uses with relatively small impervious footprints (OFF and REST). These BMPs can capture the majority of the long-term mass loading of most pollutants from most land uses in these soils, falling below 50 percent in reducing metals in stormwater flowing from residential developments.

Rows shaded in green present the results of applying LID BMPs appropriate for group D soils, roof runoff harvesting supplemented by dispersion in single-home land uses, plus treating the remaining runoff with EDBs. Comparing annual runoff volumes with and without LID, it can be seen that removing roof runoff from the storm drain system affords very significant benefits in reducing surface discharge and putting much of that water to productive use. Compared to directing all site runoff to EDBs, LID is expected to reduce volume by almost 10 times in the REDEV case, by about five times for the various residential land uses, 3.6 times for the large commercial development, and around twice for the OFF and REST cases. This management strategy can recover over 3/4 of the stormwater that would otherwise go down the drain in the intense redevelopment case, approximately 2/3 for the multi- and single-family residential cases, over half in the COMM development, and almost half in the office and restaurant cases with relatively small roof footprints.

Reduction of volume translates to decreases in pollutant loadings also. The combination of LID and EDB treatment is estimated to raise copper and zinc reductions to about 70 to over 90 percent in all except the developments with relatively low roof proportions (60-65 percent in these cases). TSS predictions come in at a quite consistent 75-82 percent across land uses. Total phosphorus estimates are a similarly consistent 63-71 percent, a bit higher in the highly impervious REDEV case.

Effectively managing roof runoff gives a way out of the dilemma posed by group D soils in the Bay Area. The analysis has demonstrated that harvesting this runoff stream, supplemented by ground dispersion techniques with sufficient space, shows strong promise to reduce the majority of flow inputs to municipal storm drain systems while conserving water. Moreover, this strategy can also stem the majority of solids, copper, zinc, and phosphorus transport to receiving waters.

Table 2. Runoff Volume and Pollutant Loading Reductions with Conventional and Low-Impact Development (LID) Best Management Practices (BMPs) for Eight Land Use Case Studies in Hydrologic Group D Soils

	COMM[a]	OFF[a]	REST[a]	REDEV[a]	MFR[a]	Lg-SFR[a]	Sm-SFR[a]	SINGLE
Total annual runoff with no BMPs (ac-ft)	5.29	0.80	0.47	0.12	8.57	75.66	1.74	0.10
Total annual runoff with CDS units[b] (reduction)	5.29 (0.0%)	0.80 (0.0%)	0.47 (0.0%)	0.12 (0.0%)	8.57 (0.0%)	75.66 (0.0%)	1.74 (0.0%)	0.10 (0.0%)
Total annual runoff with EDBs[b] (reduction)	4.43 (16.3%)	0.63 (21.3%)	0.36 (23.2%)	0.11 (8.1%)	7.48 (12.7%)	65.27 (13.7%)	1.50 (13.7%)	0.09 (13.3%)
Total annual runoff with LID[b] (reduction)	2.22 (58.0%)	0.44 (45.0%)	0.28 (40.4%)	0.03 (78.9%)	2.80 (67.3%)	26.72 (64.8%)	0.61 (64.8%)	0.04 (65.7%)
CDS TSS reduction[b, c]	19.4%	44.8%	33.9%	22.1%	27.1%	37.1%	37.1%	37.7%
CDS TCu reduction[b, c]	0.4%	11.0%	4.2%	0.9%	2.7%	7.3%	7.3%	7.6%
CDS TZn reduction[b, c]	25.3%	29.1%	25.5%	25.5%	24.1%	25.6%	25.6%	25.9%
CDS TP reduction[b, c]	25.9%	63.7%	54.3%	35.7%	46.7%	57.6%	57.6%	58.2%
EDB TSS reduction[b, c]	64.7%	78.1%	74.9%	66.5%	62.8%	70.3%	70.3%	70.9%
EDB TCu reduction[b, c]	57.9%	51.6%	56.4%	53.2%	51.4%	43.5%	43.5%	43.6%
EDB TZn reduction[b, c]	57.6%	49.6%	48.9%	58.1%	48.5%	47.7%	47.7%	48.0%
EDB TP reduction[b, c]	44.4%	67.6%	63.3%	52.8%	56.3%	64.4%	64.4%	64.7%
LID + EDB TSS reduction[b, c, d]	74.6%	80.3%	77.0%	81.5%	79.4%	81.3%	81.3%	81.8%
LID + EDB TCu reduction[b, c, d]	71.9%	60.3%	62.2%	82.3%	73.8%	68.9%	68.9%	69.5%
LID + EDB TZn reduction[b, c, d]	79.7%	65.1%	60.9%	92.3%	78.9%	76.4%	76.4%	77.0%
LID + EDB TP reduction[b, c, d]	63.1%	69.8%	66.0%	75.2%	69.4%	70.8%	70.8%	71.1%

[a] COMM—retail commercial; OFF—office building; REST—restaurant; REDEV—commercial/residential redevelopment; MFR—multi-family residential; Lg-SFR—large-scale single-family residential; Sm-SFR—small-scale single-family residential; SINGLE—single family home

[b] CDS— continuous deflective separation; EDBs—extended-detention basins; reduction—comparison with no BMPs

[c] TSS—total suspended solids; TCu—total recoverable copper; TZn—total recoverable zinc; TP—total phosphorus

[d] LID + EDB—roof runoff harvesting for COMM, OFF, REST, REDEV, AND MFR; harvesting supplemented by dispersion of roof runoff for Lg-SFR, Sm-SFR, and SINGLE; treatment of remaining runoff by EDBs

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Critique of Certain Elements of "Low Impact Development Metrics in Stormwater Permitting"

By Richard Horner

GENERAL CONCLUSION

While the authors drew certain negative (and not always well-founded, as explained below) conclusions about a maximum 3-5 percent effective impervious area ("EIA") site design criterion, the results of the report's analysis overall contribute to the growing consensus that implementing LID according to a numeric metric is technically feasible in both new development and redevelopment contexts. The results thus buttress my findings in analyses performed earlier for San Diego and Ventura Counties and for the San Francisco Bay Area (Horner 2006; 2007a, b) and support the feasibility of meeting a 5% EIA standard in southern California. However, the report's suggestion that a "delta volume" standard be adopted would depart from standard and well-accepted practice in the United States, resulting in significantly greater volumes of stormwater with concomitant, significant increases in the mass volume of a range of pollutants in stormwater.

CRITIQUE OF WATER QUALITY TREATMENT DESIGN BASIS

The authors of Low Impact Development Metrics in Stormwater Permitting ("the report") propose and employ in their case studies a quantity they term "excess stormwater runoff," which forms the basis for their sizing and designing of low impact development ("LID") facilities to treat stormwater runoff. In footnote 21 on page 31, the authors have defined "excess stormwater runoff" as the volume of post-development runoff minus pre-development runoff for the 85th percentile storm event (or for an equivalent water quality design event). However, using the differential volume ("delta volume") between pre- and post-development conditions breaks the long-standing national and state precedent of using the full volume of stormwater discharged from the developed site as the basis for stormwater best management practices ("BMPs") that store runoff for longer than a few minutes.

The virtually universal adoption (see examples below) of the full water quality volume instead of the delta volume occurred for good reasons. The total runoff volume from the 85th percentile event—the prevailing design standard in southern California—was determined through objective analysis to represent the point above which substantially diminishing returns in water quality improvement would accompany considerable size enlargement and, therefore, cost (Guo and Urbonas 1996). The analysis identified the *full* volume generated by the 85th percentile event—not some lesser quantity like the delta volume—as the appropriate threshold at which the decrease in benefits accelerates.

The use of a differential hydrologic measure that compares pre- and post-development states is common in the management of storm runoff quantity (i.e., hydromodification). The pre- vs. post-development measure is appropriate in that situation because successfully matching pre-

and post-development hydrologic characteristics causes no modification in the hydrologic status of the receiving water and, hence, no negative physical effects. When managing water quality, in contrast, any untreated volume (in the delta volume scenario, this would be the amount that originally flowed from the undeveloped land) would deliver to the receiving water the many pollutants characteristic of urban runoff. There, these pollutants would create negative physical, chemical, and biological effects. On the other hand, if the appropriate water quality volume is used (i.e., no less than the full volume of the 85th percentile event), the LID-based stormwater management BMPs should deliver no pollutants to the receiving water, since the retention and reuse or infiltration of that volume is practicable and achievable, as I have demonstrated separately by analyzing a range of development scenarios in southern California.

The loss in treatment capacity from using the delta volume measure, and hence the loss in water quality protection, would vary depending on climatology and the characteristics of the undeveloped parcel and the developed site (type of pervious and impervious land cover, soil, slope, etc.). In the Walnut Village and 60 California case studies presented in the report, the difference ranged from 15 to 20 percent and could be higher in different scenarios. This difference is not small, considering that the National Stormwater Quality Database (Pitt, Maestre, and Morquecho 2004) shows that pollutants like solids, metals, nutrients, and bacteria are typically present in urban runoff at concentrations two to five times as high as in storm flow from undeveloped land. Discharging the pre-development volume, contaminated by urban pollutants without any water quality treatment, would subject human users and aquatic life to substantial runoff quantities with pollutant mass loadings and potentially acutely toxic pollutant concentrations. These loadings and concentrations would be increased by factors of approximately two to five, compared to the pre-development state, thus compromising the beneficial uses of the water body that existed before development. It is essential for resource protection that the full post-development volume be retained onsite through infiltration, evapotranspiration, and/or harvesting for reuse.

As pointed out above, adopting a volumetric basis for stormwater treatment design and then subjecting that full volume to onsite retention or treatment has been the rule in the United States. Jurisdictions take differing approaches to defining that volume, but, once it is set, they utilize the entire quantity as the basis for BMP design. Common approaches include the storm percentile method: a storm event of selected frequency and duration is chosen, which correlates to a certain depth of precipitation spread over a watershed area. In addition to southern California, Georgia provides an example of the first approach (http://www.georgiastormwater.com/vol2/1-3.pdf at 1.3-1):

> Treat the runoff from 85% of the storms that occur in an average year. For Georgia, this equates to providing water quality treatment for the runoff resulting from a rainfall depth of 1.2 inches.

The state of Washington employs a second approach, actually in relation to a storm percentile analysis (http://www.ecy.wa.gov/pubs/0510029.pdf at 2-28):

> Water Quality Design Storm Volume: The volume of runoff predicted from a 24-hour storm with a 6-month return frequency (a.k.a., 6-month, 24-hour storm). Wetpool

> facilities are sized based upon the volume of runoff predicted through use of the Natural Resource Conservation Service curve number equations in Chapter 2 of Volume III, for the 6-month, 24-hour storm. Alternatively, the 91st percentile, 24-hour runoff volume indicated by an approved continuous runoff model may be used.

Numerous jurisdictions, such as Maine, use the precipitation depth approach (http://www.maine.gov/dep/blwq/docstand/stormwater/stormwaterbmps/vol3/chapter2.pdf at 2-12):

> Stormwater management facilities must be designed to treat the first 1 inch of runoff ...

Maryland (http://www.mde.state.md.us/assets/document/chapter2.pdf at 2.1):

> P= rainfall depth in inches and is equal to 1.0" in the Eastern Rainfall Zone and 0.9" in the Western Rainfall Zone ...

Pennsylvania (http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=| at 3.3.4):

- Stormwater facilities shall be sized to capture at least the first two inches (2") of runoff from all contributing impervious surfaces.
- At least the first one inch (1.0") of runoff from new impervious surfaces shall be permanently removed from the runoff flow – i.e., it shall not be released into the surface Waters of this Commonwealth. Removal options include reuse, evaporation, transpiration, and infiltration.

and North Carolina (http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf at 2-2):

> Non-coastal counties: Control and treat the first 1.0" of rain. (Note: a more complex basis applies to coastal counties.)

In none of these cases does the stormwater treatment design basis involve a delta volume computation such as advocated by the authors of the report.

CRITIQUE OF CASE STUDIES

Even though the report forthrightly demonstrates technical feasibility, it nonetheless takes a somewhat negative stance by overemphasizing difficulties and high costs, both of which are poorly justified. The report, moreover, is devoid of estimates of the benefits that accrue from reducing the discharge of pollutants to receiving waters, recharging groundwater through infiltration, conserving water through harvesting and reuse, and decreasing hydromodification of

receiving waters. I made such estimates in my previous reports, and these benefits are very significant. For example, I concluded that (Horner 2007a):

> Draining impervious surfaces onto the loam soils typical of Ventura County, in connection with limiting directly connected impervious area to three percent of the site total area, should eliminate storm runoff from some development types and greatly reduce it from more highly impervious types. Adding roof runoff elimination to the LID approach (by harvesting or directing it to downspout infiltration trenches) should eliminate runoff from all but mostly impervious developments. Even in the development scenario involving the highest relative proportion of impervious surface, losses of rainfall capture for beneficial uses could be reduced from more than 85 to less than 40 percent, and pollutant mass loadings would fall by 83-95 percent from the untreated scenario when draining to pervious areas was supplemented with water harvesting.

Failure to include a discussion of such important benefits inappropriately biases the report against feasible LID numeric performance standards such as an EIA limitation. There is a somewhat grudging admission that LID based on an EIA limitation can be implemented, but this is countered with assertions that doing so will take some extra work and cost too much. Both of these negative claims should not be given much weight for the reasons stated below. Furthermore, neglecting the aforementioned very real and important benefits of robust LID implementation omits the counterbalancing consideration that the aquatic environment will be better protected with an improved site design paradigm.

Additionally, the report fails to take into account two aspects of LID that are at least relatively cost-neutral or, in many configurations, even cost-saving. First, landscaping is a normal part of developed and redeveloped sites and can serve stormwater management purposes, as well as aesthetic purposes, with little or no extra cost. Second, most LID practices primarily utilize soft infrastructure instead of more expensive hard infrastructure like extensive piping and concrete. While the cost analyses presented in the report were poorly detailed in the first place, as discussed in greater depth below, it appears that these financially mitigating factors were not even considered.

Walnut Village

The report's presentation of the multi-family residential Walnut Village redevelopment project reflects the general criticisms noted above. It demonstrates the technical feasibility of implementing LID practices according to an EIA limitation (in fact, the authors achieved an EIA of zero), stating, "this result ... illustrates that LID benefits can be achieved by both extensive implementation (i.e., routing of runoff to vegetated systems) and more intensive design of active landscaping (i.e., greater retention depth) where opportunities exist."

Nevertheless, the authors put a negative spin—unjustified, in my opinion—on this success. In one negative passage the report declares, "the 14-17 inches of retention required to capture the delta 2-year volume is much less feasible, as it would require a combination of fairly deep amended soils and significant surface storage." I contend that providing 14-17 inches of storage in surface ponding and soil pores is entirely feasible. For instance, 18 inches of amended soils

with 33 percent porosity would provide 6 inches of storage, which could be supplemented by 8-11 inches of above-grounded temporarily ponded volume, a thoroughly feasible design. Elsewhere, the report characterizes decreasing EIA from 18 to 0 percent as "difficult," although this decrease merely involves converting non-essential hardscape to landscaping. The reader is left to wonder why any developer would choose to buy and install *non-essential* asphalt or concrete (almost certainly more expensive than LID landscaping) rather than constructing vegetated BMPs that would be an asset in more ways than one. In my opinion, it is more "difficult" from fiscal and marketing perspectives to justify the use of pavement for no reason. In any case, whatever impression one has of this issue, from a technical, objective perspective, the report does not contain a reasonably complete and even-handed assessment of costs, significantly undercutting its claims of infeasibility. Likewise, subjective and undefined assertions regarding the "difficulty" of meeting even relatively high volumes (such as the two-year storm) are presented without supporting analysis or justification which, once again, limits the utility of the report.

Further, with regard to landscaping, the final sentence in the case study states, "landscape plans typically include features that restrict usage of landscaping for runoff control (e.g., tree choice can limit inundation depths and duration), therefore, it is unreasonable to assume that all landscaping may be available." There is no reason why landscaping plans should be incompatible with vegetative LID practices, however. Bioretention cells and similar LID features routinely include trees, which serve several important hydrologic roles (rainfall interception, advancing infiltration by opening conveyance pathways through soil, water storage in tissues, and transpiration). It is no challenge for landscape designers to select trees that are not limited by moisture conditions in such BMPs.

The Walnut Village site has hydrologic group B soils, to which the authors assigned an infiltration rate of 0.2 inch/hour, assuming that the soils would be "compacted". They thereby ignore a fundamental LID practice: guarding against the removal and compaction of soils outside the active building area during construction (Hinman 2005). While infiltration rates vary depending on the specific soil type within a hydrologic soil group, B soils overall have rates much above the authors' assumption; i.e., 0.5-1 inch/hour (http://www.vcstormwater.org/documents/workproducts/landuseguidelines/appC.pdf). The National Resource Conservation Service (2007) observes that, "Soils that are deeper than 100 centimeters [40 inches] to a water impermeable layer or water table are in Group B if the saturated hydraulic conductivity of all soil layers within 100 centimeters [40 inches] of the surface exceeds 4.0 micrometers per second (0.57 inches per hour) but is less than 10.0 micrometers per second (1.42 inches per hour)." It would be irresponsible building practice anywhere, and certainly in a development that is implementing LID practices, to permit such indiscriminant soil disturbance that across the landscape the infiltration rate is decreased to as little as 15 percent of its natural magnitude.

The infiltration rate assumption has consequences for the analysis and the authors' interpretation of their results. While the report shows that adequate volume attenuation could be accomplished to meet the case study's stated objectives, with the 0.2 inch/hour infiltration rate, active landscaping drain times could exceed the recommended 72-hour maximum and approach 83 hours. If the infiltration rate were just slightly higher at 0.3 inch/hour, though, drawdown would

occur 50 percent faster and easily lower the drain time beneath the maximum. Avoiding the drastic diminution in hydraulic conductivity that the authors have assumed is eminently achievable on the site's B soils and would produce an even more optimistic picture than the already successful Walnut Village hypothetical design.

The authors observe that imposing a fixed EIA standard alone promotes the routing of runoff to vegetated systems but does not boost the companion strategy of pursuing more intensive design of active landscaping. In so doing, the authors provide a valuable service in pointing out that a design basis must accompany the EIA limitation for real effectiveness. An example of such a comprehensive standard is:

> Limit effective impervious area to 3 percent. Impervious surfaces can qualify as "ineffective" only when the entire volume of runoff (based on the design storm) from those areas is captured onsite through infiltration, evapotranspiration, and/or harvesting for beneficial use. In the rare circumstance in which onsite compliance is infeasible according to established criteria, the permittee or developer shall identify opportunities for off-site mitigation in the same sub-watershed that will achieve the overall goal of reducing effective impervious area to no more than the 3 percent design standard.

60 California

Like the Walnut Village case study, the authors' presentation of the 60 California multi-use commercial/retail redevelopment project also tends in an overall manner to support my own analyses and conclusions regarding the practicability of meeting the 5% EIA standard. This case study, too, demonstrates the technical feasibility of meeting a maximum 5 percent EIA standard, in this case by employing a green roof and water harvesting on a highly constrained site. Once again, though, the authors put forth some negative interpretations that are, in my opinion, unjustified.

One such claim is that green roofs and cisterns are generally beyond the level of BMP implementation in common practice in the United States nowadays. In fact, both practices are no longer at all unusual. Without attempting any comprehensive literature review of applications, I would note that Chicago has numerous green roofs in place, most prominently on its city hall (http://www.artic.edu/webspaces/greeninitiatives/greenroofs/main_map.htm). In Seattle, green roofs top a growing number of public and private buildings (http://www.seattle.gov/DPD/GreenBuilding/OurProgram/Resources/TechnicalBriefs/DPDS_009485.asp#case). Seattle's city hall also harvests rain for graywater supply and irrigation, as does the county administration building and a neighborhood environmental education center (http://www.harvesth2o.com/seattle.shtml). The Texas Water Development Board (2005) prepared an excellent, practical manual on water harvesting at all scales, complete with examples in place and design calculations. The manual covers the entire state of Texas, whose western areas have rainfall conditions very much like southern California's. Hence, little adaptation is needed to use the manual's recommendations here.

The report also claims that the suitability of green roofs for southern California is not well understood and that, "during the rainiest times of the year in southern California, the potential

evapotranspiration is the lowest, meaning that the ability to regenerate storage capacity between storms is low." It is true that the potential is lowest during the wettest season, but, given the frequent sun and relative warmth during dry intervals in the southern California winter, the regenerative ability is still not "low." Berghage et al. (2007) performed green roof research at Pennsylvania State University (PSU). They found that over 50 percent of annual stormwater volume was retained and not discharged, even with as little as 20 mm (under 1 inch) of storage capacity, and the site reduced peak discharge rates to no more than the pre-development level for the 2-, 25-, and 100-year frequency events. PSU is located in Centre County, PA, where precipitation is not highly seasonal but tends to be slightly greater in the summer, compared to other months. Pan evaporation rates there range from 3.3 to 4.2 inches/month during June-September (http://www.pa.nrcs.usda.gov/technical/Engineering/PaRainEvapRunoff.pdf). The November-February Los Angeles pan evaporation range is 3.5 to 4.0 inches (http://www.calclim.dri.edu/ccda/comparative/avgpan.html). Therefore, Los Angeles has as much evaporation potential in the months when it most needs that potential as locations with successful green roofs elsewhere. Similar research should be performed in California, but enough encouraging evidence exists to begin establishing full-scale projects, which can be monitored to confirm performance and refine design guidance for the region.

A final negative point made by the report is that green roofs and water harvesting may conflict with existing building and health codes. Codes should not be regarded as an unbending constraint on moving to new, more environmentally beneficial technologies. As experience in the growing number of applications of both practices shows, building safety and health are not being compromised. If constraints do exist in a jurisdiction's codes, they should be examined to assess their justification and revised if no overriding reasons exist to maintain them. Indeed, it is my understanding that municipal separate storm sewer permits often if not always require that local codes be amended to support implementation of programs and approaches to reduce stormwater pollution.

Redevelopment of Kmart Site

The Kmart site redevelopment case study was based on the use of vegetated filter strips and infiltration trenches. Its primary purpose was to estimate costs for these practices by apparently taking a challenging site with relatively poor soils. As an initial manner, the decision to evaluate only one site to reach a conclusion about costs of LID practices is suspect. This is particularly the case when, as here, the report's conclusions tend to contradict mainstream evaluations of the cost of implementing LID. Such studies, including an analysis of several projects by the U.S. Environmental Protection Agency, report significant cost savings compared to traditional water quality approaches across the vast majority of building sites.

More specifically, there are several flaws in the foundation of this case study. The authors developed estimates of runoff volume in pre-development and post-development conditions by using the Natural Resources Conservation Service's Curve Number Method, which is well-known to overestimate the pre-development hydrologic characteristics and thus set the wrong targets for post-construction designs. The site has hydrologic group C soils. The authors performed calculations assuming an infiltration rate of 0.5 inch/hour, higher than the rate used for B soils in the Walnut Village case study (an unexplained discrepancy). There appears to

have been no consideration of organically amending soils to increase water storage and improve infiltration. Soil amendment for these purposes is a very common LID practice, especially in group C soils. The authors appear to have given some thought to other LID practices (tree boxes, bioretention, pervious pavement, green roofs, and water harvesting) but rejected all of them for unexplained reasons. Failure to use a broader pallet of alternatives and soil amendment indicates that the case study may not have been based on the most technically effective and/or cost-effective choices.

This case study fails to convincingly meet its objective of demonstrating what the LID designs would cost, in large part because the authors give no detail whatsoever regarding how the cost figures were derived. The per-acre and percentage-of-redevelopment costs are simply not credible unless their derivation can be traced and confirmed. The cost analysis also suffers from the general criticisms stated above regarding costs: it implicitly assigns all landscaping costs to the filter strips, although these areas would be landscaped anyway at roughly the same cost; the analysis further fails to recognize that stormwater runoff must be conveyed and managed in some way, and those obligations carry costs, which are probably higher if performed conventionally through the use of large quantities of piping and concrete. With these shortcomings in analysis, it is assuredly not justified to say, as the case study conclusions do, that, "[i]t is clear from the Kmart case study cost estimates that the proposed draft permit requirements would significantly increase the drainage costs of urban redevelopment projects." And although more difficult to monetize, environmental benefits—and their economic value to society—are entirely neglected in this case study, as in the others.

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NRDC
THE EARTH'S BEST DEFENSE

NATURAL RESOURCES DEFENSE COUNCIL

Mary Nichols, Chair
California Air Resources Board
1001 "I" St. P.O. Box 2815
Sacramento, CA 95812

August 11, 2008

Re: AB 32 Draft Scoping Plan and Appendices – Water, Urban Reuse

Dear Ms. Nichols:

We are writing today in support of the California Air Resources Board's ("CARB") inclusion of Low Impact Development ("LID") as a measure for reducing greenhouse gas ("GHG") emissions in California in the Draft Scoping Plan for AB 32, and to call on CARB to require its implementation at future development and redevelopment in the state. Attached, please find a copy of an analysis of LID's potential to reduce GHG emissions in the state, authored by the Natural Resources Defense Council, Dr. Robert Wilkinson, Director of the Water Policy Program at the UC Santa Barbara Bren School of Environmental Science and Management, and Dr. Richard Horner, member of the National Academy of Sciences-National Research Council (NASNRC) panel on Reducing Stormwater Discharge Contributions to Water Pollution. This analysis is submitted to substantiate the potential for implementation of LID practices to result in water savings, and corresponding reductions in energy use and GHG emissions, in California, and is intended as a supplement to comments submitted by NRDC on the Draft Scoping Plan's Water Sector on August 1, 2008.

LID represents a significant opportunity for climate response under AB 32, and CARB should ensure that use of LID practices is required statewide in order to achieve AB 32's goal of reducing GHG emissions in California.

Sincerely,

David S. Beckman
Noah Garrison

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NRDC COMMENT ON AB 32 SCOPING PLAN APPENDICES – WATER SECTOR

Executive Summary

Low Impact Development ("LID") represents a major opportunity for climate response under AB 32 because LID has the potential to significantly reduce California's demand for energy- and emissions-intensive imported and desalinated water. LID is a "comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds."[1] It employs cost-effective practices that can greatly increase the availability of local water supply through either the infiltration of urban runoff to recharge groundwater or the use of water harvesting to capture and store runoff from impervious surfaces for use in irrigation or graywater recycling systems. As a result, LID decreases the need to obtain water from imported sources or processes such as ocean desalination which require massive energy inputs. Thus, we support the California Air Resources Board's ("CARB") inclusion of LID as a measure under the Draft Scoping Plan, and encourage CARB to aggressively implement a regulatory structure to require the use of LID for future development in California.

NRDC, in cooperation with leading academics, has recently conducted a comprehensive study incorporating detailed analyses of land use, water supply patterns, and energy consumption of water systems in California. Based upon this study, we have concluded that through implementation of LID at new and redeveloped residential and commercial properties in the urbanized areas of southern California and limited portions of the San Francisco Bay Area alone, LID has the potential to result in savings of between 124,000 and 223,000 acre-feet (af) of water per year by 2020, with a corresponding electricity savings of 269,000 to 637,000 megawatt-hours (MWh) per year (227,500 to 408,000 af/year and 494,000 to 1,167,000 MWh/year by 2030, with increasing benefits thereafter). These results are likely conservative when compared to the water and energy savings that may actually be achieved by employing LID, as the analysis currently assumes a cautious figure for future development rates, and, additionally, does not currently take into account the potential to implement LID practices at government, public use, and industrial sites, which account for a significant percentage of the total land use in the state. Far greater water and electricity savings—and associated reductions in greenhouse gas ("GHG") emissions—would additionally result from full application of LID practices statewide.

In this comment, we discuss LID in the context of the relationship between water supply, energy, and GHG emissions in California. We present the preliminary results of our study of the potential for LID to augment local water supplies and result in a reduction of energy use and GHG emissions in the state. The essence of LID is to eliminate—or at least ameliorate—the problems generated by runoff from urban and suburban development, before they can develop, by exploiting the natural onsite infiltration and treatment abilities of soils and vegetation or by harvesting water for later reuse. LID practices include: maximizing infiltration, which recharges local and regional groundwater systems; providing retention areas and slowing runoff, which reduce flooding and erosion; minimizing projects' impervious footprint; directing runoff from impervious areas into landscaping; and, harvesting water, especially where it may provide a

[1] Low Impact Development Center, available at http://www.lowimpactdevelopment.org/ last visited July 13, 2008.

preferred alternative to infiltration and groundwater recharge due to a limited availability of permeable soils or pervious surface.[2]

By preventing site runoff altogether in many situations, LID practices are often substantially more effective at protecting water quality than many types of conventional best management practices, which rely on structural treatment devices to remove a percentage of pollution after it has already entered stormwater runoff. Further, the U.S. Environmental Protection Agency ("EPA") has stated that the "vast majority" of case studies suggest that implementing LID site designs is cost effective,[3] particularly in comparison to conventional methods. The EPA analysis was based solely on the costs of implementation, and their conclusion is strengthened considerably when economic externalities are considered; the use of LID practices can reduce strain on, and costs of, municipal storm water infrastructure, decrease the frequency and severity of combined sewer overflow events, and increase real estate values. (See section on Costs of LID, *infra*.) Since current federal and state regulatory policies already require that developed sites control post-construction stormwater runoff (see section on LID Site Design Principles and Benefits, *infra*), including LID as a measure in the Draft Scoping Plan and requiring its implementation under AB 32 presents an opportunity to reduce energy use and GHG emissions in California by simply requiring the most cost-effective means of complying with existing mandates of federal and state laws.

Because the primary goal of LID is widely viewed as the prevention of stormwater pollution, it has generally been overlooked as a means of augmenting energy-efficient, local water supplies. This has occurred despite the fact that water delivery now constitutes the largest use of electricity in California.[4] The California State Water Project ("SWP"), which pumps water a distance of 444 miles from the Sacramento-San Joaquin Delta to southern California, in the process lifting the water nearly 3000 feet over the Tehachapi Mountains,[5] is the single largest individual user of electricity in the state.[6] Further, as California confronts issues related to limited water supplies and a growing economy,[7] 20 ocean desalination plants have been proposed statewide, each of which would supply water at an energy cost comparable to the SWP.[8] By contrast, the energy required to supply groundwater can be five to ten times less than that required to supply water

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[2] See generally, Prince George's County, Maryland, Department of Environmental Resources (July 1999) Low Impact Development Hydrologic Analysis, *available at* http://www.lowimpactdevelopment.org/pubs/LID_Hydrology_National_Manual.pdf; US Department of Housing and Urban Development ("HUD") (July 2003) The Practice of Low Impact Development, *available at* http://www.huduser.org/publications/destech/lowImpactDevl.html

[3] EPA (December 2007) Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices, *available at* http://www.epa.gov/owow/nps/lid/costs07/; National Association of Home Builders (NAHB) (2002) Builder's Guide to Low Impact Development, *available at* http://www.lowimpactdevelopment.org/lid%20articles/Builder_LID.pdf. (The NAHB states "Ever wish you could simultaneously lower your site infrastructure costs, protect the environment, and increase your project's marketability? With LID techniques, you can.")

[4] California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF.

[5] DWR, State Water Project – Today, *available at* http://www.publicaffairs.water.ca.gov/swp/swptoday.cfm.

[6] Carrie Anderson (1999) Energy Use in the Supply, Use and Disposal of Water in California, Process Energy Group, Energy Efficiency Division, California Energy Commission.

[7] See, e.g., Jennifer Steinhauer, "Water-starved California slows development" New York Times, June 7, 2008 at A13.

[8] Heather Cooley, Peter H. Gleick, and Gary Wolff (June 2006) Desalination, with a grain of salt; A California Perspective, Pacific Institute, *available at* http://www.pacinst.org/reports/desalination/index.htm.

through the SWP or ocean desalination, and the energy required to harvest and reuse stormwater can be a minimum of two to six times less. (See section on energy of water supply, infra.) Since LID has the potential to offset a substantial portion of California's energy-intensive imported or desalinated water needs, it should be viewed as a vital component of AB 32's mandate to reduce GHG emissions.

LID's ability to reduce demand for imported or desalinated ocean water through infiltration and groundwater recharge is particularly appropriate in light of the fact that many, if not most, areas of the state already have infrastructure in place for the extraction and distribution of groundwater. California produces more groundwater—approximately 17 million acre-feet per year—than any other state in the country.[9] As much as 50 percent of the state's population receive some portion of their potable water supply from groundwater.[10] This includes the vast majority of the southern California area that receives water from the SWP, as nearly 50 percent of the Metropolitan Water District of Southern California's ("MWD") member agencies' water supply consists of groundwater.[11] (See Figure 1, which depicts the source and relative volume of water supply for water agencies in southern California. Though energy-intensive, imported water forms an important supply for the region, groundwater represents a significant portion of each water agency's total supply.)

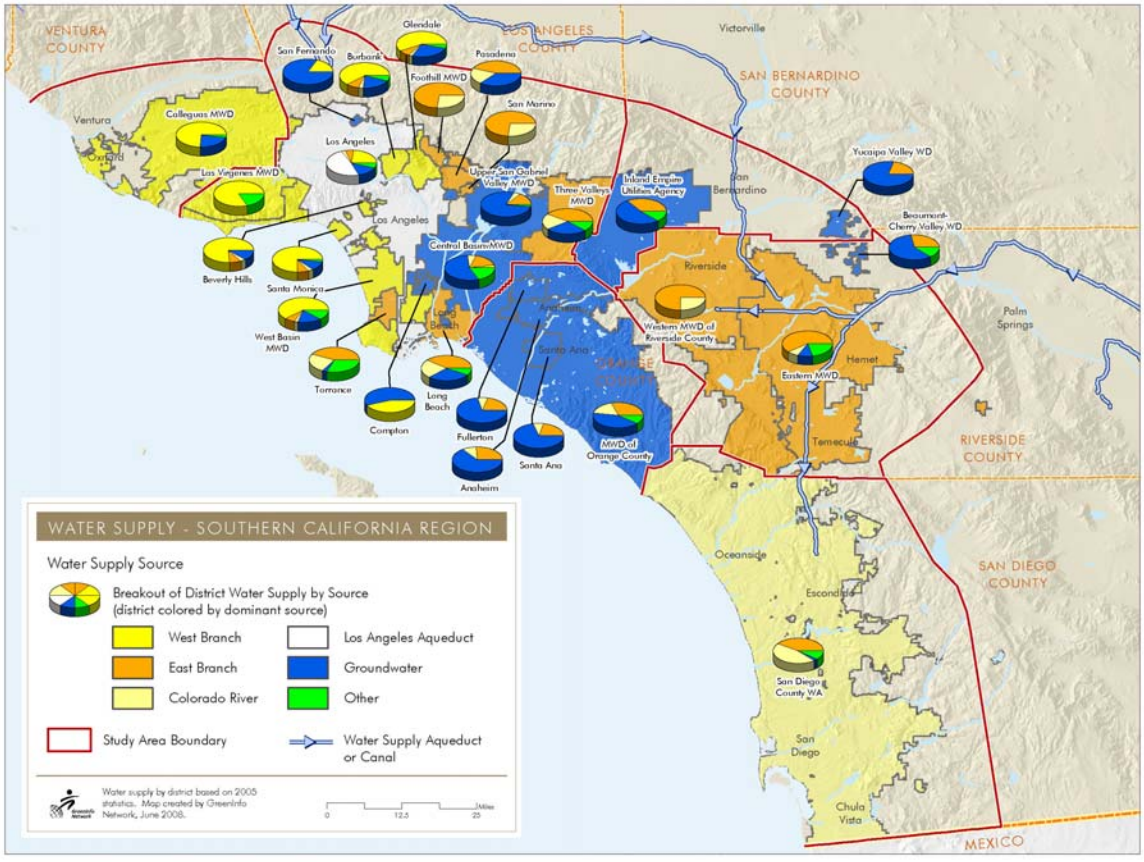

Figure 1. Water supply sources for southern California study area.

[9] U.S. Geological Survey ("USGS") (March 2004, last revised February 2005) Estimated Use of Water in the United States in 2000, *available at* http://pubs.usgs.gov/circ/2004/circ1268/ (at Table 4).
[10] DWR (October 2003) California's Groundwater – Bulletin 118 Update 2003, *available at* http://www.groundwater.water.ca.gov/bulletin118/
[11] Based on NRDC review of MWD member agencies' Urban Water Management Plans.

By increasing the availability of groundwater supply through recharge, LID can reduce the need to import water through the SWP and other such water delivery projects, thereby greatly reducing energy use and related emissions in the state.

For areas of the state where surface soil conditions or water supply patterns favor water harvesting rather than groundwater recharge, the opportunities to capture water for reuse present an equally compelling potential for reducing energy use and GHG emissions. LID techniques that emphasize capture can "reduce annual runoff volumes by almost half to more than 3/4…with much of the water saved available for a beneficial use."[12] This is relevant for regions such as the San Francisco Bay Area, which has not traditionally included groundwater as a water source in significant volumes but has been proposed as the location of four ocean desalination plants. Implementing LID to harvest water for later reuse could substantially reduce the need to supply water through ocean desalination, thus also reducing the energy use and GHG emissions that result from this highly energy-intensive process.

The potential for LID to reduce GHG emissions in California, coupled with the multiple benefits that LID provides, presents an exiting opportunity for the State to address the issue of climate change under AB 32. CARB should use the AB 32 process to ensure that regulatory structure in the State requires that LID practices be employed at all future commercial and residential development, with the possibility of expanding this requirement to include industrial and public use properties, to meet its goal of reducing GHG emissions statewide.

[12] Richard R. Horner (2007) Supplementary Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for the San Francisco Bay Area, Attached as Appendix A

Introduction to LID Site Design Principles and Benefits

By maximizing infiltration to increase groundwater recharge and by employing water harvesting techniques, LID can greatly augment the availability of local water supply and reduce the demand for energy-intensive supply from imported water sources or ocean desalination. This valuable result, and the attendant reduction in GHG emissions that LID can provide, support CARB's further development of LID as a measure under the Scoping Plan. In addition, however, LID provides exceptionally important benefits with respect to water quality, pollution abatement, and flooding and erosion control. LID practices, such as green roofs, can be designed to reduce the "urban heat island effect," thereby reducing the need for air conditioning and other energy-intensive residential and commercial uses of electricity. And by increasing green space in development projects, LID can also improve overall urban aesthetics and provide natural-looking, pleasing cityscapes. The additional open space created by LID site designs can be especially important for low-income communities otherwise disadvantaged with regard to usable urban outdoor areas.

Stormwater Runoff and Regulation

Urbanization and development increase the percentage of impervious cover (*i.e.*, surfaces such as roads, rooftops, and parking lots that prevent the infiltration of water into soil) in the landscape. Greater impervious cover, in turn, increases the volume, velocity, and duration of runoff that results from precipitation.[13] For example, a one-acre parking lot produces 16 times more runoff than a one-acre meadow.[14] This can lead to increasingly severe flooding and erosion[15] and can greatly increase levels of pollution in surface water bodies—when the increased volume of runoff flows over paved surfaces, it picks up proportionally higher levels of car wastes, pesticides, pet wastes, trash, and other contaminants, and carries them to receiving waters. In fact, EPA views urban runoff as one of the greatest threats to water quality in the country, and considers it "one of the most significant reasons that water quality standards are not being met nationwide."[16] According to EPA, "54 percent of California's impaired waterways are polluted by runoff."[17] Additionally, California experienced 4,736 beach closing and advisory days in 2007,[18] and "the largest identified pollution source" was "stormwater runoff from roads, roofs, lawns, construction sites, and other impervious surfaces."[19]

In order to prevent the pollution and other harms that result from urban runoff, the Clean Water Act requires municipalities, counties, and other dischargers to impose "controls to reduce the discharge of pollutants to the maximum extent practicable."[20] Dischargers must use

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[13] NRDC, (June 2006) Rooftops to Rivers, Green Strategies for Controlling Stormwater and Combined Sewer Overflows, *available at* http://www.nrdc.org/water/pollution/rooftops/contents.asp; California Water and Land Use Partnership, How Urbanization affects the Water Cycle, *available at* http://www.coastal.ca.gov/nps/watercyclefacts.pdf last visited July 13, 2008.

[14] Dana Beach (2002) Coastal Sprawl: The effects of urban design on aquatic ecosystems in the United States. Pew Oceans Commission, *available at* http://www.pewtrusts.org/our_work_report_detail.aspx?id=30037.)

[15] Prince George's County, *supra*, note 2.

[16] GAO (June 2001) Water Quality: Urban Runoff Programs, GAO-01-679, *available at* http://www.gao.gov/new.items/d01679.pdf.

[17] EPA (July 31, 2000) Officials Approve New California Poluted Runoff Program, *available at* http://yosemite.epa.gov/opa/admpress.nsf/8b75cea4165024c685257359003f022e/7340a18a132b249c852570d8005e13dd!OpenDocument.

[18] NRDC (July 2008) Testing the Waters 2008, *available at* http://www.nrdc.org/water/oceans/ttw/titinx.asp.

[19] NRDC (August 2007) Testing the Waters 2007, *available at* http://www.nrdc.org/water/oceans/ttw/titinx.asp.

[20] 33 U.S.C. § 1342(p)(3)(B)(iii).

"management practices, control techniques and system, design, and engineering methods, and such other provisions which are appropriate."[21] To meet these conditions, dischargers apply for permits under the National Pollutant Discharge Elimination System ("NPDES") program. Permittees in California have been increasingly required to apply controls on the volume of runoff that sites may generate in order to prevent further pollution to the state's waters.[22] For example, in 2001, the State Water Resources Control Board adopted Order WQ 2000-11, which "created objective and measurable criteria for the amount of runoff that must be treated or infiltrated," and established a requirement that treatment or infiltration occur for "85 percent of the runoff from specified categories of development."[23] One method of complying with such permit conditions has been to use conventional stormwater management practices, which involve applying structural engineering solutions to manage the increased volume of impervious runoff that occurs with development. With conventional practices, runoff is transported away from developed sites as quickly as possible—through systems of curbs, gutters, buried drainage pipes, and centralized combined sewer systems—to treatment facilities or directly to receiving waters.[24] However, because treatment occurs in this system, if at all, only after pollutants have already entered stormwater, conventional practices are often ineffective at removing pollution in urban runoff and mitigating its impacts on surface water bodies.[25]

LID Principles

In contrast, LID uses common sense and simple technology—strategically placed beds of native plants, rain barrels, "green roofs," porous surfaces for parking lots and roads, and other features—to reduce runoff by helping rainfall soak into the ground or otherwise retaining rainfall onsite, rather than polluting the nearest water body. In effect, LID mimics nature's own infiltration and filtering systems.[26] Runoff accumulates less pollution because it crosses less impervious surface, and bioswales, basins, trenches, and other infiltration devices use absorption, settling, and the soil's natural capacity to filter pollutants to achieve 70 to 98 percent contaminant removal.[27] The result is less water pollution from stormwater runoff, less flooding, replenished water supplies, and frequently more natural-looking, aesthetically pleasing cityscapes. Furthermore, LID strategies that preserve existing vegetation and include vegetated and grassy swales and tree-box filters can help sequester GHG emissions and reduce the "heat

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[21] 40 C.F.R. § 122.26(d)(2)(iv).

[22] See generally, In the Matter of the Petitions of the Cities of Bellflower et al., the City of Arcadia, and Western States Petroleum Association, State Water Resources Control Board ("SWRCB") Order WQ 2000-11 (October 5, 2000); San Diego County Phase I MS4 Permit (California Regional Water Quality Control Board, San Diego Region, Order No. R9-2007-0001, NPDES NO. CAS0108758) at 20; Ventura County Draft Phase I MS4 Permit (California Regional Water Quality Control Board, Los Angeles Region, April 29, 2008) at 57; General Phase II MS4 Permit (SWRCB Order No. 2003-0005-DWQ); Resolution of the California Ocean Protection Council Regarding Low Impact Development, May 15, 2008.

[23] Memo from Chief Counsel regarding State Water Board Order WQ 2000-11 (December 26, 2000), *available at* http://www.swrcb.ca.gov/rwqcb4/water_issues/programs/stormwater/susmp/susmp_details.shtml.

[24] HUD, *supra*, note 2; Prince George's County, *supra*, note 2; NRDC, Rooftops to Rivers, *supra*, note 13.

[25] NRDC, Rooftops to Rivers, *supra*, note 13.

[26] See Larry S. Coffman (2000), "Low-impact development design: A new paradigm for stormwater management mimicking and restoring the natural hydrologic regime." Proceedings from the National Conference on Tools for Urban Water Resource Management and Protection, February 2000, *available at* http://www.epa.gov/ORD/WebPubs/nctuw/Coffman.pdf; Low Impact Development Center (December 2007) A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption, *available at* http://www.waterboards.ca.gov/lid/docs/ca_lid_policy_review.pdf.

[27] EPA (2001) Source Water Protection Practices Bulletin, Managing Storm Water Runoff to Prevent Contamination of Drinking Water, *available at* http://www.epa.gov/safewater/sourcewater/pubs/fs_swpp_stormwater.pdf.)

island" effect in urban areas. These strategies also increase green space and open land generally. This results in enhanced property values and an increased availability of open space for community residents, which is particularly valuable in low-income communities that may otherwise have scant access to outdoor recreational areas.

Although LID incorporates a number of varied practices and technologies aimed at reducing stormwater runoff, for the purposes of increasing local water supply aimed at reducing electricity use and GHG emissions, measures that maximize infiltration and groundwater recharge opportunities to the greatest extent possible should be promoted under the Scoping Plan. Where the density of urban development or the presence of impervious soils has the potential to reduce opportunities for infiltration, LID measures that emphasize stormwater harvesting should be selected as the preferred method for increasing water supply.

Because dischargers are already required to control post-construction stormwater runoff, requiring the implementation of LID practices represents the most commonsense means of complying with the law. Given these multiple benefits and the robust contributions that LID can make to reducing GHG emissions, CARB should ensure that LID practices that emphasize groundwater recharge and water harvesting are required for dischargers statewide.

Water, Energy, GHG Emissions and Opportunities for LID in California

California's Overall Water-Energy Picture

At the national level, water systems, or the extraction, conveyance, treatment, storage, distribution, end-use, and wastewater treatment, require an estimated 75 billion kilowatt-hours (kWh) of energy per year, or about 3% of the total electricity demand in the United States.[28] In California, water systems account for a staggering 19% of total electricity use and about 33% of the non-power plant natural gas use in the state.[29] Although the energy embodied in a unit of water varies with location and source, moving large quantities of water long distances and over significant topographical features, treating and distributing water within communities, use of water, and collecting and treating the resulting wastewater, are each energy intensive processes. Water is now recognized as the *largest electricity user* in California, and both the California Energy Commission ("CEC") and the California Public Utilities Commission ("CPUC") have concluded that the energy embedded in water presents large untapped opportunities for cost-effectively improving energy efficiency and reducing emissions of GHGs.[30] Indeed, our research has demonstrated that significant opportunities for savings may be realized simply by reducing the need for the most energy-intensive supply, and for the reasons already discussed, LID is one of the easiest and most effective means of tapping into these opportunities.

The Energy Intensity of Water in California

California's water systems are uniquely energy-intensive due in large part to the pumping requirements of major conveyance systems that move large volumes of water long distances and over thousands of feet in elevation. Certain interbasin transfer systems, such as California's SWP and the Colorado River Aqueduct ("CRA"), require large amounts of electrical energy to convey water for this reason.

[28] Franklin L. Burton (1996) Water and Wastewater Industries: Characteristics and Energy Management Opportunities, Burton Engineering, Los Altos, CA, Report CR-106941, Electric Power Research Institute Report.
[29] California Energy Commission (November, 2005) Integrated Energy Policy Report, CEC-100-2005-007-CMF.
[30] *Id*.

Approximately 2,580 kWh are required to pump one acre-foot of SWP water from the Sacramento-San Joaquin Delta to Castaic on the West Branch of the SWP; 3,236 kWh/af are required to reach the Devil's Canyon Power Plant on the East Branch; and 5,418 kWh/af are required to reach Cherry Valley at the end of the East Branch. Additionally, approximately 2,000 kWh/af are required to pump Colorado River water to southern California.[31] The water from these systems is delivered raw (untreated) to those points. From there, conveyance continues by gravity or pumping to treatment and distribution systems within individual service areas. In general, service areas at higher elevations have higher energy requirements. Thus, at Cherry Valley and other locations near the terminus of the East Branch, raw water supplies are actually *more* energy intensive than estimates for desalinated ocean water (ocean desalination requires an estimated 4,400 kWh/af).

Seawater desalination has been viewed as the ultimate drought hedge, a virtually inexhaustible water source, but costs have prevented desalination from achieving widespread use. The salinity of ocean water varies, with the average generally exceeding 30 grams per liter (g/l). The Pacific Ocean is 34-38 g/l, while brackish water contains 0.5 to 3.0 g/l. Potable water salt levels, however, should be below 0.5 g/l. Using existing technologies to reduce salt levels from over 30 g/l to 0.5 g/l and lower (to meet drinking water standards) requires considerable amounts of energy for the pressure to drive water through extremely fine filters in the process of reverse osmosis. Recent improvements in energy efficiency have lessened the amount of pumping energy required for this process, but high energy-intensity is still an issue.

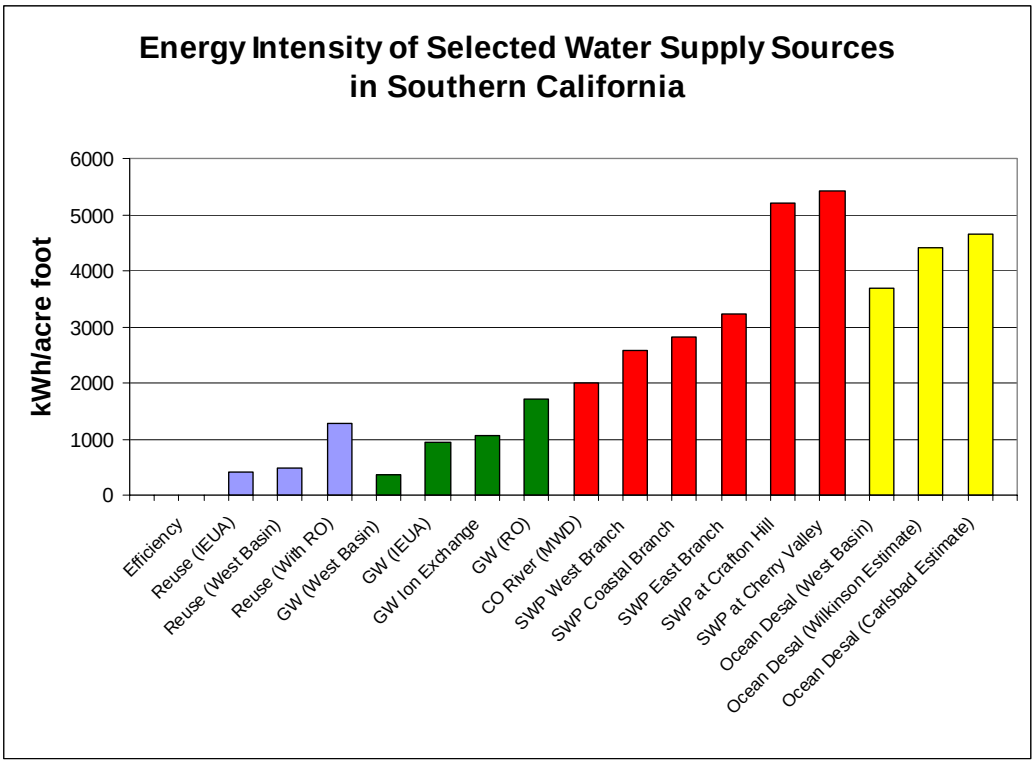

Figure 2. Based on data from IEUA, West Basin MWD, DWR, and desalination estimates.

[31] MWD (1996) Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations.

Figure 2 shows the energy intensity of major water supply options for inland and coastal locations in southern California. Each bar represents the energy intensity of a specific water supply source at selected locations in southern California. Water conservation—e.g., not using water in the first place—avoids additional energy inputs along all segments of the water use cycle and is consequently a superior option from an energy perspective where available. For all other water resources, there are ranges of energy inputs that depend on many factors, including the quality of source water, the energy intensity of the technologies used to treat the source water to standards needed by end-users, the distance water needs to be transported to reach end-users, and the efficiency of the conveyance, distribution, and treatment facilities and systems.[32]

Next to water conservation, recycled water and groundwater are lower energy intensity options than most other water resources, in many, if not most, areas of California.[33] Even with advanced treatment to remove salts and other contaminants, recycled water and groundwater (the blue and green bars) usually require far less energy than untreated imported water (red bars) and seawater desalination (yellow bars). The Chino desalter, which uses a reverse osmosis ("RO") treatment process to provide high-quality potable water from contaminated groundwater (Figure 2 above includes groundwater pumping and RO filtration), is far less energy intensive than any of the imported raw water. From an energy standpoint, greater reliance on reuse and groundwater provides significant energy benefits. From a GHG emissions standpoint, these energy benefits provide significant potential GHG emissions reduction benefits in direct proportion to their energy savings.

Groundwater pumping energy requirements vary depending on the lift required. While the CEC's Public Interest Energy Research - Industrial, Agriculture and Water program acknowledges that in many parts of the state, "[t]he amount of energy used in pumping groundwater is unknown due to the lack of complete information on well-depth and groundwater use," for other areas, the amount of energy used is well defined. "In the Tulare Lake area, with an average well depth of 120 feet, pumping would require 175 kWh per acre-foot of water. In the San Joaquin River and Central Coast areas, with average well depths of 200 feet, pumping would require 292 kWh per acre-foot of water."[34] Analysis of these different sources provides a reasonably consistent result: local groundwater and recycled water are far less energy intensive than imported water or ocean desalination.

By contrast, water pumping plants employed in the supply of imported water carry among the largest electrical loads in the state. For example, the SWP's Edmonston Pumping Plant, situated at the foot of the Tehachapi Mountains, pumps water up 1,926 vertical feet (the highest single lift of any pumping plant in the world) and is the largest *single user* of electricity in the state.[35] As

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[32] Robert C. Wilkinson, (2000) Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency, *available at* http://www.es.ucsb.edu/faculty/wilkinson.pdfs/Wilkinson_EWRPT01%20DOC.pdf.

[33] Laurie Park, Bill Bennett, Stacy Tellinghuisen, Chris Smith, and Robert Wilkinson, 2008 The Role of Recycled Water In Energy Efficiency and Greenhouse Gas Reduction, California Sustainability Alliance, *available at* http://www.sustainca.org/content/recycled_water_2.

[34] California Energy Commission (2006) Public Interest Energy Research - Industrial, Agriculture and Water, *available at* http://energy.ca.gov/pier/iaw/industry/water.html

[35] DWR (1996) Management of the California State Water Project, Bulletin 132-96, *available at* http://wwwswpao.water.ca.gov/publications/bulletin/96/b96home.html.

mentioned above, in total, the SWP *system* is the largest user of electricity in the state.[36] Because of such energy requirements, water use (based on embedded energy) is the second or third largest consumer of electricity in a typical southern California home after refrigerators and air conditioners.[37] The electricity required to support water service in the typical home in southern California is estimated to be between 14% to 19% of total residential energy demand.[38] In homes without air conditioning, this figure is even higher. The MWD estimates that energy requirements to deliver water to residential customers can equal as much as 33% of the total average household electricity use.[39] Nearly three quarters of this energy demand is for pumping imported water. Increasing the availability of energy-efficient local water supply, as LID implementation would do, could therefore result in a savings for individual end users and in an overall reduction in the energy required to supply water.

For the foregoing reasons, the Department of Water Resources has identified improvements in urban water use efficiency in its official State Water Plan as the largest new water supply for the next quarter century, followed by groundwater management and reuse. Figure 3 indicates the critical role water use efficiency, groundwater recharge and management, and reuse will play in California's water future.

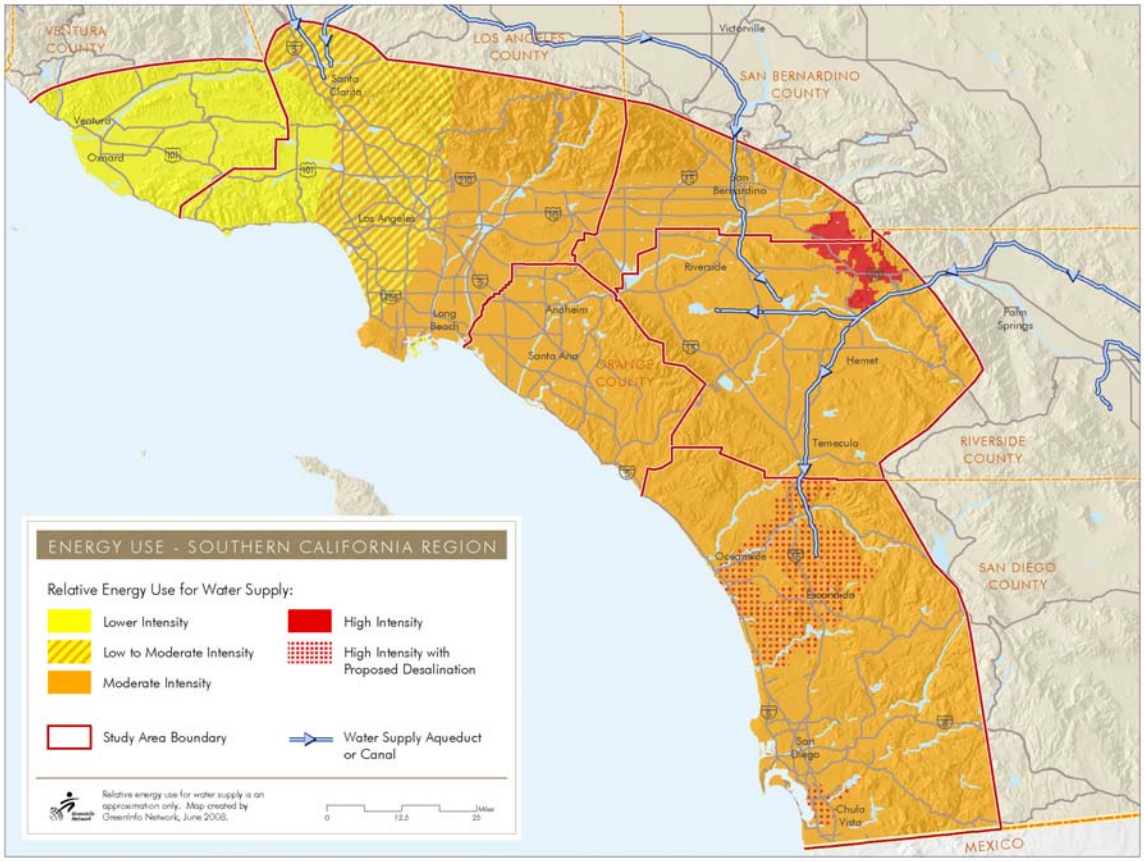

Figure 3. Energy intensity of supply by area.

[36] Carrie Anderson, *supra*, note 6.
[37] Robert C. Wilkinson, *supra*, note 32.
[38] QEI, Inc. (1992) Electricity Efficiency Through Water Efficiency, Report for the Southern California Edison Company.
[39] MWD, *supra*, note 31.

While discussing efficiency of hot and cold water use in homes and businesses, the California Energy Commission's 2005 *Integrated Energy Policy Report* ("IEPR") takes a position that is equally applicable to increasing the energy efficiency of water supplies: "[r]educing the demand for energy is the most effective way to reduce energy costs and bolster California's economy."[40] The CEC staff report notes that, "As California continues to struggle with its many critical energy supply and infrastructure challenges, the state must identify and address the points of highest stress. At the top of this list is California's water-energy relationship."[41] Thus, implementation of LID accords perfectly with the CEC's position, and CARB should aggressively adopt policies that mandate the use of LID under AB 32.

This finding is consistent with an earlier analysis that found that energy use for conveyance, including interbasin water transfer systems (systems that move water from one watershed to another) in California, accounted for about 6.9% of the state's electricity consumption.[42] Estimates by CEC's Public Interest Energy Research – Industrial, Agriculture and Water experts indicate that "total energy used to pump and treat this water exceeds 15,000 gigawatt-hours (GWh) per year, or *at least* 6.5 percent of the total electricity used in the state per year." The magnitude of these figures suggests that failing to tap energy savings derived from water efficiency improvements would be an opportunity lost.

Selection of Study Areas to Assess Potential Water, Energy, and GHG Emissions Savings
Although LID has previously been overlooked as a means of increasing local water supply, wherever water from energy-efficient sources such as groundwater extraction or rainwater recycling can be used in place of energy-intensive imported or desalinated water, LID presents a potential to reduce California's electricity usage and GHG emissions under AB 32 through recharging local aquifers or onsite water supplies. This potential exists throughout the state and can be realized at current and future development projects of virtually any scale or land use type. At present, LID is a vast, underutilized resource that the Scoping Plan should tap.

Though opportunities for augmenting water supply and decreasing energy usage and GHG emissions exist throughout the state, in deciding where to focus our analysis of LID's emissions reduction potential, we considered several factors to determine the study's geographical scope. Among these factors were:

1. Distribution of population: We selected populous locations to incorporate as many of the state's residents as possible.
2. Energy-intensity of water supply: We designed the study to include areas in the state that show the highest marginal energy use for water supply so that the greatest energy savings may be realized through the implementation of LID.
3. Adequate rainfall: We selected areas of study where rainfall is high enough to create a substantial supply of water that could be directed to infiltration or water harvesting

[40] DWR (2005) California Water Plan Update 2005, Bulletin 160-05, *available at* http://www.waterplan.water.ca.gov/previous/cwpu2005/index.cfm.
[41] Gary Klein (November 2005) California Energy Commission, California's Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E), CEC-700-2005-011-SF, *available at* http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF.
[42] Robert C. Wilkinson, *supra*, note 32.

practices in order to significantly reduce the amount of water drawn from energy-intensive sources.

4. Availability for infiltration and groundwater recharge or capture: We further selected the study areas based on either the presence of sufficient existing or potential pervious surface—including analyses of soil type and location of groundwater systems—to allow for infiltration, or the presence of sufficient development to allow for extensive water harvesting from rooftop runoff.

Following these parameters, our initial study has focused on urbanized southern California and portions of the San Francisco Bay Area. These areas incorporate the vast majority of the state's population—approximately 50 percent of the state's population resides in the counties located within the southern California study area, and an additional 20 percent live in the San Francisco Bay region.[43] These areas are also characterized by some of the highest energy use per unit of water delivered; imported water accounts for one-half or more of all domestic water supply, more than 2,000,000 acre-feet per year, in the southern California region.[44] (See Figures 1, 3. Water from the SWP, supplied at energy requirements of between 2,580 kWh/af (yellow areas) and 5,418 kWh/af (solid red areas), is used pervasively throughout this region.) The San Francisco Bay region, which historically used surface water almost exclusively, is the site of four proposed desalination plants, with an estimated capacity of between 35,800 and 108,700 af/year[45] and an embedded energy requirement of 4,400 kWh/af.[46] Further, the average rainfall throughout both regions is sufficient to result in significant runoff diversion through the use of LID; rainfall averages roughly 10 to 15 inches annually in most portions of the southern California study area, and from 18 to more than 30 inches annually in the San Francisco Bay region.[47] Finally, these areas are projected to see large scale population growth, accompanied by development that could be required, under AB 32, to implement LID practices that maximize groundwater recharge or stormwater harvesting. Thus, based on the four parameters outlined above, these two areas have some of the greatest potential to reduce energy usage and GHG emissions in California through the implementation of LID.

Southern California

The southern California study area includes San Diego County, Orange County, and portions of Ventura County, Los Angeles County, San Bernardino County and Riverside County. (See Figure 4, Map of Study Area, including a breakdown of land use designations. Of particular interest are the large tracts of residential and commercial land in which LID practices could be widely implemented.) Generally speaking, the urbanized communities of southern California are particularly well-suited to implementing LID to increase local water supplies through infiltration and groundwater recharge. Groundwater is already used in immense quantities in the region – more than 1.5 million acre-feet of groundwater are produced in areas supplied by member

[43] California Department of Finance (May 2008) E-1 Population Estimates for Cities, Counties and the State with Annual Percent Change — January 1, 2007 and 2008, *available at* http://www.dof.ca.gov/research/demographic/reports/estimates/e-1_2006-07/

[44] NRDC review of MWD member agencies' Urban Water Management Plans.

[45] Heather Cooley et al., *supra*, note 8.

[46] Another five desalination plants, with a capacity of between 46,700 and 55,800 af/yr have been proposed for operation in neighboring Monterrey Bay, directly to the south of the northern California study area. *Id.*

[47] Based on Natural Resources Conservation Service ("NRCS"), Average Annual Rainfall, 1961-1990, analyzed by NRDC (2008).

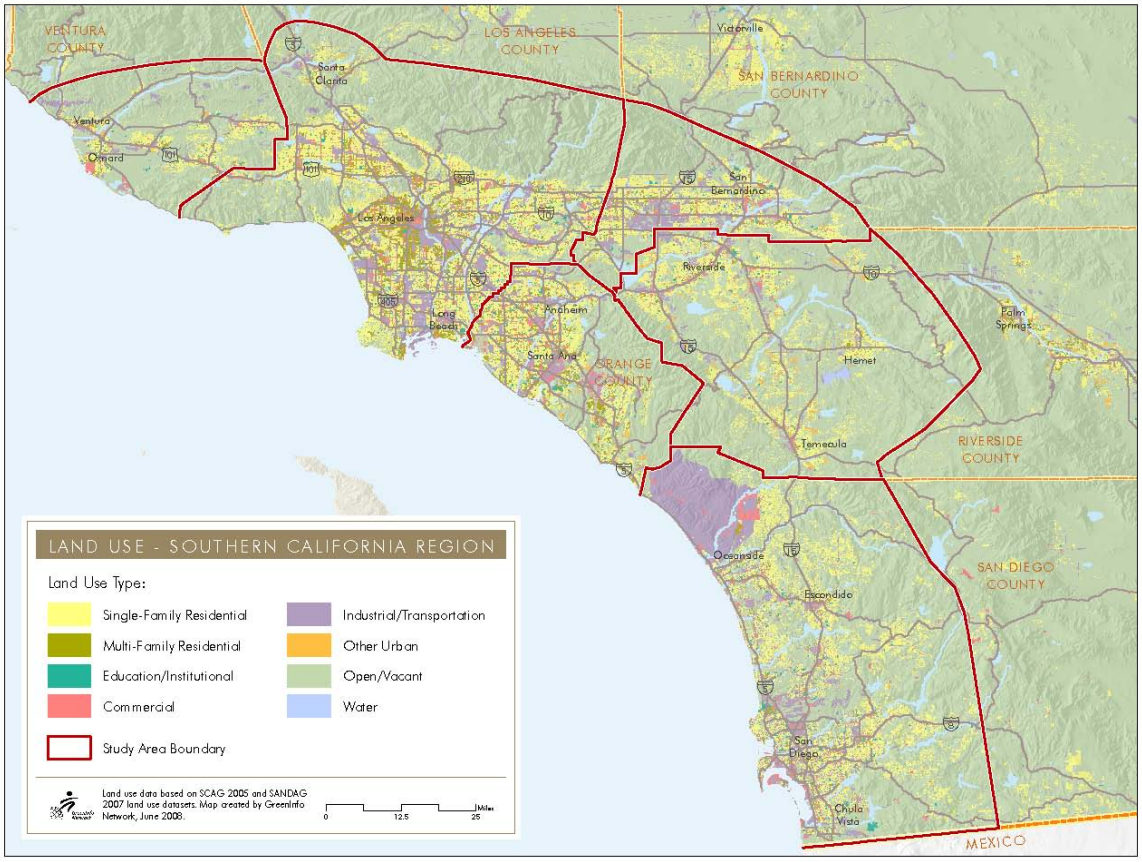

Figure 4. Map of southern California study area.

agencies of the MWD in an average year,[48] and in areas of Orange County, eastern Los Angeles County, and San Bernardino, groundwater extraction constitutes the principal source of water (see Figure 1).

Conditions for groundwater recharge are also generally favorable throughout the region. First, the regional climate includes a rainy winter season when water is relatively abundant and a lengthy dry summer season during which imported, captured, and recharge water is necessary to maintain supplies and sustain communities. Second, the geologic material underlying most of the region is highly permeable, allowing rapid infiltration into groundwater basins. For example, approximately 35-40 percent of developed lands identified as suitable for infiltration and groundwater recharge in the study overlie areas designated by the state as hydrologically vulnerable,[49] or amenable to rapid infiltration to regional aquifers that are used for potable water supply. (Figure 5.) Even outside these areas, as discussed in the section on groundwater below, there remain strong possibilities for groundwater recharge to benefit local water supply. Moreover, where soils or surface conditions are not amenable to infiltration, water harvesting can provide many of the same local water supply benefits. LID techniques favoring capture can

[48] MWD (September 2007) A Status Report on the Use of Groundwater in the Service Area of the Metropolitan Water District of Southern California, Report Number 1308, *available at* http://www.mwdh2o.com/mwdh2o/pages/yourwater/supply/groundwater/GWAS.html Plate ES-2.
[49] State Water Resources Control Board (January 15, 2008) Map of Hydrologically Vulnerable Areas.

"reduce annual runoff volumes by almost half to more than 3/4…with much of the water saved available for a beneficial use."[50] Consequently, regardless of the method used, there is tremendous potential in the southern California Study Area to increase local water supply and therefore, to reduce reliance on imported or desalinated water sources that generate considerable GHG emissions.

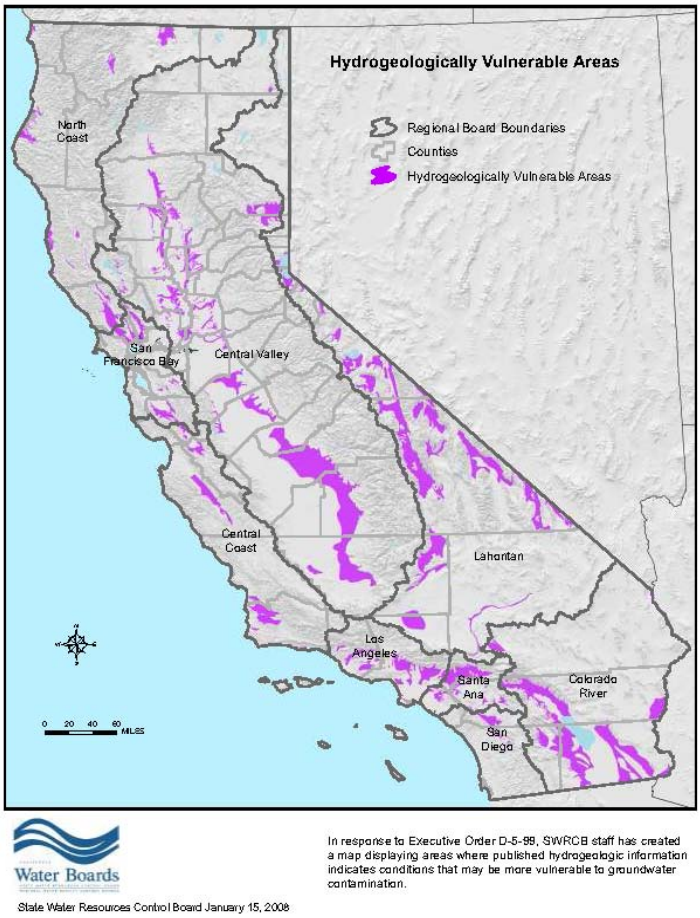

Figure 5. Hydrologically vulnerable areas of California. State Water Resources Control Board, January 15, 2008.

Groundwater

Our analysis has shown that groundwater recharge has the largest potential under AB 32 to increase local water supply and thus to reduce GHG emissions, so the process of infiltration to groundwater through LID warrants discussion. Groundwater is water beneath the earth's surface that completely saturates the small spaces and voids in rocks or between grains of sediment and other unconsolidated material.[51] In simple terms, groundwater forms when precipitation falling on land infiltrates the soil and other unconsolidated surface materials and percolates to depth, forming aquifers over millions of years. In the natural hydrologic regime, up to 40 or 50 percent of this precipitation is lost to evapotranspiration, a combination of evaporation from the soil and transpiration by plants, and up to 10 percent is converted to surface runoff that does not

[50] Richard R. Horner, *supra*, note 12.
[51] See generally, Freeze and Cherry, Groundwater 1979 at 1.

infiltrate.[52] This still leaves up to 50 percent or more of the precipitation to infiltrate the ground surface, either as shallow infiltration or as deep percolation reaching the water table. However, since development has spread throughout the state, impervious cover, such as roads, rooftops, and parking lots that prevent the infiltration of water into the soil, has increased dramatically. As impervious cover increases, water is prevented from penetrating the ground surface, the volume of runoff increases, and the volume of infiltration decreases.[53] When impervious cover reaches 75 percent and above, as it does in many dense, urban centers, this may result in a more than five-fold increase in surface runoff and a corresponding 70 percent drop in infiltration, with the greatest decrease seen in the quantity of water that percolates to sufficient depths to recharge groundwater.[54]

This reduction in potential recharge is particularly relevant for California as the nation's largest producer of groundwater. The 17 million acre-feet withdrawn in the state per year account for nearly 20 percent of all groundwater extracted in the United States each year.[55] From these extractions, approximately 30 percent of California's urban and agricultural water needs are supplied by groundwater in an average year, a figure that rises to 40 percent or more during periods of draught.[56] As such, groundwater is rightfully called "one of California's greatest natural resources,"[57] and its continued supply is integral to California's environmental, economic, and social wellbeing.

This is especially true for southern California, which relies on groundwater to supply nearly one-half of the water used by approximately 50 percent of the state's population.[58] Groundwater has been used in the southern California region for about 150 years,[59] and "the story of the growth of the region becomes the story of the utilization and application of its available waters."[60] However, since settlers drilled the first groundwater wells, an ever-increasing percentage of the landscape has been paved and covered with impervious surfaces, drastically altering the hydrologic regime that forms and replenishes the groundwater upon which the region depends. Historic land use maps of the Chino Basin in San Bernardino County exemplify this phenomenon, highlighting the type of rapid and intense urban development that has occurred in the State over the last 75 years. (Figure 6, showing a pronounced shift from agrarian to urban and residential uses.)

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[52] EPA (August 1999) Preliminary Data Summary of Urban Storm Water Best Management Practices, *available at* http://www.epa.gov/waterscience/guide/stormwater/#report.
[53] Chester L. Arnold, Jr. and James Gibbons (June 1996) "Impervious Surface Coverage: The Emergence of a Key Environmental Indicator," *J. of the Amer. Planning Assoc.* vol. 62 pages 243-258 at 244.
[54] *Id.*
[55] USGS, *supra*, note 9.
[56] DWR, *supra*, note 10.
[57] *Id.*
[58] *Id.*
[59] USGS (2003) Geohydrology, Geochemistry, and Ground-Water Simulation-Optimization of the Central and West Coast Basins, Los Angeles County, California, Water-Resources Investigations Report 03-4065, *available at* http://pubs.usgs.gov/wri/wrir034065/wrir034065.html.
[60] W.D. Mendenhall (1905) Development of underground waters in the central coastal plain region of southern California: U.S. Geological Survey Water Supply Paper 138

Land-Cover and Land-Use in the Chino Basin
1933-1993

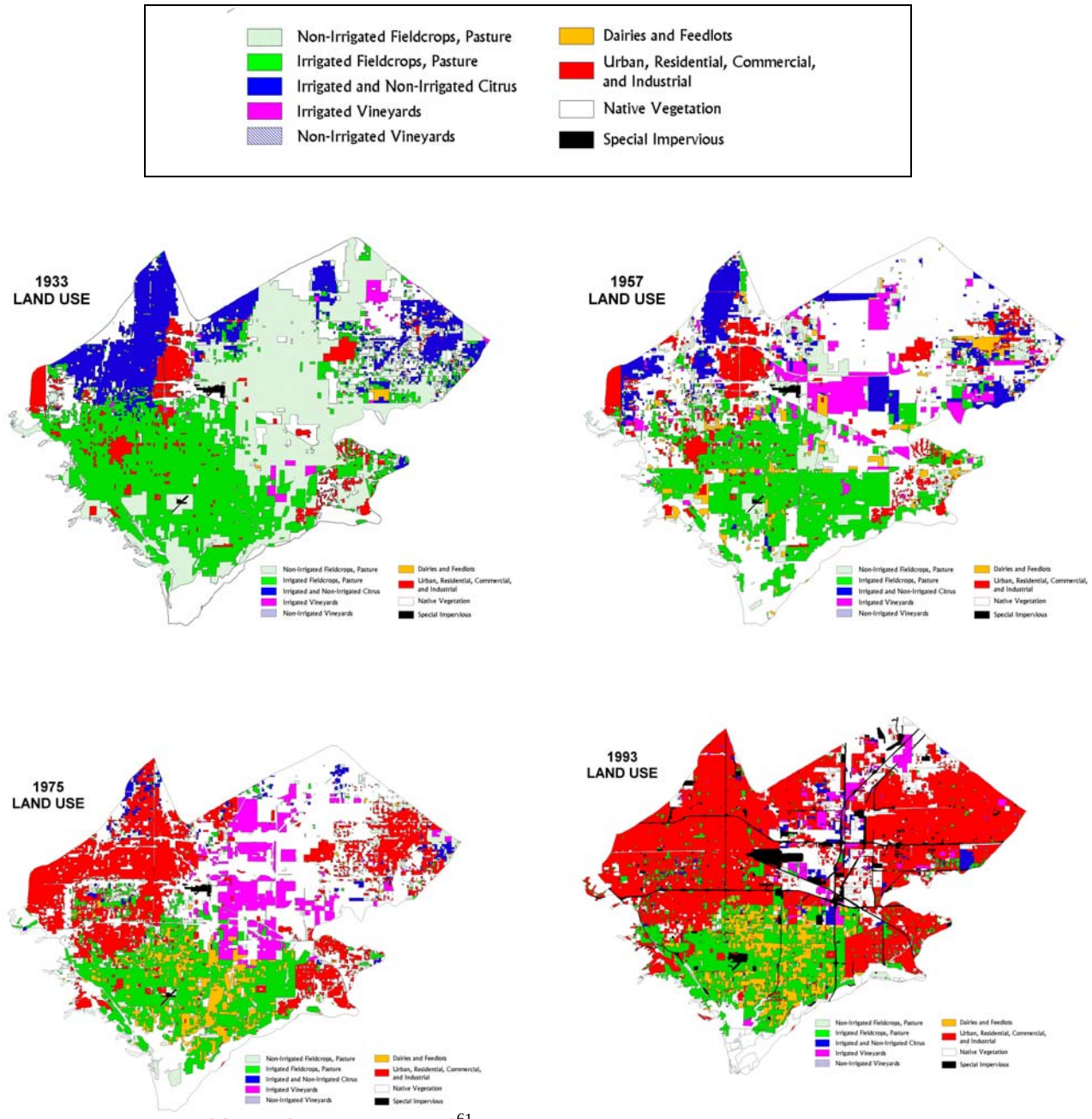

Figure 6. Source: Wildermuth Environmental[61]

[61] Wildermuth Environmental, Inc. (August 19, 1999) Optimum Basin Management Program, Draft Phase I Report, prepared for Chino Basin Watermaster, *available at* *http://www.cbwm.org/docs/engdocs/obmpphas1rep/Text/OBMP_Ph1_Report.pdf*.

The large-scale shift from agrarian or open land to urban development depicted here is characteristic of large areas of the state, which has seen its population grow from 5.7 million in 1930, to over 36.5 million in 2006.[62] As discussed above, the accompanying increase in impervious surface unbalances the normal hydrologic regime, diverts precipitation from the ground surface, and threatens regional groundwater supply. However, LID practices that maximize infiltration can greatly reduce the threat to groundwater supplies, allow for natural recharge to resume, and augment local supplies of water. As a result, despite increased development and impervious cover, LID's ability to restore natural recharge conditions can offset the need for energy-intensive imported sources of water that might otherwise be required absent the implementation of LID.

Even in areas not traditionally viewed as having ideal conditions for groundwater recharge, LID can supplement local supply through infiltration. In the Los Angeles-Orange County coastal plain aquifer system, which the Los Angeles and Orange County Water Districts and the U.S. Geological Survey have characterized in detail by drilling wells, contrasting layers of highly permeable gravels and finer-grained deposits control the region's hydrologic characteristics and have resulted in large deposits of relatively shallow groundwater separated from the deeper, regional groundwater systems by the relatively finer-grained deposits.[63]

Generally, water purveyors have ignored the shallow aquifers that characterize portions of the basin, and "because of low yields and poor water quality, little water is pumped" from them.[64] But, the continually increasing need for viable water supplies has begun to shift thinking on the potential for obtaining water from these aquifers. According to Ted Johnson, Chief Hydrogeologist at the Water Replenishment District of Southern California, the water has not generally been used for domestic or irrigation supply in recent years, "but it could be done...the water could be extracted and treated as needed for use...reverse osmosis may be needed if the water is too mineralized, or activated carbon if there is volatile organic contamination, but these technologies exist. There are entities pumping out shallow groundwater right now for dewatering purposes and we are looking at putting that water to beneficial use instead of losing it to the ocean."[65]

For areas of southern California, such as large sections of San Diego County (where in addition to supply from the SWP, a desalination plant has recently been conditionally permitted for operation), that overlie relatively impermeable soils or that do not generally contain usable regional groundwater aquifers, the greatest potential water and energy savings may be realized by implementing water harvesting practices to offset the need for imported or desalinated water. This method, discussed below in the context of northern California, offers a widely applicable means of supplementing local water supply and reducing the need for imported water and its associated GHG emissions. Thus, regardless of the LID technique utilized, LID's potential to address issues of climate change argues for its required implementation under AB 32.

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[62] U.S. Census Bureau, *available at* www.census.gov.
[63] R. Yerkes, T. McCulloh, J. Schoellhamer, and J. Vedder (1965) Geology of the Los Angeles basin, California – An introduction: U.S. Geological Survey Professional Paper 420-A, 57 p.
[64] USGS, Water-Resources Investigations Report 03-4065, *supra*, note 59.
[65] Personal communication, email, July 10, 2008.

Northern California

The northern California study area includes all or portions of San Francisco County, Marin County, Contra Costa County, Alameda County, Santa Clara County, and San Mateo County. (See Figure 7, general region of northern California study area.) As the map in Figure 8 shows, desalination plants have been proposed to supplement water supply in areas supplied by agencies including the East Bay Municipal Utilities District, Contra Costa Water Agency, San Francisco Public Utilities Commission, and Santa Clara Valley Water District. The locations served by these Water Districts offer the greatest potential for energy savings because water supply from four planned desalination plants in the study area could be offset by using LID-based water harvesting practices, and form the focus of our northern California analysis. However, additional opportunities to use LID to reduce energy usage and GHG emissions exist throughout the San Francisco Bay Area, including in Napa County and Sonoma County, as well as to the south in the Monterrey Bay region (where an additional five desalination plants are currently proposed).[66]



Figure 7. Map of land use in northern California.

The potential use of ocean desalination represents a significant influx of energy-intensive water supply, the need for most or perhaps all of which could be obviated through the implementation

[66] Heather Cooley et al., *supra*, note 8.

of LID. With limited exceptions (principally in Santa Clara County), water harvesting is more appropriate than infiltration in these areas for two main reasons. First, within the San Francisco Bay study area, except for Santa Clara County, water purveyors do not currently use groundwater as a large component of their supplies. Groundwater accounts for only about 5 percent (or 68,000 af/year) of the entire region's average annual water supply for irrigation and domestic use.[67] Extensive groundwater production does occur in the Santa Clara Valley,[68] where substantial opportunity for additional recharge exists. However, generally speaking there is no developed infrastructure to supply groundwater in the region, so implementing LID to supplement groundwater storage would not result in a near-term increase in water supply. Second, relatively impermeable soils underlie a substantial fraction of the San Francisco Bay Area,[69] and while local variation is likely to allow for some groundwater recharge to occur, in many instances, water harvesting would allow for greater water savings (and consequently greater energy savings) than infiltration.

Planned Seawater Desalination Plants as of 2006

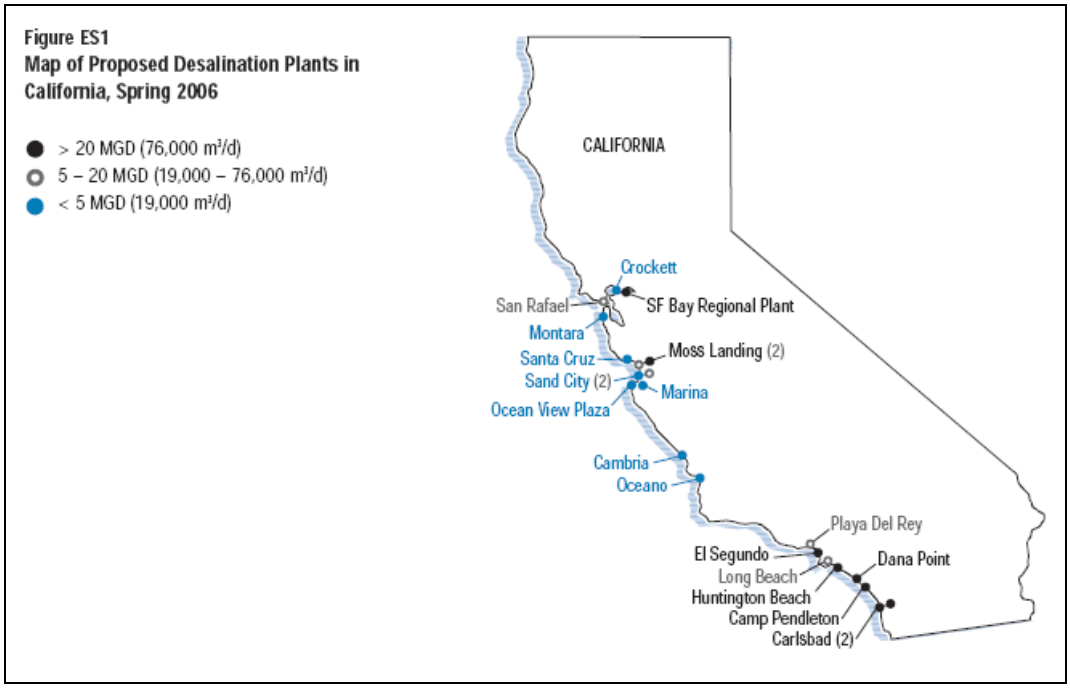

Figure 8. Source: Cooley, Heather, Peter H. Gleick, and Gary Wolff, 2006.[70]

Water harvesting is typically, though not exclusively used to capture rooftop runoff and can be applied at larger scales in commercial developments and residential subdivisions and at smaller scales using cisterns or rain barrels. Importantly for our analysis, studies have shown that

[67] DWR, *supra*, note 10.
[68] *Id.*
[69] Richard R. Horner, *supra*, note 12. (Based on a survey of soils classified under the Natural Resources Conservation Service (NRCS) Hydrologic Soils Groupings, 39.3, 68.0, 18.3, and 50.1 percent of Alameda, Contra Costa, San Mateo, and Santa Clara Counties, respectively, are classified as having D type soils that are not generally amenable to infiltration.)
[70] Heather Cooley et al., *supra*, note 8.

harvesting is successful at reducing runoff discharged to storm drain systems and at conserving water for reuse at all scales and under a variety of conditions. For example, the King Street Center in downtown Seattle uses water captured from roof runoff to supply over 60 percent of the building's toilet flushing and irrigation requirements, saving approximately 4.3 acre-feet of potable water per year.[71] On a much smaller scale, the Carkeek Environmental Learning Center in Seattle drains rooftop runoff into a 3500-gallon cistern to supply toilets.[72] Given that the average roof at a residential or commercial development accounts for at least 40 to 60 percent of the site's total impervious surface area (and therefore 40 to 60 percent of impervious surface runoff), vast quantities of water are available for harvesting to offset the need for other, more energy-intensive sources of water.

Methodology and Results of NRDC Study

Our analysis found that, in the urbanized areas of southern California and limited portions of the San Francisco Bay Area alone, LID has the potential to result in savings of between 124,000 and 223,000 acre-feet of water per year by 2020, with a corresponding annual electricity savings of between 269,000 and 637,000 megawatt-hours (MWh). These figures increase to water savings of 227,500 to 408,000 af/year, and associated energy savings of 494,000 to 1,167,000 MWh/year by 2030, with savings continuing to increase thereafter with continued development. These savings represent a substantial opportunity to reduce GHG emissions under AB 32 given the practicable nature of LID, and the fact that current state and federal laws already require that discharges address the issue of stormwater runoff, in some fashion, even before any additional regulatory framework is implemented by the AB 32 process.

Methodology

The volume of water and associated energy savings and GHG emissions reductions were calculated based on separate analyses of both urbanized southern California and portions of the San Francisco Bay Area. The analysis evaluated land use data for all commercial and residential development within both study areas, and determined the average percentage of impervious surface for each designated land use type. (See, e.g., Figure 9, Map of impervious surface in southern California. Note the increased impervious coverage in areas such as downtown Los Angeles, Santa Monica, and San Diego.) Though LID practices are ultimately applicable to any land use or development type, we have limited our initial analysis of the potential water savings that may be realized to commercial and residential development due to the availability of data regarding future and re-development rates, discussed below. Impervious surface runoff from commercial and residential development was calculated based on average rainfall compiled from the NRCS 1961-1990 data set, averaged across each of the designated land uses, in order to determine the total volume of annual impervious surface runoff from the current distribution of specified land use types within the study area. Runoff was calculated based on a runoff coefficient for impervious areas of $C = (0.009) * I + 0.05$, where I is the impervious percentage (with I = to 100 percent for fully impervious areas).

Land use and impervious surface runoff totals were additionally calculated based on the underlying soil type from a combination of U.S. Department of Agriculture STATSGO soil data and NRCS SSURGO soil data, in order to determine infiltrative capacity of soil underlying each

[71] *Id.*; see also http://www.psat.wa.gov/Publications/LID_studies/rooftop_rainwater.htm, http://dnr.metrokc.gov/dnrp/ksc_tour/features/features.htm.

[72] Anitra Accetturo (2005) Seattle Highlights Rainwater Harvesting at ARCSA 2005, *available at* http://www.harvesth2o.com/seattle.shtml.

land use type. Where infiltration and groundwater recharge was selected as the preferred method for increasing local supply, the study assumes that with adequate conditions, 100% of

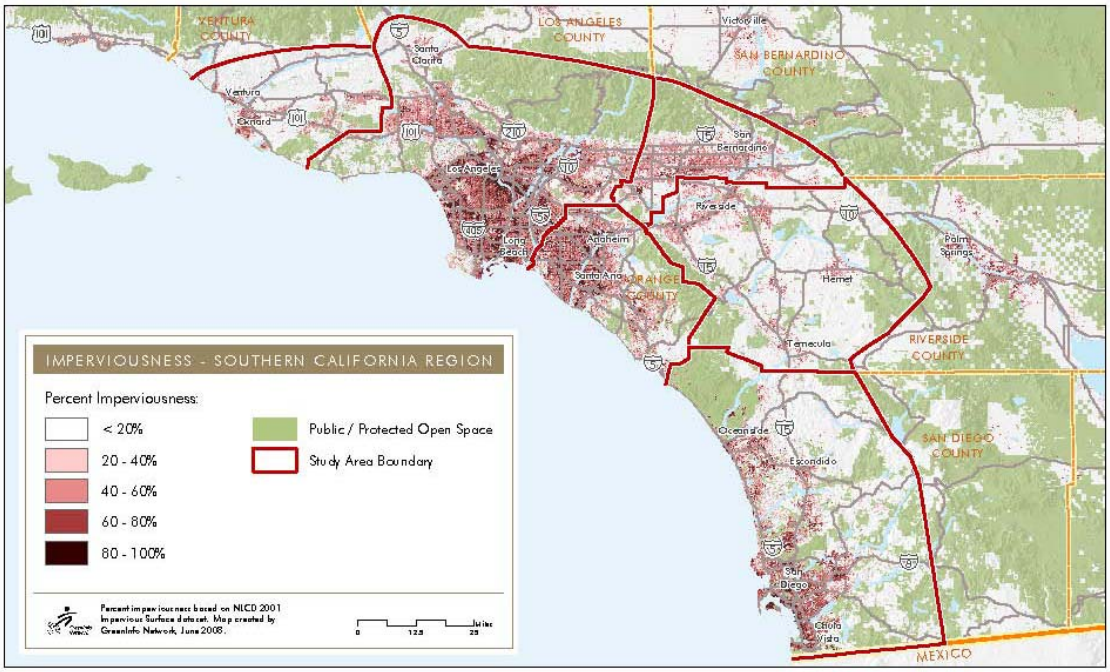

Figure 9. Map of impervious surface percentage in southern California study area.

impervious surface runoff can be infiltrated to the ground surface (though depending on the estimate used, also assumes that a portion of this water will be lost to evapotranspiration). Where impervious surface runoff occurred over areas characterized as having D soils, or soils interpreted as not ideally suited for infiltration, water harvesting of rooftop runoff, rather than groundwater recharge was assumed to result in the greatest potential savings. Water from rooftop runoff was also used as the basis for calculating the potential water savings in areas of high impervious surface content, defined as areas greater than 10 acres in size containing contiguous impervious cover of greater than 80%. (E.g., downtown Los Angeles and San Francisco, both of which are characterized by high percentage of impervious cover.) Though these areas may in many instances encompass sufficient pervious cover to infiltrate a large percentage, if not the total volume of associated impervious surface runoff, we have assumed a conservative bias in characterizing the potential opportunities for groundwater recharge, and selected water harvesting as the preferred method under these conditions.

In addition to precipitation based runoff, dry weather runoff stemming from human activities such as landscape irrigation and car washing was calculated within the southern California study area and Santa Clara portion of the northern California study area. Dry weather runoff was calculated based on a figure of 0.152 gallons per acre of pervious surface per minute for residential and commercial land use types likely to include landscaped cover. This figure was derived from the "Residential Runoff Reduction Study" performed by the Irvine Ranch Water District,[73] and extrapolated to include commercial development for this study.

[73] *Available at* http://www.irwd.com/Conservation/water_conservation_research.php.

Water savings for 2020 and 2030 were then calculated based on projected commercial and residential development rates for each county included within the study area. Development projections were provided by the Southern California Area Governments,[74] San Diego Association of Governments,[75] Association of Bay Area Governments,[76] California Department of Finance,[77] and national scale land use data.[78] Redevelopment rates were calculated based on an annual national "loss rate" of 1.37% for commercial buildings and 0.63% for residential structures.[79] These numbers are likely conservative, as the rate of development in the selected study areas exceeds national rates. This is particularly the case in light of the fact that the report forming the basis for these estimates states that, "In 2030, about half of the buildings in which Americans live, work, and shop will have been built after 2000."[80] However, based on these estimates, NRDC's study assumes that 100% of future development and redevelopment of commercial and residential property would be constructed using LID practices.

Energy savings were calculated based on reducing the volume of supply from the marginal, or highest, energy intensity source of water for each area within the southern California study area, and by reducing the use of ocean desalination water in northern California. In each instance, the volume of imported or desalination water to be offset was calculated to be reduced by the volume of water predicted to be either infiltrated for groundwater recharge or harvested through use of LID practices. In southern California, the marginal water source was determined based on a review of MWD member agency Urban Water Management Plans. The marginal source was determined to be the West Branch of the State Water Project for Ventura and one-half of Los Angeles County, and the East Branch of the State Water Project for one-half of Los Angeles County, Orange County, San Bernardino County, Riverside County, and San Diego County. Energy savings were thus calculated by determining the total amount of water to be recharged or harvested within the study area, then calculating the energy required to supply the same volume of water through the marginal supply source, less the energy required to supply the volume of water through either groundwater pumping or graywater recycling.

It should be noted that the estimates for both water savings and resultant energy savings presented here are conservative when compared to the actually available savings that may be achieved by employing LID, as the current analysis assumes a cautious figure for development rates, and, additionally, does not currently take into account the potential to implement LID practices at government, public use, and industrial sites, which account for a significant percentage of the total land use in the state. Finally, the study does not take into account the loss rate for water supplied through the State Water Project or Colorado River Aqueduct. Both of these systems lose as much as 5 percent of the total water conveyed through a combination of evaporation and leakage during the course of transport, and the additional energy required to transport or pump this water has not been factored into the above calculations. There exists both

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[74] (2008) Integrated Growth Forecast, *available at* http://www.scag.ca.gov/forecast/index.htm.
[75] Demographics, *available at* http://www.sandag.cog.ca.us/index.asp?classid=26&fuseaction=home.classhome.
[76] See, e.g., ABAG Projections 2007: Regional Projections, *available at* http://www.abag.ca.gov/planning/currentfcst/regional.html.
[77] (July 2007) Population Projections for California and Its Counties 2000-2050, *available at* http://www.dof.ca.gov/HTML/DEMOGRAP/ReportsPapers/Projections/P1/P1.php.
[78] See, e.g., Arthur C. Nelson (2004) Toward a New Metropolis: The Opportunity to Rebuild America, Brookings Institution, Washington, DC, *available at* www.brookings.edu/dybdocroot/metro/pubs/20041213_RebuildAmerica.pdf.
[79] *Id*.
[80] *Id*.

a significant potential to expand the estimated volume of savings, and significant potential that the actual energy savings are greater than those presented here. As a result, these estimates should be considered to be an accurate, though conservative estimate of the total savings that would result from implementation of this measure.

Assumptions and Variables in Estimates of Water and Energy Savings Due to LID
Following from the above methodology, we present a low, medium, and high estimate for the potential water and energy savings that LID can produce under AB 32. This range reflects the unknowns and potential variability of individual factors that may affect both infiltrative and harvest capacity, as well as the energy requirements of local supply. However, we have assumed overall a conservative rate of development for the study areas and further limited our analysis to only commercial and residential properties. Thus, all of these estimates represent conservative values for the potential savings that widespread implementation of LID practices could achieve in California. Within that framework, we have considered the following factors in developing the estimates of water and energy savings:

- Percentage of runoff directed to infiltration and groundwater recharge but lost to evapotranspiration: A study currently being conducted by the Los Angeles-San Gabriel Rivers Watershed Council ("LASGRWC"), based on an infiltration model created by the U.S. Bureau of Reclamation, has shown that the evapotranspiration loss of water retained for onsite infiltration and groundwater recharge is minimal across various soil types and development patterns, often on the order of only 10 percent of the retained flow.[81] For the most conservative estimate, we have assumed that 30 percent of the water infiltrated onsite will be lost through evapotranspiration (reflecting a situation closer to pre-development conditions, in which 40 to 50 percent of water may be lost). For our middle estimate, we have assumed a 20 percent loss rate, and for the high estimate, a 10 percent loss rate.
- Percentage of roads to be developed as greenstreets: Surface roads and sidewalks account for as much as 20 percent of the total impervious cover in residential and commercial developments within the study area. As a result, the use of "greenstreets," or streetscapes designed according to LID principles, can significantly increase the volume of water available to augment local water supply through infiltration and recharge. In our low-end estimate, we assume that 50 percent of roads constructed in areas of new development will be engineered according to LID principles. In the medium estimate, we assume that 65 percent of roads in areas of new development and 25 percent of roads in areas of redevelopment will be engineered or resurfaced according to LID principles. In the high estimate, we assume that 80 percent of roads in areas of new development and 50 percent of roads in areas of redevelopment will be engineered using LID principles.
- Percentage of retrofitted development employing LID principles: In addition to calculating a rate of redevelopment within the study areas, we include an estimate for properties that will undergo a substantial retrofit or redesign that does not include a complete rebuild or re-construction of existing structures. We have assumed the rate of retrofitting of existing development to occur at the same rate as overall redevelopment within each of the study areas. However, in the conservative estimate we assume that only 25 percent of these structures will employ LID practices, while in the medium and

[81] See generally, LASGRWC Water Augmentation Study, *available at* http://www.lasgrwc.org/WAS.htm.

high end estimates we assume that 50 percent of the retrofitted structures are re-engineered to incorporate LID practices.

- Percentage of impervious surface comprised of rooftop: While we calculate our results based on 100 percent recovery of water generated as rooftop runoff (with the remaining site runoff either directed to available pervious surface for infiltration or diverted to conventional storm sewer systems), the percentage of impervious cover present as rooftop surface area at any individual site varies significantly. However, an analysis of six different case studies of building permits in southern California found that rooftop surface averaged between approximately 40 percent and 60 percent of total impervious surface area at a given site.[82] As a result, our low end estimate assumes that water harvesting will occur from 40 percent of the impervious surface area onsite, the medium estimate assumes a 50 percent rooftop scenario, and the high estimate 60 percent of impervious surface as rooftop area.
- Energy required for extraction of infiltrated water by groundwater pumping: The energy required to pump and produce potable water through groundwater supply is determined by numerous factors, including depth of pumping and presence of salts or other mineral contaminants that may require treatment. As a result, there a wide uncertainty exists in calculating the energy requirements for augmenting water supply through groundwater recharge. Whereas pumping groundwater from large portions of the state, including the Tulare Lake region or West Basin of Los Angeles require only a few hundred kWh/af, groundwater production may require greater than 1500 kWh/af in the Chino Basin. As a result, we have assumed a moderate-to-high overall embedded energy requirement for groundwater production overall. For the low estimate, we assume a requirement of 750 kWh/af, and for the middle and high estimates, 500 kWh/af.
- Energy required for recycling of rooftop water harvesting: As with groundwater production, a wide range of potential energy requirements exists in order to provide water through rooftop recycling. We have reviewed a variety of graywater recycling systems, and find that, at low volumes for single family residences, recycling may require as much as 1,650 kWh/af, while at higher volumes, or for large scale commercial application, 700 kWh/af or less. It should be noted that in many situations, such as where water is harvested by gravity feed for subsequent use in subsurface irrigation, the net energy requirements of the system will be negligible, if not zero. However, and in order to maintain a conservative approach, for our low end estimate we assume an energy requirement of 1,650 kWh/af, for the medium estimate, 1,200 kWh/af, and for the high estimate, 700 kWh/af in order to produce recycled water for irrigation or toilet flushing.
- Local variation in soil type and infiltrative capacity: As a final variable, we recognize that there may be areas that we have identified as having the greatest potential savings supplied through infiltration and groundwater recharge (not including those areas designated as having a high percentage of impervious surface), for which water harvesting may ultimately prove to be a preferred method for augmenting water supply. In order to demonstrate that LID is capable of achieving substantial water savings and corresponding reductions in energy use and GHG emissions regardless of what LID practice is employed, we assume, in our low estimate, that 50 percent of Los Angeles County within the study area will augment water supply through infiltration, with the remaining 50 percent employing water harvesting to augment water supply. The medium

[82] Richard R. Horner, *supra*, note 12.

estimate assumes 75 percent infiltration and 25 percent capture, and the high estimate assumes 100 percent use of LID practices that emphasize infiltration.

Again, we highlight that the assumptions made here reflect a conservative bias, and even in the high estimate, an accurate, possible scenario for real-world application of LID principles under AB 32.

Results of Study
Utilizing the methodology and factors detailed above, we present the following estimates for water savings and associated energy savings within the southern California and San Francisco Bay Area study areas:

PREDICTIONS FOR SOUTHERN CALIFORNIA AND SAN FRANCISCO BAY REGION COMBINED WATER SAVINGS (Acre-feet per year, af/yr)

	2020	2030
Low	124,000	227,500
Med	172,000	315,000
High	223,000	408,000

PREDICTIONS FOR SOUTHERN CALIFORNIA AND SAN FRANCISCO BAY REGION COMBINED ENERGY SAVINGS (Megawatt-hours per year, MWh/yr)

	2020	2030
Low	269,000	494,000
Med	439,000	804,000
High	637,000	1,167,000

Under these scenarios, and in light of the assumptions made in calculating each estimate, it can be seen that the ratio of energy saved per unit of water increases significantly from the low end estimate (2,170 kWh saved per acre-foot) to the high end estimate (2,860 kWh saved per acre-foot). This difference results from the lower requirements of energy supply for groundwater or water harvesting assumed in the high estimate, which we consider to more accurately reflect likely real-world conditions based on the research presented herein. However, and regardless of the difference in total water savings, total energy savings, or energy saved per unit of water, the results compel the same conclusion to be drawn—the use of LID presents a significant, and currently untapped opportunity to reduce the use of energy required to supply water in California, and should be strongly supported by CARB in the Scoping Plan under AB 32.

Cost of LID
Finally, we call attention to the potential cost savings that may result through the implementation of LID practices, and that LID presents a cost effective method for reducing GHG emissions under AB 32. The CEC commented in its 2005 *Integrated Energy Policy Report* that: "The Energy Commission, the Department of Water Resources, the CPUC, local water agencies, and

other stakeholders should explore and pursue cost-effective water efficiency opportunities that would save energy and decrease the energy intensity in the water sector."[83] By virtually every metric considered, LID has proven to be a cost-effective method of controlling stormwater runoff. "In the vast majority of cases… implementing well-chosen LID practices saves money for developers, property owners, and communities while protecting and restoring water quality."[84] Implementing LID practices also results in a suite of positive externalities, as "LID…provides ecosystem services and associated economic benefits that conventional stormwater controls do not."[85] Overall, LID easily meets AB 32's mandate to employ cost-effective measures for reducing GHG emissions, providing further reason for its inclusion in the Draft Scoping Plan.

Traditional stormwater management practices involve the construction of complex systems of curbs, gutters, buried drainage pipes, and centralized sewers. Since, as described above, LID attempts to mimic the pre-development hydrology of a site, emphasizing onsite treatment, infiltration, and use of a site's existing drainage conditions, "[c]ost savings are typically seen in reduced infrastructure because the total volume of runoff to be managed is minimized."[86]

Costs of LID implementation may still vary greatly, depending on site and/or project conditions, the capabilities and experience of the project's designers, and the specific practices or techniques implemented.[87] However, with only "a few exceptions," EPA found that, "Total capital cost savings ranged from 15 to 80 percent when LID methods were used" instead of conventional stormwater management techniques.[88] The savings identified in the studies documented by EPA are all the more remarkable considering that they consider only the costs of installation for LID and conventional controls; the savings do not reflect or in any way monetize the additional economic benefits that LID may provide, which may further reduce the cost of LID in relation to conventional controls. The EPA study fully acknowledged this fact and stated, for one of the "few exceptions" in the report, that "The significant cost for the rooftop rainwater collection systems" installed at the site "was assumed to be offset somewhat by savings on stormwater utility bills" that were not calculated into the cost of the project.[89]

As detailed in the section above, LID practices provide multiple benefits and advantages over conventional stormwater controls. While the majority of case studies and economic assessments of stormwater management, like the EPA survey, have focused solely on the installation costs of LID, there are numerous examples of the economically beneficial externalities that result from LID, including the following:

<u>Reduced Costs of Municipal Infrastructure/Control of Combined Sewer Overflows</u>

- A 2007 ECONorthwest study highlighted a 2004 report by Brewer and Fisher that detailed four case studies of LID projects, including two residential projects, a commercial development, and an elementary school. The 2004 report found that at all

[83] California Energy Commission, *supra*, note 29.
[84] EPA, *supra*, note 3.
[85] ECONorthwest (November 2007) The Economics of Low-Impact Development: A Literature Review, *available at* http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf.
[86] EPA, *supra*, note 3; HUD *supra*, note 2.
[87] ECONorthwest, *supra*, note 85.
[88] EPA, *supra*, note 3.
[89] *Id*.

four sites LID designs managed a significantly greater volume of stormwater than conventional controls, which resulted in reduced strain on and expenditures for the local municipal stormwater system.[90] For all four locations, the economic value of the additional stormwater storage provided by LID, which ranged from $17,424 to $167,270 per project, was significantly greater than any net cost to the developer.[91]

- A case study of the Beecher Water District in Flint, Michigan showed that, by disconnecting downspouts from home sites connected to the sanitary sewer, which cost the water district a total of $15,000, and allowing the water to infiltrate into the ground naturally, the mean volume of sewer flows measured across all precipitation events decreased by 26 percent. The program saved the water district $8,000 per month in stormwater fees, reduced the costs of managing combined sewer overflows ("CSOs"), and paid for itself in just two months.[92]
- An analysis of the effectiveness of LID practices in New York City determined that, per $1,000 invested, use of greenstreets controlled more than six times the volume of water, and capturing stormwater in rain barrels controlled nearly four times the volume of water, as did construction of conventional controls such as storage tanks and other traditional CSO measures.[93]

Increased Value of Real Estate

- In a residential subdivision constructed in Sherwood, Arkansas, using LID site designs preserved natural drainage areas, increased open space from the originally planned 1.5 acres to 23.5 acres, and allowed the developer to reduce street widths from 36 to 27 feet. The design techniques enabled the development of 17 additional lots, and lots in the subdivision subsequently sold for $3,000 more than comparable lots developed with conventional controls. This generated a profit of over $1.5 million for the developer, in addition to the $678,500 cost savings of LID compared to conventional designs.[94]

Further, the operation and maintenance costs of LID are low, and have been estimated at 3-7% of the total installation costs annually.[95] Much of the maintenance of LID features can be combined with or undertaken in the course of normal landscape maintenance. According to Neil Weinstein, executive director of the Low Impact Development Center, "The misrepresentation is that LID techniques are difficult to maintain and will fail if they aren't. But most of these techniques really require minimal to no maintenance, and still function very well if they aren't maintained."[96]

All of these aspects of LID implementation indicate that the GHG emission reduction potential of LID site designs can be realized practicably and cost-effectively, thus actually saving money for those involved with its implementation. The benefits as they currently stand would argue in favor of requiring LID implementation under the Scoping Plan. But, because LID practices still

[90] ECONorthwest, *supra*, note 85.
[91] *Id.*
[92] *Id.*; M.M. Kaufman and M. Wurtz (1997) "Hydraulic and Economic Benefits of Downspout Diversion," *J. of the Amer. Water Resources Assoc.* vol. 33, pages 491-497.
[93] ECONorthwest, *supra*, note 85.
[94] EPA, *supra*, note 3; HUD, *supra* note 2.
[95] EPA, *supra*, note 3.
[96] Asa Foss (May/June 2005) Low Impact Development: An Alternative Approach to Site Design, PAS Memo, American Planning Association, *available at*, http://www.pathnet.org/si.asp?id=1592.

represent a new technology that has previously resulted in increased costs for learning, initial design, and installation,[97] "[a]s with any new approach, the cost of implementing LID will decrease as institutional experience increases and the benefits of using LID are realized in practice."[98] This future cost savings is exemplified by a recent City of Seattle greenstreet pilot project, which cost $850,000 to implement but included an "extensive budget for design and consulting with residents."[99] The manager of the City's surface water program stated, "You could take $200,000 off the price just from what we didn't know… The pilot phases that we are currently in are more expensive, but as the project becomes institutionalized, all the costs will come down. Even still, these projects are less expensive than standard projects."[100] LID will become only more cost-effective with time.

Conclusions

California is presented with an unprecedented opportunity to address the issues of climate change and its impacts on our state. California should, and must, act rapidly under AB 32 and include the broadest possible palate of measures to reduce GHG emissions. To that end, LID, which has the potential to greatly augment local water supplies through infiltration to recharge groundwater and harvesting and thereby reduce the need to rely on energy-intensive imported or desalinated water, should be aggressively implemented under AB 32.

[97] ECONorthwest, *supra*, note 85.
[98] U.S. Department of Defense (2004) Unified Facilities Criteria – Design: Low Impact Development Manual, Unifie Facilities Criteria 3-210-10, *available at* http://www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf.
[99] Asa Foss, *supra*, note 96.
[100] *Id*.

NRDC
THE EARTH'S BEST DEFENSE

ENERGY DOWN THE DRAIN

The Hidden Costs of California's Water Supply

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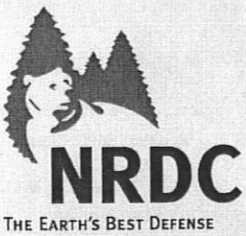

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EXECUTIVE SUMMARY

California has been through its share of scorching droughts and energy shortages, but many residents of the western United States may not realize the close connections between water and power resources. Water utilities use large amounts of energy to treat and deliver water. Even after utilities deliver water, consumers burn more energy to heat, cool, and use the water.

▸ The California State Water Project is the largest single user of energy in California. In the process of delivering water from the San Francisco Bay-Delta to Southern California, the project uses 2 to 3 percent of all electricity consumed in the state.

▸ The State Water Project burns energy pumping water 2,000 feet over the Tehachapi Mountains—the highest lift of any water system in the world. The amount of energy used to deliver that water to residential customers in Southern California is equivalent to approximately one-third of the total average household electric use in the region.

▸ Ninety percent of all electricity used on farms is devoted to pumping groundwater for irrigation.

Despite these connections, water planners at the federal, state, and local levels have largely failed to consider the energy implications of their decisions. Water agencies select water sources without assessing the energy costs of transporting the water over great distances to its users. Likewise, they fail to consider the energy savings of using less water. This kind of disregard for the energy implications of water leads to high costs for consumers and wasteful water-supply decisions.

A proper understanding of water and energy, however, can save both money and resources. Our report presents a model for how policymakers can calculate the amount of energy consumed in water use. We applied this model to three case studies in the western United States, and our analysis shows that integrating energy use into water planning can save money, reduce waste, protect our environment, and strengthen our economy. Water planners can use this model in their own regions to find similar solutions that will benefit consumers and the environment alike.

KEY FINDINGS

We quantitatively evaluated the connections between energy and water in three case studies. We used San Diego County's search for future water supply options to highlight energy use in urban water systems. Our examinations of the Westlands Water District and the Columbia River Basin illustrate energy use in agricultural settings. Our research found the following.

Water conservation lowers energy use and energy bills. The San Diego case study revealed that end use of water—especially energy intensive uses like washing clothes and taking showers—consumes more energy that any other part of the urban water conveyance and treatment cycle. This is a rather striking finding since conveyance is a much more obvious energy consumer, particularly in Southern California. Therefore, reducing water use can save significant amounts of energy. For instance, if

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San Diego relied on conservation instead of additional water from Northern California to provide the next 100,000 acre-feet of water, it would save enough energy to provide electricity for 25 percent of all of the households in San Diego.

Water recycling is a highly energy efficient water source. In both urban and agricultural settings, reusing water is far less energy intensive than any physical source of water other than local surface water. For example, Orange County is constructing a water recycling system that will use only half the amount of energy required to import the same amount of water from Northern California. Even groundwater pumping is more energy intensive in San Diego and the Westlands Water District than water recycling from urban wastewater; and the depth to groundwater in these locations is not atypical for western settings.

Orange County is constructing a water recycling system that will use only half the amount of energy required to import the same amount of water from Northern California.

Retiring agricultural land may increase energy use if the water is transferred to other agricultural or urban uses. Transferring water from retired, drainage-impaired Westlands land to urban settings would dramatically increase energy use because urban water use is typically more energy intensive. For example, we estimate that transferring the conserved water to San Diego would require an additional 1.3 billion kWh/yr compared to leaving that water in the delta. Allowing water to remain in Westlands would likely result in an increase in permanent crops and a significant increase in embedded energy ranging from 16 percent to 48 percent depending on assumptions.

Retiring agricultural land can save energy if the water is dedicated to the environment. Using data from the Westlands Water District—one of the largest agricultural users of water in the West—we concluded that ending irrigation to retired farmlands could generate large energy savings if the water remains instream. Retiring 100,000 acres of drainage-impaired farmland in Westlands, with corresponding reductions in Central Valley Project deliveries, could save at least 71 million kWh from reduced Central Valley Project pumping. This is enough to meet the residential energy needs for the city of Modesto for two months. Retiring this land could also save an additional 50 million equivalent kilowatt-hours used for cultivation and harvest.

Diverting water above dams costs power and money. Our Columbia case study demonstrates that when water is diverted for irrigation before it reaches a dam, an enormous amount of energy—the foregone energy production—is lost. For example, the foregone energy production in the Columbia Basin Project is the equivalent of 30 percent of the total energy use for the city of Seattle. This loss may be large enough, in dry years, to make it possible to pay farmers more than they could earn growing low-value crops and still have enough money to purchase environmental flows when they are most valuable.

RECOMMENDATIONS

All three of our case studies demonstrate that including energy considerations in water management decisions can lead to significant energy—and money—savings.

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The case study analysis supports two primary recommendations for how policy makers can begin to achieve these savings.

Decision makers should better integrate energy issues into water policy decision making. Looking at energy use and water use simultaneously generates valuable insights that do not arise from separate policy analyses of water and energy issues. We therefore recommend:

- Modifying state planning tools, such as the Urban Water Management Planning Act and Bulletin 160, among others, to require inclusion of energy use and costs;
- Improving coordination among resource management agencies to better identify and address the energy implications of water policy decisions;
- Conducting an energy intensity analysis of the United States Bureau of Reclamation's distribution systems and identifying regions and districts where large amounts of power are required to deliver water;
- Exploring the retirement of drainage-impaired lands in the Central Valley in order to reduce energy use and generate water to help restore the delta;
- Developing partnerships designed to produce energy, economic, and environmental benefits through voluntary water transfers in the Columbia River Basin and elsewhere, with a focus on dry-year transfers where large water diversions reduce downstream flows and hydropower generation.

Both water and energy policymakers should give water conservation higher priority. Surprisingly, policy actions that affect end uses of water may have much larger energy implications than policy actions that affect the mix of physical water sources. We conclude that conservation has much greater potential, and stronger energy-related economic and environmental benefits, than has been recognized to date. In addition, the energy benefits of conservation can generate air quality and climate change benefits. Given this strong finding, we recommend:

- Prioritizing conservation funding;
- Enforcing existing conservation requirements;
- Requiring water measurement;
- Promoting conservation through conservation pricing;
- Offering conservation incentives;
- Implementing measures to ensure conservation savings.

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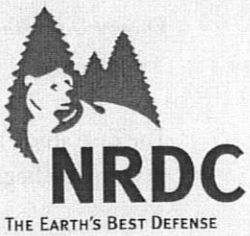
CHAPTER 1

THE HIGH COST OF ENERGY USE IN WESTERN WATER SYSTEMS



ENERGY DOWN THE DRAIN

The Hidden Costs of California's Water Supply

August 2004

Water use and energy use are closely linked. Providing and using water consume large amounts of energy. Energy production frequently uses or pollutes water.[1] Most electricity production also contributes to global climate change, which is likely to have tremendous impacts on water availability and management. Yet energy and water issues are rarely considered together. This is as true at the policy level as it is at the personal level. Most consumers certainly do not realize that saving water is an excellent way to save energy and, indirectly, to reduce air pollution.

The California Water Code notes that wasting water is an unreasonable use of energy.[2] Yet none of the existing resource planning efforts meaningfully addresses the interplay between the two issues, let alone their relationship with climate change. Even the California Energy Commission (CEC) has noted this failure. A CEC report to the state legislature noted: "The State appears to not be consciously managing its rapidly evolving water and energy policies in a coherent manner."[3] Integration of energy considerations into water policy and planning is long overdue.

This report explores the energy implications of water use and presents a methodology for incorporating energy impacts into water resource decisions. It relies heavily on data and examples from California but includes a case study from the Northwest.

THE LINKS IN THE WATER-ENERGY CHAIN

The more than 60,000 water systems and 15,000 wastewater systems in the United States are among the country's largest energy consumers, using about 75 billion kWh/yr nationally—3 percent of annual U.S. electricity consumption.[4] This demand is equivalent to the entire residential demand for the state of California and does not even include energy for what is called end use: the energy required to further treat, circulate, heat, or cool water at the consumer level.[5] Even if all of this power came from relatively clean modern natural-gas-fired power plants, producing the energy used

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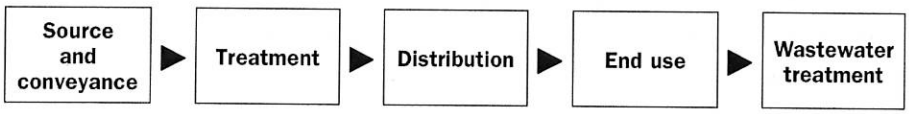
by water systems would release approximately 30 million tons of carbon dioxide—the equivalent of more than 4 million cars.[6]

Many of the peak demands for water and the energy required to treat and transport that water coincide with the peak seasonal energy demands experienced by the electrical utilities, particularly in areas with hot summers like Southern California.[7] Thus, reducing the energy required to move, use, and treat water could help avoid power outages and avoid or delay the need for new power facilities.

This report divides the water supply-use-disposal chain into five stages.[8]



▸ *Source and conveyance:* Significant amounts of energy may be required to create a usable source of water and bring it to where it will be treated or consumed. Most water used in the United States is diverted from surface sources such as rivers and streams or pumped from groundwater aquifers. Smaller amounts of freshwater are produced from salt water, brackish water, or wastewater using desalination or water-recycling technologies. Desalination requires energy to remove salts from water using reverse osmosis or other processes. Water recycling requires energy to remove pollutants from wastewater.

Water is either used near its source or transported for storage and use elsewhere. Conveying water often requires pumping the water over hills and mountains or into storage facilities—a process that can require large amounts of energy. Such systems

FROM SOURCE TO TAP: THE HIGH ENERGY COST OF MOVING WATER

Moving large quantities of water over long distances and significant elevations is a highly energy intensive task. For this reason, water systems in the West are particularly energy intensive. According to the Association of California Water Agencies, water agencies account for 7 percent of California's energy consumption and 5 percent of the summer peak demand.

The State Water Project (SWP) is the largest single user of energy in California. It consumes an average of 5 billion kWh/yr, more than 25 percent of the total electricity consumption for the entire state of New Mexico. The California Energy Commission reports that SWP energy use accounts for 2 to 3 percent of all electricity consumed in California.

The SWP consumes so much energy because of where it sends its water. To convey water to Southern California from the Sacramento–San Joaquin Delta, the SWP must pump it 2,000 feet over the Tehachapi Mountains, the highest lift of any water system in the world. Pumping one acre-foot of SWP water to the region requires approximately 3,000 kWh. Southern California's other major source of imported water is also energy intensive: pumping one acre-foot of Colorado River Aqueduct water to Southern California requires about 2,000 kWh.

In fact, according to an estimate from the Metropolitan Water District of Southern California, the amount of electricity used to deliver water to residential customers in Southern California is equal to one-third of the total average household electric use in Southern California.

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usually also have hydroelectric generators that recover some of this energy as the water falls down the other side of those hills and mountains.

▸ *Water treatment:* Water treatment facilities use energy to pump and process water. The amount of energy required for treatment depends on source-water quality. High-quality groundwater may require little treatment; surface water taken from rivers that have upstream discharges of wastewater may require significant treatment. The energy required for water treatment is expected to increase over the next decade as treatment capacity expands, new water quality standards are put in place, and new treatments are developed to improve drinking water taste and color.[9] Agricultural water generally is not treated before use.

▸ *Local water distribution:* Energy is typically required for local pumping and pressurization, but gravity pressurization and distribution are also possible when reservoirs are sufficiently higher than residences and businesses.

▸ *End uses:* Water users consume energy by further treating water (e.g. with softeners or filters), circulating and pressurizing it (e.g. with building circulation pumps or irrigation systems), and heating and cooling it.

▸ *Wastewater collection and treatment:* Treating wastewater consumes energy in pumping, aeration, and other processes. In 1995, wastewater treatment in California used approximately 1.6 billion kWh of electricity.[10]

ENERGY AND WATER USE: A CYCLE OF ENVIRONMENTAL DAMAGE

The development of the American West was facilitated by the construction of large water projects to convey water for municipal and agricultural uses. These water projects have brought important benefits, but they have also had well-documented and devastating impacts on rivers and landscapes throughout the West. Many once abundant species are now threatened or endangered due in part to these projects. When you include the massive energy production needed to operate these water projects, their environmental impacts are even greater. As one of the largest consumers of energy in the state, California's water system significantly contributes to the state's energy-related pollution.

Energy production has a wide range of damaging environmental and health effects, depending on how and where that energy is produced. Electric power plants, for instance, release dangerous levels of soot and smog, causing thousands of premature deaths, hundreds of thousands of asthma attacks, and other illnesses each year. In addition to the frequently noted air quality impacts of electric power plants, many power plants have once-through cooling systems that can significantly harm ocean and river environments. According to the Hudson Riverkeeper, a typical power plant using once-through cooling technology can kill billions of fish each year by trapping fish against intake screens or drawing fish into the facility.[11] Hydroelectric power production has far less impact on air quality, but far more negative effects on rivers and the aquatic species they support.[12]

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THE WATER-ENERGY-CLIMATE-CHANGE FEEDBACK LOOP

Energy production also leads to climate change. Power plants emit 40 percent of U.S. carbon dioxide pollution, the primary cause of climate change. Unless emissions are reduced, average U.S. temperatures could be 5 to 10 degrees Fahrenheit higher by the end of the century. Climate change has the potential to greatly affect water supply and water management. In California, climate change is likely to lead to greater risk of drought or water shortages in the summer months. At the same time, winter runoff may increase and cause a greater risk of flooding. [13]

All of these changes could have serious consequences for hydroelectric power generation. Changes in runoff have a direct impact on the amount of hydropower generated both because hydropower production decreases with lower flows and because higher flows often must be spilled past dams without producing any power. During droughts, there are two types of hydroelectric losses: less water runs through the turbines in powerhouses, and the lower reservoir level reduces the "head," thereby reducing the power produced by a given amount of water. In the Colorado River's lower basin, a 10 percent decrease in runoff reduces hydropower production by 36 percent.[14] As hydropower generation decreases, energy users are likely to turn toward fossil fuels, thereby increasing emissions that contribute to climate change. During the first five years of the 1987 to 1992 California drought, hydropower losses cost California ratepayers $3 billion and led to an increase in greenhouse gas emissions of 25 percent over normal levels.[15]

ENERGY AND WATER SUBSIDIES: THE DRIVING FORCE BEHIND INEFFICIENCY

Despite the significant environmental and health concerns caused by energy intensive water use, many current policies actually encourage this wasteful practice. Energy and water subsidies in particular help drive the cycle of inefficient and energy intensive water use by hiding the true resource costs.[16] Water subsidies increase demand for water (thereby increasing energy use) and discourage conservation. Energy subsidies encourage transporting water over distances and pumping groundwater from depths that would not be economically feasible if the water users had to pay all the costs of energy and water. Policies aimed at reducing the energy used in water supply should address these inappropriate financial signals.

Subsidies exist when prices charged do not cover the government's cost or when the price does not equal comparable market price. A 1992 report from the Department of Energy's Energy Information Administration calculated the estimated subsidy value from these two different perspectives on federal hydropower sales nationwide. The report concluded that the annual subsidy at historic cost with full cost recovery was $1.232 billion for the Bonneville Power Administration (BPA) and $505 million for the Western Area Power Administration (WAPA) in 1990. The subsidy at estimated market price of electricity was $213 million for the BPA and $1.2 billion for the WAPA.[17]

Federal power remains close to the cheapest power in any region of the country.[18] Users of federally supplied irrigation water with access to this cheap power are getting

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POWER ARBITRAGE: MAKING A PROFIT OFF SUBSIDIES

The schemes enabled by subsidized power rates can be seen in the Bureau of Reclamation's Columbia Basin Project. The project sells power to irrigators for less than 4 percent of the market rate. To take advantage of this cheap power, some water districts in the CBP have added low-head hydropower generators to their water canals. The cheap energy used to pump water into the canals is then used to help generate hydropower that the irrigators sell at a substantial profit on the open market. According to a report by the Committee on Natural Resources, this practice reduces water conservation incentives even further because every drop of water added to the canals provides more hydropower profits for the district. By allowing what is essentially a power arbitrage scheme, the Bureau of Reclamation has created an incentive for intensive pumping, leading to excess water and energy use and unnecessary environmental impacts, all at the taxpayers' expense.

a double subsidy and are receiving a distorted price signal about the value of that energy. For the Central Valley Project, energy charges vary widely from contractor to contractor. A charge of 1 cent per kWh—which a Central Valley Project representative estimated was the average for the project—is equivalent to $10 per MWh.[19] In comparison to market rate, California has long-term energy contracts for $86 per MWh.

It is difficult to calculate the full value of the subsidies given to users of federally supplied irrigation water. This difficulty helps keep the energy costs of water systems buried. Many California farmers still pay the government $2 to $20 per acre-foot for water, which represents as little as 10 percent of the "full cost" of the water, although some farmers are paying more as contracts are revised (e.g., $35 per acre-foot).[20] For new projects built or proposed by the Bureau of Reclamation, water costs are between $250 and $500 per acre-foot.[21] These water and power subsidies can have perverse results, as illustrated in the box on power arbitrage.

Including energy considerations might eliminate some of the water supply projects currently being considered in California and would more accurately show the benefits of conservation as an alternative.

MISSED OPPORTUNITIES: WATER POLICY OVERLOOKS ENERGY USE

Resource management could improve if water planning and policy reflected the critical link between water and energy. Despite a few recent efforts, however, water planning at the federal, state, and local levels has largely failed to consider energy implications. CALFED, California's Bulletin 160 series, the California Urban Water Management Planning Act, and the Memorandum of Understanding Concerning Urban Water Conservation in California (MOU) all give inadequate attention to the connections between water and energy use and policy. Although CALFED and other agencies have completed many studies that compare the costs of different water supply options, few of these studies have taken into account the energy benefits and costs of different water supply options. This is unfortunate because energy cost is a critical factor in the cost of various water management alternatives. Including energy considerations might eliminate some of the water supply projects currently being considered in California and would more accurately show the benefits of conservation as an alternative.

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Water planners at the state level also have done a very limited job of addressing energy considerations. The California Water Plan, known as Bulletin 160, updates information about current and future water supplies and water uses for all regions of the state, including an evaluation of possible options for meeting California's future water needs. The California Water Code requires that the Department of Water Resources update Bulletin 160 every five years. As recently as 1998, Bulletin 160 did not include energy considerations.

A draft of the 2003 California Water Plan was released in November 2003. For the first time, the water plan included a discussion of the impacts of global climate change on California water resources and policy. It also qualitatively considered energy prices as a factor that could affect future water use, supply, or management. Significant quantitative evaluation of energy issues was not included in the 2003 draft. Phases 2 and 3 of the update (scheduled for 2004 and 2005, respectively) might address energy issues in more detail, with quantification or modeling possible in Phase 3 (2005).

Water planning at the local level generally fails to integrate energy considerations. Under California's Urban Water Management Planning Act, every supplier of urban water to more than 3,000 customers or in quantities greater than 3,000 af/yr must adopt an Urban Water Management Plan and must update it at least every five years. The law requires that the plans contain fairly specific projections of supply, demand, and potential water conservation measures across a 20-year planning horizon. Completed plans are filed with the Department of Water Resources. The Urban Water Management Planning Act does not require water suppliers to consider the energy implications of their water management options or to factor in related energy costs and benefits when considering water conservation measures.

Most major urban water suppliers in California have committed to implementing a series of water conservation practices outlined in an MOU. The cost-benefit analysis required in the MOU does not require consideration of energy, so water suppliers may fail to implement conservation practices that are clearly cost-effective when energy is included (see Table 5 in Chapter 2 for some residential examples of this problem).

Finally, the California Environmental Quality Act requires suppliers to evaluate the potential environmental impacts of all projects, including water transfers such as the recent arrangement between the Imperial Irrigation District and the San Diego County Water Authority. But the energy implications of water decisions are so far below the radar of decision makers that the significant energy impacts of the transfer are not mentioned in the environmental impact report for the project.[22]

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CHAPTER 2

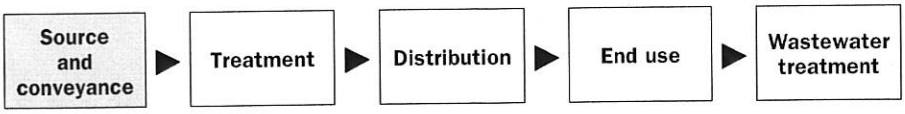
THE CONNECTIONS BETWEEN WATER AND ENERGY

As water works its way from source to tap, it typically requires many infusions of energy. We need energy to move it from its source, treat it, pipe it into businesses, consume it in our homes, and treat it before disposal. While one step in this process might not require a lot of energy—using a low-flow toilet in Los Angeles, for instance—another step may consume a great deal of energy—transporting water 2,000 feet over the Tehachapi Mountains to Southern California.[23] It is only when we look at the energy consumed in the entire water cycle that we get a clear sense of how much energy is really at stake.

This kind of whole-system calculation is called energy intensity. Energy intensity is defined as the total amount of energy required to use a specific amount of water in a specific location.[24] Energy intensity takes into account each site-specific step in the water supply-use-disposal cycle: source and conveyance, treatment, distribution, end use, and wastewater treatment.

Looking at energy intensity reveals that not all water use requires the same amount of energy. For example, since it often takes more energy to convey a gallon of water from outside the region to Southern California than it does to Northern California, saving water in Southern California can achieve greater energy savings. This in turn means that water supply options appropriate for one region of California may not be appropriate for another. To determine appropriate strategies, water planners need to understand and quantify the five components of energy intensity presented below.

SOURCE AND CONVEYANCE



California gets its water from a great variety of sources and locations, and each one relies upon a different method of transport and a different amount of energy use. California's water supply mix is illustrated in Figure 1.[25] At present, surface water and groundwater provide the primary sources of water supply in California. Use of

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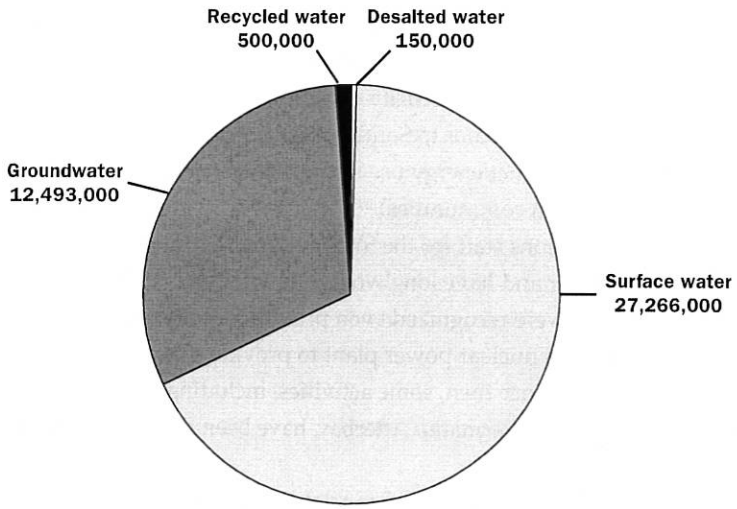
FIGURE 1
Primary Sources of Water in California in Acre-Feet per Year



desalination and water recycling is expanding and could impact the energy used for water supply in some regions.

Surface Water

Surface water makes up about 70 percent, or about 27.3 million acre-feet per year, of water use in California. The majority of precipitation falls in the northern part of the state, while the majority of the population and the majority of water use is in the southern part of the state. Table 1 lists the major projects that transport water from one region to another in California.

These water delivery systems also generate hydroelectric power as water flows through power-generating turbines. Major water conveyance systems are either net energy producers (e.g., Central Valley Project, San Francisco, and Los Angeles aqueducts) or net energy consumers (e.g., State Water Project, Colorado River Aqueduct).

TABLE 1
Major Water Projects and Water Deliveries in California

Project	Average Annual Deliveries (million acre-feet)
Central Valley Project	7
All American and Coachella Canals	3
State Water Project	2.3
Colorado River Aqueduct	1.2
Mokolumne Aqueduct	0.36
Hetch Hetchy Aqueduct	0.33
Los Angeles Aqueduct	0.2
Potter Valley Project	0.154

Source: Association of California Water Agencies and Potter Valley Project Overview

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The State Water Project and the Central Valley Project

The State Water Project (SWP) and the Central Valley Project (CVP) are two of the largest water projects in California and convey water the longest distances. The single largest user of energy in California, the SWP consumes an average of 5 billion kWh/yr, accounting for 2 to 3 percent of all electricity consumed in California.[26] On average, pumping one acre-foot of SWP water to Southern California requires approximately 3,000 kWh (this is an average net energy use figure; actual energy use varies for different Southern California communities).[27]

State and federal operations staff for the SWP and the CVP are well aware of the energy used to move water and have long worked to minimize it. The large energy requirements of the SWP were recognized even prior to its construction. Early SWP plans called for a dedicated nuclear power plant to provide electricity for the lift over the Tehachapi Mountains. Since then, some activities, including operational changes at the Oroville Dam and the Thermalito Afterbay, have been designed to reduce power use.

Both the SWP and the CVP have large financial incentives to reduce energy use. For example, the average SWP annual operating budget is about $900 million, of which at least a third is related to power costs.[28] Efficiency measures implemented by facility operators include:

- *Early water projections and energy purchases:* Each water year, the SWP makes projections for its water deliveries and develops its energy portfolios to ensure it has enough power to make these projected deliveries. Buying the power early in the water year is critical: the SWP makes advance purchases (days, weeks, or months ahead) on the power market because they are much more economical than buying on the spot market.

- *Optimizing pump scheduling:* The energy costs for water systems depend heavily on whether energy is consumed during on-peak or off-peak periods. On-peak energy is significantly more expensive than off-peak energy. Within system constraints, the SWP and the CVP try to take advantage of the price difference by pumping off-peak and generating on-peak.

- *Engineering, repairs, and maintenance:* CVP and SWP representatives say that their projects are constantly refurbishing the system to maximize power generation and minimize power use. This includes evaluating the efficiency of pumps and generators and upgrading technology.[29]

Despite these efforts at energy savings, the CVP and the SWP may become even bigger energy consumers, since both are now considering building new and expanded dams. Our analysis indicates that these new or expanded facilities are likely to be net energy consumers (see the "Can Building New Hydroelectric Dams Consume Energy?" box on page 10 for further discussion of this issue).

Conveyance and Evaporative Water Loss

Water is lost throughout the storage and conveyance process, often through evaporation and seepage as it sits in reservoirs and then travels through canals to water users.

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CAN BUILDING NEW HYDROELECTRIC DAMS CONSUME ENERGY?

The Department of Water Resources and the Bureau of Reclamation are currently investigating five proposed new and expanded surface storage facilities to determine if they are feasible water supply projects. Proponents have cited hydropower production as an additional benefit for some of these projects. Careful analysis, however, reveals that these proposed dams might in fact be net consumers of energy.

Planning agencies often overlook two important energy-related issues regarding new and expanded dam projects: the first is off-stream location. Several of the facilities under consideration (Sites, Los Vaqueros, and some of the proposed sites on the Upper San Joaquin River) are off-stream facilities—constructed not on major streams, but in side canyons. These projects would require pumping water uphill into the reservoir. Energy would be generated when water is released from storage, but each of these facilities would be a net consumer of energy. Another of these proposed projects, the Delta Wetlands project, would be constructed on subsided delta islands. In this case, gravity would fill the reservoir, but energy would be required to pump water back into delta channels and deliver it to the SWP or other users. This facility would also be a net energy consumer.

The second often-overlooked issue is the amount of energy required to deliver the water generated by these new storage facilities. The water generated by new surface storage facilities could go to many water users. The closest potential user, Central Valley agriculture, however, will not be able to afford water from these facilities unless it is highly subsidized.

The other biggest market opportunity for the water is Southern California. But SWP water delivered to Southern California is very energy intensive, with a weighted average requirement for delivery of 2,947 kWh/af.[30] This energy requirement is so great that the energy required to convey this water would exceed the energy generated at the new dam. For example, one of the proposed expansions includes raising Shasta Dam. This is the best-case scenario since it would generate more new energy per acre-foot of additional storage than any other surface storage facility under consideration, both because Shasta is an on-stream reservoir that does not require pumping to fill the reservoir and because raising an existing reservoir generates more hydraulic head than a similarly sized new reservoir. Nevertheless, our analysis suggests that if the yield were delivered to Southern California, this project would result in a net consumption of 380 kWh/af.* In summary, all of the surface storage facilities under consideration by CALFED would be net consumers of energy if the water they generate were delivered to Southern California.

* See Larry Dale, et. al., *The Impact of Electricity Prices on the Cost of Five Options to Increase Southern California's Urban Water Supplies*, prepared for NRDC, 2003.

These losses increase the effective amount of energy required per usable gallon of water. Reservoir losses are not critical from an energy perspective when the reservoir is filled by gravity. But they may be critical if pumping takes place upstream of the reservoir (e.g., the Eastside Reservoir in Southern California) or if pumping is required to fill the reservoir, as in many of the current proposals for off-stream storage in California.

Reducing losses from reservoirs and conveyance systems could add to the available water supply and could generate additional hydroelectric energy. Reducing these losses would also lower the energy intensity of water supplies because it would

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decrease the amount of energy used to transport water that is eventually lost (carriage water). The SWP has not done an analysis of conveyance losses but estimates these losses to be 5 percent.

The CVP has not done an analysis of its evaporative losses either. Instead, its models use assumed conveyance losses for evaporation and seepage south of the delta. CVP operations assume a loss of 150,000 acre-feet out of 3 million acre-feet delivered, or approximately 5 percent.

When comparing imported water to other sources, such as recycling or desalination, a full energy accounting would include the energy required to move water to the point where it evaporates or seeps out of the conveyance system. This energy would be added to the energy required to transport the water actually delivered.

Groundwater

Groundwater represents about 30 percent of the water used in California, or approximately 12.5 million af/yr. This is 1.5 million acre-feet more than is naturally replenished, a pattern referred to as overdraft. Agriculture uses 85 percent of the withdrawn groundwater, and municipal areas use 15 percent. Most is used locally in the area overlying the aquifer.

California does not measure or regulate groundwater withdrawals, so groundwater data are incomplete. Therefore, it is not possible to calculate exactly how much energy is used in pumping groundwater. The California Department of Water Resources has estimated groundwater use and well depths in three areas that represent two-thirds of the groundwater used in the state. In the Tulare Lake Basin, with an average well depth of 120 feet, groundwater pumping requires 175 kWh/af. In parts of the San Joaquin River Basin and the Central Coast region where groundwater depth is closer to 200 feet, pumping requires approximately 292 kWh/af. Based on these estimates, electricity used for pumping groundwater in these areas would average 2.25 billion kWh/yr at a 70 percent pumping efficiency.[31] If this represents two-thirds of the state's groundwater use—and if all groundwater were pumped with electricity—then statewide electrical energy use for groundwater pumping would be approximately 3.4 billion kWh/yr.

In some areas, greater depth to groundwater requires even greater energy use. For example, pumping in Los Angeles requires 580 kWh/af.[32] Staff of the Sweetwater Authority and the Yuima Muncipal Water District in San Diego County report 467 and 661 kWh/af, respectively, are used on average to pump groundwater in their service areas (see Chapter 3). Staff of the Westlands Water District report that groundwater pumping in the district requires an average of 740 kWh/af (see Chapter 4).

Groundwater overdraft is a growing issue in some agricultural areas, like the Central Valley. As groundwater levels decline, an increasing amount of energy is needed to lift that groundwater to the surface. Jointly managing surface and groundwater resources, known as conjunctive use, holds promise as an approach to increasing water supplies in the West. Any analysis of conjunctive use projects must recognize and include the energy costs of retrieving the stored water from groundwater basins. However, if conjunctive use helps to recharge overdrafted

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groundwater basins, it could decrease the average use of energy for pumping groundwater. The California Energy Commission has expressed serious concerns about the CALFED conjunctive use proposals and CALFED's inattention to their energy implications.[33]

Desalination

Ninety-seven percent of the earth's water is too salty to drink or grow crops. However, salt water can be converted to freshwater through a process called desalination. Desalination has been limited in the United States because of its high cost: less than 1 percent of California's current water supply comes from desalination. However, it is a topic of growing interest as technological advances are reducing desalination costs.

The economics of desalination are directly tied to the cost of energy: energy constitutes approximately 40 percent of total costs. There are various methods of desalination, each requiring different amounts of energy. Energy use can vary within methods as well, depending on source water quality and design details.

The most common choice for new desalination plants today is reverse osmosis, in which salty water is filtered under high pressure through a semipermeable membrane. This method accounts for 90 percent of California's current desalination capacity. In 1999, desalination capacity in California was estimated at approximately 150,000 af/yr in more than 150 plants, the majority of which are small industrial plants. The 30 plants that are used for municipal purposes total about 80,000 af/yr.[34]

There are currently about two dozen desalination facilities proposed for along the California coast, with a total output of about 220,000 acre-feet.[35] The California Energy Commission is compiling data to determine how the energy demands of these proposed facilities could affect the state's power grid.

Current energy requirements and total costs for desalination vary widely depending on project specifics. For a seawater desalination plant under investigation by the Municipal Water District of Orange County, energy requirements are estimated at 5,500 kWh/af. The Carslbad seawater desalination project in San Diego County is estimated to use 5,400 kWh/af (see Chapter 3). Even lower energy use may be possible. Staff of Ionics Corporation report the new Trinidad seawater desalting plant will use about 4,800 kWh/af.[36] A proposed seawater desalting plant serving the Inland Empire Utilities Agency would use approximately 4,400 kWh/af.[37]

One of the models for lowering energy costs for desalination is colocating facilities with coastal power plants. Many of these power plants have destructive once-through cooling systems, however, and desalination should not be used to justify extending the life of these harmful facilities. In order for desalination projects—including colocated facilities—to gain acceptance, they will need to demonstrate a net reduction of environmental impacts.

Another opportunity for reducing energy requirements is to use desalination to treat brackish groundwater, which can produce water at a lower total cost and a lower energy cost than ocean desalination. Brackish groundwater treatment has enormously varying energy requirements depending on source water quality. Desalting brackish groundwater at the Chino Desalter Facility requires 1,700 kWh/af, while

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CAN DESALINATION REDUCE ENERGY USE?

While desalination is very energy intensive on a per-unit basis, in some cases the flexibility it allows may result in lower total energy use.

The Marin Municipal Water District faces such an opportunity. The district is considering a desalination facility that would replace part of its contract with the Sonoma County Water Agency. The agency contract requires the district to purchase Russian River water at times of the year in which the water is not needed, in a classic "use it or lose it" arrangement. While the pumping needed to import Russian River water consumes less energy than desalination on a per-unit basis, the district would be forced to buy much more of it than it would need to produce with desalination.

With desalination, the district could shift more to its domestic reservoir supply—the least energy intensive source—in most year types, with desalination available as a dry-year supplement. The district's use of desalination to address peak demands could reduce its overall energy use.

In a dramatically different approach, private companies can also cover the cost of building and operating desalination plants in return for long-term contracts that require water agencies to purchase large volumes of desalinated water. Many Southern California projects are taking this approach. This could require desalination plants to operate at maximum capacity in order to drive down the unit cost, which could increase energy and air quality impacts.

the Reynolds water treatment plant in San Diego County reports only 405 kWh/af for treating brackish groundwater (see Chapter 3).[38] The same technology can be used to clean up groundwater impaired by other contaminants.

While the process of desalination remains expensive as a water supply option, it can have a variety of potential benefits relative to other sources of supply, including:

▸ *Local supply:* Desalination is typically done close to the place of use, so energy requirements for conveyance are likely to be lower than they would be for imported water supplies.

▸ *Reliability:* Desalination makes water available in all water years, while surface water and groundwater supplies may be limited in dry years. This reliability is extremely valuable to urban water users.[39]

▸ *Operational flexibility:* If the water is not needed, a desalination facility can be turned off. This is in contrast to the take-or-pay provisions of some water contracts. For the advantages and potential pitfalls of this approach, see the box on desalination above.

▸ *Water quality:* Desalination can produce very high-quality water, required by some water districts for blending with some of their lower-quality water supplies.

▸ *Potential ecosystem benefits:* Leaving surface water supplies instream and using desalinated water as a partial replacement can generate substantial ecosystem benefits.

Desalination may be a reasonable part of a water supply plan in areas where the energy costs of importing more supplies are high and where alternative water

Desalination makes water available in all water years, while surface water and groundwater supplies may be limited in dry years. This reliability is extremely valuable to urban water users.

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sources could be environmentally damaging. This is particularly true when full life-cycle energy costs are considered along with the benefits of desalination, such as reliability, ecosystem restoration, and water quality.

However, before moving forward with desalination on a large scale, districts must recognize that very little is known about its impact on marine and coastal environments. Few, if any, studies have been conducted on marine resource impacts from the large-scale desalination facilities in the Middle East and Caribbean. The range of potential adverse environmental impacts that may arise from desalination facilities include siting and construction, waste discharge, energy consumption, coastal development, and injury and death of aquatic life from water intakes.[40] These must all be explored and adequately addressed before development of desalination facilities begins. In most cases, conservation or water recycling may offer better, cheaper, and less environmentally damaging alternatives.

Water Recycling

In most cases, conservation or water recycling may offer a better, cheaper, and less environmentally damaging alternative to desalination.

The California Water Code defines recycled water as "water which, as a result of treatment of waste, is suitable for a direct beneficial use or controlled use that would not otherwise occur."[41] By 2020 more than 3 million acre-feet of wastewater will be generated annually by California's urban coastal areas; much of this could be recycled.

Recycled water is most commonly used for groundwater recharge or for landscape or irrigation purposes. While there have been some proposals for direct potable reuse of recycled water, these projects have not been implemented in the United States. Figure 2 shows municipal recycled water use in California in 2000.[42] Recycled water use is currently estimated to be within a range of 450,000 to 580,000 af/yr.[43] In addition to this officially recycled water, hundreds of thousands of acre-feet of treated wastewater are released into rivers and become part of the downstream water supply.

The energy costs for water recycling are the incremental treatment costs required to treat wastewater to the standard necessary for its intended use, and any energy required to convey the water to its place of use. Costs vary depending on the type of project being developed, the degree of treatment required, and the proximity of the water treatment plant to the location where the recycled water will be used.

In 2001, California legislation created a recycled water task force within the Department of Water Resources. The task force was assigned the responsibility of identifying impediments to using more recycled water in California, along with possible solutions. The task force's report was completed in June 2003 and asserts that California could recycle 1.5 million af/yr by 2030, with an investment of nearly $11 billion for additional infrastructure.[44]

Recycled water is already serving as an important element of water supply for many communities. As with desalination, water recycling offers reliability benefits, since it is available even in drought years. The energy costs for recycled water are likely to be lower than the costs for most other supply-side options, including desalination.

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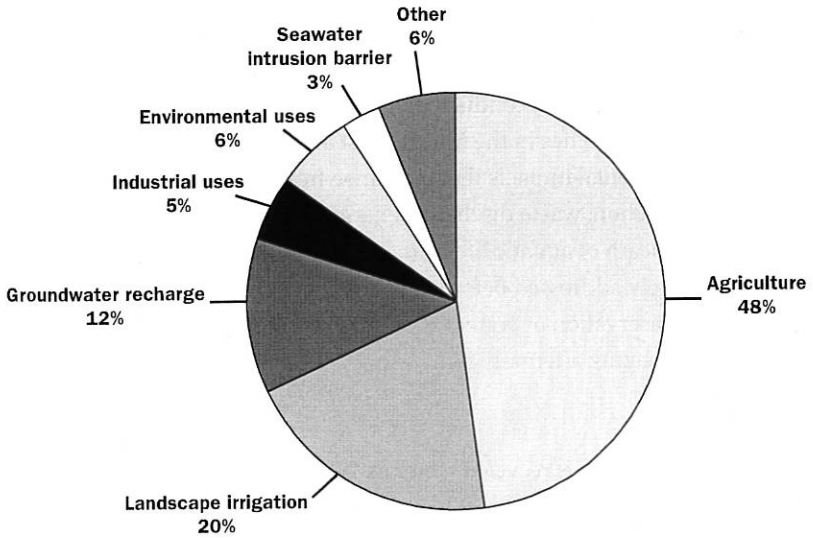
FIGURE 2
Recycled Water Use in California in 2000



The energy costs for recycled water are likely to be lower than the costs for most other supply-side options, including desalination.

The Orange County Water District is constructing a groundwater replenishment system—a water-recycling system that will replace an existing Orange County water recycling facility and will provide a new water supply for the area. Water from the system will be used as a seawater intrusion barrier as well as to augment groundwater supplies. Water costs for that component of the district's supply will be reduced by nearly half, since it will be less expensive to treat as well as produce the water locally than to import water.[45] In particular, producing the recycled water will require only half the energy it takes to bring water to Orange County from Northern California.[46] The system is expected to begin delivering water in 2007.

A few other examples of the many water recycling projects in California include:

▸ A joint project of the Dublin San Ramon Services District and the East Bay Municipal Utility District, in which 2,800 acre-feet of recycled wastewater are used to recharge the aquifer annually;

▸ South Bay and Long Beach, where recycled water is injected into formations that are part of the basin's aquifers to prevent seawater intrusion;

▸ Los Angeles County, where the Central Basin Recycled Water Project delivers approximately 4,000 acre-feet annually to more than 150 industrial, commercial, and landscape irrigation sites;

▸ South Bay Water Recycling in San Jose, which delivers around 16,000 af/yr to landscape irrigation customers;

▸ Monterey County Water recycling projects that provide recycled water for agricultural irrigation.

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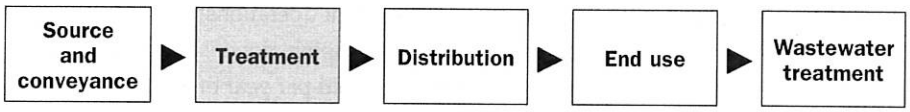
TREATMENT



Treatment is the second stage in the water use cycle, and generally applies only to urban water. The average direct electricity requirement for surface-water treatment plants is 450 kWh/af, with the bulk of that energy going to pump treated water.[47] Since pumping costs are directly related to the volume of water that must be pumped, reductions in demand for treated water will directly reduce this energy use. Energy efficient pumping systems can also make a significant difference in power bills and can reduce demand on energy infrastructure. Opportunities include installing premium efficiency motors and adjustable speed drives, selecting efficient pumps, using effective instrumentation and controls, and managing pumping operations by the efficient use of available storage and highly efficient pumping units.[48]

Data from the San Diego case study (see Chapter 3) confirm that energy for treatment is quite small. The Perdue Water Treatment plant reports using only 41 kWh/af; the Escondido-Vista plant reports 48 kWh/af; and the Levy Water Treatment Plant reports 68 kWh/af.

By reducing peak demand, water conservation can eliminate or delay the need for expanding treatment facilities or decrease the size of the expansion needed.

Most surface water sources require treatment, usually consisting of chemical additions, coagulation and settling, filtration, and disinfection. Urban water suppliers are moving in the direction of more energy intensive treatment methods of disinfection such as ozonation and ultraviolet radiation for health and safety reasons.[49] In many groundwater systems, disinfection is the only treatment required. Physical-chemical processes are used only in those cases where excessive concentrations of specific constituents have to be reduced.

Water treatment facilities are sized to meet peak demands. The lowest demand for water occurs in winter months when the requirements for outside water use are greatly reduced. Peak demand occurs in the summer when consumers irrigate for crops and landscaping. As mentioned in Chapter 1, many of the peak demands for water coincide with the peak seasonal demands experienced by the electrical utilities.[50] By reducing peak demand, water conservation can eliminate or delay the need for expanding treatment facilities or decrease the size of the expansion needed. By decreasing peak demands on the electrical utilities, water conservation can also help avoid power shortages.

LOCAL DISTRIBUTION



Water systems must transport water from the intake source to treatment facilities, then to local storage facilities, and finally to the customer. Most of the energy

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involved in municipal water systems is used for pumping. For a city of 50,000 people, approximately 2 million kWh/yr are required for all plant operations, with more than 1.6 million kWh of that amount needed for the pumping alone.[51] Assuming 2.6 persons per household and 0.5 acre-foot per household per year of water consumption, this pumping-only estimate converts to about 170 kWh/af delivered to customers.

These are average figures. In many cases, energy for pumping is much higher. According to members of the San Diego County Water Authority staff, there is enormous variation in the energy used to distribute water from their treatment plants to customers. Limited data from the San Diego case study support this belief. The Levy-Helix Water District, for example, reports an average of 215 kWh/af to deliver water to its customers; however, half the distribution grid is pressurized by gravity since some treatment plants are significantly elevated above end use locations. The electrically pressurized portion of their distribution system reportedly uses about 430 kWh/af. The distribution system for the North City (San Diego) water recycling facility reportedly uses about 940 kWh/af.

Many urban water distribution systems were placed underground more than 50 years ago, and leaks caused by corrosion of pipe material or other problems can lead to the loss of significant amounts of potable water. Distribution system losses increase the energy intensity of water supply by requiring utilities to treat and convey water that will be lost. Losses vary significantly among urban suppliers: typically from 6 to 15 percent, but as high as 30 percent.[52] Approximately 2 percent of this lost water goes to unmetered use for firefighting, construction, and flushing drains and hydrants.

One approach to improving management of local distribution and reducing energy costs involves using a supervisory control and data acquisition (SCADA) system. The SCADA system consists of a central computer that integrates the operation of water-system control points, such as pumps, reservoirs, and metering stations, even when located far away from one another.

Fresno installed a SCADA system in 1988. The SCADA system saves Fresno $725,000 per year in energy and water costs by doing the following:[53]

- Continuously monitoring the pumping energy required for each gallon of water that every well produces;
- Turning on the pumps at the most cost-effective wells first;
- Selecting wells according to optimum time-of-day electrical rates;
- Providing better control of water-line pressure, which reduces leakage.

With the SCADA system continuously monitoring and managing the pumps, Fresno saves energy and money both by reducing the energy consumed by the pumps and by saving water that previously was lost to leakage. While many urban districts use SCADA systems, not all systems are being operated to reduce energy use. Some agricultural districts are also installing SCADA systems and variable frequency motor drives that are more efficient under partial loads, allowing them to save both water and energy.[54]

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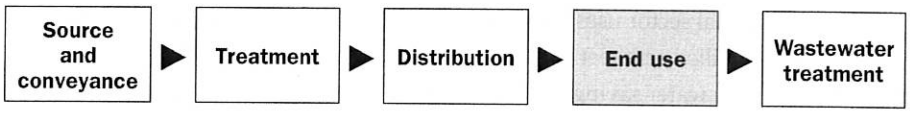
THE END USE OF WATER



Once a customer receives water, additional energy may be needed to heat, cool, purify, or pump that water in preparation for its intended use. Changes in the amount or quality of water needed for some of these uses can further increase the amount of energy consumed in the process. The literature on water use contains little information on energy use integral to water end use beyond domestic fixtures and appliances. The San Diego case study (Chapter 3) and to lesser extent the Westlands and Columbia case studies (Chapters 4 and 5) evaluate this issue to the extent possible given the resources available for this report. This is an area of great significance for future research and energy and water policy.

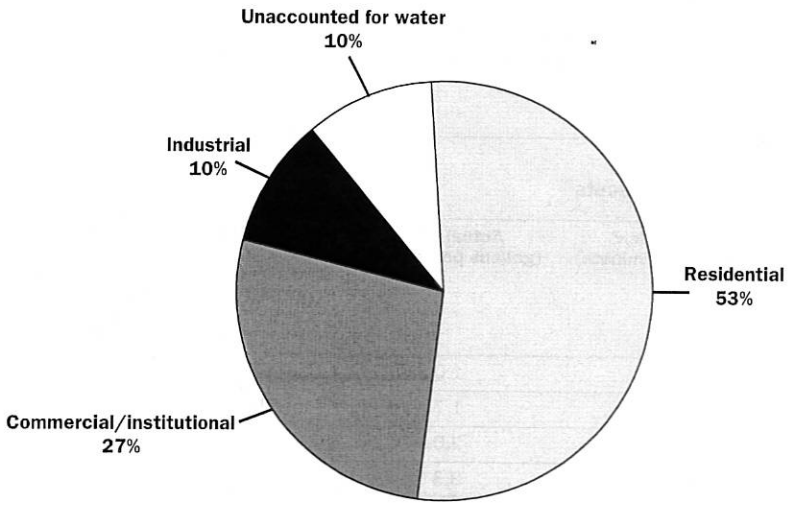
While there are efficiency improvements that can reduce the energy inputs required at each stage of the water use cycle, the greatest energy and water savings come from reducing water consumed by various end uses. Conservation at the end use stage eliminates all of the "upstream" energy required to bring the water to the point of end use, as well as all of the "downstream" energy that would otherwise be spent to treat and dispose of this water.

Conservation at the end use stage eliminates all of the "upstream" energy required to bring the water to the point of end use.

Urban Water Use

California urban water use in 2000 was approximately 7 million acre-feet.[55] Urban use is typically divided into residential and nonresidential use, with nonresidential use further divided into commercial, industrial, and institutional uses (CII). The breakdown of urban water use in California is illustrated in Figure 3.

FIGURE 3
Urban Water Use in California



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Residential Water Use

California's residential sector uses almost 4 million af/yr. A new study found that approximately 1.4 million acre-feet of this use could be saved with existing cost-effective technologies.[56] These water savings would also provide substantial energy savings from avoided conveyance, treatment, distribution, end use, and wastewater treatment.

Hot Water Use

A study of 1,200 homes in 14 cities looking at residential water use found that the top four indoor uses were:[57]

- Toilet (26.7 percent);
- Clothes washer (21.7 percent);
- Shower (16.8 percent);
- Faucet (15.7 percent).

Energy use and savings from the latter three items on this list, which all use hot water, are presented in Tables 2 through 4.[58] Savings from toilets are discussed separately below.

Conserving water from some hot-water-using devices may not be cost-effective when water savings are considered alone. But as Table 5 demonstrates, the measures are very cost-effective when energy savings are included.[59] Where the table indicates

TABLE 2
Estimated Energy Use by Showerheads

	Rated Flow (gallons per minute)	Actual Flow (gallons per minute)	Estimated Energy Use per Household* (kWh/yr)	Estimated Savings per Household with a 2.5 gpm showerhead (kWh/yr)
1994–present	2.5	1.7	1,128	
1980–1994	3.0	2.0	1,328	200
1980–1994	4.0	2.7	1,793	665
Pre-1980	5.0–8.0	4.3	2,855	1,727

*Assumes 5.3 minutes per person per day; 2.64 persons per household; 0.13 kWh of electricity per gallon of water at 106 degrees.

TABLE 3
Estimated Energy Use by Faucets

	Rated Flow (gallons per minute)	Actual Flow (gallons per minute)	Estimated Energy Use per Household* (kWh/yr)	Estimated Savings per Household with a 1.5 gpm Faucet or Aerator (kWh/yr)
1994–present	1.5	1.0	445	N/A
1994–present	2.5	1.7	756	311
1980–1994	3.0	2.0	890	445
Pre-1980	3.0–7.0	3.3	1,468	1,023

*Assumes 8.1 minutes per person per day; 2.64 persons per household; 0.057 kWh per gallon of water at 80 degrees.

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TABLE 4
Estimated Energy Use by Clothes Washers

	Water Use (gallons per minute)	Energy Use (kWh per load)	Estimated Energy Use per Household* (kWh/yr)	Estimated Savings per Household with a 27 gpm Clothes Washer (kWh/yr)
1998–present	27	1.6	632	N/A
1990–present	39	3.0	1,185	553
1980–1990	51	3.9	1,540	908

*Assumes 0.41 loads per person per day; 2.64 persons per household. Applies only to households with clothes washers.

TABLE 5
Accounting for Energy Benefits from Indoor Residential Water Conservation

	COST OF CONSERVED WATER (DOLLARS PER ACRE-FOOT CONSERVED)	
Device Installed (natural replacement)	Without Energy Benefit	With Energy Benefit
2.5 gallon-per-minute showerhead	$324	–$736
Average high-efficiency clothes washer (includes vertical and horizontal axis machines)	$865	–$177
Average high-efficiency dishwasher	$862	–$102

negative costs of conserved water, energy savings alone more than pay for the conservation investment.

Federal and state programs to promote market transformation, along with state and local rebate programs, can accelerate the adoption of these technologies.[60]

Cold Water Savings

Toilets and landscaping account for the two largest residential uses of water. Both use cold water and do not require significant end use energy. However, conservation of cold water can still save upstream and downstream energy inputs. Pacific Gas & Electric estimates that conveyance, treatment, distribution, and disposal energy requirements average 1,788 kWh/af statewide.[61] These requirements are much higher in Southern California, where conveyance alone averages close to 3,000 kWh/af.

Toilet flushing represents the largest single use of water inside the home. While older toilets use as much as 6 gallons per flush, federal and state water-efficiency laws now standardize flush volumes at a maximum of 1.6 gallons per foot for all new toilets. Many water utilities in California have conserved significant quantities of water by installing ultra low-flow toilets. Statewide, however, there are significant additional savings still available from ultra low-flow toilet retrofits.[62] Ultra low-flow toilets do not save end use energy because toilets don't use hot water, but they can save conveyance, distribution, and treatment energy.

Landscape water use represents approximately 40 percent of residential use in California. A recent study estimates that California residents could save from

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25 to 40 percent of their landscape water use by improving management practices and applying already existing technology, such as rainwater cisterns and gray-water systems that reuse household wastewater for irrigation. These savings could be achieved relatively quickly and would reduce water use by 360,000 to 580,000 per year.[63]

One potentially effective way to target landscape water use is through rates. More than 2 million California residents are charged a fixed rate for water usage. This system fails to reward those who conserve and punish those who waste. Fixed rates are usually used when meters have not been installed. Lack of meters in turn allows leaks to go undetected. Data show that per-capita water use is about one-third less in areas where water users are billed based on volumetric rates rather than fixed rates. Metering is one of the most basic and effective water conservation tools. Recent legislation requires some unmetered cities in California to install water meters and bill water users on the basis of water use, and proposed legislation (AB 2572, Kehoe) would address the remaining unmetered cities.

Commercial/Industrial/Institutional Water Use

California's commercial, industrial, and institutional (CII) sector accounts for more than 30 percent of urban water demand, or around 2.5 million acre-feet.[64] More than 50 percent of the total CII water use is for cooling and heating, which requires energy inputs.[65] Recent studies estimate that cost-effective conservation could reduce CII water use by 15 to 50 percent.[66] In California, a recent study estimates that the CII sector could save 39 percent of the water it uses, which would correspond to statewide savings of 1 million acre-feet.[67]

Data show that per-capita water use is about one-third less in areas where water users are billed based on volumetric rates rather than fixed rates.

Commercial customers often have the same water needs as residential users, e.g., toilets, sinks, laundries, kitchens, and landscaping. The most frequently used commercial conservation measures include plumbing fixtures and appliance retrofits or replacement and more efficient landscaping. Institutional customers, such as schools and universities, hospitals, government buildings, prisons, and military installations, primarily use water for heating and cooling, domestic uses, and landscape irrigation.

Industrial water use primarily falls into five categories:

- Cooling and heating
- Industrial processing
- Washing
- Adding as a direct ingredient
- Landscaping

Data on water-related energy use in industry are scant. The Department of Energy asks manufacturers to report energy information on many end uses, but water treatment (e.g., heating, cooling, treating water) is not one of the end uses. Instead it gets embedded into broader end use categories. This makes it difficult to estimate industrial water-related energy use.

The most common conservation measures used in the industrial sector include site-specific engineering modifications of water-using equipment and processes.[68] Despite the potential for large savings in the CII sector, a study done for the American

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DISHWASHERS AND WASHING MACHINES: HOW AN INCREASE IN ENERGY INTENSITY CAN STILL LEAD TO OVERALL ENERGY SAVINGS

Energy intensity measures the amount of energy used per unit of water. Some water sources are more energy intensive than others; for instance, desalination requires more energy than wastewater recycling. Water conservation technology may either increase or decrease energy intensity.

Yet when water planners make decisions, they should look not just at energy intensity, but also at the total energy used from source to tap. In the case of water conservation, some programs may consume a lot of energy at one stage in the energy-water-use cycle, but still decrease the amount of energy used overall. The following three examples illustrate the interplay between energy intensity and total energy use.

Water conservation may increase energy intensity and increase total energy use. A particular irrigation technology could reduce water use by 5 percent, but require so much energy to operate that it increases the energy intensity per acre-foot of water by 10 percent. This could increase total energy use by 4.5 percent.

Water conservation may increase energy intensity and decrease total energy use. The average high-efficiency dishwasher increases the energy intensity of dishwashing by 30 percent, but it reduces water use by 34 percent. As a result of using less water—and therefore less energy to convey water from the source to the dishwater—the net total energy needed to wash dishes would decline by 14 percent.

Water conservation may decrease energy intensity and decrease total energy use. The average high-efficiency clothes washer reduces water use by 29 percent, as compared with average low-efficiency machines, and simultaneously lowers energy intensity by 27 percent. Energy intensity declines because mechanical aspects of the machines (agitators, etc.) are also improved. By reducing total water use and energy intensity, total energy use is reduced by 48 percent.

Water Works Association Research Foundation found that certain types of large water-using facilities such as correctional facilities, military bases, and utility systems have been ignored by many audit programs and have thus not received recommendations for conservation measures. The study further noted: "improved coordination and cooperation among water, wastewater, and energy utilities are needed to realize the water efficiency potential in the CII sector."[69]

Landscape water use represents the single greatest use in the CII sector. In 2000, 38 percent of CII water use in California was used for landscape irrigation.[70] A recent study estimates that it is possible to reduce this water use by 50 percent.[71] One important tool for achieving these savings is better management of landscape water use. Frequently, the same meter is used to measure a property's indoor and outdoor water use. In these complex mixed-use situations, it may be difficult to even know how much water is being applied to the landscape. Proposed legislation (AB 2298, Plescia) would require a dedicated landscape meter for new construction with more than 10,000 square feet of irrigated acreage and for existing properties with more than one acre of irrigated landscape. This would enable water agencies to establish water budgets for these large landscapes and to target landscape water waste with appro-

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priate rate structures. Dedicated landscape meters would also enable landscape managers to better ensure the efficiency and proper functioning of irrigation systems.

Urban Conservation

Since end use appears to consume the most energy in the water-supply-use chain, water conservation programs hold enormous energy conservation potential. Much of the urban water conservation occurring in California is driven by national and state efficiency standards for certain water appliances and by the Memorandum of Understanding Regarding Urban Water Conservation in California (MOU)—an agreement signed by most of the large urban water suppliers in California outlining a series of water conservation best management practices. The MOU and the California Urban Water Conservation Council (composed of signatories to the MOU) deserve much credit for advancing urban water conservation in California.

Nevertheless, significant conservation potential remains beyond what the MOU requires.

- The MOU does not require agencies to implement all cost-effective conservation strategies, but rather specifies levels of implementation (i.e., percentage of customers to be audited or number of toilets to be replaced).

- The Urban MOU has minimal requirements for CII water use, demanding only that utilities survey and offer incentives to 10 percent of their CII customers, and to achieve 3 percent CII water savings through implementation of a CII ultra low-flow toilet program by 2004.

- Because the Urban MOU targets a limited number of customers for landscape audits, even full implementation of the MOU will probably generate only a small portion of these total potential landscape water savings.

- The MOU pays scant attention to energy. For example, MOU signatories are not required to include energy savings when determining if a best management practice is cost-effective.

The neglect is mirrored by the energy utilities, which pay little attention to saving water. The only water-saving elements typically included in energy conservation programs are those that save hot water. This is unfortunate because, as noted throughout this report, saving even cold water can save significant amounts of energy, depending on the source of that water.

Some energy utilities have noted the link between water and energy use and have targeted their public messages accordingly. Public education materials from the Sacramento Municipal Utility District note: "a tremendous amount of electricity is used to run the pumps that obtain, purify, and bring water to your house and then transport wastes to your regional wastewater utility. To help reduce this energy use, the Sacramento Municipal Utility District and the Sacramento Area Water Works Association ask that you avoid using large amounts of water during the peak energy demand hours of 11 A.M. to 7 P.M."[72] Unfortunately, this approach is still the exception.

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In sum, while energy savings are possible at all stages of the water supply cycle, water conservation programs may be the most cost-effective way of reducing the total energy involved in urban water use. In particular, programs aimed at reducing water use in areas with energy intensive supplies may yield the most cost-effective water and energy savings.

Agricultural Water Use

Agriculture uses approximately 80 percent of the developed water supply in California. In 1995, this amounted to almost 34 million acre-feet.[73] In 1995, California agriculture used approximately 4.4 billion kWh of electricity for groundwater pumping and irrigation purposes, and more than 11 billion kWh for all purposes.[74] Ninety percent of all electricity used on farms is used for groundwater pumping.[75]

For agriculture south of the delta, significant energy may be required for conveying surface water supplies, and reducing water use can translate into energy savings. For agriculture in some other regions of California, such as the Sacramento Valley, surface supplies are gravity fed and reducing surface water use will not translate into saving conveyance energy. Yet even in these areas, improving water use efficiency may save energy by decreasing groundwater pumping and reducing energy required for local distribution. However, in some cases, energy savings from reduced surface water deliveries or reduced groundwater pumping may be partially or fully offset by increased energy requirements of some water-efficiency technology.

Given the proper price signals—especially elimination of subsidies—farmers may shift to lower-water-use/higher-value crops.

Improving the efficiency of irrigation systems through better water measurement and irrigation scheduling, installation of micro-irrigation systems, tailwater recovery systems, and other measures can reduce agricultural water use on farms. [76] In addition to improving irrigation efficiency, farmers can also reduce water use by shifting to lower-water-use crops. While crop choice is made based on a wide variety of factors, resource costs play a significant role. Given the proper price signals—especially elimination of subsidies—farmers may shift to lower-water-use/higher-value crops. For example, a 1992 California Energy Commission report to the state legislature found that agriculture's response to the seven-year drought and changes in energy rates "was to shift production from low-value to high-value crops (e.g., from alfalfa to tomatoes). Even with higher costs, the agricultural economy was robust and these high-value crops were able to absorb those costs."[77]

Dry years present a particular challenge for both water and energy systems: demands are greater while supplies are reduced. In dry years, water systems generate less power. Not only does less water run through the turbines in powerhouses, but also the lower reservoir levels reduce the water pressure and thus reduce the power produced by a given amount of water. Unfortunately, dry years tend to result in increased power demand. During dry years, water systems will need to pump more water—and therefore consume more energy—because irrigators (and other consumers) are getting less water from rainfall. Also, in low water years, farmers are more likely to rely on groundwater pumping, which increases the demand for power.

A voluntary program of compensated dry-year fallowing of agricultural lands could generate a substantial dry-year water supply. However, depending on the source and

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disposition of the transferred water, these programs may not save energy. Quantified examples of the potential energy and water benefits or costs of permanent or dry-year land-retirement programs are provided in the Westlands Water District (Chapter 4) and Columbia Basin (Chapter 5) case studies. As discussed in the Columbia River Basin case study, such programs can provide significant benefits to the agricultural economy.

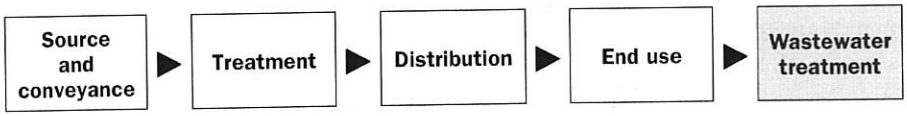
Agricultural Water Conservation

California currently lacks a comprehensive program for agricultural water use efficiency. Agricultural water users established the Agricultural Water Management Council, which developed a list of best management practices, but environmental groups have been critical of the council's process because it fails to adequately address water measurement, and it relies on a purely voluntary approach. Only four water management plans were submitted to the council last year.

CALFED's efforts to develop an agricultural water-use efficiency program have also been a disappointment. CALFED staff worked with environmental and agricultural stakeholders and agency representatives to identify specific benefits related to water flow, timing, and quality that can be achieved through agricultural water use efficiency, and to establish quantifiable objectives for the portion those benefits for which agriculture should be responsible. This program could allow for inclusion of energy costs and benefits, although inclusion of energy costs is not currently required in the cost-benefit analysis that must be submitted with project proposals.

Unfortunately, the task of implementing the CALFED Agricultural Water-Use Efficiency Program has been passed on to the Department of Water Resources, where it languishes. Updating quantifiable objectives is supposed to be an ongoing process, yet no additional objectives have been developed or refined since the program was given to the department. There is no process in place for evaluating progress toward meeting quantifiable objectives. CALFED has not even initiated its required three-year evaluation of progress toward meeting quantifiable objectives. The program never adopted any enforcement mechanisms or consequences for not meeting the program objectives.

WASTEWATER TREATMENT



Wastewater systems generally include three components: collection systems (sewers and pumping stations), treatment facilities, and effluent disposal or reuse. Collection and disposal or reuse require energy for pumping, while treatment requires energy for pumping, running treatment operations, and processing solids. In 1995, wastewater treatment in California used approximately 1.6 billion kWh of electricity.[78] Given California's continued growth, current energy use for wastewater treatment is likely to be significantly higher.

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TABLE 6
Energy Use in Wastewater Treatment

Treatment	1-mgd facility (kWh/af)	100-mgd facility (kWh/af)	100-mgd facility with energy recovery (kWh/af)
Trickling filter	580	225	130
Activated sludge treatment	750	340	225
Advanced treatment	865	400	280
Advanced treatment with nitrification	980	520	400

Estimates of the energy used in water treatment depend on facility size, type of processing, and efficiency. Some facilities (typically larger facilities) recover energy from biogas combustion, which reduces their net consumption. Average energy use is illustrated in Table 6.[79]

Frank Burton conducted a study computing a weighted average over the range of facility sizes and estimates the following net energy requirements: 440 kWh/af for activated sludge, 501 kWh/af for advanced wastewater treatment without nitrification, and 640 kWh/af for advanced wastewater treatment with nitrification. The study estimated that by 2008, 50 percent of U.S. wastewater treatment capacity would include nitrification.

Energy used for wastewater plants in the San Diego case study (see Chapter 3) ranged from 816 kWh/af for the Santee Basin plant to 1,272 kWh/af for the North City (San Diego) plant. Variation may be wider than these numbers suggest since all water from the Santee Basin plant is reused either in recreational lakes or for irrigation after treatment to tertiary standards.

Water conservation can reduce the energy required for treating wastewater and can eliminate the need for new or expanded facilities. The 1996 Clean Water Needs Survey submitted to Congress by the Environmental Protection Agency identified more than $139 billion in capital costs for water quality projects and other related work eligible for funding through state revolving funds established under the Clean Water Act. Close to $100 billion of this amount is flow-related and could be delayed or reduced through water conservation.

Water conservation can also reduce wastewater treatment operating costs. In Orange County, California, conservation-induced reductions in wastewater flows generated energy savings in collection systems pumping, influent pumping, aeration, and outfall pumping. Taken together, these energy savings amounted to $11,047 per year for each million gallons per day of reduced flow. These savings are equivalent to about $10 per acre-foot of reduced flow. Capital costs savings were estimated to be worth more than 10 times this amount for the Orange County system.[80]

ADDITIONAL ENERGY IMPLICATIONS OF WATER POLICY

This chapter has focused on the energy embedded in water use—the energy directly applied during the five stages of the water use cycle through activities such as

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pumping, heating, and cooling. However, the energy implications of water policy extend far beyond the energy embedded in water. For example, if a water allocation decision results in a factory closure, the factory would save both the energy embedded in water use and any other energy required for operating the facilities, such as heating, lighting, and industrial processing. The implications of a water policy decision may include changes in embedded energy use, as well as changes in other types of energy use.

In agriculture, water policy decisions may affect the amount of water applied to a field, and the energy required to obtain and apply that water. Savings from these changes represent the embedded energy component. In addition, water policy decisions that result in altered crop patterns may affect the amount of energy required for harvest, cultivation, and processing. These changes represent additional energy implications of the policy.

In situations where water for irrigation is diverted upstream of hydropower generation facilities, deciding to irrigate means deciding to forego hydropower generation. This lost hydropower generation is not included when calculating the amount of energy embedded in water, yet these hydropower opportunity costs are also energy implications of water resource decisions. (Chapter 5 explores these additional energy implications in the Columbia River setting.)

This report has focused so far on energy embedded in water. But additional energy implications can be quite significant. While a complete analysis of the full energy implications of water policy decisions is beyond the scope of this report, for illustration purposes, we do analyze some of the additional energy implications of the specific water policy decisions discussed in the case studies.

Where water for irrigation is diverted upstream of hydropower generation facilities, deciding to irrigate means deciding to forego hydropower generation.

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CHAPTER 3

SAN DIEGO COUNTY—ENERGY AND URBAN WATER

Like many California water agencies, the San Diego County Water Authority (SDCWA) is attempting to find additional water sources to meet its current and projected water demands. SDCWA staff estimate that at least an additional 100,000 af/yr of end use water will be required in 2020. Efforts to develop these supplies are well under way. However, analysis of supply alternatives historically has neglected consideration of energy implications. This chapter illustrates the type of results SDCWA would obtain if they analyzed supply choices from an energy perspective.

The preliminary results of our San Diego analysis indicate that:

- End use constitutes the largest component of energy embedded in the urban water-use cycle.
- Conservation and recycling appear to be the most energy efficient sources of water if local surface supplies are not available.
- Water supply decisions can significantly affect energy use. These energy implications warrant inclusion in water supply planning and other water management policy decisions.

A MODEL FOR QUANTIFYING ENERGY IN WATER USE

This chapter introduces a spreadsheet model systematically quantifying the energy use implications of water management decisions in an urban setting. This tool can help policymakers throughout the western United States to better understand the energy implications of their water demand management and water supply decisions. Chapters 4 and 5 apply the model in two agricultural settings: the Westlands Water District in California's Central Valley and Washington's Columbia Basin Project.

The model tracks the energy inputs for the five stages of the water use cycle.[81] This allows planners and policymakers to manipulate these inputs and predict the energy impacts of different water policy choices, such as constructing a desalination facility or implementing a water conservation program. A discussion of the methodological

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issues involved in constructing this model is presented in the box below. The full model is presented in Appendix A.

The case studies include enough specific data to reach some policy conclusions. They also help to identify areas where future research would be most worthwhile. Readers are cautioned that the case studies are illustrations of our methods, not full implementations of them. The methods require more location-specific information than could be assembled with the resources available during preparation of this report.

The San Diego case study illustrates how one can evaluate the energy implications of water policy decisions in an urban setting. The data sources, and assumptions used

METHODOLOGICAL ISSUES

As in all modeling efforts, there is a boundary question about which energy inputs should be included or excluded from the energy intensity estimates. We include energy used directly in managing water, e.g., pumping, heating, cooling, pressurization, and treatment. The method in this report is not a life-cycle analysis that accounts for indirect energy use such as the energy needed to manufacture and install a water pipeline.

For simplicity, the analysis only lists energy inputs that would change across water policy decisions. For example, the method does not quantify hydroelectric production in the State Water Project or Central Valley Project facilities prior to water intakes in the San Joaquin Delta, and it does not quantify gasoline or diesel fuel used to service these facilities. The policy decisions analyzed in this report would have little impact on these energy uses, so they are excluded.

The method uses water delivered to customers as the denominator of our energy intensity ratios. A qualitative definition of energy intensity is the amount of energy used per unit of water. Because water losses occur in the supply-use-disposal chain, however, there is more than one way to quantitatively define energy intensity. An acre-foot of water diverted by the State Water Project might yield only 0.95 acre-feet of water delivered to a water treatment plant because water evaporates and leaks from aqueducts and canals. If moving that amount of water were to take 100 kWh of energy, one could say that the energy intensity is either 100 kWh/af or 105.3 kWh/af (100/0.95). This same logic applies throughout the supply-use-disposal chain. One must choose water quantities at some point in the chain to use as the denominator in all of the energy intensity calculations in the chain in order to have consistent and meaningful results.

The method treats energy use as linear in the quantity of water transported or used. This is clearly not true at the scale of individual pumps because pumps are more efficient when operating near full capacity. They will use more energy per acre-foot lifted if they are running at half capacity. The linear assumption is often accurate, however, at larger scales because one of several pumps in a bank of pumps can be turned off or on in order to pump less or more water.

Not all energy used to pump or transport water is electric energy. For example, diesel fuel is increasingly used to pump water on farms, and natural gas is typically used to heat water in urban settings. The energy measure in this report is equivalent kilowatt-hours, which is the sum of actual kilowatt-hours and fossil-fuel use converted to kilowatt-hours. The conversion assumes that the fuels were used in thermal power plants to produce electricity.

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in the San Diego case study, are listed in Appendix B. The data, however, may not be representative enough of the entire SDCWA service area to support final policy decisions on some issues.

THE SAN DIEGO CONTEXT

We chose San Diego County for our urban-water-supply case study because it involves a wide range of actual and potential water sources and conservation opportunities. The SDCWA is a regional water wholesaler that has been operating since 1944. It purchases water from the Metropolitan Water District of Southern California to sell to 23 member agencies located within the western third of San Diego County (920,000 acres; 1,437.5 square miles) and serves nearly 3 million residents. The water needs of the member agencies and their retail customers are diverse since the agencies consist of six cities, four water districts, eight municipal water districts, three irrigation districts, a public utility district, and a federal military reservation.

The average annual raw water supply in the SDCWA service area for 1996 through 2000 was approximately 685,000 acre-feet. Average annual raw water supplied by the SDCWA in 2020 is predicted to increase to about 810,000 acre-feet. Because water is lost in conveyance, treatment, and distribution, water currently delivered to customers is around 610,000 af/yr, while projected deliveries in 2020 are about 710,000 af/yr.

Key Water Supply Facts

- The Metropolitan Water District obtains water for the SDCWA from the Colorado River Aqueduct (about 470,000 af/yr) and the State Water Project (about 83,000 af/yr) and delivers it to the SDCWA at the boundary of Riverside and San Diego counties.
- Water is delivered from the SDCWA to its member agencies through two gravity-fed aqueducts containing five large-diameter pipelines (274 miles total).
- Water is delivered from the member agencies to retail customers via approximately 7,800 miles of pipeline.
- The local groundwater provides about 30,000 af/yr. One groundwater source is brackish and is treated to potable standards.
- Wastewater recycling provides about 18,000 af/yr.
- Surface water reservoirs are primarily used as terminal storage for imported water.
- The local surface water supply is about 86,000 af/yr.

Water in three of the five principal SDCWA pipelines is treated outside the county at the Metropolitan Water District's Skinner Water Treatment Plant in Riverside County. The SDCWA member agencies also operate 10 raw water treatment plants. Most water delivered by member agencies is treated potable water. The exceptions are recycled wastewater and untreated—raw—water provided for agricultural

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purposes. Member agencies operate 14 wastewater treatment plants and 24 water recycling facilities.

The SDCWA has encouraged water conservation and investments in end use efficiency, both directly and through membership in the California Urban Water Conservation Council—the implementing agency for the Memorandum of Understanding for Urban Water Conservation in California. The SDCWA also recognized that energy and water savings can occur together and began a successful partnership with San Diego Gas and Electric, the regional energy supplier, over 10 years ago. Since the collaboration began, more than 550,000 low-flow showerheads have been installed. Over five years ago, SDCWA partnered with San Diego Gas & Electric to offer financial incentives for installing horizontal-axis clothes washers.

THE SEARCH FOR ADDITIONAL WATER SOURCES

To supplement its current water supplies and plan for the future, the SDCWA has been working for years to arrange a 75-year water transfer agreement with the Imperial Irrigation District, located in southeastern California. The final transfer agreement, signed on October 16, 2003, calls for the SDCWA to receive up to 200,000 af/yr of water. Deliveries will ramp upward during the term of the agreement, providing an average of about 143,000 af/yr over the life of the agreement. The SDCWA will provide the Imperial Irrigation District with up-front payments of $20 million and payments for the transferred water starting at $258 per acre-foot and increasing each year, according to a set price schedule. Additional costs will be incurred to "wheel" this water to San Diego.

The SDCWA also recognized that energy and water savings can occur together and began a successful partnership with San Diego Gas and Electric, the regional energy supplier, over 10 years ago.

In its Regional Water Facilities Master Plan of 2000, the SDCWA identified reducing its dependence on imported water in general and its dependence on water imported from the Colorado River in particular as critical to making its water supplies more stable and reliable. Toward this end, the SDCWA has attempted to diversify and expand its local sources of water, specifically targeting seawater desalination as the preferred alternative.

The SDCWA has considered developing a seawater desalination facility at Encina, which would be constructed adjacent to the Encina Power Station. This project would be the largest seawater desalination plant in the Western Hemisphere, producing 50 million gallons per day (56,000 acre-feet annually) of fresh water. The project is similar to other reverse-osmosis facilities being constructed around the world, including new operating plants in Florida and Trinidad. This new water source would supply up to 8 percent of the region's water needs.

In addition to developing the Encina facility, the SDCWA is evaluating other coastal locations that may be suitable for a regional seawater desalination facility. For example, the SDCWA is currently evaluating the feasibility of a desalination plant adjacent to the South Bay Power Plant in Chula Vista. Other coastal sites being evaluated include the San Onofre Nuclear Generating Station at the north end of San Diego County and sites as far south as the Mexican border.

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SDCWA is not investigating or supporting any project to import water via ocean-going water bags towed by tug from Northern California or other points north. Nonetheless, the analysis includes an evaluation of water-bag supply to San Diego County as an interesting point of comparison with long-distance transport in canals and pipes. Readers should not construe inclusion of an alternative in this report as an endorsement by the authors or as a comment on the feasibility or appropriateness of any alternative.

RESULTS OF THE CASE STUDY

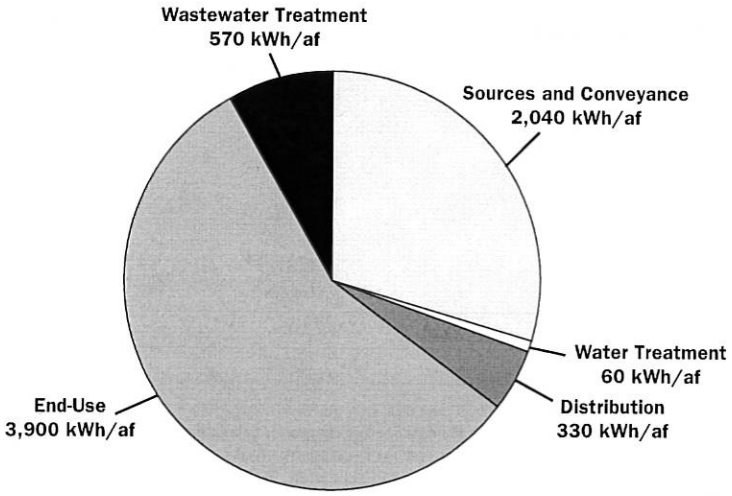
The SDCWA was able to provide some data for all five steps in the water-supply-use-disposal chain. Data from other locations were then used to supplement the analysis when San Diego data were not available. Consequently, the results of the case study analysis should be interpreted cautiously. Remember that the case studies demonstrate the methods and the importance of applying them, but they are based on limited data. Care should be taken in relying on this case study for final decision making until the data sources and assumptions are verified or modified appropriately.

End Use Energy Dominates the Water Use Cycle

Our research revealed that the end use of San Diego's water—heating it for showers, for instance, or pressurizing it for car washes—consumes by far the most energy in the whole water delivery chain. This is a rather striking result given that San Diego County imports most of its water from long distances, requiring large amounts of energy for conveyance.

Figure 4 describes the distribution of estimated total energy use per acre-foot (6,900 kWh) among the five components of the supply-use-disposal chain. Energy use that is integral to end use of water dominates the total.

FIGURE 4
Estimated Energy Intensity Components of Water in San Diego County



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The relatively large amount of energy associated with end use is composed of three types. First, water is sometimes heated for use—for example, for taking showers in homes, for washing dishes in restaurants, or for manufacturing in some industrial facilities. Second, water is sometimes recirculated, pressurized, or lifted in use. Examples include cooling towers, recirculating hot water loops in newer residences, additional pressurization in high-rise buildings, and irrigation pipe pressurization or lifts from canals on farms. Finally, some energy use comes in close conjunction with water use, and may increase or decrease when water is conserved, but is not directly embedded in water. For example, energy is used to run air conditioning compressors that are water-cooled.

The summary number for estimated energy use integral to water end use shown in Figure 4 is presented in more detail in Table 7.[82] The energy intensity estimates are based on the data and assumptions listed in the table notes and are more fully described in Appendix B. Zeros are used when energy use is implausible. "Not Estimated" means data were inadequate to support a credible estimate. The numbers in the table are not significant to the digits shown, but are presented this way to facilitate comparison with other tables and figures.

The estimates in Table 8 probably understate energy use integral to water use because data on water-related energy use in the commercial, industrial, and

TABLE 7
Estimated Energy Use Integral to Water End Use in San Diego County

Water Use Category	Estimated Percent of Total Use in 2010 (8)	Estimated Energy Intensity (kWh/af) (8)
Residential	**58%**	
Toilets and leaks	14%	0
Dishwashers	1%	27,200
Clothes washers	8%	11,650
Showers, faucets, and bathtubs (1)	12%	6,700
Landscape irrigation	23%	0
Commercial, industrial, and institutional	**32%**	
Kitchen dishwashers	0.5%	27,200
Prerinse nozzles	0.2%	6,700
Other kitchen use	1.2%	Not Estimated
Laundries	0.6%	11,650
On-site wastewater treatment (2)	5.8%	800
Water-cooled chillers (3)	2.4%	67,700
Single pass cooling (3)	2.4%	0
Landscape irrigation	12.1%	0
Other heated water (4)	0.3%	6,700
Other unheated water (5)	6.5%	Not Estimated
Agricultural (6)	**10%**	**Not Estimated**
Totals and weighted average (7)	**100%**	**3,900**

Notes: (1) Showers and tubs heated to 105 degrees; faucet water conservatively assumed to be cold. (2) Estimate shown is for on-site wastewater treatment. (3) Assumes 50 percent of cooling water is single pass since the SDCWA provides financial incentives for water-efficient cooling investments. (4) CII water heating estimate from Sezgen and Koomey (1995), less other CII water heating estimated separately. (5) May use energy for recirculation or pressurization. (6) Data not available for San Diego County. (7) May differ from figures shown due to rounding. (8) Numbers are not significant to digits shown, but presented this way to facilitate comparison with other tables and figures.

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TABLE 8
Energy Intensity of Sources of Water in San Diego County

	Energy Intensity (equivalent kWh/af)	Notes
Current Source Weighted Average:	**2,040**	
San Francisco Bay Delta (SWP)	3,240	Wilkinson (2000)
Colorado River (CRA)	2,000	Wilkinson (2000)
Local surface water	80	Raw water lift to treatment plants
Local groundwater	570	
Recycling	400	Includes one brackish groundwater treatment facility at 405 kWh/af
Potential Sources:		
Imperial Irrigation District	2,110	CRA (2000) plus hydroelectricity not generated in the All American Canal (110)
Seawater desalination	4,200	SDCWA seawater desalination facility at Encina
Water bags	1,180	900 mile tow

Our analysis shows that satisfying all growth in water demand via conservation would reduce the overall energy intensity of the SDCWA water supply by 13 percent.

institutional (CII) and agricultural sectors are incomplete, and the analysis conservatively omits some uses of energy for which credible estimates could not be made at present (e.g., CII process water heating or recirculation, and water lift or pressurization for agricultural irrigation).

Conservation and Water Recycling are the Least Energy Intensive Sources of Potential Supply

Our analysis shows that satisfying all growth in water demand via conservation would reduce the overall energy intensity of the SDCWA water supply by 13 percent. In comparison, satisfying all growth in water demand via recycling would reduce overall energy intensity by only 4 percent, while using seawater desalination to satisfy growth would increase overall energy intensity by 5 percent.

Table 8 presents the energy intensity of actual and potential sources of water in San Diego County. The first line in the table shows the weighted average energy use for the current mix of water sources.

The results presented above can be taken a step further by assessing the energy intensity implications of various "sources" of additional water (Table 9). An additional 100,000 af/yr implies an additional 108,000 af/yr of water from desalination or recycling facilities because 7 percent of water is estimated to be lost in distribution (i.e., 100,000/0.93 = 108,000). It implies an additional 113,000 af/yr of water delivered to San Diego County via the State Water Project, the Colorado River Aqueduct (presumably Imperial Irrigation District water rerouted to San Diego), or water bags because an estimated 5 percent more is lost in treatment. Or it implies no additional water, but conservation of about 16 percent of the estimated 610,000 af/yr of water actually delivered to customers today after losses in conveyance, treatment, and distribution.

As in the rest of this report, the total energy use is divided by the quantity of water delivered to the end user to calculate the average energy intensity. That

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TABLE 9
The Energy Intensity for Satisfying 100,000 af/yr of Additional Demand

	Source and Conveyance Energy (kWh/af)	Water Treatment (kWh/af) (1)	Distribution (kWh/af) (2)	End Use (kWh/af) (3)	Wastewater Treatment (kWh/af) (4)	Total (kWh/af)
Status quo	2,040	60	330	3,900	570	6,900
Status quo plus scenario:						
Conservation	1,780	50	290	3,400	500	6,020
Recycling	1,830	50	330	3,900	500	6,610
Water bag transfer	1,950	60	330	3,900	570	6,810
Imperial Irrigation District transfer	2,080	60	330	3,900	570	6,940
Additional State Water Project	2,240	60	330	3,900	570	7,100
Seawater desalination	2,400	50	330	3,900	570	7,250

Notes: (1) The conservation, recycling, and desalination scenarios assume the additional 100,000 acre-feet of water do not require treatment, reducing the average energy intensity of treatment from 60 to 50 kWh/af delivered to customers. (2) Conserved water does not need to be distributed, reducing the energy intensity of distribution from 330 to 290 kWh/af delivered. (3) Conservation assumes no energy is conserved when water is conserved, but no energy is expended to conserve water either. (4) Wastewater is not generated by conservation or by recycling if recycled water is used for landscape irrigation, reducing energy intensity from 570 to 500 kWh/af delivered.

quantity is 710,000 af/yr in all but the conservation scenario. In order to make a fair comparison, however, the conservation scenario also uses a denominator of 710,000 af/yr, although only 610,000 af/yr would actually be delivered to customers. This is an appropriate adjustment because this level of conservation would meet the same need as 710,000 acre-feet would if San Diego were to choose to obtain additional water from the State Water Project or the other sources included in this analysis.

The table shows that water conservation is the far superior water "source" from an energy perspective. Of course, other considerations are relevant to the choice among "source" alternatives. For example, seawater desalination and recycling probably offer greater reliability benefits than the other alternatives.

Energy Implications of Water Supply Decisions Are Large and Warrant Inclusion in Water Supply Planning

Our analysis shows that not only are conservation and recycling the most energy efficient sources of new water supply, but also that shifting to conservation and recycling would generate large energy savings. Total energy savings from relying on conservation instead of additional State Water Project water to provide the next 100,000 acre-feet of water could be approximately 767 million kWh, or enough to provide the annual electricity for 118,000 households—25 percent of all of the households in the city of San Diego.[83] The scale of these potential energy benefits can also be illustrated by another comparison. The amount of energy that this conservation option would save is equal to 150 percent of the maximum annual output of the proposed—but now inactive—62.4 MW Chula Vista II power plant.[84] Relying on recycling rather than additional State Water Project water would save 348 million kWh, or enough to provide for the annual electricity needs of 53,500 households. Total energy use of the alternatives for adding 100,000 acre-feet to the status-quo water supply are presented in Table 10.

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This case study demonstrates that water policy choices can save significant amounts of energy. The magnitude of these potential savings has important implications for decision-makers. An integrated approach to assessing San Diego's water supply options could save water and energy, and reduce emissions that contribute to climate change and other air pollution problems. Future planning efforts should capitalize on these opportunities. The type of analysis presented in this case study can easily be incorporated into local and regional water supply planning. Consultation between water agencies, state energy agencies, and local energy utilities can help California better manage our precious water and energy resources.

TABLE 10
Total Energy Use and Savings from San Diego Water Supply Options

Status quo plus scenario	Average Energy Intensity (equivalent kWh/af)	Total Energy Required for Water Supply (million kWh/yr)	Savings from Conservation Rather than an Additional 100,000 af/yr of Physical Supply (million kWh/yr)
Conservation	6,020	4,274	Not Applicable
Recycling	6,610	4,963	689
Water bag transfer	6,810	4,835	561
Imperial Irrigation District transfer	6,940	4,927	653
Additional State Water Project	7,100	5,041	767
Seawater desalination	7,250	5,148	874

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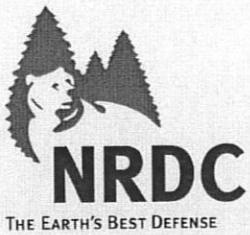
CHAPTER 4

WESTLANDS WATER DISTRICT—ENERGY AND AGRICULTURAL WATER



ENERGY DOWN THE DRAIN

The Hidden Costs of California's Water Supply

August 2004

The Westlands Water District is one of the largest agricultural water users in California and the western United States. The district faces long-standing problems associated with soil quality and poor water drainage and is now negotiating with the Department of the Interior to retire—permanently fallow—a large portion of its agricultural lands.[85] In fact, the district has already started the fallowing process by retiring 33,000 acres. Retiring land presents significant implications for California's water use, since it raises the question of where water formerly used for crops will go instead. Our report asks and answers the question: how much energy will be required to use the water in a different way?

This report provides a case study of land retirement in Westlands because the results will be timely and could inform a real policy decision process. The study also illustrates more generally the energy-related issues and data that are necessary for evaluating energy impacts of agricultural water management decisions. Energy impacts have not previously been accounted for in analyses of land-retirement proposals.

This case study evaluates three alternatives for the disposition of the water formerly used to irrigate retired lands in the Westlands Water District: the water could be used to enhance environmental flows in the delta; it could be used on other land within the district; or it could be transferred to other agricultural or urban uses.

As with the San Diego example, care should be taken in making final policy decisions based on this case study without more detailed analysis. In particular, we present some information in the case study that is relevant to land-retirement decisions generally, but is not specific to the land currently proposed for retirement. This information is presented, rather, as an exploration of a new methodology that could be applied in other settings.

Our Westlands analysis indicates that:

▸ Significant amounts of energy can be embedded in agricultural water use. Agricultural water allocation decisions can have large energy impacts that warrant inclusion in analyses of water policy alternatives.

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▸ The total energy implications of agricultural water policy decisions extend far beyond the energy embedded in water. To the extent possible, analyses of energy impacts should include harvest, cultivation, and other energy inputs.

▸ Retiring land south of the Sacramento–San Joaquin Delta and transferring water to environmental flows could save significant amounts of energy—the equivalent of powering more than 18,000 households for one year.

▸ Retiring land south of the delta and transferring water to urban users could dramatically increase energy use. For example, if water were transferred to San Diego County, energy use would increase by more than a factor of 8—that is, by more than 1.2 billion kWh/yr.

▸ Retiring land and allowing water to remain in the district for agricultural use would likely result in an increase in permanent crops, such as orchards, which under plausible assumptions would increase electricity use by 48 percent and total energy use by 16 percent.

Retiring land south of the Sacramento–San Joaquin Delta and transferring water to environmental flows could save significant amounts of energy—the equivalent of powering more than 18,000 households for one year.

The model used for the San Diego case study (Appendix A) was modified and simplified for the Westlands case study because many aspects of the urban water cycle (e.g., treatment before use) are usually not present in the agricultural sector. These modifications are described in Appendix C.

THE WESTLANDS CONTEXT

The Westlands Water District in California is one of the largest agricultural users of water in the West. It has a service contract with the United States Bureau of Reclamation for up to 1,150,000 acre-feet of water per year from the Central Valley Project (CVP). As a junior user in the overcommitted CVP system, Westlands currently receives on average about 65 to 70 percent annually of this amount.

Westlands' total water supply in 2001 was about 1,050,000 acre-feet. Of this total, about 200,000 came from groundwater. A 1980 study by the Bureau of Reclamation, the United States Geological Survey, and Westlands estimated that the sustainable yield of the deep confined aquifer under Westlands is in the range of 100,000 to 135,000 acre-feet. More recent district analysis of monitoring data suggests that the annual average sustainable yield might be as high as 200,000 acre-feet. Table 11 presents the district's

TABLE 11
Westlands Water District Estimates of Water Sources in 2002

Source of Water	Estimates for 2002
CVP deliveries	775,194 acre-feet
Groundwater	200,000 acre-feet
Private transfers	72,000 acre-feet
Additional district supplies	60,000 acre-feet
Total	**1,107,194 acre-feet**

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estimates of its water sources in 2002. These figures were used in the analysis in this report.

Local groundwater has lower quality than CVP water. Depth to groundwater below the surface varied in 2001 from about 100 feet to 500 feet.[86] Energy consumption per acre-foot of groundwater pumped by the district is about 740 kWh.[87]

Westlands currently includes about 600,000 acres, 95 percent historically irrigable.[88] Approximately 470,000 acres were actually irrigated in 2002. Irrigation water is supplied by the San Luis Unit of the CVP and groundwater wells. Water provided to Westlands by the CVP is diverted from the Sacramento–San Joaquin Delta by the Tracy Pump Station and transferred south via the Delta-Mendota Canal. It is lifted several hundred feet, allowed to flow by gravity for about 150 miles, and is sometimes lifted another several hundred feet into the San Luis Reservoir. Some electricity is generated when water is released from the reservoir, but this offsets only about 70 percent of the energy used to fill the reservoir.[89]

Water is conveyed from the vicinity of the San Luis Reservoir to Westlands via the San Luis and Coalinga Canals. Westlands operates and maintains the 12-mile concrete-lined Coalinga Canal and the Pleasant Valley Pumping Plant, as well as other re-lift stations. Westlands' permanent distribution system consists of closed, buried pipes that convey water from the San Luis Canal, the Coalinga Canal, and a 7.4-mile unlined canal from the Mendota Pool. Approximately 88 percent of the irrigable land in the district is served by the system.

Technology for water distribution has become more efficient over the years. In 1996, about 36 percent of irrigated land was watered by gravity distribution alone, about 21 percent by pressurized distribution alone, and the remaining 43 percent by a combination. By comparison, acreage irrigated only by gravity distribution was 63 percent in 1985 and 43 percent in 1990.

Water provided to Westlands by the CVP is lifted several hundred feet, allowed to flow by gravity for about 150 miles, and is sometimes lifted another several hundred feet into the San Luis Reservoir.

CASE STUDY RESULTS

Substantial Energy Is Embedded in Westlands' Water Use

Sources and conveyance appear to represent the largest portion of energy embedded in Westland's water use. Our analysis indicates that substantial amounts of energy

TABLE 12
Energy Intensity of Surface Water Transport to the Westlands Water District

Location of Energy Use	Energy Intensity (kWh/af)
Tracy Pump Station (1)	238
Lift from O'Neal Forebay (1)	59
Lift to San Luis Reservoir	300
Hydroelectric generation from releases from the San Luis Reservoir (2)	–210
Dos Amigos Pump Station	138
Total CVP to the San Luis Canal	**435–525**
Pleasant Valley Pump Station	238
Total CVP to the Coalinga Canal	**673–763**

Notes: (1) The State Water Project Banks Pump Station is a parallel path for water en route to the San Luis Reservoir and eventually Westlands. Its energy use is nearly identical to the CVP pumps. (2) A negative number represents energy recovery, not use.

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TABLE 13
Electrical Energy Requirements to Lift or Pressurize Sprinkler Systems

Activity	Approximate kWh/af
Flood irrigation without on-farm lift	0
Lifting water 10 feet for flood irrigation	30
Low-pressure sprinklers	100
Permanent set sprinklers	205

are required to deliver water to Westlands' fields, whether surface or groundwater. Energy required for water pumping in the CVP is presented in Table 12.[90] Totals in the table are approximate and lower than actual consumption per acre-foot because water losses between pumping locations are not accounted for. Ranges represent uncertainty about whether water to Westlands should be charged 90 kWh/af for lift into or release from the San Luis.[91]

Our analysis indicates that substantial amounts of energy are required to deliver water to Westlands' fields, whether surface or groundwater.

The amount of energy required to deliver water to a field in Westlands can vary widely depending on the location of that field within the district. Net electric energy consumption by the CVP to deliver water to canals in the Westlands Water District varies from about 435 to 763 kWh/af.[92] In addition, staff members report that district lift from the canals consumes about 245 kWh/af.[93] This implies that water available to farmers at the boundaries of their properties requires between 435 and 1,008 kWh/af.

Once water has been delivered to the field, additional energy may be required to lift and pressurize that water. Table 13 summarizes some average on-farm energy requirements for these irrigation purposes. It assumes a 10-foot lift and pressurization for the sprinklers. The figures are estimated from unit prices for electricity and expenditures per acre for water pumping and pressurization provided by the California Energy Commission in 2001 for grapes and almonds. The figures in the table are not specific to Westlands. The energy required for permanent set sprinklers is 20 to 47 percent of the energy required to deliver water to farms within Westlands (435 to 1,008 kWh/af). This demonstrates that energy used in on-farm water delivery systems can be significant in agricultural settings, depending on the types of crops grown and the choice of irrigation system.

Hydroelectric power issues are relatively insignificant for the Westlands analysis. Hydroelectric power production from the CVP is substantial (more than 4.5 billion kWh/yr), but nearly all irrigation water supply—such as that to Westlands—occurs downstream of CVP hydroelectric facilities. Therefore, there is no direct trade-off between irrigation and power generation as there is in the Columbia Basin study that follows. In addition, none of the scenarios analyzed in this case study would result in a dramatic change to hydroelectric operations upstream of the delta.

Energy Implications of Land Retirement Extend Beyond Water Delivery and Use

As discussed in Chapter 2, the full energy implications of a water policy decision may extend beyond the energy embedded in the water. In this case, permanent land

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TABLE 14
Energy Intensity of Liquid Fuels Used to Cultivate and Harvest Crops

Crop	Energy Intensity (kWh equivalent per acre)
Alfalfa—California	145
Alfalfa—Ohio	205
Almonds	341
Almonds	373
Cotton—Alcala	472
Cotton—Pima	545
Tomatoes, processing	1,255
Tomatoes, fresh	710
Tomatoes, "typical" California	1,389
Wheat	247

Notes: Gasoline and diesel fuel converted to BTUs at 150,000 per gallon; BTUs converted to equivalent kWh at 10,239 per equivalent kWh.[94]

retirement would affect energy use in ways that are not captured by looking only at energy embedded in irrigation. In addition to irrigation, farms consume energy by operating farm machinery preparing soil, applying fertilizers and pesticides, and harvesting crops.

Permanent land retirement would affect energy use in ways that are not captured by looking only at energy embedded in irrigation.

This nonirrigation energy use varies enormously across crops.[95] Table 14 presents some sample calculations of gasoline and diesel energy used in agriculture. Again, these are not specific to Westlands but illustrate the type of analysis that is required to understand the energy implications of agricultural water use decisions. Energy used for irrigation is not included in the gasoline and diesel-fuel energy consumption estimates unless a power takeoff from farm machinery is used to drive a water pump.

To determine the nonirrigation energy savings from a land-retirement program, it is necessary to determine which crops will be phased out. Table 15 presents projected 2020 cropping patterns for Westlands without significant land retirement.[96] Crops projected for lands with shallow groundwater represent drainage-impaired lands that are candidates for retirement. The projection is extremely uncertain because it is based on estimated future market prices for crops obtained by extrapolation from historical trends and expert opinion. These trends and opinions may be altered by changes in other parts of the western United States and international agricultural regions that have not been evaluated. Nonetheless, Table 15 is the best available data on the types of crops that might not be grown in drainage-affected areas if significant retirement programs are implemented.

Cotton takes up more than a third of the acreage likely to be grown on land with shallow groundwater. Cotton also represents a midpoint in its nonirrigation energy use listed in Table 16, roughly 500 equivalent kWh/acre. Therefore, a rough estimate of the nonirrigation energy savings associated with retiring 100,000 acres of land is approximately 50 million equivalent kWh. Note that these are nonelectric savings that have been converted to kWh. Although these potential savings are not available to other customers as electricity, they are important additional implications of land

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TABLE 15
Forecast Demand for Westlands Crops in 2020

Crop	Shallow Groundwater (thousands of acres)	Remainder (thousands of acres)
Alfalfa hay	8.04	0.96
Cotton	73.72	83.76
Field crops	5.57	14.80
Irrigated grain	9.19	1.72
Grapes	1.40	8.02
Irrigated pasture	0.23	0.8
Orchards	2.75	55.03
Row crops	31.22	109.83
Sugar beets	0.98	0.96
Subtropicals	3.55	1.03
Tomatoes	17.45	97.56
Dry-land grain	14.00	0.00
Fallow and nonbearing trees and vines	22.39	11.99
Total: (577,000 acres)	**190.49**	**386.46**

Our analysis indicates that dedicating water from retired lands to environmental flows in the delta would have the greatest energy benefits.

retirement because of the potential for air quality and global warming benefits that are beyond the scope of this analysis.

Dedicating Water to Environmental Flows Could Save Significant Energy

Long-standing problems associated with inadequate drainage, low quality of existing drainage water, and responsibility for management and disposal of drainage flows have led to recent proposals to retire—permanently fallow—200,000 acres within the district.[97] Under a Westlands proposal, farmers would receive federal payment for a significant part of the cost of land retirement, and the Westlands Water District would obtain or keep title to the land and all water associated with the land.

In concept, there is broad support for the retirement of drainage-impaired land on the west side of the San Joaquin Valley. However, current proposals are controversial for a variety of reasons not discussed in this report, including disposition of conserved water and the claim that the public cost of the retirement is higher than the public benefits that will be obtained. This case study considers three alternatives for the disposition of the water formerly used to irrigate the retired lands: dedicating the water to enhance environmental flows, transferring the water to other water users, and retaining the water for irrigation on other Westlands land. Summary statistics for the three alternatives are presented in Figure 5.

Our analysis indicates that dedicating water from retired lands to environmental flows in the delta would have the greatest energy benefits. The land targeted for retirement is predominantly downslope of the San Luis Canal and therefore receives water by gravity. On-farm pressurization is reported by Westlands staff to be minimal for these lands. Consequently, a conservative estimate of energy saved by reducing CVP water deliveries to Westlands, with that water left in the

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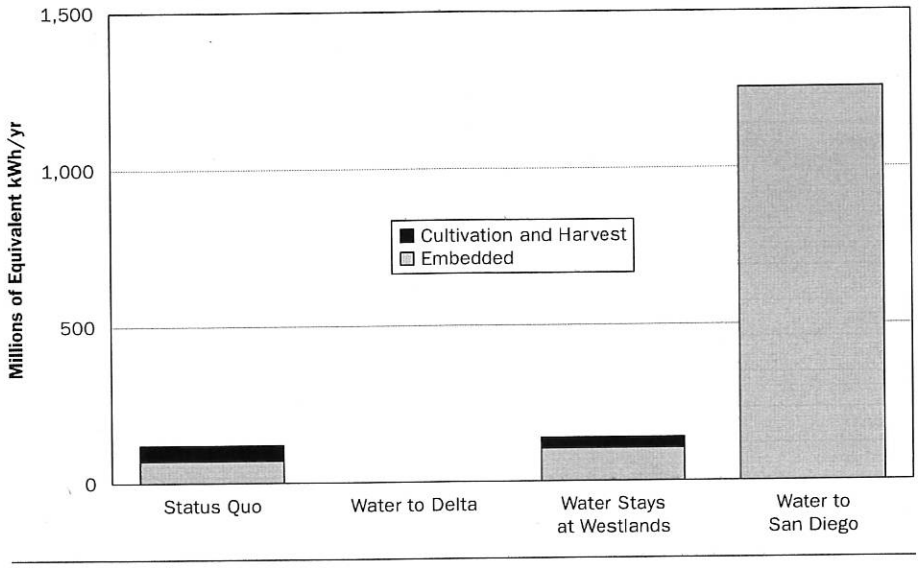
FIGURE 5
Annual Energy Use by Water Disposition Scenario



San Francisco Bay-Delta for environmental purposes, is approximately 435 kWh/af. While average applied water in the district is 2.34 af/acre (1.1 million acre-feet divided by 470,000 cropped acres in 2002), not all of this is CVP water that could be dedicated to environmental flows. Since CVP water represented 70 percent of the district's 2002 supplies, we assume that 70 percent of the average applied water is CVP supply. Therefore, a 100,000-acre land-retirement program could save approximately 71 million kWh of electricity, or enough to power 11,000 households for a year.[98]

The full energy implications of land retirement extend beyond the energy embedded in water. Retiring 100,000 acres in Westlands and dedicating the conserved CVP water to environmental flows in the delta could have total energy implications of 121 million equivalent kWh (71 million kWh of embedded energy plus 50 million equivalent kWh used for cultivation and harvest).

It is important to note, however, that reduced groundwater pumping within the district would save even more electricity. Pumping groundwater alone uses about 740 kWh/af.[99] Electricity savings would be around 120 million kWh/yr if CVP deliveries were maintained and the district decreased groundwater pumping in the equivalent amount. Any pattern of reduction in total water use in the district implies significantly less electric and total energy use. However, given the lack of groundwater regulation in California at the moment, a retirement agreement would need to include special legal and enforcement provisions in order to ensure any reduction in groundwater pumping.

This analysis has implications for the Environmental Water Account, included in the CALFED Bay-Delta Program Record of Decision, signed in August 2000. The Environmental Water Account was created to provide water to compensate water

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users for delta pumping reductions needed to protect endangered species, and, if enough water remains, to restore the bay-delta ecosystem. From an operational perspective, this complex arrangement can be identical to dedicating existing water consumed by irrigation to delta protection. The Environmental Water Account water can come from a number of sources, including the purchase of surface and groundwater and purchases north or south of the delta. The extraction of groundwater for the Environmental Water Account requires greater energy than purchases from existing gravity-fed surface water facilities. Water purchases from agriculture north of the delta would result in changes in agricultural operations with relatively small conveyance energy benefits. The Environmental Water Account water purchased from CVP contractors south of the delta, such as Westlands, would generate greater conveyance energy benefits than water purchased north of the delta. The greatest conveyance energy benefits from Environmental Water Account purchases in the Central Valley would be achieved from purchases of surface water from the Central Valley location with the greatest lift for imported delta irrigation supplies—Kern County.

Transferring the Water to Urban Users Would Dramatically Increase Energy Use

Transferring water from Westlands to urban locations would significantly increase energy use. Table 16 presents the conveyance energy that would be required to transfer the water to urban users.[100] As documented in the San Diego case study, other parts of the water cycle—water treatment, distribution, end use, and wastewater treatment—also use energy. Figure 5 uses data from the San Diego case study and Table 16 to estimate the energy use that would result if water conserved by retiring 100,000 acres in Westlands were transferred to San Diego. Total energy use—all electricity in this scenario—would increase by more than eight times the energy use in the status quo: more than 1.2 billion kWh/yr.

Water from land retirement at Westlands could also be transferred to other agricultural users. Transfers to locations that use less energy for conveyance (e.g., north of Westlands, such as the Sacramento Valley area) would have net energy benefits unless the types of crops and irrigation systems at the new location were sufficiently more energy intensive than those on retired lands at Westlands. In contrast, transfers to locations that use more energy for conveyance (e.g., south of Westlands, such as Kern County) would have net energy costs unless the types of

TABLE 16
Energy Used to Deliver Water to Various Users

Representative Points of Delivery	Energy Intensity (kWh/af)
Environmental flows in the Sacramento–San Joaquin Delta	0
Westlands Water District	435–1008
San Jose area	1,165
Santa Barbara area	2,826
Northern Los Angeles Basin	2,580
Southern Los Angeles Basin	3,236

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crops and irrigation systems at the new location were sufficiently less energy intensive than those on retired lands in the district.

Retaining Water at Westlands Could Increase Energy Use

Westlands proposes to keep water formerly used to irrigate retired lands and reallocate this water to remaining agricultural lands within the district. Determining the energy implications of this policy requires forecasting the impact of water supply changes on cropping patterns. For example, land retirement without reduction in CVP deliveries creates greater reliability and availability of water per acre of land still farmed. One recent study estimates that a 39 percent increase in permanent crops, such as orchards, would result from increased reliability of water supply.[101] These reliability benefits are one reason Westlands has been pursuing its own land-retirement program.

District staff report that this level of increased tree planting would consume about an additional 170,000 af/yr.[102] Assuming for illustration purposes that permanent set sprinklers are used to deliver this amount of water previously delivered by gravity to retired lands, electricity use would increase by about 200 kWh/af. This would amount to about 35 million kWh/yr, as shown in Figure 5. In addition, irrigating orchard lands might require an additional 245 kWh/af for district lift from the canals, increasing electricity use even more than is presented in Figure 5.

The impact on other energy use on farms, however, might be positive. Tree crops tend to use less energy for cultivation and harvest than row crops. Figure 5 shows a reduction in energy used in cultivation and harvest that reflects 150 equivalent kWh per acre saved by switching from cotton to almonds. This type of change might amount to 15 million equivalent kWh/yr less energy use.

Overall, allowing Westlands to continue using water now applied to the retired lands would increase total energy use by approximately 19 million equivalent kWh/yr under the assumptions used. These assumptions illustrate the type of analysis that is important to perform when evaluating land-retirement proposals, such as the one for Westlands, but are only approximately accurate and should not be relied upon in making final decisions about land retirement in Westlands.

The analysis in this case study demonstrates three points that are relevant to agricultural water management decisions and worthy of further research:

- The importance of accounting for end use energy in agriculture;
- The importance of understanding the changes in land use or cropping patterns that are likely to result from a land-retirement decision;
- The importance of clearly defining, in an enforceable manner, the ultimate disposition of water no longer required to irrigate land that is retired.

Unfortunately, these concerns could not be quantified in further detail within the resources available for this report. But our analysis demonstrates that these concerns are quantitatively significant relative to energy use in agricultural water conveyance and distribution—a point that had not been established prior to this report.

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CHAPTER 5

THE COLUMBIA RIVER BASIN—ENERGY AND HYDROPOWER

The Columbia River supports powerful farming, hydropower, and environmental interests, and their competing concerns reveal just how complex the relationship between energy and water can be.

Thanks to its unique plumbing, the Columbia River has numerous hydroelectric dams located downstream of major irrigation diversions. As a result, energy and water policy discussions have been more integrated here than elsewhere in the West. Despite this initial progress, however, water and energy planners in the region have a long way to go toward fully integrating energy and water policy. This shortcoming was brought into sharp focus by the drought and energy crisis of 2001, when energy production demands caused farmers, industry, and the environment to suffer severely.

In this chapter, we examine the energy implications of diverting irrigation water upstream of hydroelectric facilities. Our analysis leads to several key findings:

▸ A substantial amount of energy is embedded in the water consumed by agricultural users where substantial pumping is required to deliver water.

▸ When accounting for the energy costs of irrigation along rivers that have hydroelectric dams downstream of major irrigation diversions, policymakers must examine both the energy used to deliver the water to the field and the energy foregone, or not produced, as a result of taking water out of the river before a dam.

▸ In future droughts, cost-effective water transfers may make it possible to improve conditions for salmon, power generation, and agriculture.

The model used in the Westlands Water District chapter was abbreviated for this case study to focus on the diversion of water for agricultural purposes upstream of hydroelectric facilities. Nonetheless, the Columbia analysis shares the methodology used in the other case studies, and is described in Appendices A and C.

While the Westlands and San Diego case studies focused on the energy embedded in agricultural and urban water use, this case study takes the analysis a step further by examining another important energy implication of water use: energy production that is lost or foregone as a result of water policy decisions. This

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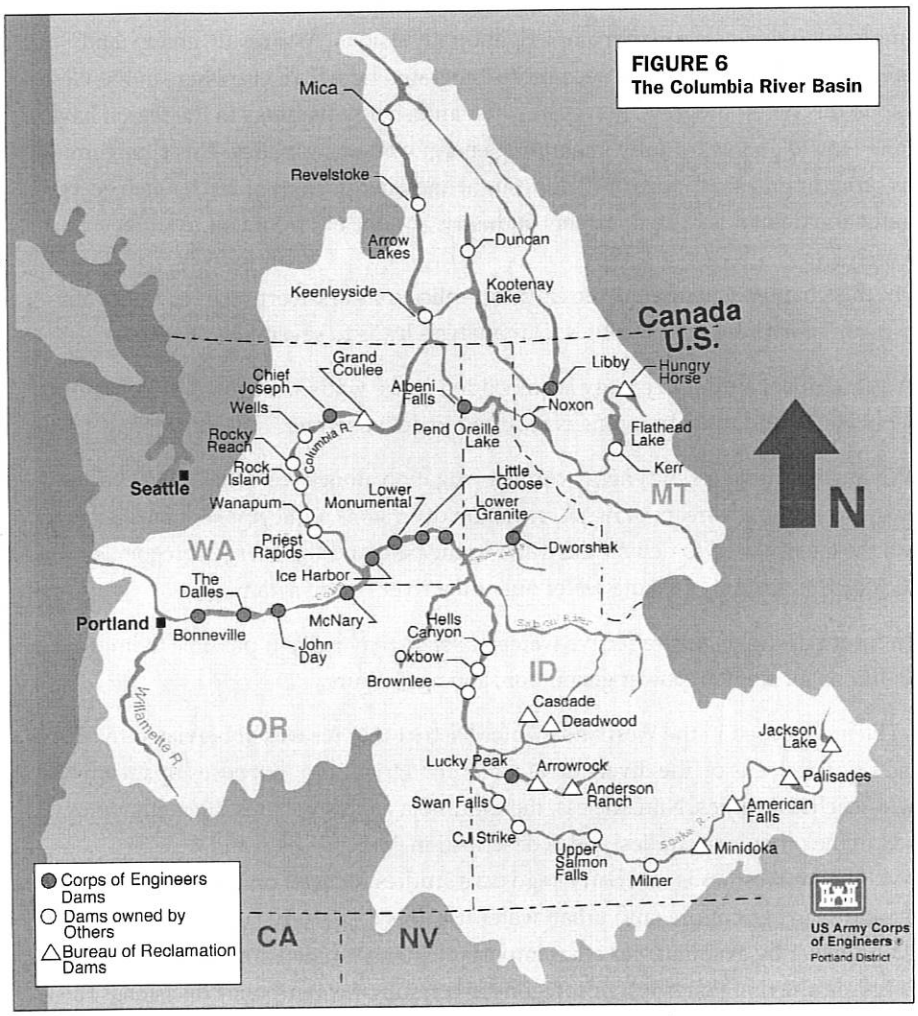
opportunity cost must be included in any calculation of how much energy is embedded in water use.

This case study also includes a discussion of the energy required to plant, cultivate, and harvest crops—additional energy use associated with water used by agriculture. By more fully analyzing the energy implications of water used in agriculture, this methodology allows for the more accurate calculation of the potential energy savings of dry-year fallowing agreements. Water marketing arrangements are increasingly common throughout the West. This methodology allows us to demonstrate the potential energy benefits of some of these transfers.

THE COLUMBIA RIVER CONTEXT

The Columbia River travels over 1,200 miles from its headwaters to the Pacific Ocean, draining a watershed of 259,000 square miles and discharging an annual average of 160 million acre-feet (Figure 6). The Columbia and Snake Rivers are, respectively, the



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12th and 13th longest rivers in the nation. This river system is an international and interstate resource that provides the basis for the region's charm, history, environment, recreational opportunities, and agricultural and industrial successes.

The Decline of the Columbia River Ecosystem

Human activities have taken a heavy toll on the Columbia River and its fisheries. The Columbia once supported more than 11 million salmon and steelhead annually, but by the 1990s, the river supported only about one million anadromous fish.[103] This remaining population consists of a majority of unsustainable hatchery fish and a very small population of wild spawning fish. Table 17 presents the 12 evolutionarily significant units of anadromous fish now listed under the Endangered Species Act as endangered or threatened in the basin. A variety of causes are responsible for this decline; however, diversions and dams have played a primary role.

Unfortunately, an effective response to restore Columbia fisheries has not yet emerged. Fishery management is particularly complicated due to perceived conflicts among energy, irrigation, and the environment.

Hydropower on the Columbia River

Dams in the Columbia River system represent 95 percent of the region's hydroelectric supply and produce 60 percent of its electricity.[104] The 31 dams owned by the Bureau of Reclamation and the Army Corps of Engineers make up the Federal Columbia River Power System (FCRPS). In 2000, the National Marine Fisheries Service issued a Biological Opinion (BiOp) regarding the impacts of the FCRPS on anadromous fish. The BiOp recommended 199 actions to enable listed fish populations to survive rather than continue to decline.[105]

The actions regarding hydropower call for augmenting flows and spilling water through spillways or bypasses. The 2000 BiOp also recommends specific quantities of water for flow augmentation and spill at the federal hydroelectric dams. If insufficient progress is made toward restoring fisheries, stronger measures, such as breaching four Lower Snake River dams, may need to be pursued.

TABLE 17
ESA Listed Fish of the Columbia Basin

	Endangered	Threatened
Resident Fish	Kootenai River white sturgeon	Bull Trout
Anadromous Fish	Snake River sockeye Upper Columbia River spring Chinook Upper Columbia River steelhead	Snake River spring/summer Chinook Snake River fall Chinook Snake River steelhead Middle Columbia River steelhead Lower Columbia River Chinook Lower Columbia River steelhead Columbia River chum salmon Upper Willamette River Chinook Upper Willamette River steelhead

Source: U.S. Bureau of Reclamation, Finding and Commitments. Implementing December 2000 Biological Opinions for the Federal Columbia River Basin System and Other Related Actions, 2001.

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Agriculture in the Columbia Basin

The diversion of millions of acre-feet of water from the Columbia Basin has enabled farmers to grow crops in the arid climate of the interior Northwest. While the economy has diversified in the last 20 years, agriculture remains a major industry. Major crops in the Columbia Basin include potatoes, alfalfa, sugar beets, wheat, and onions. The potential crops in much of this region are limited by the relatively short growing season for high-altitude farmland.

About 6 percent of the Columbia's flows are diverted for agricultural purposes.[106] While this seems like a low number, the National Marine Fisheries Service says that "Water withdrawals for irrigation throughout the Columbia River Basin have an enormous effect on the flow of the Snake and Columbia rivers, especially during dry years when river volumes are low."[107]

THE DROUGHT OF 2001

The drought of 2001 in the Pacific Northwest was one of the worst on record, comparable to the drought of 1977. By the summer of 2001, instream flows were naturally low and were further exacerbated by water diversions. The pumps for some of these diversions consumed significant amounts of energy. Low rainfall affected farms and reduced hydropower generation. Spot market power was prohibitively expensive because of the California electricity crisis. Salmon advocates, irrigators, and generators feared the worst. Decisions made during 2001 imposed major hardships on the environment, particularly salmon. With naturally producing salmon populations already at disastrously low levels, management of the Columbia River pushed many species closer to extinction.

Hydropower Impacts from the Drought

Understandably, Northwest utilities were concerned about avoiding blackouts during the summer of 2001. Bonneville Power Administration (BPA) responded by declaring an emergency situation, thereby avoiding carrying out some of the BiOp actions designed to help salmon recover, including much of the scheduled spill over the dams for fish passage. Utilities also launched several energy load-reduction programs and encouraged conservation.

The two largest agriculture load-reduction programs were run by the Idaho Power Company in Idaho and the BPA in the Columbia Basin Project. Some programs paid farmers not to pump irrigation water, freeing up for other uses the energy typically used for pumping and leaving water in the river for downstream generation. Most of this water was sent through the generating plants rather than spilled. Other non-BPA load-reduction programs simply purchased the hydropower used to pump irrigation water, leading farmers to substitute diesel generation to run their pumps, worsening air pollution and generating no in-river benefits.

The drought response included industrial load-reduction programs as well. One major focus of this effort was the energy intensive aluminum smelting industry. Creative BPA load-reduction programs cut power use during 2001 while ensuring continued compensation for plant workers.[108] The load-reduction programs during

Other load-reduction programs simply purchased the hydropower used to pump irrigation water, leading farmers to substitute diesel generation to run their pumps.

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2001 allowed the BPA to continue exporting significant amounts of power to assist California during its power crisis. This demand for energy exports increased the challenges facing those managing the Columbia River system.

Although the drought required major efforts in the energy arena, the overall response to the drought was considered a success for the utilities. No blackouts made the headlines during the drought of 2001 in the Northwest.

Agriculture Impacts of the Drought

In the agricultural community, there was little that could be termed a success. Higher energy prices increased costs. The drought caused yields to fall. Low commodity prices worsened conditions. Because of overproduction, farmers were earning only $1.50 per 100 pounds of potatoes, although it takes $4 to $5 to grow a hundred pounds, leading the United States Farm Services Agency to institute a program to buy potatoes and raise prices.[109]

The irrigation buyback programs offered by utilities provided a lifeline for some of the unfortunate farmers facing low commodity prices and high energy cost. However, despite the financial appeal of the buyback programs, for a variety of reasons, it remained far more difficult to obtain water in the Upper Snake River than in other regions. By way of contrast, the Washington State Department of Ecology spent more than $300,000 to secure in-stream flows from farmers through 21 leases during this same drought.[110]

During 2001, buyback programs helped some farmers to survive during difficult farming conditions. According to one media report, "Some Idaho farmers reported that kilowatt hours were their best crop [in 2001]."[111] Implementing the recommendations discussed in Chapter 6 would allow farmers to use their water rights to provide a cushion against the challenging conditions facing them in the agricultural market.

Environmental Impacts of the Drought

For Columbia Basin fish, things were even bleaker. Already struggling to migrate past numerous dams, anadromous fish faced even lower flows because of the drought. In the Hanford Reach, 1.6 million young Chinook were stranded. In 2001, the drought prevented the agencies from meeting any of the BiOp objectives. Relying on the drought emergency, federal agencies reduced spills over the summer to only 10 percent of BiOp recommendations. The Fish Passage Center and the National Marine Fisheries Service both found that "the lowest survivals and slowest travel times for smolts resulted from the lowest flow and spill that has occurred in recent years."[112] In harsher terms, Save Our Wild Salmon characterized the hydropower operations as a "massacre."[113]

According to the Fish Passage Center, "the suspension of Biological Opinion measures resulted in very poor in-river migration conditions in 2001."[114] For endangered fisheries, 2001 represented another disturbing step toward extinction rather than recovery.

Lessons from the 2001 Drought

Was there any way to meet expected electricity needs without sacrificing the salmon? Some groups believed so. In a letter addressed to Congress on March 19, 2001,

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environmental groups, scientists, and Native American tribes proposed that water be obtained from a point higher in the Columbia Basin, so that instream flows could be maintained while hydropower generators met their needs.

Clearly, hydropower generation was given the highest priority for Columbia water resources in 2001. Agricultural, industrial, and fishery interests all suffered, but there were no blackouts in the Northwest that year. Many farmers and industrial interests were compensated for reduced power—and water—use. Fish and fishery interests, including fishermen and Native Americans, however, had no choice and bore major hardships. In short, during 2001, several key factors came together:

- The drought worsened conditions for hydropower production.
- Exacerbated by diversions and power operations, the drought threatened the environment, particularly salmon.
- Spills over hydroelectric dams were inadequate.
- River flows were inadequate.
- Power prices peaked, due to the electricity crisis in California.
- Commodity prices were low.

These factors and the priorities given to the various uses of water in the Columbia River system led to a particularly unfortunate outcome—Idaho farmers lost money and plowed under unwanted, but water intensive, potatoes, while fish and hydropower production suffered from a lack of water. It is important for us to learn from this experience. It may be possible to address all of these problems during dry years by capturing some of the energy opportunity cost embedded in irrigation water in this region.

Idaho farmers lost money and plowed under unwanted, but water intensive, potatoes, while fish and hydropower production suffered from a lack of water.

CASE STUDY RESULTS

The Columbia case study examines energy implications of water use in one large federal project, the Columbia Basin Project (CBP). This project is located near Grand Coulee Dam, upstream of many of the Federal Columbia River Power System hydroelectric generating facilities. To simplify this effort, this analysis focused on the implications of only one crop, potatoes. Potatoes are one of the major crops in the Columbia Basin. Just as salmon are an iconic wildlife species for the Pacific Northwest, potatoes are agriculture's signature crop in parts of the region.

Significant Amounts of Energy Are Embedded in Agricultural Water Use

In the Columbia Basin Project, delivering water requires a significant amount of energy: 340 kWh per acre-foot. Our analysis of embedded energy use is shown as source and conveyance energy in Figure 7. This figure also shows the energy required to plant, cultivate and harvest this crop—385 kWh per acre-foot. Cultivation and harvest energy use, however, comes primarily in the form of diesel fuel consumption. Saving this energy is not, therefore, translatable directly into electricity. Nevertheless, it is also an important energy implication of water use by agriculture.

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TABLE 18
Downstream Generation Gain from Reduced Diversion

Site	Net Energy Gain (kWh/af)
Columbia Basin Project	745
Upper Salmon	250
Walla Walla	140
Deschutes	36
Upper Snake	806

Energy Generation Opportunity Costs Must Be Added to Embedded Energy Costs

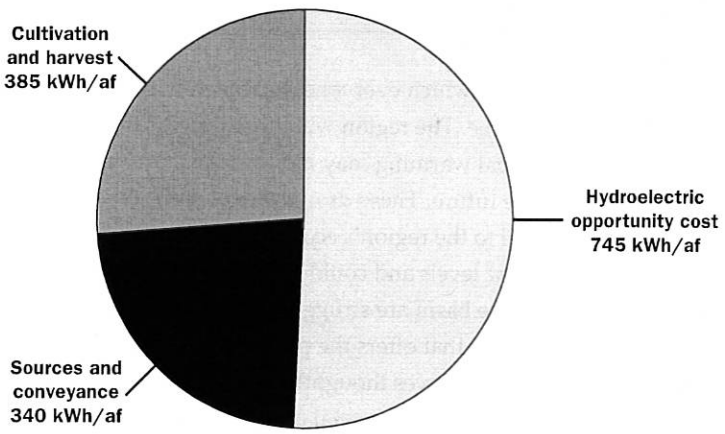
Because diversions from the CBP are upstream of major hydroelectric generation facilities, these diversions reduce the amount of water passing through those downstream facilities. Thus, one result of CBP diversions is a significant reduction in potential energy production. Figure 7 shows that this opportunity cost is 745 kWh/af. This hydroelectric opportunity cost was taken from Table 18, which summarizes the per-acre-foot energy potential of water at five points in the river system. Predictably, the energy opportunity costs in upper watersheds, above major hydroelectric dams, are extremely significant. In the case of the CBP, the energy opportunity cost is actually greater than the energy used to deliver water and to cultivate and harvest crops (725 kWh/af combined). Clearly, in regions like the Columbia River Basin, a full understanding of the energy implications of water use must include energy opportunity costs.

The total electricity implications of water used by the Columbia Basin Project can be estimated by multiplying the total electricity embedded in each acre-foot of water (to pump water from the Columbia River to the users) and potential downstream generation benefits from water released below the CBP (1,085 kWh/af—including both conveyance and downstream hydroelectric generation) times the annual average amount of water diverted by the CBP (2.4 million af/yr).[115] This exercise reveals that the embedded energy and potential generation benefits of the Columbia Basin Project alone amount to more than 2,600 gigawatt-hours per year, or nearly 25 percent of total annual energy consumption of the city of Seattle. An analysis of other diversions in the upper Columbia and Snake River systems would reveal similarly significant energy implications.

Water Transfers Could Benefit All Parties in Future Droughts

By combining embedded energy and opportunity costs, Figure 7 reveals the potential energy benefits of dry-year water transfers involving the Columbia Basin Project in

FIGURE 7
Energy Intensity of Water of Potatoes from Reduced Diversions



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the future. Of the 1,470 equivalent kWh/af total energy implications of CBP water use, 1,085 consist of electricity used to pump water plus electricity not produced because water was diverted upstream of hydroelectric facilities.

This analysis demonstrates that if all water diversions to the Columbia Basin Project were to cease and if all of this water were instead run through downstream hydroelectric facilities, the additional energy produced would be more than 2,600 gigawatt-hours per year. We do not mean to suggest that this would be an appropriate reallocation. However, this analysis reveals the significant potential energy benefits that could accrue from realizing some of this potential under some circumstances. The BPA has conducted an analysis looking at different hydrological conditions that has reinforced this conclusion.[116]

During dry years, and especially when power costs are high and agricultural commodity prices are low, the value of this energy potential may be large enough for voluntary fallowing programs to pay farmers more than they could earn growing low-value crops and still have enough money left to purchase environmental flows. Such an arrangement would pay farmers to forego farming on some of their land, leaving more water in the river. Some of the conserved water could be used to generate additional energy, and some used to generate environmental benefits. Such hybrid energy and environmental transfers could improve low-flow conditions in places such as in the Hanford Reach, which suffered the large fish kill discussed previously. They could also help provide the spills from hydroelectric facilities required by the 2000 BiOp. During the disastrous conditions seen in 2001, voluntary fallowing arrangements could also have been beneficial to many farmers who lost money as a result of high production and low crop prices. In short, the opportunity for farmers, ratepayers, and the environment to mutually benefit from dry-year land fallowing in the Columbia Basin is significant.

Experience in other states suggests that the greatest concerns regarding the type of marketing arrangements that this document recommends are likely to emerge from rural agricultural communities. We take these concerns seriously and will explore them further in a forthcoming report.

The embedded energy and potential generation benefits of the Columbia Basin Project alone amount to nearly 25 percent of total annual energy consumption of the city of Seattle.

CONCLUSION

There are a few things upon which everyone associated with the management of the Columbia River would agree. The region will face droughts in the future. In fact, by reducing snowpacks, global warming may increase the frequency and severity of drought conditions in the future. These droughts will reduce the reliability of energy supplies that are essential to the region's economic vitality. Salmon populations are already at dangerously low levels and could be seriously imperiled in future droughts. And farmers in much of the basin are struggling to survive due to low crop prices and high costs. Any strategy that offers the potential to provide benefits in each of these interconnected areas deserves thoughtful evaluation. Voluntary dry-year marketing arrangements offer the potential to improve conditions for salmon, increase energy production, and provide badly needed income for farmers. The

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Some of the conserved water could be used to generate additional energy, and some used to generate environmental benefits.

potential impacts of such arrangements on local communities should be carefully evaluated. However, if designed properly, such arrangements could significantly strengthen the region's economy and protect many thousands of jobs from potentially disruptive energy shortages.

On the Columbia River and on other river systems, a better understanding of the energy implications of water use can help managers design strategies in the future that will better meet the needs of our economy and environment. In these cases, the careful, regulated use of market principles offers the potential to produce broad benefits reflecting modern environmental values.

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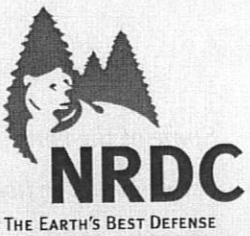
CHAPTER 6

RECOMMENDATIONS FOR WATER POLICY



ENERGY DOWN THE DRAIN

The Hidden Costs of California's Water Supply

August 2004

The case studies in this report support water policy conclusions that are widely applicable in the western United States. Overall, our analysis indicates that energy implications of water policy decisions are large and warrant inclusion in water and energy policy decisions. All three case studies demonstrate that inclusion of energy considerations can improve resource management decisions and avoid potentially significant unintended energy consequences.

ENERGY IN URBAN WATER USE

The most striking conclusion is that the amount of energy required for end uses of water is the largest component of energy use in the urban water supply cycle. Therefore, urban conservation, particularly for energy intensive uses such as clothes washers and commercial cooling towers, is important regardless of the source of the water or location of its use. San Francisco, as well as Los Angeles, should be aggressively pursuing water conservation.

This finding implies that policy actions that affect water use may have much larger energy implications than policy actions that affect the mix of physical water sources. This is true in San Diego, at the most energy intensive "ends" of the State Water Project and Colorado River Aqueduct, but it is even more valid in other locales.

However, our analysis also reiterates that conveying water can be highly energy intensive. Since conservation saves all of the "upstream" energy inputs as well as end use inputs, conservation in areas with energy intensive water supplies will save substantially more energy than conservation in other areas.

Another conclusion from the urban case study—as well as the agricultural analysis—is that water reuse is far less energy intensive than any physical source of water other than local surface water. The San Diego case study explicitly supports this point, and tailwater recovery uses far less energy than urban water recycling since it usually requires no more than lifting tailwater from low points to high points on each farm. Even groundwater pumping is more energy intensive in San Diego and the Westlands Water District than water recycling from urban wastewater; and the depth to groundwater in these locations is not atypical for western settings.

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ENERGY IN AGRICULTURAL WATER USE

In agricultural settings, energy use varies widely and it is not possible to generalize about which stage of water use dominates. Source and conveyance and end use of water appear to demand the largest portions of energy in water use, but their respective energy use will vary by water source, district location, topography, and irrigation technology, among other factors.

The energy impacts of agricultural water policy decisions may also extend beyond the energy embedded in water use. For example, in some cases, water policy decisions may affect the amount of energy used for harvest and cultivation, which can be quite large. The Westlands Water District case study shows that the energy implications of land fallowing are complicated and worthy of further study, not just in Westlands but in other settings where fallowing (permanent, dry-year, or rotational) is being considered.

Our analysis indicates that the energy impacts of fallowing farmland depend largely on where the water formerly used to irrigate that land is sent instead. From an energy perspective, a combination of conservation and water recycling may be the best path for meeting growing urban needs, while water freed up in agriculture due to efficiency improvements and fallowing might be the best source to satisfy environmental flow needs.

From an energy perspective, a combination of conservation and water recycling may be the best path for meeting growing urban water needs.

Finally, the Columbia case study demonstrates that foregone hydroelectric production (energy opportunity cost) can be very significant when irrigation water is diverted above power production facilities. For example, the foregone energy production in the Columbia Basin Project is the equivalent of 25 percent of the total energy use for the city of Seattle. In some cases, particularly during times of high energy prices, it may be possible to purchase water from farmers for environmental flows and finance those purchases through the additional hydropower revenues. Our analysis strongly suggests that environmental flows and quality can be enhanced in the Columbia Basin without permanent land retirement or reduction in power production, at least in some dry years.

IMPLICATIONS OF THE CASE STUDIES

The analysis in this report supports two primary recommendations:

Decision makers should better integrate energy issues into water policy decision making. The background information in Chapters 1 and 2 and the case studies in Chapters 3, 4, and 5 demonstrate that looking at energy use and water use simultaneously generates valuable insights that do not arise from separate policy analyses of water and energy issues. The specific policy and planning recommendations that flow from this primary recommendation are presented below. Many of these recommendations are potentially relevant—with appropriate modification to account for differences in the policy context—outside California and the Columbia Basin.

Water conservation should be given higher priority by policy planners in both water and energy sectors. Although many planners in the water sector support conservation,

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conservation program implementation has been slow. We conclude that conservation has much stronger economic and environmental benefits than has been recognized to date. Given this strong finding, a policy agenda for promoting water conservation is presented below.

RECOMMENDATIONS FOR WATER RESOURCE PLANNING

Water resource planning must incorporate energy considerations. Given the close relationship between water use and energy use, water and energy policies should be managed comprehensively. State energy and environmental policies must provide consistent encouragement for cities and agriculture to invest in cost-effective energy and water demand-side strategies.

Federal Level

▸ **Perform Energy Intensity Analysis.** The Bureau of Reclamation should perform an energy intensity analysis of its distribution system and identify regions and districts where large amounts of power are required to deliver water. State agencies and the Bureau of Reclamation should fully implement water-use efficiency programs in those regions and should include calculation of energy benefits in determining the cost-effectiveness of water conservation measures in those areas.

▸ **Produce a Power Balance.** The Bureau of Reclamation and the Power Marketing Authorities should produce a power balance that reconciles power generation and purchases with power consumption. There are many discrepancies between the Power Marketing Authorities and the Bureau of Reclamation data sources, which make it difficult to construct a full picture of energy generation and use. For example, given the available data, it's not possible to balance total energy resources (generation and purchases) with energy disposition (sales, consumption, and transmission losses.)

▸ **Change Energy Use Reporting Requirements.** The Department of Energy should ask manufacturers to report energy information on water heating, recirculation, pressurization, and other functions in separate categories rather than embedding that use in broader categories.

▸ **Include Energy in NEPA Evaluations.** The National Environmental Policy Act analyses for water supply issues should take particular care to address energy and related air quality impacts.

State Level

▸ **Revise the Urban Water Management Planning Act.** The legislature should revise the Urban Water Management Planning Act to require water suppliers to consider the energy implications of their water management options, and to factor in related energy costs and benefits when considering water conservation measures or water supply projects.

The legislature should revise the Urban Water Management Planning Act to require water suppliers to consider the energy implications of their water management options.

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► **Include Energy Intensity in Bulletin 160.** The Department of Water Resources should include a regional energy intensity analysis in Bulletin 160 and should identify ways to reduce the energy intensity of water use on a regional basis.

► **Integrate Energy Costs into Economic Analysis of Water Management Alternatives.** CALFED should modify this analysis to include energy costs and benefits from the various CALFED alternatives and to evaluate the economic cost of various alternatives under a variety of energy price scenarios. CALFED should carefully evaluate claims that new water storage facilities will increase net energy production.

► **Coordinate Among Resource Management Agencies.** The Department of Water Resources should consult with the California Energy Commission and the Public Utilities Commission on the potential energy impacts of proposed water policies. For example, the Department of Water Resources should work with the California Energy Commission to evaluate how the proposed increase in delta pumping capacity would affect total energy consumption as well as load shape.

Regional/Local Level

► **Modify the MOU.** The California Urban Water Conservation Council should modify the MOU to require coordination with energy utilities and include energy costs and benefits in the cost-effectiveness methodology.

► **Investigate Energy Implications of Dry-Year Strategies.** The Metropolitan Water District of Southern California, the Department of Water Resources, and the California Energy Commission should investigate the different energy implications of dry-year strategies for Southern California, taking into consideration the premium value of energy during dry years and focusing on regional self-reliance.

► **Include Energy in Integrated Resource Planning.** Water agencies should include energy in their integrated resources plans. These plans should quantify the energy benefits of conservation and water recycling projects.

► **Reduce Energy and Environmental Impacts of Desalination.** Desalination proponents should minimize the energy and environmental impacts of desalination by: 1) looking for opportunities to use this technology on brackish and contaminated groundwater, 2) exploring desalination for use as peak or drought supply rather than base supply, and 3) seeking opportunities to reduce freshwater diversions.

Land Fallowing and Water Transfers in California, the Columbia Basin, and Beyond

Land fallowing and water transfer policies under consideration in California and throughout the West should specifically address the following points:

► **Include Energy in Environmental Analyses.** Environmental analyses for water transfer proposals should explicitly review the energy and subsequent air quality implications of the transfer proposal. The environmental impact report for the Imperial Irrigation District–San Diego transfer did not evaluate these impacts.

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▸ **Plan for Energy Costs in Environmental Water Purchases.** Purchasers for CALFED's environmental water account should include in their purchase plans the conveyance energy benefits of purchasing account water from sources south of the delta. The retirement of drainage-impaired land in the Westlands Water District presents an opportunity to save energy and provide water for environmental restoration.

▸ **Build a Consensus for Dry-Year Contingency Plans on the Columbia River.** The Bureau of Reclamation should initiate a discussion with the Power Marketing Authorities, salmon advocates, regulatory agencies, and farmers in the Northwest regarding the development of a mutually beneficial dry-year contingency plan, designed to provide benefits for agriculture, energy, and the environment along the lines of the scenario presented in Chapter 5.

▸ **Focus on Rivers with Diversions Upstream of Hydropower Plants.** Policy makers around the West should investigate the potential for dry-year partnerships on river systems where there are large water diversions upstream of hydropower facilities and degraded rivers.

RECOMMENDATIONS FOR ADVANCING WATER CONSERVATION

Our analysis shows that the most effective way to reduce energy related to water use is to consume less water. In addition to reducing the energy required for end use, conservation eliminates all of the upstream energy required to bring the water to the point of use, as well as all of the downstream energy that would otherwise be consumed to treat and dispose of this water. In many cases, conservation provides the most cost-effective water supply option, particularly once energy costs are included. The federal, state, and local governments, as well as water and energy utilities, should prioritize conservation. To increase conservation, decision makers should:

In many cases, conservation provides the most cost-effective water supply option, particularly once energy costs are included.

Conservation Funding

▸ **Prioritize Conservation Funding.** State, federal, and local budget problems will limit the availability of public funding for many programs. Nonetheless, investment in conservation may forestall or avoid larger public investments for drinking water, clean water infrastructure, or power generation facilities, and it will help stretch available funds.

Conservation Requirements

▸ **Implement Existing Requirements.** The Bureau of Reclamation should implement the water conservation planning requirements of the Central Valley Project Improvement Act and Reclamation Reform Act.

▸ **Ensure Compliance with the MOU.** The Department of Water Resources should require anyone receiving water from the State Water Project, directly or indirectly, to fully implement the terms of the Memorandum of Understanding Concerning Urban Water Conservation in California.

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Water Measurement and Pricing

► **Enact Universal Measurement Legislation.** All water use in the state, including surface and groundwater, should be measured, and water users should be charged for each unit of water they use. This is a precondition for efficient water use. The CALFED Authority should meet its commitment to develop legislation requiring appropriate measurement of water use for all water users in California.[117] This legislation should require:

▷ Measurement and volumetric billing of all urban and agricultural water use;
▷ Dedicated meters for large landscapes;
▷ Submetering of multi-family housing.

► **Conduct Groundwater Monitoring.** The CALFED Authority should develop and the legislature should adopt groundwater monitoring legislation to improve management of this unregulated resource.[118]

The CALFED Bay-Delta Authority should require full implementation of conservation measures, including water measurement and volumetric pricing, as a prerequisite for receiving any program benefits.

► **Eliminate Subsidies.** The federal government should phase out irrigation, energy, and crop subsidies, which encourage wasteful use of water and energy, as well as cultivation of low-value crops and cultivation of marginal lands where irrigation contributes to water quality problems.

► **Establish Wastewater Volumetric Pricing.** The legislature should pass legislation requiring wastewater agencies to bill their customers volumetrically. Flat rates for wastewater fail to deliver a price signal to customers to reduce their indoor water use. Volumetric billing of wastewater is already endorsed by Best Management Practice 11 in the Urban MOU. This measure has strong precedent in other states: in Texas and Florida, more than 97 percent of sewer rates are volumetric and in Arizona 68 percent are volumetric. In California, only 13 percent of the state's wastewater treatment providers bill by volume.

► **Require Dedicated Meters for Large Landscapes.** The legislature should pass AB 2298 (Plescia), requiring dedicated meters to measure landscape water use. This complements Best Management Practice #5 in the Urban MOU, and would provide a valuable conservation tool for water agencies and landscape managers.

► **Establish Rates for Outdoor Water Use.** Water agencies should establish seasonal or tiered water rates to target outdoor water use. The Urban MOU has not yet successfully addressed outdoor water use. Rate structures are an effective tool for targeting outdoor water use.

Conservation Incentives

► **Tie CALFED Benefits to Conservation.** The CALFED Bay-Delta Authority should require full implementation of conservation measures, including water measurement and volumetric pricing, as a prerequisite for receiving any program benefits.

► **Broaden Energy Conservation Programs.** Energy utilities should broaden their water conservation efforts to include all water use, not just the conservation of heated water.

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► **Pursue Conservation above the MOU.** The CALFED Bay-Delta Authority and its member agencies should develop programs targeted at obtaining water conservation savings beyond the levels specified in the MOU. The MOU does not require implementation of all cost-effective conservation. Indeed, while much of the focus in CALFED and elsewhere tends to be on implementation of the best management practices, there remain significant cost-effective conservation savings beyond those practices.

► **Link Loans to Conservation Achievements.** The State Board and Department of Health Services should tie clean-water and drinking-water revolving-fund loans to conservation achievements. The state operates two federally authorized revolving funds that provide loans to local agencies for certain drinking water and wastewater infrastructure investments. California's total estimated needs for these expenditures is approximately $30 billion. A large percentage of these needs are flow-related and could be delayed or reduced if projected flows or volumes were reduced through conservation. As a condition to granting revolving-fund support, the State Board and Department of Health Services should require applicants to demonstrate that all projects for which funding is being sought have been sized and timed to account for full implementation of conservation programs.

Conservation Assurances

► **Adopt Best-Management-Practice Certification.** The CALFED Authority should adopt a best-management-practice certification process for urban conservation with consequences for noncompliance.[119]

► **Establish Agricultural Water-Use Efficiency Objectives.** The Department of Water Resources should finalize the remaining quantitative objectives for agricultural water use efficiency and an assurances package that includes consequences for failing to meet those objectives. The Department of Water Resources should conduct the overdue evaluation of progress toward meeting the quantitative objectives.

► **Verify Water Savings.** The Department of Water Resources must include a monitoring component in all water conservation grants to verify conservation savings and track disposition of conserved water. Expediting distribution of funds should not take precedence over good science.

► **Revise the Cost-Benefit Analysis.** The Department of Water Resources should revise the cost-benefit methodology required as part of the water-use efficiency grant process to require inclusion of energy costs and benefits.

► **Pass a Retrofit-Upon-Resale Law.** The state legislature should adopt a retrofit-upon-resale law requiring replacement of inefficient toilets with ultra low-flow toilets upon sale of a home. Such ordinances are in effect in Los Angeles, Santa Monica, San Diego, and other cities. The Urban MOU requires signatories to adopt programs that are at least as effective as a retrofit-upon-resale ordinance, but to date, few programs have achieved that level of implementation. The California real estate

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market remains incredibly strong, and a retrofit-upon-resale requirement would have little impact on this market.

► **Improve the Model Landscape Ordinance.** The existing model landscape ordinance, developed in response to AB 325, is deficient in several respects. The California legislature should pass legislation to revise and improve the model ordinance.

AREAS FOR ADDITIONAL RESEARCH

Our research highlighted several areas where additional data could improve energy intensity analysis and facilitate the integration of energy considerations in water policy. Some of these are listed below:

► **Investigate Evaporative and Conveyance Losses.** The California State Water Project, the Central Valley Project, and water districts, agencies, and companies should conduct analyses of evaporative and conveyance losses throughout their systems, not just in large canals, aqueducts, and distribution piping.

► **Go Beyond Appliances.** The Department of Energy or another party should analyze energy use integral to end use of water beyond domestic fixtures and appliances.

► **Fund Research in Water Use Efficiency.** The Department of Water Resources should fund research to address remaining areas of uncertainty in water use efficiency, including the relationship between evaporation and transpiration and the potential for reducing irrecoverable losses through reductions in evaporation.

► **Study the Link Between Water Policy and Emissions.** The Department of Water Resources or another party should extend the models presented in this report to estimate changes in air emissions resulting from water policy decisions. Demonstrating the linkage all the way through to air quality would greatly strengthen the policy recommendation that water management decisions should account for the energy dimension.

► **Examine the Climate Change Implications for Water Policy.** The Department of Water Resources and the California Energy Commission should evaluate the climate change implications of water policy.

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APPENDIX A

URBAN MODEL DESCRIPTION

We have modified and expanded the methodology of Wilkinson into a user-friendly spreadsheet to determine the energy embedded in water use from source to disposal.[120] Filling out the spreadsheets completely would require full information about actual and potential water and water-related energy use in San Diego County. Full information is never available in practice, but the information gaps that will exist are not known in advance, so this type of spreadsheet is the best analytical starting point. Note that the spreadsheets include water sources that are being considered for San Diego but are not actual (e.g., seawater desalination, transfer from the Imperial Irrigation District, and water bags towed by sea from Northern California).

The eight Excel spreadsheets we used are organized in three layers (see Figure A-1):

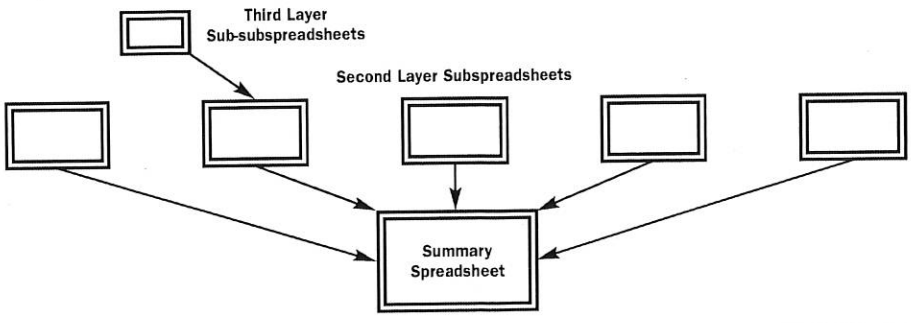
1. One summary spreadsheet.

2. Five subspreadsheets, one each for sources, water treatment, water distribution, end use, and wastewater treatment. Water recycling projects are considered to be sources of water. Their energy use consists of the energy required to upgrade water from discharge-suitable quality into reuse-suitable quality.

3. Two sub-subspreadsheets, one each for groundwater sources and water recycling sources.

Copies of the spreadsheets are available from Pacific Institute.

FIGURE A-1
Diagram of the Flow Between Spreadsheets



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The summary spreadsheet does not allow for data input, while the other seven spreadsheets require data input. All eight spreadsheets perform calculations. The five steps in the water-supply-use-disposal chain fix the number of spreadsheets in the second layer. The number of the third-layer spreadsheets depends on the circumstances. Each third-layer spreadsheet allows the user to assemble disaggregated data about one aggregate item in a second-layer spreadsheet. For example, the groundwater spreadsheet contains data on various groundwater sources that are aggregated into a single column in the sources and conveyance spreadsheet.

SUMMARY SHEET (TOP LAYER)

The summary spreadsheet does not allow inputs, and incorporates data directly from the penultimate spreadsheets (and indirectly from the subpenultimate spreadsheets). Here, the user can gain an overview of the energy embedded in water use as a function of the five principal energy components of urban water cycles. The effect of new water sources or conservation measures on energy use can be analyzed in the summary spreadsheet through changes in the data inputs of the other spreadsheets.

Row 5 summarizes the volume of water that enters each of the five principal energy components. Decreases in volume that occur between the first (sources and conveyance) and last (wastewater collection and treatment) of these components reflects water loss (both consumptive and nonconsumptive) that occurs during the water cycle. Row 6 summarizes the average annual energy use for each of the five steps in the supply-use-disposal chain, with total energy use summed across the five components presented in column K. Because these are total energy use figures for each component, their sum is an accurate number—it reflects total energy use in the chain based on the mix of supplies, the level of conservation, and so forth, input to the other spreadsheets.

Row 7 calculates the energy factor, a ratio of energy consumed (kWh/yr) to water consumed for end uses (af/yr), thus normalizing energy consumption per unit across the five principal energy components. The total of the energy factors for row 7 is in column K. Row 8 reports the energy factors as percentages and contains the data used to create "The Percent Energy Use in the Five Components of Urban Water Systems" graph. This graph visually depicts the percentage energy use by the urban water system component and helps to show where energy is being consumed under the assumptions that have been input. Although the first summary spreadsheet that a user of the model creates should reflect actual conditions, one can examine counterfactual scenarios by changing the inputs in the penultimate and subpenultimate spreadsheets.

SUBSPREADSHEETS (SECOND LAYER)

We have organized this layer of spreadsheets according to the five steps described previously: 1) sources and conveyances, 2) water treatment, 3) distribution, 4) end use, and 5) wastewater collection and treatment. Each subspreadsheet has a similar

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format and requires three types of data: 1) average annual volume (in af/yr) of water "in," 2) average annual energy use (in kWh/yr), and 3) percentage of water loss. Several spreadsheets require additional data and are noted as such in the following descriptions.

Sources and Conveyances

This category represents the energy required for the extraction of raw water from its source and the conveyance of water to the site of treatment, either via pumping or water transport (e.g. water bags). For example, it requires more than 3,200 kWh/yr of energy to pump water from intakes in the delta through the State Water Project to San Diego (row 8, column C). For water recycling and desalination, this category includes the energy required to extract usable water from wastewater, brackish water, or salt water. San Diego potentially obtains water from the seven sources and conveyances listed as columns in this spreadsheet.

For each source and conveyance, the following inputs are required and calculations are performed. The average annual water supplied (in acre-feet) from each source and conveyance is input and is summed across to obtain a total average annual water supply (row 5, column K). Using the data from row 5, row 6 calculates the percentage of water supplied by each source and conveyance. The cells in row 6 are locked, meaning the user cannot change the percentage of water supplied by each source and conveyance. Users may investigate how changing the water supply and conveyance portfolio (i.e. percentage of water supplied by each source and conveyance) affects energy use by changing the water supply data in row 5. Users may also change the total average annual water supply (but keep the water supply and conveyance portfolio constant) to investigate how absolute rather than relative changes affect energy use.

The percentage of water loss that occurs after removal from a source and/or during conveyance may be input into row 7. This is useful information if available, but is not necessary for the calculations leading to the summary spreadsheet. If water "in" is input for all cells in all the spreadsheets, percent loss is the difference between water "in" to one step of the chain and water "in" to the next step of the chain. The input for percentage of water loss here provides an alternative method for estimating the amount of water into the next step in the chain if the user is unable to obtain "in" data for the next step (in this case, water treatment).

The average annual energy use (in kilowatt-hours) required for each source and conveyance is input in row 8 and is summed across sources and conveyances to obtain total average annual energy use (row 8, column K). Row 9 allows for the user to enter comments regarding the quality of the water supply should there be any unusual aspects of a water source and conveyance. The quality of raw water will often affect energy used to treat it, with more than average energy used if raw water is brackish and less than average energy used if raw water is from a desalting facility or very high-quality natural source.

The groundwater sources and water reuse columns are calculated from sub-penultimate spreadsheets described below. These subspreadsheets keep the sources

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and conveyance spreadsheet manageable. We recommend using a subspreadsheet when more than two facilities exist for a column in a penultimate spreadsheet.

Water Treatment

This category represents the energy required for the processes that occur within a water treatment facility to obtain treated water that meets potable water health standards. Often, filtration or flocculation and sedimentation, followed by disinfection, are adequate. There are 10 water treatment facilities that process water treated in San Diego County. In addition, the Metropolitan Water District delivers treated water from the Skinner treatment plant in Riverside County. For simplicity, the model structure assumes that the location of the treatment facility (e.g., in the county or out of the county) does not affect the energy used to convey and distribute water to customers.[121]

The inputs required and calculations performed for the water treatment spreadsheet are the same as those for the sources and conveyances spreadsheet. As in the sources and conveyances spreadsheet, the user can enter information regarding water quality, highlighting the variation in energy factors across plants.

Distribution

This category represents the energy required for any pressurization or pumping that occurs as treated water leaves the water treatment facility and for the transport of treated water through the distribution blocks. There are many distribution zones within San Diego County. Note that the spreadsheet is constructed as if each distribution zone conveys water from one or more treatment plants to end users. If water were to pass through two distribution zones between treatment plant and end users, the spreadsheet would need to be modified to account for energy use "in series" rather than "in parallel."

The distribution spreadsheet does not allow for the user to enter notes regarding water quality. The assumption is that all water is of the same quality (i.e., treated to potable standards). Otherwise, the inputs required and calculations performed are the same as those for the sources and conveyances spreadsheet.

End Use

This category represents the energy required for all end uses; i.e., those that are measured via metered water consumption. Urban water users are primarily those in the municipal and industrial sector. For the general spreadsheet, we divide water use into the two large categories typical of urban water supply planning: 1) residential and 2) commercial, industrial, and institutional (CII). We further subdivide residential use into categories that apply throughout the western United States: clothes washers; dishwashers; showers, tubs, and faucets; toilets; turf landscape; and non-turf landscape. We do not subdivide CII uses at this time.

The inputs required and calculations performed for the end use spreadsheet are the same as those for the sources and conveyances spreadsheet, with the exception that average annual energy use includes kilowatt-hours actually used plus thermal energy converted to kilowatt-hours at a heat rate of 10,239 British thermal units

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per kilowatt-hour. This conversion represents the electrical energy that could be produced at average thermal power plant efficiency if thermal energy were in fact converted to electricity prior to use. This is necessary to report total energy intensity numbers (equivalent kilowatt-hours), but should not be misinterpreted as actual kilowatt-hours used in any category.

Energy use during end use is in addition to the energy used to pressurize water in distribution systems. Some end uses do not use additional energy. For example, flush toilets with gravity sewers do not use additional energy, so the cell for energy use by toilets contains a zero value. Similarly, irrigation systems that operate solely from distribution pressure do not use additional energy unless they have electrically operated valves or control systems. In contrast, any use of hot water involves additional energy, as do appliances that include motors, pumps, automatic valves, timers, and so forth (e.g., clothes washers or recirculating pumps at car washes).

In this sense, end use energy is no different than source and conveyance, treatment, distribution, and disposal energy. It is one of five parts of a chain of energy uses that must be added to obtain total energy use associated with each acre-foot of water used by customers.

However, end use represents a unique step among the five parts of the supply-use-disposal chain. It is the only step where conservation saves energy in the other four steps. Reducing water losses in conveyance will reduce the amount of energy associated with each acre-foot delivered. But it will not reduce total energy consumed in other steps if water delivered to customers is held constant. Reductions in distribution losses (the biggest part of "unaccounted-for water") are similar. But reductions in water consumption will affect total energy use in all five parts of the chain, even though it may not reduce the amount of energy associated with each acre-foot of use.

Stated another way, total energy use depends on the average energy factor of a system (average kWh/af delivered to customers) and the total water consumption of the system (acre-feet). Conservation doesn't necessarily affect the average energy factor, although it may, but it will always affect total energy use. Many water conservation technologies also reduce energy use, so conservation will often save energy in total and pull down the average energy factor of the system. However, some water conservation measures use more energy than pre-conservation practices, driving up the average energy factor of the system. But even if the average energy factor is driven up because energy is being substituted for water, speaking in the jargon of economics, total energy use can still decline because the increased energy in end use may be smaller than the energy savings from reducing the customer's need for water.

The linked spreadsheets account for these possibilities. First, one inputs average energy use associated with water use in each category (e.g., CII) or subcategory (e.g., clothes washers). Then, when considering implementation of water conservation measures, one both reduces total end use of water by the amount of conservation and adjusts the energy use in each end use category and subcategory to reflect energy use after implementation of that amount of conservation. The adjusted energy use inputs may be higher or lower than before conservation. If lower, the

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average system energy factor and total system energy consumption will decline. If higher, the average system energy factor will increase but total system energy consumption may increase or decrease.

Wastewater Collection and Treatment

This category represents the energy required for the transport of wastewater to the wastewater treatment facility—lift requirements are significant in many places and all wastewater treatment processes, which usually consist of a series of physical processes (e.g., pumping, screening, and filtration), chemical processes (e.g., chlorine addition), and biological processes (e.g., microbial removal of contaminants) to prepare wastewater and waste solids for release back into the environment. San Diego County has 14 wastewater treatment facilities.

The wastewater collection and treatment spreadsheet is similar to the other spreadsheets with respect to data input and calculations; any unusual wastewater treatment requirements can be noted in the bottom row.

SUB-SUBSPREADSHEETS (THIRD LAYER)

The sub-subspreadsheets perform calculations, the results of which feed into the subspreadsheets. Thus, the subspreadsheets remain streamlined with a consistent format while background calculations are conducted in the sub-subspreadsheets. Based on our evaluation of San Diego County, we believe that two spreadsheets in the third layer are adequate to model any water system. Another spreadsheet for local reservoirs might be necessary if energy use or production from those reservoirs were significant. In San Diego County, however, energy used to charge the reservoirs with imported water is included in the import columns of the source and conveyance spreadsheet, and energy production from the reservoirs is reported to be very small. This is typical for relatively small terminal reservoirs in a system that depends heavily on imported water.

Groundwater Sources

The objective of this spreadsheet is to determine the average annual volume of water that comes from each of the groundwater sources (row 5) and the average annual energy use associated with each groundwater source (row 7). Energy requirements are due primarily to pumping and conveyance of groundwater. Groundwater pumps are either electric or gas; if they use gas, energy use in therms is converted into kilowatt-hours (row 6). Row 8 allows the user to input information regarding the quality (e.g. brackish water, seawater) of the groundwater source if it is unusual. The weighted averages from the groundwater sources spreadsheet are linked to the groundwater column in the sources and conveyances spreadsheet.

Water Reuse Projects

The objective of this spreadsheet is to determine the average annual volume of water (row 5) that comes from each of the water recycling projects and the average annual

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energy use associated with water recycling (row 7). Energy requirements are due primarily to pumping and conveying recycled water. Row 8 allows the user to input data regarding the water quality associated with each water reuse project. The results from the water reuse projects spreadsheet are linked to the water reuse column in the sources and conveyances spreadsheet.

San Diego has 24 water reuse projects; the water from these projects is primarily used for agriculture, landscaping, and irrigation purposes. Note that this is the energy used to upgrade water from a quality level adequate for legal discharge to the quality level required for reuse. Energy used to treat wastewater to discharge quality is included in the wastewater collection and treatment subspreadsheet.

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APPENDIX B

SAN DIEGO CASE STUDY DATA SOURCES AND ASSUMPTIONS

▸ The State Water Project (SWP) pumping energy is from Wilkinson.[122] Flow from Devil's Canyon to the San Diego County Water Authority (SDCWA) is assumed to be by gravity via Lake Perris, the Diamond Valley Lake, or Lake Skinner. Energy intensity is assumed to be for water delivered to Devil's Canyon. That is, water losses in the SWP are already accounted for in this energy intensity figure.

▸ The Colorado River Aqueduct (CRA) pumping energy is from Wilkinson.[123] Flow to the SDCWA is assumed to be by gravity via Lake Mathews, the Diamond Valley Lake, or Lake Skinner. Energy intensity is assumed to be for water delivered to Lake Mathews, or equivalent.[124] That is, water losses in the CRA are already accounted for in this energy intensity figure.

▸ Water-bag towing expenditures are for diesel fuel energy from Spragg for a 400-mile round-trip from the Mad River to Monterey, adjusted for a 900-mile round-trip from the Mad River to San Diego.[125] Energy expenditures were converted to kilowatt-hours equivalent using $1.50 per gallon, 150,000 BTU per gallon, and 10,239 BTU required to produce each kilowatt-hour.

▸ Hydroelectricity is not produced in the Colorado River between the intake of the CRA and the intake of the All American Canal.[126]

▸ Hydroelectric power not produced in the All American Canal if water were transferred to San Diego is based on an average of 2.85 million af/yr of flow in the canal and an average of 3 million kWh/yr of hydroelectricity produced from that flow.[127] Adjusting for an assumed 5 percent loss of water in the CRA, these figures yield 110 kWh lost per acre-foot delivered to San Diego County.

▸ Energy use per acre-foot for the SDCWA Seawater Desalination Facility at Encina is from SDCWA staff.[128]

▸ Raw water lift to treatment plants is from SDCWA. Staff provided data for the Levy and Perdue water treatment plants.[129] It is assumed to be representative of other plants in the county and the Skinner treatment plant operated by the Western Municipal Water District in Riverside County.

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▸ Groundwater lift data are from SDCWA. Staff provided data for the Yuima Municipal Water District and the Sweetwater Authority.[130]

▸ Energy use in water recycling is from SDCWA. Staff provided data for supplemental treatment at San Elijo and Santee Basin and brackish groundwater treatment at Reynolds.[131]

▸ Energy use in water treatment is from SDCWA. Staff provided data for Vista (Escondido), Levy, and Perdue water treatment plants.[132]

▸ Water loss in water treatment was assumed to be 5 percent based on calculations at the Perdue (Sweetwater) treatment plant.[133]

▸ Energy use in water distribution is from the Helix Water District's distribution system from the Levy treatment plant and the North City recycled water system.[134] Note that about half the distribution system flow from Levy is pressurized by gravity, so pump pressurization requirements are higher per acre-feet than the figures used. Our analysis uses the weighted average figure because, according to SDCWA staff, significant portions of the distribution system in San Diego County are pressurized by gravity.[135]

▸ Distribution loss (unaccounted-for water) is assumed to be 7 percent based on one estimate of the sum of losses in regional distribution and local distribution provided by SDCWA staff.[136]

▸ Water use in the SDCWA service area in 2010 is projected to be 32 percent CII (commercial, industrial, and institutional uses); 58 percent residential (41 percent single-family, 17 percent multi-family); and 10 percent agricultural, according to SDCWA staff.[137] Our analysis assumed these figures are also roughly representative of current use.

▸ Residential water use is assumed to be 60 percent indoor, 40 percent outdoor.[138]

▸ Indoor use is further disaggregated according to the Awwa Research Foundation: toilets, 26.1 percent; clothes washers, 22.7 percent; showers, 17.8 percent; faucets, 15.4 percent; leaks, 12.7 percent; baths, 1.8 percent; dishwashers, 1.4 percent; other, 2.1 percent.

▸ CII use was disaggregated as in Gleick et al: 38 percent landscaping, 6 percent kitchen (composed of 24 percent dishwashers, 14 percent pre-rinse nozzles, 62 percent other kitchen), 15 percent cooling, 14 percent restroom, 18 percent process, 2 percent laundry, and 7 percent other.[139]

▸ Energy use in clothes-washers and dishwashers are averages from the Department of Energy's Energy Star website.[140] Energy use in showers and baths assumes heating from 60 to 105 degrees Fahrenheit; faucet water is conservatively assumed to be unheated.

▸ All dishwasher energy savings are assumed to be from reduced consumption of hot water; three-quarters of clothes-washer savings are assumed to be from reduced consumption of hot water.[141]

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► Water-cooled chiller energy consumption of 0.5 kWh/ton from the Federal Energy Management Program website.[142]

► Evaporative water consumption and the ratio of evaporative consumption to blowdown in water-cooled chillers from city of San Jose.[143]

► CII energy use for water heating from Sezgen and Koomey.[144]

► Energy use in industrial wastewater treatment in the United States is from Amarnath,[145] conservatively assuming the reported $2.5 billion of annual fuel and energy expenditures for treatment were for diesel fuel or gasoline at $1.50 per gallon, with heat content of 150,000 BTUs per gallon.[146]

► Industrial water use for the United States also from Amarnath, but cross-checked against United States Geological Survey Circular 1081.[147]

► Energy use in wastewater treatment is from SDCWA. Staff provided data for the North City and Santee Basin facilities.[148] Note that energy intensity per acre-foot treated is significantly higher than the energy intensity presented in Figure 4 because the latter is energy intensity per acre-foot of end use. Only 46 percent of countywide water use is estimated to enter the wastewater system because landscape and agricultural water use, pipe leaks, and some CII processing and cooling water are not tributary to wastewater treatment plants.

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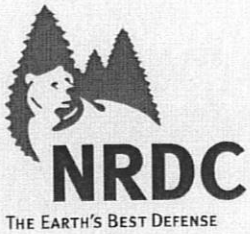
APPENDIX C

AGRICULTURAL MODEL DESCRIPTION



ENERGY DOWN THE DRAIN

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The agricultural model structure is parallel to the urban model presented in Appendix A. However, a number of modifications were required to account for differences between urban and agricultural settings. Some of the differences include:

- Sources other than surface and groundwater, recycled water, and conservation are rarely used for agriculture. For example, desalination for agricultural use is unheard of. The economic value of agricultural products is not high enough to justify the more expensive sources of water used in urban settings.
- Water for agriculture is rarely treated unless it is reclaimed from a wastewater source.
- Hydroelectric production opportunities and trade-offs are often more complicated for agricultural water than urban water.
- Agricultural water is often distributed to end use (the plants in the fields) by gravity in open channels, although pressurized distribution via sprinklers or drip irrigation systems is also common. Often, water is lifted a short height—such as 10 feet—from the distribution canal to the field.
- On-farm redistribution from irrigation-tailwater-return ponds is growing in popularity as a way of conserving water and reducing discharge of pollutants. The urban analogy is on-site water reuse by industry. However, industrial water reuse usually involves treatment, while on-site agricultural reuse usually does not.
- The water quality standards for recycled wastewater intended for agricultural reuse are lower than for urban reuse, which implies less energy consumption per unit of water recycled. Recycling wastewater for agricultural purposes is common in the western United States, especially in landlocked areas where discharge to receiving waters is restricted either during the dry season or year-round.

There is no treatment spreadsheet since agricultural water is not treated between source/conveyance and distribution. As in the urban model, distribution is separated into generic blocks. End uses are defined as crop type/irrigation system combinations. For example, one could grow almonds with flood irrigation or with permanent sprinklers. Energy for pressurizing the sprinklers or lifting water from edge-of-farm canals is included in end use energy, not in distribution energy. In

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concept, a spreadsheet for drainage management would replace the wastewater treatment spreadsheet in the urban model. In the Westlands Water District, however, drainage management other than tailwater-return ponds does not use energy. Tailwater-return energy use is accounted for in the third-layer water-reuse spreadsheet that feeds the sources and conveyances spreadsheet. The groundwater spreadsheet is conceptually identical to the urban model.

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ENDNOTES

1 The use of water in producing energy is an important subject but is beyond the scope of this report. For information on this issue see, for example Ellen Baum, et al., *The Last Straw: Water Use by Power Plants in the Arid West*, (Boston: The Clean Air Task Force and the Land and Water Fund of the Rockies, 2003).

2 California Water Code, Section 522.

3 California Energy Commission, *Agricultural Rates in California* (Sacramento, California: California Energy Commission, 2001), p. 9.

4 Electric Power Research Institute, *Energy Audit Manual for Water/Wastewater Facilities*, (Palo Alto: 1999), Executive Summary.

5 There are 11.5 million households in California (U.S. Census). Each of these households consumes an average of 6,500 kWh/yr. "California Energy Consumption by Sector," available at http://energy.ca.gov/electricity/consumption_by_sector.html.

6 Nathanael Greene and Roel Hammerschlag, "Small and Clean Is Beautiful: Exploring the Emissions of Distributed Generation and Pollution Prevention Policies," in *The Electricity Journal*, June 2000, pp. 50–60.

7 Frank Burton, *Water and Wastewater Industries: Characteristics and Energy Management Opportunities* (Palo Alto, CA: Electric Power Research Institute, 1996), pp. 3–9.

8 Robert C. Wilkinson combines treatment and distribution; i.e., he divides the water chain into four stages in *Methodology for Analysis of the Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures* (Santa Barbara, CA: University of California, Santa Barbara, Environmental Studies Program, 2000).

9 Electric Power Research Institute, Executive Summary.

10 Carrie Anderson, *Energy Use in the Supply, Use, and Disposal of Water in California*, (Sacramento: California Energy Commission, 1999), p.9.

11 "Power Plants Kill Billions of Fish," available at: www.riverkeeper.org/campaign.php/fishkills/the_facts/178. For additional information on the impacts of power plants on aquatic resources, see, for example, Peter Raimondi's testimony before the Central Coast Regional Water Quality Control Board, July 10, 2003, entitled "Cooling Water System: Findings Regarding Clean Water Act Section 316(b), Diablo Canyon Power Plant." This testimony is available at: www.swrcb.ca.gov/rwqcb3/Facilities/Diablo/Diablo.htm.

12 For more information on these impacts see, for example, Bruce Driver and Gregg Eisenberg, *Western Hydropower: Changing Values/New Visions, Independent Report to the Western Water Policy Review Advisory Commission* (Boulder, CO: 1997); and Phillip Williams, "The Flood Next Time: Restoring Living Rivers," in *World Rivers Review*, February 2000, p. 6.

13 For further discussion of global climate change and its impacts on water supply, see Peter H. Gleick and D. Briane Adams, *Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States, the Report of the Water Sector Assessment Team for the U.S. Global Change Research Program* (Oakland, CA: Pacific Institute, 2000); Victor S. Kennedy, et al., *Coastal and Marine Ecosystems and Global Climate Change: Potential Effects on U.S. Resources* (Arlington, VA: Pew Center on Global Climate Change, 2002); Jay R. Lund, et al., *Climate Warming and California's Water Future* (Davis, CA: Department of Civil and Environmental Engineering, University of California, 2003), Kirkman O'Neal, *Effects of Global Warming on Trout and Salmon in U.S. Streams* (Washington, DC: Defenders of Wildlife, 2002); N. Leroy Poff and Mark Brinson, *Aquatic Ecosystems and Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States* (Arlington, VA: Pew Center on Global Climate Change, 2002); and *Confronting Climate Change in California: Ecological Impacts on the Golden State* (Cambridge, MA: Union of Concerned Scientists, 1999).

14 *Climate Changes the Water Rules: How Water Managers Can Cope With Today's Climate Variability and Tomorrow's Climate Change* (Delft, The Netherlands: The Dialogue on Water and Climate, 2003). This collaborative report is available at: www.waterandclimate.org/report.htm.

15 Peter H. Gleick and Linda L. Nash, *The Societal and Environmental Costs of the Continuing California Drought* (Oakland, CA: Pacific Institute, 1991).

16 A full discussion of water and power subsidies is beyond the scope of this report. For more information on the magnitude of these extensive subsidies, see, for example, Norman Myers and Jennifer Kent, *Perverse Subsidies: How Misused Tax Dollars Harm the Environment and the Economy* (Washington, DC: Island Press, 1998); Committee on Natural Resources, *Taking from the Taxpayer: Public Subsidies for Natural Resource Development* (Washington: U.S. Government Printing Office, 1994); B. Delworth Gardner, *Plowing Ground in Washington: The Political Economy of U.S. Agriculture* (San Francisco: Pacific Research Institute for Public Policy, 1995); Ronald Bailey, ed., *The True State of the Planet* (New York: Competitive Enterprise Institute, 1995); and Dr. E. Phillip LeVeen and Laura B. King, *Turning Off the Tap on Federal Water Subsidies* (New York: NRDC, 1985).

17 Committee on Natural Resources, p. 64.

18 Committee on Natural Resources, p. 66.

19 The Central Valley Project no longer charges a power rate for its water deliveries. In part, this seems to be because it does not want to be subject to oversight by FERC or other agencies. Instead, the Central Valley Project includes a per-acre-foot power charge for water deliveries. The per-acre-foot energy rates vary widely from contractor to contractor, ranging from one penny to $4.96 per acre-foot. Jesus Reynoso, Water Rate-Setting Section, United States Bureau of Reclamation Finance Office, personal communication, April 2003.

20 *Mid-Pacific Region 1999 Irrigation Water Rates, Central Valley Project* (Sacramento, CA: U.S. Bureau of Reclamation, Mid-Pacific Region, 1999).

21 B. Delworth Gardner, *Plowing Ground in Washington: The Political Economy of U.S. Agriculture* (Pacific Research Institute for Public Policy), p. 296.

22 Our San Diego case study shows that about 2,100 kWh/af will be required to support the transfer. About 5 percent of this amount (100 kWh/af) is hydroelectricity not produced in the All American Canal; the other 2,000 kWh/af are used as electricity to pump the transferred water through the Colorado River Aqueduct. Each 100,000 af/yr of water transferred to San Diego, therefore, may increase electricity demand by 210 million kWh/yr. This is certainly not negligible, and should have been discussed in the environmental impact review.

23 S. Joshua Newcom, "Dealing with the Shock: Shedding Light on the Link Between Water and Power in California," in *Western Water*, September/October 2001, p. 7.

24 Wilkinson, p. 6.

25 Surface and groundwater figures come from Department of Water Resources, *Bulletin 160-98*; recycled water figure comes from Department of Water Resources, *Water Recycling 2030: Recommendations of California's Recycled Water Task Force*, 2003; desalination figure comes from Department of Water Resources, *Bulletin 160-03*, 2003 stakeholder draft.

26 Carrie Anderson, *Energy Use in the Supply, Use, and Disposal of Water in California* (Sacramento: California Energy Commission, 1999) p. 1.

27 Wilkinson, p.7.

28 Steve Kashiwada, State Water Project, personal communication, June 2002.

29 Barry Mortimer, Central Valley Project, May 2002, and Steve Kashiwada, State Water Project, personal communication, June 2002.

30 Larry Dale, et al., *The Impact of Electricity Prices on the Cost of Five Options to Increase Southern California's Urban Water Supplies* (prepared for NRDC, 2003), p. 4.

31 Anderson, p.4.

32 Larry Dale, et. al., 2003.

33 California Energy Commission, p. 16.

34 Department of Water Resources, *California Water Plan Update 2003–Stakeholder Draft*, (Sacramento, CA: 2003).

35 *Seawater Desalination and the California Coastal Act (DRAFT)* (Sacramento, CA: California Coastal Commission, 2003).

36 John Kiernan, personal communication, March 2003.

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37 Wilkinson.

38 Ibid.

39 Barakat & Chamberlin, Inc., *The Value of Water Supply Reliability: Results of a Contingent Valuation Survey of Residential Customers* (Sacramento, CA: California Urban Water Agencies, 1994).

40 The Ocean Conservancy, *Desalination: An Overview*, prepared for May 5, 2003, Environmental Roundtable Meeting in San Francisco.

41 California Water Code Section 13050 (n).

42 Department of Water Resources, Recycled Water Task Force, *Water Recycling 2030: Recommendations of California's Recycled Water Task Force*, (Sacramento: June 2003), p.7.

43 Ibid., p.5.

44 Ibid., p.5.

45 Newcom, p.12.

46 "Water Pipeline Project Underway in Orange County," Orange County Water District Press Release, February 19, 2004, available at: http://www.gwrsystem.com/news/releases/040219.html.

47 Burton, pp.3–30. In addition to direct energy costs for water treatment, substantial energy is also required to produce the chemicals used for water treatment. Those costs, while beyond the scope of this report, are part of the life-cycle energy costs of water.

48 Burton, p. ES–5.

49 Burton, p. ES–4.

50 Burton, pp. 3–9.

51 Burton, pp. 3–27.

52 *Draft WUE Program Plan* (Sacramento, CA: CALFED Bay-Delta Program, 1999), pp.5–21.

53 National Renewable Energy Laboratory, "Cities Cut Water System Energy Costs," 1994.

54 Irrigation Training and Research Center, *Variable Frequency Drives and SCADA—Are They Worthwhile Investments?* ITRC Report 02-006 (San Luis Obispo, CA: California Polytechnic State University, 2002).

55 Gleick, et al., p.3.

56 Gleick, et. al., p.2.

57 Peter W. Mayer, et al., *Residential End Uses of Water* (Denver, CO: American Water Works Association Research Foundation, 1999).

58 Tables 3 through 5 modified from Amy Vickers' *Handbook of Water Use and Conservation: Homes, Landscapes, Business, Industries, Farms* (Amherst, MA: WaterPlow Press, 2001).

59 Gary H. Wolff and Peter H. Gleick, "The Soft Path for Water," in *The World's Water: The Biennial Report on Freshwater Resources* (Washington, DC: Island Press, 2002).

60 For a complete discussion of residential conservation measures, see Vickers, and Gleick, et.al., 2003.

61 *Codes and Standards Enhancement Initiative For FY2003: Title 20 Standards Development, Comments of PG&E Regarding Proposed Residential Clothes Washer Water Factor Standards* (Docket No. 03-AAER-01) (RCW) November 11, 2003, p. 11. Comments were prepared for PG&E by Energy Solutions.

62 Gleick, et al.

63 Gleick et al., p. 63.

64 Gleick, et al., p.2.

65 Vickers, p.232.

66 Benedykt Dziegielewski, et al., *Commercial and Insitutional End Uses of Water* (Denver, CO: American Water Works Association Research Foundation, 2000).

67 Gleick, et al., p.2.

68 For additional descriptions of CII water conservation measures, see Vickers; Gleick, et.al.; and Miriam Pye, *Making Business Sense of Energy Efficiency and Pollution Prevention* (Washington, DC: American Council for an Energy Efficient Economy, 1998).

69 Vickers, p.235.

70 Gleick, et.al., p.83.

71 Ibid. p.91.

72 "Conservation Tips," Sacramento Municipal Utility District, available at: www.smud.org/residential/saving/conservation.html.

73 Department of Water Resources, *California Water Plan Update: Bulletin 160-98.*

74 Anderson, p.6. This latter figure includes energy used in food processing such as water sterilization, pumping, reclamation for washing, and other purposes.

75 California Energy Commission, p.1.

76 The Department of Water Resources does not have a good estimate of agricultural water use efficiency. While the CALFED water use efficiency program plan estimates average statewide water use efficiency as 73 percent, there is good reason to doubt this estimate. The estimate is based on data from the Westlands Water District during a limited number of irrigation seasons—a very limited and nonrepresentative sample. For additional discussion of agricultural water conservation, see Vickers; Ronnie Cohen and Jennifer Curtis, *Agricultural Solutions: Improving Water Quality in California Through Water Conservation and Pesticide Reduction* (New York: NRDC, 1998); Elise Fulstone, *The Role of Improved Irrigation Technologies in Helping Farmers Meet Environmental and Economic Challenges* (Washington, DC: Environmental and Energy Study Institute, 1997); and Department of Water Resources, *Agricultural Efficient Water Management Practices that Stretch California's Water Supply* (Sacramento, CA: 1995).

77 California Energy Commission, p. 5.

78 Anderson, p. 9.

79 Table 8 is modified from Burton.

80 Edward R. Osann and John E. Young, *Saving Water, Saving Dollars: Efficient Plumbing Products and the Protection of America's Waters* (Washington, DC: Potomac Resources, 1998), p. 10. Capital cost savings from reductions in wastewater flows will vary tremendously by location, particularly for older systems designed for certain flows. For new systems, however, water conservation and reduced wastewater flows should translate more reliably into reduction in wastewater capital costs.

81 To create this spreadsheet, we modified and expanded the methodology of Wilkinson (2000) to determine the energy embedded in water use from source to disposal.

82 The residential, commercial/industrial/institutional (CII), and agricultural percentages of total use in the table are from San Diego County Water Authority staff for the year 2010. They were disaggregated using data from the Awwa Research Foundation (1999) and Gleick (2003).

83 U.S. Census Bureau, Census 2000 figures available at: www.census.gov.

84 California Energy Commission, "Chula Vista Power Project, Chula Vista, Emergency Peaker Project," Energy Commission Docket Number: 01-EP-3. Available at: www.energy.ca.gov/sitingcases/peakers/chulavista/.

85 For more information about the environmental implications of drainage water and conflicts over responsibility for management and disposal of drainage flows, see, for example, *Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Jaoquin Valley*, (Sacramento, CA: U.S. Department of Interior and California Resources Agency, 1990).

86 The district is within the Tulare Lake groundwater basin, and Westside and Pleasant Valley subbasins. Historic groundwater depth maps are available from the Westlands Water District at: www.westlandswater.org/maps/dgwmapsel.htm and the Department of Water Resources online database, available at: http://wdl.water.ca.gov.

87 Russ Freeman, Resources Division, the Westlands Water District, personal communication, June 2003.

88 The original district included approximately 376,000 acres. It is currently referred to as Priority Area I (PAI). Most of PAI is east of the San Luis Canal and has gravity water service. Small recirculating pumps are used to pressurize supply laterals serving land adjacent to the San Luis Canal that is too high to be served through gravity laterals. The Westplains Water Storage District merged with Westlands in 1965, adding 210,00 acres. These lands are referred to as Priority Area II (PAII). Much of it is west and upslope of the San Luis Canal. It is served by pumping from the San Luis Canal and gravity supply from the Coalinga Canal. About one-third of the land between the San Luis Canal and the Coalinga Canal is served by pumping from the San Luis Canal. About 18,000 acres were added to the district subsequent to the Westplains merger. These lands are referred to as Priority Area III (PAIII). Unlike

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PAI and PAII, PAIII does not have a water service contract. It receives surplus Central Valley Project water or hardship water when available from the bureau during drought periods to preserve trees and vines.

89 Barry Mortimeyer, chief, Central Valley Operations, U.S. Bureau of Reclamation, personal communication, June 2003.

90 The unit factors are for water moved at the point of energy use. Due to system losses, actual energy used per acre-foot of water delivered is higher, as discussed in Chapter 2. In this case study, conveyance losses were not included due to data limitations.

91 Barry Mortimeyer, chief, Central Valley Operations, U.S. Bureau of Reclamation, personal communication, May 2003.

92 Since water in the canals cannot be differentiated by recipient, just as electrons in power lines cannot be labeled "for customer A," it is unclear how the 90 kWh/af net consumption of storing water in San Luis should be allocated. Westlands Water District staff claim it should not be allocated to them (Russ Freeman, Resources Division, The Westlands Water District, personal communication, July 2003) because priority is given to deliveries to exchange contractors and wildlife refuges. But it is not clear how these priorities affect timing of deliveries or that it is appropriate to differentiate this energy by recipient. An equally valid approach would be to charge a percentage of 90 kWh/af to all recipients, where the percentage reflects the percentage of water passing the San Luis Reservoir outlet that is pumped into and then recovered from San Luis Reservoir.

93 The 245 kWh/af figure does not apply to every acre-foot of Central Valley Project water delivered in the district since the district lifted only about 400,000 af/yr, or about 50 percent of Central Valley Project deliveries, in 2002.

94 Pimental and cost and return studies prepared by the University of California Cooperative Extension, which are available at www.agecon.ucdavis.edu/outreach/crop/cost.htm.

95 We have not, for example, estimated the energy embedded in the materials used on farm. Pimental and Pimental provide such data for around a dozen examples, including some relatively old data on tomato production in California. In that example, gasoline and diesel fuel account for a little more than half of the embedded energy inputs. See D. Pimental, and M. Pimental, editors, *Food, Energy, and Society* (Niwot, Colorado: University of Colorado Press, 1996).

96 W. Illingworth, D. Mitchell, L. Dale, A. Fargeix, R. T. Mott, and S. Msangi, *Analysis of Economic Impacts of Proposed Land Retirement in Westlands Water District, Final Report* (Westlands Water District, May 2003).

97 Permanent retirement of up to 200,000 acres of land within the Westlands Water District has been proposed by the district itself. According to Illingworth, et.al., the Westlands Water District is developing plans to purchase and retire up to 100,000 acres of land within the district. The district would retain ownership of these lands and would redirect the water from these lands to non-drainage impaired land within the district. An additional 100,000 acres of land retirement may take place if an agreement is reached with the Department of the Interior.

98 100,000 acres times 2.34 acre-feet of water-use-per-acre times 435 kWh per acre-foot times 70 percent = 71 million kWh.

99 Russ Freeman, Resources Division, the Westlands Water District, personal communication, June 2003.

100 Wilkinson (2000) and Table 12 of this report.

101 W. Illingworth, D. et.al., May 2003.

102 Russ Freeman, Resources Division, the Westlands Water District, personal communication, August 2003.

103 *Pocket Guide: The Northwest Power Planning Council's Fast Facts about the Columbia River Basin*, (Portland, Oregon: Northwest Power and Conservation Council, 1992), p. 9.

104 Ibid.

105 The National Marine Fisheries Service's RPAs are "expected to cost $1 billion a year, significantly more than the $800 million estimated one-time cost of breaching the four dams," (*Chicago Tribune*, March 5, 2001).

106 Foundation for Water and Energy Education, "What Makes the Columbia River Basin Unique and How We Benefit," available at: www.fwee.org/c-basin.html.

107 The National Marine Fisheries Service Press Release NOAA 97-R136, "Federal Fishery Agency Calls for a No-Net-Loss Approach to New Irrigation Pumping in Columbia Basin," May 16, 1997. Available at: www.publicaffairs.noaa.gov/pr97/may97/noaa97-r136.html.

108 Bonneville Power Administration, "Aluminum Companies Chip In," *Journal of the Bonneville Power Administration*, February 2001, p.2.

109 Linda Mapes, "Abundant Idaho Water Tied Up Tight," *Seattle Times*, April 29, 2001.

110 Washington State Department of Ecology, *2001 Drought Response Report to the Legislature*, (Olympia, WA: 2001), p. 18.

111 Joel R. Hamilton and R. Garth Taylor, "The Idaho Power Irrigation Electricity Buyout," *Idaho Economics*, November 2001.

112 Michele DeHart, manager, Fish Passage Center, in a letter to Rich Zabel, National Marine Fisheries Service, commenting on the National Marine Fisheries Service draft report on survival estimates for spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs during 2001, February 27, 2002.

113 "The [Federal Salmon Plan]'s flow and spill provisions were not met on even a single day during 2001," Save Our Wild Salmon, *Failing Salmon, Failing People*, (Seattle, 2001), Executive Summary.

114 Fish Passage Center *Annual Report* (Portland, OR: 2001), p. xix.

115 This estimate assumes that energy used to grow potatoes is an average for the project area. The assumption needs verifying, but it is useful for illustration purposes and is plausible based on cultivation and harvest energy estimates per acre-feet of water use developed in the Westlands case study.

116 Bonneville Power Administration, "Follow Up Questions for Power Net Revenue Improvements," *Sounding Board*, March 2004, p. 2.

117 The CALFED Bay-Delta Program Record of Decision indicates that the program will produce a "definition of appropriate measurement by the end of 2001," and that it will work "to develop legislation for introduction and enactment in the 2003 legislative session requiring the appropriate measurement of all water uses in the state of California," (record of decision, p. 63). CALFED has missed both of these dates.

118 The record of decision was adopted in August 2000 by state and federal water management agencies. The plan states that "CALFED agencies will support legislation that encourages groundwater management at the sub-basin level," (record of decision, p.47). We are not aware of progress toward the enactment of this legislation.

119 The record of decision states that "(By) the end of 2002, CALFED Agencies will implement a process for certification of water suppliers' compliance with the terms of the urban MOU, including implementation of best management practices for urban water conservations," (record of decision, p. 62). CALFED has missed this target.

120 Wilkinson.

121 This assumption is worthy of further research in some settings. Since both treated and untreated water are delivered to San Diego County in pipelines rather than canals, the assumption is probably valid in our case study. But it may not be valid in all settings since friction losses in pipelines often exceed those in open channels.

122 Robert C. Wilkinson, *Methodology for Analysis of the Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures* (Santa Barbara, CA: University of California, Santa Barbara, Environmental Studies Program, 2000).

123 Wilkinson.

124 Robert Wilkinson, Professor, University of California Santa Barbara, personal communication, September 2003.

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127 CH2Mhill, Final Environmental Impact Report/Environmental Impact Statement, Water Conservation and Transfer Project, Imperial Irrigation District, June 2002; Henrik Olstowski, superintendent of general power generation, Imperial Irrigation District, personal communication June 2003.

128 Jeff Stephenson, water resources specialist, San Diego County Water Authority, personal communication, June 2003.

129 Ibid.

130 Ibid.

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135 Ibid.

136 Ibid.

137 Ibid.

138 Peter H. Gleick, D. Haasz, C. Henges-Jeck, V. Srinivasan, G. Wolff, and A. Mann, *Waste Not Want Not: The Potential for Urban Water Conservation in California* (Oakland: Pacific Institute, 2003).

139 Ibid.

140 "Energy Star Qualified Clotheswashers" list and "Energy Star Qualified Dishwashers" list, available at: www.energystar.gov/ia/products/prod_lists/clotheswash_prod_list.pdf and www.energystar.gov/ia/products/prod_lists/dishwash_prod_list.pdf, respectively.

141 Amy Vickers' *Handbook of Water Use and Conservation: Homes, Landscapes, Business, Industries, Farms* (Amherst, MA: WaterPlow Press, 2001).

142 United States Department of Energy, "How to Buy an Energy Efficient Water-Cooled Chiller," available at: www.eere.energy.gov/femp/procurement/wc_chillers.html.

143 City of San Jose Environmental Services Department, *Water Conservation Guide for Office Buildings and Commercial Establishments* (San Jose, California: City of San Jose, 1992).

144 Osman Sezgen and Jonathan G. Koomey, *Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting* (Berkeley, California: University of California Berkeley, Lawrence Berkeley National Laboratory, 1995).

145 A. Amarnath, *Maximizing Wastewater Reduction for Process Industries*, TR-1114205 (Palo Alto: Electric Power Research Institute, 1999).

146 Ibid.

147 U.S. Geological Survey, "Estimated Use of Water in the United States, 1990," in *USGS National Circular* 1081, available at: http://water.usgs.gov/watuse/wucircular2.html.

148 Jeff Stephenson, Water Resources Specialist, San Diego County Water Authority, personal communication, June, 2003.

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Low Impact Development Metrics in Stormwater Permitting

Prepared for the Ventura Countywide Stormwater Quality Management Program and the Orange County Stormwater Program

Prepared by Geosyntec Consultants and Larry Walker Associates with assistance from Hawks and Associates

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Low Impact Development Metrics in Stormwater Permitting

I. Introduction and Purpose

Over the past decade, the U.S. EPA, the State Water Resource Control Board, and the Regional Boards have begun promoting and requiring the preferential use of Low Impact Development (LID) strategies to protect and improve water quality from new development and redevelopment projects. LID may be defined as site design incorporating LID Best Management Practices (BMPs) that strive to more closely mimic natural hydrology so as to reduce pollutant loads in post-development discharges and reduce hydromodification impacts. LID begins with functional conservation of watershed resources, reducing impacts of development, and then using innovative management practices to meet stormwater objectives; it is not the use of the management practices alone[1]. Site preservation practices coupled with small-scale BMPs that rely on the environmental services of vegetation and soils or systems that mimic these services comprise the LID approach.

It has also become increasingly clear that site design using LID alone cannot solve the problems with urban stormwater runoff. A watershed level approach that includes preventative actions is needed. Recently, a report prepared by the National Research Council for the US EPA[2] found that a comprehensive strategy must address impacts at a variety of scales and work to curb the development patterns that drive excess imperviousness and watershed disturbance. This marks the next phase in the evolution of stormwater management. It requires a much broader range of planning strategies, including urban infill, redevelopment, mixed use development, compact neighborhood design, and multi-modal transportation systems – all hallmarks of smart growth – to minimize watershed disturbance and impervious cover through compact community form, reuse of land, and shrinking the transportation footprint. This progression merges smart growth, urban design, and LID to address impacts at the site and builds on a growing body of research that is changing the way we look at the problem of stormwater runoff and the solutions we use to solve it. It presents the opportunity to apply new solutions across a wider range of scales and development contexts: using green infrastructure at site, neighborhood, district, community, and regional scales; minimizing pavement not only through permeable alternatives, but also by planning to reduce the overall transportation footprint; not only disconnecting impervious surfaces, but making fewer of them while reusing and retrofitting those that already exist.

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[1] *A Review of Low Impact Development Policies: Removing Institutional Barriers To Adoption*. Commissioned and sponsored by the California State Water Resources Control Board Stormwater Program and The Water Board Academy. December 2007.

[2] *Urban Stormwater Management in the United States*. Committee on Reducing Stormwater Discharge Contributions to Water Pollution, Water Science and Technology Board, Division on Earth and Life Studies, National Research Council of the National Academies.

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Currently, there is intense discussion among the regulatory agencies, regulated communities, and environmental groups as to an appropriate metric for ensuring reasonable consideration and implementation of LID by new development and redevelopment projects. Recent draft MS4 permits have created an opportunity to further the discussion. Concurrently, the Southern California Coastal Water Research Project (SCCWRP) has undertaken technical studies related to developing analysis tools for hydromodification. This white paper has been prepared to: 1) to assess the practicality and environmental outcomes of the LID metrics proposed in the draft April 2008 Ventura Countywide and the November 2008 Orange Countywide NPDES permits, and 2) to identify and evaluate alternative metrics for implementation of LID strategies and improving environmental outcomes.

II. Background

The municipal separate storm sewer system (MS4) permits issued throughout the state since the early 1990's have required permittees to address the adverse impacts to creeks, rivers, streams and coastal waters that can arise from the imprint of urban development on the landscape. Urbanization creates rooftops, driveways, roads, and parking lots (Schueler and Holland[3] use the term *imperviousness* as the unifying theme for understanding the adverse hydrologic impacts of urbanization) which (1) increase the timing and volume of rainfall runoff (compared to pre-development conditions) and (2) provide a source of pollutants that are flushed or leached by rainfall runoff into aquatic systems. The environmental consequences of these impacts can be loss or impairment of aquatic beneficial uses due to:

- Water quality degradation from increased loadings of sediment, nutrients, metals hydrocarbons, pesticides, and bacteria;
- Stream channel instability and habitat loss from increased stream flows;
- Increased water temperatures from solar energy absorption by urban surfaces and elimination of riparian shading, and
- Loss of groundwater recharge.

Assessments of stream system integrity show that these adverse impacts start to become apparent when as little as 3% to 5% of the watershed is urbanized without adequate runoff controls. These findings have led to the incorporation of a 5% effective impervious area requirement as one element of a prescribed performance standard for land development projects in recently issued MS4 permits in Southern California.

BMPs for controlling stormwater quality and hydrologic impacts from new development and redevelopment projects include site design (LID; smart growth), source control, treatment control, and hydromodification control BMPs. Effective management of wet and dry weather runoff water quality begins with limiting increases in runoff pollutants and flows at the source. Site design and source control BMPs are practices designed to

[3] Schuler, T.R. and H.K. Holland. The Practice of Watershed Protection, The Center for Watershed Protection, 2000.

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minimize surface runoff and the introduction of pollutants into runoff. Treatment control BMPs are designed to remove pollutants once they have been mobilized by rainfall and runoff but can also reduce runoff volume. Hydromodification control BMPs are specifically designed to control increases in post-development runoff flows and/or volumes. Hydromodification control can be accomplished with a combination of site design, hydrologic source control, and/or detention.

On April 29, 2008 the Los Angeles Regional Water Quality Control Board (LA Regional Water Board) issued the draft tentative NPDES permit for the Ventura County MS4. This draft permit applies to the Ventura Watershed Protection District, Ventura County, and the 10 incorporated cities within Ventura County. The relevant provision of this draft permit for this discussion is Part 4, Section E, Planning and Land Development Program. Although this provision has multiple requirements for new development and redevelopment, it may be summarized as follows:

- Reduce the effective impervious area to 5% or less of the total project area[4];

- Treat the volume of runoff from the 85th percentile storm event (a minimum of 0.75 inches) and meet the performance standards in the form of effluent limitations noted in attachment C of the draft permit; and

- Install hydromodification controls such that Erosion Potential (Ep) in streams is maintained at a value of 1, unless an alternative value can be shown to be protective.[5]

Similarly, on November 10, 2008 the Santa Ana Regional Water Quality Control Board (Santa Ana Regional Board) issued the draft NPDES permit for Orange County Resources and Development Management Department and the incorporated cities in Orange County that are located within the Santa Ana River watershed. The relevant provision of this draft permit is Section XII, New Development (including Significant Redevelopment). As with the Ventura draft permit, the section is extensive but may be summarized as follows:

- Reduce the effective impervious area to 5% or less of the total project site[6];

[4] In the draft permit, impervious surfaces may be considered "ineffective" if the storm water runoff is: (1) drained into a vegetated cell, over a vegetated surface, or through a vegetated swale, all having soil characteristics either as native material or amended medium using approved soil engineering techniques; or (2) collected and stored for reuse such as irrigation, or other reuse purpose; or (3) discharged into an infiltration trench or other infiltration system. The draft Ventura Permit does not include sizing criteria for these three options.

[5] The draft Ventura Permit requires the permittees to develop watershed specific Hydromodification Control Plans (HCPs) that establish hydromodification management standards. In the interim, projects that impact less than 50 acres shall implement hydromodification controls such that the 2-year, 24-hour storm event post development peak flow and volume match the pre-development peak flow and volume within 1%. "Pre-developed" is defined in the draft permit as "native vegetation and soils that existed at the site prior to first development."

[6] The pervious areas to which the runoff from the impervious areas are connected should have the capacity to percolate at least the excess runoff volume from a two-year storm event.

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- Treat the volume of runoff from the 85th percentile storm event; and

- Evaluate potential for hydromodification impacts and if potential for impacts is identified then implement hydromodification controls to mitigate those impacts. There are no hydromodification impacts if:

    1. The volumes and the time of concentration of storm water runoff for the post-development condition do not exceed those of the pre-development condition for a two-year frequency design storm event by more than 5%; or
    2. All downstream conveyance channels are engineered, hardened and regularly maintained to ensure design flow capacity, and no sensitive stream habitat areas will be affected; or
    3. The total effective impervious area on a site is increased by less than 5% in new development projects; or
    4. The post-development 2-year hydrograph is no more than 10% greater than pre-development hydrograph.

- If a hydrologic condition of concern exists, then the Water Quality Management Plan shall include an evaluation of whether the project will adversely impact downstream erosion, sedimentation or stream habitat. In cases where excess volume cannot be infiltrated or captured and reused, discharge from the site must be limited to a flow rate no greater than 110% of the pre-development 2-year peak flow.

Another relevant effort, mentioned in both the draft April 2008 Ventura Countywide and the November 2008 Orange Countywide NPDES permits, is an ongoing technical study by SCCWRP on the assessment and management of hydromodification effects[7]. The goal of this SCCWRP project is to develop a series of predictive models, applicable to a range of stream types that support implementation of hydromodification management measures. This project will answer the following questions:

1) Which streams are at the greatest risk of hydromodification effects?
2) What are the anticipated effects (in terms of increased erosion, sedimentation, or habitat loss) associated with increases in impervious cover?
3) What are some potential management measures that could be implemented to offset hydromodification effects? How effective are they likely to be?

This SCCWRP project was initiated in 2007 and is anticipated to be completed in 2010.

[7] See: http://www.sccwrp.org/view.php?id=247.

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Although slightly different, the two draft permits rely on the use of effective impervious area (EIA) as a key element of the metric to gage the level of implementation of LID strategies.

The Permittees' concerns related to these LID requirements are as follows:

1. The draft permits lack fully integrated and technically sound approaches to stream protection for new development. The separated provisions for LID, treatment controls, and hydromodification controls are disjointed, confusing and in some cases duplicative. These provisions, as written, leave much to the discretion of design engineers and compliance assessment extremely difficult.

2. The draft permits potentially create significant disincentives for redevelopment and smart growth projects. The application of single metrics for all types of development and individual sites (e.g., 5% EIA) in the draft permits work against redevelopment, infill, and smart growth projects, and other mandates, such as AB375, for more sustainable patterns of urban development. Furthermore the cost for complying for redevelopment projects is disproportionately higher than for new development projects.

3. The draft Ventura permit does not account for scale of application. All sites must meet the 5% EIA standard even though this metric was derived from watershed-scale studies[8].

4. The EIA standard may lead to poor LID implementation. Compliance with 5% EIA can be manipulated and not result in the goal of mimicking pre-development hydrology.

5. The requirement for 5% EIA and encouragement of infiltration does not allow considerations of the overall site water balance and could lead to unnatural levels of deeper infiltration. Excessive infiltration could cause groundwater issues, including habitat changes in downstream water bodies that were formerly dry most of the year, raised groundwater levels and associated geotechnical issues, and/or issues with brownfields or naturally occurring pollutants being mobilized (e.g., selenium).

6. Preliminary results of the SCCWRP hydromodification study are available.[9] The project report states that management actions aimed at mitigating the effects of hydromodification will be most effective when tailored to different stream types. One-size-fits-all practices based on "single factor" geomorphology (e.g., a simple erosion index) or extrapolation of impervious area studies across stream types is not

[8] Stein, Eric D. and Susan Zaleski, 2005. Managing Runoff to Protect Natural Streams: The Latest Developments on Investigation and Management of Hydromodification in California. Southern California Coastal Water Research Project Technical Report 475. December 2005.

[9] Bledsoe, Brian, Robert Hawley, and Eric D. Stein. Stream Channel Classification and Mapping Systems: Implications for Assessing Susceptibility to Hydromodification Effects in Southern California. Southern California Coastal Water Research Project Technical Report 562. April 2008.

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likely to protect streams. Tools that account for land use change effects on both the continuous flow regime and sediment delivery are much more likely to manage hydromodification effects on streams in southern California.

7. The EIA metric, though conveniently simple, does not reflect the current understanding of stream dynamics and susceptibility to hydromodification as indicated in current and ongoing research.[10] To protect stream channel geomorphology and habitat, permit standards ideally should reflect channel conditions and rely on channel-related metrics.

In addition to these concerns, any effort to prescribe the implementation of LID must also address the enforceability of design standards, public acceptance, long-term maintenance and operation of numerous small-scale systems, and potential conflict with water conservation goals and broader sustainable development objectives. Another key consideration needs to be the context of the management effort, specifically the beneficial use that can be realized in highly modified stream channels within urbanized floodplains. For the purpose of this white paper, the discussion is focused on EIA requirements and the integration of LID controls, treatment BMPs, and hydromodification controls into one cohesive water quality protection strategy.

III. LID Case Studies

Approach

Three case studies were conducted using actual redevelopment projects to evaluate the feasibility of utilizing landscaping and other LID BMPs, consistent with preserving the fundamental character of the development, while evaluating the effectiveness of such an approach in meeting draft MS4 permit LID BMP performance standards.

The first two case studies (i.e., Walnut Village and 60 California) were completed utilizing the following three performance standards:

1) Reduction of effective impervious area[11] to less than 5%;
2) Retention[12] of the difference between pre-development and post-development runoff volume for the water quality storm (SUSMP) event (i.e., the "delta" WQ volume); or

[10] Roesner and Bledsoe, 2003. Research Needs: Physical Effects of Wet Weather Flows on Aquatic Habitats, WERF; and Pomeroy, Roessner, Coleman, and Ranking, 2008. Protocols for Studying Wet Weather Impacts and Urbanization Patterns, WERF.

[11] As defined by the Ventura County Draft Permit, impervious surfaces may be rendered "ineffective" if the stormwater runoff is: (1) drained into a vegetated cell, over a vegetated surface, or through a vegetated swale, having soil characteristics either as native material or amended medium using approved soil engineering techniques; (2) collected and stored for reuse such as irrigation, or other reuse purpose; or (3) discharged into an infiltration trench. The draft Ventura Permit does not include sizing criteria for these three options.

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3) Retention of the difference between pre-development and post-development runoff volume for the 2-year design storm event (i.e. the "delta" 2-year volume).

The first two case studies were completed with the underlying philosophy that for the proposed LID requirements to be implementable, the fundamental character of the development project should not change. The following assumptions were made for these case studies:

1) Site boundaries are fixed and LID requirements cannot be fulfilled on adjacent parcels of land.
2) Building and parking footprints are fixed in size.
3) Limited modifications to site design may be considered feasible if conditions 1 and 2 are met.
4) Pervious pavement constitutes disconnection of that area, but cannot be used in high-traffic areas.
5) Proprietary BMPs do not constitute disconnection of impervious areas unless they incorporate substantial volume-reduction mechanisms.

An additional redevelopment case study of a commercial site in the City of Ventura (i.e., the Kmart site) was conducted. This case study investigated the cost impacts of the following two performance standards:

1) Retention of the difference between pre-development and post-development runoff volume for the water quality storm (SUSMP) event (i.e., the "delta" WQ volume); or
2) Retention of the difference between pre-development and post-development runoff volume for the 2-year design storm event (i.e. the "delta" 2-year volume).

Note that the intent of the third case study was primarily to evaluate the cost of implementing LID BMPs, while the intent of the first two case studies was to evaluate the feasibility and hydrologic effectiveness of various interpretations of the LID BMP performance standards in both draft permits, regardless of the cost to the project.

The following limitations to all three case studies are acknowledged:

- The case studies, as is the case with most investigations of feasibility, relied on subjective assumptions and interpretations which were based on professional judgment; and

[12] Retention is defined as the capture and elimination of stormwater through percolation, evapotranspiration, or use.

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- Computational methods used to evaluate effectiveness were simplified, as utilization of complex methods could be interpreted as reducing transparency while increasing the required level of effort.

Case Study Results

The case study results are summarized below. Each case study is presented in its entirety in Attachment A.

Walnut Village

Walnut Village is a 7.6 acre multi-family redevelopment project in the City of Anaheim in Orange County. Proposed development consists of a main building with interior courtyards and two sets of smaller structures. Primary parking is provided below the grade of the large central building with some parking at the surface. The site is bordered on the west and north by a fire access road. Landscaping is generally present as narrow strips along some building edges and around the perimeter of the sites. Except for one vegetated filter strip, the landscaping in the proposed design does not accept runoff from adjacent impervious area.

The project as proposed has a total imperviousness of 84% and an EIA of 76%. Soils at the site are characterized as Class B[13] soils and the site and surrounding area are flat. The water quality design storm depth for this location was estimated to be 0.7 inches and the 2-year storm depth was estimated to be 2 inches.

Reduction of Effective Impervious Area

Modifications to stormwater routing and site design were identified in an attempt to meet the goal of reducing effective impervious area (EIA) to less than 5%. In this effort, it was critical to understand which areas of the site could be made available for vegetated treatment and/or infiltration. Based on site plans, the courtyard areas located over the underground parking structure could not accept runoff from adjacent impervious areas because water could not be infiltrated over the parking structures. Perimeter landscaping was deemed potentially appropriate for infiltration, thus disconnection of impervious area was achieved by routing runoff through these areas. Parking areas, driveways, and fire roads were routed to drain to landscaping where possible. It was assumed that entry driveways represented high traffic areas that would not be suitable for pervious pavement.

[13] Soils are classified by the Natural Resource Conservation Service into four Hydrologic Soil Groups based on the soil's runoff potential. Soil groups do not necessarily correspond to soil types, however, in southern California. Group B is generally consistent with silt loam or loam. It has a moderate infiltration rate when thoroughly wetted.

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A reduction from 76% EIA to 18% EIA was achieved by converting passive landscaped areas (those that do not accept runoff from adjacent impervious areas) to active landscaped areas (those that do accept runoff from adjacent impervious areas) and routing rooftop and some parking lot drainage over this area. A reduction to 0% EIA was achieved through converting non-essential hardscape to active landscaping.

Reduction of effective impervious area to less than 5% of the project area appears to be feasible, but in order to achieve this goal, additional active landscaping was created. It is important to note that this conclusion is based on limited available information of site constraints that may not have been evident from project documentation.

To estimate the approximate effectiveness of the disconnection scenarios in retaining stormwater, simple exploratory calculations were used for three levels of implementation:

A. All actively landscaped areas assumed to retain and infiltrate or evapotranspire one inch of water over its surface,
B. Half of the actively landscaped areas assumed to retain and infiltrate or evapotranspire six inches of water over its surface, or
C. All of the actively landscaped areas assumed to retain and infiltrate or evapotranspire six inches of water over its surface.

The results of these calculations, expressed as the amount of runoff retained in a given storm event (in watershed inches), are presented in Table 1 below.

Table 1: **Approximate Retention Depth for Various Disconnection Scenarios and Types of Active Landscaping Employed**

		Effective Retention Depth (Watershed Inches)		
Disconnection Scenarios		**76% EIA**	**18% EIA**	**0% EIA**
A	1" retention over all active landscape	0.01	0.06	0.08
B	6" retention over half of active landscape	0.04	0.19	0.24
C	6" retention over all active landscape	0.08	0.39	0.47

The depth retained on the site was both a function of the reduction in impervious area and EIA and the increase in depth retained in actively landscaped areas. The results in Table 1 show that an increase from 1 inch retained to 6 inches retained over active landscaping (moving down the columns in Table 1) had a more pronounced effect than reducing the EIA from an easily achieved value (18%) to a more difficult to achieve value (0%) (moving left to right in Table 1). Certainly this result is a function of the cases that were selected, but nonetheless illustrates that LID benefits can be achieved by both extensive implementation (i.e., routing of runoff to vegetated systems) and more intensive design of active landscaping (i.e., greater retention depth) where opportunities exist. A fixed percent EIA LID metric promotes only the former option, but does not address the design of the LID BMP that is being used to disconnect the impervious area, and therefore does

not address the different levels of effectiveness that might be achieved for the same % EIA.

Volume Retention Scenarios

Storage volumes required to retain the delta water quality and delta 2-year events were calculated using the methodology contained in the Orange County Drainage Area Management Plan (DAMP). Assumptions and resulting volumes are provided in Table 2 below.

Table 2: **Differential Volume of Runoff in WQ and 2-year Storm Event**

Storm	Storm Depth (inches)	Imperviousness[1]	Runoff Coefficient[2]	Runoff Depth (watershed inches)	ΔV (watershed inches)
WQ	0.70	0	0.15	0.11	0.45
	0.70	84	0.79	0.55	
2-year	2.05	0	0.15	0.31	1.31
	2.05	84	0.79	1.62	

[1] Imperviousness = 0 in the undeveloped condition and 84% in the post-developed condition.
[2] Table A-1 of OC DAMP, page 7-II-46

The required retention depths over all active landscaping for the delta water quality and delta 2-year events were computed using simplified volumetric routing assumptions and are shown in Table 3 below for two scenarios. Scenario X represents the case where the volumetric retention requirements are provided in active landscaping, while scenario Y represents the case where all pavement is assumed to be pervious pavement (i.e., self-mitigating) and remaining volumetric requirements are provided in active landscaping. An infiltration rate under active landscaping representative of compacted B soils (0.2 inches per hour) was assumed to explore the range of drawdown times that could be expected for the required retention depths.

Table 3: Required Depth of Retention in Active Landscaping to Achieve Volumetric Retention Requirements and Range of Approximate Drawdown Times

Disconnection Scenarios[1]		Required Retention Depth in All Active Landscaping (inches)		Time to Drain at 0.2 inches per hour [3] (hours)
		Delta WQ (0.45 watershed inches)	Delta 2-yr (1.31 watershed inches)	
X	Retention over all Active Landscaping	5.7	16.6	28 – 83
Y	Retention of 0.70 inches over all pavement[2], with remaining volume retained in active landscaping	3.7	14.6	18 – 73

[1] Analysis is for the 0% EIA case, which assumed 8% of the site was active landscaping.
[2] Based on assumption that all paved areas can be designed to be self-mitigating (i.e. pervious pavement) for entire WQ storm; however, pavement does not accept building runoff.
[3] 0.2 inches per hour is at the high end of typically assumed saturated hydraulic conductivity for compacted B soils under long-term operation. Actual infiltration rates must be based on site-specific testing which

was not available for this site. The low end of the reported range is for the Delta WQ volume and the high end is for the Delta 2-yr volume.

The range of required retention depths over the active landscaping shown in Table 3 is not unreasonable, at least to retain the delta water quality volume, but it would require priority to be placed on converting all active landscaping to an LID BMP designed and maintained specifically as a retention facility. However, the 14-17 inches of retention required to capture the delta 2-year volume is much less feasible, as it would require a combination of fairly deep amended soils and significant surface storage. The drawdown time for such a depth is at or above the upper limit of what would typically be allowed for a surface storage facility to avoid vector concerns (72 hrs), which could be mitigated by the storage of some volume in soil pores but indicates that performance would be substantially reduced in sequential storm events. From this calculation, it is also apparent that feasibility is strongly dependent on site-specific infiltration rates. The retention of the lesser delta volume (i.e., Delta WQ) appears to be more feasible, but is also dependent on the ability to make use of all active landscaping for intensive BMPs and the site-specific infiltration rates. In addition, landscape plans typically include features that restrict usage of landscaping for runoff control (e.g., tree choice can limit inundation depths and duration), therefore, it is unreasonable to assume that all landscaping may be available.

60 California

60 California Street is a proposed four-story, multi-use commercial/retail redevelopment project in the City of Ventura in Ventura County. The site encompasses 0.14 acres in the downtown area. Nearly the entire project site is covered by the building roof, with only a negligible buffer around the edges. The surrounding area is highly urbanized and no vegetation exists directly on the site with the exception of two palm trees in planters on the sidewalk. These planters do not accept runoff from the site or the adjacent road. The total project imperviousness and EIA are 100%. Soils at the site are characterized as C soils and the slope of site and surrounding land is approximately 2 percent. The water quality design storm depth was assumed to be 0.75 inches and the 2-year storm depth was estimated to be 2.7 inches.

Reduction of Effective Impervious Area

For this case study, the project land cover and proposed drainage patterns were first identified. Next, opportunities for "disconnection" of impervious area through the use of green roofs and cisterns for reuse were identified. The practicability of meeting the first goal (<5% EIA) was evaluated based on what could be achieved on the site in this manner without changing the fundamental site characteristics. Because the nature of the project is that of a multi-story building built to the lot lines, there is no opportunity to create vegetated areas for infiltration. The volume of cistern storage and effective retention depth of green roofs were computed and evaluated for their reasonableness and probable effectiveness.

Green roofs rely on highly porous media and moisture retention layers to store intercepted precipitation and to support vegetation that can reduce the volume of

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stormwater runoff via evapotranspiration. As proposed,[14] the building's roof contains several features that limit the spatial applicability of a green roof (e.g., a tower, 2V:1H sloped perimeter). Thus, approximately 4,300 ft^2 of the total 6,200 ft^2 roof is available to support vegetated cover. Runoff from roof area that cannot be covered in green roof would need to be captured through the use of a cistern for reuse in flushing toilets and irrigating indoor plants in the building. Dry wells are also considered an acceptable means to disconnect impervious area, but were not considered to be feasible given the high density of development (dry wells are generally located away from building foundations) and the indication of poor soil infiltration rates (C soils) at the project site. The case study found that a reduction in EIA to less than 5% can be achieved, but with a combination of green roof and cisterns.

Green roofs can be engineered to store a range of precipitation depths through the use of different design features. It is important to note that green roofs do not eliminate volume through infiltration; only through evapotranspiration (ET). Regeneration of storage by means of ET is generally slower than by means of infiltration, indicating that antecedent conditions may be more important for performance of green roofs than for infiltration-based BMPs. Similarly, cisterns may be designed for any volume, but do not infiltrate water; rather water is held for reuse, the rate of which may be the limiting factor in how much water should be stored or the availability of storage during sequential rainfall events.

Reduction of effective impervious area to less than 5% of the project area appears to be feasible if the definition of EIA does not include a volumetric retention requirement to render an area ineffective or the cost implication of the improvements. The retention depth values shown in Table 4 below are based on typical design parameters for green roofs and cisterns, which are BMPs that are generally beyond the level of BMP implementation in common practice in the United States at this time. In order to achieve <5% EIA, rainwater collection and reuse or re-engineering of the building roof to eliminate areas of steep slope would be required. It is important to note that this conclusion is based on limited available information of site constraints that may not have been evident from project documentation.

To estimate the approximate effectiveness of the disconnection scenarios in retaining stormwater, simple exploratory calculations were used for two levels of implementation. Runoff volumes were generated by assuming that all rainfall on rooftops would run off, and were reduced as a function of the type of disconnection implemented. Results are presented as the amount of runoff retained in a given storm event, expressed as watershed inches (Table 4), assuming dry antecedent conditions.

[14] Note, the project consists of construction of a new building; retrofit of green roofs onto existing buildings is a much more challenging proposition.

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Table 4: Approximate Retention Depth for Two Disconnection Scenarios

Disconnection Scenarios		Effective Retention Depth (Watershed Inches)		
		100% EIA	31% EIA (no cistern)	3% EIA (Green roof and cistern)
A	0.5 in of retention over green roof	NA – No retention BMPs	0.15	0.27[1]
B	2 in of retention over green roof		0.58	1.08[2]

[1] With 1-500 gallon cistern.
[2] With 1-2,000 gallon cistern.

Table 4 shows that the depth retained on the site due to LID BMPs was dependent on the design criteria selected for the green roofs and cisterns. It was generally difficult to achieve fairly high retention depths within typical ranges of design criteria for these BMPs, especially for Scenario B.

Volume Retention Scenarios

Storage volumes required to retain the delta water quality and delta 2-year events are provided in Table 5 below.

Table 5: Differential Volume of Runoff in WQ and 2-year Storm Event

Storm	Storm Depth (inches)	% Imperv	Runoff Coefficient[1]	Runoff Depth (watershed inches)	ΔV	
					(watershed inches)	(gallons)
WQ	0.75	0	0.15	0.11	0.64	2,550
	0.75	100	1.0	0.75		
2-year	2.7	0	0.15	0.31	2.39	9,530
	2.7	100	1.0	2.7		

[1] Table A-1 of OC DAMP, page 7-II-46; all rainfall on rooftops assumed to run off

To help understand the quantity of storage that would be required to retain the delta volumes, the two scenarios were explored (Table 6).

Table 6: Required Cistern Storage Volume to Achieve Volumetric Retention Requirements

Disconnection Scenarios[1]		Required Cistern Volume (gal)	
		Delta WQ (2,550 gal)	Delta 2-yr (9,530 gal)
X	Green roof retaining 0.5 in of water and remainder captured by cistern.	1,210	8,200
Y	Green roof retaining 2 in of water and remainder captured by cistern.	Cistern not required	4,170

[1] Analysis is for 0% EIA, assuming use of green roof and a cistern.

The range of required storage volumes is not unreasonable but would require that a viable and sufficient demand exists for the stored water and that reuse of stormwater within the

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buildings would be permitted. An exception is noted for Scenario Y, in which the volume of water stored by the green roof is sufficient to mitigate the delta of the water quality-sized storm and does not rely on storage and reuse.

It is important to note that suitability of both green roofs and storage/reuse systems for southern California is not well understood and there is a lack of test data on long term performance. Generally, during the rainiest times of the year in southern California, the potential evapotranspiration is the lowest, meaning that the ability to regenerate storage capacity between storms is low. During the summer, green roofs would likely need to be irrigated to sustain healthy vegetation and to reduce fire danger. Likewise, irrigation demand for stormwater stored in a cistern is generally highest over the long summer months when limited rainfall is likely to occur. This is not meant to say that the solutions would not work, but that they are possibly not the most climate-appropriate technologies. In addition, their use may conflict with existing building and health codes.

Kmart Site

This case study site is of a former Kmart center located within the City of Ventura. The 12.4 acre site is in a highly urbanized area along South Victoria Avenue and includes a department store, a grocery store, and two restaurants. Currently, the site is covered by building roof and parking lot, with some inactive vegetation (curbed off trees) within the main parking lot.

The focus of this case study was to evaluate the cost of complying with the draft Permit requirement. As the draft Ventura County permit does not include volumetric criteria for the disconnection of impervious area, it was necessary to assume a range of volumetric criteria to render impervious area "ineffective." To facilitate this study, two possible volumetric interpretations of the draft Ventura permit requirement were considered:

- High volume interpretation – the difference between pre-development[15] and post-development runoff for a 3.1-inch storm (2-year, 24-hour rainfall event).
- Low volume interpretation – the difference between pre-development and post-development runoff for a 0.75-inch storm (approximate SUSMP water quality event).

It is recognized that the draft stormwater permit hydrologic controls are related to other drainage controls set by county or cities for the rarer, but larger runoff and flood events. For this case study, drainage/flood control and water quality BMPs were assumed to be the same for both scenarios and no cost was assigned to them. This assumption means that the cost developed for the low volume retention scenario would need to be increased to account for appropriately sized treatment BMPs, and potentially hydromodification controls, whereas the high volume retention scenario would have already fulfilled treatment requirements and potential hydromodification requirements.

[15] Consistent with Draft Ventura County permit language, "pre-development conditions" were assumed to refer to the site condition prior to any development.

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The case study included estimating required detention volume, selecting and sizing LID BMPs, and estimating the order of magnitude lifecycle costs. These costs are also compared to a range of potential site redevelopment costs to provide prospective on the total cost of redevelopment. The BMP sizing and cost results are developed to provide a practical example to evaluate the draft permit requirements.

Estimates of runoff volume in pre-development and post-development conditions were developed using the NRCS Curve Number Method for both design storm scenarios. The differences or "delta" of these volumes are shown in Table 7 below.

Table 7: Runoff Estimates from Kmart Site[1]

Permit Interpretation	Design Storm (inches per 24-hour)	Pre-Development[2] Runoff (Ac-Ft[3])	Post-development Runoff (Ac-Ft)	Delta Volume: BMP Criteria (Ac-Ft)
High Volume	3.1	0.41	2.38	1.97
Low Volume	0.75	0.00	0.32	0.32

Notes:
1. Total site area equal 12.4 acres.
2. Pre-development = native vegetation and soils that existed prior to the first development
3. Ac-Ft = Acre-feet

LID BMPs were selected to treat the "delta" volume in both design storm scenarios assuming the LID BMP would control the draft permit hydromodification volume in a treatment train approach: vegetated filter strips followed by aggregate-filled infiltration trenches. For the low volume interpretation, it was assumed that a 1-foot wide filter strip would be provided prior to water entering the ribbon drains. For the high volume interpretation of LID requirements, it was assumed that filter strips would be sized to 5 percent of the tributary impervious area, yielding filter strips approximately 25 feet wide, collecting runoff prior to flowing into the infiltration trenches. It was assumed for this case study that infiltration trenches would be designed to drain in 72 hours into Ventura County Soil Type 3 (NRCS Category C) soils with a Ventura County standard infiltration rate of 0.5 inches per hour. This infiltration rate is the minimum for infiltration trenches. Assuming an aggregate porosity of 0.35, a trench depth of 8 feet, for the high volume interpretation, two basins were sized, one 600 feet long and 42 feet wide, the other 290 feet long and 18.5 feet wide. The low volume interpretation required an 8 foot deep basin 900 feet long and 5.5 feet wide. The project could also comply with LID criteria by using a variety of BMPs such as tree boxes, bioretention, pervious pavement, and other LID BMPs, however, the filter strip/infiltration trench treatment train was assumed based on its simplicity and suitability for a constrained commercial site.

The present worth cost estimates for the two volume retention scenarios ranged from approximately $17,000 per acre to $100,000 per acre for the 12.4 acre site (Table 8). For the high volume interpretation, 1.9 watershed inches (1.97 Ac-Ft) of water would need to be infiltrated. The LID BMPs for this scenario occupied 10 percent of the site; the filter strips covered approximately 5 percent of the site and the infiltration trenches covered approximately 5 percent of the site. Under the low volume interpretation of LID

requirements, 0.3 watershed inches (0.32 Ac-Ft) would need to be infiltrated. The LID BMPs for this scenario included an approximately one-foot wide vegetated filter strip placed along the drainage collection features of the site and infiltration trenches covering approximately 1 percent of the project site. The cost results presented in Table 8 are approximate and should be considered as an order-of-magnitude, relative comparison based on engineering experience and limited field data.

Table 8: Present Worth Cost Comparison of Kmart Case Study

Case Study	Proposed Permit Costs[1]	% of Total Redevelopment Cost[2]
High volume interpretation (2-year storm)	$1,290,000	4 – 22%
Low volume interpretation (0.75-inch storm)	$208,000	1 – 3%

[1] LID BMP Costs are developed as 20-year present worth (lifecycle) costs using a 4 percent interest rate.
[2] Assuming other present worth costs of redevelopment range from $6 million to $32 million

Case Studies Conclusions

The following conclusions can be drawn from the case studies:

- In all of the case studies, it was possible to achieve less than 5% EIA based on the criteria provided in the draft Ventura Countywide permit that defines under what conditions imperviousness may be assumed to be disconnected. It is important to note that such conditions do not define engineering sizing criteria.
- The lack of a sizing criteria in the definition of EIA in the draft Ventura Countywide permit resulted in a wide range of possible interpretations, effectiveness (measured as retained runoff volume), and costs. In fact, the first case study (Table 1) showed that a site with an EIA of 18% could be designed to retain more runoff than a site with an EIA of 0%.
- An EIA criterion coupled with a volumetric matching requirement is a much more difficult performance standard to meet as it requires a focused effort to design retention BMPs for a large portion of the project area.
- The same or better hydrologic effectiveness (reduction in runoff volume) may be achieved through more intensive application of LID BMPs where opportunities exist, compared to a scenario in which LID features are spread more extensively throughout the project site, but with less emphasis on volumetric retention. For example, the first case study (Table 1) showed that 6 inch retention over all the active landscape area with 76% EIA provided the same runoff volume retention as 1 inch retention over all the active landscape area with 0% EIA. Therefore, if reduction in runoff volume is the desired outcome, a volumetric reduction standard would be more constructive than a % EIA standard.
- The feasibility of retaining the delta runoff volume on site in landscaped areas is highly dependent on the site-specific infiltration rate.

- Retention of the delta WQ storm volume is more feasible than the delta 2-year volume.
- The 60 California case study showed that it was possible to achieve less than 5% EIA in a downtown redevelopment scenario, but required use of LID BMPs such as green roofs and large volume cisterns due to typical high density downtown redevelopment site constraints. However, this case study did not consider cost implications.
- It is clear from the Kmart case study cost estimates that the proposed draft permit requirements would significantly increase the drainage costs of urban redevelopment projects. The LID BMP costs of the high volume interpretation would challenge the feasibility of the project, being as much as 22% of the total cost. The low volume interpretation could be as much as 3% of the total cost although this estimate does not include the cost for complying with the treatment and hydromodification controls.
- It is also clear from the Kmart case study that the ability to implement LID BMPs on the site without substantially reducing the developable area is dependent on the volumetric criterion that is selected. In the high volume scenario, a significant amount of area (approximately 10 percent of the site) was required for LID BMPs, while in the low volume scenario, the area requirements were less.

IV. Alternative Metrics Currently Used in Other Jurisdictions for LID Implementation

Representative MS4 permits within California and other key states were reviewed for alternative approaches to regulating low impact design and hydromodification. In addition, LID implementation and hydromodification control metrics that have been adopted by jurisdictions via ordinance, guidance, or technical manuals were reviewed. The discussion below summarizes the findings of this review.

Example LID and Hydromodification Performance Standards

In the course of our research, many MS4 permit language examples were obtained. A summary of the LID and hydromodification control performance standards from these various MS4 permits is provided in Table 9 below. A summary of example LID implementation and hydromodification control requirements that have been adopted by jurisdictions via ordinance, guidance, or technical manuals is provided in Table 10 below.

Additional details are provided in Attachment B.

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Table 9: Comparison of LID and Hydromodification Performance Standards in Various Stormwater Permits

Regulatory Program	LID Performance Standard	Hydromodification Control Performance Standard	Type of Performance Standard	
			LID	Hydromodification
Washington State Phase I and Phase II Permits (Stormwater Management Manual for Western WA) (February 2005)	1. Infiltrate, disperse, and retain stormwater runoff onsite to the maximum extent feasible without causing flooding or erosion impacts. 2. Roof downspout control BMPs, dispersion, and soil quality BMPs required.	1. Match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. 2. Standard requirement is waived for sites that will reliably infiltrate all the runoff from impervious surfaces and converted pervious surfaces.	Narrative and prescriptive site design/LID BMP requirements with no LID metric	Flow duration control
San Diego MS4 Permit (January 2007) and Interim HMP Standard (October 2007)	1. Drain a portion of impervious areas into pervious areas prior to discharge to the MS4. The amount of runoff from impervious areas that is to drain to pervious areas shall correspond with the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors. 2. Properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors. 3. Construct a portion of walkways,	1. For flow rates from 20% of the pre-project 5-year runoff event (0.2Q5) to the pre-project 10-year runoff event (Q10), the post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10% over more than 10% of the length of the flow duration curve. 2. For flow rates from 0.2Q5 to Q5, the post-project peak flows shall not exceed pre-project peak flows. For flow rates from Q5 to Q10, post-project peak flows may exceed pre-project flows by up to 10% for a 1-year frequency interval. For example, post-project flows could exceed pre-project flows by up to 10% for the interval	Prescriptive site design/LID BMP requirements with no LID metric	Flow duration control

Regulatory Program	LID Performance Standard	Hydromodification Control Performance Standard	Type of Performance Standard	
			LID	Hydromodification
	trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.	from Q9 to Q10 or from Q5.5 to Q6.5, but not from Q8 to Q10. 3. LID may be implemented to manage hydromodification impacts, using design procedures, criteria, and sizing factors (ratios of LID BMP volume or area to tributary area) specified by the Co-permittees. The Co-permittees' LID BMP designs and sizing factors shall be determined using continuous simulation of runoff from a long-term rainfall record.		
Draft San Francisco Bay Area Municipal Regional NPDES Permit (December 2007)	1. Drain a portion of impervious areas into pervious areas prior to discharge to the MS4. The amount of runoff from impervious areas that is to drain to pervious areas shall correspond with the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors. 2. Properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.	1. Ep = 1.0. Match flow rates and durations from a critical low flow of 10% of Q2 up to the pre-project 10-yr peak flow.	Prescriptive site design/LID BMP requirements with no LID metric	Erosion Potential and Flow duration control

Regulatory Program	LID Performance Standard	Hydromodification Control Performance Standard	Type of Performance Standard	
			LID	Hydromodification
	3. Construct a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.			
Sacramento MS4 Permit (September 2008)	1. Consider and incorporate all appropriate and applicable LID components and measures that have been successfully and effectively implemented in other municipal areas.	1. Hydromodification Management Plan shall require controls to manage the increases in the magnitude (e.g., flow control), frequency, volume and duration of runoff.	Narrative	Narrative. No numeric requirements
Central Coast Regional Board Phase II Permit SWMP Notification Letter (February 2008)	1. Minimum 30-ft buffer zone for riparian areas and wetlands. 2. Watershed-based Hydromodification Management Plans should incorporate LID strategies to achieve an EIA of 3% - 10% of watershed area.	1. All projects: ≤5% EIA. 2. Projects that add and/or replace 5,000 sf impervious area: match post-construction hydrograph to the undeveloped hydrograph within 1% for a range of events with return periods from 1-yr to 10-yrs. 3. Project > 2 acres: preserve pre-construction drainage density (miles of stream length/square miles of watershed) for all drainage areas serving a 1st order stream[16] or larger and post-project time of concentration ≥ pre-project time of concentration.	Prescriptive site design/LID BMP requirements and EIA limit	EIA limit, match hydrograph, and match drainage density and time of concentration.

[16] A first order stream is defined as a stream with no tributaries.

Regulatory Program	LID Performance Standard	Hydromodification Control Performance Standard	Type of Performance Standard	
			LID	Hydromodification
Draft West Virginia Phase II Permit (August 2008)	1. Develop quantifiable objectives, with a time frame for achieving them, for eight watershed elements. 2. Infiltrate, evapotranspirate, and reuse the first 1 in of rainfall from a 24-hr storm preceded by 48 hrs of no measurable precipitation. This first 1 in of rainfall must be 100% managed with no discharge to surface waters. 3. A reduction of 0.1 in from the 1 in infiltration/ evapotranspiration/ reuse standard may be applied to any of the following types of development. Reductions are additive such that a maximum reduction of 0.5 inch is possible for a project that meets all five criteria: a) Redevelopment b) Brownfield redevelopment c) High density (>7 units per acre) d) Vertical Density, (Floor to Area Ratio (FAR) of 2 or >18 units per acre) e) Mixed use and Transit Oriented Development (within ½ mile of transit)	1. "Hydromodification" is included in the definitions, but no specific performance standard is included in the draft permit.	Prescriptive site design/LID BMP requirements and volume retention standard. Allowance for reduction in volume retention standard for infill/ redevelopment/ Smart Growth	N/A

Regulatory Program	LID Performance Standard	Hydromodification Control Performance Standard	Type of Performance Standard	
			LID	Hydromodification
	4. For projects that cannot meet 100% of the infiltration/ evapotranspiration/reuse requirement on-site, two alternatives are available: off-site mitigation and payment in lieu. 5. These alternatives are only available, in combination or alone, for up to 0.4 in of the original obligation at a 1:1.5 ratio, i.e., mitigation or payment in lieu must be for 1.5 times the amount of stormwater not managed on site.			
Draft SWRCB Construction General Permit (March 2008)	1. Runoff volume from 85th percentile storm event ≤ pre-project runoff volume.	1. Post-project time of concentration ≥ pre-project time of concentration. 2. Preserve pre-project drainage density.	Match runoff volume	Match drainage density and time of concentration

Table 10: Comparison of LID and Hydromodification Requirements Adopted by Jurisdictions

Jurisdiction	LID Requirements	Hydromodification Control Requirements	Type of Performance Standard	
			LID	Hydromodification
Pierce County, WA Stormwater Management & Site Development Manual (2005)	1. Retain 65% of the site in open space or natural resource protection areas where feasible. 2. Within the County's Urban Growth Area, when retention of 65% native vegetation cannot be achieved, residential LID projects shall retain a minimum of 50% native soil/vegetation protection areas and provide specified BMPs. 3. Commercial and industrial LID projects shall retain a minimum of 25% native soil/vegetation protection areas and provide specified BMPs. 4. The required order of preference for LID BMP selection: • Infiltrate where Type A and B soil exists. • Bioretention areas (rain gardens) or vegetated channels designed with detention (Type C and D soils). • Dispersion techniques for roof runoff to rain gardens. • Dispersion of road runoff into natural resource protection areas down gradient of the road.	1. Match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. 2. The definition of the pre-developed condition is the native vegetation and soils that existed on the site prior to 1800 A.D.	Volume reduction with sizing metric related to site design and water quality storm. Sliding scale for maximum impervious area based on project type	Flow duration control

Jurisdiction	LID Requirements	Hydromodification Control Requirements	Type of Performance Standard	
			LID	Hydromodification
	• Pervious pavements outside the traveled lane, within driveways, and within parking stalls. • More conventional collection, conveyance, and detention methods.			
Draft Etowah Aquatic Habitat Conservation Plan (December 2007)	1. Priority 1: Runoff volume from 2-yr/24-hr event ≤ pre-development (forested) runoff volume for 2 –yr/24-hr event 2. Priority 2: Runoff volume from 2-yr/24-hr event ≤ pre-development 95% forested + 5% impervious runoff volume for 2 –yr/24-hr event 3. Development nodes: Runoff volume ≤ volume from project site with 50% less impervious area.	1. Preservation, restoration and/or reforestation (with native vegetation) of any stream buffers protected through other regulations; and 2. Erosion prevention measures such as energy dissipation and velocity control; and 3. 24-hour extended detention storage of the 1-year, 24-hour return frequency storm event. This requirement may be reduced or waived through the use of other structural and nonstructural measures that allow for infiltration of runoff. The storage volume may be reduced by the volume that is infiltrated.	Match runoff volume with a sliding scale based on protection of endangered species (i.e. Priority 1 – most sensitive species present to Priority 3 – no endangered species present).	Match peak flow
City of Santa Barbara (June 2008)	Small Projects: 1. Voluntary use of basic LID options. Medium Projects: 2. Mandatory use of basic LID options.	Large Projects: 1. Post-project peak flow rate ≤ pre-development peak flow rate for 2, 5, 10, and 25-yr/24-hr events	Prescriptive site design/LID BMP requirements and volume retention standard.	Match peak flow

Jurisdiction	LID Requirements	Hydromodification Control Requirements	Type of Performance Standard	
			LID	Hydromodification
	Large Projects: 1. Runoff volume from 25-yr/24-hr event ≤ pre-development runoff volume for 25-yr/24-hr event, or 2. Runoff volume from one-inch/24-hr storm event, whichever is larger			
County of Los Angeles Department of Public Works Draft Low Impact Development Standards Manual (December 2008)	Single Family Residential <5 Units: 1. Install a minimum of 2 LID BMPs from a list provided in the manual. Non-Residential or Residential ≥ 5 units: 1. First preference is to infiltrate the difference in the post-project SUSMP design storm runoff volume and the undeveloped SUSMP design storm runoff (ΔV). 2. Second preference is to store and reuse ΔV. 3. Third preference is to treat ΔV and release slowly (detention). 4. If the Director of Public Works determines that compliance with the above 3 LID requirements is technically infeasible, the applicant shall submit a proposal for approval by the Director that incorporates design features	1. Match the flow velocity, flow volume, and depth/width of flow for the SUSMP, LID, 2, 5, 10, 25, and 50-year storm events. 2. Conduct sediment transport analysis to determine long-term impacts of streambed accretion and degradation for major drainages.	Prescriptive site design/LID BMP requirements and volume retention or detention standard.	Match peak flow, volume, and depth/width of flow, consider reduction in sediment supply

Jurisdiction	LID Requirements	Hydromodification Control Requirements	Type of Performance Standard	
			LID	Hydromodification
	demonstrating compliance with the LID requirements to the maximum extent practicable.			
Contra Costa County Clean Water Program C.3. Guidebook (September 2008)	1. The CCCWP's LID design guidance (Chapter 4 of the Guidebook) was crafted to ensure LID facilities comply with the NPDES permit's hydraulic sizing requirements for stormwater treatment facilities and flow control facilities. 2. Self-retaining areas are designed to retain the first one inch of rainfall without producing any runoff. 3. Drainage from roofs and paving can be directed to self-retaining areas. The maximum ratios are 2 parts impervious: 1 pervious (treatment only) or 1 part impervious: 1 pervious (treatment and flow control).	1. Show no increase in impervious area and no increase in efficiency of drainage collection and conveyance. 2. Use the design procedures and design criteria in the Guidebook, and the Program's sizing tool, to select and size BMPs for flow control (also meets treatment requirements). 3. Use a continuous-simulation model and 30 years or more of hourly rainfall data to simulate pre-project and post-project runoff, including the effect of proposed control facilities to show that post-project runoff does not exceed pre-project rates and durations. 4. Show that all downstream channels between the project site and the Bay/Delta are enclosed pipes, are engineered hardened channels, are subject to tidal action, or are aggrading. 5. Propose and implement appropriate in-stream restoration projects to fully mitigate potential risk.	Sizing metric for BMPs included in manual to meet water quality and/or hydromodification control standard. Volume retention standard for self-retaining areas.	Flow duration control

The example LID performance standards listed in Table 9 and Table 10 above generally fall into one (or a combination) of the following two general categories:

1. *Prescriptive site design and LID BMP requirements with no metric*. Examples of this approach include the Stormwater Management Manual for Western Washington, San Diego MS4 Permit, and Draft San Francisco Bay Area Municipal Regional NPDES Permit. Narrative site design and LID BMP performance standards are included, with some specific BMPs required, typically to the "maximum extent practicable."

2. *Site design and LID BMP requirements with metrics*. The Pierce County Stormwater Management & Site Development Manual provides an example of a sizing metric related to site design (e.g., retain 65% of the site in open space or natural resource protection areas where feasible). Several of the examples incorporate metrics based on volume reduction (e.g., infiltrate, evapotranspire, or reuse the first one inch of rainfall). The Central Coast Regional Board Phase II Permit SWMP Notification Letter incorporates an LID performance standard based on limiting effective impervious area at the watershed scale related to hydromodification control.

Note that none of the example LID performance standards listed in Table 9 and Table 10 included a requirement for 5% EIA at the project level. Also note, the following statement from the State Water Resources Control Board[17]:

> "… existing development exerts a tremendous pollution impact largely due to the resulting, developed landscape and its associated runoff characteristics. Addressing it by matching pre-development hydrology may not always be possible because many urban areas lack land for stormwater control and natural hydrology has been altered so significantly. **In these instances, the urban stormwater regulations in Portland and Washington, D.C. that require volume retention can serve as appropriate models. (emphasis added)"**

A feature that is common to several of the example performance standards and requirements are recognition of site conditions that limit the feasibility of implementing infiltration (e.g., the San Diego MS4 Permit, the Draft San Francisco Bay Area Municipal Regional NPDES Permit, and the County of Los Angeles Department of Public Works Low Impact Development Standards Manual). These standards and requirements generally allow for use of other types of site design and LID BMPs in these circumstances.

One of the more interesting approaches is the draft West Virginia Phase II Permit LID performance standard, which incorporates a metric that allows for a credit in the volumetric reduction standard for redevelopment projects, brownfield redevelopment,

[17] *A Review of Low Impact Development Policies: Removing Institutional Barriers To Adoption*. Commissioned and sponsored by the California State Water Resources Control Board Stormwater Program and The Water Board Academy. December 2007.

high density projects, mixed use projects, and transit oriented development (within ½ mile of transit). Also, two alternatives are available for projects that cannot meet the onsite infiltration/evapotranspiration/reuse volumetric requirement: 1) off-site mitigation, and 2) payment in lieu. Both of these off-site options require a ratio of 1:1.5 of the original volumetric obligation to the off-site mitigation, and cap the total amount of off-site mitigation that is allowable to a fraction of the total obligation.

The draft Etowah Aquatic Habitat Conservation Plan (HCP) is an example of a watershed specific study that was prepared by a group of jurisdictions to mitigate take of three species listed under the Endangered Species Act. The stormwater management policy of the Etowah Aquatic HCP is centered around a stormwater ordinance that includes performance standards for water quality protection, stream channel protection, and flood protection. In addition, the Etowah Aquatic HCP stormwater ordinance includes a performance standard that limits the volume of runoff in areas most critical to the survival of the fish species covered under the Etowah Aquatic HCP. The areas where the Runoff Limits apply are known as Priority Area 1 and Priority Area 2. Priority Area 1 is home to the most sensitive species protected by the HCP and so has the most restrictive standard. Priority Area 2 supports species that are less sensitive and has a less restrictive standard. Parts of the Upper Etowah that do not currently provide essential habitat to any imperiled fish are classified as Priority Area 3 and are not subject to the Runoff Limits.

V. Land Development Performance Standard

Overview of Use of EIA as a Metric

Effective impervious area as a metric for LID BMP implementation has serious limitations, however, the use of EIA as a planning principle may be relevant to overall watershed protection goals. In 2003, the Water Environment Research Foundation published a report entitled "Physical Effects of Wet Weather Flows on Aquatic Habitats: Present Knowledge and Research Needs"[18]. This report emphasized the limitations of current attempts to link stream impacts to gross measures of development such as imperviousness, observing that these measures provide little meaningful information to understand key processes and to create practical strategies for mitigation. The authors contended that conveyance and storage facilities in urban drainage systems exert a strong influence on runoff hydrology, but this fact is not recognized in studies that attempt to relate stream impacts to gross imperviousness only. They stressed that predictive models of reach-scale habitat changes must account for the connectivity and conveyance of the drainage system and relevant stormwater controls. Moreover, more recent research on the effects of development on aquatic habitat indicate that the preferred metrics rely on hydrologic measures that reflect the watershed response to not only changes in imperviousness, but effects of the drainage infrastructure and stream conditions.[19]

[18] Roesner, L.A., and Bledsoe, B.P., 2003. Physical Effects of Wet Weather Flows on Aquatic Habitats: Present Knowledge and Research Needs, Water Environment Research Foundation, 00-WSM-4.

[19] Protocols for Studying Wet Weather Impacts and Urbanization Patterns. Water Environment Research Foundation 03WSM3, 2008.

Per Schueler's *Cautionary Note*[20], while the research on impervious cover and stream quality is compelling, it is doubtful whether it can serve as the sole foundation for legally defensible regulatory actions at this time. Key reasons include: 1) the research has not been standardized, so different investigators have used different methods to define and measure/estimate imperviousness; 2) researchers have employed a wide number of techniques to measure stream quality characteristics that are not always comparable to each other; 3) most of the studies have been confined to a few ecoregions, and few studies have been conducted in California; 4) the absolute measure of watershed imperviousness that could cause stream instability depends on many factors, including watershed area, land cover, vegetative cover, topography, and soil type; development impervious area and connectedness; longitudinal slope of the river; channel geometry; and local boundary materials, such as bed and bank material properties and vegetation characteristics; and 5) none of the studies has yet examined the effect of widespread application of stormwater treatment, LID controls and/or hydromodification control practices on impervious cover/stream quality relationships.

Proposed Land Development Performance Standard

LID Controls

The following approach to establishing a reasonable, quantitative LID metric is suggested based on our case study analysis and review of alternative LID MS4 performance standards and requirements for new development and redevelopment.

STEP 1 – SITE DESIGN PLANNING PRINCIPLES. Technical literature and policy studies conducted to date unanimously conclude that to effectively implement site design and LID BMP techniques, regulatory and management strategies must be developed for, and integrated into, project planning, design and environmental review phases and processes. Planning principles for controlling the adverse effects of new development and significant redevelopment emphasize the need to address potential impacts in the earliest stages of the development planning process, namely during the site assessment, site planning and layout, vegetation planning, and grading planning stages.

Preliminary and final project plan submittals prepared for priority projects should integrate site design strategies and LID BMPs into project design to infiltrate, disperse, and retain runoff onsite to the extent technically feasible and appropriate. In determining the degree to which site design strategies and LID BMPs must be implemented, it is appropriate for projects to consider the scale of development, site planning BMPs employed, and volume and flow controls achieved by other BMPs and measures implemented for a project area, including, without limitation, regional, subregional and site-specific treatment control, hydromodification, and LID measures and BMPs. Permittees should incorporate a site design planning principle to achieve an effective impervious area of no more than 5% of watershed area, depending on local conditions. Local conditions are particularly important in highly urbanized areas with improved

[20] Schueler, Thomas R. and Heather K. Holland, 2000. The Practice of Watershed Protection, Article 1, "The Importance of Imperviousness", pp. 7 – 18.

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drainage channels, in which case the use of EIA as a site design planning principle is less effective and relevant.

The following site design planning principles should be implemented for each project at the applicable project planning scale (Master Planned Community/Tract Map or Project Site) unless shown to be infeasible or inappropriate given applicable goals and constraints:

1. Master Planned Community/Tract Map Site Design Measures

   (a) Cluster development to preserve open space.

   (b) Provide riparian buffers.

   (c) Preserve and/or restore and enhance natural slopes and native vegetation on slopes adjacent to natural drainage systems.

   (d) Minimize impervious areas by incorporating open space and/or parks.

   (e) Locate development on least infiltrative soils.

   (f) Utilize infiltration properties of sandy soils for groundwater recharge when migrating pollutants or groundwater levels are not a problem.

   (g) In areas not subject to mass grading, delineate and flag the smallest site disturbance area possible and restrict temporary storage of construction equipment in these areas to minimize soil compaction.

   (h) Use vegetated or infiltration-based treatment control and/or hydromodification control BMPs.

   (i) Construct streets, sidewalks, and parking lot aisles to the minimum widths specified in the land use code and in compliance with regulations for the Americans with Disabilities Act (ADA) and safety requirements for fire and emergency vehicle access.

   (j) Construct trails with open-jointed paving materials, granular materials, or other pervious materials, in compliance with regulations for ADA and safety requirements for fire and emergency vehicle access.

   (k) Use native and/or non-native/non-invasive, climate-appropriate landscaping vegetation that requires less watering and chemical application.

   (l) Use efficient irrigation technologies and centralized irrigation controls for landscape watering in common areas, commercial areas, multiple family residential areas, and parks.

   (m) Identify potential water reuse options.

2. Project-level Site Design Measures

   (a) Drain impervious areas into pervious areas prior to discharge to the MS4. The amount of runoff from impervious areas that is to drain to pervious

areas shall correspond with the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.

(b) Properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors..

(c) Use vegetated or infiltration-based treatment control and/or hydromodification control BMPs.

(d) Use efficient irrigation technologies for landscape watering.

(e) Do not use copper or zinc building materials for roof gutters and downspouts.

STEP 2 – LID BMP PERFORMANCE STANDARD. Priority projects should prioritize the selection of LID BMPs to remove stormwater pollutants, reduce stormwater runoff volume, and promote groundwater infiltration and stormwater reuse in an integrated approach to protecting water quality and managing water resources. One or a combination of the three LID BMP options listed below should be implemented. The order of preference is for options 1 and 2 first (with equivalent preference), and option 3 second.

LID BMP options include:

1. BMPs that promote infiltration.
2. BMPs that store and reuse stormwater runoff.
3. BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction and integrate multiple uses, and BMPs which percolate runoff through engineered soil and allow it to discharge downstream slowly.

The LID BMP(s) should be sized, at a minimum, to infiltrate, evapotranspire, reuse, or collect and detain the LID design runoff volume, which is defined as the excess runoff[21] from the water quality design storm event. It is recognized that LID BMPs may be sized to provide treatment control and/or hydromodification control in addition to meeting the LID performance standard, as applicable and feasible.

If a priority project is not able to implement one of the above three LID BMP requirements due to technically infeasibility, in whole or in part, the priority project should incorporate design features demonstrating compliance with the LID BMP requirements to the maximum extent practicable.

[21] Excess storm water runoff = volume of post-development runoff minus pre-development runoff for the 85th percentile storm event (or equivalent water quality design event).

LID BMP Options

LID BMP Option 1: BMPs that Promote Infiltration and Groundwater Recharge. Infiltrate stormwater runoff throughout the project site where possible. This can be accomplished on a lot-by-lot, subregional, and/or regional scale.

Infiltration may not be possible in all development scenarios. Exceptions may include, but are not limited to, the following:

- Locations where seasonal high groundwater is within 10 feet of the surface.
- Within 100 feet of a water supply well.
- Brownfield development sites or other locations where pollutant mobilization is a documented concern.
- Locations with potential geotechnical hazards as outlined in a report prepared and stamped by a licensed geotechnical engineer.
- Locations with soil infiltration rates that do not support infiltration-based BMPs.[22]
- Locations where excessive infiltration to groundwater could cause adverse biological impacts to hydraulically connected ephemeral or intermittent natural drainage courses.
- Development projects in which the use of infiltration BMPs would conflict with local ordinances and building codes.
- Locations where excessive infiltration could cause health and safety concerns.

LID BMP Option 2: BMPs that Store and Reuse Stormwater Runoff. Store and reuse stormwater runoff. Storage and reuse of the LID design volume may not be possible in all development scenarios. Exceptions may include but are not limited to the following:

- Projects that would not provide sufficient irrigation demand or (where permitted) domestic grey water demand for use of stored runoff due to limited landscaping or extensive use of low water use plant palettes in landscaped areas.
- Projects that are required to use reclaimed water for irrigation of landscaping.
- Development projects in which the storage and reuse of stormwater runoff would conflict with local, state or federal ordinances or building codes.
- Locations where storage facilities would cause potential geotechnical hazards as outlined in a report prepared and stamped by a licensed geotechnical engineer.
- Locations where storage and reuse could cause health and safety concerns.

LID BMP Option 3: BMPs that Incorporate Vegetation. LID BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction, integrate multiple

[22] Infiltration should be regarded with caution in soils with an infiltration rate less than 0.5 inches per hour.

uses and/or BMPs which percolate runoff through engineered soil and allow it to discharge downstream slowly shall be implemented. These LID BMPs shall be sized to collect and detain the LID design. These LID BMPs include, but are not limited to, bioretention with underdrains, dry extended detention basins, constructed wetlands, green roofs, planter boxes, sand filters, vegetated buffers, vegetated swales, and wetponds.

Redevelopment and Infill Projects

To promote redevelopment and infill projects, it is recommended that a credit system be established such as a reduction of 0.15 inch from the LID design runoff volume that would be applied to any of the following types of projects. Reductions are additive such that a maximum reduction of 0.65 inch is possible for a project that meets all five criteria:

a) Redevelopment
b) Brownfield redevelopment
c) High density (>7 units per acre)
d) Vertical Density, (Floor to Area Ratio (FAR) of 2 or >18 units per acre)
e) Mixed use and Transit Oriented Development (within ½ mile of transit)

LID Implementation

Compliance with the LID BMP requirements may not be feasible in all development scenarios. In these situations, the priority project shall demonstrate the infeasibility of compliance with the LID requirements in the project report submittal to the satisfaction of the permittee. The LID goal of mimicking natural hydrology by increasing groundwater recharge, enhancing water quality, and preventing degradation to downstream natural drainage courses should be used in the evaluation, approval, and implementation of alternative BMPs, as well as any determination of infeasibility.

Priority projects that cannot meet the LID BMP performance standard onsite shall incorporate design features demonstrating compliance with the LID BMP requirements to the maximum extent practicable.

Priority projects that infiltrate, evapotranspire, reuse, or collect and detain less than the LID design runoff volume onsite (even after the application of redevelopment credits) should mitigate the remaining LID design runoff volume either with off-site mitigation or via payment in lieu. The permittee must develop and fairly apply criteria for determining the circumstances under which these alternatives would be available. A determination that standards cannot be met on site may not be based solely on the difficulty or cost of implementing measures, but must include multiple criteria that would rule out an adequate combination of infiltration, evapotranspiration, reuse, and detention.

Off-site mitigation or payment in lieu, in combination or alone, should meet the original obligation. For either of these options to be available, the permittee must create an inventory of appropriate mitigation projects, and develop appropriate institutional standards and management systems to value, evaluate and track transactions.

Off-site mitigation. LID BMPs may be implemented at another location in the same or equivalent sewershed/watershed as the original project, approved by the permittee. The permittee should identify priority areas within the sewershed/watershed in which mitigation projects can be completed. Mitigation must be for retrofit or redevelopment projects, and cannot be applied to new development.

Payment in lieu. Payment in lieu may be made to the permittee, who will apply the funds to a public stormwater project.

Treatment Control

Consistent with the current draft permit requirements, it is recommended that treatment control BMPs be designed and implemented for the remaining water quality volume or flow not already addressed by LID BMPs.

Hydromodification Control

Until such time that the Southern California Storm Water Monitoring Coalition (SMC) completes the Hydromodification Control Study, an interim hydromodification control criterion to protect natural drainage systems[23] is suggested as follows:

- Projects disturbing land area of less than fifty acres should include LID BMP(s) such that, at a minimum, the 2-year 24-hour storm event post-development runoff volume is less than the 2-year 24-hour storm event pre-development runoff volume. Alternatively, hydromodification controls should control runoff by matching the pre-development flows and durations for the continuous range of return periods from 10 percent of the two year to the 10-year, based on long-term rainfall records. Within this range, the post-project flow duration curve should not deviate above the pre-project flow duration curve flows by more than 10 percent, and shall not deviate above the pre-project flow duration curve flows over more than 10 percent of the length of the curve. A site specific critical flow may substitute for the lower return period (10 percent of the two year) if available.
- For projects disturbing more than 50 acres, the project should develop and implement a Hydromodification Analysis Study that demonstrates that the pre-project sediment transport capacity (erosion potential) in the receiving channel is maintained to within an identified tolerance based on local or regional data. The analysis shall be based on a continuous simulation of the long-term, local rainfall record, with acceptable hydrologic models and assumptions.

VI. Conclusions

[23] Projects that discharge to non-susceptible stream channels are exempt; see hydromodification control exemptions.

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This white paper was prepared to facilitate discussion among the regulatory agencies, regulated communities, and environmental groups as to appropriate metrics for ensuring reasonable implementation of LID and an integrated strategy for water quality protection for discharges from new development and redevelopment projects.

Case studies of three redevelopment projects were presented that showed that using effective impervious area as a metric with no size requirement can result in a wide range of possible hydrologic effects and costs. The same or greater reduction in runoff volume may be achieved through more intensive application of LID BMPs where opportunities exist, compared to a scenario in which LID features are spread more extensively throughout the project site, but with less emphasis on volumetric retention. For example, the first case study showed that 6 inch retention over all the active landscape area with 76% EIA provided the same runoff volume retention as 1 inch retention over all the active landscape area with 0% EIA. Therefore, if reduction in runoff volume is the desired outcome, a volumetric reduction standard would be more constructive than a % EIA standard. Although retention of the delta water quality storm volume appears to be a more reasonable standard than the delta 2-year storm volume, the feasibility of retaining the delta runoff volume on site in landscaped areas is highly dependent on the site-specific infiltration rate. The second case study showed that it was possible to achieve less than 5% EIA without consideration of cost in a downtown redevelopment scenario, but LID BMPs such as green roofs and large volume cisterns were necessitated by site constraints.

The Kmart case study cost estimates showed that the proposed draft permit requirements would significantly increase the drainage costs of urban redevelopment projects. The cost to infiltrate the change in runoff in the 2-year, 24-hour storm event would challenge the feasibility of the redevelopment project, estimated to cost approximately 22% of the total project cost. On the other hand the cost to infiltrate the change in runoff from the water quality design storm is estimated to cost 3% of the total project cost. It is also clear from the Kmart case study that the ability to implement LID BMPs on the site without substantially reducing the developable area is dependent on the volumetric criterion that is selected. In the high volume scenario, a significant amount of the project area (approximately 10 percent of the site) was required for LID BMPs, while in the low volume scenario, the area requirements were much less.

Representative MS4 permits within California and other key states and LID implementation and hydromodification control metrics that have been adopted by jurisdictions via ordinance, guidance, or technical manuals were reviewed and summarized to illustrate alternative approaches to regulating low impact design and hydromodification. These example performance standards and requirements were shown to vary widely, but generally fell into two categories. Some standards relied on prescriptive site design and LID BMP requirements but included no sizing metric. Narrative site design and LID BMP performance standards were also included, with some specific BMPs required, typically to the "maximum extent practicable." Other standards and requirements incorporated sizing metrics. Sizing metrics include metrics related to site design and metrics based on volume reduction. The Ventura Countywide and Orange

Countywide draft MS4 permits currently appear to be unique in prescribing metrics based primarily on effective impervious area.

EIA as a planning goal may be a reasonable metric for watershed protection, but as an LID BMP implementation metric it has serious limitations. Effective impervious area at the watershed scale may be used at the project planning stage. An approach to establishing a reasonable, quantitative LID metric is suggested based on our case study analysis and review of alternative LID MS4 performance standards and requirements for new development and redevelopment.

VII. Recommendations

The suggested approach begins with site design planning principles that should be implemented for each project at the applicable project planning scale (Master Planned Community/Tract Map or Project Site) unless shown to be infeasible or inappropriate given applicable goals and constraints. A LID BMP performance standard is suggested that requires priority projects to implement one or a combination of three types of LID BMPs, with priority placed on option 1 and option 2 equally:

1. BMPs that promote infiltration.
2. BMPs that store and reuse stormwater runoff.
3. BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction and integrate multiple uses, and BMPs which percolate runoff through engineered soil and allow it to discharge downstream slowly.

The LID BMP(s) should be sized, at a minimum, to infiltrate, evapotranspire, beneficially use, or collect and detain the LID design runoff volume, which is defined as the excess runoff from the water quality (SUSMP) design storm event. The LID BMPs can be sized to provide treatment control and/or hydromodification control in addition to meeting the LID performance standard, as applicable and feasible. A reduction (i.e., credit) in the LID design runoff volume would be allowed to promote redevelopment, infill, and smart growth projects. Finally, projects that cannot meet the LID BMP performance standard onsite would be required to incorporate design features demonstrating compliance with the LID BMP requirements to the maximum extent practicable. Projects that infiltrate, evapotranspire, reuse, or collect and detain less than the LID design runoff volume onsite after proving infeasibility would be required to mitigate the remaining LID design runoff volume either in off-site mitigation or via payment in lieu.

The proposed hydromodification performance standard, if incorporated into the revised MS4 Permits, would ensure a reasonable level of interim LID implementation by new development and redevelopment projects until the SCCWRP studies are completed and their recommendations are considered.

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ATTACHMENT A - LID Case Studies

Walnut Village

60 California

Ventura Kmart Site

SARB_011422

Case Study: Walnut Village

Project Description

Walnut Village is a proposed multi-family redevelopment project in the City of Anaheim. The site encompasses 7.6 acres at the corner of Walnut Street and Ball Road. Proposed development consists of a main building with interior courtyards and two sets of smaller structures along Walnut Street. Primary parking is provided below the grade of the large central building with some parking at the surface. The site is bordered on the west and north by a fire access road.

Landscaping is generally present as narrow strips along some building edges and around the perimeter of the sites. Except for the vegetated filter strip, the landscaping does not accept runoff from adjacent impervious area. Key project characteristics are provided in Table 1 below.

The site can be divided into three drainage areas based on the BMP that provides treatment. Stormwater runoff from the site, as proposed, is treated by a StormFilter® vault, Aqua-Guardian® catch basin inserts, and a vegetated filter strip. A site plan with proposed land cover, drainage areas, and stormwater BMPs is shown in Figure 1 below.

Table 1: Project Characteristics

Characteristic	Value	Source
Area, ac	7.6	Project WQMP, submitted to City of Anaheim, August, 2007
Total Imperviousness, %	84%	Delineation of project land uses
Effective Impervious Area, %	76%	Project WQMP, submitted to City of Anaheim, August, 2007
Soil Type/Description	Soils at the site are characterized as B soils	Orange County Hydrology Manual Soils Maps (1986)
Approximate slope of site and surrounding land, ft/ft	Approximately 0.005	Google Earth
Water Quality Storm Depth, in	0.7	OC DAMP, 2003
2-yr Storm Depth, in	2.05	OC Hydrology, 1986

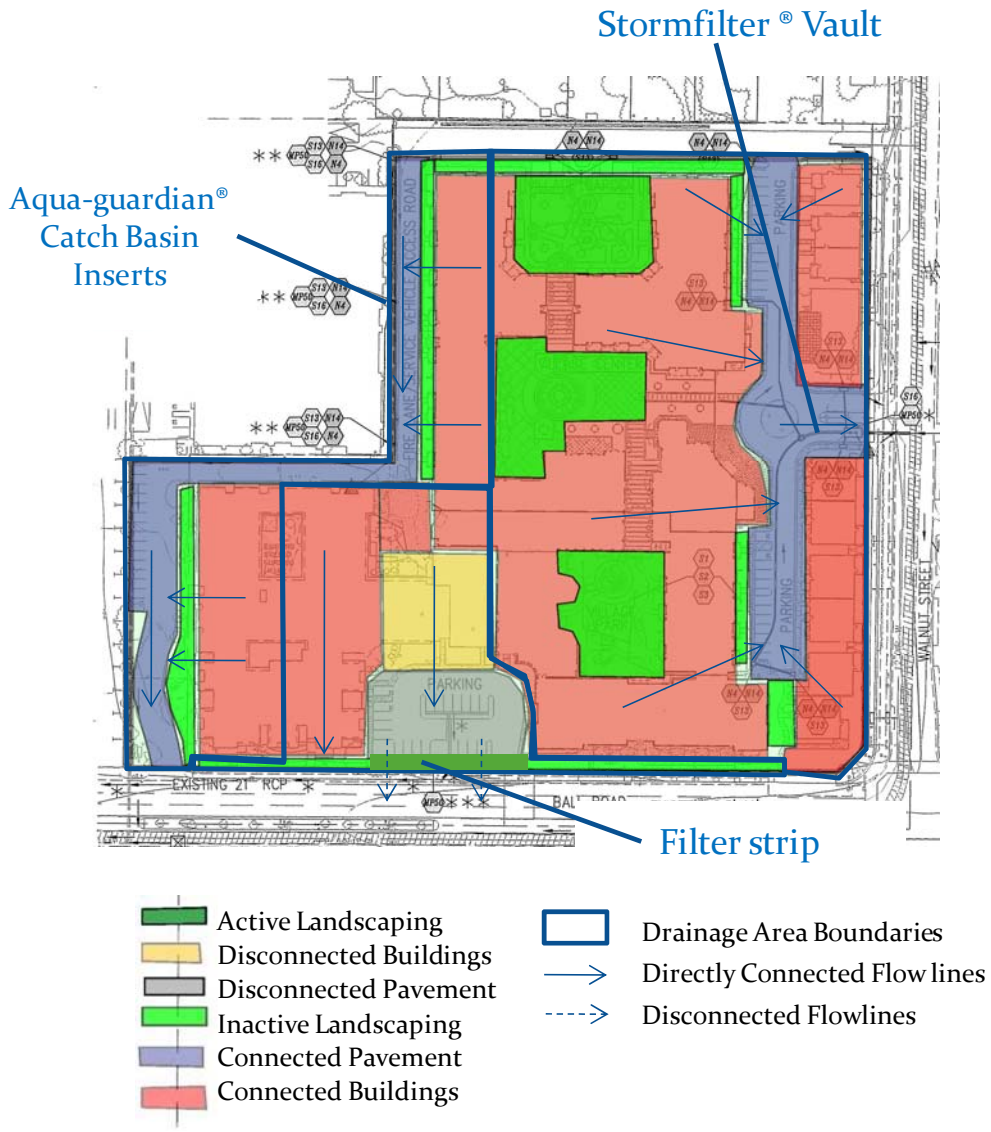

Figure 1: Site land cover and drainage areas

Case Study Assumptions

This case study was completed with the underlying philosophy that for the proposed LID requirements to be feasible they must not necessitate changes to the fundamental character of the project. The follow assumptions were made:

6) Site boundaries are fixed and LID requirements cannot be fulfilled on adjacent parcels of land.
7) Building and parking footprints are fixed in size.

8) Limited modifications to site design may be considered feasible if conditions 1 and 2 are met.
9) Pervious pavement constitutes disconnection of that area, but cannot be used in high-traffic areas.
10) Proprietary BMPs do not constitute disconnection of impervious areas unless they incorporate substantial volume-reduction mechanisms.

Case Study Methodology

This case study considered the feasibility and effectiveness of three design goals, as derived from the Ventura Countywide and Orange Countywide draft MS4 permit requirements described in the main body of this white paper:

3) Reduction of effective impervious area[24] to less than 5%,
11) Retention[25] of the difference between pre-development and post-development runoff volume for the water quality storm event (i.e., the "delta" WQ volume), and
12) Retention of the difference between pre-development and post-development runoff volume for the 2-yr storm event (i.e. the "delta" 2-year volume).

The case study effort first identified the project land cover and proposed drainage patterns. It then identified opportunities for "disconnection" of impervious area through conversion of passive landscaped areas (those that do not accept runoff from adjacent impervious areas) to active landscaped areas (those that do accept runoff from adjacent impervious areas). It also identified minor site design modifications that would allow for addition of more active landscaping or conversion of additional passive landscaping to active landscaping. The practicability of meeting the first goal (<5% EIA) was evaluated based on what could be achieved on the site in this manner without changing the fundamental character of the site. It was important to consider that since routing water through a small strip of landscaping does not fulfill water quality treatment requirements, the disconnection had to be achieved in a way such that water overflowing the active landscaping would be routed to a downstream BMP (in this case, StormFilters or Aqua-Guardian CBIs).

The second part of the case study considered the depth of runoff that must be retained over landscaped areas to achieve the retention goals (#2 and #3). While the first goal, consistent with the draft Ventura Countywide Permit, does not specify a volume of runoff that must be retained as a result of disconnection, the draft Orange Countywide Permit requires that the difference in pre-development and post-development runoff for the 2-yr storm be retained as a result of

[24] As defined by the Ventura County Draft Permit, impervious surfaces may be rendered "ineffective" if the stormwater runoff is: (1) drained into a vegetated cell, over a vegetated surface, or through a vegetated swale, having soil characteristics either as native material or amended medium using approved soil engineering techniques; (2) collected and stored for reuse such as irrigation, or other reuse purpose; or (3) discharged into an infiltration trench. The draft Ventura Permit does not include sizing criteria for these three options.
[25] Retention is defined as the capture and elimination of stormwater through percolation, evapotranspiration, or use.

disconnection. This represents Goal 3, while Goal 2 represents an intermediate level of control between #1 and #3 that has been incorporated into the draft County of Los Angeles Department of Public Works Low Impact Development Standards Manual.

To determine the depth that actively landscaped areas would need to retain, the "delta" water quality and "delta" 2-year storm volumes were computed. In one case it was assumed that all of the delta volume would be stored in active landscaping. In another, it was assumed that driveways and parking areas would be mitigated by pervious pavement up to the water quality depth. The remaining volume required to be retained onsite would be spread over the actively landscaped area to determine the required depth.

Limitations

Two major limitations are acknowledged:

- This case study, as is the case with most investigations of feasibility, relied on subjective assumptions and interpretations which were based on professional judgment; and
- Computational methods used to evaluate effectiveness were simplified, as incorporation of complex methods reduces transparency while increasing the required level of effort.

Thus, the investigations contained herein are not promoted as defensible against all points of view, nor are they promoted as precise. Rather, they are intended to illustrate concepts in a way that does not intentionally introduce bias, while providing planning level results that are open to the scrutiny of the reader.

Case Study Results and Discussion

Effective Impervious Area

Modifications to stormwater routing and site design were identified in an attempt to meet the goal of reducing effective impervious area (EIA) to less than 5%. In this effort, it was critical to understand which areas of the site could be made available for infiltration. Based on site plans, the courtyard areas located over the underground parking structure could not be assumed to accept runoff from adjacent impervious areas because water could not be infiltrated over the parking structures. Perimeter landscaping was deemed potentially appropriate for infiltration, thus disconnection of impervious area was achieved by routing runoff through these areas. Parking areas, driveways, and fire roads were routed to drain to landscaping where possible. It was assumed that entry driveways represented high traffic areas that would not be suitable for pervious pavement.

The project as proposed has 76% EIA. Two degrees of disconnection were achieved in this study, illustrated in Figures 2 and 3 below. Figure 2 shows a reduction to 18% EIA simply by converting passive landscape to active landscape and purposefully routing rooftop drainage over this area. Figure 3 shows a reduction to 0% EIA achieved through adding active landscaping where non-essential hardscape had existed previously.

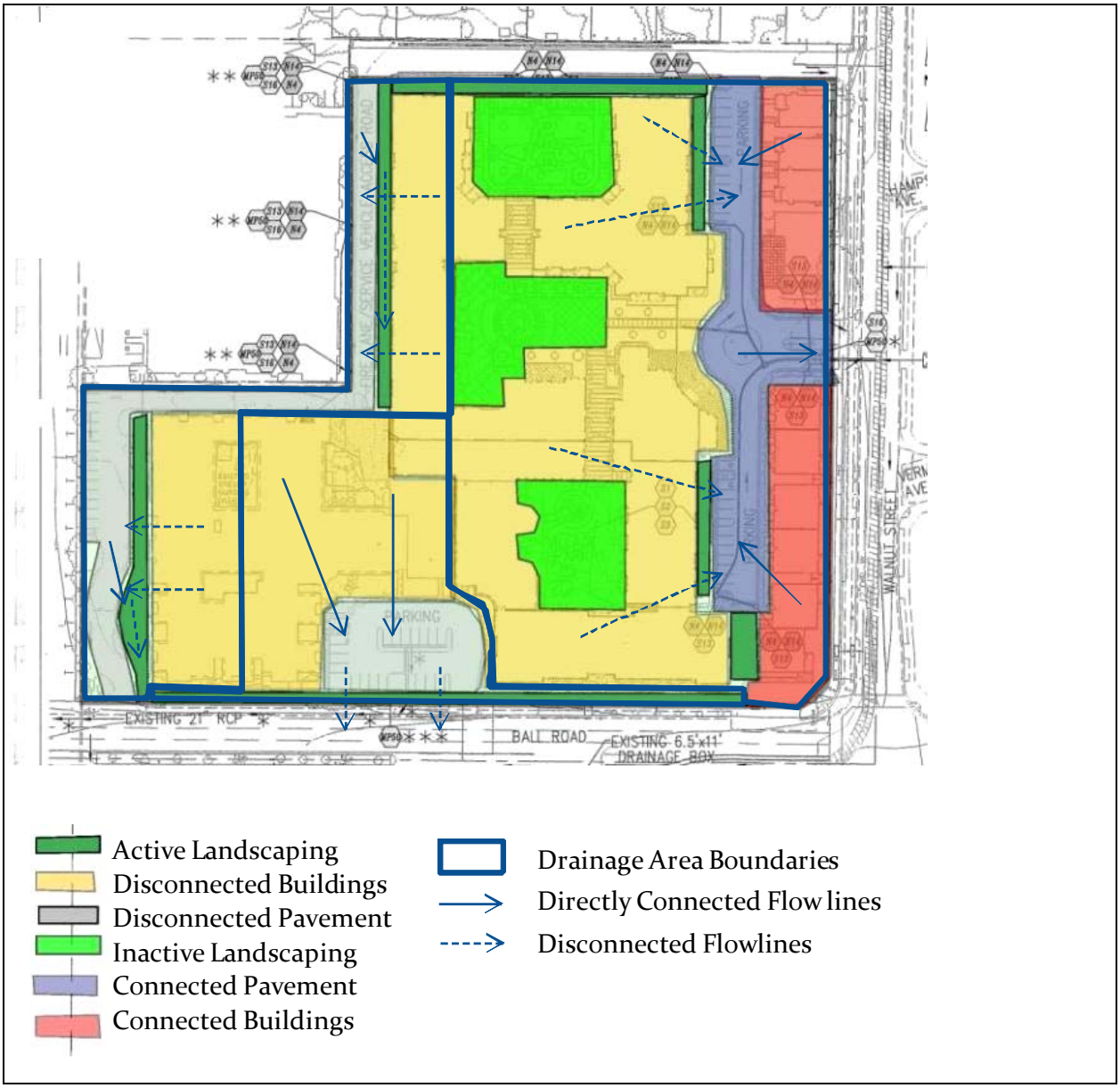

Figure 2: Disconnection scenario resulting in 18% EIA

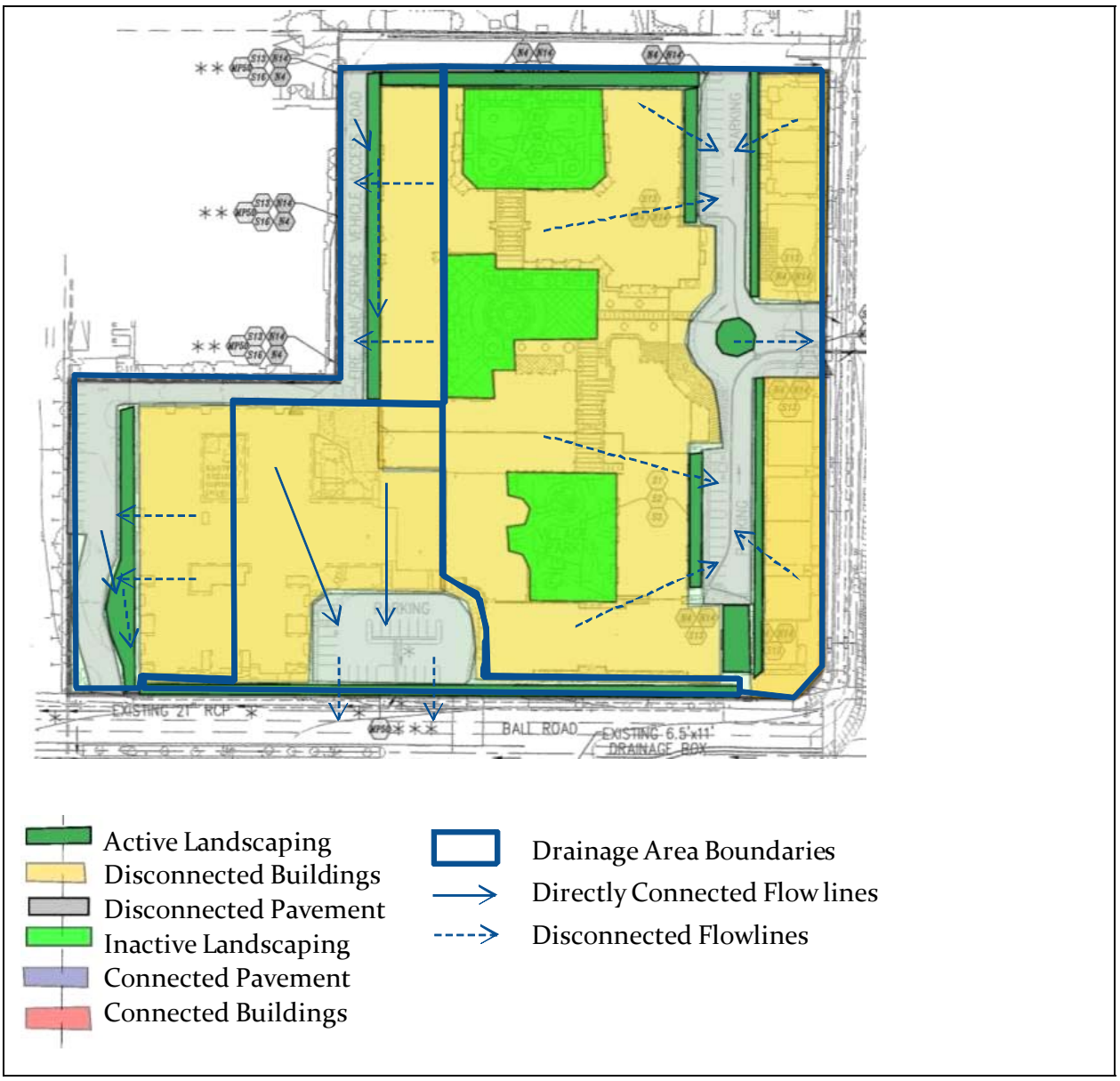

Figure 3: Disconnection scenario resulting in 0% EIA

Table 2 below summarizes the land cover of each disconnection scenario and the runoff coefficients assume for calculation of runoff volumes from each.

Table 2: Land Cover Distribution for Various Disconnection Scenarios

Project Land Cover	Assumed RC	Project Scenarios (areas in acres)		
		76% EIA	18% EIA	0% EIA
Disconnected				
Parking, Sidewalks and Roads	0.9	0.30	1.13	1.70
Building	1.0	0.30	3.93	4.59
Inactive Landscape	0.1	1.10	0.71	0.71
Active Landscape	0.0	0.10	0.49	0.60
Directly Connected				
Parking, Sidewalks and Roads	0.9	1.44	0.63	0.00
Building	1.0	4.36	0.71	0.00
Total Project Area		7.60	7.60	7.60
% Impervious		84%	84%	83%
% EIA		**76%**	**18%**	**0%**

To estimate the approximate effectiveness of the disconnection scenarios in retaining stormwater, simple exploratory calculations were used for three levels of implementation:

A. Baseline turf landscaping over all actively landscaped areas assumed to retain and infiltrate or evapotranspire one inch of water over its surface,
B. Enhanced landscaping over half of the actively landscaped areas assumed to retain and infiltrate or evapotranspire six inches of water over its surface,
C. Enhanced landscaping over all of the actively landscaped areas assumed to retain and infiltrate or evapotranspire six inches of water over its surface,

Runoff volumes were generated using the runoff coefficients and acreages shown in Table 2, and were reduced as a function of the type of disconnection implemented and the area of active landscaping in each scenario. Results are presented as the amount of runoff retained in a given storm event, expressed as watershed inches (Table 3).

Table 3: Approximate Retention Depth for Various Disconnection Scenarios and Types of Active Landscaping Employed

Disconnection Scenarios		Effective Retention Depth (Watershed Inches)		
		76% EIA	18% EIA	0% EIA
A	1" retention over all active landscape	0.01	0.06	0.08
B	6" retention over half of active landscape	0.04	0.19	0.24
C	6" retention over all active landscape	0.08	0.39	0.47

Reduction of effective impervious area to less than 5% of the project area appears to be feasible if the definition of EIA does not include a volumetric retention requirement to render an area ineffective. In order to achieve <5% EIA, additional active landscaping was created. It is

important to note that this conclusion is based on limited available information of site constraints that may not have been evident from project documentation.

From Table 3, it is noted that the depth retained on the site due to LID measures was both a function of the reduction in EIA and the increase in depth retained in actively landscaped areas. It can be seen that an increase from 1 watershed-inch retained to 6 watershed-inches retained over active landscaping (moving down the columns in Table 3) had a more pronounced effect than reducing the EIA from a easily achieve value (18%) to a more difficult to achieve value (0%) (moving left to right in Table 3). Certainly this result is a function of the cases that were selected, but nonetheless illustrates that LID benefits can be achieved by both extensive implementation and more intensive design of active landscaping (i.e., greater retention depth) where opportunities exist. A fixed % EIA LID metric promotes only the former option.

Retention Scenarios

Storage volumes required to retain the delta water quality and delta 2-year events were calculated using methodology contained in the Orange County Drainage Area Management Plan (DAMP). The DAMP method is based on the Rational Method using a constant runoff coefficient. This method may not be the most appropriate method to use for larger storms (such as the 2-yr storm), but it was employed as a simple and easily-understood method. Assumptions and resulting volumes are provided in Table 4 below.

Table 4: Differential Volume of Runoff in WQ and 2-year Storm Event

Storm	Storm Depth (inches)	Imperviousness	Runoff Coefficient[1]	Runoff Depth (watershed inches)	ΔV (watershed inches)
WQ	0.70	0	0.15	0.11	0.45
	0.70	84	0.79	0.55	
2-year	2.05	0	0.15	0.31	1.31
	2.05	84	0.79	1.62	

[1] Table A-1 of OC DAMP, page 7-II-46

To help understand the nature of active landscaping or BMPs that would be required to retain the delta volumes, the following scenarios were explored:

X. Distribution of required retention volume over all active landscaping under the 0% EIA scenario.
Y. Assumed use of pervious pavement to mitigate up to 0.70 inches over all paved area with remaining volume retention spread over actively landscaped area in the 0% EIA scenario.

The required retention depth over all active landscaping was computed using simplified volumetric routing assumptions and is show in Table 5 for Scenarios X and Y. An infiltration rate representative of compacted B soils (0.2 inches per hour) was assumed to explore the range of drawdown times that could be expected for the required retention depths.

Table 5: Required Depth of Retention in Active Landscaping to Achieve Volumetric Retention Requirements and Range of Approximate Drawdown Times

Disconnection Scenarios		Required Retention Depth in All Active Landscaping (inches)		Time to Drain at 0.2 inches per hour [2] (hours)
		Delta WQ (0.45 inches)	Delta 2-yr (1.31 inches)	
X	Retention over all Active Landscaping	5.7	16.6	28 – 83
Y	Retention of 0.70 inches over all pavement[1], with remaining volume retained in active landscaping	3.7	14.6	18 – 73

[1] Based on assumption that all paved areas can be designed to be self-mitigating for entire WQ storm; however, pavement does not accept building runoff.
[2] 0.2 inches per hour is at the high end of typically assumed saturated hydraulic conductivity for compacted B soils under long-term operation. Actual infiltration rates must be based on site-specific testing which was not available for this site. The low end of the reported range is for the Delta WQ volume and the high end is for the Delta 2-yr volume.

The range of required retention depths over the active landscaping is not unreasonable, however, would require priority to be placed on converting all active landscaping to an LID BMP designed and maintained specifically as a retention facility. In the range of 14-17 inches of retention, as required to capture the delta 2-year volume, this would require a combination of fairly deep amended soils and significant surface storage. The drawdown time for such a depth is at or above the upper limit of what would typically be allowed for a surface storage facility to avoid vector concerns (72 hrs), which could be mitigated by the storage of some volume in soil pores but indicates that performance would be substantially reduced in sequential storm events. From this calculation, it is also apparent that feasibility is strongly dependent on site-specific infiltration rates.

The retention of the lesser delta volume (i.e., Delta WQ) appears to be more feasible, but is also dependent on the ability to make use of all active landscaping for intensive BMPs and the site-specific infiltration rates.

Conclusions

The following conclusions can be drawn from this case study:

- In the case study considered, it was possible to achieve less than 5% EIA with no sizing metric.
- The lack of a sizing metric in the definition of EIA resulted in a wide range of possible effectiveness (measured as retained runoff volume).
- The same or better effectiveness in reducing runoff volume may be achieved through more intensive application of LID features where opportunities exist, compared to a scenario in which LID features are spread more extensively throughout the project site, but with less emphasis on volumetric retention. In other words, this case study showed that 6 inch retention over all the active landscape area with 76% EIA provided the same

runoff volume retention as 1 inch retention over all the active landscape area with 0% EIA.

- An EIA criterion coupled with a volumetric retention metric is a much more difficult performance standard as it requires a focused effort to design and maintain active landscaping as retention BMPs for a large portion of the project area.
- The feasibility of retaining the delta runoff volume on site is highly dependent on the site-specific infiltration rate.
- Retention of the delta WQ storm volume appears to be more feasible than the delta 2-yr volume. To retain the delta 2-year volume would require a combination of fairly deep amended soils and significant surface storage. The drawdown time for such a depth is at or above the upper limit of what would typically be allowed for a surface storage facility to avoid vector concerns.

SARB_011432

Case Study: 60 California

Project Description

60 California Street is a proposed four-story, multi-use commercial/retail redevelopment project in the City of Ventura. The site occupies 0.14 acres between East Santa Clara and East Main Street on South California Street. While miscellaneous uses exist on site, nearly the entire lot is covered by the building roof, with only a negligible buffer around the edges. The site is bordered by restaurants and shops to the north and south. Parking does not appear to be provided onsite unless it is below grade. A four-story city parking lot is adjacent to the site and presumably provides parking for the site.

The surrounding area is highly urbanized and no vegetation exists directly on the site with the exception of two palm trees in planters on the sidewalk. These planters do not accept runoff from the site or the adjacent road. Key project characteristics are provided in Table 1 below. Under the proposed conditions, stormwater is conveyed from the roof in four downspouts that presumably tie directly to the off-site storm drain. These downspouts divide the site into four drainage areas. A site plan with proposed stormwater drainage system is shown in Figure 1 below.

Table 1: Project Characteristics

Characteristic	Value	Source
Area, ac	0.14	Project Site Plans, submitted to City of Ventura, Sep-Oct 2007
Imperviousness, %	>95%	Delineation of project land uses; primarily roof; minor planter boxes
Effective Impervious Area, %	100%	Project Site Plans, submitted to City of Ventura, Sep-Oct 2007
Soil Type/Description	Soils at the site are characterized as C soils	Ventura County Hydrology Manual (2006)
Approximate slope of site and surrounding land, ft/ft	Approximately 0.02	DesignARC Grading and Utility Plan (2007)
Water Quality Storm Depth, in	0.75	Volume-based criteria #3, p 57 of 115, in Draft Ventura Co Permit
2-yr Storm Depth, in	2.7	Ventura County Hydrology Manual, 2006. Adjusted from 50 yr depth per multipliers from 1993 manual

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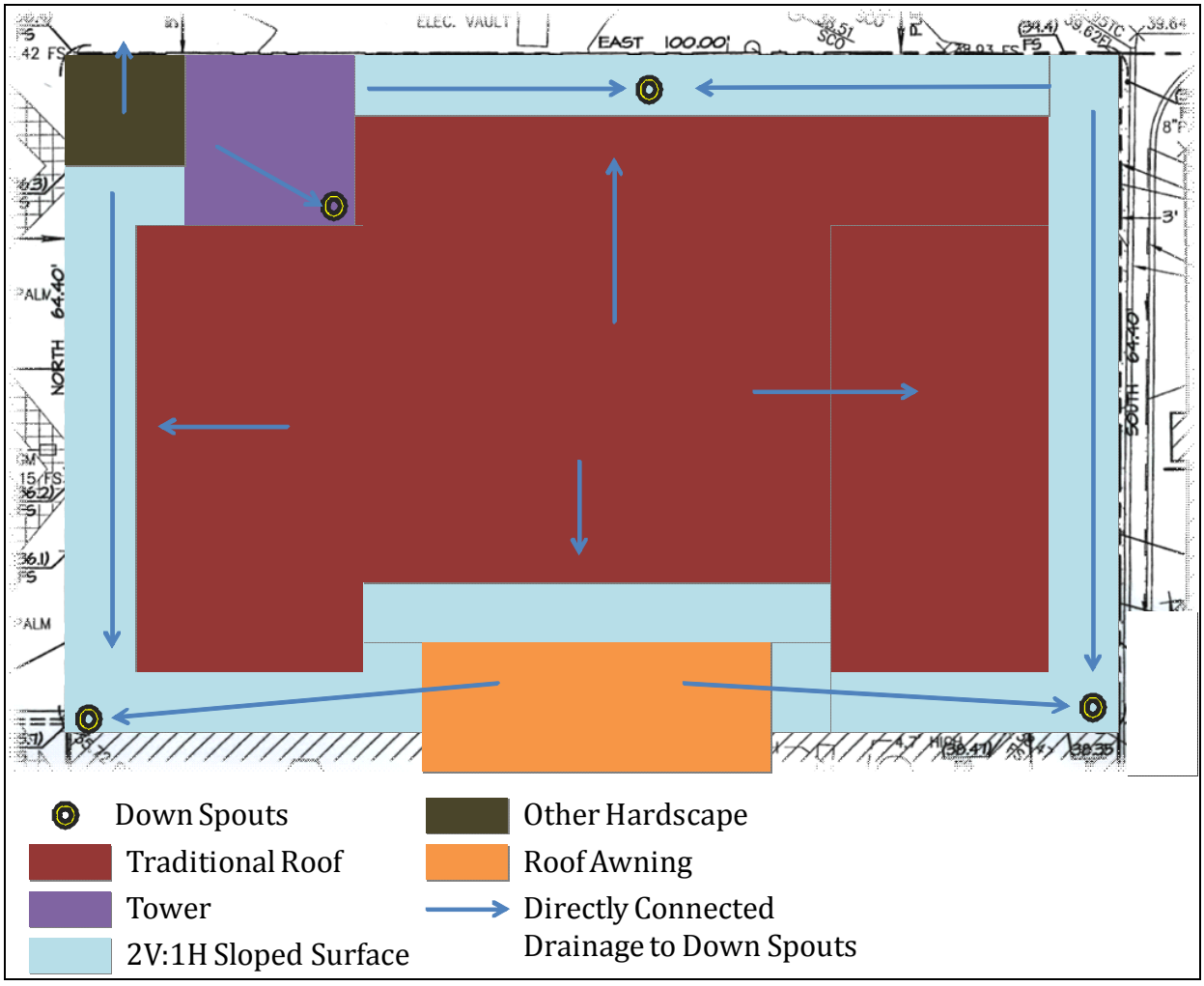

Figure 1: Site land cover and drainage areas

Case Study Assumptions

This case study was completed with the underlying philosophy that for the proposed LID requirements to be feasible they must not necessitate changes to the fundamental character of the project. The follow assumptions were made:

1) Site boundaries are fixed and LID requirements cannot be fulfilled on adjacent parcels of land.
2) Building and parking footprints are fixed in size.
3) Limited modifications to site design may be considered feasible if conditions 1 and 2 are met.
4) Pervious pavement and/or green roofs constitute disconnection of that area, but pervious pavement cannot be used in high-traffic areas and green roofs cannot be used on steeply sloped roofs.

5) Proprietary BMPs do not constitute disconnection unless they incorporate substantial volume-reduction mechanisms.

Case Study Methodology

This case study considered the feasibility and effectiveness of three design goals, as derived from the Ventura Countywide and Orange Countywide Draft MS4 permit requirements described in the main body of this white paper:

1) Reduction of effective impervious area[26] to less than 5%,
2) Retention[27] of the difference between pre-development and post-development runoff volume for the water quality storm event (i.e. the "delta" WQ volume), and
3) Retention of the difference between pre-development and post-development runoff volume for the 2-yr storm event (i.e. the "delta" 2-year volume).

The case study first identified the project land cover and proposed drainage patterns. It then identified opportunities for "disconnection" of impervious area through the use of green roofs and cisterns for reuse. The practicability of meeting the first goal (<5% EIA) was evaluated based on what could be achieved on the site in this manner without changing the fundamental character of the site. Because the nature of the project is that of a multi-story building built to the lot lines, there is no opportunity to create vegetated areas for infiltration.
The second part of the case study considered the infrastructure required to achieve the retention goals (#2 and #3). While the first goal, consistent with the draft Ventura Countywide Permit, does not specify a volume of runoff that must be retained as a result of disconnection, the draft Orange Countywide Permit requires that the difference in pre-development and post-development runoff for the 2-yr storm be retained as a result of disconnection. This represents Goal 3, while Goal 2 represents an intermediate level of control between #1 and #3 that has been incorporated into the draft County of Los Angeles Department of Public Works Low Impact Development Standards Manual.

The volume of cistern storage and effective retention depth of green roofs were computed and evaluated for their reasonableness and probable effectiveness.

Limitations

Two important limitations are acknowledged:

[26] As defined by the Ventura County Draft Permit, impervious surfaces may be rendered "ineffective" if the storm water runoff is: (1) drained into a vegetated cell, over a vegetated surface, or through a vegetated swale, having soil characteristics either as native material or amended medium using approved soil engineering techniques; (2) collected and stored for reuse such as irrigation, or other reuse purpose; or (3) discharged into an infiltration trench. The draft Ventura Permit does not include sizing criteria for these three options.
[27] Retention is defined as the capture and elimination of stormwater through percolation, evapotranspiration, or reuse.

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- This case study, as is the case with most investigations of feasibility, relied on subjective assumptions and interpretations which were based on professional judgment; and
- Computational methods used to evaluate effectiveness were simplified, as incorporation of complex methods reduces transparency while increasing the required level of effort.

Thus, the investigations contained herein are not promoted as defensible against all points of view, nor are they promoted as precise. Rather, they are intended to illustrate concepts in a way that does not intentionally introduce bias, while providing planning level results that are open to the scrutiny of the reader.

Case Study Results and Discussion

Effective Impervious Area

Modifications to the baseline design configuration were identified in an attempt to reduce the impervious area to less than 5 percent. Due to the site's small size and highly urban setting, few options were available. Little to no space is available on the site at the ground level for retaining stormwater. The use of a green or vegetated roof was considered as a means of reducing the runoff from the primary impervious surface on the site: the roof of the building. Green roofs rely on highly porous media and moisture retention layers to store intercepted precipitation and to support vegetation that can reduce the volume of stormwater runoff via evapotranspiration. As proposed, the building's roof contains several features that limit the spatial applicability of a green roof (e.g., a tower, 2V:1H sloped perimeter). Thus, approximately 1,900 ft^2 of the total 6,200 ft^2 roof is unavailable to support vegetated cover.

Runoff from roof area that cannot be covered in green roof could be captured through the use of a cistern for reuse in flushing toilets and irrigating indoor plants in the building. Per the draft Ventura Countywide Permit requirements, the capture of runoff in cisterns constitutes disconnection of that impervious area. No minimum cistern volume is required per the draft permit.

Dry wells are also included as an acceptable means to disconnect impervious area in the draft permit, but were not considered to be feasible given the high density of development (dry wells are generally located away from building foundations) and the indication of poor soil infiltration rates (C soils) at the project site.

Based on this discussion, a reduction in EIA to less than 5% can be achieved, but only by means of a combination of green roof and cisterns for reuse of stormwater.

Figures 2 and 3 below illustrate disconnection scenarios. Table 2 below summarizes the land cover of each disconnection scenario.

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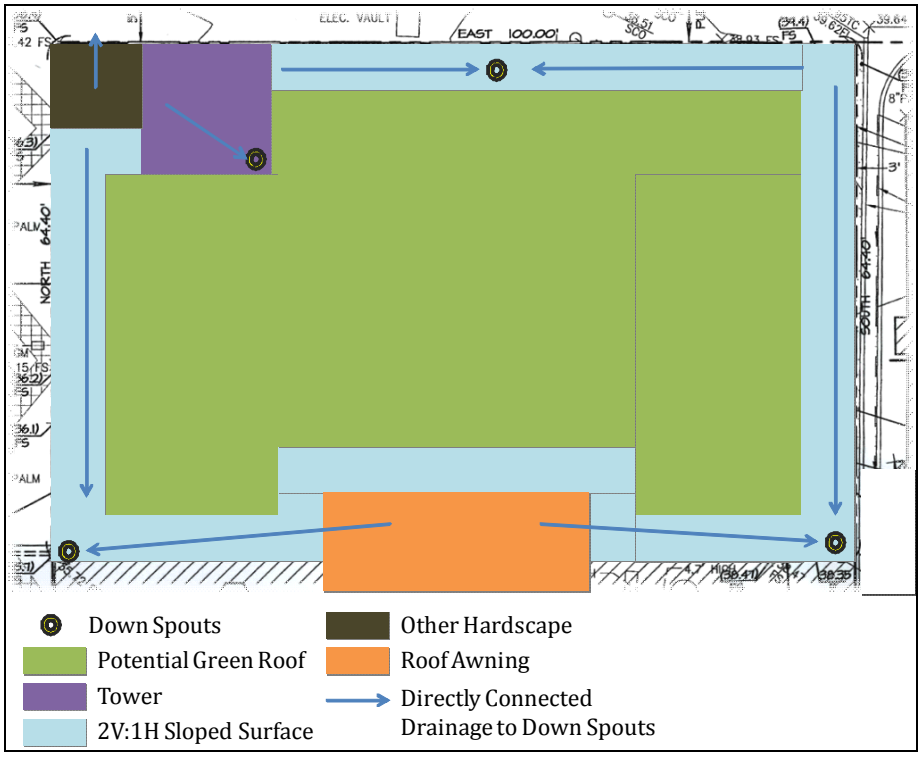

Figure 2: Disconnection scenario resulting in 31% EIA

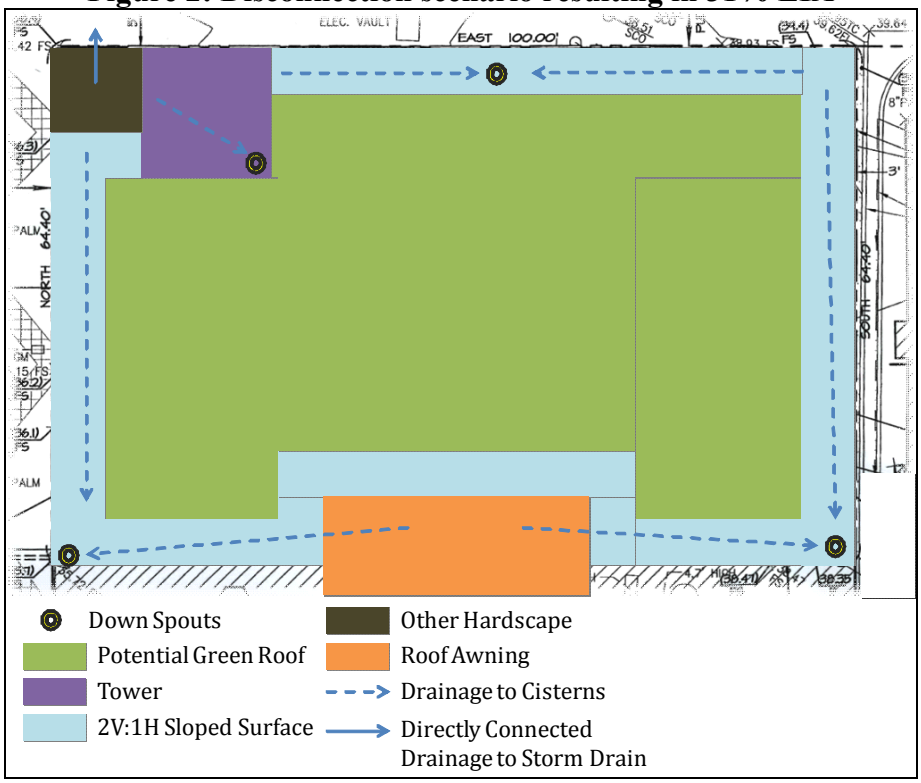

Figure 3: Disconnection scenario resulting in 3% EIA

Table 2: Land Cover Distribution for Various Disconnection Scenarios

Project Land Cover	Project Scenarios (areas in sf)		
	100% EIA	**31% EIA**	**<5% EIA**
Miscellaneous hardscape (directly connected)[1]	200	200	200
Building (directly connected)	6,200	1,900	0
Disconnected via green roof	0	4,300	4,300
Disconnected via cistern	0	0	1,900
Total Project Area	6,400	6,400	6,400
% EIA	**100%**	**31%**	**3%**

[1] Miscellaneous hardscape consists primarily of entryway areas that cannot feasibly be converted to vegetation.

Green roofs can be engineered to store a range of precipitation depths through the use of different design features. It is important to note that green roofs do not eliminate volume through infiltration; only through evapotranspiration. Regeneration of storage by means of ET is generally slower than by means of infiltration, indicating that antecedent conditions may be more important for performance of green roofs than for infiltration-based BMPs.

Similarly, cisterns may be designed in any volume, and also do not infiltrate water; rather water is held for reuse, the rate of which may be the limiting factor in how much water should be stored.

To estimate the approximate effectiveness of the disconnection scenarios in retaining stormwater, simple exploratory calculations were used for two arbitrary levels of implementation:

A. 0.5" of retention over green roof and 1-1,000 gallon cistern,
B. 2" of retention over green roof and 1-2,000 gallon cistern,

Runoff volumes were generated by assuming that all rainfall on rooftops would run off, and were reduced as a function of the type of disconnection implemented. Results are presented as the amount of runoff retained in a given storm event, expressed as watershed inches (Table 3), assuming dry antecedent conditions.

Table 3: Approximate Retention Depth for Various Disconnection Scenarios

Disconnection Scenarios		Effective Retention Depth (Watershed Inches)		
		100% EIA	**31% EIA (no cistern)**	**3% EIA (Green roof and cistern)**
A	0.5 in of retention over green roof and 1-500 gallon cistern	NA – No retention BMPs	0.15	0.27
B	2 in of retention over green roof and 1-2000 gallon cistern		0.58	1.08

Reduction of effective impervious area to less than 5% of the project area appears to be feasible if the definition of EIA does not include a volumetric retention requirement to render an area ineffective. The effectiveness values shown in Table 3 are based on typical design parameters for green roofs and cisterns, which are BMPs that are generally beyond the typical level of BMP implementation in common practice at this time (although not unheard of). In order to achieve <5% EIA, rainwater collection and reuse or re-engineering of the building roof to eliminate areas of steep slope would be required. It is important to note that this conclusion is based on limited available information of site constraints that may not have been evident from project documentation.

Table 3 shows that the depth retained on the site due to LID BMPs was highly dependent on the design criteria selected for green roofs and cisterns. It was generally possible to achieve fairly high retention depths within typical ranges of design criteria for these BMPs.

Retention Scenarios

Storage volumes required to retain the delta water quality and delta 2-year events were calculated using methodology contained in the Orange County Drainage Area Management Plan (DAMP). The DAMP method is based on the Rational Method using a constant runoff coefficient. This method may not be the most appropriate method to use for larger storms (such as the 2-yr storm), but it was employed as a simple and easily-understood method. Assumptions and resulting volumes are provided in Table 4 below.

Table 4: Differential volume of runoff in WQ and 2-year storm event

Storm	Storm Depth (inches)	% Imperv	Runoff Coefficient[1]	Runoff Depth (watershed inches)	ΔV (watershed inches)	ΔV (gallons)
WQ	0.75	0	0.15	0.11	0.64	2,550
	0.75	100	1.0	0.75		
2-year	2.7	0	0.15	0.31	2.39	9,530
	2.7	100	1.0	2.7		

[1] Table A-1 of OC DAMP, page 7-II-46; all rainfall on rooftops assumed to run off

To help understand the quantity of storage that would be required to retain the delta volumes, the following scenarios were explored:

X. Green roof retaining 0.5 inches of water and remainder captured by cistern.
Y. Green roof retaining 2 inches of water and remainder captured by cistern.

The required cistern volume is show in Table 5 for Scenarios X and Y.

Table 5: Required cistern storage volume to achieve volumetric retention requirements

Disconnection Scenarios		Required Cistern Volume (gal)	
		Delta WQ (2,550 gal)	Delta 2-yr (9,530 gal)
X	Green roof retaining 0.5 in of water and remainder captured by cistern.	1,210	8,200
Y	Green roof retaining 2 in of water and remainder captured by cistern.	Cistern not required	4,170

It is noted that the range of required storage volumes is not unreasonable but would require that a viable and sufficient demand exists for the stored water and that use of stormwater as grey water within the buildings would be permittable. An exception is noted for Scenario Y, in which the volume of water stored by the green roof is sufficient to mitigate the delta of the water quality-sized storm and does not rely on storage and reuse.

It is important to note that suitability of both green roofs and storage and reuse systems for southern California is not well understood. Generally, during the rainiest times of the year in southern California, the potential evapotranspiration is the lowest, meaning that the ability to regenerate storage capacity between storms is low. During the summer, green roofs would likely need to be irrigated to sustain healthy vegetation and to reduce fire danger. Likewise, irrigation demand for stormwater stored in a cistern is generally highest over the long summer months when limited rainfall is likely to occur. This is not meant to say that the solutions would not work, but that they are possibly not the most climate-appropriate technologies. In addition, their use may conflict with existing building and health codes.

Conclusions

The following conclusions can be drawn from this case study:

- In the case study considered, it was not exceedingly difficult to achieve less than 5% EIA, but innovative LID BMPs such as green roofs and cisterns were necessitated by site constraints.

Case Study: Kmart Site

Project Description

This case study site is of a former Kmart center located within the City of Ventura. The 12.4 acre site is in a highly urbanized area along South Victoria Avenue and includes a department store, a grocery store, and two restaurants. Currently, the site is covered by building roof and parking lot, with some inactive vegetation (curbed off trees) within the main parking lot.

Key project characteristics are provided in Table 1 below. In the existing condition, stormwater is conveyed from the northeast corner of the site along two main ribbon drains and discharges at the southwest corner (based on limited field data, Google Earth elevations, and previous site visits). A site plan with existing stormwater drainage system is shown in Figure 1 below. It is assumed that the general use of the site would not change with redevelopment, but that redevelopment activities would exceed thresholds triggering the draft permit requirements associated with LID, water quality, and hydromodification.

Table 1: Kmart Site Project Characteristics

Characteristic	Value	Source
Area, ac	12.4	Photomapper, 2005
Pre-development Impervious area, percent	0 percent	Assumed based on definition of pre-development in Draft Permit
Current Imperviousness coverage, percent	93 percent	Aerial Photography
Current Effective Impervious Area, percent	93 percent	Aerial Photography
Approximate slope of site and surrounding land, ft/ft	Approximately 0.02	Aerial Photography
Soil Type/Description	Soils characterized as NRCS Category B or Ventura County soil Type 3	Ventura County Hydrology Manual (2006)
Water Quality Storm Depth, in	0.75	Volume-based criteria #3, p 57 of 115, in Draft Ventura Co Permit
2-yr Storm Depth, in	3.1	Ventura County Hydrology Manual, 2006

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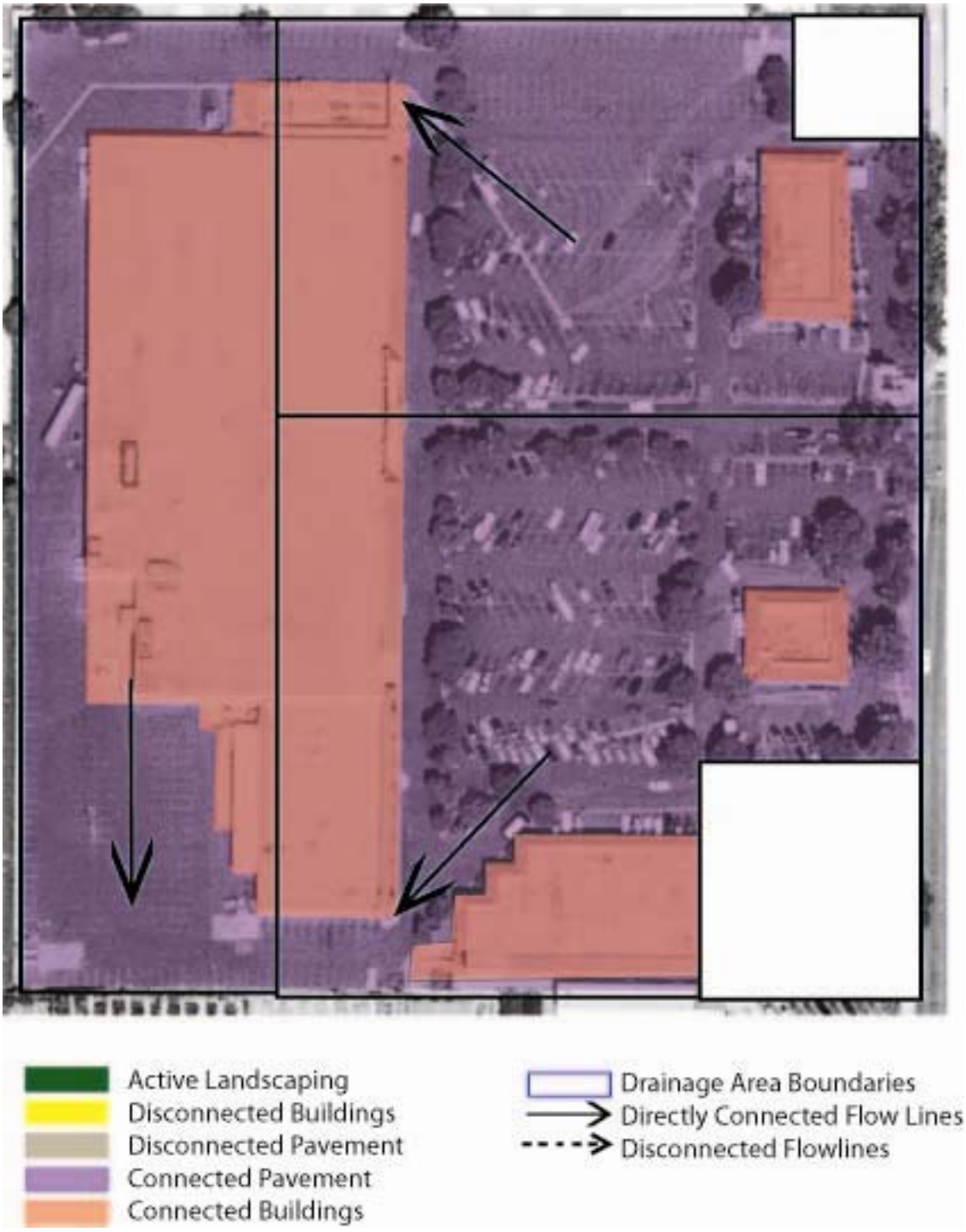

Figure 1: Kmart Site - Land Cover and Drainage Pattern
(Background image from Google Earth™ 2008)

Case Study Assumptions

The draft Ventura County permit does not include volumetric criteria for the disconnection of impervious area nor does it define a design storm type. Because the intent of this case study was

to evaluate the cost of complying with the draft Ventura permit requirement, and because the type of facilities requiring compliance with the draft Ventura permit would operate through capture and retention of runoff volume, it was necessary to assume a range of volumetric criteria to render impervious area "ineffective."

To facilitate this study, many possible interpretations of the draft permit requirements were considered. In one high volume interpretation, to achieve 5% EIA could mean infiltrating 95% of the volume of runoff from the site. This would be greater than what is required for hydromodification control, and would likely preclude the need for separate treatment control BMPs. This interpretation was considered possible but beyond the probable intent of the draft permit. Thus, the following two interpretations were considered for analysis:

- High volume interpretation - interim hydromodification control requires detaining the difference between pre-development[28] and post-development runoff for a 3.1-inch storm (2-year, 24-hour rainfall event). On top of this, to achieve 5% EIA for the site, a vegetated filter strip was added.
- Low volume interpretation – Detain the difference between pre-development and post-development runoff for a 0.75-inch storm (approximate 85th percentile (SUSMP) rainfall event). A vegetated filter strip was added to achieve 10% EIA for the site (LA County LID Manual goal).

It is recognized that the draft stormwater permit hydrologic controls are related to other drainage controls set by county or cities for the rarer, but larger runoff and flood events. For this case study, drainage/flood control and water quality BMPs were assumed to be the same for both scenarios and no cost was assigned to them. This assumption means that the cost developed for the low volume retention scenario would need to be increased to account for appropriately sized treatment BMPs, and potentially hydromodification controls, whereas the high volume retention scenario would have already fulfilled treatment requirements and potential hydromodification requirements.

The focus of this analysis was on the LID criteria and the costs associated with the range of possible interpretations in the two scenarios above.

Case Study Methodology

The case study included estimating required detention volume, selecting and sizing LID BMPs, and estimating the order of magnitude lifecycle costs. These costs are also compared to a range of potential site redevelopment costs to provide prospective on the total cost of redevelopment. The BMP sizing and cost results are developed to provide a practical example to evaluate the draft permit requirements.

Estimates of runoff volume in pre-development and post-development conditions were developed using the NRCS Curve Number Method for both design storm scenarios. The differences or "delta" of these volumes are shown in Table 2.

[28] Consistent with Draft Ventura County permit language, "pre-development conditions" were assumed to refer to the site condition prior to any development.

Table 2: Runoff Estimates from Kmart Site

Permit Interpretation	Design Storm (inches per 24-hour)	Pre-Development Runoff (Ac-Ft)	Post-development Runoff (Ac-Ft)	Delta Volume: BMP Criteria (Ac-Ft)
High Volume	3.1	0.41	2.38	1.97
Low Volume	0.75	0.00	0.32	0.32

Notes:
Pre-development = native vegetation and soils that existed prior to the first development
Ac-Ft = Acre-feet

LID BMPs were selected to treat the "delta" volume in both design storm scenarios assuming the LID BMP would control the draft permit hydromodification volume in a treatment train approach: vegetated filter strips followed by aggregate-filled infiltration trenches.

Filter strips operate by collecting runoff into shallow sheet flow through dense vegetation, slowing the velocity of runoff and promoting filtering, sediment deposition, and some volume reduction due to infiltration. The CASQA BMP Handbook (2003) recommends that filter strips be sized at a 1:1 ratio with contributing impervious area in order to provide full water quality treatment; however, because filter strips were assumed to be followed by downstream infiltration trenches, they were only intended to provide pre-treatment and this requirement was reduced. It is clear that providing an area of filter strip equivalent to the tributary pervious area would constitute a very large impact to other uses on this case study site. For the low volume interpretation, it was assumed that a 1-foot wide filter strip would be provided prior to water entering the ribbon drains. This is quite small for filter strips by typical standards, but is not outside of the potential interpretation of LID requirements contained in the draft permit. For the high volume interpretation of LID requirements, it was assumed that filter strips would be sized to 5 percent of the tributary impervious area, yielding filter strips approximately 25 feet wide, collecting runoff prior to flowing into the infiltration trenches. This width is more consistent with typical guidance for water quality treatment.

Infiltration trenches are designed to capture runoff, filling during a storm event and emptying slowly via infiltration following the event. It was assumed for this case study that infiltration trenches would be designed to drain in 72 hours into Ventura County Soil Type 3 (NRCS Category C) soils with a Ventura County standard infiltration rate of 0.5 inches per hour. This infiltration rate is the minimum for infiltration trenches. Assuming an aggregate porosity of 0.35, a trench depth of 8 feet, for the high volume interpretation, two basins were sized, one 600 feet long and 42 feet wide, the other 290 feet long and 18.5 feet wide. The low volume interpretation required an 8 foot deep basin 900 feet long and 5.5 feet wide.

The project could also comply with LID criteria by using a variety of BMPs such as tree boxes, bioretention, pervious pavement, and other LID BMPs, however, the typical treatment train described above was assumed for its simplicity and based on its suitability for a constrained commercial site.

Costs

Anticipated capital and operation/maintenance costs were developed using information from the California Stormwater Quality Association data (CASQA, 2003) along with supplemental information from the Environmental Protection Agency data (EPA, 2007) for infiltration trenches and vegetated filter strips.

Capital cost estimates for vegetated filter strips included the removal of impervious surface at $0.30 per square foot and revegetation at about $0.70 per square foot for a total of $1 per square foot. Operation and maintenance costs for the vegetated filter strips were assumed to be $350 per acre per year. Capital costs estimates for infiltration trenches were developed by assuming that the rock matrix would have a porosity of 35 percent and cost $5 per cubic foot of volume. Operation and maintenance costs for the infiltration trench option were assumed to be 10 percent of construction costs per year. These simple cost assumptions for the selected BMPs could be further developed, but were used herein to show the magnitude of potential costs. It is important to note that impacts to usable land area resulting from LID implementation were not factored into this analysis.

Plans to redevelop the site could range from simply remodeling the interior of the Kmart building to demolishing the Kmart building and constructing a new shopping mall or business park. The footprint of the Kmart building is approximately 130,000 ft^2. Order-of-magnitude costs for the redevelopment plans can range from about $50/$ft^2$ for remodeling to $250/ ft^2 for new commercial construction, which result in a total cost estimate for this site of $6 million to $32 million.

Limitations

Two major limitations are acknowledged:

- This case study analysis was based on professional judgment and limited field data;
- Simplified BMP selection and computational methods were used for this order-of-magnitude cost evaluation of the scenarios. Incorporation of complex analytical methods would reduce transparency while increasing the required level of effort.

Thus, the investigations contained herein are not promoted as being an ideal case study that evaluates all the issues of the draft permit. Rather, they are intended to illustrate concepts in a way that does not intentionally introduce bias, while providing planning level results and order-of-magnitude cost estimates that are open to the scrutiny of the reader.

Case Study Results and Discussion

The two scenarios produced vastly different cost estimates.

For the high volume interpretation of the draft permit language, 1.9 watershed inches or 85,800 cubic feet (1.97 Ac-Ft) of water would need to be infiltrated. The LID BMPs for this scenario

used 10 percent of the site for LID BMPs included filter strips covering approximately 5 percent of the site, and infiltration trenches covering approximately 5 percent of the site. (See Figure 2). The capital and O&M costs for this interpretation of the permit requirements are provided in Table 3.

Under the low volume interpretation of LID requirements, the delta (or difference) in volume from the pre-development condition to the proposed condition would need to be infiltrated making up 0.3 watershed inches or 13,900 cubic feet (0.32 Ac-Ft). LID BMPs for this scenario would include an approximately one-foot wide vegetated filter strip placed along the drainage collection features of the facility and infiltration trenches covering approximately 1.0 percent of the project site (Figure 3). The capital and O&M costs associated with this scenario are provided in Table 3.

The cost results of the case studies presented in Table 3 are approximate and should be considered as an order-of-magnitude, relative comparison based on engineering experience and limited field data.

Table 3: Present Worth Cost Comparison of Kmart Case Study

Case Study	Proposed Permit Costs[1]	% of Total Redevelopment Cost[2]
High volume interpretation (2-year storm)	$1,290,000	4 – 22%
Low volume interpretation (0.75-inch storm)	$208,000	1 – 3%

[1] LID BMP Costs are developed as 20-year present worth (lifecycle) costs using a 4 percent interest rate.
[2] Assuming other present worth costs of redevelopment range from $6 million to $32 million



Figure 2: Illustration of LID BMPs to meet the high volume interpretation of draft permit requirements
(Background image from Google Earth™ 2008)

From Figure 2, it can be seen that substantial impacts to the site may result from the implementation of LID BMPs if the high volume interpretation is used.



Figure 3: Illustration of LID BMPs to meet the low volume interpretation of draft permit requirements
(Background image from Google Earth™ 2008)

From Figure 3, it can be seen that much less impact results from implementing LID BMPs commensurate with the low volume interpretation of the draft permit requirements.

Conclusions

It is clear from the cost estimates in Table 3, that the proposed permit will significantly increase the drainage costs of urban redevelopment projects. These costs will vary widely, from approximately $0.2 million to $1.3 million in this case, based on interpretation of draft permit requirements.

The LID BMP costs of the high volume interpretation would challenge the feasibility of the total redevelopment, being as much as 22% of the total cost. The low volume interpretation can also be significant, being as much as 3% of the total cost.

It is also clear from Figure 2 and 3 that the ability to implement LID BMPs on the site without substantially reducing the developable area is dependent on the volumetric criterion that is selected. In the high volume scenario, the amount of area (approximately 10 percent of the site) is required for LID BMPs, while in the low volume scenario the area requirements are much less (approximately 1 percent of the site).

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ATTACHMENT B - Example LID and Hydromodification Metrics

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Stormwater Management Manual for Western Washington

The Stormwater Management Manual for Western Washington establishes minimum requirements for new development and redevelopment projects of all sizes and provides guidance concerning how to prepare and implement stormwater site plans. The Department of Ecology updated the 2001 Stormwater Management Manual for Western Washington in 2005 to correct errors, clarify statements, update design criteria and procedures, and apply recent research. The Manual is intended to provide project proponents, regulatory agencies, and others with technically sound stormwater management practices which are presumed to protect water quality and instream habitat and to meet the stated environmental objectives of the applicable regulations. The following minimum requirements establish LID and hydromodification control performance standards:

Minimum Requirement #5: On-site Stormwater Management. Projects shall employ On-site Stormwater Management BMPs to infiltrate, disperse, and retain stormwater runoff onsite to the maximum extent feasible without causing flooding or erosion impacts. Roof Downspout Control BMPs, functionally equivalent to those described in Chapter 3 of Volume III, and Dispersion and Soil Quality BMPs, functionally equivalent to those in Chapter 5 of Volume V, shall be required to reduce the hydrologic disruption of developed sites.

The objective of this requirement is to use inexpensive LID practices on individual properties to reduce the amount of disruption of the natural hydrologic characteristics of the site. "Flooding and erosion impacts" include impacts such as flooding of septic systems, crawl spaces, living areas, outbuildings, etc.; increased ice or algal growth on sidewalks and roadways; earth movement/settlement, increased landslide potential; erosion, and other potential damage. Based upon gross level applications of continuous runoff modeling and assumptions concerning minimum flows needed to maintain beneficial uses, watersheds must retain the majority of their natural vegetation cover and soils, and development projects must meet the Flow Control Minimum Requirement (see Minimum Requirement #7 summarized below), in order to avoid significant natural resource degradation in lowland streams. The Roof Downspout Control BMPs and the Dispersion and Soil Quality BMPs are insufficient to prevent significant hydrologic disruptions and impacts to streams and their natural resources. Therefore, local governments should look for opportunities to encourage and require additional LID BMPs through updates to their site development standards, critical areas ordinances, and land use plans.

Minimum Requirement #7: Flow Control. Projects must provide flow control to reduce the impacts of stormwater runoff from impervious surfaces and land cover conversions. This requirement applies to projects that discharge stormwater directly, or indirectly through a conveyance system, into a river or stream, except for projects that discharge to a large river (Flow Control-Exempt Receiving Waters named in an appendix) in accordance with the following restrictions:

- Direct discharge to the exempt receiving water does not result in the diversion of drainage from any perennial stream classified as Types 1, 2, 3, or 4 in the State of Washington Interim Water Typing System, or Types "S", "F", or "Np" in the Permanent Water Typing System, or from any category I, II, or III wetland; and

- Flow splitting devices or drainage BMPs are applied to route natural runoff volumes from the project site to any downstream Type 5 stream or category IV wetland:

    - Design of flow splitting devices or drainage BMPs will be based on continuous hydrologic modeling analysis. The design will assure that flows delivered to Type 5 stream reaches will approximate, but in no case exceed, durations ranging from 50% of the 2-year to the 50-year peak flow.

    - Flow splitting devices or drainage BMP's that deliver flow to category IV wetlands will also be designed using continuous hydrologic modeling to preserve pre-project wetland hydrologic conditions unless specifically waived or exempted by regulatory agencies with permitting jurisdiction; and

- The project site must be drained by a conveyance system that is comprised entirely of manmade conveyance elements (e.g., pipes, ditches, outfall protection, etc.) and extends to the ordinary high water line of the exempt receiving water; and
- The conveyance system between the project site and the exempt receiving water shall have sufficient hydraulic capacity to convey discharges from future build-out conditions (under current zoning) of the site, and the existing condition from non-project areas from which runoff is or will be collected; and
- Any erodible elements of the manmade conveyance system must be adequately stabilized to prevent erosion under the conditions noted above.

The following require construction of flow control facilities and/or land use management BMPs that will achieve the standard requirement for western Washington:

- Projects in which the total of effective impervious surfaces is 10,000 square feet or more in a threshold discharge area, or

- Projects that convert ¾ acres or more of native vegetation to lawn or landscape, or convert 2.5 acres or more of native vegetation to pasture in a threshold discharge area, and from which there is a surface discharge in a natural or man-made conveyance system from the site, or
- Projects that through a combination of effective impervious surfaces and converted pervious surfaces cause a 0.1 cubic feet per second increase in the 100-year flow frequency from a threshold discharge area as estimated using the Western Washington Hydrology Model or other approved model.

That portion of any development project in which the above thresholds are not exceeded in a threshold discharge area shall apply Onsite Stormwater Management BMPs in accordance with Minimum Requirement #5.

State Water Board Construction General Permit

The State Water Resource Control Board's most recent draft of the Construction General Permit (CGP), released in March 2008, contains new development and redevelopment stormwater performance standards for regulated[29] construction projects located outside of a Phase I or Phase II jurisdiction that address water quality and hydromodification control.[30]

The CGP's performance standard related to water quality protection requires regulated projects to replicate the pre-project runoff volume for the 85th percentile storm event (or the smallest storm event that generates runoff, whichever is larger). The CGP emphasizes runoff reduction through onsite storm water reuse, interception, evapotranspiration, and infiltration through non-structural controls and conservation design measures. Dischargers are given the option of using an excel spreadsheet (provided in an appendix) to calculate the required runoff volume or a watershed process-based, continuous simulation model such as the EPA's Storm Water Management Model (SWMMM) or Hydrologic Simulation Program Fortran (HSPF).

The CGP's performance standard related to hydromodification control requires regulated projects to maintain predevelopment drainage densities and times of concentration in order to protect channels and encourages projects to implement setbacks to reduce channel slope and velocity changes that can lead to aquatic habitat degradation. The CGP also requires regulated projects to predict post-construction average annual soil loss using the RUSLE. Rather than prescribe a specific one-size-fits all modeling method in the CGP, the State Water Board staff intend to develop a stream power and channel evolution model-based framework to assess channels and to develop a hierarchy of suitable analysis methods and management strategies.

West Virginia Draft Phase II Permit

The draft West Virginia Phase II permit incorporates watershed protection elements and site and neighborhood design elements. The purpose of watershed protection elements is to manage the impacts of stormwater on receiving waters that occur because of regional or watershed-scale management decisions. The primary purpose of site and neighborhood design elements is to manage the impacts of stormwater on receiving waters that occur because of site and neighborhood design management decisions. The technical principles of these management practices have many complementary similarities, and must be implemented in tandem.

Watershed Protection Elements. The watershed protection elements must be incorporated into the subdivision ordinance or an equivalent document and into all relevant policy documents as they come up for regular review. Planning documents include comprehensive or master plans,

[29] Construction activity subject to the General Permit includes any construction or demolition activity, clearing, grading, grubbing, or excavation or any other activity that results in a land disturbance if more than one acre is disturbed, is part of a larger plan, if the activity is part of more activities in a municipality's Capital Improvement Project Plan.

[30] Fact Sheet for Water Quality Order 2008-XX-DWQ State Water Resources Control Board (State Water Board) National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges Associated with Construction Activity (General Permit).

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subdivision ordinances, general land use plans, zoning codes, transportation master plans, specific area plans, or unified development ordinances. The permit does not stipulate specific baselines or standards for these elements in order that the permittees may develop criteria that meet the characteristics of their watershed(s).

The permittees must develop quantifiable objectives, with a time frame for achieving them, for the following eight watershed elements:

(1) Minimize the amount of impervious surfaces (roads, parking lots, roofs, etc.) within each watershed, by minimizing the creation, extension and widening of parking lots, roads, and associated development.

(2) Preserve, protect, create and restore ecologically sensitive areas that provide water quality benefits and serve critical watershed functions. These areas may include, but are not limited to; riparian corridors, headwaters, floodplains and wetlands.

(3) Implement management practices that prevent or reduce thermal impacts to streams, including requiring vegetated buffers along waterways, and disconnecting discharges to surface waters from impervious surfaces such as parking lots.

(4) Prevent disturbances of natural water bodies and natural drainage systems caused by development, including roads, highways, and bridges.

(5) Avoid development in areas that are particularly susceptible to erosion and sediment loss.

(6) Implement standards to protect trees, and other vegetation with important evapotranspirative qualities.

(7) Implement policies to protect native soils, prevent topsoil stripping, and prevent compaction of soils.

(8) Implement water conservation policies that will reduce both stormwater and non- stormwater discharges via storm sewer systems.

Site and Neighborhood Design. The permittees must develop a program to protect water resources by requiring all new and redevelopment projects to control stormwater discharge rates, volumes, velocities, durations and temperatures. The permittee must implement and enforce via ordinance and/or other enforceable mechanism(s) the following requirements for new and redevelopment:

1. Site design standards for all new and redevelopment that require, in combination or alone, management measures that infiltrate, evapotranspirate, and reuse of, at a minimum, the first one inch of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation. This first one inch of rainfall must be 100% managed with no discharge to surface waters. An Underground Injection Control permit may be required when certain conditions are met.

2. The following additional water quality requirements, as applicable:

    a) A project with reasonable potential for pollutant loading(s) must provide water quality treatment for pollutants of concern (e.g., petroleum hydrocarbons at a vehicle fueling facility) before infiltration.

b) A project that cannot implement adequate preventive or treatment measures to ensure compliance with groundwater and/or surface water quality standards, must properly convey stormwater to a NPDES-permitted wastewater treatment facility or via a licensed waste hauler to a permitted treatment and disposal facility.

c) A project that discharges or proposes to discharge to any surface water or ground water that is used as a source of drinking water must comply with all applicable source water protection policies and plans.

3. When considered at the watershed scale, certain types of development can either reduce existing impervious surfaces, or at least create less 'accessory' impervious. Incentive standards may be applied to these types of projects. A reduction of 0.1 inches from the one inch infiltration/evapotranspiration/reuse standard may be applied to any of the following types of development. Reductions are additive such that a maximum reduction of 0.5 inch is possible for a project that meets all five criteria.

   a) Redevelopment
   b) Brownfield redevelopment
   c) High density (>7 units per acre)
   d) Vertical Density, (Floor to Area Ratio (FAR) of 2 or >18 units per acre)
   e) Mixed use and Transit Oriented Development (within ½ mile of transit)

4. For projects that cannot meet 100% of the infiltration/evapotranspiration/reuse requirement on-site, two alternatives are available: off-site mitigation and payment in lieu. The permittee must develop and fairly apply criteria for determining the circumstances under which these alternatives will be available. A determination that standards cannot be met on site may not be based solely on the difficulty or cost of implementing measures, but must include multiple criteria that would rule out an adequate combination of infiltration, evapotranspiration and reuse such as: too small a lot outside of the building footprint to create the necessary infiltrative capacity even with amended soils; a site use that is inconsistent with capture and reuse of stormwater; too much shade or other physical conditions that preclude adequate use of plants.

   These alternatives are only available, in combination or alone, for up to 0.4 inches of the original obligation at a 1:1.5 ratio, i.e., mitigation or payment in lieu must be for 1.5 times the amount of stormwater not managed on site. For either of these options to be available, the permittee must create an inventory of appropriate mitigation projects, and develop appropriate institutional standards and management systems to value, evaluate and track transactions.

   Off-site mitigation. Infiltration/evapotranspiration/reuse measures may be implemented at another location in the same sewershed/watershed as the original project, approved by the permittee. The permittee shall identify priority areas within the sewershed/watershed in which mitigation projects can be completed. Mitigation must be for retrofit or redevelopment projects, and cannot be applied to new development.

   Payment in lieu. Payment in lieu may be made to the permittee, who will apply the funds to a public stormwater project.

5. When public streets or parking lots are repaired, modified or reconstructed opportunities to improve stormwater management using infiltration and evapotranspiration measures shall be

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included in the design work. During the next permit term formal design standards for streets and parking lots will be required per the street and parking design assessment undertaken this permit term.

Draft Etowah Aquatic Habitat Conservation Plan

The draft Habitat Conservation Plan (HCP) for the issuance of an Endangered Species Act Section 10(a)(1)(B) permit for Incidental Take in the Etowah watershed was prepared by a group of jurisdictions to mitigate take of the amber darter (Percina antesella), Etowah darter (Etheostoma etowahae) and Cherokee darter (Etheostoma scotti) and to assure their survival and recovery. [31] The Etowah River is a major headwater tributary of the Coosa River system in northern Georgia. The basin is exceptional for its aquatic biodiversity, with 76 extant native fish species, including three species listed under the Endangered Species Act (ESA) and six others that are considered imperiled but not currently listed. Five Federally listed mussel species were once found in the Etowah, though all but one are now considered extirpated. A species of brachycentrid caddisfly also is considered imperiled because it is believed to exist only in the Etowah and Hiawassee Rivers.

The Etowah Aquatic HCP Stormwater Management Policy was developed by a technical committee of professionals and local government staff from the Etowah watershed through several meetings from 2004 to 2006. It was the intent of the HCP Steering Committee that the Stormwater Management Policy be adopted by all jurisdictions participating in the HCP prior to receiving an Incidental Take Permit from US Fish and Wildlife Service and that, once implemented, the policy would help minimize and mitigate the take of imperiled aquatic species in the Etowah Watershed.

The stormwater management policy of the Etowah Aquatic HCP is centered around a stormwater ordinance adapted from the Metropolitan North Georgia Water Planning District ("Metro District") ordinance. The two ordinances are identical in many important respects so that jurisdictions within the Metro District can meet both requirements in a single set of regulations. Both ordinances include performance standards for water quality protection, stream channel protection, and flood protection. In addition, the Etowah Aquatic HCP stormwater ordinance includes a performance standard that limits the volume of runoff in areas most critical to the survival of fish species covered under the Etowah Aquatic HCP. This "Runoff Limit" standard is critical to protecting imperiled species of the Etowah.

The areas where the Runoff Limits apply are known as Priority Area 1 and Priority Area 2. Priority Area 1 is home to the most sensitive species protected by the HCP and so has the most restrictive standard. Priority Area 2 supports species that are less sensitive and has a less restrictive standard. Parts of the Upper Etowah that do not currently provide essential habitat to any imperiled fish are classified as Priority Area 3 and are not subject to the Runoff Limits. The Runoff Limit for a site in a Priority 1 area is equal to that of an undeveloped, forested site for the two-year design storm. That is, the volume of runoff for the site must not exceed the volume of

[31] Draft Etowah Aquatic Habitat Conservation Plan, December 14, 2007. http://www.etowahhcp.org/background/documents/2007_12_14_draft_etowah_hcp_sections_1_9.pdf.

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runoff that would occur under a forested condition, for small storms, given the soils present. The Runoff Limit for a site in a Priority 2 area is set at the equivalent of 5% impervious cover. Therefore, new development and major redevelopment must employ stormwater management practices that make the site act as if it had no more than 5% impervious cover (and the remainder forested). In both Priority Areas 1 and 2, local governments can designate some locations as "development nodes," where Runoff Limits are significantly relaxed. The Runoff Limit for a development node is set at 50% of the actual impervious cover for the site. For example, a site with 60% impervious cover must reduce the runoff to the amount expected from the site if it had only 30% impervious cover (and the remainder forested).

To meet the Runoff Limits, developers can use "Better Site Design" techniques to reduce the amount of impervious cover, as well as various stormwater infiltration best management practices to return runoff to the soil. Use of these practices is supported by an engineering manual and by a training program. An optional Better Site Design checklist has been developed to assist local governments in working with developers in pre-construction meetings to use these practices. Jurisdictions are also encouraged to amend regulations to allow the use of all Better Site Design techniques, although this is not required.

County of Los Angeles Department of Public Works Low Impact Development Standards Manual

All new development and redevelopment under the jurisdiction of the County of Los Angeles is required to meet LID requirements. The goals of LID are to increase groundwater recharge, enhance water quality, and prevent degradation to downstream natural drainage courses.

Requirements for Small Scale Residential Projects

Residential development and redevelopment of 4 units or less, or remodels affecting more than 50 percent of the original home footprint are not required to complete hydrologic analysis for the project site, but must include at least 2 of the following items into the site design:

- Porous pavement: Install porous pavement that allows rainwater to infiltrate through it. Porous pavement includes, but is not limited to: porous asphalt, porous concrete, ungrouted paving blocks, and gravel. At least 50% of the pavement on the lot shall be porous.

- Downspout routing: Each roof downspout shall be directed to one of the following BMPs. The sum of the capacity of the downspout BMPs shall be at least 200 gallons.

    a. Cistern/rain barrel. Direct roof downspouts to a rain barrels or cisterns. The stored stormwater can then be used for irrigation or other nonpotable uses.

    b. Rain garden/planter box. Direct roof downspouts to rain gardens or planter boxes that provide retention and treatment of stormwater.

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- Disconnect impervious surfaces. Slope driveways and other impervious surfaces to drain toward pervious surfaces. If possible, runoff should be directed toward vegetated areas or water quality BMPs. Limit the total area not directed toward vegetated areas or water quality BMPs to 10% or less of the area of the lot.

- Dry well. Install a dry well to infiltrate stormwater. The dry well shall be sized to hold at least 200 gallons of stormwater.

- Landscaping and landscape irrigation. Plant trees near impervious surfaces to intercept rainfall in their leaves. Trees planted adjacent to impervious surfaces can intercept water that otherwise would have become runoff. Two trees shall be planted on each parcel so that they overhang impervious surfaces. Install irrigation systems that minimize water usage and eliminate dry-weather urban runoff.

- Green roof. Install a green roof to retain and treat stormwater on the rooftop. A green roof shall cover at least 50% of the total rooftop area.

Requirements For Large Scale Development

All residential developments of 5 units or greater and all nonresidential developments shall follow the LID Hydrologic Analysis techniques outlined in the Hydrologic Analysis Section of this manual.

LID Requirements

Large scale residential and nonresidential development projects shall prioritize the selection of BMPs to treat stormwater pollutants, reduce stormwater runoff volume, and promote groundwater infiltration and stormwater reuse in an integrated approach to protecting water quality and managing water resources.

BMPs shall be implemented in the following order of preference:

1. BMPs that promote infiltration,
2. BMPs that store and beneficially use stormwater runoff,
3. BMPs that utilize the runoff for other water conservation uses including but not limited to BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction and integrate multiple uses, and BMPs which percolate runoff through engineered soil and allow it to discharge downstream slowly.

If the Director of Public Works determines that compliance with the above 3 LID requirements is technically infeasible, in whole or in part, in response to an applicant's submittal, the Director shall require the applicant to submit a proposal for approval by the Director that incorporates design features demonstrating compliance with the LID requirements to the maximum extent practicable.

The LID goals of increasing groundwater recharge, enhancing water quality, and preventing degradation to downstream natural drainage courses shall be used in the evaluation, approval, and implementation of LID BMPs, as well as any determination of infeasibility.

Onsite Infiltration Requirements

The excess volume (ΔV) determined by the hydrologic analysis in Chapter 4 shall be infiltrated throughout the project site whenever possible. This can be accomplished on a lot-by-lot or on a sub-regional scale provided that equivalent benefit can be demonstrated. The following requirements apply:

- Infiltrate the ΔV from each lot at the lot level, or
- Infiltrate the ΔV from the entire project site, including streets and public right-of-way, in sub-regional facilities. The tributary area of a sub-regional facility shall generally be limited to 5 acres, but may be exceeded per the Director of Public Works.

Infiltration may not be possible in all development scenarios. Exceptions may include but are not limited to the following technical feasibility and implementation parameters:

- Locations where seasonal high groundwater is within 10 feet of the surface.
- Within 100 feet of a groundwater well used for drinking water.
- Brownfield development sites or other locations where pollutant mobilization is a documented concern.
- Locations with potential geotechnical hazards as outlined in a report prepared and stamped by a licensed geotechnical engineer.
- Locations with natural, undisturbed soil infiltration rates of less than 0.5 inches per hour that do not support infiltration-based BMPs.
- Locations where infiltration could cause adverse impacts to biological resources.
- Development projects in which the use of infiltration BMPs would conflict with local, state or federal ordinances or building codes.
- Health and Safety concerns

Onsite Storage and Reuse Requirements

When infiltration is not possible, on-site storage and reuse of the ΔV is the next preferred LID BMP option. Storage and reuse of the ΔV may not be possible in all development scenarios. Exceptions may include but are not limited to the following technical feasibility and implementation parameters:

- Projects that would not provide sufficient irrigation or (where permitted) domestic grey water demand for use of stored runoff due to limited landscaping or extensive use of low water use plant palettes in landscaped areas.

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- Projects that are required to use reclaimed water for irrigation of landscaping.

- Development projects in which the storage and reuse of stormwater runoff would conflict with local, state or federal ordinances or building codes.

- Locations where storage facilities would cause potential geotechnical hazards as outlined in a report prepared and stamped by a licensed geotechnical engineer

- Health and Safety concerns

Water Conservation Requirements

When infiltration or storage and reuse of the ΔV is not possible, LID BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction, integrate multiple uses and/or BMPs which percolate runoff through engineered soil and allow it to discharge downstream slowly shall be implemented. These LID BMPs shall be sized to detain and treat the ΔV.

Infeasibility

Compliance with the LID requirements in this manual in whole or in part may not be feasible in all development scenarios. In these situations, the applicant shall demonstrate the infeasibility of compliance with the LID requirements and submit a proposal for approval by the Director that incorporates design features demonstrating compliance with the LID requirements to the maximum extent practicable.

Water Quality Treatment Requirements

The runoff from the water quality design storm event associated with the developed site hydrology described in Chapter 4 must be treated before discharge in compliance with the National Pollutant Discharge Elimination System Municipal Stormwater Permit for the County of Los Angeles.

Hydromodification Requirements

California Drainage Law is a complicated and complex area with respect to the rights of upper and lower landowners. Therefore, it is in everyone's best interest to require developments to analyze all the factors that may contribute to changed drainage characteristics, which may contribute to downstream drainage impacts (increased flooding and erosion). Below is an outline of the procedure required to analyze drainage impacts on off-site property.

1. All projects are required to conduct hydrology and hydraulic analysis for SUSMP, LID, 2, 5, 10, 25, and 50-year storm events per the LACDPW Hydraulic and Hydrology manuals.

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2. HEC-RAS is required as the standard for analyzing changes in flow velocity, flow volume, and depth/width of flow for all natural drainage courses.
3. Sediment transport analysis using HEC-RAS, SAMS, and HEC-6 is required to determine long-term impacts of streambed accretion and degradation for major drainage courses with Capital Storm flow rates (Q) greater than 5,000 cubic feet per second.
3. All projects are required to fully mitigate off-site drainage impacts caused by hydromodification and changes in water quality, flow velocity, flow volume, and depth/width of flow under all 7 hydrologic scenarios above.
4. If not fully mitigated, the developer is required to obtain Drainage Acceptance letters from impacted downstream property owners. If Drainage Acceptance letters cannot be obtained and mitigation is not feasible, the developer must recommend to Regional Planning that a Statement of Overriding Consideration be included in the California Environmental Quality Act document to disclose that there will be significant unmitigated downstream drainage impacts.

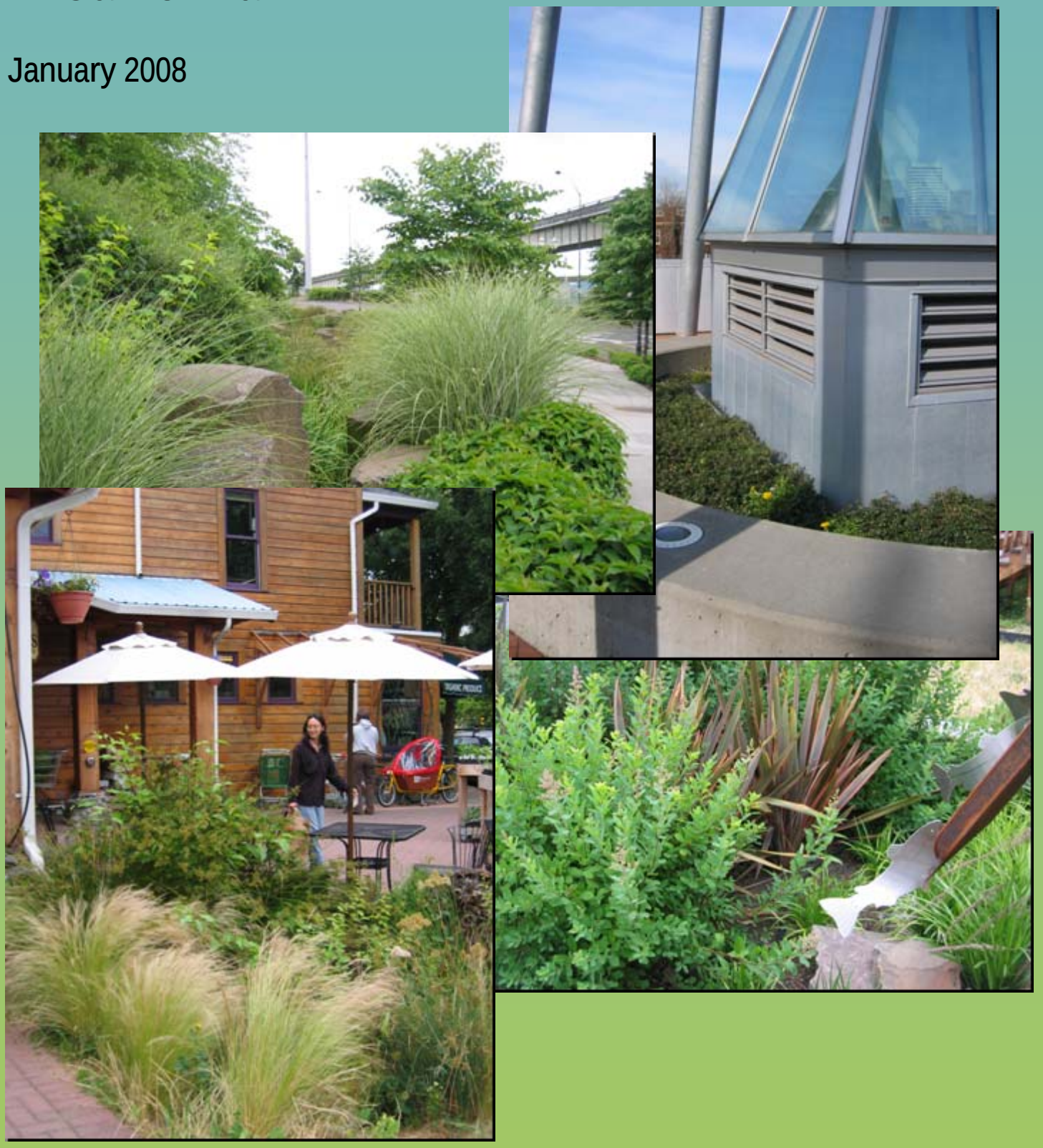
Hydromodification Exemptions

All projects which comply with one or more of the following conditions are exempt from conducting a full analysis for hydromodification impacts. Applicants must still demonstrate that the project mitigates for hydromodification impacts to the satisfaction of the Director of Public Works.

- Projects that disturb less than one acre and add less than 10,000 square feet of new impervious area.
- Projects that do not increase impervious area or decrease the infiltration capacity of pervious areas compared to pre-project conditions.
- Projects that are replacement, maintenance, or repair of an existing permitted flood control facility.
- Projects within a watershed or sub-watershed where a geomorphically-based watershed study has been prepared that establishes that the potential for hydromodification impacts is not present based on appropriate assessment and evaluation of relevant factors, including: runoff characteristics, soils conditions, watershed size and conditions, channel conditions, and proposed levels of development within the watershed.
- Projects that discharge directly or via a storm drain into concrete or significantly hardened channels, which, in turn, discharge into a sump area under tidal influence, or other receiving water that is not susceptible to hydromodification impacts.
- Projects for which have hydrologic control measures that include sufficient sub-regional, regional, in-stream control measures, or a combination thereof such that hydromodification will not occur.

State and Local Policies Encouraging or Requiring Low Impact Development in California

January 2008



Prepared for the
Ocean Protection Council of California

Prepared by
TETRA TECH
SARB_011463

State and Local Policies Encouraging or Requiring Low Impact Development in California

Final Report

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January 2008

SARB_011465

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Executive Summary

Stormwater pollution occurs when rain falls onto developed areas. Under natural conditions, much of the rainwater soaks into the soil, returning to streams, lakes, and other waterbodies through the ground. Surface runoff is usually limited and is slowed by dense vegetation. With development, specifically with the creation of impervious surface such as streets, driveways, sidewalks, and roofs, rain is prevented from infiltrating into the ground, causing it to flow over the surface in much larger quantities. Along the way this runoff mobilizes pollutants and transports them to waterbodies where they eventually flow to the Pacific Ocean.

In California, 691 waterbodies are considered impaired because water quality is too poor to support designated uses.[1] Of these impaired waterbodies, 110 are bays and harbors, 39 are estuaries, and 4 are tidal wetlands, indicating that pollution is affecting California's coastal resources. Urban runoff-related pollutants, such as pathogens, nutrients, metals (e.g., mercury, copper, lead), sediment, and toxic chemicals, are among the top causes of impairment statewide. Many California communities have issued a standing warning to avoid swimming, surfing, or other contact recreation at beaches for 72 hours after rainstorms due to high bacterial counts and increased concentrations of other potentially harmful pollutants being discharged from stormwater outfalls. Beach closures and swimming restrictions are commonly attributed to urban runoff, in some cases even during dry weather. Urban runoff can cause physical damage by accelerating stream channel erosion, modifying instream aquatic habitat, and altering riparian zones. Flood damage can also be more frequent and severe when runoff is not properly mitigated.

The effects of urban runoff have been exacerbated by stormwater management techniques popularized after World War II, in which drainage systems were designed to rapidly convey vast amounts of stormwater through gutters and pipes with no attenuation or pollutant removal. These high-volume, high-velocity flows have eroded stream channels, destroyed habitat, and caused flooding and property damage.

In the past decade a stormwater management technique called Low Impact Development (LID) has been gaining ground as the preferred method for mitigating stormwater impacts. The technique minimizes hardscape and uses the pervious surfaces on a development site, such as landscaped areas, to infiltrate and/or temporarily store runoff, allowing the site to more closely mimic a "natural" state with respect to hydrology. LID site design incorporates such diverse practices as bioswales, filter strips, flow-through planter boxes, porous pavement, cisterns, rain barrels, green roofs, and other micro-scale best management practices, allowing a great deal of flexibility in design. Widespread application of LID practices is expected to help restore the natural water balance when used in redevelopment and infill applications, which is particularly important in urbanized areas to help reverse the ill effects of past development. LID is also expected to maintain the hydrologic balance and reduce pollutants in newly developing areas, helping to ensure protection of high-quality water resources.

Regulations are in place in California and nationwide to prevent and/or mitigate the effects of stormwater pollution. The California State Water Resources Control Board and Regional Water Quality Control Boards have set requirements for municipalities and construction sites to control stormwater under the National Pollutant Discharge Elimination System regulations. Municipal stormwater permits developed by the Regional Water Quality Control Boards in Southern California and the San Francisco Bay area have begun to incorporate explicit LID requirements. These requirements are not standardized and only apply locally, however, limiting their impact statewide. The draft Construction General Permit includes incentives to incorporate LID techniques in stormwater plans statewide and will apply to most new and redevelopment. However, comprehensive state legislation could be adopted to "set the bar" for LID

[1] EPA. 2008. *2006 Section 303(d) List Fact Sheet for California.* http://iaspub.epa.gov/waters/state_rept.control?p_state=CA

incentives and requirements to ensure that all of the State's water resources are protected. Recommended language should be based on existing models within California and in other areas, integrating the "best of the best" while balancing the needs of large, urban communities with those of smaller, suburban or rural communities.

Beyond statewide legislation, other opportunities exist to integrate LID into related programs and initiatives. Stormwater concerns dovetail nicely with smart growth, watershed protection, water conservation, and green building initiatives, for example. Dialog and partnerships among State and local agencies, environmental groups, trade associations, water agencies, academia, and citizen groups will be essential for LID to become "business as usual" in California, with benefits not only to water quality but also for community livability and sustainability.

This report includes background information on stormwater pollution and impervious surface effects (Section 1). Section 2 presents an overview of LID principles and practice along with highlights of agencies and organizations that have incorporated LID. Section 3 categorizes a variety of options for state, regional, and local LID requirements, while Section 4 summarizes existing stormwater regulations in California and elsewhere and integrates these examples into recommendations for statewide LID legislation if the state were interested in adopting such requirements. Section 5 discusses ways in which LID can be incorporated into local codes, ordinances, and standards, along with programmatic steps communities can take to improve LID program administration. Key elements of progressive stormwater codes and ordinances are included as models for other communities. Finally, a procedure and criteria are presented that would assist a State agency in evaluating applications if grant funding is made available for local LID planning and implementation projects.

This report is intended to describe ways in which LID practice can be enhanced in California on state, regional, and local levels. It is meant to complement the policy analysis and recommendations outlined in the December 2007 report from the California State Water Resources Control Board Stormwater Program and The Water Board Academy, *A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption*. Other recent reports provide a different perspective on LID, such as two 2007 reports evaluating costs and benefits of LID practices: *The Economics of Low Impact Development: A Literature Review* by ECONorthwest[2] and the U.S. Environmental Protection Agency's *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*.[3] Technical guidance for LID is continually being developed on the local and regional levels, and many of these guidance manuals provide valuable, location-specific guidelines for LID applicability along with detailed design, installation, and maintenance specifications.

[2] ECONorthwest. 2007. *The Economics of Low Impact Development: A Literature Review*. http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf.

[3] EPA. 2007. *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*. http://www.epa.gov/owow/nps/lid/costs07/documents/reducingstormwatercosts.pdf.

1 Introduction

1.1 Overview of Impervious Surfaces

The term impervious surface refers to land cover, both natural and human-made, that cannot be penetrated by water. Consequently, precipitation that falls on impervious surfaces does not infiltrate into the soil. Instead, it runs off to a pervious area where all or a portion infiltrates into the soil, or it continues to travel down-slope on impervious surfaces, including saturated soils, until it is eventually conveyed to a ditch, a storm drain network, or a receiving waterbody. Most of the impervious cover in an urban watershed or subwatershed is from rooftops, roads, sidewalks, driveways, parking lots, and recreational facilities (e.g., tennis courts, swimming pools, etc.).

Impervious surface is typically measured as total impervious area or effective impervious area. Total impervious area includes all impervious cover in the watershed and is typically represented as a percent of the entire watershed area. Effective impervious area is the portion of impervious cover that is directly connected to stormwater conveyance systems or receiving waterbodies. Effective impervious area tends to be a better proxy for hydrologic and pollutant impacts from development because flows from these areas are not infiltrated, evaporated, or otherwise treated before being discharged to waterbodies. In many cases, a large portion of total impervious area can be "disconnected" by diverting flows to pervious surfaces such as landscaped areas. For example, gutter downspouts on residential homes can be disconnected to direct flows over the lawn or into infiltration basins.

Both the amount of impervious area and the relationship between total and effective impervious areas vary according to land use.[4] For example, work in the Puget Sound area revealed that total impervious area in low-density residential sites averaged approximately 10 percent, with an effective impervious area of only 4 percent. In commercial and industrial areas, however, total impervious area averaged about 90 percent. Almost all of the total impervious area is also effective impervious area because of the lack of pervious areas to break up direct connections.

1.2 Effects of Increased Imperviousness

Watershed imperviousness plays an important role in determining the conditions in waterbodies because it leads to more runoff. Increased runoff carries more pollutants to receiving waters and transports them faster than they would normally travel with the help of streets, driveways, parking lots, rooftops, sidewalks, curbs, gutters, and storm drain pipes. Increased runoff also has physical effects on streams and rivers—the larger, faster flows are more erosive and can alter the size, shape, and habitat quality of channels. Higher runoff volumes also exacerbate flooding and property damage.

Impervious cover is an inescapable attribute of development and a permanent part of the urban/suburban landscape. As might be expected, there is a linear relationship between impervious surface in a given area and the amount of runoff generated. What is unexpected is what this means in terms of both the volume of water generated and the rate at which it exits the surface. Depending on the degree of impervious cover, the annual volume of storm water runoff can increase to anywhere from 2 to 16 times the predevelopment amount.[5] Impervious surface coverage as low as 10 percent can destabilize a stream channel, raise water

[4] Caraco, D., R. Claytor, P. Hinkle, H.Y. Kwon, T. Schueler, C. Swann, S. Vysotsky, and J. Zielinski. 1998. *Rapid Watershed Planning Handbook*. Center for Watershed Protection, Ellicott City, MD.

[5] Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1(3): 100–111.

temperature, and reduce water quality and biodiversity.[6] One study found that connected imperviousness levels between 8 and 12 percent represented a threshold region where minor changes in urbanization could result in major changes in stream condition.[7] Table 1 provides a detailed summary of the effects of urbanization and increased imperviousness on streams.

Table 1. Urbanization Effects on Streams. [8]

Effect	Description
Bankfull and subbankfull floods increase in magnitude and frequency	The peak discharge associated with the bankfull flow (the 1.5- to 2-year return storm) increases sharply in magnitude in urban streams. Channels experience more bankfull and subbankfull flood events each year and are exposed to critical erosive velocities for longer intervals.
Dimensions of the stream channel are no longer in equilibrium with its hydrologic regime	The hydrologic regime that defined the geometry of the predevelopment stream channel irreversibly changes, and the stream experiences higher flow rates on a more frequent basis. The higher-flow events of the urban stream are capable of moving more sediment than before.
Channels enlarge	The customary response of an urban stream is to increase its cross-sectional area to accommodate the higher flows. This is done by streambed downcutting, channel widening, or a combination of both. Urban stream channels often enlarge their cross-sectional area by a factor of 2 to 5 depending on the degree of impervious cover in the upland watershed and the age of development.
Stream channels are highly modified by human activity	Urban stream channels are extensively modified in an effort to protect adjacent property from streambank erosion or flooding. Headwater streams are frequently enclosed within storm drains, while other streams are channelized, lined, and/or "armored" by heavy stone. Another modification unique to many urban streams is the installation of sanitary sewers underneath or parallel to the stream channel.
Upstream channel erosion contributes greater sediment load to the stream	The prodigious rate of channel erosion coupled with sediment erosion from active construction sites increases sediment discharge to urban streams. Researchers have documented that channel erosion constitutes as much as 75 percent of the total sediment budget of urban streams. Urban streams also tend to have a higher sediment discharge than non-urban streams, at least during the initial period of active channel enlargement.
Dry weather flow in the stream declines	Because impervious cover prevents rainfall from infiltrating the soil, less flow is available to recharge ground water. Consequently, during extended periods without rainfall, baseflow levels are often reduced.
Wetted perimeter of the stream declines	The wetted perimeter of a stream is the proportion of the total cross-sectional area of the channel that is covered by flowing water during dry weather, and it is an important indicator of habitat degradation in urban streams. Given that urban streams develop a larger channel cross-section at the same time that their base flow rates decline, it follows that the wetted perimeter will become smaller. Thus, for many urban streams, this results in a very shallow, low-flow channel that "wanders" across a very wide streambed, often changing its lateral position in response to storms.

[6] Schueler, T. 1995. *Site Planning for Urban Stream Protection*. Metropolitan Washington Council of Governments, Washington, DC.

[7] Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales. *Environmental Management* 28(2): 255–266.

[8] U.S. Environmental Protection Agency. 2005. *National Management Measures to Control Nonpoint Source Pollution from Urban Areas*. Office of Water, Washington, DC.

Table 1. Urbanization Effects on Streams. [8]

Effect	Description
Instream habitat structure degrades	Urban streams are routinely scored as having poor instream habitat quality, regardless of the specific metric or method employed. Habitat degradation is often exemplified by loss of pool and riffle structure, embedding of streambed sediments, shallow depths of flow, eroding and unstable banks, and frequent streambed turnover.
Large woody debris is reduced	Large woody debris is an important structural component of many low-order stream systems because it creates complex habitat structure and generally makes the stream carry more water. In urban streams, the quantity of large woody debris found in stream channels declines sharply because of the loss of riparian forest cover, storm washout, and channel maintenance practices.
Stream crossings and potential fish barriers increase	Many forms of urban development are linear in nature (e.g., roads, sewers, and pipelines) and cross stream channels. The number of stream crossings increases in direct proportion to impervious cover, and many crossings can become partial or total barriers to upstream fish migration, particularly if the streambed erodes below the fixed elevation of a culvert or pipeline.
Riparian forests become fragmented, narrower, and less diverse	The important role that riparian forests play in stream ecology is often diminished in urban watersheds as tree cover is often partially or totally removed along the stream as a consequence of development. Even when stream buffers are preserved, encroachment often reduces their effective width and native species are supplanted by exotic trees, vines, and ground covers.
Water quality declines	The water quality of urban streams during storms is consistently poor. Urban storm water runoff contains moderate to high concentrations of sediment, carbon, nutrients, trace metals, hydrocarbons, chlorides, and bacteria. Although considerable debate exists as to whether storm water pollutant concentrations are actually toxic to aquatic organisms, researchers agree that pollutants deposited in the streambed exert an undesirable impact on the stream community.
Summer stream temperatures increase	The impervious surfaces, ponds, and poor riparian cover in urban watersheds can increase stream temperatures by several degrees. Because temperature plays a central role in the rate and timing of instream biotic and abiotic reactions, such increases have an adverse impact on streams. In some regions, summer stream warming can irreversibly shift a cold-water stream to a cool-water or even warm-water stream, resulting in deleterious effects on salmonids and other temperature-sensitive organisms.
Reduced aquatic diversity	Urban streams are typified by fair to poor fish and macroinvertebrate diversity, even at relatively low levels of watershed impervious cover or population density. Declines in sensitive species have been observed at levels of impervious cover as low as 4 percent. Impervious cover in highly urbanized areas comprising greater than 25 percent of a watershed may even preclude the Clean Water Act goal of "fishable" waters. The ability to restore predevelopment fish assemblages or aquatic diversity is constrained by a host of factors, including irreversible changes in carbon supply, temperature, hydrology, lack of instream habitat structure, and barriers that limit natural recolonization.

Figure 1 shows the relationship between impervious cover and aquatic insect diversity; Figure 2 shows the relationship between imperviousness and fish diversity.

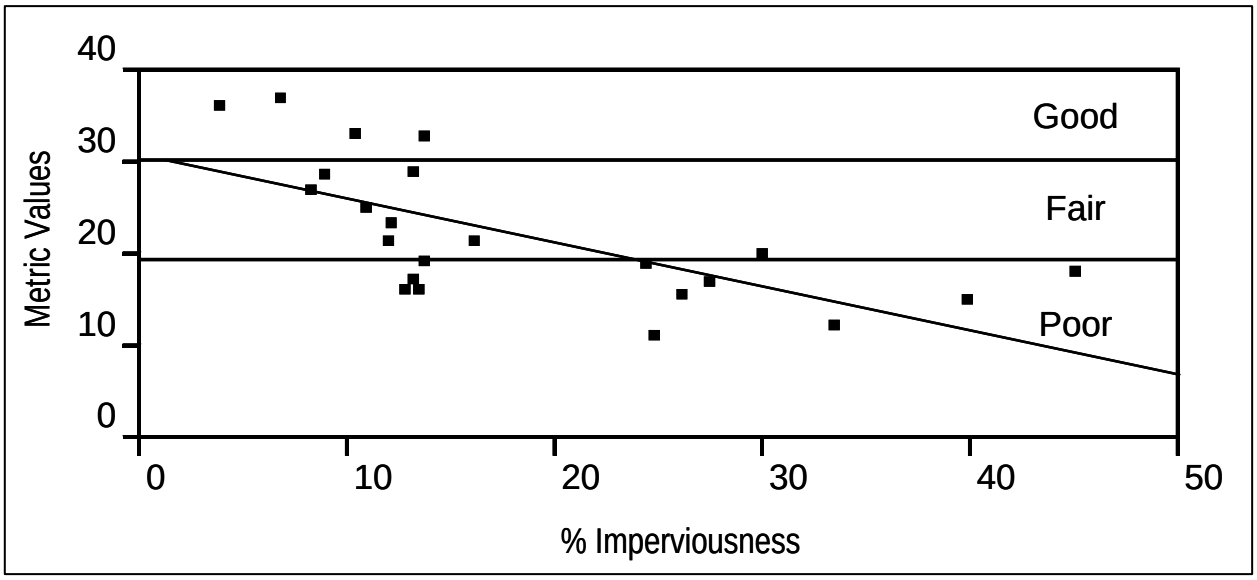

Figure 1. Relationship between impervious cover and aquatic insect diversity in Anacostia River subwatersheds (Schueler and Galli, 1992, as cited in Schueler, 1995).

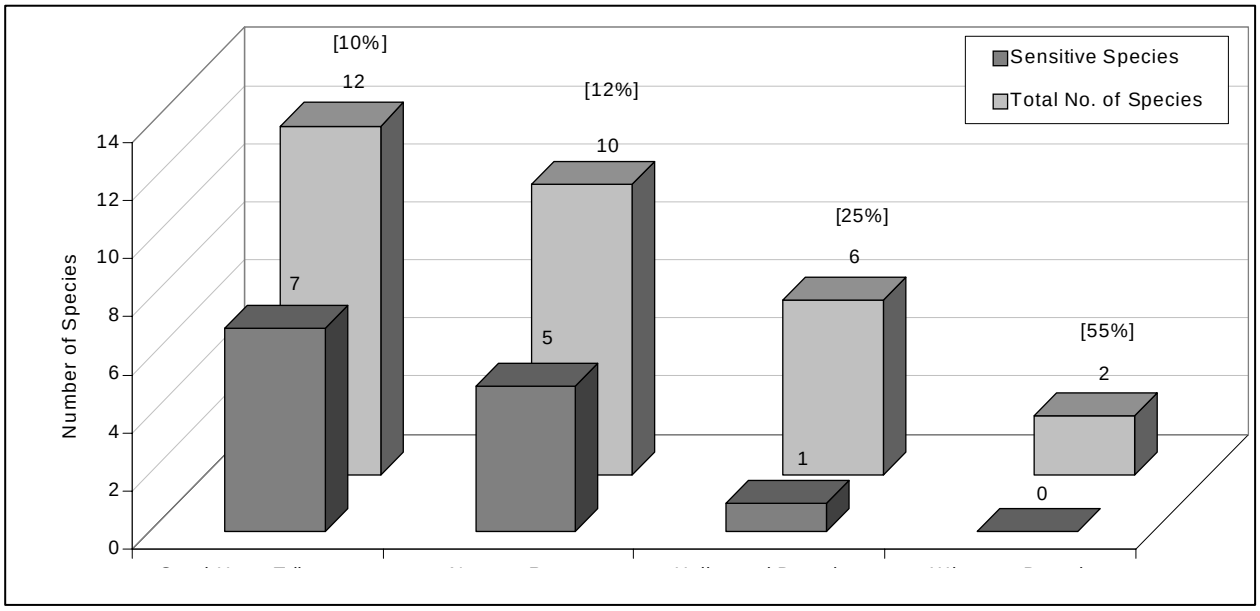

Figure 2. Fish diversity in four subwatersheds of different impervious cover in the Maryland Piedmont (Schueler and Galli, 1992, as cited in Schueler, 1995).

2 Low Impact Development

2.1 What is Low Impact Development?

According to the Low Impact Development Center, Low Impact Development, or LID, is a stormwater management strategy concerned with maintaining, mimicking or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives. LID addresses stormwater through small, cost-effective site design and landscape features that are distributed throughout the site. In shorthand, LID is often referred to as a requirement that the post-development stormwater runoff profile equal the pre-development conditions, both in terms of volume and rate.

Best management practices associated with LID typically come in the form of "green" or non-structural practices. Some conventional practices are often used, such as dry detention basins and swales. Modified landscaping is increasingly popular since cities often already have landscaping codes in place.[9] The modifications include use of engineered soils for water handling purposes, tree canopy requirements, use of native landscaping, and the use of cisterns and other runoff storage devices. In residential settings, rain gardens, coving, and storage devices such as rain barrels and cisterns are being promoted or required. While conventional house designs often directed downspouts to paved driveways, new designs for both pervious driveway surfaces and diverted flow into natural areas are likely to become standard practice.

While initial LID practices were mainly written for new residential subdivisions, a new generation of practices (and combination of practices) has emerged for commercial applications and urban settings that cannot rely on large parcels for infiltration. As such, green roofs, permeable paving, improved parking lots, and landscaping are gaining attention. In some cases, a combination of "green" techniques and structural practices (e.g., vaults) will be needed to meet performance goals.

While many communities are adopting informal guidelines on LID, regulatory recognition of LID is increasing at the State and local levels. Established LID programs exist at the State level in Maryland, Washington, and Massachusetts. Some States have adopted LID requirements for sensitive areas, for example the Pinelands region of New Jersey. Among cities, Portland, Oregon, and Chicago, Illinois, are leaders.

LID programs vary around the country, with differing performance standards, definitions, and regulatory structures. In most cases, the program first establishes the baseline natural hydrologic regime, and sets development performance based on meeting targets for runoff volume, runoff rates, and pollutant loads.

With LID, it is important to strike a balance that recognizes the impact that development has on ecology and hydrology. Establishing the baseline, pre-development condition may seem simple, but it would be unrealistic to expect that true pre-development conditions can be achieved fully. The baseline might be set higher where waterbodies are impaired, for example, requiring development to mimic the hydrology of a forest, even if the predevelopment condition provides lower ecological services. On the other end of the spectrum, some locales set the pre-development condition based on the status of the site immediate to construction. Thus, redevelopment of a 100 percent impervious site under this type of regulation need only meet minimal (or no) on-site stormwater requirements. Realistic requirements should be written to strike a balance: achieve improvement over existing conditions but take into account economic development goals and site constraints.

[9] Note that California has State standards for commercial landscaping; this code is currently being amended under 2006 legislation for water conservation.

For regulatory structures, LID can be introduced in several ways:

- A new, stand-alone code
- Integrated codes (that is, integrated into existing zoning and building codes)
- Subdivision regulations, sub-area plans, or specific plans
- Guidelines
- Alternative compliance programs

Like other planning programs, LID is constantly evolving. Research and policy options for LID at a larger scale are now underway. In fact, one of the weaknesses of early LID efforts was its confinement to individual sites and projects. Green highways and green infrastructure are commanding a great deal of attention. LID at the district scale is also likely to gain profile for development designs where individual lots are not likely to meet strict performance measures. Finally, policy options for retrofitting existing development with LID techniques will gain attention, in particular for built out watersheds draining to impaired waterways.

2.2 LID ON MULTIPLE SCALES: CONSIDERING SMART GROWTH

The intersection of development and watershed planning tends to settle upon one concept: impervious surface. As discussed in section 1, the importance of imperviousness cannot be under-stated and is well known as an indicator of watershed health. Limiting the effects of impervious surface is becoming more common in local zoning codes in the form of impervious surface caps, requirements to disconnect impervious surfaces, and infiltration requirements. Because they are contained in zoning codes, the policies tend to apply to individual sites. Thus, limiting effective impervious surface coverage on individual sites has emerged as the preferred regulatory instrument for limiting the effects of impervious surfaces.

While this approach works in some development contexts, there can be applications that limit the full potential of LID. For new development, it is possible for individual sites to meet LID specifications, even as they add to wider disturbance arising from cumulative and induced development impacts. These often-overlooked impacts arise not because of LID, but because of the underlying pattern of dispersed development. Second, site-level application of LID can pose a challenge in districts that coordinate a higher intensity of development on a compact footprint because space for infiltration may be limited, for example transit area planning, redevelopment of older downtowns, and master-planned town centers.

Early smart growth projects were isolated and did not make full use of on-site and/or distributed stormwater management. Although new designs call for narrow roads, the curbs, gutters and conveyance systems rely on conventional, untreated drainage. For developed areas, improving impaired waterways will be met through retrofits of existing development, not new development. Even though urban redevelopment projects have an implicit watershed benefit by reusing impervious surface, each project will need to contribute to stormwater management and improvement. This is often missing from urban public works planning, in part because the development operating system was built on conventional curb-and-gutter drainage.

These points illustrate the importance of scale when assessing and evaluating low impact and smart growth policies. Those scales include the watershed (or region), the subwatershed (or district), and the site, simultaneously. Successfully coordinating watershed management and reducing the impacts of development typically occur within a comprehensive plan.

2.3 LID ON THE GROUND IN CALIFORNIA

There are a number of California organizations who have made great strides in researching, implementing, and developing guidance for LID. The following are highlights from the California Department of Transportation (Caltrans) and three regional, umbrella stormwater organizations: the Santa Clara Valley Urban Runoff Pollution Prevention Program, the Contra Costa Clean Water Program, and the Alameda Countywide Clean Water Program.

2.3.1 Caltrans

Caltrans has several programs underway to address the installation and retrofit of State roads and highways, though the work can apply to non-State roads as well. Because roads traditionally represent a high degree of connected impervious cover, special attention should be devoted to retrofitting streets with LID. The following summary introduces several Caltrans programs underway that incorporate LID activity.

Best Management Practice Retrofit Pilot Program (2004, 316 pages) – This pilot program was initiated to assess the potential for large-scale retrofit of Caltrans roads with stormwater BMPs. Thirty-two pilot sites in the Los Angeles and San Diego regions were outfitted with a variety of structural and non-structural BMPs. The program produced information on the effectiveness of BMPs in pollutant removal efficiencies, as well as the technical feasibility of the BMPs as retrofits in highway and support facility settings. LID techniques, such as swales, biofiltration, and infiltration, were tested both alone and as part of a "treatment train," where several BMPs were installed in a series. http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/new_technology/CTSW-RT-01-050.pdf

Storm Water Quality Handbook: Project Planning and Design Guide (2007, 354 pages) – This recently revised Handbook incorporates several "green" features, including reference to the 2004 BMP Retrofit study listed above. The foremost consideration in stormwater design is preservation of the maximum amount of vegetative condition no matter the context. The Handbook also notes up front that the requirements are minimal; any roadway within an MS4 would be subject to additional post-construction (or permanent) stormwater management practices. An important feature of the Handbook is the presentation of Accepted Water Quality Treatment BMPs and specifications for their construction, operation, and maintenance. Many techniques used in prominent "green streets" retrofits are included (for example infiltration devices and bioswales). http://www.dot.ca.gov/hq/oppd/stormwtr/Final-PPDG_Master_Document-6-04-07.pdf

2.3.2 Stormwater Management Programs

The issuance of municipal stormwater permits has created a new generation of programs dedicated to not only permit compliance, but also to integration of stormwater runoff into other watershed management and regional planning efforts. In some organizations, stormwater management is housed in traditional flood control programs, while in other programs, new, stand-alone programs were formed to address NPDES requirements. The proliferation of smaller programs has led to larger umbrella organizations like the Bay Area Stormwater Management Agencies Association (BASMAA), which serves as a regional liaison among local and regional governments and the Regional Water Quality Control Boards. Three notable local programs are the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), the Contra Costa Clean Water program, and the Alameda Countywide Clean Water Program (ACCWP).

In 2001, the San Francisco Bay Regional Water Quality Control Board reissued the NPDES permit for MS4s and included a measure called "C.3." As noted previously in this report, this measure, which was landmark, extended stormwater practices to new development and redevelopment projects. Both

SCVURPPP and the Contra Costa programs developed comprehensive program materials to address the new requirements. Details are presented below.

Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)

SCVURPPP is a program addressing water quality in thirteen cities and towns in the Santa Clara Valley. These cities and towns are responsible for implementing a municipal stormwater permit issued by the San Francisco Bay Regional Water Quality Control Board. According to the program's Website (http://www.scvurppp-w2k.com/default.htm), the five goals of the Program include:

- Permit Compliance
- Establishing Determinants of Success
- Adjusting Activities to Change
- Achieving Acceptance of Urban Runoff Management Activities
- Integrating Urban Runoff Program Elements into Other Programs

To meet these goals, the Program offers a number of services, including workshops, fact sheets, guidance manuals, interpretation of permit requirements, model language, targeted reports, and presentations. For LID, the following products are particularly helpful:

- Stormwater Pollution Control Requirements: What Developers, Builders and Project Applicants Need to Know (Fact Sheet) http://www.scvurppp-w2k.com/pdfs/0506/C3%20flyer%20update%20120505.pdf
- Understanding Hurdles To Using Better Site Designs for Water Quality Protection (PowerPoint presentation: http://www.scvurppp-w2k.com/project_reports_fy0304/Hurdles.pdf)
- Addressing Fire Department and Public Safety Concerns http://www.scvurppp-w2k.com/project_reports_fy0304/potential_hurdles_fire_dept_100803.pdf
- Developments Protecting Water Quality: A Guidebook of Site Design Examples http://www.scvurppp-w2k.com/permit_c3_docs/SCVURPPP_Site_Design_Manual.pdf
- Applicability of New C.3 Provisions – Development Flow Chart http://www.scvurppp-w2k.com/project_reports_fy0304/Stormwater_Requirements_Checklist.pdf
- Site Design Guidance for Review of Local Codes and Standards http://www.scvurppp-w2k.com/pdfs/dvlpmnt_plcs/report/III_Conc_Conflicts_and_Rcmdns.PDF

Contra Costa Clean Water Program (CCCWP)

The Contra Costa Clean Water Program (www.cccleanwater.org) was formed by representatives of Contra Costa County, nineteen of its incorporated cities, and the Contra Costa County Flood Control and Water Conservation District. The CCCWP strives to eliminate stormwater pollution through public education, inspection and enforcement activities as well as outreach to industrial dischargers, residents and businesses. The CCCWP members are responsible for implementing the requirements of a municipal stormwater permit issued by the San Francisco Bay Regional Water Quality Control Board.

CCCWP has emerged as a leader in intergration of LID into the land development process. For LID, the following products are particularly helpful:

- Stormwater Control Plans and the Development Review Process (PowerPoint Presentation: http://www.cccleanwater.org/Publications/Oct06Workshop/SWControlPlans&DevReviewProcess.ppt)
- Contra Costa Approach (I): Experience So Far Using LID to Implement Stormwater Treatment Requirements (PowerPoint Presentation: http://www.cccleanwater.org/Publications/StormCon-5-06/5-ContraCostaApproach-I-Dalziel-Cloak.ppt)

- Sizing Integrated Management Practices Sizing Calculator – this model supports site designers in choosing and sizing LID techniques http://www.cccleanwater.org/new-developmentc3/stormwater-c3-guidebook/, See Appendix I

Alameda Countywide Clean Water Program (ACCWP)

Like other stormwater programs, the Alameda Countywide Clean Water Program (ACCWP, http://www.cleanwaterprogram.org/indexFlash.htm) has been active in developing information on meeting the C.3 provisions for new development and redevelopment. For LID, ACCWP has addressed one of the thornier issues related to both structural and non-structural BMPs—maintenance. The following templates have been developed and are applicable to any stormwater program.

- How to Use the Templates http://www.cleanwaterprogram.org/uploads/6.0%20Template%20Intro%20FINAL.pdf
- Vegetated Swale Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.1%20Veg%20Swale%20template%20FINAL.doc
- Vegetated Buffer Strip Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.2%20Buffer%20Strip%20template%20FINAL.doc
- Tree Well Filter Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.3%20Tree%20well%20filter%20template%20FINAL.doc
- Media Filter Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.4%20media%20filter%20template%20FINAL.doc
- Flow-Through Planter Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.5%20flo-thru%20plntr%20template%20FINAL.doc
- Bioretention Area Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.6%20Bioretention%20Area%20template%20FINAL.doc
- Infiltration Trench Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.7%20Infiltration%20Trench%20template%20FINAL.doc
- Extended Detention Basin Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.8%20Detention%20Plan%20template%20FINAL.doc

Emeryville is a member of ACCWP and is recognized nationally as a leader in ultra-urban LID. In 2003, the City obtained a grant to develop "Guidelines for Dense, Green Development" (http://www.ci.emeryville.ca.us/planning/pdf/stormwater_guidelines.pdf). Emeryville faces a built environment that appears to preclude many LID techniques, including clay soils, legacy contaminants, and few green spaces. However, the City used the research behind the guidelines, the planning process, a BMP sizing spreadsheet, and code changes to institute reform. Note that the City did not only focus on new development and redevelopment, but also looked to the city's infrastructure for opportunities.

2.4 REGULATIONS GOVERNING NEW AND REDEVELOPMENT IN CALIFORNIA

2.4.1 Background

California has been delegated the authority to develop and administer Clean Water Act programs. Because the State's landscape varies dramatically, the responsibility has been divided among nine regional water quality control boards (RWQCBs). The State Water Resources Control Board (SWRCB) is the agency that oversees the nine regional boards. Under the SWRCB, each RWQCB acts as a semi-autonomous water quality agency. Under the State Porter-Cologne Water Quality Act (Porter-Cologne), each RWQCB is required to develop its own Basin Plan that contains water quality objectives and criteria for the region. The RWQCBs must use their judgment to determine water quality objectives that provide for "reasonable protection of beneficial uses and the prevention of nuisance." Within their Basin Plans, the RWQCBs must also specify plans for meeting the objectives, which include actions to be taken, a timeline for proposed actions, and a plan for evaluating success with achieving the objectives.

The State Water Quality Control Board and the nine RWQCBs have begun work on a number of LID initiatives[10] including:

- Requiring use of LID through site-specific and general permits
- Advocacy and outreach to local governments through the Water Board's Training Academy and regional workshops
- Research on incorporating LID language into Standard Urban Storm Water Mitigation Plan (SUSMP) requirements
- Funding of LID-related projects through consolidated grants program
- Funding through CWA 319 funds to support research on the applicability of the Impervious Surface Analysis Tool (ISAT) for land use planners and for the California Water and Land Use partnership (CaWaLUP) through the Center for Water and Land Use at U.C. Davis Extension

2.4.2 California Regulations

The integration of LID into local development codes will not occur in a regulatory vacuum. As localities draft land development codes, there are many, often competing, objectives involved with each and every parcel. Stakeholders interested in economic development, traffic, neighborhood preservation, housing, and equity, are among many players who shape decisions both at the larger policy level and during individual approval processes. As such, new requirements for stormwater management will enter an already complex regulatory environment, and California is no exception. In fact, there are several legal and policy issues unique to California that must be considered if LID is to be successfully integrated into State and local land development codes.

Stormwater Construction General Permit

The Construction General Permit is issued by the State Water Resources Control Board (SWRCB) and regulates stormwater discharges from construction activities (new development and redevelopment) at sites that disturb one or more acres. All construction projects in the state meeting the size criterion must submit a notice of intent to the RWQCB to obtain coverage under the permit. NOI submission requires development of a stormwater pollution prevention plan (SWPPP) that specifies how stormwater and

[10] SWRCB. 2003. *Low Impact Development - Sustainable Storm Water Management*. http://www.waterboards.ca.gov/lid/index.html. Accessed October 18, 2007.

pollutants will be managed during and after construction. A revised Construction General Permit has been proposed but is not yet approved. The following are features of the draft permit:

The permit seeks to limit hydromodification impacts that can adversely affect downstream channels and habitat. Specifically, for all projects disturbing one acre or more, the permit requires that the post-development volume of runoff from impervious surfaces approximates the pre-project runoff volume. Projects that disturb more than two acres have additional requirements to (1) preserve post-construction drainage divides and (2) maintain or extend pre-project time of concentration. Projects that disturb more than 50 acres must (1) preserve pre-construction drainage patterns by distributing their non-structural and structural controls within all drainage areas serving first order streams or larger and (2) maintain or extend pre-project time of concentration.

Applicants for coverage under the permit are required to submit a map and worksheets that demonstrate compliance with the above requirements. Detailed instructions are provided for calculating the volume of runoff that needs to be managed (or more sophisticated watershed models can be used).

LID is specifically incorporated into the draft permit in that it offers volume credits for the following types of nonstructural practices:

- Tree canopy cover
- Downspout disconnections
- Impervious area disconnection
- Vegetated swales
- Permeable pavers

The Construction General Permit is an important tool for stormwater management and LID promotion because it covers the entire state, whereas municipal stormwater regulations only apply to municipalities with populations greater than 10,000, small communities located within major metropolitan areas, and towns and cities specifically identified by the State based on projected growth rate or special water quality concerns.

Municipal Stormwater Permits

The Regional Water Quality Control Boards have issued permits to large, medium, and small municipalities throughout California to develop and implement multi-faceted stormwater management programs. Many of these programs, particularly those in large metropolitan areas, have been in place since the early 1990s. One of the main components of stormwater management programs is to regulate stormwater impacts from new development. Municipalities accomplish this by setting minimum runoff control and treatment requirements and reviewing and approving development plans that specify appropriate stormwater best management practices (BMPs).

On October 5, 2000, the SWRCB adopted Order WQ 2000-11, a precedential decision concerning the use of Standard Urban Storm Water Mitigation Plans (SUSMP) [11] in MS4 permits for new development and significant redevelopment projects. The SWRCB found that the SUSMP standards, which essentially require that urban runoff generated by 85 percent of storm events from specific development categories be infiltrated or treated, reflected the MEP standard. The SUSMP requirements were initially adopted by the Los Angeles RWQCB to require treatment controls for new and significant redevelopment projects. Because of the precedent set by Order WQ 2000-11, the RWQCBs' MS4 permits must be consistent with applicable portions of the State Board's decision and include SUSMP requirements. A statewide policy

[11] The term SUSMP is used by the Los Angeles and San Diego Regional Water Boards, but other Boards have adopted different terms for the new development requirements (such as Water Quality Management Plans, Development Standards, or Stormwater Quality Urban Implementation Plans).

memorandum (dated December 26, 2000) interprets the Order to provide broad discretion to RWQCBs and identifies potential future areas for inclusion in SUSMPs and the types of evidence and findings necessary. Such areas include ministerial projects, projects in environmentally sensitive areas, and water quality design criteria for retail gasoline outlets. Because each RWQCB has discretion to interpret and modify the requirements in the State Board order, each permit can have slightly different SUSMP requirements.

A number of RWQCBs have explicitly required the preferential use of LID to manage stormwater. The following are examples of LID provisions from recent permits or draft permits:

Los Angeles Municipal Stormwater Permit

The Los Angeles Municipal Stormwater Permit (Order 01-182, NPDES Permit # CAS004001) specifies that development projects are required to

- Maximize the percentage of pervious surfaces to allow percolation of stormwater into the ground
- Minimize the quantity of stormwater directed to impervious surfaces and the MS4
- Minimize pollution emanating from parking lots through the use of appropriate Treatment Control BMPs and good housekeeping practices
- Properly design and maintain Treatment Control BMPs in a manner that does not promote the breeding of vectors
- Provide for appropriate permanent measures to reduce stormwater pollutant loads in stormwater from the development site

The permit requires control of the post-development peak stormwater runoff discharge rates, velocities, and duration (peak flow control) in natural drainage systems that mimic pre-development hydrology to prevent accelerated stream erosion and to protect stream habitat.

Under SUSMP provisions, single-family hillside homes are required to:

- Conserve natural areas
- Protect slopes and channels
- Provide storm drain system stenciling and signage
- Divert roof runoff to vegetated areas before discharge unless the diversion would result in slope instability
- Direct surface flow to vegetated areas before discharge unless the diversion would result in slope instability

SUSMP requirements apply to sites that discharge to an Environmentally Sensitive Area (ESA), create 2,500 square feet or more of impervious surface area, and discharge stormwater that is likely to impact a sensitive biological species or habitat.

The permit allows municipalities to establish alternative compliance programs that offer participation in regional or sub-regional stormwater mitigation projects for development sites that receive a waiver for impracticability in meeting the performance requirements.

San Diego Municipal Stormwater Permit

The San Diego Municipal Stormwater Permit (Order No. R9-2007-0001, NPDES No. CAS0108758) specifies that municipalities develop requirements for all development projects that include LID BMPs where feasible that “maximize infiltration, provide retention, slow runoff, minimize impervious footprint, direct runoff from impervious areas into landscaping, and construct impervious surfaces to minimum

widths necessary." There is also a requirement to establish or maintain buffer zones for natural waterbodies, where feasible. Where buffer zones are infeasible, project proponents are required to implement other buffers such as trees, access restrictions, etc., where feasible.

The permit further specifies LID BMP requirements to collectively minimize directly connected impervious areas and promote infiltration at Priority Development Projects[12] as follows:

- For Priority Development Projects with landscaped or other pervious areas, drain a portion of impervious areas (rooftops, parking lots, sidewalks, walkways, patios, etc) into pervious areas prior to discharge to the MS4. The amount of runoff from impervious areas that is to drain to pervious areas shall correspond with the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.
- For Priority Development Projects with landscaped or other pervious areas, properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.
- For Priority Development Projects with low traffic areas and appropriate soil conditions, construct a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.

The permit specifies other LID BMPs to be implemented at all Priority Development Projects where applicable and feasible:

- Conserve natural areas, including existing trees, other vegetation, and soils
- Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised
- Minimize the impervious footprint of the project
- Minimize soil compaction
- Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions, etc.)

Municipalities must update SUSMP BMP requirements to add LID and source control BMPs (including siting, design, and maintenance criteria) and to define minimum requirements to maximize the use of LID practices and principles.

Restrictions are set forth for infiltration of runoff from areas that generate high levels of pollutants to protect groundwater. Specifically, this entails pretreatment (e.g., sedimentation, filtration) for infiltration BMPs, diversion of polluted dry weather flows, a minimum distance from seasonally high groundwater table, a minimum horizontal distance from wells, and restrictions on land uses that can drain to infiltration

[12] Priority Development Projects include housing subdivisions of 10 or more dwelling units, commercial developments and developments of heavy industry greater than one acre, automotive repair shops, restaurants, all hillside development greater than 5,000 square feet, ESAs, parking lots 5,000 square feet or larger or with 15 or more parking spaces and potentially exposed to urban runoff, streets, roads, highways, freeways, and retail gasoline outlets. Priority Development Projects also include those redevelopment projects that create, add, or replace at least 5,000 square feet of impervious surfaces on an already developed site that falls under the project categories or locations listed previously. Within three years of adoption, Priority Development Projects will also include all other pollutant generating projects that result in the disturbance of one acre or more of land.

BMPs (e.g., industrial or light industrial activity, high vehicular traffic areas, automotive repair shops, car washes, fleet storage areas, nurseries).

Redevelopment projects that create, add or replace at least 5,000 square feet of impervious surfaces on an already developed site that falls under the Priority Development Project categories are subject to tiered requirements as follows:

- If redevelopment results in an increase of less than fifty percent of the impervious surfaces of a previously existing development, and the existing development was not subject to SUSMP requirements, the numeric sizing criteria applies only to the addition and not to the entire redevelopment site.
- Where redevelopment results in an increase of more than fifty percent of the impervious surfaces of a previously existing development, the numeric sizing criteria applies to the entire development.

Waivers of numeric sizing criteria can be granted when all available BMPs have been considered and rejected as infeasible. Alternative compliance for waiver recipients can be allowed by contributing the cost savings to a storm water mitigation fund that can be used on projects to improve urban runoff quality within the watershed of the waived project.

Draft Ventura Stormwater Permit

The Draft Ventura Stormwater Permit sets overall goals for stormwater management at regulated development sites[13] as follows:

- Minimize the percentage of impervious surfaces on land developments to support the percolation and infiltration of storm water into the ground.
- Minimize pollutant loadings from impervious surfaces such as roof-tops, parking lots, and roadways through the use of properly designed, technically appropriate BMPs (including Source Control BMPs such as good housekeeping practices), Low Impact Development Strategies, and Treatment Control BMPs.

All regulated projects are required to integrate LID principles into project design. LID strategies are required to be the first BMPs considered for a development site, followed by integrated water resources management strategies and multi-benefit landscape features, all of which contribute to the overall goals of LID. The least preferred BMP type is modular/proprietary treatment control BMPs.

The draft permit requires that all new and redevelopment projects reduce "the percentage of Effective Impervious Area (EIA) to less than 5 percent of total project area." Impervious surfaces may be rendered "ineffective" if the storm water runoff is

- Drained into a vegetated cell, over a vegetated surface, or through a vegetated swale, having soil characteristics either as native material or amended medium using approved soil engineering techniques; or

[13] Projects required to meet new development standards include all development projects equal to 1 acre or greater of disturbed area; industrial parks, commercial strip malls, retail gasoline outlets, restaurants, streets, roads, highways, freeway construction, and automotive service facilities with 5,000 square feet or more of surface area; parking lots with 5,000 square feet or more of surface area or with 25 or more parking spaces; redevelopment that results in the creation or addition or replacement of 5,000 square feet or more of impervious surface area on an already developed site on development categories listed previously; projects located in or directly adjacent to, or discharging directly to an Environmentally Sensitive Area (ESA), where the development will discharge storm water runoff that is likely to impact a sensitive biological species or habitat or will create 2,500 square feet or more of impervious surface area; and single-family hillside homes.

- Collected and stored for beneficial use such as irrigation, or other reuse purpose; or
- Discharged into an infiltration trench.

Redevelopment requirements are based on the extent to which redevelopment activities[14] alter the site, as follows:

- Where redevelopment results in an alteration to more than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to post development storm water quality control requirements, the entire project must be mitigated.
- Where redevelopment results in an alteration to less than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to post development storm water quality control requirements, only the alteration must be mitigated, and not the entire development.

Local jurisdictions can develop Redevelopment Project Area Master Plans (RPAMPs) for redevelopment projects within redevelopment project areas[15] to set unique requirements to balance water quality protection with the needs for adequate housing, population growth, public transportation and management, land recycling, and urban revitalization. Goals for hydromodification control are to prevent accelerated downstream erosion and to protect stream habitat in natural drainage systems. The permit specifies that a project's pre-development storm water runoff flow rates and durations be maintained based on a stream's Erosion Potential. Controls may include on-site, regional, or subregional hydromodification control BMPs, LID strategies, or stream restoration measures, with preference given to LID strategies and hydromodification control BMPs. A hydromodification control study is underway to determine an appropriate hydromodification management plan for the region. Until that plan is complete, projects under 50 acres are required to match within 1 percent the 2-year, 24-hour pre-development hydrograph and projects larger than 50 acres are required to implement a Hydromodification Analysis Study.

Local jurisdictions can establish a regional or sub-regional storm water mitigation program to substitute in part or wholly for on-site post-construction requirements. Conditions for the mitigation program are that the projects result in equivalent or improved storm water quality, protect stream habitat, are fiscally sustainable and have secure funding, promote cooperative problem solving by diverse interests, and be completed in four years or less including the construction and start-up of treatment facilities. Local jurisdictions can also set up mitigation funding to fund regional or subregional solutions to stormwater pollution where a waiver for impracticability is granted, funds become available, off-site mitigation is required because of loss of environmental habitat, or where an existing water resources management plan exists that has an equivalent or improved strategy for stormwater pollution mitigation.

Local jurisdictions are required to provide outreach to stakeholders and develop a LID technical guidance section for the regional stormwater guidance manual, which includes objectives and specifications for integration of LID strategies, including LID credits.

Draft San Francisco Bay Area Municipal Regional Permit

Provision C.3 of the Draft Municipal Regional Permit for the San Francisco Bay Region (RWQCB 2) requires that all new development and redevelopment projects encourage the inclusion of the following

[14] Routine maintenance activities, emergency redevelopment activities required to protect public health and safety, and existing single-family structures that do not create, add, or replace 10,000 square feet of impervious area are exempted from redevelopment requirements.

[15] Redevelopment project areas include city center areas, historic district areas, brownfield areas, infill development areas, and urban transit villages.

LID-related measures: minimizing land disturbance and impervious surfaces (especially parking lots); clustering of structures and pavement; disconnecting roof downspouts; use of micro-detention, including distributed landscape detention; preservation of open space; protection and/or restoration of riparian areas and wetlands as project amenities.

New development and redevelopment projects that create and/or replace 10,000 square feet or more of impervious surface are considered "regulated projects" and are subject to post-construction stormwater management requirements. This includes commercial, industrial, residential developments as well as road and paved trail projects, with some exclusions. Starting July 1, 2010, the 10,000 square foot threshold will lowered to 5,000 square feet.

For redevelopment projects where more than 50 percent of the impervious surface of a previously existing development is altered, the entire project, consisting of all existing, new, and/or replaced impervious surfaces, must be included in the treatment system design. Where less than 50 percent of the impervious surface is altered, only the new and/or replaced impervious surface of the project must be included in the treatment system design.

Projects that meet EPA's Brownfield Sites definition, low-income and senior citizen housing developments, and Transit-Oriented Development projects that minimize the new or replaced impervious surface onsite can provide alternative compliance by installing, operating and maintaining equivalent offsite treatment at an off-site project in the same watershed or contributing equivalent funds to a regional project, to be completed within 3 years after the end of construction.

Regulated projects are required to implement the following LID measures:

- Install landscaping that minimizes irrigation and runoff, promotes surface infiltration, and minimizes the use of pesticides and fertilizers.
- Conserve natural areas, to the extent feasible, including existing trees, other vegetation, and soils.
- Minimize the impervious footprint.
- Minimize disturbances to natural drainages.
- For regulated projects with landscaped or other pervious areas, drain a portion of impervious areas into pervious areas before discharging to the storm drain and properly design and construct pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope and other pertinent factors.
- For regulated projects with low traffic areas and appropriate soil conditions, construct a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.

Regulated projects are required to select stormwater treatment systems in the following order of preference:

- Stormwater treatment systems that reduce runoff, store stormwater for beneficial reuse, and enhance infiltration to the extent that is practical and safe.
- Multi-benefit natural feature stormwater treatment systems, such as landscape-based bioretention systems, vegetated swales, tree wells, planter boxes, and green roofs.
- Prefabricated and/or proprietary stormwater treatment systems.

The permit stipulates that stormwater discharges from hydromodification projects, which create and/or replace one acre or more of impervious surface, "shall not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition. Increases in runoff flow and volume shall be managed so that post-project runoff shall not exceed estimated pre-project rates and durations, where such

increased flow and/or volume is likely to cause increased potential for erosion of creek beds and banks, silt pollutant generation, or other adverse impacts on beneficial uses due to increased erosive force." Hydromodification controls include onsite, regional, and instream controls and measures.

Single-family home projects that create and/or replace 5,000 square feet or more of impervious surface are required to implement one or more of the following LID-related BMPs:

- Diverting roof runoff to vegetated areas before discharge to storm drain.
- Directing paved surface runoff flow to vegetated areas before discharge to storm drain.
- Installing driveways, patios and walkways with pervious material such as pervious concrete or pavers.

The permit requires that groundwater be protected through site evaluation and source control measures when infiltration practices are used. Infiltration devices are prohibited unless pretreatment is used in industrial and light industrial applications, areas subject to high vehicular traffic, automotive repair shops; car washes, fleet storage areas, nurseries, and other land uses that pose a high threat to water quality.

The permit requires regulated municipal permittees to update their General Plans to integrate water quality and watershed protection with water supply, flood control, habitat protection groundwater recharge, and other sustainable development principles and policies.

City of Salinas MS4 Permit

The City of Salinas MS4 Permit (Order R3-2004-0135, NPDES Permit # CA0049981) was issued by the Central Coast RWQCB in 2004. The permit includes provisions that, though not called low impact development, are intended to achieve results similar to low impact development requirements. Relevant provisions include a requirement to incorporate water quality and watershed protection principles into planning procedures and policies. The permit defines such procedures/policies as the General Plan or equivalent plans. The identified goal is "to direct land use decisions and require implementation of consistent water quality protection measures for all development projects."

The permit specifies that watershed protection principles and policies consider:

- Minimizing the amount of impervious surfaces and directly connected impervious surfaces in areas of new development and redevelopment
- Using on-site infiltration of runoff in areas with appropriate soils where there is no threat to groundwater quality
- Preserving and creating/restoring riparian corridors, wetlands, buffer zones, and other areas that provide important water quality benefits
- Limiting disturbance of natural waterbodies and natural drainage systems
- Requiring developers to prepare and submit studies analyzing pre- and post-project pollutant loads and flows resulting from projected future development
- Requiring incorporation of structural and non-structural BMPs to mitigate the projected increases in pollutant loads in runoff

The permit also specifies that restrictions be in place for infiltration BMPs to ensure that groundwater quality standards are not violated.

Waivers can be granted on a project-by-project basis for infeasibility. As specified by the order, Salinas "may propose a waiver program that would require any developers receiving waivers to transfer the savings in cost, as determined by the Permittee, to a storm water mitigation fund" subject to RWQCB approval. Funds are to be used for urban runoff quality improvement projects in the same watershed as

the waived project. Waivers can only be granted "when all appropriate structural treatment BMPs have been considered and rejected as infeasible."

The permit also requires Salinas to provide a description of necessary modifications to existing codes and ordinances and an implementation schedule for these modifications.

General Plans

General Plans (required under Government Code section 65300 *et seq*) were first introduced in the 1920's to plan and coordinate development. Like other areas of the country, the General Plan orchestrates local government Departments, their budgets and community goals, and is implemented by the zoning code and subdivision regulations. In California, State law mandates several required elements: Land Use, Circulation, Housing, Conservation (including Air and Water Quality), Open Space, Noise and Safety. Cities may also include other elements, such as Economic Development. In addition to required elements, the State required study, identification and presentation of detailed information, for example, the allowable uses within zoning codes and land subject to flooding. In 1971, a consistency requirement strengthened the elements within General Plans; development and zoning amendment need to be consistent with the General Plan. Thus, legal decisions affecting growth and development often hinge on the content and exact wording contained within General Plans.

Cities often adopt "Specific Plans" within the General Plan, which act like a special zoning code for a specific area, such as a Downtown Plan or a Master Planned Community.

All General Plans must comply with State law, and be updated as State laws are updated or revised. Finally, General Plans must go through a rigorous review under the California Environmental Quality Act.

Specific Area Plans

California, like other areas around the country, is addressing the shortcomings of conventional zoning and the associated environmental impacts. Successfully addressing impacts tends to occur not from adjusting parameters within codes, but with wholesale change to the alignment of public and private space within districts, such as downtowns, Master Plans, and corridors. Specific area plans are essentially "overlay" zones that orchestrate the relationships among sites, infrastructure, open space, drainage, and uses. Specific area plans have been increasingly used to introduce use mix (and hence reduce trip-making), encourage walkability, redevelop older towns and cities, and develop master-planned communities.

California Environmental Quality Act

California Environmental Quality Act (CEQA) analysis is a major part of the development landscape in California. The purpose of CEQA is to fully vet environmental impacts related to land development decisions and determine whether environmentally preferred options exist. CEQA is perhaps best presented as a step-wise process:

Step 1: The Application of CEQA – CEQA applies to "projects," which are defined as actions approved at the discretion of a local government (such as issuing a permit). In some instances the discretionary action can involve very small projects, and in others, large ministerial projects need to no CEQA review at all. There is a list of exemptions, such as demolition permits, small infill sites, and affordable housing projects in urban areas. In addition, there are categorical exemptions, such as projects less than 10,000 square feet, and projects of three homes or fewer.

Step 2: The Initial Study – If CEQA applies, an initial study is undertaken to determine whether there will be "significant environmental effects. This is among the most litigated parts of the process and is loosely defined. For stormwater, note that thresholds and checklists have been turned down in

Courts for determining significance, even as checklists and thresholds gain in popularity for stormwater management programs.

Step 2a: Mitigated Negative Declaration – If the environmental impacts are easily identified and mitigated, a developer is often asked to mitigate those impacts up front, in essence reducing the impacts below the "significance" threshold that triggers further CEQA review. LID requirements may come into play for this step in CEQA.

Step 3: The Environmental Impact Report (EIR) – If the Initial Study shows the potential for significant impacts, an EIR must be prepared. EIRs are at the "public information" core of CEQA and can be far-ranging in detail and scope. Because EIRs can take months to prepare and significant up-front cost, there is some evidence that the process drives smaller projects and players out of contention. In presenting impacts to the public, the EIR must present the following:

- Significant environmental effects
- Unavoidable environmental effects
- Significant irreversible environmental change
- Alternatives to the project (for example, an alternative design or a "no build: alternative)
- Cumulative Impacts arising in combination with other projects
- Growth-inducing impacts
- Mitigation measures that will be adopted

Step 4: Local Government Action – Even with significant impacts a local government may approve a projects. However, the government may also deny the project, approve one of the alternatives, or specify mitigation measures.

At the State level, the Office of Planning and Research issues CEQA guidelines, which, despite the name, are mandatory. They spell out rules on process and content. For stormwater, the new NPDES regulations, as well as emerging research on LID and BMPs, will likely enter into State language on data collection and analysis, in particular for General Plans.

CEQA is also recognized for what it does not do. Regional (or watershed) cooperation is not among the outcomes sought. Alternatives analyses are typically not informative, and there is little direction (other than often contradictory Court decisions) that helps streamline CEQA. Moreover, the data most related to watershed-wide impacts (analysis of cumulative and growth-inducing impacts) are the weakest elements within CEQA review.

Subdivision Map Act

The original intent of the Subdivision Map Act was to denote clear title to plots of land. Over the years, the Act was used by land speculators who would produce older maps to claim rights to subdivision as land development rules tightened. However, the strongest attribute of the Act is the establishment of fees and exactions. The ability to impose impact fees, require dedication of land, and provision of infrastructure have their roots in the Act; LID requirements may need to be framed within this exaction process.

Exactions in California have been at the center of legal activity for decades, and will shape effective LID requirements, in particular the dedication of land for infiltration or stormwater management. In a nutshell, the cases have been:

Erlich v. Culver City – This case tried to resolve a myriad of loosely related decisions on impact fees. In the end, tests were established for different project types. A "reasonable relationship" test must be met when exactions are required of all developers as a matter of broad policy. The stricter rough proportionality/essential nexus test is to be used with single developers.

Nollan v. California Coastal Commission – This Supreme Court case established the "direct nexus" test between a project and the exaction required. (The same year, AB 1600 was passed, which requires local governments to identify how fees and exactions are to be used). "Nexus studies" are now a routine part of the development approval process; for supra-site level LID, measuring the wider stormwater impacts and how they are addressed beyond site level impacts will likely loom large.

Dolan v. Tigard – This Supreme Court Case decision builds on the Nollan case, and specifies that not only does a local government need to show a nexus, but also the final exaction must have a "rough proportionality" to the project. This will likely come into play with CEQA analyses that show induced growth, and LID assignments that might be required outside the boundaries of the project (the logic will follow the process of determining developer exactions for an off-site Highway interchange *and* the roads within the boundaries of a project).

The end result of all these cases strengthens the role of the General Plan. Thus, if the State requires LID via General Plans, the reasonable relationship test must be met. However, cities and Counties that do not include LID in General Plans may need to perform a higher level of analysis to link exactions and project review.

The use of maps in planning and zoning is widespread but has legal bearing in decisions on subdividing land. Developers often produce a "tentative map" to show lots, improvements, and response to initial feedback from regulators Local governments at this stage have leverage over site design, land conservation, and other matters. Developers will often seek a "vested tentative map," which grants entitlements for a period of time. Once approvals are accepted, the developer produces a final map. Note that localities can deny maps based on incompatibility with the General Plan, physical unsuitability of the site, or environmental damage.

Affordable Housing

Affordable housing in California is not only the grist of national headlines but is now firmly established in State law. Cities are required to develop density bonus programs for affordable housing and provision of second units. The nexus between affordable housing and environmental protection is also well recognized. California's 2003 "Environmental Goals and Policy Report[16]" clearly links low density housing, sprawl, and environmental degradation. The city of San Jose has established policies that essentially recognize certain affordable housing projects as stormwater BMPs. The logic behind this is that if affordable housing is not provided on a small footprint near jobs and services, the demand will exert itself elsewhere in the watershed, most likely on a much larger footprint and on land providing watershed services.

This linkage is likely to emerge in LID policymaking in several ways. First, laws allowing second units on a property will run squarely into strict on-site LID requirements, especially if local rules cap impervious coverage in areas with traditionally small home sites. Opponents of the new stormwater rules are already raising affordable housing shortages as the primary consequence of potential policies. However, a second linkage will emerge as variations of the San Jose policy. If affordable and workforce housing are primary drivers of imperviousness, then "housing as a low impact strategy" will emerge as a powerful practice. The key will be quantifying the relationship. Finally, in largely built-out areas, particularly in coastal California, where improving stormwater will primarily arise from retrofit, any successful LID policy may need to pull together other programs to help underwrite on-site BMPs, in particular for areas struggling to attract redevelopment interest under current rules.

[16] California Office of Planning and Research. 2003. *Governor's Environmental Goals and Policy Report*. http://opr.ca.gov/planning/publications/EGPR--11-10-03.pdf. Updated November 10, 2003. Accessed October 18, 2007.

Roadways

According to the Center for Watershed Protection, "habitat for cars" comprises more than half of all impervious surface coverage. Overly wide road standards (sometimes referred to as "geometric standards) are a culprit. In California, road standards tend to follow the Institute for Transportation Engineers guidebooks and standards established by local Fire Protection Districts.

Advocates for smart growth, climate change, and watershed health agree that road standards need to change for a reduced impact. Work over the past decade has revealed the impetus for over-engineered roadways: (1) national standards provide local governments with a tested and low-risk model, (2) emergency responders direct standards to maximize access for equipment and maneuverability, (3) a sprawling pattern dictates the hierarchical systems of increasingly wide roadways to funnel traffic (as opposed to a grid, which disperses traffic), even though developers provide local roads, and (4) seismic requirements for highly engineered roadbeds and shoulders.

The October 2007 California fires and earthquakes highlighted the role of roads and access; thus discussions on lower-impact roads in rural areas might not gain traction. This may, however, strengthen the argument for lesser road impact in areas inside the urban/wild interface. The U.S. Environmental Protection Agency's Smart Growth program recently awarded the Congress for New Urbanism a grant to address road widths and design nationwide because mandating new road geometry in legislation is not likely to succeed given the competing safety, community, and environmental goals. This will dovetail with previous work by the Sacramento-based Local Government Commission and the Sustainable Streets effort within the University of California-Irvine (UC Irvine). In addition, Caltrans is developing a "smart mobility" scorecard that will be used in future funding decisions, and researchers at UC Davis are working on a green streets initiative and, in cooperation with Caltrans, incorporation of trees into highway systems that can aid in stormwater mitigation.

Initial research from UC Irvine shows that the environmental street design discussion is bifurcated into two areas: (1) sustainable streets with an emphasis on stormwater, or (2) mobility and design. There is a need to shepherd the two into one effort to achieve both objectives.

3 Types of LID Requirements

There are a number of ways in which LID criteria can be incorporated into statewide, regional, or local stormwater requirements. Table 2 lists the different approaches and briefly describes advantages and disadvantages of each.

Table 2. Types of LID Criteria

Type	Advantages	Disadvantages
Uniform Performance Standards		
Uniform performance standards	Ease of administration	Insensitive to site constraints, unique conditions, and development context
Uniform performance standards with list of accepted BMPs	• Ease of administration • Certainty for planners/ developers	BMP lists may be outdated, in particular for emerging LID BMPs
Uniform performance standards with list of accepted BMPs and predetermined list of exemptions	• Ease of administration • Certainty for planners/ developers • Exemptions can be tailored	• BMP lists may be outdated • Exemption list may no include full range of constraints • Exemption process can be resource intensive • Potential for exemptions to become rule if not carefully crafted
Tiered Performance Standards		
Tiered criteria based on subwatersheds	• Criteria can be established based on pollutants/ development context of subwatershed • Can address flooding within the subwatershed	• Subwatershed mapping needs to be developed and supported by strong data collection program. • Subwatersheds may lie across several jurisdictions, which would require cooperation or uniform rules
Tiered criteria based on predetermined geographical areas	Criteria can be established within established geographical or jurisdictional boundaries	Rules established for a jurisdiction may not capture entire subwatershed
Tiered criteria based on development parameters: infill, new development, and redevelopment	Criteria can be targeted based on watershed function lost or designed to match BMPs to development contexts	May be seen as relaxing rules for one type of development
Tiered criteria based on economic development parameters	• Can be used to attract development to distressed areas (in particular where watershed benefits would be achieved via redevelopment) • Ease of administration where economic development areas are supported by existing programs • Can be used to attract investment for repairing infrastructure.	Some economic development districts lie in areas in most need of higher performance standards for volume or pollutant removal

Table 2. Types of LID Criteria

Type	Advantages	Disadvantages
With Supporting Credit System		
Hydrology criteria supported by credit manual	Credits can be advantageous for practices that are not easily measured or for which performance has not been established. Credits typically easier to administer than exemptions since they are front-loaded into the process.	Relief provided by credits may not be justified by analysis, paperwork or application fee. Credits may not apply to all development contexts and may result in uneven regulatory playing field. Small stormwater programs may not have resources to develop credit manual.
With Alternative Compliance Process		
Limited alternative compliance options with prescribed triggers and process for developing a "Finding of Impracticability"	• Alternative compliance is advantageous where there are numerous site constraints or varying landscape considerations • Alternative compliance programs can be used to fund district or regional BMPs • Alternative compliance programs can be written to support preferred practices where on-site BMPs are not practical	• The list of triggers may not encompass entire range of conditions or constraints • The process for "Finding of Impracticability" may be burdensome for smaller developers/sites • Widespread use can lead to lesser application of BMPs on individual sites
Case-by-case	Case-by-case application may be needed where a "Finding of Impracticability" or need is not apparent or where there are a number of constraints	Evaluation process is resource-intensive
With Exemptions		
Exemption process spelled out in regulations or technical manual	• Exemptions allow flexibility in *de minimis* situations • Exemption process can ease administration and add certainty	Widespread use of exemptions can erode the effectiveness of the BMP program
Case-by-case	Case-by-case assessment allows for closer examination of site conditions and considerations	Evaluation process is resource-intensive
Tied to Other Water Performance Standards and Programs (e.g., TMDLs, Anti-Degradation)		
LID criteria with reference to methodology for determining BMP performance required	Integrating Clean Water Act programs can make use of existing data and improve efficiency of administration	CWA programs have differing legal processes that may be challenged with integrated program requirements
LID criteria with monitoring and triggers	Monitoring results can tailor BMP response to specific pollutant reduction or elimination needs	• Monitoring results subject to challenge, which may extend process • May not be sensitive to upstream/downstream considerations (i.e. downstream permittees carry BMP responsibility for upstream loadings) • Response may need larger action than additional triggers for on-site BMPs

Table 2. Types of LID Criteria

Type	Advantages	Disadvantages
LID Criteria included in Technical Manual	• Only bare-boned ordinance, with reference to technical manual, needed • Technical manual can be a better vehicle for presenting information on size, type, and installation of BMPs that respond to wider variety of environmental pressures (such as habitat or land conservation) • Eliminates multiple manuals for different programs • Technical manuals can be written for a specific plan (e.g. downtown) to coordinate and integrate land development and BMP designs	More than one manual may be needed when there is a wide variety of environmental or development circumstances
LID criteria included in technical manual with levels of service (LOS)	• Setting LOS can help establish benchmarks within the program manual itself and assist in measuring results and reporting • LOS can either be environmental LOS or programmatic LOS (or both)	Benchmarks may be viewed as non-compliance triggers
Other		
Tied to other environmental performance standards and programs (e.g. greenhouse gas, energy, anti-sprawl)	• Best practices for other environmental programs offer watershed benefits (e.g., reduction of auto use) • Can help attract grant dollars for multi-objective programs	Ties to other mandates may be challenged as over-reaching in terms of achieving CWA compliance
Developed via inter-jurisdictional programs	• Can help avoid shifting development to areas with lesser standards and criteria • Coordination can allow better leveraging of resources • Many California jurisdictions have already formed regional alliances, thus models exist	• Smaller jurisdictions may be reluctant, in particular where larger jurisdictions have adopted stringent rules • May require development of unified land development regulations, which is time consuming • Administration requires frequent collaboration, which can be time-intensive

4 Options for State LID Statute Requirements

California has yet to implement a statewide policy governing LID or smart growth, though both regulatory and non-regulatory approaches can be used to promote LID implementation. (Non-regulatory approaches that build on existing initiatives are described in Appendix A.) In major metropolitan areas of the state, LID and smart growth policies are being incorporated into municipal stormwater permits; however, these requirements are not being applied to rapidly growing exurban areas. The Construction General Permit, currently undergoing revision, will apply to construction activities disturbing greater than one acre in all areas of the state and is expected to include a more progressive LID approach to stormwater management. Because California already has mechanisms in place or soon to be in place that require or encourage the use of LID, proposed state statute requirements should draw from these precedent approaches. A major benefit of a state statute for LID would be to provide consistency for how LID is addressed in stormwater Phase I communities, Phase II communities, and those areas not regulated under the municipal stormwater program.

Low impact development techniques and natural drainage are a logical first step for the design of any area planning. Care must be taken, however, in crafting regulatory language related to LID. Where regulations and performance standards are written exclusively for individual sites, the ability to credit the collective natural system can be lost, giving developers little incentive to use natural systems for multiple sites. Even where the regulations note that natural drainage should be given preference, the performance standards for individual parcels form the legal baseline. Likewise, the most effective water quality and runoff management program may be a shared system, not the additive effects of plot-level BMPs. Watershed planners and localities need to be given this option.

Any state statute requiring LID needs to be crafted with extensive stakeholder input, particularly from the Regional Water Quality Control Boards and regulated stormwater municipalities who have already done extensive work incorporating LID into permits and programs. The State should make every effort to avoid undermining progressive requirements already in place in some areas (particularly southern California and the Bay area) by setting performance standards that are less stringent than current requirements. On the other hand, the requirements should not be so stringent that smaller municipalities that have less experience with LID and stormwater management will have trouble implementing them. New legislation should balance water quality needs with existing and future capacity to implement LID requirements.

The following is a set of key concepts, including regulated projects, requirements, credits, waivers, and alternative compliance mechanisms, that a state statute on LID could address. It is important to note that this text is not intended to be statute language, per se, but it could serve as a foundation for a set of legal requirements that define minimum, progressive standards while allowing flexibility at regional and local levels to account for existing regulatory mechanisms and differing environmental conditions and management objectives. These recommendations are based on precedents from within California (described in Section 2.4) and from other states (a compendium of LID requirements from other states can be found in Appendix B).

4.1 Recommended Low Impact Development Requirements for California

A state statute on LID will likely need to address the following key concepts:

- **General Plans** – provide language on low impact development into the Land Use and Conservation Elements of General Plans
- **Specific Plans** – inserts language on establishing tiered design review for specific plans requiring an assessment and use, to the extent practicable, of natural drainage systems

- **Regulated projects** – defines the threshold for projects that need to address the LID requirements, including schools, universities, and other public facilities (i.e., no exemptions for non-traditional MS4s)
- **Requirements** – describes the requirements for LID statewide (will likely be further specified in NPDES permits or local regulations)
- **Stormwater credits** – provides the authority to issue credits that encourage better stormwater practices
- **Waivers** – provides the authority to waive requirements when certain conditions are met
- **Alternative compliance** – provides authority for innovative practices, in lieu of payments or mitigation
- **Definitions** – defines key terms

The key concepts above are further discussed below in the format of a hypothetical state statute. Each element is intended to encourage, facilitate, or require implementation of LID and is based on precedents from within California and from other states. Additional areas that might be included in an LID statute are penalties for noncompliance, enforcement, and regional variations.

4.1.1 General Plans

Local jurisdictions shall incorporate low impact development and natural drainage techniques into the Land Use and Land Conservation Elements of General Plans.

4.1.2 Specific Plans

Local jurisdictions shall amend procedures regulating the development of specific planning to include opportunities to incorporate and preserve natural drainage into the overall design of specific areas. This shall also apply to Master Plans.

4.1.3 Regulated Projects

Regulated development projects include (1) new development creating at least 5,000 square feet of total impervious surface area and (2) redevelopment that results in the creation, addition, or replacement of 5,000 square feet or more of impervious surface area on an already developed site, not including road resurfacing or repair projects.

Local jurisdictions shall have the authority to set a lower threshold of total impervious surface area to be more inclusive of sites that discharge to environmentally sensitive areas or impaired waterbodies, hillside sites, sites with a high likelihood of pollution generation, sites with highly erodible soils, or other areas requiring special protection from stormwater impacts.

4.1.4 Requirements

Regulated development projects shall be required to implement site design, source control, and stormwater treatment measures to control post-development stormwater volume and peak flows (stormwater discharge rate, velocity, and duration) to mimic pre-development hydrology, prevent accelerated stream erosion, protect stream habitat, and provide for the reuse of stormwater.

Source controls and low impact development techniques shall be the primary methods for managing post-construction stormwater on a development site. Additional stormwater detention, retention, and treatment practices shall be implemented as needed to manage excess stormwater to meet water quality and hydrologic goals.

Regulated development projects shall reduce the percentage of effective impervious area to less than five percent of total project area by draining stormwater into landscaped, pervious areas. The pervious areas shall be designed and constructed to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slopes, and other pertinent factors.

For redevelopment projects where the redevelopment results in an alteration to 50 percent or more of impervious surfaces of a previously existing development, the entire project, consisting of all existing, new, and/or replaced impervious surfaces, shall be required to meet these performance requirements.

For redevelopment projects where the redevelopment results in an alteration to less than 50 percent of impervious surfaces of a previously existing development, only the new and/or replaced impervious surface of the project shall be required to meet these performance requirements.

Note: an alternate requirement would be to require that redevelopment projects reduce impervious surface by 20 percent or provide water quality treatment of 20 percent of the site's imperviousness, or achieve a combination of both imperviousness reduction and water quality treatment equal to 20 percent.

4.1.5 Stormwater Credits

Local jurisdictions shall have the authority to reduce the required capture volume of stormwater retention practices by offering credits for low impact development techniques implemented on a development site that reduce total and effective impervious surface area and intercept, capture, infiltrate, evaporate, or reuse stormwater. Local jurisdictions that choose to employ a stormwater credit system shall develop and submit to the Regional Water Quality Control Board for approval a methodology for applying credits to stormwater management sizing calculations. The methodology shall include a procedure for verifying that low impact development techniques were implemented as described in the site design.

4.1.6 Waivers

Local jurisdictions shall have the authority to grant a waiver of the performance requirements on a project-by-project basis if a development site owner demonstrates that all available best management practices have been considered and rejected as infeasible due to site constraints. Local jurisdictions shall notify the Regional Water Quality Control Board within 60 days of granting a waiver for infeasibility. The notification shall include the evidence of infeasibility and the nature of the alternative compliance payment or activity to be implemented.

Alternative and Innovative Compliance

Local jurisdictions shall have the authority to establish joint low impact development and stormwater planning practices that can be shown to deliver superior protection to the applicable stormwater performance standards.

Payment in Lieu

Local jurisdictions shall have the authority to establish a regional or subregional stormwater management fund to pay for watershed projects that have stormwater benefits (e.g., regional stormwater management systems; riparian, wetland, or coastal restoration projects). Development site owners that have been granted waivers for infeasibility may be offered the option of a payment to this fund in lieu of meeting the performance requirements. The amount of this payment shall be determined by the local jurisdiction and shall be based on the estimated water quality and hydrologic impacts of stormwater discharges from the development site.

Mitigation Projects

Local jurisdictions shall have the authority to establish an alternative compliance program that offers development site owners who have received a waiver for infeasibility the option to participate in regional or sub-regional stormwater mitigation projects. Mitigation projects shall impact the same receiving water as the development site wherever possible and offer an equivalent level of environmental benefits.

4.2 DEFINITIONS

Best Management Practices – Methods, measures, or practices designed and selected to reduce or eliminate the discharge of pollutants to surface waters from point and nonpoint source discharges including storm water. BMPs include structural and nonstructural controls, and operation and maintenance procedures, which can be applied before, during, or after pollution-producing activities.

Effective Impervious Surface Area – The area of hardened surfaces that do not infiltrate stormwater and drain directly to a storm drain system, open channel, or natural stream.

Low Impact Development – A stormwater management strategy concerned with maintaining, mimicking or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives. It involves implementing small-scale, site design and landscape features that are distributed throughout a development site and result in the infiltration and treatment of runoff from impervious surfaces.

Regulated Development Projects – New development creating at least 5,000 square feet of total impervious surface area and (2) redevelopment that results in the creation, addition, or replacement of 5,000 square feet or more of impervious surface area on an already developed site, not including road resurfacing or repair projects.

Specific Area Plan – A specific area plan is a relatively detailed plan for the development of a particular part of a city (both new development and redevelopment), which may include a master environmental impact review.

Total Impervious Surface Area – The total area of hardened surfaces that do not infiltrate stormwater, including paved streets, sidewalks, parking lots, buildings, and roofed areas.

5 LID in Local Codes and Ordinances

5.1 OPTIONS FOR INCORPORATING LID

Many land use and development decisions take place at the local level, so managing the impacts of impervious cover first requires an understanding of the local codes and standards that direct the size and placement of hardscape. Land development codes tend to operate at both the site level and at the larger city or county scale. The larger scale codes can be found in subdivision regulations, geometric dimensions for streets, and general plans. In California, master plans and specific plans coordinate the "footprint" of both the public realm (streets, parks) and individual lots even when the entire site is carried out as one project.

At the site scale, zoning ordinances, landscape codes, and building codes direct a building's bulk dimensions, parking, placement, and landscaping. Parking codes merit special attention because parking looms as one of the larger features in the built environment. Parking may be included within individual zoning codes, within specific or master plans, or in a city-wide code.

Municipalities have a number of options for integrating LID and smart growth into codes and the development approval process. For example, they can choose to implement a voluntary or regulatory approach, or they can choose a hybrid program that incorporates both voluntary and required elements. Table 3 describes options for integrating LID into existing land development ordinances, including some advantages and disadvantages of each approach.

Table 3. Approaches for Integrating LID Into Local Codes and Ordinances

Approach	Advantages	Disadvantages
Voluntary Measures – The least rigid process for implementation is to establish voluntary guidelines.	Since some LID measures reduce costs, or have benefits that exceed conventional practices, developers and homeowners may gravitate to LID. Voluntary measures also have the benefits of allowing flexibility and creativity since prescribed practices are not in place. Because the practices are voluntary, developers do not have to worry about sanctions for improperly installed or maintained BMPs.	As implied by the name, adoption is voluntary, and may require extensive outreach and education of the benefits.
Incentives-Based Approach – Communities may adopt voluntary or regulatory LID practices that are accompanied by an incentives program.	Incentives can help introduce new practices, or help bridge costs where LID installations are higher (as compared to conventional practices). Incentives can also be offered to induce developer interest in neighborhoods targeted for redevelopment.	Departments would have to establish new funding streams, which can be a challenge.
LID Ordinance – Communities may adopt stand-alone LID ordinances.	Stand-alone ordinances are easy to draft and enact.	A separate code may be confusing because it may not consider (or even conflict with) similar regulations on stormwater performance criteria or landscaping codes. Developers and site designers must refer to multiple codes. If changes to the code are needed, improvements must go through the sometimes lengthy process of code change.

Table 3. Approaches for Integrating LID Into Local Codes and Ordinances

Approach	Advantages	Disadvantages
Stormwater Management Ordinance – May require or encourage LID as part of a stormwater management ordinance.	Phase II communities are adopting post-construction ordinances to fulfill MS4 permits. LID can be incorporated into these ordinances without having to create a separate ordinance. Stormwater management performance standards can be key to the implementation of LID.	Communities will still need to review and revise development codes to eliminate or minimize barriers to LID.
LID Ordinance with Reference to Design Manual – Many communities oversee site and district design through design manuals.	Design manuals can go into more detail on LID selection and sizing. Design manuals can also integrate several development objectives at once, for example, combining LID with transportation-oriented development, use mix and/or redevelopment. Established design guidelines may be readily adapted to integrate natural drainage and LID. Perhaps the biggest benefit is that any fine-tuning of a design guideline does not need to go through that same process as code change.	Guidelines can be resource and time intensive. Cities with a variety of landscapes, development formats, and terrain will likely need to develop several guidelines.
Rezoning to Match General Plan Updates or NPDES MS4 Permit Requirements – Some cities use the General Plan process to introduce new zoning and land development regulations.	Applying new zoning codes clearly denotes site design and construction parameters. Emerging NPDES permits with on-site or LID requirements require a coordinated change in General Plans and ordinances.	The rezoning kicks in only where a property is developed or redeveloped (as opposed to a building rehabilitation). New zoning code requirements on LID could result in many non-conforming properties. If new LID requirements are viewed as a downzoning, cities and counties will be faced with addressing these concerns.
Building Code Changes – Building code changes can also be modified to integrate LID practices.	This is an option in cities or counties without zoning. In addition, building code changes may be more easily passed than a zoning code overhaul. Where the minimum land disturbance triggers are not met with NPDES permitting, building code changes can be changes to trigger LID with building rehabilitation. Even where rezoning occurs, building code changes may be necessary for green roof and onsite storage (e.g., cisterns and vaults).	Building code changes may not cover site design. In addition, LID at the district scale would not be thoroughly addressed if only building codes are amended.
Overlay Zoning – Overlay zoning is an increasingly popular method of introducing new requirements. While some overlay codes supersede the underlying zoning, in many cases, the overlay zoning is an option.	Overlay zoning can be matched to Master Planned development and Specific Plans to overcome the disadvantages of older, conventional zoning codes. For LID, an overlay zone can match BMPs to specific stressors, TMDLs or restoration needs.	Where the overlay is an option, cities or counties may need to offer incentives to increase the chances that the overlay will be adopted.

Table 3. Approaches for Integrating LID Into Local Codes and Ordinances

Approach	Advantages	Disadvantages
Alternative Compliance – Alternative compliance (including "fee in-lieu-of" programs and waivers) are a universal feature of any land development code.	Alternative compliance recognizes the wide variety of environmental or development conditions. While infiltration is a key feature of LID, many areas are unsuitable for infiltration practices (e.g., where the water table is high or where legacy contaminants pose a risk). "Fee in-lieu-of programs" can be designed to address the highest priority stormwater or flooding problems first.	Widespread waivers of alternative compliance can undermine the original environmental program. Cities must be able to quantify the fee associated with in-lieu-of programs. Some programs are seen as a developer giveaway.
Credit System – Credits for LID are increasingly popular, especially for stormwater and drainage requirements.	Credits are often used to promote environmentally preferable practices. They can also be used where the water resource benefits are difficult to fully quantify (e.g., preventative BMPs and smart growth practices). Where financial incentives are unavailable, credits can be used since they often lower costs. Cities and counties can use credit systems to attract development to certain areas (depending on how the credit system is structured).	Credits tend to put pressure on quantification to ensure fairness and environmental compliance. Thus, the advantage of crediting practices that are difficult to quantify is reduced. Credit systems can be resource intensive and are difficult to rescind once practices become commonplace. Where localities set strict initial performance standards, a credit system can be viewed as "going backwards" since the performance standard is viewed as the starting point for all projects.

While it may seem that instituting LID performance standards into zoning codes is straightforward, reducing and eliminating excess impervious cover is typically a multi-stage effort. This is because established zoning and land development codes have been built over time with input from a variety of parties with an interest in zoning parameters. Municipalities undertaking code and ordinance changes to incorporate LID should tailor their approach to the local context, taking into consideration existing development patterns, watershed conditions, stakeholder input, and other factors that will affect the opportunities for BMP implementation. Table 4 describes changes to codes that are appropriate for different types of development in urban, suburban or edge, and rural settings.

Table 4. Code Changes for Different Development Types and Settings

Development Type	Urban Codes	Edge Codes	Rural Codes
New Development	In highly developed urban areas, new development is likely to install impervious cover in the last absorptive places, though lot sizes are likely to be small. Codes should look at the stormwater functions lost and whether there are "hotspot" issues related to legacy contaminants. In urban areas, combinations of structural techniques (vaults) and small scale distributed landscaping are emerging practices to balance stormwater handling and water conservation. Code amendments will need to balance structural/non-structural techniques. Green roof technology improvements are responding to the range of environmental conditions. In Southern California, there is fear that green roofs would require irrigation most of the year. Moreover increased roof weight can trigger additional seismic requirements.	On the edge, new development is likely to consist of Master Planned Communities that are urban in nature (i.e., high levels of trip-making, demand for mix of uses, school travel). Reducing the impacts of impervious surface will come from both community design and onsite practices. Where urban boundaries are not in place, there may be opportunities to tie open space proffers to stormwater management. For new development in edge and rural areas, street designs should be carefully addressed. Where the format is mainly urban, narrow connected streets will better support activities. Where the format is more rural in nature, fewer engineered factors (i.e., no sidewalks) will form design. Note that "Campus Zoning" is replacing office park zoning. While the new designs emphasize green features onsite, the transportation remains auto-dominant.	Many rural areas of California lie outside of NPDES regulations. Some new low impact designs reduce developer costs (less street infrastructure). This can assist in provision of affordable housing, but also may attract development from regulated areas. Currently, 10 to 20 acre ranchettes are emerging as a popular housing type. The environmental impacts are not well-defined, however there are rural design/code options to lessen those impacts (e.g., shared facilities for stables, RV parking on a smaller footprint). New development in rural areas is likely to undergo increased CEQA scrutiny, in particular for induced growth, cumulative impacts and transportation-related climate change.
Redevelopment	Redevelopment projects in urban areas are likely to be part of a specific plan. Reducing the impacts of replaced imperviousness thus will rely on coordination of hardscape and open spaces. There may be socioeconomic factors in addressing redevelopment via NPDES. The additional requirements may further depress development interest in certain neighborhoods, thus cities may need to combine stormwater control with economic incentives.	Redevelopment at the urban edge may consist of a mix of new development and redevelopment. Thus, reducing the effects of imperviousness may involve reviews of specific plans, corridor redevelopment planning, use of remaining natural drainage and onsite measures. Parking codes are likely to dominate discussions where auto-dominant landscapes are being retrofitted with pedestrian features.	Rural "smart growth" designs often focus on historic downtown areas, crossroads and corridors. Code changes will need to recognize the watershed benefits of compact design.

Table 4. Code Changes for Different Development Types and Settings

Development Type	Urban Codes	Edge Codes	Rural Codes
Infill	Like new development, infill may involve a net increase in impervious surface. In urban areas, the increasing size of infill housing and its character are the subject of code changes; the stormwater regulations may also fit in these discussions and might be used as a tool to negotiate better housing and landscape design. New stormwater regulations are likely to put pressure on the construction of second units, in particular in areas with smaller lot sizes.	Infill projects need to be assessed for proximity to existing centers to determine community design features. Like urban areas, the character of infill housing in older neighborhoods is entering code change discussions. Form-based codes were authorized in State law, and are being adopted. Their role in stormwater management is to lessen the impact of vacant properties (since reuse is made easier with flexible form). Likewise FBCs are typically part of a coordinated district, which necessarily includes shared drainage.	Rural infill may be most common in rural industrial centers where transportation and water infrastructure were constructed to support past/current industrial uses. These areas may be candidates for small industry seeking attractive sites with green amenities.
Retrofits	In urban areas, the most important stormwater improvements, especially coastal cities, may arise from retrofitting properties and infrastructure with LID techniques in areas important for volume control and treatment. However, since NPDES permits only apply to new development and redevelopment, cities may want to use alternative compliance or “in-lieu-of fees” to address retrofit directly. In addition, cities will need to address retrofits through non-NPDES programs. Note that code changes were required to encourage use of solar devices. Local governments may need to add similar language to balance onsite practices in built out areas with property protection from runoff.	Retrofits on the urban edge are likely to focus on residential areas (since they comprise the largest area of developed land). Thus, both NPDES and non-NPDES programs will be needed. Like other retrofit programs, “punching holes” in existing impervious areas can direct improvements. There is also more opportunity for riparian buffers in areas that are less than built out.	The issue of retrofits for rural areas is small, though there may be increased opportunities for transfer of development rights for water harvesting or watershed water balance (for example where increased densification is balanced by an “offset”). However, in agricultural areas, the combined mandates for low impact development and water conservation will drive demand for different stock for commercial landscaping in urban and edge areas.

5.2 LID ELEMENTS OF CODES AND ORDINANCES

As described in Section 5.1, municipalities can employ a variety of approaches for integrating LID into codes and ordinances. A review of codes and ordinances that encourage or require LID from progressive stormwater programs around the country (summarized in Appendix C) shows that there are a number of common elements to the codes and ordinances. Based on these findings, the following are initial steps that communities can take to incorporate LID into their local codes and ordinances:

- Adopt goals and objectives for stormwater management.
- Conduct technical analyses to evaluate and determine appropriate performance standards that help you meet goals and objectives.
- Finalize performance standards.
- Conduct a review of existing ordinances and manuals to identify (1) the need for additional ordinances and (2) needed revisions to existing ordinances to create requirements or incentives for LID and remove barriers to LID. This includes review of existing stormwater, sedimentation and erosion control, subdivision, zoning, and/or unified development ordinances. (A checklist is presented in Appendix D that outlines key features of ordinances and common elements where LID can be incorporated or where barriers may exist.)
- Conduct roundtable discussion of needed ordinance revisions. This discussion should include sectors of the development community, bankers, DOT officials, environmentalists, and local government departments, etc.
- Based on recommendations from the roundtable discussions, draft new ordinance (e.g., stormwater management ordinance) and proposed text revisions for existing ordinances.
- Hold public meetings and public hearings.
- Adopt ordinances.

5.3 OVERCOMING PROCESS BARRIERS TO CODE REFORM

In addressing aspects of codes and development regulations that may pose a barrier to LID, it is important to recognize that the code parameters were put in place to address a particular policy or development matter. Established codes and standards can be difficult to change for a variety of reasons:

- *Fair application of development rules.* One broad standard may be viewed as serving any project that meets size or use standards.
- *Ease of administration*. One enforced standard is easier to implement than several codes.
- *Investment in the status quo.* Stakeholders adjust operations to existing zoning and anticipate financial loss or risk in any change.
- *Legal support*. By using a recognized national code, cities and counties may feel "covered" when safety or other concerns are brought forward with development projects.
- *Margin of safety*. The over-design of infrastructure and development is often attributed to risk reduction for extreme weather or emergency response events.
- *Resource constraints.* Amending standards or offering a choice of codes and standards requires human and financial resources. During project or site review, there are resource implications for training staff or altering engineering models.

- *Lack of outreach and education*. Even as models for better development emerge, there can be a lag time in obtaining buy-in from developers, the public and local Departments.
- *The desire for uniformity and predictability among development projects*. The desire for uniformity is evident in both the public and private sectors. Developers and their financial backers often associate a uniform development style with reduced risk. For cities and the larger public, a move away from conventional development can also be viewed as a risk to the tax base and property values.

5.4 PROGRAM-BUILDING STEPS

Before the effective date of ordinance revisions, a new local program needs to be established to implement the LID provisions. In fact, depending on the degree of local support, work should begin on building program elements during the period of public discussion if the effective date of the ordinance revisions is to be soon after their adoption. Otherwise, the effective date of the ordinance revisions should be delayed by 6 months to one year to allow for capacity building.

The local government is encouraged to have implemented the following steps prior to the effective date of the ordinance revisions:

1. Develop stormwater design manual or revise existing manual to incorporate LID techniques.
2. Develop tools or standardized methods for evaluating compliance with the Performance Standards. These are to be used by project applicants and staff.
3. Develop Standard Operating Procedures for
    - Development review
    - Inspections (including inspections check list; inspections/maintenance documentation procedures; database to manage inspection/maintenance history)
    - Enforcement
4. Conduct analysis of new staffing requirements. Hire staff as needed.
5. Train new and/or existing staff on use of the Design Manual; evaluation methods; standard operating procedures.
6. Conduct workshops for the development community on new requirements. This should ease the transition and minimize mistakes in early submittals.
7. Develop program evaluation framework, including benchmarks to ensure that goals are being met.
8. Be patient and creative. Work with the applicant to find solutions. Remember there is a transition phase when staff and project applicants are learning and helping work out the “kinks” in the manual, evaluation methods, and Standard Operating Procedures. Treating the program as a partnership will increase the likelihood of long-term support and success.

Appendix A: Options for Enhancing LID in California Policies

The following is a list of policies and programs in California through which LID can be promoted or enhanced. The list includes a description of the policy or program, including how it is related to LID, and action items that might be considered to remove barriers to LID implementation and better integrate LID into planning and development policies and practices. This list is intended to be fairly comprehensive, and as a result some of the options may be determined to be infeasible in California for a variety of reasons. This list is not static, as new policies and programs arise regularly. Discussions with other LID stakeholders will likely generate additional policies/programs and action items that should be added to this list.

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A. State Environmental Policies
B. Building and Zoning Standards
C. Streets, Roads, and Highways
D. Parking Lots
E. Landscaping
F. Open Space
G. Schools
H. District Planning, Redevelopment, and Infill

A. STATE ENVIRONMENTAL POLICIES

Like many states, California has delegated oversight of infrastructure and the built environment to many entities. As such, many policies can work at cross-purposes and funding priorities may be misaligned. To ensure adequate coordination and mutual support for LID and other environmental goals, State policies should be reviewed and aligned.

Issues

A1. ***Blanket application of a "Meadow" Performance Standard for LID may result in degradation***
Many LID equations set a baseline, pre-development condition against which stormwater management performance can be gauged. A common requirement is that the hydrology of a development site mimics that of a meadow. The "meadow" equation has the effect of treating conversion of a meadow and conversion of an abandoned parking lot as equal in terms of runoff. While this might be desirable in some situations, there could be degradation in other cases, for example if the pre-development condition is a forest, which has greater stormwater attenuation than a meadow. This approach to LID performance also fails to recognize receiving water condition. It may be necessary to institute a two-tiered approach where the first line of questions examines loss of ecosystem services. Thus, conversion of a meadow or forest would require a higher level of treatment and control than conversion of an impacted site.

A2. ***Many State agencies have recently updated codes and standards to include "green practices," though LID is not well represented***
Many improved guidance documents, manuals and directives were recently released (in 2006 and 2007), representing enormous efforts to integrate environmental planning, site design, and operations. Erosion controls for the construction phase of development seem to be the top stormwater priority, as exemplified in the new scorecard for High Performing Schools and the General Services manual.

A3. ***General Plans do not explicitly address LID***
General Plans guide land use and future development and can affect the amount and placement of impervious surfaces in watersheds. General Plans that do not integrate stormwater concerns with other pressing environmental issues such as water supply, total maximum daily loads (TMDLs), water conservation and

infrastructure might allow or encourage development patterns that adversely impact waterbodies. Explicitly incorporating LID goals into General Plans will help to ensure that watershed impacts will be considered on a regional planning scale.

A4. ***Communities require education on LID approaches***
Many local governments have not been educated on the benefits of LID and how to incorporate LID approaches into stormwater management plans, codes, or ordinances.

A5. ***LID not integrated into State Environmental Goals and Policy Report***
Every four years the Governor is required by State law to update the State Environmental Goals and Policy Report. The report was last updated in 2004. The top three priorities in the Report are summarized as follows: (1) to promote infill development and equity, (2) to protect environmental and agricultural resources, (3) to encourage efficient development patterns. Using LID approaches, these three priorities can be addressed to meet State environmental goals.

A6. ***LID projects using CWA §319 funds require a 40 percent non-federal match***
This federal program is among the most popular sources of money for model or pilot projects to mitigate runoff. However, the program requires a 40 percent non-federal match. Over $5 million has been available for projects, which must be implementation projects of between $250,000 and $1 million.

A7. ***Proposition 218 limits stormwater utility formation***
Stormwater utilities are widespread and growing as a way to manage stormwater and drainage. In California, stormwater utility formation is limited due to Proposition 218. Legislation has been introduced to place stormwater funding outside of Proposition 218. In many areas of the country, utilities (actually credits from utility fees) have been an effective means for fostering LID based on monetary incentives (especially for larger businesses and lots).

A8. ***LID is not incorporated into Clean Water Revolving Loan Funds***
The State Water Resources Control Board (SWRCB) sets priorities for the use of funds under the Clean Water State Revolving Loan Fund through annual "Intended Use Plans," in general directing money to the most pressing health and environmental problems first.

Opportunities and Action Items

Legislative

A9. Establish through legislation a statewide requirement that new State-owned buildings and those undergoing renovation to buildings/grounds meet the standard that post-development stormwater peak flow rate and volume from the site match the pre-development stormwater peak flow rate and volume. Note that this is a stringent requirement that may be controversial because this standard may not be feasible where soils are contaminated, in ultra-urban areas, or where the groundwater table is high. An alternative compliance option should be offered to allow developers to provide equivalent watershed benefits where site limitations prevent achievement of the performance standard onsite.

A10. For General Plans, require a new "Water Element" to combine water supply, stormwater, TMDLs, watershed planning, water conservation, LID, water infrastructure, and floodplain management. If legislation to require a Water Element is too aggressive, provide policy support for communities that choose to adopt a water element, including LID. The Local Government Commission's handbook on the Ahwahnee Water Principles (http://www.lgc.org/ahwahnee/principles.html) includes model policy language and information on the initial content for a Water Element.

Aspirational

A11. Develop a prototype two-tiered approach to stormwater that tiers post-construction best management practice (BMP) requirements based on the loss of ecosystem services.

A12. Sponsor a review of California State programs based on barriers or support for joint LID/planning, policy, funding and regulation. Provide suggestions to overcome barriers and highlight best practices. The review may cross-reference the top priorities and include LID.

A13. Sponsor or co-sponsor a regional Low Impact Development Conference to aid in education and training. OPC, in coordination with the State and Regional Water Boards, could develop workshops and training seminars to educate planning authorities and communities on how to incorporate LID approaches into growth strategies; how to design, implement, and evaluate LID approaches; and how to ensure long-term maintenance of LID practices.

A14. Sponsor a mock or pilot CEQA analysis of build-out for a region comparing an LID scenario with current zoning to provide a "ready alternatives analysis" based on LID.

A15. Contact the State's Office of Planning and Research to begin work on integrating low impact designs and development into the State Environmental Goals and Policy Report. This would strengthen the priority to "protect environmental and agricultural resources," which is now geared towards preserving farmland and open space, and should be a complement to the priorities of promoting infill and encouraging efficient land use.

Funding

A16. Support efforts to exempt stormwater funding from Proposition 218 limitations.

A17. Provide part of the 40 percent match for section 319 funding for LID pilot projects, LID planning or other activities covered under Clean Water Act §319.

A18. Work with the SWRCB to assess where changes to the "Intended Use Plans" for the Clean Water State Revolving Loan Fund might be combined with LID to improve water quality. The SWRCB notes in their 2007 Annual Report, Section II, that only 6 percent of funds were delivered to nonpoint source programs, though they will pursue increasing this amount because nonpoint source projects are critical to water quality. In addition, the SWRCB may be open to a "fix it first" alignment of funds for certain water funding programs.

A19. Assist municipalities in seeking grants from the Proposition 84 Storm Water Grant Program that provide matching grants to local public agencies for the reduction and prevention of storm water contamination of rivers, lakes, and streams.

A20. Work with the SWRCB to see where LID can be inserted into Supplemental Environmental Projects, which are financial contributions made as part of an enforcement action under the Clean Water Act. These projects must address the harm reported in the violation. Thus, an enforcement action for lack of sediment control at a construction site might include a LID retrofit for a public park experiencing erosion problems.

B. BUILDING AND ZONING STANDARDS

Building codes and standards are used to prescribe an expected level of health, safety and structural safeguards. These codes are commonly adopted by reference or integrated into local zoning codes. While these codes are vital for numerous reasons, inflexible "one-size-fits-all" codes tend to dictate a development format that cumulatively does not meet new or emerging challenges, in particular environmental challenges. For example, within building codes, traditional drainage parameters are written to move water away from building foundations and into streets through as direct a route as possible. Cities in California are in the process of revising their building codes to adopt new standards based on updates to the California Building Code, as well as other codes such as plumbing, electrical and fire.

Issues

B1. ***Provisions of the California Building Code preclude LID implementation***
The California Building Code includes many site, building and foundation codes, some of which may limit the use of infiltration BMPs. For example, limitations associated with expansive soils, seismic requirements and foundation integrity could all limit onsite infiltration, in particular on small sites where area for infiltration is limited. The new codes include language that allows localities to designate alternative drainage requirements, though this language is vague and does not specifically promote LID.

B2. ***Building footprint limits can drive imperviousness on a larger scale***
Maximum building footprint limitations place an upper bound on the building footprint size (e.g., a footprint can be no more than 30 percent of site coverage). While this is often a strategy for LID because it ostensibly reduces the impervious area attributed to a building, lower caps can drive inefficient land development at a larger scale by spreading out building imperviousness. In addition, parking often ends up occupying the space not used for the building.

B3. ***Building height limits and minimum frontage requirements can spread development outward***
Where development demand is high, building height restrictions tend to spread development outward. Where setbacks are small, this can lead to "horizontal density," which leaves little room to manage stormwater and forces an overall larger degree of low-density, highly impervious development. Minimum frontages (e.g., 100 feet) mandate a large parcel footprint for even smaller establishments.

B4. ***Rigid setbacks can limit LID application***
A setback is the minimum distance a building's side may be constructed from the front right-of-way and adjoining properties. Small setbacks have advantages (they support compact formats) and disadvantages (they leave little room for landscaping and aesthetics). Large setbacks of 30 feet or more add to driveway, walkway and other impervious infrastructure lengths. On the other hand, the larger the setback, the greater the opportunity for infiltration. Setbacks also tend to be rigid, preventing site designers from optimizing infiltration depending on individual site characteristics.

B5. ***New guidance for State buildings includes little direction on post-construction stormwater control***
The California Department of General Services updated its Best Practice Manual for State Buildings (http://www.documents.dgs.ca.gov/green/BPM-bbmbt.pdf) in 2006. The new manual includes information on managing construction site runoff but offers little information on managing post-construction stormwater onsite and provides no information on performance standards.

Opportunities and Action Items

Legislative

B6. Require all State buildings (new and substantial remodeling) to institute LID requirements for buildings, grounds and parking. Work with stakeholders to determine the development and redevelopment thresholds for LID requirements and retrofits.

Aspirational

B7. Sponsor an examination of the California Building Code to see which provisions might impede infiltration and LID, or which provisions require clarification on the use of LID. Use the review to suggest changes to the Building Code to meet multiple goals and provide assistance to local governments that have adopted the California Building Code by reference or are in the process of adopting the updated codes.

B8. Support a program for municipal building and zoning code audits to support environmental improvement (i.e., the audits would address not only stormwater via LID, but watershed, transportation, and heat island issues through more efficient forms of development and redevelopment).

Funding

B9. Provide incentives (i.e., funding for LID and stormwater-related implementation projects) and guidance to communities who agree to audit and modify local codes and standards to allow or promote LID.

C. STREETS, ROADS, AND HIGHWAYS

The design of highways, streets and roads has a high degree of impact on watersheds. The location of new roads, the geometric standards that govern road construction, the width of rights-of-way, and the connections among sites to the larger stormwater conveyance system are all factors that affect the degree of stormwater impacts from development. In addition, roads, even small roads with minimal shoulders, fracture important drainage networks and alter local hydrology.

One emerging issue is construction and improvement of roads in rural areas at the urban-wildland interface. On the one hand, improved roads assist in firefighting response, which is a pressing issue in developed areas adjacent to forests and scrubland. However, improved roads in rural areas can send signals that the areas are prepared to handle more development, which can contribute to sprawl and increased regional imperviousness.

Issues

C1. ***Overly wide street widths***

Street width in California is written into the State Streets and Highway Code, Section 1805 (http://www.legaltips.org/california/california_streets_and_highways_code/). The code requires that the width of all city and county streets and county highways (other than bridges, alleys, lanes and trails) shall be at least 40 feet wide. A county board of supervisors may elect smaller streets only by a unanimous vote of its members; within cities the requirement is a 4/5 vote. Also, emergency responders tend to request overly large street widths for maneuvering large equipment and vehicles. Engineering guides used throughout California establish minimum street and right-of-way widths, which can also include bike lanes, sidewalks, medians and planters. Efforts to reengineer streets, including reduced widths, are underway, mainly through Specific Area Plans.

C2. ***Overly wide sidewalks and sidewalks on both sides of the street***

While walkability is a popular amenity and even integral to transportation, wide sidewalk requirements on both sides of the street add impervious cover. In addition, the Americans with Disabilities Act requirements direct sidewalk placement and widths, which are needed for accessibility.

C3. ***Inefficient street layouts***

Most states, including California, have built highway systems based on a hierarchical model. This model funnels traffic from residential projects to local streets, to arterials and then to freeways. The system tends to arise where development is unconnected and scattered throughout a watershed. This adds to imperviousness and congestion, reduces options for alternative routes, and limits non-auto modes of travel.

Title 14 of California's Public Resource Code includes minimum road standards for wildland areas. Many county manuals mandate certain concrete, asphalt and substrate materials, in part to bear the weight of larger vehicles (often up to 40,000 pounds). Many cities and counties adopt standards developed by Fire Protection Districts (for example Ventura County's access standards, http://fire.countyofventura.org/departmentservices/fireprevention/standards/index.asp). These rules require certain paving materials and can prohibit the use of pervious pavers and alternative materials for access ways, parking lots, shoulders and turnarounds. Even where codes only apply to certain fire-prone areas, the standards are sometimes adopted for the entire county or city.

C4. ***Funding for streets and highways from the California State Controller does not encourage LID***

In 2004, the California State Controller's Office issued Guidelines Relating to Gas Tax Expenditures For Cities and Counties (http://www.sco.ca.gov/aud/gastax/gastax2004.pdf) to describe how funds collected for vehicles and gas, the major source of transportation infrastructure funding for localities, may be used. This authoritative document was developed to assist cities in determining how gas taxes may be used for street and highway improvement. While LID techniques appear to be included in the narrative, the definitive list of techniques that may be used, even for environmental mitigation and retrofits, is dominated by engineering approaches.

Opportunities and Action Items

Legislative

C5. Require that LID be incorporated into any new Caltrans road project, where feasible. Work with Caltrans planners to identify appropriate BMPs and performance standards for different types of road projects.

C6. Require LID retrofitting with any State-sponsored repair or maintenance project. This may include new materials for shoulders, the use of paving alternatives or improvements to stormwater management. Work with stakeholders and Caltrans to determine repair/maintenance project thresholds for the use of LID retrofits.

C7. Remove the 40-foot minimum street width from the Street and Highway Code for city and county streets.

Aspirational

C8. Work with Caltrans planners on the following programs that can include an LID or "green streets" component:

- Add an LID component or develop an LID matrix for "Corridor System Management Planning" projects intended to retrofit major corridors (http://www.dot.ca.gov/dist3/departments/planning/corridorplanning.html)
- Incorporate LID goals and objectives into the "Regional Blueprint Project" and the "Blueprint Learning Network" (http://www.dot.ca.gov/hq/tpp/offices/orip/bln.html).

C9. The Congress for the New Urbanism recently was awarded a grant to work with emergency responders nationwide on the issues of street widths, design and access. The State could support work on the paving materials and street design aspects of the project, since these should be part of the larger discussion. The State may also want to explore discussions on vehicle and apparatus design, since road designs are driven by the need to support vehicle size and weight. In California, the Local Government Commission has developed State-specific materials and training.

C10. Develop a High Performing Infrastructure report that integrates all utilities and infrastructure located in public rights-of way, including natural drainage (similar to that developed by New York City, http://www.designtrust.org/publications/publication_03hpig.html).

C11. Contact the California State Controller's Office to update and clarify language related to use of gas tax funding for environmental improvements and LID. Note that the Controller's Office has also issued Guidelines on use of Traffic Congestion Relief Funds (http://www.sco.ca.gov/aud/traffic/ab2928.pdf), which states that:

> Funds may also be used for the cost of work that is associated with and incidental to a street or road maintenance or reconstruction project within the street or road right-of-way, provided the work is necessary and/or required to bring the street or road to current design standards.

Further language refers to "associated curb and gutter work," though the overall wording tends to imply engineering approaches. The State can approach the Controller to see if specific guidance on "green streets" can be developed.

Funding

C12. Caltrans is developing a "smart mobility" scorecard to institute a new prioritization system for allocating funds. This scorecard will be used to underwrite investments in street systems that better support existing developments and pedestrian and bike infrastructure and improvements. This same type of scorecard might be used in distribution of stormwater infrastructure and nonpoint source funding.

D. PARKING LOTS

The impact of parking cover tends to fall into two categories: (1) decisions on overall parking supply and (2) the design of individual spaces and lots. In general parking is oversupplied due to the use of high minimum standards, requirements from financial lenders, and the lack of incentives to share parking among individual land uses. In general, workable reductions in the footprint of parking require a multi-disciplinary, planning approach.

Issues

D1. ***Parking lot landscaping requirements preclude infiltration***
Many parking lot codes require a continuous elevated curb around landscaped areas, which eliminates the ability to direct runoff into natural areas.

D2. ***Parking lot surface requirements limit porous pavement application***
Some parking codes limit the material selection to asphalt and concrete, prohibiting the use of permeable pavements.

D3. ***Overly large parking space dimensions***
Many codes require minimum space dimensions, as well as dimensions for drive aisles. In some cases, residential codes require a minimum number of spaces for recreational vehicles in addition to automobiles. Overly generous stall dimensions can increase parking lot imperviousness by 15 percent.

D4. ***Minimum required number of parking stalls leads to too many spaces***
Parking allotments often overstate actual demand and a minimum standard allows for more parking at the developer's discretion. The Institute for Transportation Engineers' "Parking Generation" establishes minimum number of parking stalls rather than maximum. Financial institutions tend to require extra parking as a margin of safety for overflow, even though extra spaces tend to be factored into the minimums. All of these factors contribute to increased parking lot impervious surface.

D5. ***Shared/joint parking and loading prohibited or not incentivized***
Many local codes either prohibit joint/shared parking, or give little incentive to do so. As such, the system errs on the side of oversupply for each project that is built or redeveloped, resulting in additional impervious surface.

D6. ***Zoning code limitations on charging for parking***
Many California cities prohibit charging for parking for any spaces that are required by code. This eliminates a market-based tool for to manage parking demand.

D7. ***Parking costs are "bundled" into rents***
Parking costs are "bundled" into rents, which (1) charges parking costs to renters who do not own cars and (2) conceals the true cost of parking. One strategy being used across the country is the unbundling of parking and rent costs, which provides more transparency on the costs of parking and can reduce parking demand. Lower demand means smaller lots.

Opportunities and Action Items

Legislative

D8. For parking lots serving State buildings, require that any maintenance or resurfacing project affecting more than 20 percent of the lot include LID retrofits that address runoff for the entire lot (or some negotiated percentage of the lot based on site constraints).

D9. Require that all sections within municipal zoning codes related to parking present both a minimum and maximum parking space allotment. Alternatively, require all State buildings to adhere to both minimum and maximum parking numbers.

D10. Draft enabling legislation allowing cities and counties to treat any surface parking over and above the minimum prescribed amount differently in stormwater management calculations. For example, developments

with excess parking space would be required to manage 150 percent of the stormwater volume or provide an equivalent degree of off-site management/retrofit.

D11. Prohibit the practice of limiting parking charges for any parking required under code.

D12. Craft legislation requiring the unbundling of parking costs for residential sites that are within one mile of heavy rail or fixed guideway transit stations, one half mile of bus transfer stations and one quarter mile of bus stops. Proximity to public transit offers residents alternatives to driving/parking, allowing them to choose not to pay for parking once costs become transparent.

Aspirational

D13. Provide a model parking sharing arrangement to foster joint and shared parking.

Funding

D14. Provide funding for communities to conduct parking demand studies.

D15. Fund pilot projects testing innovative parking lot designs and the use of innovative materials.

E. LANDSCAPING

The landscaped areas of development and redevelopment sites offer opportunities for stormwater management, even on small parcels in ultra-urban areas. However, cities often develop guidance documents and zoning code language that result in undesired environmental practices (e.g., the use of fertilizer- and water-dependent plants, limitations on efficiently using open space for infiltration, and engineering requirements that inhibit runoff capture and treatment).

Issues

E1. ***Landscaping codes and ordinances can conflict with LID***
Most California localities include landscaping ordinances within their zoning codes. LID in urban areas generally applies to commercial landscaping, including multi-family residential projects and landscaping within parking lots. Some landscaping codes reduce areas for stormwater infiltration by not specifying appropriate infiltrative soils. Others encourage raised landscaping by requiring planting areas be protected by curb or wheel stops, which eliminates the ability to treat runoff in landscaped beds. In addition, some codes limit the use of non-plant materials, such as gravel, to 10 percent of the area. This limits the ability to use rocks and gravel for energy dissipation, which is essential for hydromodification control. The lack of understanding how LID approaches can be incorporated into landscaped areas often result in a greater amount of land area dedicated for traditional stormwater controls and conveyance.

E2. ***Water conservation is not explicitly linked to LID and stormwater management***
In 2006 new legislation took effect under the Water Conservation in Landscaping Code (http://www.cuwcc.org/ab2717_landscape_task_force.lasso). Language on stormwater infiltration and reuse is in the legislation, though it is not strong. As new stormwater permits are issued, a bond will need to be forged among LID, permit performance standards, and the landscaping rules. Note that much of the language on water conservation in landscaping pivots on water budgets and irrigation. The use of LID will affect these budgets, though little research has been done to determine how stormwater infiltration will ultimately be factored into these budgets.

E3. ***Many exemplary landscaping codes include requirements for maintenance***
Maintenance of stormwater BMPs, including LID techniques, is often overlooked, resulting in reduced performance in handling volume and removing pollutants. Audits of the Phase I program by EPA showed that lack of maintenance was the top weakness of the stormwater program. As such, zoning codes that include maintenance (including inspection and enforcement) can be modified and used to sustain the benefits of LID.

Opportunities and Action Items

Legislative

E4. Require greater minimum area dedicated to landscaping in development and redevelopment codes. Require that a Landscape Plan include a site evaluation of existing conditions (soil hydrology, vegetation) to consider in designs before grading or other impacts to the site have taken place. Provide model ordinance for these changes.

Aspirational

E5. Contact the California Urban Water Conservation Council (http://www.cuwcc.org/home.html) on integrating LID into new guidance and model codes. The language on infiltration exists and provides an "in" for LID, but it is not strong. The potential exists for codes to be written without factoring in water budget changes that arise from capturing water onsite. Some work is underway: the Urban Water Conservation Council must develop a model code by January 1, 2009, with local ordinance adoption within one year.

E6. Develop a cross-program education and communications strategy for LID, including options for urban areas, master planned areas, new development, redevelopment and infill.

E7. Provide technical assistance (e.g., guidance, trainings) for incorporating LID into local codes and for design, installation, and long-term maintenance of landscape-based BMPs, including pesticide, fertilizer, and herbicide use.

E8. Work with the California Nursery Growers Association on ramping up plant selection and practices to meet both LID and upcoming water conservation standards. http://www.nurserygrowers.org/index.html.

F. Open Space

California has many programs devoted to preservation of open space, forests, park land, and desert land. Last year, legislation limiting development in floodplains increased protection of streamside open space. Urban open space, parkland and forestry are important but often overlooked opportunities to manage runoff. To make the most efficient use of open space for stormwater management, areas that have natural drainage properties amenable to LID should be dedicated for this use. Minimum open space requirements that do not take into consideration these site properties may not provide adequate stormwater management benefits.

Issues

F1. ***Minimum open space requirements might drive inefficient land use***
California requires minimum open space for multi-family residential projects. While open space is an important component for urban areas, large minimums may be driving inefficient land use without providing meaningful natural or recreational spaces. The open space requirements for multi-family residential projects are often in addition to other requirements such as parking, setbacks, internal circulation, sidewalks, club houses and other amenities. In addition, many local codes disallow land devoted to onsite stormwater management to count towards the minimum open space provisions. However, reducing open space is likely to be controversial because most assessments of the value of open space do not consider any countervailing effects on efficient use of land.

F2. ***Inconsistent and inadequate buffer widths***
Aquatic buffers serve as natural boundaries between local waterways and existing development. They help protect water quality by filtering pollutants, sediment, and nutrients from runoff. Other benefits of buffers include flood control, stream bank stabilization, stream temperature control, and room for lateral movement of the stream channel. Good aquatic buffer ordinances specify the size and management of the stream buffer and are a specific planning tool to protect stream quality and aquatic habitat. Buffers can be multifunctional, serving as areas for sheet flow and infiltration to reduce stormwater pollutants and volume, improve baseflow conditions and increase groundwater recharge.

F3. ***The Williamson Act can be used to prioritize preservation of infiltration areas***
The California Land Conservation Act of 1965 (Williamson Act) enables local governments to enter into contracts with private landowners for the purpose of restricting specific parcels of land to agricultural or related open space use. Landowners receive property tax assessments based upon farming and open space uses as opposed to developed market value. Local governments receive an annual subvention of forgone property tax revenues from the State via the Open Space Subvention Act of 1971.

Opportunities and Action Items

Legislative

F4. Create a Williamson Act/Open Space Subvention Act of 1971 counterpart for infiltration and aquifer recharge. Base the program on areas best suited for infiltration. Alternatively, allow localities to include infiltration as "production" under the Williamson Act in areas delineated for aquifer protection.

F5. Require that open space designations be reviewed during local plan review to assure that the area is used in the most efficient manner for present and future needs, including stormwater management and groundwater recharge. The State can provide model ordinance language to require open space designation review.

Aspirational

F6. Provide examples of supplying land-efficient open space from other parts of the country, in particular for dense urban districts. Alternatively, develop and promote examples of open space landscaping that supports both stormwater handling and active/passive recreation (e.g., using soccer fields as infiltration basins, developing water gardens with aesthetic and stormwater treatment functions).

F7. Encourage local governments to adopt ordinances that apply minimum buffer widths and maintenance requirements to all lots that are contiguous with or directly adjoin an intermittent or perennial stream or river, particularly those identified in and consistent with impairments or threatened/sensitive species.

G. SCHOOLS

School building and renovation offer LID opportunities. The decision of whether to redevelop an existing school or build anew at another location has broad watershed implications. First, older schools tend to be located on smaller sites. Secondly, the increasing costs of land and construction exert financial pressure to build on cheaper, more distant, and undeveloped land. A variety of factors then feed into the ultimate footprint of the school, including parking, pick-up, fields, classroom size and the like. California has been a national leader in school siting reform, including a push to use schools as centers of community and voter approval of funding to provide green retrofits.

Schools provide an ideal opportunity to demonstrate LID approaches to the public because they serve as polling places and meeting locations in addition to educational facilities. Operation and maintenance can generally be assured at schools. Placement of stormwater management features on school grounds can provide opportunities for LID outreach and education to children and adults. There are still areas of improvement needed, in particular as it relates to the overall stormwater and carbon footprints of new schools.

Issues

G1. ***"Schools as Centers of Community" policies can be used to promote LID***
California has instituted "Schools as Centers of Community" policies over the past decade to efficiently supply services, parks and facilities. School parking lots, fields, land and landscaping may provide capacity to address local flooding, provide land or storage for stormwater and otherwise address stormwater hotspots.

G2. ***School Facility Hardship Grant Program might discourage LID and/or redevelopment***
California's School Facility Hardship Grant Program, which provides grants to correct safety problems, discourages school districts from considering renovation options for historic schools by limiting funding if renovation costs exceed 50 percent of the cost of new construction. This can limit renovation of already

developed properties, which might include incorporation of LID into landscaped areas. This policy may encourage school construction on undeveloped lands, which increases impervious area (newer schools typically have a larger footprint), requires additional infrastructure and can increase brownfield or vacant land(if the old school property is not redeveloped.

Opportunities and Action Items

Legislative

G3. Require LID for new school construction. Where feasible, require use of school property for collective drainage and infiltration. For new and existing schools, require water harvesting equal to a locally preferred design storm (for example the design storm used for transportation projects). Where possible encourage school construction or reconstruction on infill or redeveloped lands and discourage construction on undeveloped lands. The State can provide incentives (i.e., funding for LID and stormwater-related implementation projects) and guidance to communities who agree to modify local codes and standards to promote infill and redevelopment.

Note that the California Department of General Services and California High Performing Schools initiative recently launched its $100 million High Performing Schools Program, funded by Proposition 1D in 2002. The criteria for selection and level of funding is based on a scorecard (http://www.chps.net/manual/documents/CHPS-NewConstruction_Scorecard_060821.xls), which only has a non-required stormwater item for "minimizing runoff," although other factors might reduce runoff, such as a factor to "minimize parking."

Aspirational

G4. Under recent legislative changes, school districts may develop Master Environmental Impact Reports (EIRs). The State can work with the Department of Education's facilities group to integrate LID into all master EIRs for educational facilities.

G5. Encourage passage of State legislation to require new school construction to meet LEED Silver standards.

Funding

G6. Sponsor water infrastructure upgrades to include LID in existing schools. By underwriting new infrastructure for historic schools, energy and water costs can decrease and in some cases they can address deferred maintenance that might otherwise feed into the renovation cost calculation and tip the decision to new construction. One group that has been effective at this is TreePeople in Los Angeles.

H. District Planning, Redevelopment, and Infill

Increasingly, cities and counties are turning to district planning for efficient delivery of services, coordinated infrastructure, and economic development. Although most LID codes and examples have been applied to individual sites, one key to effective implementation is how the larger area performs for watershed health and restoration. This involves how streets are designed; what the use mix is; how accessible common trips are to jobs, home and school; the extent to which site elements are shared; the footprint of development; and how open space is used (or set aside).

In California, there has been an upsurge in district planning. New models of district planning have been launched and fine-tuned in California, including form-based codes, new urbanism, transit-oriented development, and a new Leadership in Energy and Environmental Design (LEED) pilot for neighborhood development (LEED-ND). For redevelopment, main streets, infill and highway corridors have been the focus of activity. For new development, traditional neighborhood design, master-planned communities, conservation or cluster subdivisions, mixed-use projects (sometimes called "lifestyle centers"), and planned unit development projects, are common formats.

The regulatory structure for district planning typically rests on specific area planning. These plans often occupy a separate section within zoning codes and have detailed maps and infrastructure plans. Financing for districts is complex. For redevelopment, redevelopment agencies usually oversee special financing through tax-increment

financing. Impact fees can pay for new development, though "community financing districts," or Mello-Roos districts (see http://www.mello-roos.com/pdf/mrpdf.pdf), are increasingly used to pay for construction, operation and maintenance. Note that Mello-Roos districts can also be formed for redevelopment districts, though the more common application is for new development.

Issues

H1. ***LID requirements are often written to apply to individual projects, which results in uneven application***
LID is often defined as a site-level approach, and as such, many LID regulations set one uniform performance standard across all "projects" that are part of a "common development plan." Developers of large greenfields projects have leeway in arranging lots and open space to meet the performance standard. For example, if a new development must be limited to no more than 10 percent impervious cover, individual home sites need not meet this requirement as long as the overall development plan has less than 10 percent cover. However, for redevelopment, most projects are individual sites with little or no space or flexibility for BMP design. This creates a situation where a large greenfield project allows flexibility as a common development plan, but redevelopment must meet the entire performance standard within the site boundaries.

H2. ***Research on district-level LID is limited***
Most research on LID efficacy has been conducted on individual sites. The most robust data for a subdivision, from the Jordan Cove National Nonpoint Source Monitoring Program project in Connecticut (http://www.jordancove.uconn.edu/), was only recently released.

H3. ***LID often designates hydrology as the indicator of environmental impacts***
By their regulatory nature, stormwater rules have the farthest reach into zoning codes. These rules tend to emphasize stormwater peak flow attenuation and volume capture, causing hydrologic performance to outweigh other important environmental issues that are considered in non-regulatory planning documents, such as infill and redevelopment priorities and regional growth patterns that can affect watershed health.

H4. ***Suburban-style LID requirements can run counter to the planning, transportation and climate emphasis on compact design***
Meeting strict stormwater performance standards in urban areas can be much more difficult than in open areas with room for swales, infiltration and detention. While LID techniques can decrease costs for greenfields applications, they can pose higher costs for urban developers, since underground vaults are often needed to augment urban green building, streetscape and landscape BMPs to meet performance standards.

H5. ***Barriers to redevelopment***
Many barriers stand in the way of redevelopment projects compared to new development in greenfield areas. Developers who undertake redevelopment face different (and almost always more) barriers to redevelop a parcel than those who build new projects in greenfields. Barriers include small, odd-shaped lots, multiple ownership, localized economic blight, outdated infrastructure, increased number of required permits and opposition from existing residents and businesses.

H6. ***Redevelopment sites may not offer the same level of receiving water and flood mitigation benefits***
Redevelopment sites differ based on a number of factors that affect LID applicability and efficacy, such as the condition of infrastructure, pollutants of concern, economic development prospects, restoration potential and degree of impervious cover. Most LID requirements apply a blanket threshold and performance level based one or more gross categories (e.g., "new development" or "significant redevelopment"). This blanket approach does not account for constraints at individual redevelopment sites that might limit LID implementation. Strict performance rules might preclude redevelopment of an infill property, despite significant community benefits and the regional benefit of concentrating imperviousness in the urban center and reducing sprawl. Also, some receiving waters in heavily urbanized areas are so impaired that only through redevelopment will there be opportunities to install onsite practices and provide restoration opportunities.

H7. ***There is growing belief that subwatershed planning is the best structure for matching BMPs to runoff stressors***
The easiest method for developing regulations is through uniform performance standards that apply equally to all sites within a jurisdiction. However, this may not adequately match BMPs to the development context, economic factors, and specific stormwater problems, especially related to redevelopment and retrofits.

Moreover, the Basin Plans developed by Regional Water Quality Control Boards often do not align with land development plans, Integrated Regional Watershed Management Plans, and NPDES stormwater requirements.

H8. ***General Permits discourage infill***
Construction Activities Stormwater General Permit (or local grading permits) are often inflexible in their stormwater management requirements and as a result discourage infill and redevelopment that could incorporate LID. Many stormwater codes do not encourage infiltration practices because of the perceived potential contamination issues. Also, some developers perceive that LID practices require a much greater area and that they dramatically reduce the buildable area. These misperceptions, along with a lack of recognition that integrated management practices can be shoehorned into required landscaping (i.e., stormwater planters), leads developers to dismiss the LID approach.

Opportunities and Action Items

Legislation

H9. Create legislation directing the SWRCB to more fully develop "Redevelopment Project Area Master Plans" as described in the draft Ventura County Municipal Stormwater Permit.

H10. Introduce legislative language to classify certain affordable housing/infill projects as post-construction BMPs based on their location and configuration in the watershed (according to General Plans and local housing plans). This program might be based on the spreadsheet model such as that developed by Grand Rapids, Michigan, or others, which estimate the impervious cover prevented by directing housing construction to infill areas identified for growth.

H11. Sponsor legislation to require consideration of natural drainage as an initial step within Subdivision Map Act, as well as rules on Master Plans and Specific Area Plans.

Aspirational

H12. Sponsor an analysis of pilot neighborhoods in the LEED-ND program to see if they meet stringent stormwater requirements (for volume, treatment and flow control). Similarly, conduct a survey of LEED-certified buildings to see how they perform relative to stormwater performance standards in permits. Note that this may be somewhat risky if the first generation of buildings fail to meet recent performance standards. For a list of projects in LEED-ND, see http://www.usgbc.org/ShowFile.aspx?DocumentID=2960.

H13. Sponsor a pilot analysis of the stormwater, climate, and other environmental impacts of vacant property (i.e., the runoff volume created and miles traveled past "dead" sites). Develop strategies to encourage redevelopment and improvement of these sites (requiring LID where feasible). Alternatively or in addition, lobby for the establishment of a program, such as a neighborhood improvement initiative, to convert these sites to parks/open spaces that act as "urban sponges" that capture and infiltrate stormwater from adjacent properties.

H14. Sponsor a pilot study to align major water planning documents (e.g., Basin Plan, Integrated Regional Watershed Management Plan) with regional and local requirements (e.g., stormwater permit requirements and local zoning codes) with respect to LID goals and requirements.

H15. Sponsor a study of "community facilities districts" or Mello-Roos, to see how LID would be treated (or constrained) for new development, infill and redevelopment. Investigate the legal structure and issues related to construction, operation and long-term maintenance under such districts. Because the maximum term and maximum bond amount must be specified up front, this research could provide guidance on assessing this cost. Finally, the study should include an analysis of costs for LID versus traditional conveyance systems as they relate to overall costs for the district.

H16. Create a tool similar to "redevelopment ready" districts that pools existing and planned stormwater improvements for multiple redevelopment sites and considers shared drainage and LID for a pre-permitted district. This will help "level the regulatory playing field" between greenfield and infill development sites by allowing more flexibility for placement of stormwater features in the redevelopment district.

Funding

H17. Fund a project to better describe LID techniques based on development settings in California similar to the effort underway within the Congress for New Urbanism based on the "transect." The transect establishes seven transect zones based on intensity of development and urban form. This approach was used to develop new street standards and could serve as a model for stormwater management as well.

H18. Provide funding for localities that are taking a subwatershed approach to matching BMP selection, development context and pollutants of concern.

H19. Provide matching funds for BMPs installed in mixed-use housing projects. Such a program would need to prioritize funding based on multi-objective planning needs, location in a watershed or alignment with redevelopment/housing program needs.

H20. Provide funding to retrofit or supply LID for small-scale, stand-alone businesses or business districts in economically challenged neighborhoods.

Appendix B: LID Policies Outside of California

The following is a brief summary of stormwater- and LID-related policies from other states that have relatively innovative requirements. It also includes a new requirement for federal buildings and a summary of the LEED-ND standards.

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Connecticut
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District of Columbia
Maryland
Massachusetts
New Jersey
Ohio
Pennsylvania
Rhode Island
Vermont
Virginia
Wisconsin
Federal Government
Leadership in Energy and Environmental Design Neighborhood Development (LEED-ND)

CONNECTICUT

Policy Structure	The Connecticut Clean Water Act (CCWA) of 1967 (P.A. 67-57) launched Connecticut's modern water pollution control program. This statute (Chapter 446k of the Connecticut General Statutes (CGS)) forms the authority for Connecticut's Department of Environmental Protection to regulate discharges to surface waters under both the CCWA and the federal NPDES Program.
Impervious Surface	Stormwater management requirements are triggered for projects one acre or larger or industrial development creating 10,000 square feet or more of impervious cover. Residential projects with fewer than 5 dwelling units are required to manage stormwater only if final impervious cover will exceed 30%. Impervious cover should be measured from the site plan and includes all impermeable surfaces that are directly connected to the stormwater treatment practice such as paved and gravel roads, rooftops, driveways, parking lots, sidewalks, pools, patios and decks.
Infiltration	Developers are required to maintain predevelopment groundwater recharge volume to the MEP through the use of infiltration measures. The groundwater recharge volume (GRV) is the post-development design recharge volume (i.e., on a storm event basis) required to minimize the loss of annual pre-development groundwater recharge. The GRV is determined as a function of annual pre-development recharge for site-specific soils or surficial materials, average annual rainfall volume, and amount of impervious cover on a site.
Innovative Measures	Typical of other states
LID Requirements	No requirements, but the 2004 Connecticut Stormwater Quality Manual contains summary descriptions of small-scale LID practices. The design sections of this Manual contain more detailed guidance for similar, larger-scale stormwater treatment practices such as bioretention, infiltration, and filtration system.
LID Incentives	N/A
Redevelopment	N/A
Links to Language	Statute: http://www.cga.ct.gov/2005/pub/Chap446k.htm Connecticut Stormwater Quality Manual: http://www.ct.gov/dep/cwp/view.asp?a=2721&q=325704

DELAWARE

Policy Structure	The Delaware Sediment and Stormwater Regulations set forth requirements for post-construction stormwater management.
Impervious Surface	N/A
Infiltration	The regulations include guidelines and technical standards for the use of infiltration practices but do not require a particular level of infiltration.
Innovative Measures	The Delaware Sediment and Stormwater Regulations state that the state's overall goal is to utilize stormwater management as a means to minimize water quantity and water quality impacts and to mimic pre-development hydrology to the MEP in regards to the rate, volume, and duration of flow. Projects in certain watersheds (Mill Creek, Little Mill Creek, Red Clay Creek, White Clay Creek, Persimmon Creek, and Shellpot Creek) need to control runoff volume to mimic pre-development land use conditions using recharge, infiltration, and reuse where site conditions allow.
LID Requirements	The state's preferred option for water quality protection is the use of "Green Technology BMPs." Other practices can only be considered after the preferred practices have been eliminated for engineering or hardship reasons as approved by the plan approval agency.
LID Incentives	N/A
Redevelopment	N/A
Links to Language	Delaware Sediment and Stormwater Regulations: http://www.dnrec.state.de.us/dnrec2000/Divisions/Soil/Stormwater/Regs/SSRegs_4-05.pdf Green Technology Guidance: http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/DURMM_TechnicalManual_01-04.pdf

DISTRICT OF COLUMBIA

Policy Structure	The District of Columbia is working with EPA to revise its NPDES permit to add innovative LID features. These were outlined in a letter to EPA dated November 27, 2009. Permit language had not been finalized at the time of this report's publication.
Impervious Surface	N/A
Infiltration	The regulations include guidelines and technical standards for the use of infiltration practices but do not require a particular level of infiltration.
Innovative Measures	Initiatives include • A tree-planting goal of planting and maintaining 13,500 trees in the manner recommended by the Green Build-Out Model. Current tree planting rate is more than 4,000 trees per year. • Development of a master LID implementation list and construction of 17 LID projects by August 2009. • Conversion of paved or hardened areas throughout the District, such as traffic street medians and large sidewalk areas into green space in the form of pocket parks or green streets. • LID incentives will be extended to include rain barrels and downspout disconnections. • Installation of approximately 50 rain gardens and 125 rain barrels and disconnection of 200 downspouts. Review of District properties for feasibility of green roof retrofits. Commitment to include green roofs on new buildings and major renovations where feasible.

DISTRICT OF COLUMBIA

LID Requirements	N/A
LID Incentives	The District plans to develop legislation to establish tax credits or other incentives programs for installation of green roofs on non-governmental buildings.
Redevelopment	N/A
Links to Language	Letter of agreement sent from the District to EPA outlining new LID measures (and other changes to their NPDES permit requirements): http://www.epa.gov/reg3wapd/npdes/dcms4.htm

MARYLAND

Policy Structure	The state recently adopted the Stormwater Management Act of 2007 that requires that Environmentally Sensitive Design (ESD), which is similar to LID, be implemented to the MEP. The Act also specifies the practices considered to be ESD. Previously, ESD had been encouraged through stormwater credits (see LID incentives). The purpose and scope of the previous (adopted in 1983) stormwater regulations (Code of Maryland Regulations 26.17.02,) states that "the primary goal of the State and local stormwater management programs is to maintain after development, as nearly as possible, the predevelopment runoff characteristics." Under the state stormwater regulations, all counties are required to adopt stormwater ordinances. The stormwater regulations specify minimum requirements for the county stormwater ordinances. The stormwater design manual interprets the stormwater regulations and provides guidelines and credits towards compliance.
Impervious Surface	From 2000 SW Design Manual page 1.13: Performance Standard 1: Site designs shall minimize the generation of stormwater and maximize pervious areas for stormwater treatment.
Infiltration	Recharge volume required as part of BMP design. The goal of this requirement is to maintain existing or predevelopment recharge rates.
Innovative Measures	Typical of other states
LID Requirements	The 2007 Act is likely to result in LID-related requirements.
LID Incentives	From page 5.17 of 2000 Stormwater Design Manual: Developments less than 15% impervious can be exempt from structural practices if they employ environmentally sensitive development techniques, which have LID elements including disconnection of rooftop runoff, use of grass swales, and dedication of natural areas. The manual provides other credits under the broader umbrella of Innovative Site Planning.
Redevelopment	From Code 26.17.02.05: Reduce existing imperviousness by 20%, or provide water quality treatment for 20% of site's imperviousness, or use a combination of imperviousness reduction and water quality treatment equal to 20%, or implement a locally approved practical alternative (e.g., fees, off-site implementation, watershed or stream restoration or retrofitting).
Links to Language	Stormwater Management Act of 2007: http://mlis.state.md.us/2007RS/chapters_noln/Ch_121_sb0784T.pdf

MASSACHUSETTS

Policy Structure	EPA is responsible for issuing stormwater general permits for construction sites disturbing more than one acre under the NPDES General Permit for Stormwater Discharges from Construction Activities. Although EPA is issuing authority, the MADEP reviews the conditions of each permit, certifies the program unconditionally, or with specific conditions according to requirements of Section 401 of the Federal CWA. In addition to the EPA NPDES requirements, the MADEP has state standards for stormwater discharges which are enforced through different MADEP regulations, including, but not limited to, the Mass. Wetlands Protection Act regulations (310 CMR 10.00), Mass. 401 Water Quality Certification regulations (314 CMR 9.00), and Mass. Surface Water Quality Discharge Standards (314 CMR 3.00 and 4.00).
Impervious Surface	N/A
Infiltration	From the Stormwater Management Policy Handbook: "Recharge must be provided to offset the recharge lost due to site development to the maximum extent practicable and determined using the existing (pre-development) soil conditions [according to hydrologic soil group]."
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	N/A
Redevelopment	From the Stormwater Management Policy Handbook: Redevelopment of previously developed sites must meet the Stormwater Management Standards to the maximum extent practicable. However, if it is not practicable to meet all the Standards, new (retrofitted or expanded) stormwater management systems must be designed to improve existing conditions. Definition -- Redevelopment projects include: Maintenance and improvement of existing roadways, including widening less than a single lane, adding shoulders, and correcting substandard intersections and drainage, and repaving; and Development, rehabilitation, expansion, and phased projects on previously developed sites, provided the redevelopment results in no net increase in impervious area.
Links to Language	SW Management Handbooks and other documents: http://www.mass.gov/dep/water/laws/policies.htm#storm

NEW JERSEY

Policy Structure	Stormwater management requirements are specified in the New Jersey Administrative Code (NJAC), Title 7, Chapter 8 Stormwater Management. Major developments (defined as disturbing one or more acres of land or increasing impervious surface by one-quarter acre or more) are required to comply with the stormwater management rules. When municipalities, counties, or regional governments develop stormwater management plans, they must use the stormwater rules as minimum standards.
Impervious Surface	*7:8-5.3 Nonstructural stormwater management strategies* requires that standards be met using nonstructural practices to the MEP, including minimizing and disconnecting impervious surface.
Infiltration	The state requires that developers demonstrate through hydrologic and hydraulic analysis that (1) the site and its stormwater management measures maintain 100 percent of the average annual preconstruction groundwater recharge volume for the site, or (2) that the increase of stormwater runoff volume from pre-construction to post-construction for the 2-year storm is infiltrated. This groundwater recharge requirement does not apply to

NEW JERSEY

	projects within the "urban redevelopment area," or to projects subject to restrictions related to industrial uses and other land uses producing potentially high pollutant concentrations that could impact ground water quality; also see exemptions under 7:8-5.2d.
Innovative Measures	Typical of other states
LID Requirements	*7:8-5.3 Nonstructural stormwater management strategies* requires, to the maximum extent practicable, that performance standards (N.J.A.C. 7:8-5.4 and 5.5) be met by incorporating nonstructural stormwater management strategies into the design that: • Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss. • Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces. • Maximize the protection of natural drainage features and vegetation. • Minimize the decrease in the time of concentration from pre-construction to postconstruction. • Minimize land disturbance including clearing and grading. • Minimize soil compaction. • Provide low-maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers and pesticides. • Provide vegetated open-channel conveyance systems discharging into and through stable vegetated areas. The State has developed a Nonstructural Strategies Point System to assess whether developers have implemented nonstructural controls to the MEP. Alternative compliance is available with justification. Any land area used as a non structural stormwater management measure to meet the performance standards in N.J.A.C. 7:8-5.4 and 5.5 shall be dedicated to a government agency, subjected to a conservation restriction filed with the County Clerk's office, or subject to Department approved or equivalent restriction that ensures that measure or an equivalent stormwater management measure approved by the reviewing agency is maintained in perpetuity.
LID Incentives	N/A
Redevelopment	Urban redevelopment areas are exempt from recharge requirements. For redevelopment, the water quality provisions of the Stormwater Management rules only apply if the impervious surface onsite increases by at least 0.25 acres.
Links to Language	Stormwater Management Rule Related Information: http://www.state.nj.us/dep/watershedmgt/rules.htm Stormwater Management Rule: N.J.A.C. 7:8 text: http://www.nj.gov/dep/rules/adoptions/2004_0202_watershed.pdf New Jersey Stormwater Best Management Practices Manual: http://www.njstormwater.org/bmp_manual2.htm Nonstructural Strategies Point System Information: http://www.nj.gov/dep/rules/adoptions/2004_0202_watershed.pdf

OHIO

Policy Structure	In Ohio, responsibility for regulating storm water is held by both local and state authorities. Locally, municipalities, townships and counties all have authority to regulate storm water. Ohio EPA, authorized by the regulations at Chapter 6111 of the Ohio Revised Code (ORC), administers the state regulations that require storm water permits for construction sites. These requirements established the basis of the permit requirements contained in the 2003 Ohio Environmental Protection Agency General Permit for Storm Water Discharges Associated with Construction Activity under the National Pollutant Discharge Elimination System. Draft permits specific to portions of the Olentangy River watershed and portions of the Big Darby Creek Watershed are in development. In addition to the rules and general permit, Ohio specifies stormwater performance and design criteria and sediment and erosion control standards in the 2006 Rainwater and Land Development Manual. Ohio also specifies stormwater control standards in the 1980 Ohio Stormwater Control Guidebook.
Impervious Surface	N/A
Infiltration	N/A
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	N/A
Redevelopment	Under General NPDES permit requirements in Appendix of 2006 manual: Redevelopment projects are required to either reduce the existing, pre-construction impervious area of the site by 20%, or capture and treat 20% of VWQ. Linear projects, which do not creation new impervious surfaces, are exempt from post-construction stormwater management requirements, although they are required to minimize the number and width of stream crossings.
Links to Language	Ohio Revised Code Chapter 6111: http://codes.ohio.gov/orc/6111 Rainwater and Land Development Manual: http://www.dnr.state.oh.us/default/water/rainwater/default/tabid/9186/Default.aspx

PENNSYLVANIA

Policy Structure	The Pennsylvania Storm Water Management Act of 1978 (Act 167) provides the legislative basis for statewide stormwater management. Stormwater management plans must be developed by the respective counties in a given watershed and be implemented by the affected municipalities through the adoption of stormwater ordinances. Pennsylvania provides design and review guidelines for stormwater management in its 2006 Pennsylvania Stormwater Best Management Practices Manual.
Impervious Surface	N/A
Infiltration	Strongly encouraged in the stormwater manual
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	N/A

PENNSYLVANIA

Redevelopment	Though not required, the stormwater manual recommends the following guideline: 20 percent of existing impervious area, when present, shall be considered meadow (good condition) in the model for existing conditions for redevelopment. Ch 7 of the Stormwater manual provides guidelines for Brownfield redevelopment.
Links to Language	Pennsylvania Stormwater Management Act: http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/StormwaterMgmtAct.pdf Pennsylvania Stormwater Best Management Practices Manual and related documents: http://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/stormwatermanagement/default.htm

RHODE ISLAND

Policy Structure	The State of Rhode Island recently passed An Act Relating to Towns and Cities—Establishing the Smart Development for a Cleaner Bay Act of 2007. An updated stormwater design manual, which will incorporate these requirements, is under development. These requirements will apply to any development previously subject to stormwater review, including development within MS4s under NPDES Phase I and II jurisdiction. In addition, the Coastal Resources Protection Council administers the Special Area Management Plans (SAMPs) that include more stringent stormwater and buffer requirements. The Urban Coastal Greenways Policy applies to the cities of Cranston, East Providence, Pawtucket, and Providence.
Impervious Surface	N/A
Infiltration	Maintain pre-development groundwater recharge and infiltration on site to the MEP.
Innovative Measures	Typical of other states
LID Requirements	The state requires that low impact-design techniques be used as the primary method of stormwater control to the MEP. Under the Urban Coastal Greenways Policy, development plans must be reviewed by a professional who has completed an LID training course and has received an LID Master Design Certificate. The draft stormwater manual sets Minimum Standard 1: Nonstructural and Small-Scale Upland Management, which states that nonstructural and small-scale upland management designs must be used to the fullest extent practicable in order to reduce the generation of the water quality volume. It also requires that structural control use be avoided where the water quality volume cannot be managed via nonstructural and small-scale practices (i.e., pollution hot spots).
LID Incentives	The volume required for the permanent pool of a wet pond can be reduced if rooftop runoff is infiltrated on-site. This procedure allows rooftops to be subtracted from total impervious areas, thus reducing the total amount of runoff routed to the permanent pool. Infiltration of rooftop runoff should be restricted to residential buildings or other buildings that do not have air pollution, venting, cooling, or heating equipment located on the roof.
Redevelopment	Redevelopment appears to be treated the same as new development, where only the increase in disturbance and imperviousness is required to be treated.
Links to Language	An Act Relating to Towns and Cities—Establishing the Smart Development for a Cleaner Bay Act of 2007: http://www.rilin.state.ri.us/BillText07/SenateText07/S0808Aaa.pdf Draft Rhode Island Stormwater Design & Installation Standards Manual, Chapter 4—Nonstructural and Small-Scale Upland Management: http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/stwater/pdfs/upman.pdf

VERMONT

Policy Structure	Vermont Statues Annotated (VSA) Title 10 § 1264 authorizes the creation of state stormwater permits. Chapters 18 and 22 of the Environment Protection Rules regulate the discharge of post-construction stormwater. State post-construction stormwater standards are specified in one of two general permits depending upon the condition of the receiving water – General Permits 3-9010 and 3-9015. The Vermont Stormwater Management Manual Volumes 1 and 2 describe regulatory requirements and technical guidance, respectively.
Impervious Surface	For new development and applicable redevelopment, either (a) the existing impervious surface shall be reduced by 20% or (b) a stormwater treatment system shall be designed to capture and treat 20% of the water quality volume from the existing impervious area or (c) a combination of (a) and (b) can be used such that, when combined, a minimum 20% reduction/treatment is achieved.
Infiltration	According to the Stormwater Manual Volume I, the average annual recharge rate for the prevailing hydrologic soil group(s) shall be maintained in order to preserve existing water table elevations.
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	Stormwater credits are offered for the use of: • Natural Area Conservation • Disconnection of Rooftop Runoff • Disconnection of Non-Rooftop Runoff • Stream Buffers • Grass Channels • Environmentally Sensitive Rural Development
Redevelopment	Impervious surface and water quality treatment requirements apply to the portion of existing impervious surface that is redeveloped; the existing impervious surface only needs to comply with any previous permit requirements.
Links to Language	Stormwater Management Rule for Unimpaired Waters: http://www.vtwaterquality.org/stormwater/docs/sw_rule-unimpaired.pdf Stormwater Management Rule for Impaired Waters: http://www.vtwaterquality.org/stormwater/docs/sw_rule-impaired.pdf The Vermont Stormwater Management Manual Volume 1: http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf

VIRGINIA

Policy Structure	Stormwater management standards can be found at erosion and sediment control law [Title 10.1, Chapter 5, Article 4] and regulations [4VAC50-30] as amended by the Virginia General Assembly in July 2006. These rules establish the requirements for the state and local erosion and sediment control and storm water management programs that regulate land-disturbing activity greater than 10,000 square feet. The Chesapeake Bay Preservation Area Designation and Management Regulations [9 VAC 10-20-10 et seq.] (also known as the Bay Act), adopted in 1990 and amended in December 2001, regulate development impacts, including storm water management, within the Chesapeake Bay watershed. The Virginia Department of Environmental Quality and Department of Conservation and Recreation jointly administer the regulations. The Department of Conservation and Recreation administers the resource protection and management area regulations.

VIRGINIA

Impervious Surface	Performance-based criteria are based on a site's pre-project impervious cover compared to the average impervious cover for that land use. More stringent pollutant controls are required if the proposed development is expected to increase impervious cover over the average cover for that land use. Development is required to minimize impervious area in Resource Management Areas.
Infiltration	N/A
Innovative Measures	Typical of other states
LID Requirements	§ 10.1-603.4 of The Virginia Soil and Water Conservation Board is required by state law to: "Encourage low impact development designs, regional and watershed approaches, and nonstructural means for controlling stormwater."
LID Incentives	N/A
Redevelopment	Redevelopment is allowed in Resource Protection Areas, but no increase in imperious cover is allowed. Under Virginia Stormwater Management Regulations, local governments must enact ordinances that require redevelopment, as well as new development, to control and treat stormwater runoff beyond pre-development conditions.
Links to Language	Virginia Stormwater Management Law: http://www.dcr.virginia.gov/soil_&_water/documents/vaswmlaw.pdf Virginia Stormwater Management Regulations: http://www.dcr.virginia.gov/soil_&_water/documents/vaswmregs.pdf Virginia Stormwater Management Handbook: http://www.dcr.virginia.gov/soil_&_water/stormwat.shtml#pubs

WISCONSIN

Policy Structure	State Statute 281.16 (2) (a) authorizes the Wisconsin Department of Natural Resources (WDNR) to promulgate water quality performance standards. Under this law, WDNR established Chapter NR 151 of the state code, which contains runoff pollutant performance standards.
Impervious Surface	N/A
Infiltration	Requirements to infiltrate to the MEP a percentage of the predevelopment runoff volume; Residential 90%; Non-residential 60% or 10% of the 2-yr, 24-hour event. As a cap, no more than 2% of the site is required as an effective infiltration area. Some exemptions apply.
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	N/A
Redevelopment	For all redevelopment and infill under 5 acres, BMPs are required to control to the MEP 40% of the total suspended solids that would normally run off the site based on an average annual rainfall. Infill occurring 10 or more years after Oct. 2002 is required to meet the new development standard of 80% TSS.
Links to Language	State Code Chapter NR 151—Runoff Management: http://www.legis.state.wi.us/rsb/code/nr/nr151.pdf

FEDERAL GOVERNMENT

The "Energy Independence and Security Act of 2007," which was signed into law December 19, 2007, contains a provision in Title IV, Energy Savings in Building and Industry, Subtitle C, High Performance Federal Buildings:

Sec. 438. Storm Water Runoff Requirements for Federal Development Projects.

The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

This provision requires all Federal development and redevelopment projects with a footprint above 5,000 square feet to achieve predevelopment hydrology to the "maximum extent technically feasible." This standard may differ from the MEP standard set forth in stormwater regulations.

This provision will likely result in much more focus on LID ,with more companies interested in learning how to develop and apply "design, construction, and maintenance strategies" that preserve pre-development technology, so that they can maintain existing, or obtain new, Federal government construction contracts. Also, the establishment of these requirements for Federal facilities is expected to have the effect of "mainstreaming" LID BMPs for non-federal facilities.

LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN NEIGHBORHOOD DEVELOPMENT STANDARDS

The U.S. Green Building Council develops and maintains the Leadership in Energy and Environmental Design (LEED) rating systems that promote energy conservation and sustainable design within the building industry. USGBS formed a partnership with the Congress for the New Urbanism and the Natural Resources Defense Council to develop a LEED rating system at the neighborhood scale. A pilot version of the LEED for Neighborhood Development (LEED-ND) Rating System has been released by the partnership[17] that seeks to promote neighborhood designs that minimize resource consumption and pollution and achieve sustainability. The pilot program will be used to test and refine the standards before they are released for industry-wide application. Of the 238 pilot projects selected for the program, 40 projects are located in California.[18]

The ND standards are divided into four categories:

- The **Smart Location and Linkage (SLL)** category evaluates how a development's location impacts urban sprawl, resource use, and environmental impacts.
- The **Neighborhood Pattern and Design (NPD)** category evaluates the layout of the neighborhood and the extent that each use provides social and environmental benefits.
- The **Green Construction and Technology (GTC)** category evaluates the construction process and the design of the structures within the neighborhood, seeking to reduce environmental contamination and site disturbance while promoting resource conservation and energy efficiency.
- **Innovation and Design Process (IDP)** category provides credit to neighborhood projects that achieve greater innovation than what is required or credited in the rating system. This category also gives credit for the involvement of an accredited professional.

Under each category, the rating system specifies prerequisites and credits. Prerequisites are required before an applicant is eligible for the certification, and credits provide the applicant with points towards different certification levels (certification, silver, gold, and platinum).

[17] USGBC, CNU, and NRDC. 2007. Pilot Version LEED for Neighborhood Development Rating System. A Partnership of the U.S. Green Building Council (USGBS), the Congress for New Urbanism (CNU), and the Natural Resources Defense Council (NRDC). http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148.

[18] USGBC, CNU, and NRDC. 2007b. LEED for Neighborhood Development Registered Pilot Project List. A Partnership of the U.S. Green Building Council (USGBS), the Congress for New Urbanism (CNU), and the Natural Resources Defense Council (NRDC). https://www.usgbc.org/ShowFile.aspx?DocumentID=2960.

Standards that Directly Contribute to Stormwater Management

The ND standards contain a number of prerequisites and credits related to stormwater management. The following paragraphs describe each prerequisite or credit in more detail.

- **SLL Prerequisite 4: Wetland and Waterbody Conservation:** An applicant meets this standard if the site includes no land within 100 feet of wetlands or waterbodies. The standard can also be met if 1) the site is located on a previously developed site; and 2) any wetland or waterbody impacts are compensated through on-site or off-site restoration. For sites that are not previously developed and contain wetlands or waterbodies, the rating system limits the percent of on-site impacts allowed according to the street grid density of the development. The applicant is also required to retain at least 90 percent of the average annual rainfall or 1 inch of rainfall from 75 percent of the development footprint within the impacted area. Retention methods must infiltrate, reuse, or provide for the evapotranspiration of the rainfall amount. This standard contributes to stormwater management by reducing the impact to the natural hydrology and water quality functions of a development site.
- **SLL Prerequisite 6: Floodplain Avoidance:** Similar to the above prerequisite, the Floodplain Avoidance standard is met if the site does not contain any land within the 100-year floodplain. The standard is also met if the site is located on an infill or previously developed site and the National Flood Insurance Program (NFIP) requirements are followed when developing land within the 100-year floodplain. For sites that do not meet these conditions, the standard can only be met if land within the 100-year floodplain is not developed. This standard contributes to stormwater management by reducing the impact to the natural hydrology and water quality functions of a development site.
- **SLL Credit 8: Steep Slope Protection:** This standard provides credit for either avoiding development on steep slopes or restoring vegetation to previously developed steep slopes. Credit is provided according the severity of the slopes and the proportion of steeped sloped land that is protected or restored. An exemption is included for steep slopes that are isolated by more than 30 feet from other steeply sloped areas. This standard contributes to stormwater management by reducing the runoff and erosion generated on steep slopes during storm events.
- **SLL Credits 9, 10 and 11: Habitat or Wetland Conservation:** These standards provide credits for habitat or wetland conservation on the development site. To receive credit under SLL Credit 9, the applicant must inquire with a state's Natural Heritage program and other wildlife or fish agencies to determine whether significant habitat exists on the development site. The applicant must protect in perpetuity the habitat and an appropriate buffer, as delineated by a qualified professional. For previously developed sites, the applicant can receive credit for using native plants for 90 percent of the site vegetation and refraining from the use of invasive plants. The standard also provides credit for conserving wetlands and waterbodies and planning buffers around the development footprint to protect water quality, habitat, and hydrologic functions. SLL Credit 10 provides credit for habitat or wetlands restoration on an area equal to or greater than 10 percent of the development. Invasive species removal is required to achieve credit for restoration. SLL Credit 11 provides credit for developing a long-term management plan for on-site habitat, wetlands, or waterbodies. Through the conservation of habitat and wetland areas, these standards contribute to stormwater management by preserving pervious areas, natural drainage paths, and other areas that maintain pre-development hydrology and water quality functions.
- **NPD Credit 6: Reduced Parking Footprint:** This standard provides credit for limiting surface parking and using multistory or underground parking, carpool spaces, and bicycle parking. To receive credit, the applicant must limit surface parking facilities to no more than 20 percent of the total development footprint. The intent of the credit is to reduce the negative social and environmental impacts of parking areas. This standard contributes to stormwater management through reduction of impervious surface.
- **GCT Credit 6: Minimize Site Disturbance through Site Design:** Under this standard, an applicant can receive credit for preserving, in perpetuity, undeveloped land, including tree canopy, native vegetation, and pervious surfaces. The credit award depends on the extent of pervious development on the site and the planned density of the site. This standard contributes to stormwater management by reducing the impact to the natural hydrology and water quality functions of a development site.

- **GCT Credit 7: Minimize Site Disturbance during Construction:** This standard provides credit for establishing limits of disturbance for natural areas or preserving significant trees on the site. The standard contains specific distances required for the limits of disturbance as well as the type of trees that qualify for preservation credit. This standard contributes to stormwater management by reducing the impact to the natural hydrology and water quality functions of a development site.
- **GCT Credit 9: Stormwater Management:** This standard provides credit for applicants who implement a comprehensive stormwater management plan. The plan must effectively retain a specified amount of rainfall from the project's development footprint. The rainfall amounts vary by the humidity of the watershed's climate; developments in more humid watersheds are required to retain a greater rainfall amount than more arid watersheds. The applicant can receive from 1 to 5 points depending on how much rainfall is retained. Retention methods must infiltrate, reuse, or provide for the evapotranspiration of the rainfall amount. This standard contributes to stormwater management by reducing the stormwater runoff generated by development.

Additional Standards that Contribute to Stormwater Management

In addition to the above standards, the ND rating system contains several prerequisites and credits that more directly target smart growth and air quality goals but contribute to stormwater management in the process. Many of the credits relating to smart growth may contribute to reduced impervious surface, provided that undeveloped land is conserved in the process. Several credits promote infill and brownfield development, which decreases pressure on undeveloped land and ultimately leads to reduced stormwater impacts. Several standards promote compact development, which could lead to improved stormwater management if stormwater is controlled and treated and the compact development conserves undeveloped land in other locations. The ND standards that target automobile dependency could lead to reducing transportation-related pollutant loading as well.

Appendix C: Key Elements of Progressive Ordinances

DEVELOPMENT OF STORMWATER MANAGEMENT GOALS AND OBJECTIVES

In the case study areas, often draft goals and objectives were used to help develop stormwater management criteria and craft "scenarios" to test in watershed modeling and/or pilot-project development. Local advisory groups or boards were used to help draft the preliminary goals and objectives.

Clearly, different communities have different goal and objective statements depending on local circumstances and requirements. For example, some communities may only wish to meet Phase II requirements, while others may set higher goals than state minimum requirements due to local concerns, such as drinking water supply or habitat protection. Following are examples of goals and objectives statements from several of the case study communities. Examples 1 and 2 draw on general police powers granted local governments: protect, maintain and enhance the public health, safety, and welfare. Example 3 goes further to establish a local non-degradation goal. Finally, Example 4 sets the highest goal: maintaining and improving existing water quality.

Example Goals Statements

Example 1 (modified from Town of Chapel Hill's Land Use Management Ordinance)

"The purpose of this section is to establish minimum stormwater management requirements and controls to protect and safeguard the general health, safety, and welfare of the public residing in watersheds within this jurisdiction. This ordinance seeks to meet that purpose through the following objectives:"

Example 2 (from Charlotte-Mecklenburg Post-Construction Storm Water Ordinance, draft under public review)

"The purpose of this ordinance is to protect, maintain and enhance the public health, safety, environment and general welfare by establishing minimum requirements and procedures to control the adverse effects of increased post-development storm water runoff and non-point source pollution associated with new development and redevelopment. It has been determined that proper management of construction related and post-development storm water runoff will minimize damage to public and private property and infrastructure, safeguard the public health, safety, and general welfare, and protect water and aquatic resources."

Example 3 (modified from the Town of Huntersville Water Quality Ordinance)

"The purpose of this regulation is to establish stormwater management requirements and controls to prevent surface water quality degradation to the extent practicable in the streams and lakes within the Town Limits and Extraterritorial Jurisdiction of Huntersville and to protect and safeguard the general health, safety, and welfare of Huntersville's residents. This regulation seeks to meet this purpose by fulfilling the following objectives:"

Example 4 (modified from the City of Portland's Stormwater Management Ordinance)

"The purpose of this Stormwater Management Ordinance is to provide for the effective management of stormwater and drainage and to maintain and improve water quality in the watercourses and waterbodies within and leaving the City. This ordinance seeks to meet that purpose through the following policies and standards:"

Example Objectives Statements

Example 1 – City of Charlotte-Mecklenburg County (Note all municipalities within Mecklenburg County worked jointly with the County to develop a unified post-construction ordinance, which is currently under public review.)

"This ordinance seeks to meet its general purpose through the following specific objectives and means:

1. Establishing decision-making processes for development that protect the integrity of watersheds and preserve the health of water resources.
2. Requiring that new development and redevelopment maintain the pre-development hydrologic response in their post-development state as nearly as practicable for the applicable design storm in order to reduce flooding, streambank erosion, non-point and point source pollution and increases in stream temperature, and to maintain the integrity of stream channels and aquatic habitats.
3. Establishing minimum post-development storm water management standards and design criteria for the regulation and control of storm water runoff quantity and quality.
4. Establishing design and review criteria for the construction, function, and use of structural storm water control facilities that may be used to meet the minimum post-development storm water management standards.
5. Encouraging the use of better management and site design practices, such as the preservation of greenspace and other conservation areas, to the maximum extent practicable.
6. Establishing provisions for the long-term responsibility for and maintenance of structural and nonstructural storm water BMPs to ensure that they continue to function as designed, are maintained appropriately, and pose no threat to public safety.
7. Establishing administrative procedures for the submission, review, approval and disapproval of storm water management plans, for the inspection of approved projects, and to assure appropriate long-term maintenance."

Example 2 – (adapted from Town of Huntersville Water Quality Ordinance and from Town of Chapel Hill Land Use Management Ordinance)

a. "Minimize increases in storm water runoff from development or redevelopment in order to reduce flooding, siltation and streambank erosion, and maintain the integrity of stream channels;
b. Minimize increases in nonpoint source pollution caused by stormwater runoff from development or redevelopment that would otherwise degrade local water quality;
c. Minimize the total volume of surface water runoff that flows from any specific site during and following development in order to replicate pre-development hydrology to the maximum extent practicable;
d. Reduce stormwater runoff rates and volumes, soil erosion and nonpoint source pollution, to the extent practicable, through stormwater management controls (BMPs) and ensure that these management controls are properly maintained and pose no threat to public health or safety; and
e. Meet the requirements of the National Pollution Discharge Elimination System (NPDES) Storm Water Permit and other requirements as established by the Clean Water Act."

Example 3 – Policies and Standards (adapted from City Code, City of Portland, Oregon)

The City of Portland code lists policies rather than objectives.

a. "Stormwater shall be managed as close as is practicable to development sites, and stormwater management shall avoid a net negative impact on nearby streams, wetlands, groundwater, and

other waterbodies. All local, state, and federal permit requirements related to implementation of stormwater management facilities must be met by the owner/operator prior to facility use. Surface water discharges from onsite facilities shall be conveyed via an approved drainage facility.

b. The quality of stormwater leaving the site after development shall be equal to or better than the quality of stormwater leaving the site before development, as much as is practicable.

c. The quantity of stormwater leaving the site after development shall be equal to or less than the quantity of stormwater leaving the site before development, as much as is practicable."

As shown in the above examples, the goal or purpose statement is very general. The objectives provide more detail on what implementation of the ordinance is intended to accomplish. The objectives can be regulatory based (e.g., meet Phase II requirements), resource based (e.g., minimize increases in nonpoint source pollution), or both. Importantly, the goals and objectives set the stage for selecting appropriate performance standards and criteria, and for encouraging LID.

PERFORMANCE CRITERIA ENCOURAGING LID TECHNIQUES

The examples below reflect key elements of progressive stormwater programs' approaches to using performance criteria to encourage LID.

Example 1 – Huntersville, North Carolina's Performance Standards

The Town of Huntersville is a developing community of about 35,000 residents and part of a regional commuter rail system planned for the metropolitan area. The town has experienced a rapid conversion from a farming community to a developing residential and commercial area. In February 2002, The Town of Huntersville adopted a moratorium on the approval of new major development plans. The moratorium allowed the town to focus on writing zoning ordinance amendments that would protect the Town's rural character and open space while allowing for high density and mixed-use development in centralized locations. Huntersville's updated zoning ordinance established 15 zoning districts.

Huntersville protects open space in the rural residential, transitional residential, and traditional neighborhood-rural districts. In these districts, permitted density depends on the amount of open space preserved. The transitional zoning district doubles the density allowed per open space percentage compared to the rural districts, but a minimum of 25 percent open space is required

The updated ordinance provides incentives for developers to dedicate permanent conservation easements. Termed conservation subdivisions, these developments will preserve the rural appearance of the land when viewed from public roads and adjacent properties. In turn, the developments are exempt from lot frontage, sidewalk, planting, and other requirements. The preservation of existing, mature trees is emphasized in the conservation easement provisions.

The Huntersville zoning districts include several mixed-use and residential districts designed to encourage quality of life and convenient access to employment and services. These districts include the Neighborhood Residential, Neighborhood Center, Town Center, and Transit-Oriented districts. Automobile-oriented and industrial developments are restricted to other zoning districts so that the Town can develop pedestrian-friendly town and neighborhood centers. These zoning districts were designed to encourage convenient walking distances between residential and commercial uses. Three zones allowing varying development intensity were designated (see Figure A-1).

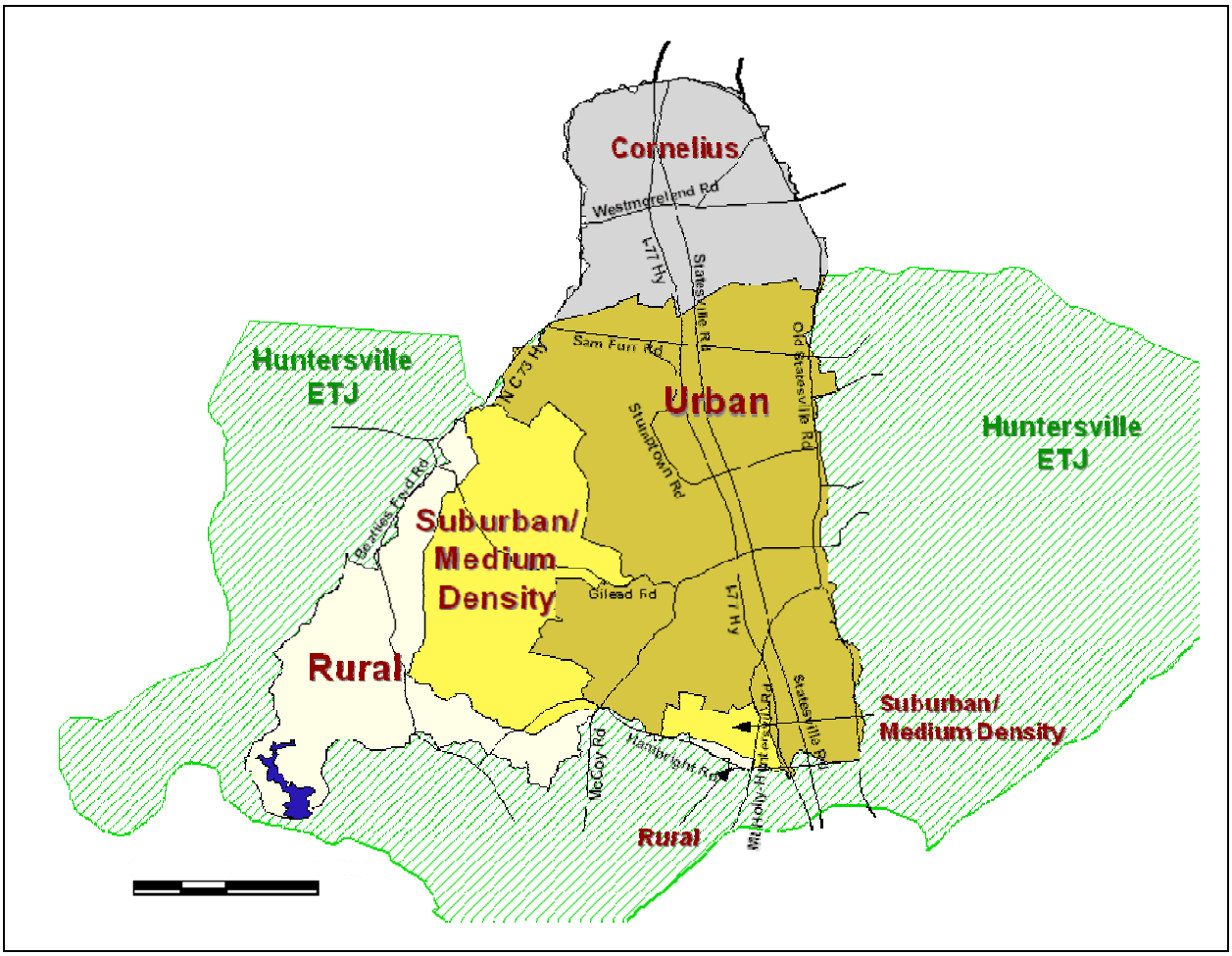

Figure A-1. Town of Huntersville's Development Zones

Huntersville included water quality measures in its ordinance, and adopted a water quality goal of no future degradation. The Town analyzed the water quality and hydrology benefits of alternative performance standards as well as the estimated cost to the landowner or developer in meeting the performance criteria and to build understanding about the cost implications of adopting more protective stormwater requirements in the Town's Ordinance. After that analysis, the Town adopted the following performance standards and required the use of LID in meeting these standards.

a. "All stormwater treatment systems used to meet these performance criteria shall be designed to achieve average annual 85 percent Total Suspended Solids (TSS) removal for the developed area of a site. Areas designated as open space that are not developed do not require stormwater treatment. All sites must employ LID practices to control and treat runoff from the first inch of rainfall.

b. LID practices or a combination of LID practices and conventional stormwater management practices shall be used to control and treat the increase in stormwater runoff volume associated with post-construction conditions as compared with pre-construction (existing) conditions for the 2-yr frequency, 24-hr duration storm event in the Rural and Transitional Zoning Districts. All other zoning districts shall meet this standard for the 1-yr frequency, 24-hr duration event.

c. Where any stormwater BMP employs the use of a temporary water quality storage pool as a part of the treatment system, the drawdown time shall be a minimum of 48 hours and a maximum of 120 hours.

d. Peak stormwater runoff rates shall be controlled for all development above 12 percent imperviousness (for the 2-yr, 24-hr and the 10-yr, 24-hr storm events). The emergency overflow and outlet works shall be capable of safely passing a discharge with a minimum recurrence frequency of 50 years.

e. No one BMP shall receive runoff from an area greater than 5 acres."

The town's Open Space performance standards are shown in Table A-1. Note that both the open space and water quality performance standards vary by planning district to meet the Town's overall smart growth objectives.

To ease overall administration and to ensure accountability, the Town developed a Stormwater BMP Design Manual and a Site Evaluation Tool that developers are required to use in project design and documenting compliance with the performance standards. (See Program Administration for more information on the Site Evaluation Tool).

Table A-1. Open Space and Density Requirements for Huntersville's Rural Residential and Traditional Neighborhood-Rural Zoning Districts

Amount of Open Space Provided	Density Permitted
0% unless tract is within a proposed greenway in which case the greenway shall be designated as open space	0.33 units per Adjusted Tract Acreage
25% - 29.9% Open Space	0.4 units per Adjusted Tract Acreage
30% - 34.9% Open Space	0.6 units per Adjusted Tract Acreage
35% - 39.9% Open Space	0.8 units per Adjusted Tract Acreage
40% - 44.9% Open Space	1.0 unit per Adjusted Tract Acreage
45%+ Open Space	1.2 units per Adjusted Tract Acreage

The performance standards required by the Town of Chapel Hill are similar to the Huntersville standards, with the following exceptions: Chapel Hill requires volume control for the 2-yr, 24-hr storm event throughout its jurisdiction. The stormwater runoff rate is controlled for the 1-, 2-, and 25-yr, 24-hr storm event (rather than the 2-yr and 10-yr storm events). The Town of Chapel Hill encourages rather than requires LID to meet its performance standards.

Each of the programs described above stipulates certain activities or types of development that are exempt from the guidelines and regulations described above. Those regulatory exemptions are as follows:

Town of Huntersville: Any new development, redevelopment or expansions that include the creation or addition of less than 5,000 sq ft of new imperviousness.

Town of Chapel Hill: Single family and two family developments and redevelopments that do not disturb more than 5,000 sq ft of land area, provided they are not part of a larger common development plan, are exempted.

Example 2 – City of Charlotte, NC and Mecklenburg County

The Charlotte-Mecklenburg Post-Construction Storm Water Ordinance (draft under public review) divides the County into five districts, each having unique performance standards. As discussed below, the performance standards necessitate the use of LID in order to meet the standards on site.

One of the first items agreed to by the stakeholders' group helping to guide development of the post-construction ordinance was the need to divide Mecklenburg County into districts. It was decided that a one size fits all approach was not appropriate, but instead districts should be drawn based upon need for protection and other criteria. An example of one of the criteria used was the presence of a federally endangered species in Goose Creek District and the Yadkin-Southeast Catawba District, which resulted in more stringent controls on new development. Areas with a very high percentage of existing development (i.e., the City of Charlotte) resulted in less stringent controls in new development. Figure A-2 shows the configuration of the districts, which were drawn along watershed boundaries. Other factors, such as close proximity to drinking water reservoirs, resulted in more stringent levels of control. Recognizing that certain areas in Mecklenburg County had unique characteristics and needs, the stakeholder group then debated basic criteria that would provide the foundation of the ordinance and meet the goals and objectives. The main categories for new performance standards were:

- Structural Water Quality BMPs: These controls are intended to remove water quality pollutants from stormwater runoff. The ordinance targets Total Phosphorus (TP) and Total Suspended Solids (TSS).
- Stream Buffers: These controls require that areas directly adjacent to streams be set aside as natural areas. Limited disturbance many be allowed depending on the distance from the stream.
- Volume and Peak Control: The controls require that the additional stormwater runoff volume and peak flow rates generated by land development activities be held back and released slowly over time so as to not cause downstream erosion and flooding.
- Open Space Requirements: These controls require that a certain percentage of a developed site be preserved as undisturbed area unless mitigation is provided.

Each District has a unique combination of these controls, depending on the level of protection needed. (See Table A-2, Summary of Performance Criteria for the Charlotte-Mecklenburg Post Construction Ordinance). It is important to note, however, that the performance standard for phosphorus removal (70 percent removal for runoff from the first inch of rainfall) applies to 4 of the 5 districts and necessitates the use of a treatment train approach using LID techniques in order to meet this standard onsite. The TP performance standard was based on an evaluation of streams in the County and loading rates needed to support designated uses (including healthy aquatic communities).

Because meeting the TP performance standard can be quite expensive for developments with high imperviousness (much more expensive on a cost per pound removed basis than developments with lower imperviousness), the Ordinance allows a flexible "buy down" option from 70 percent TP removal to 50 percent removal, and allows the City or County to use the revenue to construct BMP retrofits offsite to "make up the difference" in phosphorus loading. To reduce the cost of meeting the open space requirements, the Ordinance has offsite mitigation and onsite mitigation techniques, as well as payment-in-lieu.

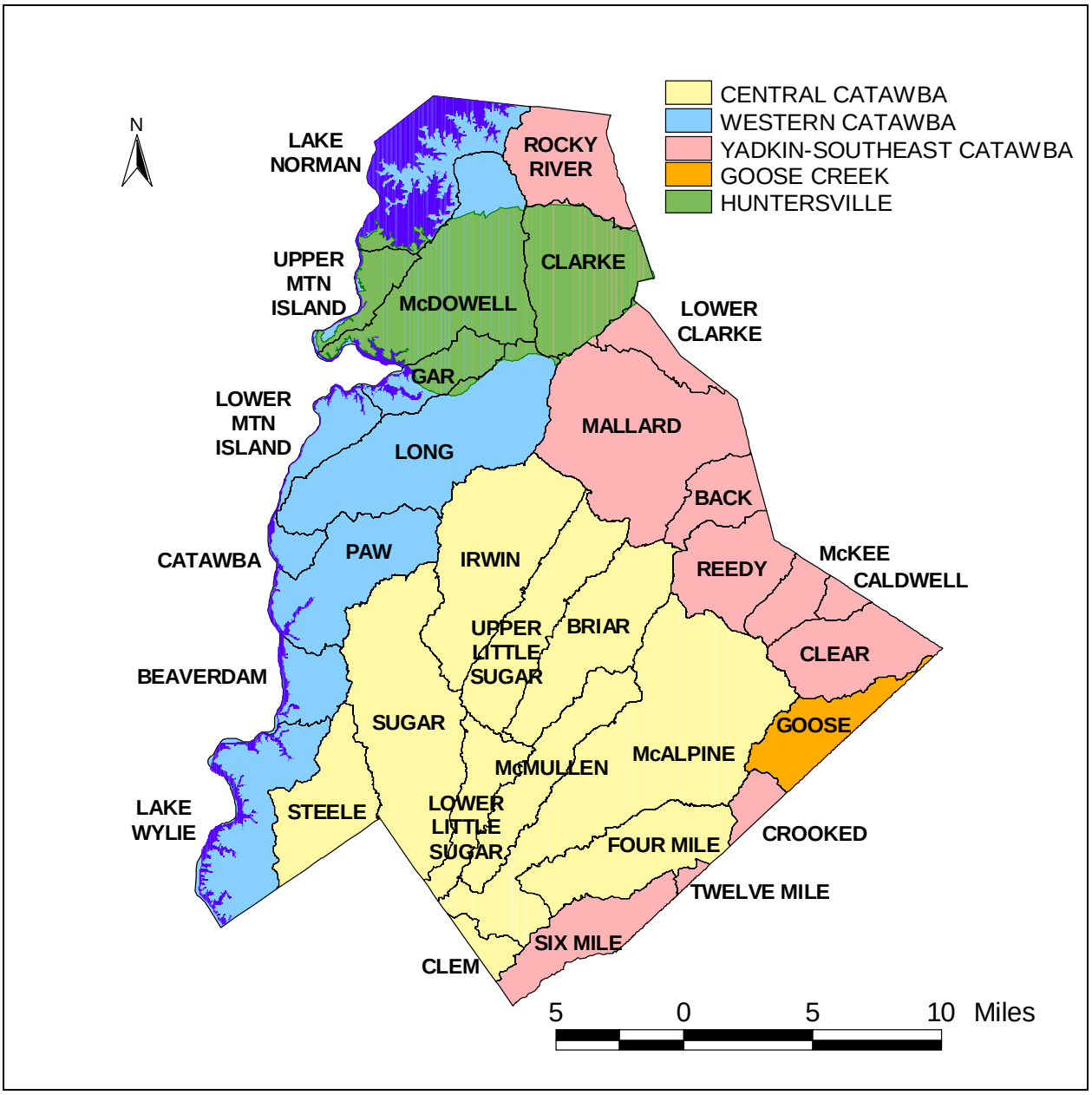

Figure A-2. Watershed Districts for Charlotte Mecklenburg Post Construction Ordinance

Table A-2. Summary of Performance Criteria for the Post-Construction Ordinance

Watershed District	Structural Water Quality BMPs	Buffers[(1)]	Volume & Peak Control	Open Space Requirements
Central Catawba	>24% BUA requires 85% TSS removal for runoff from 1st inch of rainfall; LID optional	30 ft. no build zone on intermittent and perennial streams draining < 50 acres 35 ft. (2 zones) on perennial streams draining <300 acres 50 ft (3 zones) on streams draining ≥300 acres 100 ft + 50% of floodfringe on streams draining ≥640 acres	Volume (Commercial & Residential): >24% BUA control entire volume for 1-yr, 24-hr storm Peak for Residential: >24% BUA perform a downstream flood analysis to determine whether peak control is needed and if so, for what level of storm frequency (i.e., 10, 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms Peak for Commercial: >24% BUA control the peak for the 10-yr, 6-hr storm **AND** perform a downstream flood analysis to determine whether additional peak control is needed and if so, for what level of storm frequency (i.e., 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	Open space is undisturbed area <24% BUA = 25% open space ≥24% and <50% BUA = 17.5% open space ≥50% BUA = 10% open space
Western Catawba	>12% BUA requires 85% TSS and 70% TP removal for runoff from 1st inch of rainfall; LID optional; BUA area caps apply in water supply watersheds	30 ft. no build zone on intermittent and perennial streams draining < 50 acres 35 ft. (2 zones) on perennial streams draining <300 acres 50 ft (3 zones) on streams draining ≥300 acres 100 ft + 50% of floodfringe on streams draining ≥640 acres	Volume (Commercial & Residential): >12% BUA control entire volume for 1-yr, 24-hr storm Peak for Residential: >12% BUA perform a downstream flood analysis to determine whether peak control is needed and if so, for what level of storm frequency (i.e., 10, 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms Peak for Commercial: >12% BUA control the peak for the 10-yr, 6-hr storm **AND** perform a downstream flood analysis to determine whether additional peak control is needed and if so, for what level of storm frequency (i.e., 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	Same as Central Catawba
Yadkin-Southeast Catawba	>10% BUA requires 85% TSS and 70% TP removal for runoff from 1st inch of rainfall; LID optional	50 ft undisturbed forested buffers on intermittent and perennial streams draining < 50 acres 100 ft undisturbed forested buffers plus remainder of floodplain on perennial and intermittent streams draining	Volume (Commercial & Residential): >10% BUA control entire volume for 1-yr, 24-hr storm Peak for Residential: >10% BUA perform a downstream flood analysis to determine whether peak control is needed and if so, for what level of storm frequency (i.e., 10, 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	Same as Central Catawba

Table A-2. Summary of Performance Criteria for the Post-Construction Ordinance

Watershed District	Structural Water Quality BMPs	Buffers[1]	Volume & Peak Control	Open Space Requirements
		≥ 50 acres	Peak for Commercial: >10% BUA control the peak for the 10-yr, 6-hr storm **AND** perform a downstream flood analysis to determine whether additional peak control is needed and if so, for what level of storm frequency (i.e., 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	
Goose Creek	>6% BUA requires 85% TSS and 70% TP removal for runoff from 1st inch of rainfall; LID optional; 24% BUA cap on single family residential, 50% on all other development	100 ft. undisturbed forested buffer on perennial and intermittent streams draining < 50 acres 200 ft. undisturbed forested buffer plus remainder of floodplain on perennial and intermittent streams draining ≥ 50 acres	Volume (Commercial & Residential): >6% BUA control entire volume for 1-yr, 24-hr storm Peak for Residential: >6% BUA perform a downstream flood analysis to determine whether peak control is needed and if so, for what level of storm frequency (i.e., 10, 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms Peak for Commercial: >6% BUA control the peak for the 10-yr, 6-hr storm **AND** perform a downstream flood analysis to determine whether additional peak control is needed and if so, for what level of storm frequency (i.e., 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	Same as Central Catawba
Huntersville	For developments with greater than or equal to 5,000 square feet of BUA, install LID practices to achieve 85% TSS removal for runoff from the 1st inch of rainfall; BUA area caps apply in water supply watersheds	30 ft. no build zone on intermittent and perennial streams draining < 50 acres[2] 35 ft. (2 zones) on perennial and intermittent streams draining <300 acres 50 ft. (3 zones) on streams draining ≥300 acres 100 ft. or entire floodplain on streams draining ≥640 acres	Volume: For developments with greater than or equal to 5,000 square feet of BUA, control increase in volume for 1-yr, 24-hr storm or 2-yr, 24-hr storm, depending on zoning district Peak: >12% BUA control 2-yr & 10-yr, 24-hr storm	Varies by zoning district

[1] Water supply watershed buffer requirements apply in the Western and Huntersville districts. These buffers are sometimes more restrictive than the S.W.I.M. buffer requirements, in which case the watershed buffers would apply.

[2] Will require a change to the existing Huntersville Ordinance in order to comply with minimum Phase II Post-Construction rules.

Rockdale County, GA combines the Charlotte-Mecklenburg County and Town of Huntersville approaches. Based on its watershed study, the county established performance standards for new development by planning district:

- *Urban Area.* 56 percent removal TP, 78 percent removal TSS, 57 percent removal Copper. These standards must be met by new developments in the City of Conyers (existing municipal jurisdiction and planned, long-term sewer service area).
- *Suburban/Rural Area*. 52 percent removal TP, 72 percent removal TSS, 51 percent removal Copper. These standards must be met by new developments in the county jurisdiction, excluding the drinking water supply watershed and urban area.
- *Rural Residential (Water Supply Watershed) Area.* 1 unit / 3 acres.

Rockdale County encourages LID in meeting these standards.

Each of the programs described above stipulates certain activities or types of development that are exempt from the guidelines and regulations described above. Those regulatory exemptions are as follows:

- *Charlotte-Mecklenburg, NC.* Residential development that cumulatively disturbs less than one acre and cumulatively creates less than 24% built upon area based on lot size or the lot is less than 20,000 square feet; commercial and industrial development that cumulatively disturbs less than one acre and cumulatively creates less than 24% built upon area based on lot size or the lot is less than 20,000 square feet; redevelopment that disturbs less than 20,000 square feet, does not decrease existing stormwater controls, and renovation costs do not exceed 100% of the tax value of the property; common law vested right established.
- *Rockdale County, GA.* Any development or redevelopment less than 7 percent imperviousness is exempted from enhanced volume control. Otherwise, GA Phase II stormwater control thresholds apply.

Example 3 - Portland, Oregon

The City of Portland's Sewer Development Services Administrative Rules require that the City's Bureau of Environmental Services (BES) review building permits during building plan reviews for compliance with the City's Stormwater Management Manual. Adopted in September 2004, the Stormwater Manual has the following performance criteria.

"The quality of stormwater leaving the site after development shall be equal to or better than the quality of stormwater leaving the site before development, as much as is practicable, based on the following criteria:

a. Water quality control facilities required for development shall be designed, installed and maintained in accordance with the Stormwater Management Manual, which is based on achieving at least 70 percent removal of the Total Suspended Solids from the flow entering the facility for the design storm specified in the Stormwater Management Manual.

b. Land use activities of particular concern as pollution sources shall be required to implement additional pollution controls, including, but not limited to, those management practices specified in the Stormwater Management Manual.

c. Development in a watershed that drains to streams with established Total Maximum Daily Load limitations, as provided under the Federal Clean Water Act, Oregon Law, Administrative Rules, and other legal mechanisms shall assure that water quality control facilities meet the requirements for pollutants of concern, as stated in the Stormwater Management Manual."

d. Note: additional criteria follow related to implementing these criteria onsite or on an offsite facility. Otherwise, there is an option for payment in lieu.

"The quantity of stormwater leaving the site after development shall be equal to or less than the quantity of stormwater leaving the site before development, as much as is practicable, based on the following criteria:

a. Development shall mitigate all project impervious surfaces through retention and onsite infiltration to the maximum extent practicable. Where onsite retention is not possible, development shall detain stormwater through a combination of provisions that prevent an increased rate of flow leaving the site during a range of storm frequencies as specified in the Stormwater Management Manual.

b. The Director may exempt areas of the City from the requirement a. above if flow control is not needed or desirable and if stormwater is discharged to a large waterbody directly through a private outfall or if stormwater is discharged to a waterbody directly through a separated public storm sewer having adequate capacity to convey the additional flow.

c. Any development that contributes discharge to a tributary to the Willamette River shall design facilities such that the rate of flow discharging from water quantity control facilities for up to the two-year storm does not lengthen the period of time the channel sustains erosion-causing flows, as determined by the Bureau. (Note: This criterion is required due to evidence of excessive stream bank erosion and channel erosion in most tributary streams in Portland.)

d. Facilities shall be designed to safely convey the less frequent, higher flows through or around facilities without damage.

"Note: additional criteria follow related to implementing these criteria onsite or on an offsite facility. Otherwise, there is an option for payment in lieu. The City also provided incentives for reduction of stormwater runoff and impervious area through stormwater discounts.

"Regulatory Exemptions:

"Developments less than 15,000 sq.ft. are exempted from detention (devices with orifices); development less than 500 sq.ft. is exempted from retention."

The City is currently revising its Stormwater Management Manual and will release the updated manual in late fall 2007. The revisions are intended to clarify the intent of the current standards.

Example 4 – Grand Rapids, Michigan

The city of Grand Rapids, Michigan is introducing an analytic method for calculating the amount of stormwater impacts prevented by installation of higher floor area ratios. The rationale for the policy is that, although higher density development will have a greater percentage of impervious area per acre of development, the total impervious area per residence actually will be less. This overall watershed benefit is typically not recognized in site level hydrology assessments.

The runoff reduction of a higher density project is estimated by subtracting from one, the ratio of the site's actual impervious area (AIsite) divided by the impervious area (AiLD) of a low density development having the same number of units, and converted to a percentage.

Percent Runoff Reduction = (1 – AIsite / AiLD) x 100%

The city established a performance standard of 80 percent reduction of runoff based on the performance of a vegetated roof. The city then used the same 80 percent (80%) runoff reduction as the threshold for the granting of a waiver for high density developments. The city evaluated the typical impervious surface coverage of lower density development, as shown in 0.

Table A-3. Typical Impervious Area Values for Low Density Development Types

Low Density Development Type	Average Impervious Area	Development Unit
Residential	4,700 square feet	Residence
Parking Lot	275 square feet	Park-Loading Space
Office/Commercial	1 square foot	Gross Floor Area

The analysis showed that the reduction rates allow a waiver when the follow intensity is met:

- Residential projects – 38 units/acre (compared to 5 units per acre as the low density complement)
- Parking – 744 spaces per acre or a 5-deck or higher parking structure
- Office/Commercial – Floor area ratio of 5 floors or higher

Note that the analysis did not take into account related offsite public impervious surfaces such as sidewalks, access lanes and street frontage. Because higher density development projects have smaller frontage lengths, the roadway length serving the site is less (Lemoine, to be published October 2007).

Example 5 - San Jose, California

In a 2001 Order to its co-permittees, the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) modified its C.3. regulatory requirements related to new and redevelopment. (The C.3 requirements are contained in the San Francisco Regional Water Quality Board's permit and deal with stormwater treatment).

The 2001 Order required changes to the Urban Runoff Management Plan, including some of the following elements:

- *Performance Standard Implementation*. Use planning and outreach programs to help implement the new requirements.
- *Development Project Approval Process.* Modify project review processes to incorporate new requirements. The order recommended incorporation of :
  - *Site design measures.* Address the generation of excess impervious surface coverage through site and neighborhood planning. Examples cited in the 2001 Order include minimizing land disturbance, minimizing impervious surfaces (e.g., roadway width, driveway area), minimum-impact street design (e.g., neo-traditional street design standards), and parking lot design standards.
  - *Source control measures.* Prevent stormwater pollution by mitigating pollutant loading from certain uses, such as restaurants, automobile services, and landscaping.
  - *Treatment measures.* Integrate measures into site and development plans to infiltrate or filter stormwater.
- *Limitation on Increase of Peak Stormwater Runoff Discharge Rates.* Hydrograph Modification Management Plans (HMMP) was introduced to limit discharge rates. The 2001 Order recognized that certain projects, such as transit villages, may not be able to meet all of the performance standards, but since most transit villages occur in already-developed areas, the redevelopment would be unlikely to change the stormwater characteristics of the site.
- *Waiver Based on Impracticability and Compensatory Mitigation.* The 2001 Order requires that the co-permittees establish a definition for impracticability or infeasibility, and a process to

decide which alternative compliance measures could be incorporated into the site design or decision-approval process for new development and significant redevelopment projects.

- *Update General Plans.* The order recommends looking at large scale plans for opportunities to minimize the impacts of stormwater runoff at the regional or watershed scale.

In response to the revised permit, the city of San Jose sought to incorporate the new guidance into a local stormwater ordinance that would work in concert with other rules and its long-term Visioning Plan (the 2020 Plan), as well as other smart growth initiatives.

San Jose developed rules specifying that all new and redevelopment projects had to implement Post-Construction Best Management Practices (BMPs) and Treatment Control Measures (TCMs) to the maximum extent practicable. San Jose structured its policy so that deviations from the standard requirements could be established through a finding of impracticality. San Jose's policy includes some of the more common challenges, such as soil type or legacy pollutants. The city echoed the regional policy of favoring landscape-based controls, such as biofiltering and swales. However, the city also recognized some urban areas with site constraints can make landscaped-based controls expensive or impossible for the types of projects that deliver a range of economic, housing and transportation benefits.

The San Jose policy allows flexibility and several alternative measures that complement smart growth projects. First, a project can participate in a regional or shared TCM. Instead of requiring each and every project to address its own stormwater onsite, a shared TCM can lower costs and make more efficient use of land in urban areas. The city also established a category of projects called "Water Quality Benefit Projects." According to the policy:

> "Water Quality Benefit Project – In its discretion, the City may find that Smart Growth Projects provide equivalent water quality benefit. For other projects the City may find equivalent stormwater benefits where the project sponsor provides project and/or environmental documentation showing the development of the site itself, the nature of the site design, its location in the watershed, and/or proposed change in use protects/enhances water quality."

Further, the city defined "Smart Growth Projects" as a project meeting one or more of the following criteria:

a. Significant Redevelopment Project within the Urban Core

b. Low-income, moderate income, or senior housing Development Project, meeting one of the criteria listed in other sections of the city's code

c. Brownfields Projects.

For more information, see the Santa Clara Valley Urban Runoff Pollution Prevention Program (http://www.scvurppp.org/). Also, in 2007, SCVURPPP issued an update of the Guidelines of Site Design Examples. The guidebook presents examples of built projects, BMPs and a description of BMP design. See http://www.scvurppp-w2k.com/pdfs/0607/SC_Site_Design_Manual_Final_0207.pdf . The San Jose 2020 General Plan can be found at http://www.sanjoseca.gov/planning/gp/2020_text/index_htm.htm.

Example 5 – Palo Alto, California

Within the Zoning Chapter related to Off Street Parking and Loading Regulations, the city has adopted the following language:

> "Automobile and bicycle parking requirements prescribed by this chapter may be adjusted by the director of planning and community environment in the following instances and in accord with the prescribed limitations, when in his/her opinion such adjustment will be in accord with the purposes of this chapter and will not create undue

> impact on existing or potential uses adjoining the site or in the general vicinity. (f) Transportation and Parking Alternatives. Upon demonstration to the director of planning and community environment that effective alternatives to automobile access are in effect, the director of planning and community environment may defer by not more than twenty percent the parking requirement otherwise prescribed for any use, or combination of uses on the same or adjoining sites, to an extent commensurate with the permanence, effectiveness, and the demonstrated reduction of off-street parking demand effectuated by such alternative programs. Land area required for provision of deferred parking stalls shall be maintained in reserve and shall be landscaped pursuant to a plan approved by the architectural review board demonstrating that ultimate provision of the deferred stalls will meet all requirements of this chapter. The director of planning and community environment shall set such conditions as necessary to guarantee provision of such deferred stalls whenever the building official determines the need to exist. Alternative programs which may be considered by the director of planning and community environment under this provision include, but are not limited to the following: (1) Immediate proximity to pubic transportation facilities serving a significant portion of residents, employees, and/or customers; (2) Operation of effective private or company carpool, vanpool, bus, or similar transportation programs; (3) Evidence that a proportion of residents, employees, and/or customers utilize, on a regular basis, bicycle transportation commensurate with reduced parking requirements."

(Source: Municipal Code Title 18. Zoning Chapter 18.83 Off Street Parking and Loading Regulations Section 18.83.120 www.smartcommunities.ncat.org/codes/paloalto3.shtml.)

In addition, the city allows permeable paving under the following parameters:

> "City of Palo Alto. Municipal Code. Title 18. Zoning Chapter 18-12 R-1 Single-Family Residence District Regulations Section 18.12.050 Site Development Regulations The following site development regulations shall apply in the R-1 single-family residence district. Modifications of some regulations may be applicable if the R-1 single-family residence district is combined with the special building site combining district. More restrictive regulations may be recommended by the architectural review board and approved by the director of planning and community environment, pursuant to Chapter 16.48: (r) Parking and driveway surfaces may have either permeable or impermeable paving. Gravel and similar loose materials shall not be used for driveway or parking surfaces within ten feet of the public right of way."

PROGRAM ADMINISTRATION

Stormwater management or water quality ordinances must also lay out the key elements of program administration. These include, but are not limited to, BMP operation, inspection, maintenance; enforcement; BMP design; methods for evaluating compliance with performance standards; administrative fees; etc. While detailed requirements for these elements are specified in administrative manuals which are referenced in the ordinance (e.g., BMP Design Manual), the ordinance must address program administration in order to provide enabling authority for staff and clarify overall program requirements. Below we have highlighted some of the key requirements for an effective stormwater ordinance as it relates to program administration.

BMP Operations, Inspection Maintenance and Local Enforcement

Regarding regular operations, inspections, and maintenance of BMPs, the first question that a local government needs to answer is, "Who will be required to carry out these duties?" Most local governments

have stipulated that property owners are required to carry out inspections/maintenance and ensure that the BMP is operating properly.

Concerned about whether residential homeowners and homeowners' associations will actually be able to conduct inspections and maintenance over the long-term, the City of Charlotte/Mecklenburg County has said that it will accept maintenance responsibilities from single family detached residential developments and town homes if the BMPs have been satisfactorily maintained during the two-year warranty period by the owner or designee; meet all requirements of the stormwater management ordinance and Design Manual; and include adequate and perpetual access for inspections, maintenance, repair, or reconstruction. For other residential and non-residential developments, the property owner will be required to operate and maintain the BMP facilities. The logic behind this public-private division of labor is that the commercial establishments with professional property managers are capable of carrying out inspections and maintenance duties. More and more jurisdictions with stormwater utilities are questioning whether in the future the utility should assume operations and maintenance of the stormwater BMPs and charge a stormwater utility fee to recoup the cost.

What is required of property owners when they are in charge of maintenance? Progressive ordinances require the following:

Operations and Maintenance Agreement. This legal instrument requires the property owner and its successors, heirs, and assigns to regularly inspect, maintain, and repair stormwater facilities; provides a timeframe for performing needed repairs after inspections; attaches a schedule of long-term maintenance activities to be performed; allows the local government rights of ingress and egress for inspections and monitoring; outlines the requirements for notice of violation; allows the local government to perform needed maintenance if the property owner fails to do so, and requires the property owner to reimburse the local government for all costs incurred. The inspections and maintenance requirements of the agreement depend on the BMPs onsite, but inspections are required at least annually. (Note: Such requirements are also usually outlined in the local government's Construction or Design Manual.)

Annual Inspections and Maintenance Report. This must be submitted to the jurisdiction from a qualified engineer or landscape architect.

Access Easement for Inspections of BMPs. This is a separate legal instrument which is recorded with the deed.

Performance Security for Installation and Maintenance. The local government may require submittal of a performance security or bond with surety, cash escrow, letter of credit, or other legal arrangement prior to issuance of a stormwater management permit. Typically, the local government requires such performance security for the period of BMP installation and a minimum performance bond to cover maintenance or replacement costs after construction has been completed for a certain period of time (e.g., 5 or 10 years). Durham County North Carolina requires that stormwater management permit holders maintain an approved plan and performance security for the life of the project.

What is required of the local government? Through the ordinance, the local government provides enabling authority for local staff (or the jurisdiction's designee) to carry out an inspections program including routine inspections, random inspections, and inspections based on complaints. These inspections may include reviewing maintenance and repair records; sampling discharges, surface water, water in BMPs, etc.; and evaluating the condition of the BMPs. The purpose of the inspection is to determine if the activity onsite is being conducted in accordance with the ordinance and design manual and whether the measures required in the stormwater management plan of the site are effective.

The Ordinance must also specify the consequences of noncompliance, including notice of violation, penalties (e.g., civil penalty), and remedies (e.g., withholding or disapproval of subsequent permits or certificates, injunctions, costs as lien, restoration of areas affected by failure to comply).

Design Manual for BMPs

An effective BMP design manual is a critical feature of a progressive stormwater ordinance. It is more than a set of instructions for constructing a practice to meet a regulation – it must bridge the gaps between the concepts of LID, the goals of the local stormwater management program, and the way the management practices are to be constructed. The manual should communicate the importance of the stormwater management goals, and provide education and detailed guidance to those that use it. Engineers may be accustomed to a cookie-cutter approach to design, and may not understand the reasons for a different approach, nor be familiar with LID goals of retaining stormwater onsite versus the standard approach of moving it off as quickly as possible. With these goals in mind, this section will discuss the following elements:

- How should the BMP design manual be linked to the ordinance?
- What are the important elements of the manual? What should it contain?
- What incentives can be used to encourage the use of innovative practices?

How should the BMP design manual be linked to the ordinance?

The BMP design manual and any other technical documents should be linked to the ordinance by reference. For example, the Town of Huntersville's Water Quality Ordinance says, "Specific requirements regarding the design, installation and maintenance of LID structures and a discussion of LID site planning is contained in the Huntersville Water Quality Design Manual."

It is critically important that the ordinance **does not** include details about design guidelines that achieve performance standards, nor specific assumptions about BMP performance. Current research may indicate that a particular practice achieves a certain level of pollutant removal, or that retention of a particular storm event runoff volume will prevent downstream channel erosion. However, the science of stormwater management is young and rapidly evolving. Current BMP designs may need to be updated. New research may show that a particular BMP does not remove as much of a pollutant as previously thought. Performance standards themselves may need to be changed, if over time they are not working as expected. For this reason, it is more important for the ordinance to refer to the goals of the performance standards (e.g., reduce nutrient runoff from development to protect downstream water resources, reduce impacts of stormwater volume to prevent stream channel erosion and protect biological resources). Separate documents can then be updated as needed to support the ultimate goals. If a specific design is cited in the ordinance as meeting performance standards, it will be much more difficult to change the ordinance itself.

What are the important elements of the manual? What should it contain?

BMP design manuals are quite common, and have typically grown out of a history of engineering requirements for stormwater management. Some are limited in nature. The most basic focus on design elements for peak flow control, and provide little or no context for their purpose. In locations where pollutant impacts from stormwater became an issue, practitioners began developing a larger toolbox of practices, and provided more robust design manuals with background and guidance. North Carolina's BMP manual published in 1999 (NCDENR, 1999) was produced to support recently enacted water supply watershed regulations, which required removal of 85 percent of post-construction sediment loads. The 1999 manual is 85 pages in length, covers eight separate BMPs (including bioretention areas, stormwater wetlands, and infiltration devices), and has detailed narrative about the practices, design calculations with examples, costs, and maintenance. Interest in innovative stormwater management has grown in NC, and the scope of regulation increased when a large portion of the state came under nutrient management regulations resulting from nitrogen TMDLs for large river basins. As a result, the 2007 manual (NCDENR, 2007) has grown to several hundred pages in length, covers 13 practices (including the addition of permeable pavement, green roofs, cisterns, and restored forest buffers), and has an in-depth

discussion of BMP design considerations. While the NC design manual does not promote LID per se, it does show the importance of providing a large toolbox of practices, and educating practitioners about their importance.

An LID stormwater manual should therefore provide the entire holistic framework, starting with a detailed discussion of LID, its goals, and how it represents a fundamentally different way of managing site hydrology. Performance standards specific to the managing authority should also be covered, including why they are needed and how they protect the intended resources. Finally, detailed design guidelines and examples should be provided for each BMP.

For example, Prince George's County (MD) provides two guidance documents, one with an overview of the approach (Prince George's County, 1999a) and one with details about hydrologic analysis (Prince George's County, 1999b). While it the guidance documents are not linked to any specific performance standards, they do discuss in detail the goal of mimicking pre-development site hydrology. The State of Georgia's stormwater management manual includes both a policy/overview document and a detailed design manual (Atlanta Regional Commission, 2001). The design manual provides details about the management goals, including performance standards related to storm event runoff volume, and design guidelines, specifications, and performance standard calculations for 19 BMPs.

What incentives can be used to encourage the use of innovative practices?

One of the fundamental principles of LID is to micromanage runoff and to prevent it from leaving the site. A site that uses a full suite of LID practices should have a greatly reduced volume of runoff, even during a large storm event. Performance standards often require storage and treatment of a significant volume of runoff. By receiving credit for using LID practices, developers can reduce the cost of other practices by reducing their size.

Knox County (TN) has a draft stormwater manual with good examples of how stormwater credits can be used to provide incentives for LID practices. The County's new ordinance (adopted September 2007) includes a performance standard of capturing and treating the runoff from the first 1.1 inches of rainfall, called the Water Quality Volume (WQv). The manual allows for a reduction of the WQv via six practices:

1. Natural area preservation
2. Managed area preservation (open space)
3. Routing runoff to stream and vegetated buffers
4. Using specially designed grass swales for treatment
5. Disconnection of impervious surfaces
6. Large lot neighborhoods

Each has very specific design guidelines and limitations, but used separately or together they may potentially reduce the volume of runoff that must be treated with structural practices, thus reducing the cost to the developer. The last option incorporates low housing densities requirements with other practices, and allows the developer to completely waive the WQv requirement.

Methods for Evaluating Performance Standards and Water Quality Objectives

Assessing performance standards adds a layer of complexity to the process of development review, both for the developer and the regulator. If the calculation of the site targets and how the site meets those practices is complicated, developers may find it difficult to test a variety of innovative designs, and may elect to choose a conventional design. Likewise, the reviewing authority must spend additional time reviewing the calculations and assumptions submitted by the developer for errors.

In some cases, simple calculations or spreadsheet tools may be sufficient. For instance, sediment loads could be estimated from proportions of the site under various land covers (i.e., forest, developed pervious, and impervious) using predetermined factors. A BMP or a set of BMPs treat a portion of the land covers, and the sediment they remove should be calculated using predetermined removal rates. From that, the final sediment load can be estimated.

However, when there are multiple performance standards, this can become difficult. Simple performance standard models can be used to reduce both administrative burden, and to allow the developer to explore a wider range of options. These models do not have to be complicated to learn or use. For example, the City of Huntersville uses the SET, a Microsoft Excel based spreadsheet that was developed to assess the impacts of development, including sediment and nutrient loading, on a site scale. It provides a better environment for testing multiple management practices and site configurations than do simple export calculations, and it incorporates several principles of hydraulic and water quality modeling for more realistic BMP response solutions. The tool lets the user define pre- and post-treated land use/land cover, allowing for multiple drainage areas and various combinations of practices. An important benefit of SET is that the user can test management practices in combination with each other, of a site or small catchment. In addition, both structural and nonstructural practices can be represented, offering a suite of options for evaluation. The Huntersville version of the SET calculates loads and removal for sediment, nutrients, and fecal coliform bacteria, as well as calculating a runoff volume performance standard linked to the location of the development. Other versions of the SET also calculate storm event peak flow. The SET also estimates pre- and post-development annual runoff, an important measure for LID.

LAND USE CODES ALLOWING EFFECTIVE SITE DESIGN

A strong stormwater ordinance is only half of the equation for effective stormwater management. A local government also needs to have a development ordinance that allows or even encourages effective site design for reducing or managing stormwater. While strong stormwater performance standards can provide an impetus for developers to minimize impervious area, maximize undisturbed area, and other good site design techniques, often local codes erect barriers and disincentives to implementing LID.

Local governments and developers practicing LID design over the last decade have developed some tools and methods for doing so. They have provided useful guidelines for low-impact site design, which include the following steps (Prince George's County, 1999a):

1. Identify applicable zoning, land use, subdivision, and other local regulations.
2. Define development envelope and protected areas (reduce limits of clearing and grading; use site fingerprinting).
3. Use drainage/hydrology as a design element.
4. Reduce/minimize total impervious area.
5. Develop integrated preliminary site plan.
6. Minimize directly connected impervious areas.
7. Modify/increase drainage flow paths.
8. Compare pre- and post-development hydrology (using hydrologic analysis).
9. Complete site plan.

Based on local governments' experience, USEPA, the Center for Watershed Protection, and others have developed a number of "how to" LID design documents. In taking the first step toward LID, i.e., identifying applicable zoning and land use regulations, the Center for Watershed Protection has developed *Better Site Design: A Handbook for Changing Development Rules in Your Community* (1998). The Guide

includes a Code and Ordinance Worksheet, which is a tool for reviewing the standards, ordinances, and codes that shape how development occurs in a community and how the local rules compare to the principles of better site design. In addition, the USEPA has produced a series of documents on LID. The first in the series is *Low-Impact Development Design Strategies, An Integrated Approach* (1999). This and other LID manuals are at: http://www.epa.gov/owow/nps/urban.html.

The Smart Growth Leadership Institute has conducted code audits for larger scale code and land development standards. These codes are based on concepts related to smart growth and comprehensive planning. To see their worksheet, go to http://www.epa.gov/smartgrowth/scorecards/sglicodeaudit.pdf. Also, the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) developed an audit procedure for code language for its 17 member cities, the Santa Clara Water District, and the County. Visit the "Summary of Findings" link at http://www.scvurppp-w2k.com/compare_contrast.htm (the worksheet begins on page II.14).

Tetra Tech recommends making the ordinance revisions highlighted above, either through a holistic "roundtable process" described in the *Better Site Design Handbook*, or incrementally through text amendments. However, as noted in conversations with staff of many local governments, many LID elements are currently allowed in the local ordinances, but are not encouraged and in some cases discouraged. Therefore, Tetra Tech recommends that each jurisdiction work interdepartmentally—with the Planning, Engineering and Public Works Departments—to resolve issues and remove barriers which are blocking use of the above LID practices.

Below is a checklist, Opportunities for Low-Impact Development Design Techniques, that can be used in the local ordinance review and roundtable discussion process. This checklist is adapted from *Low-Impact Development Design Strategies*, Prince George's County MD; *Better Site Design: A Handbook for Changing Development Rules in Your Community*, Center for Watershed Protection; and *State of North Carolina Model Ordinance for Water Supply Watershed Protection*. In reviewing summaries of roundtable discussions and recommendations for better site design, these are the types of issues that need to be addressed in local ordinances to remove barriers to LID.

Checklist: Opportunities for Low-Impact Development Design Techniques

Clearing and Grading

- Is disturbance of vegetated areas and riparian areas minimized?
- Do the building envelopes avoid sensitive environmental areas such as riparian areas, wetlands, high infiltration soils, steep slopes, etc.?
- Is total site disturbance minimized?

Minimizing Impervious or Built Upon Area

Streets

- For low volume residential roads and streets, are the street pavement widths between 18 to 22 feet?
- Do regulations promote or allow the most efficient street layout to reduce overall street length? This may include revising frontage requirements.
- Can the culs-de-sac radius be 35 feet or less?
- Are landscaped island or bioretention islands allowed or encouraged in culs de sac?
- Are grass swales or bioretention swales used instead of curb and gutter where slopes allow?

Parking/Driveways/Sidewalks

- For office buildings, is the parking ratio 3.0 spaces per 1000 sq.ft. of gross floor area or less?
- For commercial centers, is the parking ratio 2 to 4.5 spaces per 1,000 sq.ft. of gross floor area or less?
- Is a mass transit stop provided or nearby (if applicable)?
- Can a proposed development take advantage of opportunities for shared parking?
- Is the minimum stall width for a standard parking space 9 feet or less?
- Can parking medians (if required) have bioretention cells where feasible?
- Are driveways 9 feet or less in width?
- Are shared driveways used?
- Is on-street parking considered and imperviousness minimized (no on-street or single-side parking where allowed)?
- Are sidewalks (if required) designed to the narrowest allowable width?
- Can developments provide sidewalks on one side of street only?

Clustering Development

- To encourage clustering and open space design, are setbacks minimized (e.g., for residential lots that are ½ acre or less in size is the front setback 20 feet or less, the rear setback 25 feet or less, and the side setback 8 feet or less)?
- Does the design focus development on areas of lesser slopes and farther from watercourses?

Preserving Sensitive Areas

Wetlands

- Are existing wetlands preserved?
- Will the site design minimize hydrologic alteration to existing wetlands?

Steep Slopes

- Does the ordinance encourage or require that building footprints be concentrated on slopes 10 percent or less?
- Is disturbance minimized on slopes 15 percent to 25 percent and revegetation proposed where disturbance occurs?
- Does the ordinance promote preservation of areas with 25 percent or greater slope?

Soils

- Do the building footprints avoid highly erodible soils?
- Do the building footprints avoid soils with high permeability?

Stream Buffer

- Does the ordinance encourage or require that a 50 to 75 foot stream buffer be provided?
- Will the stream buffer remain in a natural state?

Managing Open Space

- Does the ordinance promote or require open space preservation?
- Will the preserved open space be managed in a natural condition?
- Will there be a Homeowners Association or other association that can effectively manage the open space?

After reviewing the summary of roundtable discussions and recommendations from a number of communities, it appears that some of the most challenging issues to reach consensus on include:

- *Residential street and roads widths*. The recommendation for 18 to 22 feet streets widths (for low volume traffic) often conflicts with state minimum road and street design requirements, which are in turn adopted and required by local governments before accepting a street for public maintenance. Fire departments also object to the narrower streets because they believe they are not wide enough for fire trucks to navigate.
- *Culs-de-sac.* The recommendation that a cul-de-sac have a radius of 35 feet or less can conflict with state DOT standards. For example PennDOT requires use of a circular turn around with a 40-foot minimum radius in order for municipalities to receive state funding. This standard is related to transport of liquid fuels.
- *Use of grass swales and bioretention areas rather than curb and gutter*. The major objection to this recommendation comes from local engineering and public works departments that are concerned about the maintenance of the swales and street edges and the use of swales on steeply sloped areas.
- *Use of one sidewalk rather than two.* Planning departments often object to this ordinance revision because they believe it conflicts with their goal of providing walkable communities.
- *Reducing residential setback and frontage requirements to encourage cluster development*. Planning Departments are concerned that the reduced setback/frontage requirements would be incompatible with exiting neighborhoods built under traditional subdivision requirements.

Clearly, in many cases, state DOT standards will need to be addressed in order for local governments to eliminate barriers in their ordinances related to street design. In most cases, the resistance to ordinances changes arises from competing local government departmental objectives and concerns. The planning, public works, and fire departments have to resolve these internal issues to determine the extent to which LID techniques can be incorporated into the subdivision and zoning ordinances and used in the community. For each issue, it will be important to show how other communities have overcome barriers through creative design, construction standards, approval process requirements, etc.

Appendix D: LID Grant Solicitation Draft Language and Evaluation Criteria

PURPOSE

This section includes language that could be used in a grant solicitation or request for proposals (RFP) to encourage implementation of LID at the local level. Two types of projects are envisioned: planning projects for municipalities to audit and update codes and ordinances that allow or encourage LID, and implementation projects in which communities would install LID features as part of capital improvements. Included in this grant solicitation language is a checklist for communities to quantify the extent to which codes and ordinances allow, encourage, or require LID and related measures. This checklist and other details of the grant solicitation language are intended to divide the grant applicants into categories based on progress achieved thus far. Ultimately, this solicitation language would reward communities that have already audited and updated codes and ordinances, while still providing an opportunity for financial support to communities who would like to implement code and ordinance changes but may not have had the impetus or resources in the past. Note that additional details, such as criteria and a ranking system to evaluate proposed implementation projects, would need to be included before a solicitation of this type is issued.

APPLICABLE PROJECTS

Grants under this type of solicitation would be for two types of projects: (1) planning projects that will bring about changes in codes and development of LID performance standards, and (2) implementation projects, namely capital improvement projects that have one or more LID components.

Planning Projects

These projects will involve performing a detailed audit (see Appendix A) of all zoning and development-related codes to identify conflicts with LID principles, or conducting studies to establish at the local level where barriers or long-standing practices have been identified and prevent adoption of LID (e.g., a parking utilization study). The result will be to revise code language and develop stormwater performance standards for new and redevelopment projects. Additional planning projects can include development of a performance standard for LID techniques or development of an active monitoring program for LID practices.

Implementation Projects

These projects will require that one or more LID practices be incorporated into a capital improvement project. Alternatively, the project may involve the retrofit of an existing municipal property with one or more LID practices. Examples of LID practices include porous pavement, ecoroofs, bioretention, downspout disconnection, conversion of impervious surfaces to pervious surfaces, regrading and amending soils for enhanced stormwater capture, and other integrated stormwater management techniques.

EVALUATION CRITERIA

To be evaluated for an award, applicants are required to perform a self-audit of local codes and standards using the checklist included in Appendix A. For each affirmative answer, applicants should provide a citation for the applicable development code or standard (page, section, or line number).

Eligibility

Applicants will be eligible for grant funding for planning or implementation projects based on the self-audit responses as follows:

Score of 0 to 10 points:

Applicants that score between 0 and 10 points on the self-audit are not eligible for implementation project grants. However, they are eligible for a grant to revise codes/ordinances and develop guidelines to increase their self-audit score to 15.

Score of 11 to 24 points:

Applicants that score between 11 and 24 points are eligible for implementation project grants with the condition that they revise codes/ordinances and develop guidelines to increase their self-audit score to 25.

Score of 25 or more points:

Applicants who score 25 or more points on the self-audit are eligible for an LID implementation project grant without conditions.

For planning assistance, applicants must submit a letter of good faith from the planning director or other municipal executive stating that they support code revision and standards development as proposed in the grant application.

Project Merit

Grant applications will be assessed based on project merit. In your grant application, please describe the following for each type of project:

Planning Projects:

Describe proposed changes to codes and standards to improve the self-audit score to the required minimum. List code/standard language that is in conflict with LID and discuss possible changes to remove conflicts. Describe studies that might be needed to obtain stakeholder buy-in, such as parking utilization studies or demonstration projects with emergency responders. Describe the administrative process to implement changes, including the process through which stakeholders (other municipal departments, citizen groups, developers, etc.) will be involved.

Implementation Projects:

Describe the capital improvement project and identify the LID component(s) to be incorporated. Identify the waterbody or waterbodies affected by stormwater runoff from the site and discuss how the LID features will address recognized pollutants of concern for the waterbody or waterbodies. Estimate reductions in directly connected impervious surfaces that result from LID practice implementation. Describe how the LID project fits into the larger watershed management system. Outline a plan to assess the performance of the project over the long term, and identify whether monitoring will be performed as part of this assessment. Describe how maintenance of the LID project will be assured over the long term.

Applicants proposing planning and implementation projects must submit descriptions for both project types as described above.

LOW IMPACT DEVELOPMENT CODE AND ORDINANCE SELF-AUDIT

To be evaluated for an award, applicants are required to perform a self-audit of local codes and standards using the following checklist. For each affirmative answer, applicants should provide a citation for the applicable development code or standard (page, section, or line number). Applicants will be eligible for grant funding for planning or implementation projects based on the self-audit responses as follows:

Score of 0 to 10 points:	Score of 11to 24 points:	Score of 25 or more points:
Applicants can apply for a grant to revise codes/ordinances and develop guidelines to increase the score to a minimum of 15.	Applicants can apply for a grant to revise codes/ordinances to increase the score to a minimum of 25 and propose an LID implementation project.	Applicants can apply for a grant for an LID implementation project.

A. GENERAL INFORMATION

Name of Applicant: _____

List Citations for Codes/Ordinances Relevant to Stormwater and Smart Growth: _____

_____

_____

_____

B. STORMWATER ORDINANCE

How have post-construction stormwater requirements been incorporated into local ordinances?

- ❑ A stand-alone post-construction stormwater ordinance has been developed (2 points)
- ❑ Post-construction stormwater requirements have been integrated into a development ordinance or another type of ordinance (2 points)
- ❑ Post-construction stormwater requirements were included in several different ordinances (2 points)

Attach copies of the official approval (e.g., letter, meeting minutes) showing adoption of the ordinance(s) by the municipal governing body.

- ❑ Post-construction stormwater requirements are not yet included in local ordinances (0 points)

C. GENERAL PLANS

How has post-construction stormwater management, natural drainage, or low impact development been incorporated into your General Plan?

- ❑ The General Plan has been reviewed and General Plan Elements have been amended to include natural drainage, low impact development, and post-construction stormwater management (2 points)
- ❑ The City/County is in the process of identifying where natural drainage, low impact development, and post-construction stormwater management should be included in the next update of the General Plan (1 point) Date of next General Plan update: _____
- ❑ The City/County has not yet initiated a review of the General Plan for inclusion of natural drainage, low impact development, and post-construction stormwater management (0 points)

D. CODE LANGUAGE

Please review the list of stormwater- and smart growth-related code language and check all that are included in existing codes or ordinances. If a change has been implemented already, provide a section, page, or line reference for the code change. Note this may include zoning codes, specific plans or standards issued by Transportation and Fire Protection Districts.

The items below are scored at 1 point each.

Clearing and Grading

- ❑ Do codes/ordinances regulate the disturbance of vegetated areas and riparian areas? Indicate the extent to which disturbance is limited: _____ (Reference: _____)
- ❑ Do codes/ordinances regulate the total amount of site disturbance? Indicate the extent to which disturbance is limited: _____ (Reference: _____)

Minimizing Impacts of Impervious or Built Area

Streets

- ❑ For low-volume residential roads and streets, are the street pavement widths required to be between 18 and 22 feet? (Reference: _____)
- ❑ Do codes/ordinances promote or allow the most efficient street layout to reduce overall street length? This may include revising frontage requirements. (Reference: _____)
- ❑ Do codes/ordinances allow a cul-de-sac radius to be 35 feet or less? (Reference: _____)
- ❑ Are landscaped islands or bioretention islands allowed or encouraged in culs-de-sac? (Reference: _____)
- ❑ Are LID techniques (e.g., grass swales, bioretention swales, tree planters, etc.) allowed, encouraged, or required to be used instead of curb and gutter where slopes allow? (Reference: _____)

Parking/Driveways

- ❑ Has a parking utilization study been performed and were results incorporated into codes/ordinances? (Reference: _____)
- ❑ Do codes/ordinances provide incentives for shared parking? (Reference: _____)
- ❑ Is the minimum stall width for a standard parking space allowed, encouraged, or required to be 9 feet or less? (Reference: _____)
- ❑ Can parking medians (if required) have bioretention cells where feasible? (Reference: _____)
- ❑ Is porous pavement allowed, encouraged, or required? (Reference: _____)
- ❑ Are driveways allowed, encouraged, or required to be 9 feet or less in width? (Reference: _____)
- ❑ Are shared driveways allowed, encouraged, or required? (Reference: _____)
- ❑ Is imperviousness associated with on-street parking required to be minimized (e.g., no on-street parking, or single-side parking where allowed)? (Reference: _____)

Buildings/Landscape

- ❑ Are green roofs allowed, encouraged, or required? (Reference: _____)
- ❑ Is roof runoff allowed, encouraged, or required to be directed to bioretention planter boxes, bioswales, bioretention cells, or other landscaped/pervious area? (Reference: _____)
- ❑ Are cisterns, rain barrels, or other methods for water reuse allowed, encouraged, or required? (Reference: _____)
- ❑ Has the master landscaping code been revised (or have revisions been initiated) to integrate water conservation, water reuse, and stormwater handling within landscaped areas? (Reference: _____)

Preserving Sensitive Areas

Wetlands/Floodplains

- ❑ Do codes/ordinances require prevention or mitigation of hydrologic impacts on existing wetlands and floodplains? (Reference: _____)
- ❑ Are site designs required to mitigate the impacts of hydrologic alteration to existing wetlands/floodplains by including such areas in stormwater management calculations? (Reference: _____)

Steep Slopes

- ❑ Do codes/ordinances encourage or require that building footprints be concentrated on slopes 10 percent or less? (Reference: _____)
- ❑ Do codes/ordinances require that disturbance be minimized on slopes 15 percent to 25 percent and revegetation proposed where disturbance occurs? (Reference: _____)
- ❑ Do codes/ordinances require preservation of areas with 25 percent or greater slope? (Reference: _____)

Soils

- ❑ Are building footprints required to avoid highly erodible soils? (Reference: _____)
- ❑ Are building footprints required to avoid soils with high permeability (e.g., Soil Conservation Service Soil Group A)?
  (Reference: _____)

Stream Buffers

- ❑ Do codes/ordinances encourage or require a scientifically defensible wetland/riparian buffer setback? (Reference: _____)
- ❑ Do codes/ordinances limit activities (e.g., material storage, mowing, etc.) in wetland/riparian buffer zones?
  (Reference: _____)

Managing Open Space

- ❑ Have local park and open space plans been revised to incorporate stormwater management features into pervious and landscaped areas?
  (Reference: _____)
- ❑ Have codes/ordinances governing open space for multi-family residential development been revised to include on-site water quality and quantity management of stormwater?
  (Reference: _____)
- ❑ Do codes/ordinances encourage or require open space preservation based on a regional or watershed-scale plan?
  (Reference: _____)
- ❑ To encourage clustering and open space design, are setbacks allowed, encouraged, or required to be minimized? (Reference: _____)
- ❑ Do codes/ordinances encourage or require that development be directed to already-developed areas (e.g., infill sites or corridor redevelopment areas)? (Reference: _____)

E. SCORING AND PROJECT CATEGORY

Applicants will be eligible for grant funding for planning or implementation projects as follows:

Score of 0 to 10 points:	Score of 11to 24 points:	Score of 25 or more points:
Applicants can apply for a grant to revise codes/ordinances and develop guidelines to increase the score to a minimum of 15.	Applicants can apply for a grant to revise codes/ordinances to increase the score to a minimum of 25 and propose an LID implementation project.	Applicants can apply for a grant for an LID implementation project.

Total Number of Points: _____

Please Mark the Appropriate Project Category:

❑ Planning (0-10 pts) ❑ Planning/Implementation (11-24 pts) ❑ Implementation (>25 pts)

DESIGN GUIDELINES FOR GREEN ROOFS

by Steven Peck and Monica Kuhn, B.E.S., B. Arch, O.A.A.

ABSTRACT

Green roof infrastructure promises to become an increasingly important option for building owners and community planners. As we move into the 21st century, green roofs can address many of the challenges facing urban residents. Life cycle costing indicates that green roofs cost the same or less than conventional roofing and they are an investment which provides a significant number of social, environmental and economic benefits that are both public and private in nature. These benefits include increased energy efficiency (from cooling in the summer and added insulation in the winter), longer roof membrane life span, sound insulation, and the ability to turn wasted roof space into various types of amenity space for building occupants. Green roofs filter particulate matter from the air, retain and cleanse storm water and provide new opportunities for biodiversity preservation and habitat creation. They generate aesthetic benefits and help to reduce the 'urban heat island effect' - the overheating of cities in the summer which contributes to air pollution and increased energy consumption.. This article provides an introduction to green roof infrastructure and describes how to implement and market a green roof, looks at costs, and presents three case studies.



Fig. 1– Pelgromhof Senior's Residence Green Roof Amersfort, Netherlands
Photograph courtesy of S. Marshall

Ontario Association of Architects

CMHC SCHL

HOME TO CANADIANS
Canada

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LEARNING OBJECTIVES

After reading this article you should understand:

1. The elements of a green roof
2. How to select the type of green roofs you should employ on your project
3. The public and private benefits and costs of green roofs
4. The important technical issues which must be addressed
5. Maintenance issues which ensure longevity
6. Detailed cost variables for green roofs
7. The potential of green roofs through several case studies

1.0 BACKGROUND

Green roofs are not a new phenomenon. They have been standard construction practice in many countries for hundreds, if not thousands, of years, mainly due to the excellent insulative qualities of the combined plant and soil layers (sod). In the cold climates of Iceland and Scandinavia sod roofs helped to retain a building's heat, while in warm countries such as Tanzania, they keep buildings cool. Canadian examples of early green roofs, imported by the Vikings and later the French colonists, can be found in the provinces of Newfoundland and Nova Scotia.



Fig. 2 – French Fisherman's Cottage
Fort Louisbourg, Nova Scotia, Canada
Photograph courtesy of M. Kuhn

Two modern advocates of green roof technology were the architects Le Corbusier and Frank Lloyd Wright. Although Le Corbusier encouraged rooftops as another location for urban green space, and Wright used green roofs as a tool to integrate his buildings more closely with the landscape, neither was aware of the profound environmental and economic impact that this technology could have on the urban landscape.

Until the mid-20th century, green roofs were viewed mainly as a vernacular building practice. However in the 1960's, rising concerns about the degraded quality of the urban environment and the rapid decline of green space in urban areas, renewed interest in green roofs as a "green solution" was sparked in Northern Europe. New technical research was carried out, ranging from studies on root-repelling agents, membranes, drainage, lightweight growing media, to plant suitability.

In Germany, the green roof market expanded quickly in the 1980's, with an annual growth rate of 15-20%, ballooning from one to ten million square metres. This growth was stimulated largely by state legislation, municipal grants and incentives of 35-40 Deutsch Marks/m^2 of roof greened.[3] Other European states have adopted similar types of support. Several cities now incorporate roof greening into regulations. Stuttgart, for example, requires green roofs on all new flat-roofed industrial buildings.[4] Vienna also provides subsidies and grants for new green roofs at the stages of planning, installation and 3 years post construction to ensure ongoing maintenance. Over 75 European municipalities currently provide incentives or requirements for green roof installation. A key motivator for this support has been the public benefits of storm water runoff reduction, air and water quality improvements. As a result, a new sector in the construction industry has been created, and green roofs have become a common feature in the urban landscape.

Canada and the United States are at least ten years behind Europe in investing in green roof infrastructure as a viable option for solving many quality of life challenges facing our cities. During the early 1990's several large European green roof manufacturers started to venture into the North American markets. However, the systems were hard to sell without public education, local research on technical performance, and accessible examples, especially in a cultural and political climate where many individuals, businesses, and governments do not readily invest in green technologies. This has started to change.

In Canada, landscape architect Cornelia Hahn Oberlander, architects Doug Pollard and Charles Simon, and engineers Greg Allen and Mario Kani, are some of the people who have helped to establish the first green roofs. These include the Boyne River Education Centre in Southern Ontario and Robson Square in Vancouver. More recently, a volunteer group called the *Rooftop Gardens Resource Group* and an industry group called *Green Roofs for Healthy Cities* have been working to develop the green roof market in North America. They provide information, implement demonstration projects and conduct technical research to show the benefits of this technology.

A partnership of the National Research Council's Institute for Research in Construction (IRC), Environment Canada , the City of Toronto, and *Green Roofs for Healthy Cities* has spearheaded research projects in Toronto, including the publicly-accessible roof of the City Hall.

At Laval University in Quebec, the roofing company Soprema is studying plant survivability in support of its Sopranature green roof product. A flurry of green roof-related research and demonstration activity is underway in Chicago, Portland, Winnipeg, and Ottawa. At IRC's Ottawa facilities a roof has been retrofitted to determine more detailed technical data on the performance of green roofs in areas such as energy efficiency and membrane life extension among others.

1.1 INTENSIVE AND EXTENSIVE GREEN ROOFS

A green roof is a green space created by adding layers of growing medium and plants on top of a traditional roofing system. This should not be confused with the traditional roof garden, where planting is done in freestanding containers and planters, located on an accessible roof terrace or deck. The layers of a contemporary green roof system, from the top down, include:

- the plants, often specially selected for particular applications,
- an engineered growing medium, which may not include soil,
- a landscape or filter cloth to contain the roots and the growing medium, while allowing for water penetration,
- a specialized drainage layer, sometimes with built-in water reservoirs,
- the waterproofing / roofing membrane, with an integral root repellent, and
- the roof structure, with traditional insulation either above or below.

The two basic types of green roof systems - extensive and intensive - are differentiated mainly by the cost, depth of growing medium and the choice of plants.

Extensive green roofs are often not accessible and are characterized by:

- low weight,
- low capital cost,
- low plant diversity, and
- minimal maintenance requirements.

The growing medium, typically made up of a mineral-based mixture of sand, gravel, crushed brick, leca, peat, organic matter, and some soil, varies in depth between 5-15 cm (2-6") with a weight increase of between 72.6-169.4 kg / m^2 (16-35 lbs/sf) when fully saturated.[1] Due to the shallowness of the growing medium and the extreme desert-like microclimate on many roofs, plants must be low and hardy, typically alpine, dryland, or indigenous. Typically the plants are watered and fertilized only until they are established, and after the first year, maintenance consists of two visits a year for weeding of invasive species, safety and membrane inspections.[2]

Intensive green roofs are often accessible and are characterized by:

- deeper soil and greater weight,
- higher capital costs,
- increased plant diversity, and
- more maintenance requirements



Fig. 3 – Mountain Equipment Co-op Toronto, Ontario, Canada
Soprema System of Roofing, Curb, Drainage Layer, Filter Cloth and Bagged Growing Medium
Photograph courtesy of M. Kuhn
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The growing medium is often soil based, ranging in depth from 20–60 cm (8-24"), with a saturated weight increase of between 290 - 967.7 kg/m^2 (60-200 lbs/sf). Due to the increased soil depth, the plant selection is more diverse and can include trees and shrubs, which allows for the development of a more complex ecosystem. Requirements for maintenance - especially watering - are more demanding and ongoing, and irrigation systems are usually specified. Structural and horticultural consultation and an experienced installer are recommended.

It should be noted that, depending on such site specific factors as location, structural capacity of the building, budget, client needs, and material and plant availability, each individual green roof will be different, likely a combination of both intensive and extensive systems. Table 1 summarizes the advantages and disadvantages of extensive and intensive green roof systems.

Table 1: Comparison of Extension and Intensive Green Roof Systems

EXTENSIVE GREEN ROOF	INTENSIVE GREEN ROOF
• Thin growing medium; little or no irrigation; stressful conditions for plants; low plant diversity.	• Deep soil; irrigation system; more favorable conditions for plants; high plant diversity; often accessible.
Advantages: • Lightweight; roof generally does not require reinforcement. • Suitable for large areas. • Duitable for roofs with 0 - 30° (slope). • Low maintenance and long life. • Often no need for irrigation and specialized drainage systems. • Less technical expertise needed. • Often suitable for retrofit projects. • Can leave vegetation to grow spontaneously. • Relatively inexpensive. • Looks more natural. • Easier for planning authority to demand as a condition of planning approvals.	**Advantages:** • Greater diversity of plants and habitats. • Good insulation properties. • Can simulate a wildlife garden on the ground. • Can be made very attractive visually. • Often accessible, with more diverse utilization of the roof. i.e. for recreation, growing food, as open space. • More energy efficiency and storm water retention capability. • Longer membrane life.
Disadvantages: • Less energy efficiency and storm water retention benefits. • More limited choice of plants. • Usually no access for recreation or other uses. • Unattractive to some, especially in winter.	**Disadvantages:** • Greater weight loading on roof. • Need for irrigation and drainage systems requiring energy, water, materials. • Higher capital & maintenance costs. • More complex systems and expertise.

Source: adapted from: "Greenbacks from Green Roofs: Forging a New Industry In Canada," CMHC. 1998.



Fig. 4– Queen's Quay Terminal Toronto, Ontario, Canada
Green Roof Courtyard with Skylights Architect: Zeidler Roberts
Photograph courtesy of M. Kuhn

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2.0 SELLING THE CONCEPT - BENEFITS

One of the most valuable features of green roof infrastructure is that it generates a wide range of social, economic and environmental benefits, both public and private. Many of these are still being qualified in different North America climate zones through both field tests and the use of modeling. Since each green roof installation is unique, the key to success is finding the right mix of benefits for a particular client and for their project. The following describes some of the selling points of green roofs.

2.1 PRIVATE / BUILDING OWNER BENEFITS

2.1.1 ENERGY SAVINGS

In the summer, green roof planting shades the building from solar radiation and, through the process of evapotranspiration, can reduce, if not eliminate any net heat gain. This in turn helps to cool the surrounding area, as well as decreasing the amount of energy required to cool the building.

In the winter, the additional insulation provided by the growing medium helps to decrease the amount of energy required to heat the building. The extent of the energy cost savings impact is a function of:

- the size of the building,
- its location,
- the depth of the growing medium, and
- the type of plants and other variables.

Modeling research suggests that the reduced need for air conditioning in the summer is more substantial than the value of the added insulation in the winter. Building type is a key factor in determining overall cost savings. For example in one or two storey complexes where the roof is a large portion of the building envelope, the cooling energy savings in the summer have been modelled as high as 25%.[5] A 20 cm (8") layer of growing medium and a thick layer of plants has a combined insulative value of RSI 0.14 (R20).[6] Even when the growing media freezes, studies show that 30 cm (12") of growing medium will not experience temperature drops below 0° C (32° F), even when outside temperatures are, -20°[7] Depending on the climate zone, the implementation of a green roof may also allow for a reduction in the requirements for traditional insulation. IRC and Environment Canada research is working to develop a model that will more accurately predict the energy efficiency gains of various green roof systems on different building types.

2.1.2 ROOF MEMBRANE PROTECTION AND LIFE EXTENSION

Green roofs help to protect roofing membranes from extreme temperature fluctuations, the negative impact of ultraviolet radiation, and accidental damage from pedestrian traffic. European evidence indicates that green roofs will easily double the life span of a conventional roof, and thus decrease the need for re-roofing and the amount of waste material bound for landfill. These are direct operational cost savings for the building owner. Life cycle costing data which includes the cost of deferred maintenance and replacement suggests that green roofs cost the same or less than conventional roof systems.

2.1.3 SOUND INSULATION

Green roofs can be designed to insulate for sound, with the growing medium blocking lower frequencies of sound, and the plants blocking the higher frequencies. Tests show that 12 cm (5") of growing medium alone can reduce sound by 40 db.

2.1.4. FIRE RESISTANCE

There is evidence from European manufacturers suggesting that green roofs can help slow the spread of fire to and from the building through the roof, particularly where the growing medium is saturated. However, the plants themselves, if dry, can present a fire hazard. Similar to preventing grass fires at grade, the integration of "fire breaks" at regular intervals across the roof, at the roof perimeter, and around all roof penetrations is recommended. These breaks would be made of a non-combustible material such as gravel or concrete pavers, 60 cm (24") wide, and located every 40 m (130 feet) in all directions. Other options would be the use of "fire retardant plants", such as sedums, which have a high water content, or a sprinkler irrigation system connected to the fire alarm.

2.1.5 ADDITIONAL BENEFITS

There are many specialized applications that justify additional capital expenditures for a green roof, depending on which jurisdiction the building is located in and the occupancy. For example, accessible green roofs, which provide added amenity space for the occupants, can help to increase the unit value of condominiums. In addition to the increased marketability of office or residential suites for buyers, the installation of a green roof may also help gain planning approval for projects from local building officials, community members, and rate payers associations.

Public housing agencies can provide senior citizens and families with safe, accessible green space on top of housing projects, as well as improving their quality of life. School boards can integrate curricula and provide added green space for students – outdoor rooftop classrooms. A project to demonstrate this type of application in under development with Toronto Hydro Energy Services, Toronto Catholic School Board and *Green Roofs for Healthy Cities*. Governments generate publicly accessible park space on top of parking garages, like the new Roundhouse Park in downtown Toronto. It sits above the garage of the new convention centre. Even inaccessible green space on top of commercial buildings in residential areas has significant aesthetic value and may help to speed up the approvals process for new projects.



Fig. 5 – Mountain Equipment Co-op, Toronto, Ontario, Canada
Toit vert
Photographs courtesy of M. Kuhn



Fig. 6 – Roundhouse park, Toronto, Ontario, Canada
Green roof at grade

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Hospitals and other health care facilities provide opportunities for horticultural therapy, a proven method of speeding recovery rates and reduction of drug use. A horticultural therapy green roof is currently planned for the roof of a head injury recovery centre in Northern Toronto.

Industrial buildings incorporate specialized green roofs for cooling, to provide amenity space for employees, or simply to improve the aesthetic surroundings for buildings that overlook the roof. Ecover Inc. is a Belgian manufacturer of biodegradable laundry products. Their 1992 factory, has a two-acre green roof with native grasses and wildflowers. Effluent produced by the factory is treated in an on-site sewage pond at grade and then filtered through the green roof, while at the same time acting as irrigation and nutrient source for the plants.

Green roofs are also be designed to generate urban agricultural opportunities for the production of high quality organic foods, and medicinal and ornamental plants. This has the advantage of reducing associated transportation and refrigeration costs, reducing the time and distance from field to table, ensuring ripeness at harvest, and providing new employment opportunities for city dwellers.

2.2 PUBLIC BENEFITS

Although green roofs provide many private benefits, European incentives and legislation for implementation are designed to promote the public benefits of these systems. The two most important of these public benefits are the reduction of the *urban heat island effect* and improved *storm water retention.*



Fig. 7 – Hazelburn Co-op, Toronto, Ontario, Canada
Rooftop Garden
Photograph courtesy of M. Kuhn

2.2.1 URBAN HEAT ISLAND EFFECT

The urban heat island is the overheating of urban and suburban areas, relative to the surrounding countryside, due to increased paved, built-over, and hard surface areas. Average summer temperatures in major cities across North America have been on the rise over the past decade. These artificially high summer temperatures have a range of direct and indirect negative impacts on our quality of life.

The urban heat island effect increases the use of more electricity for air conditioners and it increases the rate at which chemical processes generate pollutants such as ground level ozone. It also exacerbates heat-related illnesses. Green roofs intercept the solar radiation that would strike dark roof surfaces and be converted into heat, thereby improving energy conservation. Like urban forests and reflective roofing surfaces they absorb and/or deflect solar radiation so that it does not produce heat.

An ASHRAE simulation conducted by the City of Chicago of their City Hall green roof showed that every one degree Fahrenheit decrease in ambient air temperature results in a 1.2% drop in cooling energy use. The study suggests that if, over a period of ten years or more, all of the buildings in Chicago were retrofitted with green roofs, (30% of the total land area), this would yield savings of $100,000,000 annually from reduced cooling load requirements in all of the buildings in Chicago. The cooling would also slow the chemical processes that produce ground level ozone, nitrous oxides and smog, and help offset the production of sulphur dioxides from coal fired utilities.[8]

2.2.2 STORM WATER RETENTION

Green roofs can be designed for exceptional storm water retention capability. The plants capture and hold rainwater. Water stored in the growing media is released through evaporation and evapo-transpiration. Storm water retention rates are determined by saturated infiltration capacity, thickness of the growing media, field capacity, porosity, under-drainage layer water retention and flow, and relief drain spacing. A heavily vegetated green roof with a 20-40 cm (8-16") thick growing medium can hold between of water 10-15 cm (4-6").[9] A storm-water retention study for the City of Portland, Oregon found that if half of the buildings in the downtown area had green roofs, (219 acres), an estimated 66 million gallons of water would be retained annually. This would eliminate combined sewage overflows by 17 million gallons.[10] The study indicated that storm water discharges would be reduced between 11 and 15%.

Where jurisdictions demand lot-level storm water charges, zero runoff policies, or a requirement for storm water management ponds, this ability to retain storm water may result in direct and indirect financial incentives. In Germany, 13 municipal governments allow for a reduction in storm water charges for green roof installations. This type of measure is being considered in several North American cities. Portland, Oregon has recently adopted an incentive which awards a density bonus of 3 square feet for every square foot of green roof installed, provided that 60% of the roof area is greened.

2.2.3 AIR CLEANING

Green roofs also filter out fine, airborne particulate matter as the air passes over the plants. Airborne particulates tend to get trapped in the surface areas of the greenery. Rain washes it into the growing medium below. Plants also absorb gaseous pollutants through photosynthesis and sequester them in their leaves (later to become humus).[11] Studies show that treed urban streets have 10-15% fewer dust particles than found than similar streets without trees.[12] In Frankfurt Germany, for example, a street without trees had an air pollution count of 10-20,000 dirt particles per litre of air and a treed street in the same neighborhood had an air pollution count of less than a third of that amount.[13] Based on data from trees, one estimate suggests that a grass roof with 2,000 m^2 of unmown grass (100 m^2 of leaf surface per m^2 of roof) could cleanse 4,000 kg of dirt from the air per year (2 kg per m^2 of roof). This estimate, is probably high since the lower portion of the grass layer is too dense to be in direct contact with the air. However, even if the amount were 1/10th of what trees could remove, 10 m^2 of grass roof could still take out the significant amount of 2 kg of dirt every year.[14]

2.2.4 CREATION OF HABITAT

Green roofs can be designed as acceptable alternative habitats for some species, although they should never be considered as a justification to destroy natural habitat at grade.[15] In Europe, two types of green roof habitats have been defined and implemented, as part of a larger system of wildlife corridors in urban areas. The first is a "stepping stone" habitat that connects natural isolated habitat pockets with each other. It is important to remember that this connection can be by air only (nesting and migrating birds, insects, airborne seeds). The second is an "island" habitat that remains isolated from habitat at grade. This type of habitat would be home to selected plant varieties whose seeds are not spread by air or over short distances.

Green roofs can also be specifically designed to mimic endangered ecosystems / habitats, including the prairie grasslands of the midwest United States or the rocky alvars of Manitoulin Island and the Great Lakes Region in Canada.[16] Extensive green roofs, with their lack of human intervention, are more protected and can become home to sensitive plants that are easily damaged by walking, and to birds species that only nest on the ground. Since the soil on an inaccessible green roof is also less likely to be disturbed, it becomes a safer habitat for insects as well. The deeper the soil the more insect diversity the green roof will support.

3.0 DESIGN & IMPLEMENTATION CONSIDERATIONS

The design and implementation of a green roof project is relatively straight forward, provided the following issues are considered and dealt with. It should be noted that just as each site, each building, each building owner, and each end user is different, so each individual green roof project will vary from the next.

3.1 USE

The primary functions a specific green roof is required to perform will have a profound effect on its overall design. For example, a green roof designed to retain storm water may look very different from one whose main purpose is to brighten a hospital courtyard. Along with the question of aesthetics are inherent differences in the required depth of growing medium, the ongoing maintenance program, and overall cost. This is not to say that a green roof designed to retain storm water cannot or should not also be aesthetically pleasing. Indeed, it can be both, but limiting factors in the budget or the building structure, among others, may concentrate the focus on one or another of these functions.

3.2 LOCATION

Location of the green roof plays an important role in the design process. The height of the roof above grade, its exposure to wind, the roof's orientation to the sun and shading by surrounding buildings during parts of the day will have an impact. The general climate of the area and the specific microclimate on the roof must also be considered. Views to and from the roof may also determine where certain elements are located for maximum effect.

3.3 CONSULTANTS

Selection of professional consultants depends on the function of the green roof, the size of the project, the location of the project, and the green roof experience of the primary consultant and / or project instigator. A structural engineer may be required to determine the existing, or required, loading capacity of the roof. An architect may be required to co-ordinate the project as well as the design and detailing of the building and roof, including material specifications. A landscape architect may be required for the layout of the planting areas and the selection of the plants. A mechanical engineer may be required to calculate the heating and cooling implications of the green roof, and to discuss integration with existing and proposed rooftop mechanical equipment and drainage needs. Depending on the primary function of the green roof, specialist consultants may also include a horticulturalist; a horticultural therapist; an ecologist or biologist; a roofing consultant; a planner; an artist; and marketing / advertising professionals.

3.4 THE REGULATORY APPROVALS PROCESS

Development of a property, for a new building or in a retrofit situation, often requires a certain percentage of green space, depending on the site location and the occupancy of the building. Local planning and zoning may qualify a green roof as green space or landscaped open space. This could permit the developer to use more of the property at grade, or to qualify for a density bonus. If the green roof is accessible to tenants, it may also qualify as an amenity space for that building, with no loss of gross floor area within the building envelope. In the future, green roofs may become a requirement for certain building types, or a source of yearly tax credits for retention of storm water runoff from the site. In the meantime, a proposed green roof may be used as a consideration on environmentally sensitive sites or with environmentally sensitive community groups. Please note that the regulations within each municipality are different and should be investigated with local planning and zoning officials.

Although they are not specifically mentioned in the 1997 Ontario Building Code or the National Building Code, green roof systems are considered an extension of the roof system, and therefore must comply with requirements for structural loading and moisture protection. If the green roof is accessible for more than routine maintenance - in other words, if tenants or the public use the roof as an accessible outdoor green space - then the design must also comply with requirements for occupancy, exiting, lighting, guardrails, and barrier free access. This is not to say that a green roof project will be accepted without question provided that it conforms to the building code. Many of the plans examiners at the various building departments have never heard of this concept, let alone approved the plans for one, so an application for permit will often require an education component, along with a package of background information and test reports from product manufacturers and suppliers. Building codes vary from province to province so you should check the specific requirements prior to proceeding with a project.

3.5 STRUCTURE

Additional loading is one of the main factors in determining both the viability and the cost of a green roof installation. If a green roof is part of the initial design of the building, the additional loading can be accommodated easily and for a relatively minor cost. However, if a green roof is installed on an existing building, the design will be limited to the carrying capacity of the existing roof, unless the owner is prepared to upgrade the structure, which can be a significant investment.

Typical wet soil weighs approximately 1,597 kg per cubic metre (100 lbs per cubic foot). This is a lot, considering that in Ontario, Canada, existing roofs are typically designed for a live load of only 40 lbs per square foot (195 kg per square metre), which includes the snow load. The green roof industry has responded by developing various types of lightweight growing media. The green roof on the new library in Vancouver, British Columbia, Canada, has a 35.6 cm. (14") layer of lightweight substrate made up of sand, pumice, and compost. This weighs only 292.6 kg per square metre (60 lbs/sf) when fully saturated and did not require structural upgrading beyond the standard requirements of the British Columbia Building Code.[17]

Recent editions of the Ontario Building Code have changed requirements for snow loading. In areas like Toronto, a general snow load of only 107 kg per square metre (22 lbs/sf down from 40lbs in earlier editions) must be accommodated on the roof, with capacity for higher snow loading required only in specific areas on the roof which are subject to drifting and build-up.

This leaves 88 kg per square metre (18 lbs/sf) for a green roof installation, - enough for a simple extensive system. On inverted roof applications, where the waterproofing membrane has been applied underneath the loose-laid insulation and a layer of ballast, usually gravel or concrete pavers, the green roof can be used to replace the ballast, thereby effectively allowing an increase in the load bearing capacity of the roof by eliminating the dead load of the ballast material. A thorough analysis of the roof structure may also reveal areas where point loading can be increased - perhaps over a column or along a bearing wall, thus allowing for a combination extensive and intensive system (semi-extensive), with specific areas for deeper growing medium and larger plants. Please note that owners, tenants, and building managers should be made aware of the roof's loading restrictions, through a plan or as a part of a maintenance manual, to avoid future improper relocation or additional plantings in areas which cannot accommodate the weight.

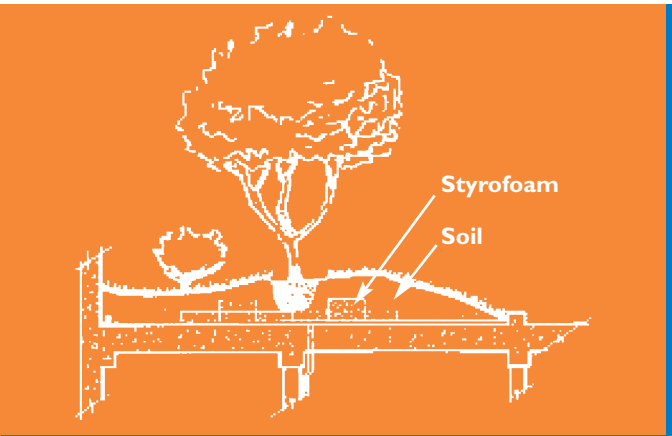
3.6 ACCESS AND EXITS

Access to the green roof site is crucial - not only for installation and ongoing maintenance, but also for bringing up materials, soil and plants. With a new building, the design of internal stairs or an extra elevator stop in the planning stages is easy and relatively inexpensive; to retrofit an existing building can become costly. Where an elevator does not go to the roof, material will have to be transported by hand up stairs and utility ladders, or hauled up with a crane, both of which can result in additional labour and equipment costs. An interior ladder or staircase may be safer than one attached on the outside of the building, and access through a "man door" is preferable to a small roof hatch. If the green roof is designed for use by tenants or the general public, then questions of access and of exiting are taken to another level altogether, from mere convenience to strict standards of safety and security as regulated by the local Building Codes.

3.7 ROOFING

One of the most important components of the green roof system is the waterproofing/roof membrane. For an existing building, the membrane should be carefully inspected to determine if it needs to be repaired or replaced before the installation. Many manufacturers of green roof systems will not provide a warranty on the green roof system if new membranes are not applied. The normal 10-15 year reroofing cycle provides a window of opportunity to investigate the potential of applying a longer lasting green roof.

Green roofs can be applied on inverted or traditional roofing systems. If the existing system is inverted, then one needs to determine whether the insulation can be replaced by an equivalent R- value of growing medium. If the insulation is to remain, then good drainage must be ensured to prevent continuous contact with water, and subsequent damage.



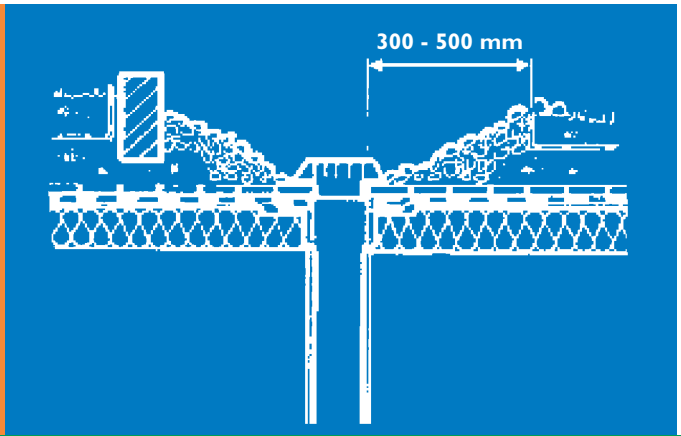


Fig. 8 – Deep Soil over Structural Column **Fig. 9 – Gravel Skirt and Vegetation Barrier Around Roof Drain**

Illustrations courtesy of R. Hippolite, based on Grundlagen der Dachbegruenung, Patser Verag, Berlin, 1989.

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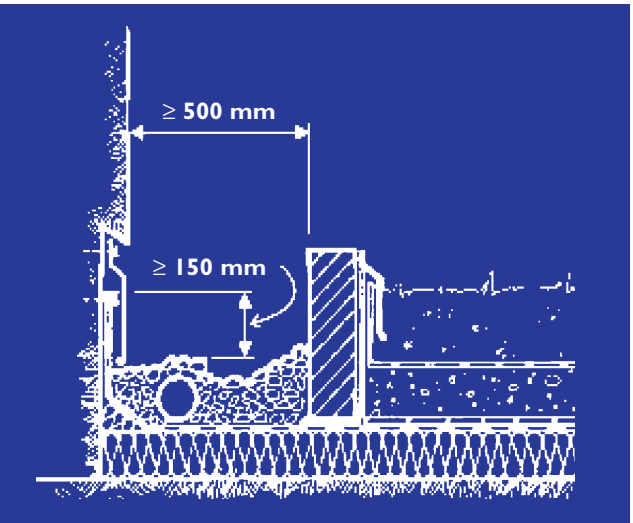
If the membrane, existing or new, contains bitumen or any other organic material, it is crucial to maintain a continuous separation between the membrane and the plant layer, since the membrane will be susceptible to root penetration and micro-organic activity. Some of the new membranes developed specifically for green roof applications, although still bituminous, now contain a root-deterring chemical or metal foil between the membrane layers and at the joint/seam lines to prevent root damage. The chemical makeup of the membrane must also be compatible with the system components with which it will be in direct contact.

Although the green roof will retain much of the rain that falls on it, maintaining proper drainage on the roof is still very important. Parapets, edges, flashing, and roof penetrations made by skylights, mechanical systems, vents, and chimneys must be well protected with a gravel skirt and sometimes a weeping drain pipe. If the drainage layer is too thin or if the routes to the roof drains become blocked, leakage of the membrane may occur, due to continuous contact with water or wet medium. The growing medium itself may sour, causing the plants to drown or rot.

On a roof slope greater than 20 degrees, the green roof installer needs to ensure that the sod or plant layer does not slip or slump through its own weight, especially when it becomes wet. This can be prevented through the use of horizontal strapping, wood, plastic, or metal, placed either under the membrane, or loose-laid on top. Support grid systems for green roofs have been designed by some green roof manufacturing companies specifically for this application.

3.8 PLANTS

Location, wind, rainfall, air pollution, building height, shade, and soil depth are all factors in determining what plants can be grown and where. The ability of plants to survive on a green roof is directly proportional to the amount of maintenance time and budget allocated to the project, particularly in the first two years when they are getting established. Climatic conditions on a rooftop are often extreme. Unless one is willing to provide shading devices, irrigation, and fertilization, the choice of planting material should be limited to hardier or indigenous varieties of grasses and sedums. Root size and depth should also be considered in determining whether the plant will stabilize in 10 cm (4") or in 60 cm (24") of growing medium. It is vital to know where the plants were previously grown and if the growing conditions were comparable to the ones on the roof to ensure their ability to adapt and flourish. Typically, extensive green roofs rely on a mixture of grasses, mosses, sedums, sempervivums, festucas, irises, and wildflowers - plants that are native to drylands, tundras, alvars, and alpine slopes. On an intensive green roof, with few exceptions, the choices are limitless.



3.9 CONSTRUCTION/INSTALLATION

Be aware of installation issues. The installers should have experience with green roof systems. In fact, it may be preferable to have one company handle the whole project, from re-roofing to planting, thus avoiding scheduling conflicts and damage claims between the various trades. It will also bring single point responsibility post-construction. Methods for getting the materials up to the roof should be discussed to determine cost and potential equipment rentals. Timing is also important.

Fig. 10 – Flashing and Gravel Barrier with Drainage Pipe at a Wall/Roof Connection
Illustration courtesy of R. Hippolite, based on Grundlagen der Dachbegruenung, Patser Verag, Berlin, 1989.

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Depending on the local climate, planting in high summer requires extra irrigation to get the plants through the heat before they are established. Fall planting will depend on the availability of suitable plant stock and time enough to allow for the plants to get established before the cold weather sets in. Some plants can be installed while dormant. If you prepare everything in the fall for spring planting there may be some erosion of the growing medium through winter wind and runoff. Covering the roof with burlap or some other material could reduce this problem. Compartmentalization of the green roof into sections may allow for easier access to the membrane and the roof drains, for inspection and maintenance, without having to pull up the whole installation.

3.10 MAINTENANCE

Both plant maintenance and maintenance of the waterproofing membrane are required. Depending on whether the green roof is extensive or intensive, required plant maintenance will range from two to three yearly inspections to check for weeds or damage, to weekly visits for irrigation, pruning, and replanting. To ensure continuity in the warranty and the upkeep, it is recommended that the fees for three to five years of this service be included in the original bid price, and that maintenance contracts be awarded to the company that installed the green roof, or to an affiliate. Intensive systems typically require more maintenance than extensive systems due to the greater diversity of plants.

Maintenance and visual inspections of the waterproofing membrane can be complicated by the fact that the green roof system completely covers the membrane. Although the green roof protects the membrane from puncture damage and solar radiation, doubling its lifespan, leaks can still occur at joints, penetrations, and flashings, due more to sloppy installation than to material failure. Regular maintenance inspections should be scheduled as for a standard roof installation, especially just before the warranty period expires. Some companies are recommending the incorporation of an electronic leak detection system between or underneath the waterproofing membrane to pinpoint the exact location of water leaks. Access strategies include keeping the sensitive areas free of plants and growing medium (gravel skirts, etc), and dividing the green roof into distinct compartments for ease of removal. Eventually, after 30-50 years, the membrane will have to be replaced. Depending on the roof size, building height, type of planting, and depth of growing medium, the system will either be removed and reinstalled over the new membrane, or replaced entirely. If the green roof can be removed and stored on the roof while the membrane is being replaced in sections, then the additional cost is "labour" only, and comparable to the original installation cost; if the green roof has to be moved off the roof, and then brought back up, costs will increase accordingly, and the arguments for starting fresh, with new growing medium and plants, become more convincing.

3.11 INSURANCE & LIABILITY

Building insurance should not increase with the addition of a green roof, unless it is made accessible for tenant or public use. All manufacturers of green roof products will provide a warranty for their products as long as they are installed as per the manufacturer's specifications. This sense of security can be a selling feature for some clients, especially institutions, even though the price is typically higher than combining individual "off-the-shelf" products which perform the same function but were not specifically designed for use in a green roof applications. If cost is a concern, then the only warranty or guarantee available for this "combining of products" will likely be related to the installation itself, and not the performance of the products.

4.0 DETAILED COST ESTIMATES AND VARIABLES

Although all green roof systems share common components, there are no standard costs for implementation. The two tables below give a range of component costs and identify some of the key variables that determine those costs.

4.1 INACCESSIBLE EXTENSIVE GREEN ROOF

(Costs assume an existing building with sufficient loading capacity; roof hatch and ladder access only. The larger the green roof, the cheaper the cost on a square metre basis.)

	Component	Cost	Notes & Variables
a)	Design & Specifications	5% - 10% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
b)	Project Administration & Site Review	2.5% - 5% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
c)	Re-roofing with root-repelling membrane	$100.00 - $160.00 per sm. ($10.00 - $15.00 per sf.)	Cost factors include type of existing roofing to be removed, type of new roofing system to be installed, ease of roof access, and nature of flashing required.
d)	Green Roof System (curbing, drainage layer, filter cloth, and growing medium).	$55.00 - $110.00 per sm. ($5.00 - $10.00 per sf.)	Cost factors include type and depth of growing medium, type of curbing, and size of project.
e)	Plants	$11.00 - $32.00 per sm. ($1.00 - $3.00 per sf.)	Cost factors include time of year, type of plant, and size of plant - seed, plug, or pot.
f)	Installation / Labour	$32.00 - $86.00 per sm ($3.00 - $8.00 per sf.)	Cost factors include equipment rental to move materials to and on the roof (rental of a crane could cost as much as $4,000.00 per day), size of project, complexity of design, and planting techniques used.
g)	Maintenance	$13.00 - $21.00 per sm ($1.25 - $2.00 per sf) for the first 2 years only.	Costs factors include size of project, timing of installation, irrigation system, and size and type of plants used.
h)	Irrigation System	$21.00 - $43.00 per sm. ($2.00 - $4.00 per sf).	*Optional, since the roof could be watered by hand. Cost factors include type of system used.

4.2 ACCESSIBLE INTENSIVE GREEN ROOF

(Costs assume an existing building with sufficient loading capacity; roof hatch and ladder access only. The larger the green roof, the cheaper the cost on a square metre basis.)

	Component	Cost	Notes & Variables
a)	Design & Specifications	5% - 10% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
b)	Project Administration & Site Review	2.5% - 5% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
c)	Re-roofing with root-repelling membrane	$100.00 - $160.00 per sm. ($10.00 - $15.00 per sf.)	Cost factors include type of existing roofing to be removed, type of new roofing system to be installed, ease of roof access, and nature of flashing required.
d)	Green Roof System (curbing, drainage layer, filter cloth, growing medium, decking and walkways)	$160.00 - $320.00 per sm. ($15.00 - $30.00 per sf.)	Cost factors include type and depth of growing medium, type and height of curbing, type of decking, and size of project. (cost does not include freestanding planter boxes.)
e)	Plants	$54.00 - $2,150.00 per sm. ($5.00 - $200.00 per sf.)	Cost is completely dependent on the type and size of plant chosen, since virtually any type of plant suitable to the local climate can be accommodated (one tree may cost between $200.00 - $500.00.
f)	Irrigation System	$21.00 - $43.00 per sm. ($2.00 - $4.00 per sf.)	Cost factors include type of system used and size of project.
g)	Guardrail / Fencing	$65.00 - $130.00 per lin.m. ($20.00 - $40.00 per lin. ft.)	Cost factors include type of fencing, attachment to roof, and size of project / length required.
h)	Installation / Labor	$85.00 - $195.00 per sm. ($8.00 - $18.00 per sf.)	Cost factors include equipment rental to move materials to and on roof, size of project, complexity of design, and planting techniques used.
i)	Maintenance	$13.50 - $21.50 per sm ($1.25 - $2.00 per sf) annually.	Costs factors include size of project, irrigation system, and size and type of plants used.

5.0 PUBLIC INCENTIVES FOR IMPLEMENTATION

Unlike Europe, few North American public policies provide direct financial incentives or regulatory requirements for green roofs in North America. Despite this, there are a number of avenues described below that may be worth pursuing on behalf of your client. These will vary considerably by jurisdiction.

5.1 STORMWATER MANAGEMENT

Some jurisdictions may reduce water and sewerage charges, or may provide financial incentives to developers or building owners who retain storm water on site. In other jurisdictions, no storm water runoff is permitted in re-developments, particularly in areas where the sewer/ storm water drainage systems are at capacity or the area has a combined sewer system. In jurisdictions that require the construction of storm water management ponds for new developments, green roofs can help to reduce the size of the ponds that would normally be required, thereby saving valuable land for other purposes.

5.2 ENERGY EFFICIENCY

Some governments have programs that provide financial support for the identification and implementation of technologies that generate energy efficiencies beyond a minimum standard, as found in the local building code. Calculation of increased R values and resulting energy reductions will be required.

5.3 OPEN SPACE REQUIREMENTS

Under the planning act and zoning by-laws, many jurisdictions require a certain percentage of the developed property to be landscaped open space and/or publicly accessible green space. Green roofs may provide opportunities to satisfy or partially satisfy these conditions, or provide a bargaining tool for additional density or other desired features that must be negotiated with the local authorities.

5.4 AESTHETIC BENEFITS

In a location where many buildings look down upon a roof, there may be opportunities to speed the approvals process or, reduce public opposition to a project, by incorporating a green roof system and designing it specifically for maximum aesthetic enjoyment.

6.0 CONCLUSION/RESOURCES

Green roofs are a proven technology that provide building owners with opportunities to utilize often wasted roof spaces for energy efficiency, storm water management, sound insulation, and aesthetic improvements. Accessible green roof systems can confer significant added value to a building's occupants or to the general public with benefits ranging from enhanced educational opportunities in schools, private "roofparks" for condominium owners, public parkland, horticultural therapy and even food production. Each green roof system should be tailored to the specific needs of the client, with the variables determining costs. As more governments come to recognize the wide range of public benefits of green roofs and how they can help to address many of the challenges facing cities, they will increasingly look to providing incentives for private building owners to undertake the additional capital costs associated with these systems. Until then, there are many niche opportunities to implement green roof systems and to help demonstrate the many benefits of this technology, including lifestyle benefits amenities.

For more information on green roofs, please visit the following web sites:

- Green Roofs for Healthy Cities
  www.greenroofs.ca
- Rooftop Gardens Resource Group
  www.interlog.com/~rooftop/
- CMHC official web site:
  Research Highlight: Technical Series:
  Greenbacks from Green Roofs Report.
  www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/01-101_e.pdf
  Buildings Innovation
  www.cmhc-schl.gc.ca/en/burema/himu/buin/buin_009.cfm

7.0 CASE STUDIES

MOUNTAIN EQUIPMENT CO-OP, TORONTO, ONTARIO, CANADA

Overview:	This inaccessible green roof garden located on downtown Toronto corporate headquarters of the Mountain Equipment Co-op. The 903 m^2 green roof area surrounds a skylight located on the second floor of the building.The roof has full sun exposure and a load capacity of 40 PSF. The green roof uses Soprema SOPRADRAIN PSE for drainage, a Soprema SOPRAFILTRE filter, and Soprema SOPRAFLOR-X growing medium. The vegetation is a wild flower meadow mix of sun flower seeds and perennial plants (contained in 4 inch pots, plantation at a density of 14 plants/m^2).
Owner:	Mountain Equipment Co-op
Construction:	Installation of the green roof took place in May 1998 and the building was constructed during Fall 1997- Winter 1998.
Partners:	Architect: Stone Kohn McQuire Vogt (SKMV) Architects, Landscape Architect: Ferris + Quinn (with recommendations from Marie-Anne Boivin of Soprema, Inc.)
Structural Engineer:	Read Jones Christopherson, Ltd.
Mechanical Engineer:	Keen Engineering Co., Ltd.
Landscape Contractor:	Top Nature
Drivers:	Some items in the program had no quantifiable economic benefit, but to the owner they contributed to social and community leadership. The building was intended to encourage discussion and debate about environmental issues and the green roof has contributed to this.

Fig. 11 – Mountain Equipment Co-op
Toronto, Ontario, Canada
Soprema Green Roof Installation and Planting
Photograph courtesy of M. Kuhn



Barriers: The possibility of added costs of structural redesign allowing for employee accessibility were barriers. Since the roof structure would have had to be further upgraded to accommodate live loads, accessibility was not incorporated into the design.

Cost: Labour and materials: $115,000 and structural upgrade: $55,000

Benefits: The green roof does have environmental and community benefits. It will also have some operating cost benefit due to thermal inertia of mass of growing medium. Successful in the establishment of the vegetation and wildlife (birds, butterflies, insects, etc.). Local developers are considering similar initiatives.

Changes: Include green roof in original design scope to cut costs. Design to provide limited access by employees for added benefit.

VANCOUVER PUBLIC LIBRARY, BRITISH COLUMBIA, CANADA

Overview: This extensive 2 400 m^2 green roof in Vancouver can be viewed from surrounding downtown office towers. The inaccessible roof is located on top the 7 storey library. It is oriented toward the city and the harbour. Four different types of trees, green and blue/green tufted fescues are planted in a lightweight growing medium which is composed of reconstituted vegetable waste, sand and pumice.

Owner: City of Vancouver

Construction: Building and green roof were constructed in 1995

Partners: Architects: Moshe Safdie and Associates and, Downs Archambault & Partners

Landscape Architect: Cornelia Hahn Oberlander

Landscape Contractor: Jackway Landscaping

Drivers: Environmental and aesthetic purposes

Barriers: None

Cost: Total cost of library green roof : approximately $250,000 ($104/sm.)

Benefits: The green roof was a great success but no quantifiable data collected



Fig. 12 – Vancouver Public Library Green Roof
Vancouver, British Columbia, Canada
Photograph courtesy of Hydrotech

SARB_011577

CITY HALL, TORONTO, ONTARIO, CANADA.

Overview: This demonstration project is located on the first floor podium roof of the Toronto City Hall building at 100 Queen Street West. The green roof is accessible to the public. It features eight different plots that represent a variety of green roof applications. Two green roof systems were manufactured by Garland and Soprema.

The eight plots include:

- 2 semi-extensive systems demonstrating a variety of plant types and landscaping techniques
- Reproduction of the now rare black oak savannah prairie ecosystem type with native plants drawn from nearby High Par
- A bird and butterfly garden with a mixture of native and non-native material
- 2 extensive green roof plots demonstrating a wide variety of plants
- 2 urban agricultural plots, one of which demonstrates some of the principles and plant types associated with permaculture

Owner: The City of Toronto

Construction: Re-roofing and green roof were constructed in the fall of 2000

Partners: City of Toronto, IRC, Environment Canada and the member companies of *Green Roofs for Healthy Cities* (Flynn Canada, Deboer Environmental Concepts, IRC Building Sciences, Sheridan Nurseries, Soprema and Garland)

Landscape Architect: Julien Marton

Drivers: Need for Technical research on performance and demonstration

Barriers: Many constituencies were involved and needed to be accommodated in order to implement the green roof.

Cost: Total cost of green roof and reroofing was approximately $265,000, which was shared by Green Roofs for Healthy Cities, the Toronto Atmospheric Fund and the federal government's Climate Change Action Fund. The City of Toronto paid for the value of traditional re-roofing which was scheduled to be replaced in 2004.

Benefits: The green roof provides an excellent opportunity for public and professional access to a variety of different types of applications in one place.

ENDNOTES

1. Soprema Roofing Inc., 1996 – marketing information.
2. Thompson, 1998, p. 49, in "Greenbacks from Green Roofs" (GBGR) see below.
3. Boivin, 1992, in GBGR.
4. Johnston, 1996, p. 48, in GBGR.
5. Pers. Com. Dr. Brad Bass, Environment Canada, Adaptation and Impacts Research Group, February 2001.
6. Bass, B., Kuhn, M., Peck S., "Greenbacks from Green Roofs: Forging a New Industry in Canada" (GBGR), CMHC. 1998 p. 24. – see for a pdf file of the report.
7. "Vegetative Roof Covers: A New Method for Controlling Urban Runoff in Urbanized Areas", C. Miller. Villanova University, October 1998.)
8. GBGR, p. 30.
9. "Urban Heat Island Initiative Pilot Project: Final Report", Prepared for City of Chicago by Roy F. Weston et. al., May 9, 2000.
10. Beckman, S.; Jones, S.; Liburdy, K. and Peters, C., "Greening Our Cities: An Analysis of the Benefits and Barriers Associated with Green Roofs". Portland State University, Planning Workshop, 1997, p. 26.
11. Minke, 1982, p. 11, in GBGR.
12. Johnston, 1996, p. 10, in GBGR.
13. Minke, 1982, p. 11, in GBGR.
14. ibid., p. 11.
15. Johnston, 1996, p. 49, in GBGR.
16. North American Wetland Engineering, 1998; and Reid, 1996.
17. Thompson, 1998, p. 49, in GBGR.

Q&A'S

1. Why are the ongoing maintenance requirements for extensive green roofs different from those required for intensive green roofs?

2. What are the environmental benefits of green roof installations for municipalities?

3. What are the cost saving benefits for building owners and developers?

4. What are the social benefits for building occupants?

5. What are the advantages of including a green roof in the design phase of a project, rather than in a retrofit situation?

6. Which areas within the Ontario Building Code regulate green roof systems?

7. Why is it recommended to separate the growing medium from the waterproofing membrane?

8. What are three reasons to create a separation between the plants and any roof penetrations?

9. Can green roof systems be installed on a sloped roof?

10. What happens to the green roof system when the waterproofing membrane reaches the end of its life cycle?

For the answers to these questions, please refer to your professional association's Web page.

NRDC
THE EARTH'S BEST DEFENSE

NATURAL RESOURCES DEFENSE COUNCIL

February 13, 2009

Via U.S. Mail and electronic mail

Ms. Carole H. Beswick and Members of the Board
Santa Ana Regional Water Quality Control Board
3737 Main Street, Suite 500
Riverside, CA 92501-3348

Re: Draft NPDES Stormwater Permit for the County of Orange, Tentative Order No. R8-2008-0030

Dear Chair Beswick and Members of the Board:

We write on behalf of the Natural Resources Defense Council ("NRDC") and Orange County Coastkeeper ("Coastkeeper"). NRDC is a national environmental advocacy organization with over 120,000 members in California and has been involved in MS4 permit matters across the state, with a focus on the implementation of low-impact development ("LID") practices. Coastkeeper is a grassroots environmental organization with 17,000 members in the region, a decade's worth of successful projects that have improved water quality, and a record of collaboration in developing solutions to the impacts of water pollution. As a general matter, we strongly support LID because it is the most effective means of addressing the water quality and quantity problems associated with urban runoff. LID practices seek to replicate pre-development hydrology through the deployment of measures that infiltrate or capture water onsite, thereby significantly reducing the amount of water and water-borne pollutants that drain from developed areas. Since urban runoff is the single greatest contributor to water pollution in California, widespread implementation of LID is vital to the health of our state's renowned ecosystems.

We believe that LID techniques are required by the Clean Water Act's "maximum extent practicable" ("MEP") standard for pollution reduction because of their practicability, low cost, and superior performance relative to conventional BMPs. Additionally, LID practices generate significant ancillary benefits—such as cost savings, reduced need for imported water, and improved aesthetics—for developers, building owners, and city residents. For all of these reasons, we support the Santa Ana Regional Water Quality Control Board's inclusion of LID practices in the Draft MS4 Permit ("Permit") for the County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County within the Santa Ana Region (Order No. R8-2008-0030; NPDES No. CAS618030).

NRDC has investigated the practicability of including specific, numeric metrics to guide LID implementation in MS4 permits in California. Working with national

storm water expert, Dr. Richard Horner, we have verified the feasibility of using the type of clear and transparent metrics that are appropriate for permits—and supported by EPA Region IX—to guide LID implementation. We have also quantified the range of pollution and water supply benefits that would accompany the use of these metrics in permits. The results of this California-focused technical work show that LID is a robust, pollution-reducing, water-supply enhancer. It is extremely cost-effective, as well, according to recent EPA evaluations.[1]

We have divided our comments into three sections that discuss:

(1) The necessity for LID implementation through a numeric performance standard that is transparent and enforceable and represents the level of compliance required to meet the MEP standard;

(2) Areas in which the Permit needs revision to clarify its requirements; and

(3) Recent expert analyses of the feasibility of implementing LID features through the type of numeric performance standard established in the Permit.

I. LID Implementation and Numeric Performance Standards

There is an emergent consensus nationwide that LID practices are the most effective stormwater management techniques, besides providing many other benefits, such as reducing the need for imported water, increasing property values, mitigating the urban heat island effect, and creating aesthetically pleasing landscapes. In California, the Ocean Protection Council, for instance, strongly endorsed LID last year by "resolv[ing] to promote the policy that new developments and redevelopments should be designed consistent with LID principles" because "LID is a practicable and superior approach … to minimize and mitigate increases in runoff and runoff pollutants and the resulting impacts on downstream uses, coastal resources and communities."[2] EPA has also called upon Regional Boards across California to prioritize the implementation of LID, even "recommend[ing] that the [South Orange County draft] permit be revised to put more emphasis on LID [and to] require[] that LID be woven into the design of specified new development and redevelopment projects."[3] In other MS4 permit contexts, EPA has also specifically endorsed the use of metrics, particularly the EIA approach in the Permit.

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[1] Environmental Protection Agency, *Reducing Stormwater Costs Through Low Impact Development (LID) Strategies and Practices* (Dec. 2007) (hereinafter "EPA LID Study").

[2] California Ocean Protection Council, *Resolution of the California Ocean Protection Council Regarding Low Impact Development* (May 15, 2008). We have enclosed a CD that includes all of the documents referenced in our letter, as well as additional information regarding the benefits and implementation of LID.

[3] Environmental Protection Agency, Comments re Draft MS4 Permit for Southern Orange County (email from Eugene Bromley) (Jan. 24, 2008) (hereinafter "EPA South OC Comments").

It is becoming clear that without requiring the implementation of LID practices designed to satisfy feasible and clear metrics, stormwater permits cannot meet the Clean Water Act's "maximum extent practicable" ("MEP") standard for pollution reduction. Critically, the prioritization of LID practices is insufficient by itself to meet the MEP standard and must be paired with a measurable requirement for the implementation of LID. Since its inception, the MS4 permitting program has been seriously hampered by a pervasive absence of numeric performance standards for the implementation of best management practices ("BMPs") such as LID. For this reason, in December 2007, the State Water Resources Control Board commissioned a report which found that "[t]he important concept across all of [the] approaches [described in the report] is that the regulations established a performance requirement to limit the volume of stormwater discharges."[4] The report also noted that "[m]unicipal permits have the standard of Maximum Extent Practicable (MEP) which lends itself more naturally to specifying and enforcing a level of compliance for low impact development."[5] EPA has highlighted similar but more specific concerns, remarking that subjective and imprecise language (such as requiring "a portion" of a site to address LID) is "vague" and that EPA recommends "more precise requirements."[6]

Various jurisdictions nationwide have begun adopting numeric performance standards for stormwater management, frequently pairing these with requirements to implement LID practices:

- **Pennsylvania:** Capture at least the first two inches of rainfall from all impervious surfaces and retain onsite (through reuse, evaporation, transpiration, and/or infiltration) at least the first one inch of runoff;[7]

- **Anacostia, Washington, D.C.:** Retain onsite the first one inch of rainfall and provide water quality treatment for rainfall up to the two-year storm volume;[8]

- **West Virginia:** Retain onsite the first one inch of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation;[9]

- **Georgia:** Treat the runoff from 85% of the storms that occur in an average year (*i.e.*, provide treatment for the runoff that results from a rainfall depth of 1.2 inches);[10]

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[4] State Water Resources Control Board, *A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption* at 23 (Dec. 2007) (emphasis added) (hereinafter "SWRCB LID Report").
[5] *Id.* at 4.
[6] EPA South OC Comments.
[7] Pennsylvania Stormwater Best Management Practices Manual, Chapter 3 at 7 (Dec. 30, 2006).
[8] *See* SWRCB LID Report at 20-21.
[9] State of West Virginia, NPDES Permit No. WV0116025 at 13-14.

- **Central Coast, California (RWQCB, Phase II):** Limit effective impervious area ("EIA") at development projects to no more than 5% of total project area (interim criteria); establish an EIA limitation between 3% and 10% in local stormwater management plans (permanent criteria);[11]

- **All Federal Buildings over 5,000 square feet** (under EPA's draft guidance for implementation of the Energy Independence and Security Act of 2007): Manage onsite (*i.e.*, prevent the offsite discharge of) the 95th percentile storm through infiltration, harvesting, and/or evapotranspiration.

For these reasons, it is imperative that the Orange County Permit require new development and redevelopment projects to implement LID practices designed in accordance with a clear performance requirement. As detailed below, we support the Permit's use of an EIA limitation as this overall performance measure, teamed with a requirement to fulfill this obligation through appropriately sized LID features. These are critical elements of the Permit as a whole and assure that it is consistent with MEP and related requirements, as well as the mainstream of stormwater control across the country. However, as discussed below, some elements of the New Development section need revision. We also support the Permit's emphasis on LID and specifically agree with the findings on pages 19-20 of the Permit, which underscore the superiority of LID practices and the usefulness of establishing an EIA limitation.

II. Suggested Revisions to the Permit's New Development Requirements

A. EIA Should Be Defined to Require Full Onsite Retention of the Design Storm, and the Volumetric Requirement to Implement the EIA Limitation Should Be Defined as the Entirety of the Design Storm Volume.

As the overarching numeric performance standard for BMP implementation, the Permit imposes a mandatory 5% EIA limitation, based on the difference between the pre-development and post-development runoff ("delta volume") for the two-year design storm. Field-based studies have demonstrated that at 3 to 5% impervious area, watersheds begin to experience deleterious impacts from development, as noted in the attached reports by national stormwater expert Dr. Richard Horner.[12] For this reason, in other permitting contexts, we have

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[10] Georgia Stormwater Management Manual, Unified Stormwater Sizing Criteria at 1.3-1.
[11] Central Coast Regional Water Quality Control Board, Letter from Roger Briggs re Notification to Traditional, Small MS4s on Process for Enrolling under the State's General NPDES Permit for Storm Water Discharges (Feb. 15, 2008) (hereinafter "Central Coast Phase II Letter").
[12] Richard Horner, *Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for Ventura County*; Richard Horner, *Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for the San Diego Region*; Richard Horner, *Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for the San Francisco Bay Area*; Richard Horner, *Supplementary Investigation of the*

recommended the establishment of a 3% EIA requirement for new development and redevelopment projects, and we recommend the same for Orange County. Dr. Horner's studies have shown the attainment of this standard onsite to be feasible in southern California.

The critical factor in determining whether an EIA limitation will be effective at reducing stormwater pollution is how the Permit defines the concept of "disconnecting" impervious surfaces such that they are rendered "ineffective" and thus do not count toward the 5% EIA requirement. This involves two different elements: (1) the volume of water that must be accommodated through stormwater BMPs and (2) the processes through which impervious surfaces can be considered "disconnected" from the storm sewer system.

On the first issue, in the Permit, as mentioned above, the volume of water for which developers must design stormwater BMPs to meet the EIA limitation is the delta volume for the two-year design storm. (Permit at p.52, fn.49.) For several reasons—most notably, the potential for calculations of pre-development volume that inflate the quantity of runoff which exists under natural conditions—NRDC does not support the use of the "delta volume" calculation and instead supports the use of the entire design storm as the volumetric requirement. (Our reasons are detailed in the attached critique by Dr. Horner,[13] which analyzes the study by Geosyntec et al., discussed below.) Thus, we suggest that the volumetric requirement for meeting the EIA limitation be revised to the full volume of the two-year design storm and that, for the sake of clarity, this crucial volumetric requirement be moved out of the footnote section and into the main text of the Permit.[14]

On the second issue, the Permit requires that BMPs have the capacity to "percolate" the design volume in order for impervious surfaces to be considered "disconnected" and effectively pervious. (Permit at p.52-53.) "Percolate," however, is not defined in the permit, and its meaning is not readily apparent. For this reason, we recommend revising the Permit such that BMPs are required to have the capacity to "infiltrate, harvest for reuse, or evapotranspire" the design storm volume. This onsite retention requirement will eliminate any ambiguity and allow for greater flexibility, as well as clarity, in meeting the EIA limitation. This change will also bring the Permit into line with other stormwater regulations around the country, which require onsite retention and thereby eliminate the potential for <u>any</u> polluted runoff from the design storm since there is no discharge.[15]

Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for the San Francisco Bay Area.

[13] Richard Horner, *Critique of Certain Elements of "Low Impact Development Metrics in Stormwater Permitting"* (Feb. 2009).

[14] We also recommend that footnote 43 on page 48 include a cross-reference to the relevant full definition of EIA later in the Permit so that footnote 43 is not misinterpreted as the controlling definition of EIA.

[15] *See, e.g.*, requirements listed in section I, above, for Anacostia, the Energy Independence and Security Act of 2007, Pennsylvania, and West Virginia.

We would not support a definition of EIA that allows for onsite treatment and discharge to the storm sewer system, as this does not guarantee that pollutants will be removed from Orange County's receiving waters. Indeed, as further discussed below, the value of retention and reuse or infiltration is substantial, when measured both in terms of the ability to meet water quality standards and when measured in terms of other water resources imperatives, such as addressing drought and long-term reduction in water supply. Our analyses, presented as part of our submittal with this letter, document the extraordinary ability of LID to "create" new water supply, but this feature is operative only when water is retained and not discharged to surface waters.[16]

B. The Permit's Waiver Provision Must Require Offsite Compliance for Any Project that Cannot Meet the EIA Limitation Onsite and Must Set a Floor that All Developments Are Required to Meet.

The Permit, as currently written, would allow unfettered waivers for projects that can make an amorphous demonstration of disproportionate costs relative to the water quality benefits achieved. (Permit at p.55.) This loophole threatens to undermine the value of the EIA limitation and the entire New Development section. NRDC can support including flexibility in the permit's LID provisions to address true instances of technical infeasibility (and we detail below an appropriate scheme based on approaches taken in other jurisdictions). But the existing provision is overbroad, not supported by the facts, and is rife with the potential for abuse.

First, at a general level, this waiver provision is irreconcilable with the general findings of EPA and others that LID in most circumstances is *less* costly—often considerably so—than alternative building or stormwater management approaches. The provision, therefore, appears to be arbitrary and fundamentally counter-factual.

More specifically, the provision has a number of other fatal flaws as drafted. First, the LID requirements in the permit are based on addressing a *practicable* design storm, as discussed further in Dr. Horner's analysis, and this storm is well within the range of sizing requirements in place across the nation. Hence, the basic permit requirement already addresses and answers the question loosely posed by the waiver provision: the benefits and feasibility of the LID requirements are well-established generally and in reference to water quality improvements specifically. LID implemented across a watershed is far more capable of ensuring the attainment of water quality standards than traditional BMPs, and since ensuring compliance with standards is a fundamental requirement of the permit, LID is similarly a necessary element in new development and redevelopment.

Second, even if a waiver provision in general were appropriate, this one is not: the Permit does not define how these costs and benefits would be weighed against each other, and

[16] *See, e.g.*, Letter from David Beckman and Noah Garrison, NRDC, to Mary Nichols, Chair, California Air Resources Board, re AB 32 Draft Scoping Plan and Appendices (Aug. 11, 2008).

while the installation of BMPs can be easily priced, the human and ecosystem benefits of reduced water pollution are much more difficult to monetize and likely to receive short shrift in any such comparison. Even using a cost-benefit approach where (as is the case in much of the Permit area) waters are impaired may have the effect of allowing new sources of pollution to contribute to existing impairments, which is not allowable legally.

Third, the waiver provision includes no limiting factors, such as a requirement that projects implement all feasible LID (or even conventional) BMPs. Fourth, the Permit does not mandate offsite mitigation for any stormwater volume that a project is unable to retain onsite. This is the most appropriate "waiver" provision, allowing offsite compliance when onsite compliance is truly technically infeasible.

To close the waiver provision's loopholes, we would recommend first that the cost-benefit calculation be changed to a requirement that project applicants demonstrate the technical infeasibility of complying with the EIA limitation. The Permit should then define technical infeasibility, which could include circumstances such as severe space constraints, underground pollutant plumes, and non-infiltrative soils. Additionally, the Permit should specify that the project applicant must implement all technically feasible BMPs to the maximum extent practicable—if infiltration is infeasible, then harvesting and evapotranspiration should be maximized. The Permit should also set a floor for compliance with the EIA limitation onsite (*i.e.*, X% of the design volume must be infiltrated, harvested, or evapotranspired at the project site) so that project applicants do not utilize the alternative compliance option for the entirety of the design volume. This is a typical requirement of similar regulations in other parts of the country and ensures better results because of the limitations of offsite mitigation.[17] Any onsite discharge up to the design storm volume should be treated for water quality purposes.

The project applicant should then be required to perform offsite mitigation for the difference in volume between what is achieved onsite and the otherwise applicable EIA requirement. This could be accomplished by rewriting the waiver provision such that it *requires* permittees to establish an "urban runoff fund" (or project applicants to construct their own offsite projects) within the same hydrologic unit. For the sake of water quality and overall programmatic equivalence, the monetary contributions required should be based not on the avoided cost for developers, but rather on the volume of stormwater that is not retained on a given site. This system should also be paired with an obligation to mitigate stormwater volume offsite at a higher ratio than 1:1, such as 1:1.5, given the generally weaker performance of offsite mitigation projects. Several jurisdictions, including West Virginia and Washington, D.C. (Anacostia), have instituted such ratios.

Finally, we note that the Permit imposes no time limitation on the expenditure of funds for offsite mitigation. We recommend that offsite mitigation projects, whether public or private, should be constructed within three years of final discretionary approval (of the original

[17] *See, e.g.*, the requirements for West Virginia and Pennsylvania.

project) by the permittee. Additionally, the Permit should require project applicants to provide the necessary funds within one month to the permittee (for public mitigation projects) or to an escrow account (for private mitigation projects).

C. The Permit Must Impose Limits on "Water Quality Credit Systems" to Ensure that Equivalent Results Are Achieved on a Watershed Basis.

The Permit allows permittees to establish a "water quality credit system" that would waive LID, hydromodification, and infiltration requirements. (Permit at p.56.) While we agree that certain projects generate environmental benefits by the very nature of their circumstances, we also believe that waivers from otherwise applicable criteria should not be granted unless they are necessary and some nexus with water quality can be demonstrated. The fundamental requirements of the Clean Water Act include attainment of water quality standards. Without further specification, the approach taken in the permit effectively (and unlawfully) would delegate to those responsible for meeting the standards the ability to waive attainment through unilateral reductions in basic technological treatment requirements. This is unwarranted, poor policy, and in all eventualities, inconsistent with the text of the Act. For this reason, we suggest that the Permit impose certain restrictions on the water quality credit system.

First, the Permit should require that the permittees justify—scientifically and quantitatively—the stormwater volume and pollutant load reductions that accrue from a particular type of development granted "credit" under the system. These reductions should correlate with the amount of credit available for the project in question. Second, the Permit should set a maximum allowable credit amount for which a single project would be eligible. Other jurisdictions with such credit systems cap the allowable credit at half of the volumetric requirement or less, for instance, whereas the Permit currently includes no cap at all.[18] Without these changes, the water quality credit system could undermine the EIA numeric performance standard altogether by allowing projects blanket waivers without any specific demonstration of technical infeasibility or equivalent stormwater volume and pollutant load reduction—this would not meet the MEP standard. Moreover, it would not reduce pollution so as to reduce water quality impairment and, particularly in circumstances such as those in Orange County where many projects discharge to impaired waters, it is flatly inconsistent with the basic legal requirements that apply to protection and restoration of waters listed as impaired pursuant to 33 U.S.C. Section 1313(d) (including TMDL waste load allocations and requirements that pertain to additional sources of pollution discharged to waters listed as impaired).

D. Additional Concerns and Comments.

Below, we have listed some additional concerns and comments regarding specific provisions within the New Development section of the Permit.

[18] *See, e.g.*, the requirements for West Virginia.

- **Prioritization of LID:** In the LID section of the Permit, the language does not clearly state a hierarchy of stormwater management BMPs. (Permit at p.52.) It merely states that onsite implementation of LID principles is the "preferred approach." Because proprietary BMPs and conventional stormwater management techniques have proven less effective than LID, this section of the Permit should clearly establish a hierarchy such that project applicants must prove the technical infeasibility of implementing LID BMPs before they resort to proprietary or conventional technologies.

- **Treatment Control BMPs:** The Permit allows project applicants to substitute "treatment control BMPs" for LID measures if certain conditions are met. (Permit at p.53.) These conditions include limiting EIA to 5% or less. However, this is antithetical to the Permit's inchoate conception of EIA as onsite retention with no discharge, as we support. By definition, treatment control BMPs that discharge treated stormwater cannot render impervious areas "ineffective" for the purposes of meeting the 5% EIA limitation. For this reason, we recommend that any projects exercising this compliance option be required to retain the volume of their discharge (multiplied by our suggested 1:1.5 offsite mitigation ratio) elsewhere in the hydrologic unit.

- **Hydrologic Conditions of Concern:** We do not support the Permit's waiver of hydromodification criteria for any project that discharges to engineered, hardened, and regularly maintained conveyance channels. (Permit at p.54.) The Clean Water Act is a restorative statute with a restorative purpose—by not subjecting a whole group of projects to hydromodification criteria, the Permit will heavily burden future restoration efforts. With stream daylighting and habitat restoration a reality nowadays, the Permit should not condemn all hardened conveyances to their present, unnatural state. Instead, it should effectuate the goal of the Clean Water Act and begin to restore natural conditions to even those streams that are most burdened by human engineering. It is also noteworthy that one outcome of hydrological controls is reduced flooding. With projections that the impacts of climate change in California will include more intense storms, it would be unwise in the extreme to allow a waiver of hydromodification requirements.

- **Applicability:** We support the applicability section's establishment of a 5,000 square foot threshold for most projects (Permit at p.46-47), but the language in XII.B.2(a) for significant redevelopment projects needs to specify in the third and fourth sentences that the relevant question is how much impervious surface was added or replaced (not increased), consistent with the first sentence.

- **Depth to Groundwater:** The Permit states that infiltration BMPs must be at least 10 vertical feet above seasonal high groundwater. (Permit at 49.) However, recent studies and state and national standards demonstrate that five feet (or even less) is a

safe threshold, and the Permit's infiltration infeasibility criteria should be changed accordingly.[19]

III. Case Studies and the Feasibility of LID Implementation

We have submitted, as attachments to this letter, several reports by Dr. Horner. These reports take into account local rainfall patterns and building typologies and demonstrate that a 3-5% EIA limitation can be feasibly implemented by various types of development projects in southern California. Dr. Horner's reports show that considerable reductions in pollutant loadings occur through the implementation of an EIA limitation with LID techniques. They also highlight that onsite retention of stormwater can result in significant water savings, as well, through infiltration and harvesting for in-building uses or landscape irrigation. Such water savings are an important ancillary benefit of LID implementation and can decrease our reliance on expensive, increasingly unreliable sources of imported water. These water savings also result in considerable greenhouse gas emission reductions because water importation machinery is the single largest user of electricity in California.[20] For these various reasons, as mentioned above, we strongly support the Permit's establishment of an EIA limitation that requires the implementation of LID practices because they are the most effective means of improving water quality while also generating other benefits.

Recently, another study (entitled "Low Impact Development Metrics in Stormwater Permitting," hereinafter "the report") of three specific existing or proposed development sites was completed by Geosyntec Consultants and Larry Walker Associates for the Counties of Orange and Ventura.[21] Despite several flaws in assumptions and methodology, as documented in the attached critique by Dr. Horner, the study in many regards bolsters the argument that implementing LID through a numerical performance standard, such as proposed in the Permit, is feasible. Regarding the 60 California project, for instance, the study remarks that "it was not exceedingly difficult to achieve less than 5% EIA." (Geosyntec et al. at p.55.) However, various supposed problems identified by the report deserve attention in this context because we feel that the EIA concept and LID practices have been mischaracterized and that the report unjustifiably condemns, or at least puts an inappropriately negative spin on, worthwhile aspects of the Orange County Draft Permit.

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[19] The Los Angeles Regional Water Quality Control Board, for instance, typically allows 5 feet of separation between onsite system leachfields and groundwater. *See, e.g.*, Draft Waste Discharge Requirements for the Malibu Lumber Facility (requiring a 5-foot separation from groundwater). The AB 885 draft regulations (California's septic tank law) would allow dispersal systems of all conventional OWTS to have only 3 feet of separation. *See* 27 CCR § 30014 (draft).

[20] *See, e.g.*, NRDC, *Energy Down the Drain* at v (Aug. 2004).

[21] Geosyntec Consultants et al., *Low Impact Development Metrics in Stormwater Permitting* (Jan. 2009).

A. The Report Relies on a Flawed Definition of EIA to Draw its Negative Conclusions about the EIA Concept Overall.

The authors base their definition of EIA on the flawed language of the current Ventura draft permit. (Geosyntec et al. at p.3.) NRDC and Heal the Bay have repeatedly commented on the lack of hydraulic sizing criteria that should apply to the EIA limitation in that permit, and we agree with the authors of the report that this loophole allows for manipulation of the EIA concept. (Geosyntec et al. at p.5.) However, by basing their analysis of EIA limitations, writ large, on a single flawed definition of the concept, the authors have compromised the applicability and usefulness of their study. They are, therefore, unable to address the true benefits of an EIA standard from a water quality perspective, benefits recognized by a wide range of agencies and experts, including Dr. Horner (in his California studies), Tetra-Tech (in a study for the Ocean Protection Council),[22] EPA (in its own comments on the South Orange County Permit and in other permit proceedings around the state),[23] and the Central Coast Regional Water Quality Control Board (which adopted a default 5% EIA standard for Phase I and Phase II communities).[24] In this sense, it is not an overstatement to suggest that by adopting something of a "straw man" and then knocking it over, the report does not credibly refute the effectiveness or practicability of EIA properly implemented. The Orange County Draft Permit does not contain the same loophole as the Ventura draft permit, and although we recommend certain changes to the Permit's definition of EIA, it can easily be insulated from the type of abuse envisioned by the authors of the report.

B. The Permit Does Incentivize Infill, Redevelopment, and Smart Growth.

The authors mistakenly claim that the Permit creates significant disincentives for infill, redevelopment, and smart growth. (Geosyntec et al. at p.5.) In truth, the permit accommodates these development typologies by enabling developers to comply with the Permit's EIA limitation through four different options at varying scales and by allowing the permittees to establish both alternative compliance measures (*i.e.*, in-lieu fees for offsite mitigation) and a water quality credit system that would lessen the requirements for the exact sites about which the authors are worried. (Permit at pp.51-53, 55-56.) The Permit has gone further than several other states in encouraging infill, redevelopment, and smart growth, and we stand behind the Regional Board's efforts to accommodate these concerns in a manner that is consistent with water quality protection.

The environmental community's willingness to accept permit requirements that can be satisfied in part offsite should not be taken for granted, as it constitutes an attempt to address other stakeholders' stated concerns and, in any case, fully addresses any reasonable concern about infill and redevelopment. We are willing to accept offsite mitigation notwithstanding the

[22] Oceans Protection Council of California, *State and Local Policies Encouraging or Requiring Low Impact Development in California* at 27 (Jan. 2008).
[23] EPA South OC Comments.
[24] Central Coast Phase II Letter.

lack of a clear need for this flexibility when the matter is analyzed objectively. For example, some of the most aggressive LID requirements have been imposed in ultra-urban environments, like Philadelphia, PA, and Anacostia, Washington, D.C., demonstrating that the supposed conflict between LID and infill and redevelopment appears to be largely rhetorical. Moreover, as noted in Dr. Horner's critique of the report (and further below), even those sites chosen to represent the most challenging circumstances for LID implementation can feasibly (and in some cases easily) implement LID as envisioned by the Permit. And of course, the record also contains Dr. Horner's analysis of the feasibility of LID implementation across a range of building typologies, showing that LID can be accommodated in virtually any building situation with robust numeric metrics.

C. With Our Recommended Revisions, the Permit Will Not Lead to Unnatural Levels of Infiltration.

The report states that the Permit's infiltration requirements could destabilize the water balance in certain locations. (Geosyntec et al. at p.5.) This might be true in some situations if the Permit required infiltration of the entire design volume; very large numbers of sites were affected; and the water balance in the affected area were otherwise undisturbed compared to natural conditions. However, none of these three factors is present and, in particular, those who would contend that the LID provisions regulating new development and redevelopment could significantly affect water balance have failed to recognize that, in most of urbanized Orange County, the natural rate of infiltration has been dramatically reduced by a century of development focused on impervious surface. While we believe that this issue is yet another poorly justified criticism of LID, we note that the permit in any case does not require infiltration, per se, but rather any of three techniques that retain water. To make this even clearer, we have recommended the inclusion of language to clarify that three techniques are allowed: infiltration, harvesting, and evapotranspiration. If infiltration is ill-advised and thus infeasible, then project applicants will simply use the other allowable techniques for retaining water onsite.

Moreover, the Technical Advisory Committee (mentioned on page 46 of the Permit) should develop criteria—for potential insertion into the DAMPs and/or guidance manuals—to determine when infiltration would be counter-productive. These criteria will guide developers in deciding whether to utilize infiltration, harvesting, or evapotranspiration, or some combination of the three, to meet the EIA limitation. Additionally, developers have the option under the Permit of paying in-lieu fees when it is infeasible to attain the Permit's otherwise applicable requirements, including the infiltration requirement. Thus, there is no reason to assume that the level of infiltration encouraged by the Permit will lead to hydrologic imbalances, and there is every reason to assume that this potential problem will be easily avoided.

D. The EIA Limitation in the Permit Is Not Intended to Function As a Hydromodification Standard, Nor Should It.

The authors of the report posit that the EIA metric does not reflect the current understanding of stream hydrology and geomorphology. (Geosyntec et al. at p.6.) It does not reflect these issues because it is not intended to, and any interpretation of the EIA limitation that transmutes it into a hydromodification standard is misguided. Limiting the effective impervious area of a site is a means of addressing water quality—not water quantity—concerns. The purpose of retaining water onsite and infiltrating, harvesting, or evapotranspiring it is to prevent all pollutant loads contained within the design storm volume from entering aquatic ecosystems. While such retention may aid projects in meeting hydromodification criteria, and does have the salutary effect of making new water supplies available, the EIA metric stands as a water quality-focused, technology-based performance standard required by the Clean Water Act. This is why the Permit also contains a section that establishes requirements for "hydrologic conditions of concern." (Permit at p.54.) Any arguments about hydromodification should properly be addressed to this section. It also bears mention that even the report's recommended performance standard suffers from the same exact "problem" as the EIA limitation, and the authors thus included a separate hydromodification control standard in their recommendation. The Permit is structured in exactly the same fashion.

E. The Report's Case Studies Fail to Demonstrate that It Is Technically or Economically Infeasible to Implement a 5% EIA Standard.

The authors purport to prove through three case studies that the EIA concept is both difficult to implement and less protective of water quality than a volumetric reduction requirement. (Geosyntec et al. at p.16.) The principle failure of this analysis is, again, that the authors used a flawed definition of EIA (with no sizing requirement) as the basis for their analysis. They effectively seek to compare the function of two techniques, one of which they define nonsensically and one of which they define reasonably. This yields skewed analyses that, accordingly, run the risk of appearing to be results-oriented to support a predetermined perspective on the Permit. Moreover, the authors' assertion that a volumetric reduction approach would be "more constructive than a % EIA standard" highlights the degree to which the inadequate language of the Ventura draft permit has biased various entities' understanding of how an EIA limitation should operate. Ultimately, EIA limitations should be volumetric reduction approaches, as the authors of the report advocate. When EIA is properly defined as a requirement for onsite retention of a certain percentage of the design storm volume, it is literally a volumetric reduction requirement, and thus all of the report's negative conclusions about EIA have no real bearing on the worth of a properly designed EIA standard. Indeed, if it is a volumetric reduction approach that the authors favor, they should support a properly designed EIA standard. With this in mind, we offer the following thoughts on the specific case studies.

1. Walnut Village

As noted by Dr. Horner in the attached letter, this case study suffers from several analytical flaws. Without repeating those flaws here, we will simply draw attention to the fact that the authors found it almost feasible (and had they used appropriate infiltration rates, it would have been entirely feasible) to meet even the most stringent of the standards they analyzed, characterizing options as merely "less feasible" and "more feasible" based on problematic assumptions described by Dr. Horner. (Geosyntec et al. at pp.8-11.) This most stringent standard—delta volume for the two-year design storm—is by definition only 5% different from the EIA standard in the Permit because the Permit bases its definition of EIA on the delta volume for the two-year design storm. Thus, the authors' third proposed standard—although nowhere described as EIA—is just 5% away from the EIA metric in the Permit. This case study, therefore, demonstrates in general terms the practicability of the Permit's approach even on a very challenging building site and even when technically unsupported limitations are assumed that make accomplishing Permit requirements more difficult than necessary.

2. 60 California

The same flaws apply to this case study analysis; however, here, the authors openly admit that the site could feasibly achieve any of the three standards they used. (Geosyntec et al. at pp.13-14.) Their sole bases for questioning the utility of apparently any LID requirement are that green roofs and cisterns are relatively new concepts and that green roofs (anecdotally) might not be climate-appropriate, hardly reasons for dismissing them out-of-hand.

The 60 California case study can in fact assist us in partially understanding the cost implications of the various performance standards analyzed by the report, although the authors themselves have performed no such economic analysis. The authors concluded that for the largest storm event analyzed (the two-year design storm, which is nearly four times the volume of the 85th percentile storm), a combination of green roof and cistern would meet the standard. This green roof would require 4,300 square feet of space (Geosyntec et al. at p.13) and need to retain at least two inches of water. Assuming that this would require an intensive green roof, which can typically hold 80-150 pounds per square foot and accommodate soil depths up to 24 inches, the roof itself would cost (at the high end) approximately $25 per square foot, or almost $108,000.[25] The accompanying cistern that would need to hold an additional 4,170 gallons would likely cost less than $10,000, plus any plumbing necessary to carry stormwater from the roof to the cistern.[26] In all, the total cost of stormwater infrastructure would likely be less than

[25] *See, e.g.*, Great Lakes Water Institute, Green Roof Installation, at http://www.glwi.uwm.edu/research/genomics/ecoli/greenroof/roofinstall.php; Steven Peck and Monica Kuhn, *Design Guidelines for Green Roofs*, available at http://egov.cityofchicago.org/webportal/COCWebPortal/COC_ATTACH/design_guidelines_for_green_roofs.pdf.

[26] *See, e.g.*, Low Impact Development Center, Rain Barrels and Cisterns, at http://www.lid-stormwater.net/raincist_cost.htm.

$125,000. Of course, this does not take into account the costs of avoided conventional stormwater infrastructure, which would reduce the added cost of the LID infrastructure by some unknown but potentially substantial amount. Indeed, EPA found that at 11 out of 12 case study sites, LID infrastructure actually cost less than conventional stormwater management practices.[27]

The total development cost for this project was around $4 million. Hence, even if conventional stormwater infrastructure cost nothing and the green roof fell in the upper range of expected costs, the ~$125,000 stormwater compliance price-tag would be only 3% of total project cost. And this is supposedly one of the most constrained sites the authors could find where compliance would be the most technically and financially difficult. Hence, the best interpretation of the authors' analysis is that the upper limit of the cost to comply with the LID requirement—even assuming the most unfavorable conditions and without any credit for offsetting infrastructure cost savings that are clearly present—is only 3%. This is well within the accepted cost for compliance with existing MS4 requirements, such as the SUSMP provisions; the State Water Resources Control Board (in the *Bellflower* decision) already has determined in precedential orders that such provisions are reasonable and appropriate.

3. Kmart

The Kmart case study analysis is the most flawed of all from a methodological standpoint. Regardless of the LID techniques proposed, the report misconstrues the requirements of the Permit such that the conclusions vis-à-vis percentage of total project cost are entirely indefensible.

As a threshold matter, the authors misunderstood that an interior remodel that does not replace or add impervious surface would not trigger the Permit's requirements. Thus, the basis for their low-end estimate of redevelopment cost is a number far below any true redevelopment cost that would be associated with actually adding or replacing roof or other impervious surfaces. The applicability section of the Permit on page 46 specifies that redevelopments must comply with the Permit *only* when they result in the addition or replacement of impervious surface. An interior "remodel" would not add or replace impervious surface; only a demolition and reconstruction would do so. Consequently, the $50 per square foot low-end estimate should be revised to a more reasonable reconstruction—not remodel—cost figure, so as to allow an accurate calculation of the relative cost of the LID features compared to total construction cost.

Typical commercial construction costs range from $160 per square foot to $350 or more per square foot.[28] The authors' high-end estimate of $250 per square foot is, hence, an average cost figure for redevelopment. Using this more appropriate range, the total project cost (for the

[27] EPA LID Study at 12.
[28] *See, e.g.*, Saylor Publications, Inc., Square Foot Building Costs, at http://www.saylor.com/lacosts.

130,000 square foot building) is $21 million to $46 million. Just with this initial change in cost estimates, the "% of total redevelopment cost" figures given in the study changes from 4-22% to 3-6% for the "high volume interpretation" and from 1-3% to 0.5-1% for the "low volume interpretation."

Digging further into the report's assumptions, the authors once again misconstrued the applicability section of the permit. If the building alone were being redeveloped and the parking lot were left in its existing condition, the project would not obligated to comply across the entire site because it would result in an alteration of less than 50% of the impervious surface, thus requiring that only the altered portion comply with the permit. As the building footprint is slightly less than 25% of the site (approximately three out of 12.4 acres), the stormwater infrastructure costs would thus drop to about $300,000 or $50,000, depending on the high vs. low volume interpretation; the "% of total redevelopment cost" figures given in the study, consequently, would drop to 0.7-1.5% or 0.1-0.2%, respectively.

If the project altered more than three acres of the parking lot, as well as the entire building footprint, then the entire site would be required to comply with the Permit. However, in this situation, to find a meaningful value for the percentage of total redevelopment cost, one would have to calculate the costs of the stormwater infrastructure and landscaping that would otherwise be required by law or desired by the developer (for instance, the developer would surely include landscaping in the parking lot for aesthetic reasons, regardless of its stormwater functionality), and those costs would have to be deducted from the 3-6% or 0.5-1% of total redevelopment cost figures calculated above. It is thus impossible to draw any real conclusions from the study because of the lack of complete cost data. Without such data, even using correct redevelopment cost assumptions, the study actually tells us nothing that we want to know in terms of the marginal costs of complying with the permit vs. complying with requirements that would exist anyway in the absence of the permit.

IV. Conclusion

We commend the Regional Board staff's efforts to prioritize LID stormwater management practices and to establish an EIA limitation as the performance standard for BMP implementation in the Permit. Studies have demonstrated that attainment of this standard is feasible, and even so, the Permit contains sufficient alternative compliance criteria that (once properly revised) should allow equivalent results while granting developers more flexibility. Nonetheless, we believe that the effectiveness of the Permit's provisions could be compromised by various defects, especially the overbroad waiver language, the delta volume sizing criterion, and the Permit's failure to specify clearly that onsite retention (and not simply capture and discharge) is required. We have recommended various ways to remedy these and other problems, and we strongly urge the Regional Board to adopt these revisions.

We look forward to working further with Regional Board staff on the Permit and encourage you to contact us with any questions regarding our suggestions or the documents we have provided.

Sincerely,

David Beckman
Bart Lounsbury
Natural Resources Defense Council

Garry Brown

Orange County Coastkeeper

Critique of Certain Elements of "Low Impact Development Metrics in Stormwater Permitting"

By Richard Horner

GENERAL CONCLUSION

While the authors drew certain negative (and not always well-founded, as explained below) conclusions about a maximum 3-5 percent effective impervious area ("EIA") site design criterion, the results of the report's analysis overall contribute to the growing consensus that implementing LID according to a numeric metric is technically feasible in both new development and redevelopment contexts. The results thus buttress my findings in analyses performed earlier for San Diego and Ventura Counties and for the San Francisco Bay Area (Horner 2006; 2007a, b) and support the feasibility of meeting a 5% EIA standard in southern California. However, the report's suggestion that a "delta volume" standard be adopted would depart from standard and well-accepted practice in the United States, resulting in significantly greater volumes of stormwater with concomitant, significant increases in the mass volume of a range of pollutants in stormwater.

CRITIQUE OF WATER QUALITY TREATMENT DESIGN BASIS

The authors of Low Impact Development Metrics in Stormwater Permitting ("the report") propose and employ in their case studies a quantity they term "excess stormwater runoff," which forms the basis for their sizing and designing of low impact development ("LID") facilities to treat stormwater runoff. In footnote 21 on page 31, the authors have defined "excess stormwater runoff" as the volume of post-development runoff minus pre-development runoff for the 85th percentile storm event (or for an equivalent water quality design event). However, using the differential volume ("delta volume") between pre- and post-development conditions breaks the long-standing national and state precedent of using the full volume of stormwater discharged from the developed site as the basis for stormwater best management practices ("BMPs") that store runoff for longer than a few minutes.

The virtually universal adoption (see examples below) of the full water quality volume instead of the delta volume occurred for good reasons. The total runoff volume from the 85th percentile event—the prevailing design standard in southern California—was determined through objective analysis to represent the point above which substantially diminishing returns in water quality improvement would accompany considerable size enlargement and, therefore, cost (Guo and Urbonas 1996). The analysis identified the *full* volume generated by the 85th percentile event—not some lesser quantity like the delta volume—as the appropriate threshold at which the decrease in benefits accelerates.

The use of a differential hydrologic measure that compares pre- and post-development states is common in the management of storm runoff quantity (i.e., hydromodification). The pre- vs. post-development measure is appropriate in that situation because successfully matching pre-

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and post-development hydrologic characteristics causes no modification in the hydrologic status of the receiving water and, hence, no negative physical effects. When managing water quality, in contrast, any untreated volume (in the delta volume scenario, this would be the amount that originally flowed from the undeveloped land) would deliver to the receiving water the many pollutants characteristic of urban runoff. There, these pollutants would create negative physical, chemical, and biological effects. On the other hand, if the appropriate water quality volume is used (i.e., no less than the full volume of the 85th percentile event), the LID-based stormwater management BMPs should deliver no pollutants to the receiving water, since the retention and reuse or infiltration of that volume is practicable and achievable, as I have demonstrated separately by analyzing a range of development scenarios in southern California.

The loss in treatment capacity from using the delta volume measure, and hence the loss in water quality protection, would vary depending on climatology and the characteristics of the undeveloped parcel and the developed site (type of pervious and impervious land cover, soil, slope, etc.). In the Walnut Village and 60 California case studies presented in the report, the difference ranged from 15 to 20 percent and could be higher in different scenarios. This difference is not small, considering that the National Stormwater Quality Database (Pitt, Maestre, and Morquecho 2004) shows that pollutants like solids, metals, nutrients, and bacteria are typically present in urban runoff at concentrations two to five times as high as in storm flow from undeveloped land. Discharging the pre-development volume, contaminated by urban pollutants without any water quality treatment, would subject human users and aquatic life to substantial runoff quantities with pollutant mass loadings and potentially acutely toxic pollutant concentrations. These loadings and concentrations would be increased by factors of approximately two to five, compared to the pre-development state, thus compromising the beneficial uses of the water body that existed before development. It is essential for resource protection that the full post-development volume be retained onsite through infiltration, evapotranspiration, and/or harvesting for reuse.

As pointed out above, adopting a volumetric basis for stormwater treatment design and then subjecting that full volume to onsite retention or treatment has been the rule in the United States. Jurisdictions take differing approaches to defining that volume, but, once it is set, they utilize the entire quantity as the basis for BMP design. Common approaches include the storm percentile method: a storm event of selected frequency and duration is chosen, which correlates to a certain depth of precipitation spread over a watershed area. In addition to southern California, Georgia provides an example of the first approach (http://www.georgiastormwater.com/vol2/1-3.pdf at 1.3-1):

> Treat the runoff from 85% of the storms that occur in an average year. For Georgia, this equates to providing water quality treatment for the runoff resulting from a rainfall depth of 1.2 inches.

The state of Washington employs a second approach, actually in relation to a storm percentile analysis (http://www.ecy.wa.gov/pubs/0510029.pdf at 2-28):

> Water Quality Design Storm Volume: The volume of runoff predicted from a 24-hour storm with a 6-month return frequency (a.k.a., 6-month, 24-hour storm). Wetpool

> facilities are sized based upon the volume of runoff predicted through use of the Natural Resource Conservation Service curve number equations in Chapter 2 of Volume III, for the 6-month, 24-hour storm. Alternatively, the 91st percentile, 24-hour runoff volume indicated by an approved continuous runoff model may be used.

Numerous jurisdictions, such as Maine, use the precipitation depth approach (http://www.maine.gov/dep/blwq/docstand/stormwater/stormwaterbmps/vol3/chapter2.pdf at 2-12):

> Stormwater management facilities must be designed to treat the first 1 inch of runoff ...

Maryland (http://www.mde.state.md.us/assets/document/chapter2.pdf at 2.1):

> P= rainfall depth in inches and is equal to 1.0" in the Eastern Rainfall Zone and 0.9" in the Western Rainfall Zone ...

Pennsylvania (http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=| at 3.3.4):

- Stormwater facilities shall be sized to capture at least the first two inches (2") of runoff from all contributing impervious surfaces.
- At least the first one inch (1.0") of runoff from new impervious surfaces shall be permanently removed from the runoff flow – i.e., it shall not be released into the surface Waters of this Commonwealth. Removal options include reuse, evaporation, transpiration, and infiltration.

and North Carolina (http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf at 2-2):

> Non-coastal counties: Control and treat the first 1.0" of rain. (Note: a more complex basis applies to coastal counties.)

In none of these cases does the stormwater treatment design basis involve a delta volume computation such as advocated by the authors of the report.

CRITIQUE OF CASE STUDIES

Even though the report forthrightly demonstrates technical feasibility, it nonetheless takes a somewhat negative stance by overemphasizing difficulties and high costs, both of which are poorly justified. The report, moreover, is devoid of estimates of the benefits that accrue from reducing the discharge of pollutants to receiving waters, recharging groundwater through infiltration, conserving water through harvesting and reuse, and decreasing hydromodification of

receiving waters. I made such estimates in my previous reports, and these benefits are very significant. For example, I concluded that (Horner 2007a):

> Draining impervious surfaces onto the loam soils typical of Ventura County, in connection with limiting directly connected impervious area to three percent of the site total area, should eliminate storm runoff from some development types and greatly reduce it from more highly impervious types. Adding roof runoff elimination to the LID approach (by harvesting or directing it to downspout infiltration trenches) should eliminate runoff from all but mostly impervious developments. Even in the development scenario involving the highest relative proportion of impervious surface, losses of rainfall capture for beneficial uses could be reduced from more than 85 to less than 40 percent, and pollutant mass loadings would fall by 83-95 percent from the untreated scenario when draining to pervious areas was supplemented with water harvesting.

Failure to include a discussion of such important benefits inappropriately biases the report against feasible LID numeric performance standards such as an EIA limitation. There is a somewhat grudging admission that LID based on an EIA limitation can be implemented, but this is countered with assertions that doing so will take some extra work and cost too much. Both of these negative claims should not be given much weight for the reasons stated below. Furthermore, neglecting the aforementioned very real and important benefits of robust LID implementation omits the counterbalancing consideration that the aquatic environment will be better protected with an improved site design paradigm.

Additionally, the report fails to take into account two aspects of LID that are at least relatively cost-neutral or, in many configurations, even cost-saving. First, landscaping is a normal part of developed and redeveloped sites and can serve stormwater management purposes, as well as aesthetic purposes, with little or no extra cost. Second, most LID practices primarily utilize soft infrastructure instead of more expensive hard infrastructure like extensive piping and concrete. While the cost analyses presented in the report were poorly detailed in the first place, as discussed in greater depth below, it appears that these financially mitigating factors were not even considered.

Walnut Village

The report's presentation of the multi-family residential Walnut Village redevelopment project reflects the general criticisms noted above. It demonstrates the technical feasibility of implementing LID practices according to an EIA limitation (in fact, the authors achieved an EIA of zero), stating, "this result ... illustrates that LID benefits can be achieved by both extensive implementation (i.e., routing of runoff to vegetated systems) and more intensive design of active landscaping (i.e., greater retention depth) where opportunities exist."

Nevertheless, the authors put a negative spin—unjustified, in my opinion—on this success. In one negative passage the report declares, "the 14-17 inches of retention required to capture the delta 2-year volume is much less feasible, as it would require a combination of fairly deep amended soils and significant surface storage." I contend that providing 14-17 inches of storage in surface ponding and soil pores is entirely feasible. For instance, 18 inches of amended soils

with 33 percent porosity would provide 6 inches of storage, which could be supplemented by 8-11 inches of above-grounded temporarily ponded volume, a thoroughly feasible design. Elsewhere, the report characterizes decreasing EIA from 18 to 0 percent as "difficult," although this decrease merely involves converting non-essential hardscape to landscaping. The reader is left to wonder why any developer would choose to buy and install *non-essential* asphalt or concrete (almost certainly more expensive than LID landscaping) rather than constructing vegetated BMPs that would be an asset in more ways than one. In my opinion, it is more "difficult" from fiscal and marketing perspectives to justify the use of pavement for no reason. In any case, whatever impression one has of this issue, from a technical, objective perspective, the report does not contain a reasonably complete and even-handed assessment of costs, significantly undercutting its claims of infeasibility. Likewise, subjective and undefined assertions regarding the "difficulty" of meeting even relatively high volumes (such as the two-year storm) are presented without supporting analysis or justification which, once again, limits the utility of the report.

Further, with regard to landscaping, the final sentence in the case study states, "landscape plans typically include features that restrict usage of landscaping for runoff control (e.g., tree choice can limit inundation depths and duration), therefore, it is unreasonable to assume that all landscaping may be available." There is no reason why landscaping plans should be incompatible with vegetative LID practices, however. Bioretention cells and similar LID features routinely include trees, which serve several important hydrologic roles (rainfall interception, advancing infiltration by opening conveyance pathways through soil, water storage in tissues, and transpiration). It is no challenge for landscape designers to select trees that are not limited by moisture conditions in such BMPs.

The Walnut Village site has hydrologic group B soils, to which the authors assigned an infiltration rate of 0.2 inch/hour, assuming that the soils would be "compacted". They thereby ignore a fundamental LID practice: guarding against the removal and compaction of soils outside the active building area during construction (Hinman 2005). While infiltration rates vary depending on the specific soil type within a hydrologic soil group, B soils overall have rates much above the authors' assumption; i.e., 0.5-1 inch/hour (http://www.vcstormwater.org/documents/workproducts/landuseguidelines/appC.pdf). The National Resource Conservation Service (2007) observes that, "Soils that are deeper than 100 centimeters [40 inches] to a water impermeable layer or water table are in Group B if the saturated hydraulic conductivity of all soil layers within 100 centimeters [40 inches] of the surface exceeds 4.0 micrometers per second (0.57 inches per hour) but is less than 10.0 micrometers per second (1.42 inches per hour)." It would be irresponsible building practice anywhere, and certainly in a development that is implementing LID practices, to permit such indiscriminant soil disturbance that across the landscape the infiltration rate is decreased to as little as 15 percent of its natural magnitude.

The infiltration rate assumption has consequences for the analysis and the authors' interpretation of their results. While the report shows that adequate volume attenuation could be accomplished to meet the case study's stated objectives, with the 0.2 inch/hour infiltration rate, active landscaping drain times could exceed the recommended 72-hour maximum and approach 83 hours. If the infiltration rate were just slightly higher at 0.3 inch/hour, though, drawdown would

occur 50 percent faster and easily lower the drain time beneath the maximum. Avoiding the drastic diminution in hydraulic conductivity that the authors have assumed is eminently achievable on the site's B soils and would produce an even more optimistic picture than the already successful Walnut Village hypothetical design.

The authors observe that imposing a fixed EIA standard alone promotes the routing of runoff to vegetated systems but does not boost the companion strategy of pursuing more intensive design of active landscaping. In so doing, the authors provide a valuable service in pointing out that a design basis must accompany the EIA limitation for real effectiveness. An example of such a comprehensive standard is:

> Limit effective impervious area to 3 percent. Impervious surfaces can qualify as "ineffective" only when the entire volume of runoff (based on the design storm) from those areas is captured onsite through infiltration, evapotranspiration, and/or harvesting for beneficial use. In the rare circumstance in which onsite compliance is infeasible according to established criteria, the permittee or developer shall identify opportunities for off-site mitigation in the same sub-watershed that will achieve the overall goal of reducing effective impervious area to no more than the 3 percent design standard.

60 California

Like the Walnut Village case study, the authors' presentation of the 60 California multi-use commercial/retail redevelopment project also tends in an overall manner to support my own analyses and conclusions regarding the practicability of meeting the 5% EIA standard. This case study, too, demonstrates the technical feasibility of meeting a maximum 5 percent EIA standard, in this case by employing a green roof and water harvesting on a highly constrained site. Once again, though, the authors put forth some negative interpretations that are, in my opinion, unjustified.

One such claim is that green roofs and cisterns are generally beyond the level of BMP implementation in common practice in the United States nowadays. In fact, both practices are no longer at all unusual. Without attempting any comprehensive literature review of applications, I would note that Chicago has numerous green roofs in place, most prominently on its city hall (http://www.artic.edu/webspaces/greeninitiatives/greenroofs/main_map.htm). In Seattle, green roofs top a growing number of public and private buildings (http://www.seattle.gov/DPD/GreenBuilding/OurProgram/Resources/TechnicalBriefs/DPDS_009485.asp#case). Seattle's city hall also harvests rain for graywater supply and irrigation, as does the county administration building and a neighborhood environmental education center (http://www.harvesth2o.com/seattle.shtml). The Texas Water Development Board (2005) prepared an excellent, practical manual on water harvesting at all scales, complete with examples in place and design calculations. The manual covers the entire state of Texas, whose western areas have rainfall conditions very much like southern California's. Hence, little adaptation is needed to use the manual's recommendations here.

The report also claims that the suitability of green roofs for southern California is not well understood and that, "during the rainiest times of the year in southern California, the potential

evapotranspiration is the lowest, meaning that the ability to regenerate storage capacity between storms is low." It is true that the potential is lowest during the wettest season, but, given the frequent sun and relative warmth during dry intervals in the southern California winter, the regenerative ability is still not "low." Berghage et al. (2007) performed green roof research at Pennsylvania State University (PSU). They found that over 50 percent of annual stormwater volume was retained and not discharged, even with as little as 20 mm (under 1 inch) of storage capacity, and the site reduced peak discharge rates to no more than the pre-development level for the 2-, 25-, and 100-year frequency events. PSU is located in Centre County, PA, where precipitation is not highly seasonal but tends to be slightly greater in the summer, compared to other months. Pan evaporation rates there range from 3.3 to 4.2 inches/month during June-September (http://www.pa.nrcs.usda.gov/technical/Engineering/PaRainEvapRunoff.pdf). The November-February Los Angeles pan evaporation range is 3.5 to 4.0 inches (http://www.calclim.dri.edu/ccda/comparative/avgpan.html). Therefore, Los Angeles has as much evaporation potential in the months when it most needs that potential as locations with successful green roofs elsewhere. Similar research should be performed in California, but enough encouraging evidence exists to begin establishing full-scale projects, which can be monitored to confirm performance and refine design guidance for the region.

A final negative point made by the report is that green roofs and water harvesting may conflict with existing building and health codes. Codes should not be regarded as an unbending constraint on moving to new, more environmentally beneficial technologies. As experience in the growing number of applications of both practices shows, building safety and health are not being compromised. If constraints do exist in a jurisdiction's codes, they should be examined to assess their justification and revised if no overriding reasons exist to maintain them. Indeed, it is my understanding that municipal separate storm sewer permits often if not always require that local codes be amended to support implementation of programs and approaches to reduce stormwater pollution.

Redevelopment of Kmart Site

The Kmart site redevelopment case study was based on the use of vegetated filter strips and infiltration trenches. Its primary purpose was to estimate costs for these practices by apparently taking a challenging site with relatively poor soils. As an initial manner, the decision to evaluate only one site to reach a conclusion about costs of LID practices is suspect. This is particularly the case when, as here, the report's conclusions tend to contradict mainstream evaluations of the cost of implementing LID. Such studies, including an analysis of several projects by the U.S. Environmental Protection Agency, report significant cost savings compared to traditional water quality approaches across the vast majority of building sites.

More specifically, there are several flaws in the foundation of this case study. The authors developed estimates of runoff volume in pre-development and post-development conditions by using the Natural Resources Conservation Service's Curve Number Method, which is well-known to overestimate the pre-development hydrologic characteristics and thus set the wrong targets for post-construction designs. The site has hydrologic group C soils. The authors performed calculations assuming an infiltration rate of 0.5 inch/hour, higher than the rate used for B soils in the Walnut Village case study (an unexplained discrepancy). There appears to

have been no consideration of organically amending soils to increase water storage and improve infiltration. Soil amendment for these purposes is a very common LID practice, especially in group C soils. The authors appear to have given some thought to other LID practices (tree boxes, bioretention, pervious pavement, green roofs, and water harvesting) but rejected all of them for unexplained reasons. Failure to use a broader pallet of alternatives and soil amendment indicates that the case study may not have been based on the most technically effective and/or cost-effective choices.

This case study fails to convincingly meet its objective of demonstrating what the LID designs would cost, in large part because the authors give no detail whatsoever regarding how the cost figures were derived. The per-acre and percentage-of-redevelopment costs are simply not credible unless their derivation can be traced and confirmed. The cost analysis also suffers from the general criticisms stated above regarding costs: it implicitly assigns all landscaping costs to the filter strips, although these areas would be landscaped anyway at roughly the same cost; the analysis further fails to recognize that stormwater runoff must be conveyed and managed in some way, and those obligations carry costs, which are probably higher if performed conventionally through the use of large quantities of piping and concrete. With these shortcomings in analysis, it is assuredly not justified to say, as the case study conclusions do, that, "[i]t is clear from the Kmart case study cost estimates that the proposed draft permit requirements would significantly increase the drainage costs of urban redevelopment projects." And although more difficult to monetize, environmental benefits—and their economic value to society—are entirely neglected in this case study, as in the others.

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FEB 18 2009

February 13, 2009

By E-mail and U.S. Mail

Gerard Thibeault
Executive Officer
California Regional Water Quality Control Board, Santa Ana Region
3737 Main Street, Suite 500
Riverside, CA 92501-3348

Subject: Comment Letter, Tentative Order No. R8-2008-0030 NPDES No. CAS618030

Dear Mr. Thibeault:

Thank you for the opportunity to comment on *Waste Discharge Requirements for the County of Orange, Orange County Resources and Development Management Department* (sic) *and the Incorporated Cities of Orange County Within the Santa Ana Region Areawide Urban Storm Water Runoff Orange County* (Tentative Order No. R8-2008-0030). The County as Principal Permittee welcomes the opportunity to provide comments. The Permittees were involved in the development of these comments and the cities of Anaheim, Brea, Costa Mesa, Cypress, Fountain Valley, Fullerton, Garden Grove, Huntington Beach, Irvine, La Habra, La Palma, Laguna Hills, Placentia, Santa Ana, Seal Beach, Stanton, Tustin and Westminster have directed that they be recognized as concurring entities with this letter.

In summary, our comments conclude that the draft Tentative Order must be revised for five key reasons including that the new requirements:

- Are outside the scope of the authority given by the Federal Clean Water Act to the SARWQCB
- Lack sound technical basis
- Increase administrative burdens without scientific justification
- Over-extend the regulatory reach of local agencies
- Create new requirements for new development and re-development projects without justification.

The Orange County Stormwater Program (the "Orange County Program" or "Program") has been in existence under a National Pollutant Discharge Elimination System (NPDES) permit since 1990. This permit was re-issued in 1996 and 2002. In 2006, the Permittees submitted a Report of Waste Discharge (ROWD) in anticipation of permit renewal in 2007. The basis of this document was a comprehensive program assessment undertaken using a multiple lines of evidence approach, including audit findings, facilitated workshops, and the California Stormwater Quality Association (CASQA) Municipal Stormwater Program Effectiveness

Assessment Guidance. The ROWD identified many positive program outcomes and proposed changes and added program development commitments to the Drainage Area Management Plan (DAMP) where the assessments indicated the need for improvement.

In the ROWD and proposed plan (the 2007 DAMP), the Permittees committed to enhancing program implementation, developing BMPs for identified countywide water quality constituents of concern, and establishing a watershed-based approach to water quality planning and protection to complement the countywide management effort. While the Permittees want to commend your staff on both their efforts to incorporate the recommendations made in the ROWD into the Tentative Order and willingness to support the deliberations of the land development stakeholder group, a number of key concerns must be recognized. These concerns, which relate to the proposed new requirements intended to increase Permittee accountability, extend the regulatory reach of local jurisdictions, incorporate additional TMDLs, and create a new basis for the land development requirements of the Order, are now being significantly amplified by the worsening deterioration of the economy. Indeed, a significant number of Permittees have specifically expressed their concern regarding the creation of additional mandates at a time of forced staff reductions and increasingly severe fiscal circumstance.

The substantial body of programmatic performance and environmental quality data that informed the ROWD has since been augmented by two additional annual reports. While the Permittees believe that the additional reports largely affirmed the ROWD commitments, this comprehensive and augmented dataset presents a basis and an opportunity for a cooperative and informed consideration and resolution of the Permittees' concerns. In this regard, the current series of stakeholder meetings to discuss the Tentative Order's land development provisions, as well as the meeting with your staff on January 29, 2009, have been productive. We look forward to continuing to meet with you to discuss the areas of contention and to achieve a timely resolution. In the interim, we have summarized our overarching concerns with the Tentative Order as General Comments in this letter and provide additional comments and concerns in the following Attachments:

- Attachment A: Legal and policy issues and comments
- Attachment B: Technical comments and suggested revisions
- Attachment C: Monitoring and Reporting Program comments

GENERAL COMMENTS

I. Increasing Administrative Burden

At the inception of the Orange County Program the County of Orange, as Principal Permittee, and the 26 Permittees developed a DAMP to serve as the principal policy and programmatic guidance document. Since 1993, the DAMP has been modified through an adaptive management process to reflect the needs of the Permittees, ensure Permittee accountability, and deliver positive water quality and environmental outcomes. The DAMP now provides definitive guidance to each Permittee in the development of its Local Implementation Plan (LIP), which specifically describes how the Orange County Program will be implemented on a city/jurisdiction basis. Concurrently, the annual progress report has been developed into a rigorous systematic assessment of program effectiveness that is conducted at jurisdictional, watershed and countywide levels of resolution, using the CASQA Municipal Stormwater

Program Effectiveness Guidance, and with identified *headline measures* of programmatic performance. The Tentative Order requires additional reporting to the Regional Board staff. The Permittees believe that adjusting the existing reporting processes, rather than creating additional reporting requirements, is the most effective approach to increasing transparency and accountability. Such an approach also offers the additional potential benefit of identifying opportunities to reduce the administrative burden of the Program for both the Regional Board and for the Permittees.

II. Extending the Regulatory Reach of Local Jurisdictions

In the most recent annual report, the Permittees noted that over 30,000 industrial and commercial facilities in Orange County were subject to inspection for compliance with local water quality ordinances. Nonetheless, the Tentative Order includes new requirements that arbitrarily increase the universe of commercial facilities subject to inspection, mandates the annual inspection of treatment controls in completed land development and re-development projects, and more prescriptively turns the attention of the Permittees toward residences and mobile businesses. Key elements of this overarching concern are the significant resource implication for cities and the absence of technical justification.

The Permittees, in the detailed program assessment that preceded the ROWD, did not discern a rationale for a more inclusive inspection of commercial enterprise nor is one presented in the Findings of the Tentative Order. With land development projects, the installation and subsequent maintenance of treatment controls certainly needs to be verified. However, self certification is already a verification mechanism being used by Permittees and it and other third party verification mechanisms should not be precluded by the Order in exclusive favor of Permittee inspection. The current opportunity to strategically re-consider the use of inspection resources should be used to target and focus these activities rather than simply expand their scope. Furthermore, given the current state of the economy, the Permittees, like all municipalities, are facing shrinking budgets and the Regional Board should give great weight to the best use of limited resources in achieving water quality objectives.

The prescribed creation of a residential program also needs to be carefully considered. The effectiveness of *Project Pollution Prevention*, the public education and outreach initiative of the Orange County Program, has been validated by public opinion surveys that show incremental, but also statistically significant, increases in public awareness of stormwater issues and positive changes in protective behaviors. The new residential program requirements therefore appear duplicative of the current public education and outreach obligations that have already produced and continue to yield positive measurable outcomes. However, there is also a separate concern that prescribed efforts to "require residents to implement pollution prevention measures" (XI. 2) will engender resistance among some segments of the public and be counter-productive to long term efforts to engender stewardship. The justification for this additional program when current requirements have produced positive outcomes has not been provided and we recommend that it be deleted from the Tentative Order.

The last area of prescribed new regulatory oversight is mobile businesses. The Permittees have already produced educational materials for these businesses, cooperatively developed wash water disposal options with Orange County's sewering agencies, and coordinated on enforcement. The further required regulation of these businesses is a potentially resource intensive undertaking that currently appears to lack a strong technical rationale.

III. Creating a New Basis for the Land Development Requirements of the Order.

The Model Water Quality Management Plan (WQMP) prepared for the Third Term Permit explicitly recognizes the channel stability implications of watershed urbanization and provides for this potential impact to be addressed as a hydrologic condition of concern. It also requires consideration of Site Design Best Management Practices (BMPs), now more commonly referred to as Low Impact Development (LID) BMPs. The commitment made in the ROWD was to adjust the Model WQMP to incorporate work being undertaken on hydromodification by the Southern California Coastal Water Research Project, which is still pending. Since that time, various hydrograph matching requirements have appeared in municipal stormwater permits, including the Tentative Order and an Effective Impervious Area (EIA) of 5% or less has appeared as a performance standard for land development.

The EIA requirement for land development is inappropriately establishing a watershed assessment metric as a site specific performance standard. It is also establishing an unreliable surrogate for flow reduction (see case study discussion in Attachment B) as the basis for conformance with the stormwater mandate. Moreover, there is currently no clear technical consensus on control standards for hydromodification (also noted in Attachment B). In addition, the Permittees believe that the highly urbanized condition of Orange County's watersheds in the Santa Ana Region needs to be carefully considered. Over the period of the next permit, new development will be composed almost entirely of infill or redevelopment projects that will subject to other mandated development standards intended to encourage denser development. These additional mandates will present a significant challenge to developing and implementing effective approaches to both LID and hydromodification for achieving prescribed levels of site performance and meaningful ecological outcomes.

The uncertainties and challenges noted above have been highlighted in the series of stakeholder meetings convened specifically to examine the land development provisions of the Tentative Order. This group's discussions, in which the County actively participates, have been helpful to facilitating broader understanding of the perspectives of key constituencies and productive in identifying a number of early general areas of agreement. While these general areas have already been discussed with you, they are reiterated below and endorsed as the basis for initial adjustments to the current land development provisions of the Tentative Order. The general areas of agreement, which may be "backstop" or "default" requirements until a watershed based standard can be developed either through a watershed specific plan or an updated watershed action plan, are:

1. Performance standards for implementing Low Impact Development BMPs other than an EIA percentage (3-5%) are acceptable if a technically equivalent standard can be identified.

2. Sizing LID BMPs to capture the 85th percentile storm event (current DAMP criteria for water quality volume) is an acceptable alternative to EIA as a performance standard provided that technically-based, strict, and clear feasibility criteria are developed for any project that cannot meet the LID BMP requirements.

3. Prioritized LID/SUSMP BMPs for water quality volume capture are represented by: a) infiltration BMPs; b) harvesting and reuse BMPs; c) vegetated (or evapotranspiration)

BMPs including bioretention and biofiltration. Water quality volume not captured by LID BMPs shall be treated consistent with DAMP requirements

It should also be noted that any new or revised obligations with respect to land development would require a minimum of at least 12 months for the Permittees to develop the technical resources and effectively implement new standards, including training and guidance for the development community.

IV. Using Available Programmatic Performance and Environmental Quality Data

In advance of preparing the ROWD the Permittees undertook a detailed program assessment drawing upon prior annual report findings, a comprehensive environmental quality database, audit findings, facilitated workshops, and the CASQA Municipal Stormwater Program Effectiveness Assessment Guidance. This assessment provided a strong technical basis for improvements to the Orange County Program recommended in the ROWD and which have been subsequently validated in later annual progress reports. These informational resources and, in particular, the environmental quality database, have been compiled at great expense and provide unique and site specific information on the state of Orange County's surface waters and the performance of the Orange County Program. Strong technical justification developed from the information that has been compiled over the last 18 years by the Permittees is needed to support requirements in the Tentative Order supplemental to the ROWD recommendations. New requirements must also be consistent with the federal stormwater regulations and within the scope of the Clean Water Act. The Tentative Order has attempted to step outside the scope of the authority provided by the Clean Water Act by including the regulation of non-point sources. The Permittees believe that these sections of the Tentative Order should be revised to be in compliance with the appropriate federal laws.

We appreciate the effort that you and Regional Board staff have devoted to the development of the fourth term permit for the Orange County Program. We look forward to meeting with you and the staff to quickly resolve the Permittees' concerns regarding the Tentative Order to ensure that it meets our mutual goals.

Thank you for your attention to our comments. If you have any questions or need additional information please contact Richard Boon at (714) 955-0670 or Chris Crompton at (714) 955-0630.

Sincerely,

Mary Anne Skorpanich
Director, OC Watersheds Program

cc: City Permittees

ATTACHMENT A

LEGAL ISSUES AND COMMENTS ON TENTATIVE ORDER NO. R8-2008-0030 NPDES NO. CAS618030

INTRODUCTION

Attachment A contains the principal legal comments of the County of Orange (the "County") on Tentative Order No. R8-2008-0030 dated November 10, 2008 ("Tentative Order").

The County has endeavored to provide a complete set of comments on the Tentative Order. However, the County reserves the right to submit additional comments relating to Tentative Order No. R8-2008-0030 and the supporting Fact Sheet/Technical Report to the Regional Board in the future.

COMMENTS

THE TENTATIVE ORDER IMPROPERLY ATTEMPTS TO PRESCRIBE CONDITIONS THAT GO BEYOND THAT REQUIRED BY FEDERAL LAW

The Tentative Order includes new requirements that are more demanding than those mandated by federal law. One specific example is the significant increase in the universe of commercial facilities subject to inspection. Federal Clean Water Regulations governing MS4 systems do not require operators of those systems to have an inspection program for construction, industrial, and commercial sites. For the Regional Board to include these new commercial facilities as part of the Permittees inspection program, the Regional Board must consider the economic effects of this expansion as stated by the California Supreme Court in ***City of Burbank v. State Water Resources Control Bd.*** (2005) 35 Cal. 4th 613. In that case, the Supreme Court stated that:

> "The federal Clean Water Act reserves to the states significant aspects of water quality policy (33 U.S.C. § 1251(b)), and it specifically grants the states authority to 'enforce any effluent limitation' that is not 'less stringent' than the federal standard (33 U.S.C. § 1370). It does not prescribe or restrict the factors that a state may consider when exercising this reserved authority, and thus it does not prohibit a state-when imposing effluent limitations that are more stringent than required by federal law-from taking into account the economic effects of doing so." (***City of Burbank***, 35 Cal. 4th at 627)

The mere fact that the State has the authority under section 402(p)(B) of the Clean Water Act to prescribe conditions in excess of those specifically enumerated by Congress or the U.S. EPA does not mean that those requirements automatically fall under the umbrella of federal regulation. To the extent that a requirement contained in the Tentative Order is more prescriptive or specific than those outlined in the Clean Water Act and accompanying

regulations, the Regional Board must comply with the statutory requirements set forth in the California Porter-Cologne Water Quality Control Act.[1]

Furthermore, Article XIII B, section 6 of the California Constitution requires the State to give funding to reimburse local governments for the costs associated with a new program or higher level of service mandated by the Legislature or any State agency. Cal. Const., art., XIII B, § 6. An exception is made for "mandates of . . . the federal government which, *without discretion*, require an expenditure for additional services or which *unavoidably make the providing of existing services more costly*." Cal. Const. art., XIII B, § 9(b) (emphasis added); ***Sacramento v. California (Sacramento II)***, 50 Cal. 3d 51 (1984). However, this exception applies only where "the State had no 'true choice' in the manner of implementation." ***Hayes v. Commission on State Mandates***, 11 Cal. App. 4th 1564, 1593-94 (1992) (citing ***Sacramento II***). As discussed above, the Tentative Order's new inspection requirements go beyond what is required under the Clean Water Act. Thus, to the extent the Regional Board chooses to exercise discretion to impose such requirements on the Permittees, it must comply with the prohibition against unfunded mandates set forth in the California Constitution.

THE TENTATIVE ORDER IMPROPERLY INTRUDES UPON THE PERMITTEES' LAND USE AUTHORITY IN VIOLATION OF THE TENTH AMENDMENT OF THE U.S. CONSTITUTION AND IMPOSES A PRESCRIPTIVE STANDARD AS TO COMPLIANCE WITH THE TENTATIVE ORDER

To the extent that the Tentative Order relies on federal authority under the Clean Water Act to impose land use regulations and dictate specific methods of compliance, it is in contravention to the separation of powers between the regional board and the local governments. Furthermore, to the extent the Tentative Order requires a Municipal Permittee to include Low Impact Development (LID) principles, specifically the 5% or lower Effective Impervious Area (EIA) standard, in local land use regulations, it also violates the Tenth Amendment of the U.S. Constitution. According to the Tenth Amendment:

> "The powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people."

Article XI, section 7 of the California Constitution guarantees municipalities the right to "make and enforce within [their] limits all local police, sanitary and other ordinances and regulations not in conflict with general laws." The United States Supreme Court has held that the ability to enact land use regulations is delegated to municipalities as part of their inherent police powers to protect the public health, safety, and welfare of its residents. *See* ***Berman v. Parker*** (1954) 348

[1] The Porter-Cologne Water Quality Control Act requires that all regulations adopted pursuant to State law must be "reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible." Water Code § 13000. Furthermore, any regulations relating to discharges must be based on water quality objectives that are "reasonably required for that purpose." Water Code § 13263. All water quality objectives adopted by the Regional Board must be reasonably achievable and take into account a variety of factors including, but not limited to, those factors enumerated in Water Code section 13241.

U.S. 26, 32-33. Because it is a constitutionally conferred power, land use powers cannot be overridden by State or federal statutes.

The requirement that an EIA of 5% or less be incorporated in all new development and significant redevelopment projects is a considerable encroachment upon the inherent police powers specifically delegated to municipalities. The Clean Water Act only grants the Regional Board authority to regulate the discharges of pollutants through the NPDES program. Flow or volume of water is not a pollutant under the Clean Water Act. Although stormwater runoff may contain pollutants, the attempted regulation of the volume and/or flow of stormwater runoff by an EIA of 5% or less through the Tentative Order is prescriptive and effectively a land use control. The Regional Board must stay within the scope of authority provided by the Clean Water Act. Finding A.3 of the Tentative Order requires the Permittees to reduce to the Maximum Extent Practicable (MEP), through the implementation of BMPs, the discharge of pollutants in urban stormwater from the MS4s in order to support attainment of water quality standards. A standard of 5% or less EIA does not give the Permittees flexibility in the methods of achieving the water quality objectives as contemplated by the Clean Water Act and the Findings of the Tentative Order. Moreover, Water Code Section 13360 prohibits the Regional Board from specifying the manner in which Permittees are to comply with the MEP standard. This standard is an impermissible mandate on how the Permittees are to comply with the MEP and the Regional Board needs to consider various methods or approaches to achieving the goal of reduction of pollutants in the stormwater runoff and not rely strictly on a prescriptive standard.

THE TENTATIVE ORDER IMPROPERLY ATTEMPTS TO REGULATE NON-POINT SOURCES IN VIOLATION OF THE CLEAN WATER ACT

A. The Source of Selenium in the MS4 is a Non-Point Source and Should Not Be Subject to the NPDES Permit

Selenium found in the MS4 occurs by way of groundwater seepage or "rising groundwater." In Part III.3.i.c of the Tentative Order discusses rising groundwater in the context of an illicit discharge/improper disposal aspect of the program in the Federal Regulations. (See 40 C.F.R. 122.26(d)(2)(iv)(B)). The stated expectation for this section is that any problematic pollutant sources would be dealt with by either the removal of the discharge or by requiring the discharger to obtain an individual NPDES permit. The key concept here is discharge. The Clean Water Act defines a discharge as "The term 'discharge of a pollutant' and the term 'discharge of pollutants' each means (A) any addition of any pollutant to navigable waters from any point source, (B) any addition of any pollutant to the waters of the contiguous zone or the ocean from any point source other than a vessel or other floating craft.)."[2] For the addition of selenium to be a discharge, it would need to originate from a point source - i.e. there would need to be an individual or entity

[2] 33 USC 1362 (14) - The term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture.

that the MS4 Permittees could require to obtain an individual NPDES permit to cease the illicit discharge.

The Clean Water Act regulations define a load allocation (LA) as "the portion of a TMDL's pollution load allocated to a non-point source, stormwater source for which an NPDES permit is not required, atmospheric deposition, groundwater, or background source." (See 40 C.F.R. Section 1302(f)). The seepage of groundwater into surface waters falls within this definition. Additionally, as selenium is a naturally occurring element and accumulated through natural processes, the source is natural background. And, per the State's Non-Point Source Policy, seepage of groundwater into surface water can be classified as a non-point source. Furthermore, Finding C.8 of the Tentative Order specifically states that, "[t]his order is intended to regulate the discharge of pollutants in urban stormwater runoff from anthropogenic sources and/or activities within the jurisdiction and control of the Permittees and is not intended to address background or naturally occurring pollutants or flows." Thus, the selenium attributed to non-point sources cannot be regulated by the Tentative Order. To the extent that the Regional Board believes that selenium can be attributed to a point source, these NPDES-regulated stormwater discharges must be addressed by the wasteload allocation (WLA) component of the TMDL. (See 40 C.F.R. § 130.2(h)).

Part XVIII.B.3 of the Tentative Order states:

> "A collaborative watershed approach to implement the nitrogen and selenium TMDLs for San Diego Creek and Newport Bay is expected. As long as the stakeholders are participating in and implementing the collaborative approach, if approved, they will not be in violation of this order with respect to the nitrogen and selenium TMDLs for San Diego Creek and Newport Bay. In the event that any of the stakeholders does not participate, or if the collaborative approach is not approved or fails to achieve the TMDLs, the Regional Board will exercise its option to issue individual waste discharge requirements or waivers of waste discharge requirements."

The collaborative watershed approach is expected to be based on regional BMPs in order to address the diffuse nature of the non-point source rising groundwater as well as point sources where implementation of site-specific treatment controls is infeasible. Permittee participation in any program to address the rising groundwater LA of the TMDL will be on a voluntary basis.

B. Agricultural Sources are Non-Point Sources and are Not Subject to the NPDES Permit

Part III of the Tentative Order requires the Permittees to prohibit illicit/illegal discharges (non-stormwater) from entering into the MS4 unless they are authorized by NPDES permit or not prohibited in accordance with Section III.3 of the Tentative Order. Section III.3.i enumerates the specific discharges that are not prohibited unless they are substantial contributors of pollutants to the MS4 and the receiving waters. The Regional Board has included the discharge of "irrigation water from agricultural sources" in Section III.3.i.c.

The County opposes the inclusion of this phrase as worded. Agricultural sources are specifically excluded from the NPDES program as the definition of point source "does not include agricultural storm water discharges and return flows from irrigated agriculture." 33 U.S.C. Section 1362(14). The inclusion of irrigation water from "agricultural sources" goes beyond the requirements of federal law. The County requests that the Regional Board rely upon the authority of the Clean Water Act and include the discharges that are enumerated in 40 C.F.R. 122.26(d)(2)(iv)(B)(1) which specifically includes, "irrigation water" but not "irrigation water from agricultural sources."[3]

THE TENTATIVE ORDER IMPOSES INSPECTION REQUIREMENTS ON THE PERMITTEES THAT WOULD VIOLATE THE FOURTH AMENDMENT

Part VI.2 states:

> "The Permittees shall carry out inspections, surveillance, and monitoring necessary to determine compliance with their ordinances and permits. The Permittees' ordinance must include adequate legal authority to enter, inspect and gather evidence (pictures, videos, samples, documents, etc.) from industrial, construction and commercial establishments."

Through this statement, the Regional Board is requiring the Permittees to violate the Fourth Amendment's prohibition on illegal searches and seizures. The Fourth Amendment to the U.S. Constitution states:

> "The right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated; and no Warrants shall issue but upon probable cause, supported by Oath or affirmation, and particularly describing the place to be searched, and the persons or things to be seized."

The Fourth Amendment is clear in its policy of protecting the security and privacy rights of individuals against unpermitted or unwarranted governmental invasions. The Permittees' ordinance cannot allow unpermitted entry into private property for the purpose of inspection or collection of evidence to ensure compliance with the Permittees' Water Quality Ordinance. Any entry into an industrial, construction or commercial establishment must be by permission of the

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[3] See 40 CFR 122.26(d)(2)(iv)(B)(1).
A description of a program, including inspections, to implement and enforce an ordinance, orders or similar means to prevent illicit discharges to the municipal separate storm sewer system; this program description shall address all types of illicit discharges, however the following category of non-storm water discharges or flows shall be addressed where such discharges are identified by the municipality as sources of pollutants to waters of the United States: water line flushing, landscape irrigation, diverted stream flows, rising ground waters, uncontaminated ground water infiltration (as defined at 40 CFR 35.2005(20)) to separate storm sewers, uncontaminated pumped ground water, discharges from potable water sources, foundation drains, air conditioning condensation, *irrigation water*, springs, water from crawl space pumps, footing drains, lawn watering, individual residential car washing, flows from riparian habitats and wetlands, dechlorinated swimming pool discharges, and street wash water (program descriptions shall address discharges or flows from fire fighting only where such discharges or flows are identified as significant sources of pollutants to waters of the United States); (emphasis added)

owner or through administrative warrant as provided for in the County's existing Water Quality Ordinance. The County requests that Part VI.2 be amended to state:

> "The Permittees shall carry out inspections, surveillance, and monitoring necessary to determine compliance with their ordinances and permits. The Permittees' ordinance must include adequate legal authority, to the extent permitted by California and Federal Law and subject to the limitations on municipal action under the constitutions of California and the United States, to enter, inspect and gather evidence (pictures, videos, samples, documents, etc.) from industrial, construction and commercial establishments."

THE TENTATIVE ORDER INAPPORPRIATELY IMPLEMENTS TMDLS DEVELOPED BY U.S. EPA FOR IMPAIRED WATER SEGMENTS IN THE LOS ANGELES REGION

Part XVIII.B.4 of the Tentative Order requires Permittees with discharges tributary to Coyote Creek or the San Gabriel River to meet WLAs for Coyote Creek. Part XVIII.B.5 requires the County, as Principal Permittee, to develop a monitoring program to monitor flows in Coyote Creek. The results are to be evaluated against numeric targets for Coyote Creek. (We refer to these two provisions as the "Coyote Creek TMDL provisions.") The Tentative Order does not indicate how the WLAs or numeric targets were developed. There is a reference in Part XVIII.B.1 to a Coyote Creek TMDL developed by U.S. EPA and the Los Angeles Regional Board. Presumably this refers to the TMDLs for Metals and Selenium for San Gabriel River and Impaired Tributaries established by U.S. EPA for the Los Angeles Region (the "San Gabriel River Metals TMDL").[4]

The County objects to the Coyote Creek TMDL provisions for several reasons. First, the provisions would essentially implement a TMDL for a segment of Coyote Creek that is not listed as impaired. That is not permissible under the Clean Water Act. Under the Clean Water Act and U.S. EPA's implementing regulations, states are to identify impaired water segments ("water quality limited segments" or "WQLS"), rank them in order of priority, and then establish TMDLs for those segments according to their ranking. *See, e.g.,* ***San Francisco Bay Keeper v. Whitman***, 297 F.3d 877, 880 (9th Cir. 2002). Coyote Creek is in the San Gabriel River watershed. Its upper reach is located in Orange County within the jurisdiction of the Santa Ana Regional Board. Its lower reach is in Los Angeles County within the jurisdiction of the Los Angeles Regional Board. The Los Angeles Regional Board has listed the lower reach as an impaired water segment under section 303(d) of the Clean Water Act.[5] The Santa Ana Regional Board, however, has not listed the upper reach as an impaired segment, nor has it proposed the

[4] Neither the Fact Sheet for the Tentative Order nor the Findings in the Tentative Order provide any detail on the Coyote Creek TMDL provisions. The Fact Sheet discusses the San Gabriel River Metals TMDL not in the TMDL section of the document but rather in a section titled "Sub-Watersheds and Major Challenges." The County agrees that attempting to implement and enforce a TMDL developed for one region by the Regional Board of another region would be a "major challenge."

[5] The Los Angles Regional Board's current "2006 CWA Section 303(d) List of Water Quality Limited Segments Requiring TMDLs" identifies 13 miles of Coyote Creek as impaired for various pollutants and stressors.

upper reach for listing as impaired under section 303(d). *See* Santa Ana Regional Board, **2006 CWA Section 303(d) List of Water Quality Limited Segments Requiring TMDLs**.

Because the upper reach of Coyote Creek is not listed as an impaired segment (*i.e.*, a WQLS), it is not appropriate to establish a TMDL for that segment.[6] The fact that the upper reach (nonimpaired) flows into the lower reach (impaired) of the Coyote Creek is irrelevant. If the Regional Board could establish WLAs for nonimpaired water segments simply because they flow into impaired segments, it would render meaningless the mechanism for listing water ***segments***, and then developing TMDLs for those ***segments***. *See, e.g.,* State Water Resources Control Board, ***Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List***, adopted September 30, 2004. Rather than calling for TMDLs on a segment by segment basis, under the Tentative Order's "tributary discharge" approach the Clean Water Act would simply have required TMDLs on a watershed-wide basis.

The second reason the County objects to the Coyote Creek TMDL provisions is that they effectively implement a TMDL where no implementation plan currently exists. As the Tentative Order acknowledges, there is no implementation plan for the Coyote Creek TMDL.[7] An implementation plan "describes the approach and required activities required to ensure that the allocations are met." *See* State Water Resources Control Board, ***Total Maximum Daily Loads (TMDL) Questions & Answers***, (April 2001). Until a TMDL, including an implementation plan, is incorporated into the Regional Board's Basin Plan, the TMDL is not enforceable. *Id.*

For other established TMDLs in the Santa Ana Region, where no implementation plan has been adopted, the Tentative Order simply requires that the Permittees continue participating in the development of the implementation plans. *See, e.g.,* Parts XVIII.B.1 and 3. For the Coyote Creek TMDL, however, the Tentative Order requires Permittees to develop and implement source control BMPs designed to meet the Coyote Creek WLAs and to monitor Coyote Creek flows and evaluate the results against Coyote Creek numeric targets for total recoverable metals. In other words, Permittees are required to effectively implement the Coyote Creek TMDL. However, unless a Coyote Creek TMDL is developed and incorporated into the Santa Ana Basin Plan, the Santa Ana Regional Board cannot require Permittees to implement the TMDL. Accordingly, the County objects to the Coyote Creek TMDL provisions.[8]

Finally, and related to the above grounds, the County objects to the Coyote Creek TMDL provisions to the extent the Regional Board appears to be attempting to adopt and implement a TMDL for the upper reach of Coyote Creek without going through the rigorous public process

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[6] States may adopt "informational" TMDLs for water segments not identified as impaired. These are "estimated" TMDLs, for the purpose of developing information only. *See* Clean Water Act Section 303(d)(3).

[7] As noted above, the Coyote Creek TMDL referenced in Part XVIII.B.1. of the Tentative Order presumably refers to the TMDLs for Metals and Selenium for San Gabriel River and Impaired Tributaries established by U.S. EPA for the Los Angeles Region.

[8] The Tentative Order provides that Permittees' source-control BMPs will be required "until a TMDL implementation plan is developed." As noted above, if the Santa Ana Regional Board amends its Basin Plan to incorporate a TMDL (including an implementation plan) for the upper reach of Coyote Creek, Permittees may be required to meet a waste load allocation to implement the TMDL. An implementation plan developed by the Los Angeles Regional Board for the lower reach of Coyote Creek and incorporated into the Los Angeles Basin Plan would be irrelevant to dischargers located in the Santa Ana region tributary to the upper reach of Coyote Creek.

required to establish and implement a TMDL. If the Regional Board intends to establish, implement, and enforce TMDLs for the upper reach of Coyote Creek, it needs to conduct a water body assessment for the segment, develop LAs and WLAs for the segment, develop an implementation plan for meeting the allocations, amend the Santa Ana Basin Plan to incorporate the TMDLs, and allow public participation in the process. *See* State Water Resources Control Board, ***Total Maximum Daily Loads (TMDL) Questions & Answers***, (April 2001). It cannot simply adopt the allocations and implementation plan developed by or for another Regional Board for a downstream waterbody.[9]

An example of how cross-jurisdictional TMDL development could occur is found in the San Francisco Regional Board's mercury TMDL for the San Francisco Bay. In that TMDL, the San Francisco Regional Board included a waste load allocation for sources within the Central Valley Region whose discharges are tributary to San Francisco Bay. However, at the same time, the Central Valley Regional Board was developing its own mercury TMDL for upstream water bodies. The San Francisco Regional Board's WLA for the Central Valley Watershed, in effect, represents the reduction that will be obtained once the Central Valley Regional Board's TMDL is implemented. In other words, the San Francisco Regional Board's allocation is more of an accounting mechanism that assures sources within the jurisdiction of the San Francisco Regional Board are credited with the reductions that will be obtained through the Central Valley Regional Board's TMDL once it is implemented.[10] The San Francisco Board did not attempt to enforce its WLA on Central Valley Region sources, nor did the Central Valley Regional Board simply adopt the San Francisco Board's allocation as its own.[11]

CONCLUSION

In summary, the Tentative Order has included requirements that are outside the scope of authority given to the Regional Board by the Clean Water Act's NPDES program. The goal of the Tentative Order is to reduce the discharge of pollutants in urban stormwater runoff to waters of the U.S. to the maximum extent practicable to protect water quality standards. The Regional Board must ensure that the requirements in the Tentative Order are not prescriptive and are in compliance with federal law. The County hopes that the Regional Board will consider the numerous methods in which compliance with the MEP standard can be accomplished and that

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[9] Both the Fact Sheet and the Findings state that Permittees are "expected to implement programs and policies consistent with the metals and selenium TMDLs for the San Gabriel River watershed." In other words, they are "expected" to implement the Coyote Creek TMDLs developed for the Los Angeles region.

[10] San Francisco Regional Board staff refused to assign allocations to individual Central Valley sources, stating that "these sources are outside our jurisdiction, and the Central Valley Water Board is developing mercury TMDLs that will more effectively address these sources . . ." ***Staff Report, Proposed Amendment to the Water Quality Control Plan (Basin Plan) for the Sun Francisco Bay Region to Establish San Francisco Bay Mercury Total Maximum Daily Load (TMDL) and Implementation Plan***, Meeting Date: September 15,2004.

[11] Perhaps a better example of how to address waters crossing jurisdictional boundaries can be found in the Tennessee E. Coli TMDL approved by U.S. EPA. *See,* ***Total Maximum Daily Load (TMDL) for E. Coli in the South Fork Holston River Watershed*** (September 2006). The Tennessee TMDL identifies impaired waters in a portion of the watershed that is located in Virginia. Tennessee did not attempt to adopt a TMDL for the Virginia waters or impose allocations. Rather, it simply acknowledged the issue and indicated that Virginia is addressing it through its own TMDL for fecal coliform.

the Regional Board will not impose requirements that are appropriately handled through other regulatory mechanisms.

ATTACHMENT B

TECHNICAL ISSUES AND COMMENTS ON TENTATIVE ORDER NO. R8-2008-0030 NPDES NO. CAS618030

INTRODUCTION

Attachment B contains the principal technical comments of the County of Orange (the "County") on Tentative Order NO. R8-2008-0030 dated November 10, 2008 ("Tentative Order"). These comments are divided into three sections: (1) General Comments; (2) Findings; and (3) Sections. At times, the issues and concerns raised will pertain to more than one section of the Tentative Order.

The County has endeavored to provide a complete set of comments on the Tentative Order. However, the County reserves the right to submit additional comments relating to Tentative Order No. R8-2008-0030 and the supporting Fact Sheet/Technical Report to the Regional Board in the future.

GENERAL COMMENTS

TENTATIVE ORDER IS INCONSISTENT REGARDING THE NAMING OF THE PERMITTEES THAT ARE REGULATED

The Tentative Order inconsistently identifies the Permittees in three primary locations, a) the subject line in the Fact Sheet, b) the header in the Tentative Order, and c) the header in the Monitoring and Reporting Program (MRP). All references should consistently identify the Permittees as:

"The County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County within the Santa Ana Region"

FINDINGS

TENTATIVE ORDER REQUIREMENTS AND NUMERIC EFFLUENT LIMITS

- **Maximum Extent Practicable (A.3., page 2)**
  The Tentative Order includes a definition of Maximum Extent Practicable (MEP) that is inconsistent with current case law, the Fact Sheet and the definition included in the current NPDES permit.

  The Fact Sheet States (VI., page 13):

  Maximum Extent Practicable (MEP) means to the maximum extent feasible, taking into account equitable considerations of synergistic, additive, and competing factors,

including but not limited to, gravity of the problem, technical feasibility, fiscal feasibility, public health risks, societal concerns, and social benefits.

However, the Tentative Order states (A.3., page 2):

MEP is not defined in the Clean Water Act; it refers to management practices, control techniques, and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of pollutants taking into account considerations of synergistic, additive, and competing factors, including, but not limited to, gravity of the problem, technical feasibility, fiscal feasibility, public health risks, societal concerns, and social benefits.

By modifying the definition of MEP to include "and such other provisions as the Administrator or the State determines appropriate for the control of pollutants…", the Regional Board appears to have determined, contrary to current case law, that the discretion that the state has to use "such other provisions" is a part of the definition of MEP. However, we would strongly disagree with that interpretation and submit that this discretion is outside of the definition of MEP and, therefore, subject to California law.

Under federal law, municipal stormwater discharges must comply with section 402(p) of the Clean Water Act, which requires that cities reduce stormwater to the maximum extent practicable. (33 U.S.C. Section 1342(p)(3)(B)(iii)) Whenever a Regional Board imposes pollutant restrictions in a wastewater discharge permit more stringent than what federal law requires, California law requires the Board to take into account the public interest factors of Water Code section 13241, which includes economic factors and the cost of compliance. (City of Burbank v. State Water Resources Control Bd. (2005) 35 Cal.4th 613, 627.). Thus, if the Regional Board seeks to impose any requirements that go beyond those set forth in section 402(p), the Regional Board must evaluate the public interest factors in Water Code section 13241 prior to permit adoption.

As such, the County recommends that the Finding be modified as follows to be consistent with the Fact Sheet definition:

MEP is not defined in the Clean Water Act; it refers to management practices, control techniques, and system, design and engineering methods, ~~and such other provisions as the Administrator or the State determines appropriate~~ for the control of pollutants taking into account considerations of synergistic, additive, and competing factors, including, but not limited to, gravity of the problem, technical feasibility, fiscal feasibility, public health risks, societal concerns, and social benefits.

- **Illegal Discharges Definition (N.70., page 22)**
  The explanation in Finding N.70, that the first term permit required the Permittees to: ... (2) eliminate illegal and illicit discharges to the MS4s…is incorrect. Section II. 9 of NPDES N. CA 8000180 established a responsibility for the Permittees to *Respond to emergency situations such as ..... illegal discharges/illicit connections*. Further, Section II.1. of this permit required the dischargers to …*prohibit illegal discharges*. In response

to these obligations, the Permittees developed and adopted local legal authority creating a prohibition on *illicit connections* and *prohibited discharges* (see Sec. 9-1-40. of the Codified Ordinances of the County of Orange for example). The Finding should be revised for consistency with this programmatic history and specific use of the terms *illicit connection* and *prohibited discharge* in Orange County.

- **Illegal Discharges Definition (N.70., page 22)**
  Finding N.70, for the first time, defines illegal discharges to include "any discharge (*or seepage*) to the municipal separate storm sewer that is not composed entirely of stormwater and not one of the authorized discharges" [emphasis added]. This is problematic for several reasons.

  First, this new definition of illegal discharges will significantly impact the Permittees' resources and does not fit within the context or intent of the illegal discharges/illicit connections (ID/IC) program. The Permittees have a program to address illegal discharges (Section 10 of the Drainage Area Management Plan and Local Implementation Plan). This comprehensive program includes procedures for detecting, responding to, investigating and eliminating these types of discharges in an efficient and timely manner. Including "seepage" in this definition means that the Permittees may now have to use a series of resource intensive investigations in order to detect these types of discharges within the channels and underground pipes. Further – they would then have to investigate these discharges, but do not have a way to eliminate them given that the discharges are resulting from groundwater seeping into the channels. Short of sealing the channel bottom and walls, which is not technically feasible, these types of discharges can not be eliminated. Thus, it is unclear how the Permittees can be expected to include this whole new category of passive, groundwater seepages into the ID/IC program and remain in compliance with the permit.

  Second, the inclusion of a new category of discharges, "seepage", seems counter to the definition of illicit discharges provided in Finding 11 on page 4. The definition states"Illicit discharge means any *disposal*, either intentionally or unintentionally, of material or waste that can pollute urban runoff or create a nuisance. [emphasis added]". This definition includes an intent to actively "dispose" of a material or waste. It does not seem to include passive groundwater seepage that enters the storm drain system.

  The County recommends that the Finding be modified as follows:

  Illegal discharge means any discharge ~~(or seepage)~~ to the municipal separate storm sewer that is not composed entirely of stormwater except for the authorized discharges listed in Section III of this permit. Illegal discharges include the improper disposal of wastes into the storm sewer system.

NEW DEVELOPMENT/SIGNIFICANT REDEVELOPMENT – WQMP/LIP/LID

- **Effective Impervious Area (L.62., page 19)**
  Finding 62 identifies that USEPA has determined that, by limiting the effective impervious area (EIA) of a development site to 5% or less, downstream impacts could be minimized. However, USEPA, in several statements made by Dr. Cindy Lin at the November 14, 2008 CASQA General Meeting, has recently suggested that the 5% EIA metric should only be considered as an example and that USEPA is open to consideration of other metrics for low impact development (LID).

  > "At EPA Region IX, we're strongly promoting LID strategies that lead to infiltration, evapotranspiration, capture and re-use of stormwater to maintain or restore natural hydrology and improve water quality."
  >
  > "We're encouraging permitting agencies to, as much as possible, incorporate LID provisions into MS4 permits with clear, measurable, and enforceable requirements."
  >
  > "The new MS4 permits should include quantitative requirements to enable all parties to clearly identify performance expectations for LID implementation and permit provisions should include specific enforceable and measurable requirements that will result in water quality improvement."
  >
  > "We completely understand that there is still the science going on, but it is now our job also to have some kind of a target goal and so, for us, even with Ventura County having a 5% effective impervious area, we're not saying that that is what you absolutely have to do. We are saying – here's an example of a draft permit with something that is specific, that's concrete, that's quantitative, that we can understand. That, later when we come back, we can say – did we meet this goal?"
  >
  > "Given your best judgment, your expert opinion, on what you experience and what you are seeing on the ground, what are those specific requirements you can give back to your Regional Board. We want to make sure that there is something workable. We are asking that you come to us and say – this is what we can do, this is what we can put in a permit."

  Further, at the same November 14, 2008 CASQA General Meeting the principal author of the cited Southern California Coastal Water Research Project (SCCWRP) study effectively refuted the notion that their work constituted advocacy for a 5% EIA performance standard for land development. These comments and observations point to the lack of a technical consensus on a performance standard for land development intended to produce urbanized landscapes that better mimic the hydrological response of undeveloped areas.

  The County would submit that, in order to resolve current uncertainty and ensure that the technically valid objectives for the land development program are established, there

needs to be an opportunity to continue to develop a contextual approach for Orange County through a stakeholder driven process that incorporates input from those engaged in design and implementation of LID based practices. In addition to resolving areas of technical uncertainty, such a process would also provide an opportunity to integrate stormwater management into efforts to comply with other mandates such as SB 375, which requires the development of sustainable community strategies, and AB1881, which focuses on water conservation. Alternative language for Finding 62. is provided below.

~~*62. The USEPA has determined that by limiting the effective impervious area of a development site to 5% or less, downstream impacts could be minimized (also see the SCCWRP study20). A limited study conducted by Dr. Richard Horner21 concluded that a 3% EIA standard for development is feasible in Ventura County. These principles are incorporated into requirements for new developments and redevelopment projects.*~~

62. *There are many different quantitative metrics and approaches that have been approved and/or are being considered throughout California and the country to ensure that LID-based principles are incorporated into development projects The variety of metrics and approaches is a result of the fact that this is a newly emerging area for stormwater programs and the uncertainty regarding the technical feasibility of implementation and the nexus to water quality benefits.*

Integration of LID into new and redevelopment stormwater standards has taken several forms including (but not limited to) peak flow controls, volume reduction, onsite retention, volume reduction tied to a pollutant load target, and impervious area reduction. Examples of each approach are provided below.

- *Peak flow controls - post-project/development is equal to or less than pre-project/development plus treatment control*

  Contra Costa County: Requires peak flow control (post-development ≤ pre-development) plus treatment control. Standards also prioritize the use of BMPs with the first preference being no net increase of impervious cover and second preference being the use of specified infiltration practices. The framework for compliance demonstration makes use of the preferred practices easier than conventional practices, such as detention basins. This requirement applies to both new development and significant redevelopment alike. Available at: www.cccleanwater.org/new-developmentc3/stormwater-c3-guidebook/.

- *Volume reduction – post-project/development stormwater runoff volumes be reduced to levels equal to or less than pre-project/development stormwater runoff volumes*

  Los Angeles County: Recently adopted an ordinance that requires that post-development stormwater runoff volumes be reduced to levels equal to or less than pre-development stormwater runoff volumes. This requirement applies to

both new development and redevelopment alike. Available at: http://planning.co.la.ca.us/spGreenBuildingProgram.htm.

- *Onsite retention - onsite retention of the volume from a specified design storm.*

  City of Santa Barbara: Requires the onsite retention of the runoff volume from 1-inch/24 hr storm. This requirement applies to both new and redevelopment and does not specify preference for low impact development strategies (e.g., possible that requirement could be met through use of detention basin or on-site retention. Available at: www.santabarbaraca.gov/NR/rdonlyres/91D1FA75-C185-491E-A882-49EE17789DF8/0/Manual_071008_Final.pdf

- *Volume reduction tied to a pollutant load target*

  State of Virginia: Virginia is considering the use of a volume reduction requirement tied to a target phosphorus load reduction. Developers must apply LID strategies to meet the target phosphorus load. If the target load cannot be met solely through the use of LID strategies, additional conventional BMPs (such as wet ponds) can be used to meet the remaining load requirement. Available at: www.cwp.org/Resource_Library/Center_Docs/SW/RRTechMemo.pdf.

- *Impervious area reduction - significant redevelopment projects reduce existing site imperviousness by some percentage (typically 10-20%).*

  State of Maryland: Requires that all significant redevelopment projects reduce existing site imperviousness by 20%. Where site conditions prevent the reduction of impervious area, BMPs (preference is stated for LID strategies) shall be implemented to provide treatment control for at least 20% of site imperviousness. A combination of impervious area reduction and treatment controls may be used. The State is in the process of revising the Maryland Stormwater Design Manual to better integrate LID strategies for new development. A summary of the redevelopment policy can be found at: www.mde.state.md.us/assets/document/Urban_redevelopment%202005.pdf.

In order to identify and implement the most appropriate metric and approach for development in the Orange County area, the permittees should utilize a stakeholder driven process and engage those experienced with LID design and implementation, those engaged in LID research, those engaged in review and approval of development projects, as well as other interested stakeholders including the Regional Board, and environmental groups.

- **Existing Model WQMP (L.63., page 20)**
  Finding 63 refers to the Model WQMP developed by the Permittees and the requirements for inclusion of site design, source control, and treatment control BMPs for new development and significant re-development projects. However, this discussion does not recognize the inclusion in the Model WQMP of *Section 7.II -3.2.4 Identify Hydrologic Conditions of Concern (HCOC)*. This section identifies the process to determine if a project site's hydrologic regime would be considered a condition that would have a significant impact on downstream natural channels and habitat integrity, alone or in conjunction with impacts of other projects. Where downstream conditions of concern have been identified, the project is required to maintain the pre-project hydrologic conditions affecting downstream conditions of concern by incorporating site design, source control, and treatment controls. Since adoption of the Model WQMP, new development and significant re-development projects are required to perform this assessment and incorporate appropriate BMPs to ensure existing hydrologic conditions are maintained. Certain jurisdictions have employed HCOC mapping efforts to assist developers in identifying areas where HCOC conditions exist. The County proposes a mapping effort to identify HCOC areas in the Santa Ana Region of Orange County while an appropriate LID metric is developed. This effort will provide a tool that project proponents can use to better comply with the existing HCOC requirements of the Model WQMP.

  The County recommends that additional language be added to Finding 63. to provide an interim measure and tool to protect susceptible areas while the development standards are being revised.

  Incorporated into the Model WQMP and required in the development of a WQMP for new development and significant re-development projects is Section 7.II -3.2.4 "Identify Hydrologic Conditions of Concern (HCOC)". An HCOC exists if a change to a project site's hydrologic regime would be considered a condition of would have a significant impact on downstream natural channels and habitat integrity, alone or in conjunction with impacts of other projects. Currently, new development and significant re-development projects are required to perform this assessment and incorporate appropriate BMPs to ensure existing hydrologic conditions are maintained. Certain jurisdictions have employed HCOC mapping efforts to assist developers in identifying areas where HCOC conditions exist. In the interim, while the development standards are being revised, the permittees will conduct an HCOC mapping effort in the first six months after adoption of the Order to identify HCOC areas in the Santa Ana Region of Orange County.

SECTIONS

DISCHARGE LIMITATIONS/PROHIBITIONS

- **"Presumption" and Public Education Requirements (III. 3. i. Page 30)**
  Consistent with the federal regulations and prior permits, Section III.3. of the Tentative Order notes that certain discharges need not be prohibited by the Permittees unless they are identified as a significant source of pollutants. The Tentative Order also notes in Section III.3. that changes to the list of exempted discharges (including changes made by the Regional Board) should be predicated on a finding that a particular type of discharge is a significant source of pollutants. There is no finding in the Tentative Order that justifies the requirement that all of these previously exempted discharges should now be presumed to be significant sources of pollutants until determined otherwise.

  The Tentative Order also requires the Permittees to incorporate public education and outreach activities directed at reducing certain categories of discharges even if they are not substantial contributors of pollutants to the MS4s and receiving waters (such as air conditioning condensate, passive footing drains, etc.). In the absence of any supportive finding regarding either of these new requirements, the Discharge Limitations/ Prohibitions section of the Tentative Order (Order No. R8-2002-0010)should be retained.

- **Categories of Discharges (III. 3. i. c. Page 31)**
  The Tentative Order includes a new category of discharge "irrigation water from agricultural sources". Although the discharge limitations/prohibitions have typically included a category entitled "landscape irrigation, lawn garden watering and other irrigation waters" the nexus to agriculture sources has never been made in previous permits and is counter to the federal regulations [40 CFR 122.26(d)(2)(iv)(B)(1)].

  The proposed inclusion of the new category is also inconsistent with the Findings and Fact Sheet, specifically:

  > Finding C.13, page 5 – "*Urban* activities also generate non-storm water discharges such as air conditioning condensate, *irrigation runoff*, individual residential car washing, etc., generally referred to as de minimus type of discharges." [emphasis added]
  >
  > Finding M.68, page 21 – "The MS4s generally contain non-storm water flows such as *irrigation runoff*, runoff from non-commercial car washes, runoff from miscellaneous washing and cleaning operations, and other nuisance flows *generally referred to as de-minimus discharges*." [emphasis added]
  >
  > Finding S. 87, page 27 – "The Coastal Zone Act Reauthorization Amendments of 1990 (CZARA), Section 6217(g), requires coastal states with approved coastal zone management programs to address non-point source pollution impacting or threatening coastal water quality. CZARA addresses five sources of non-point pollution: *agriculture*, silviculture, *urban*, marinas, and hydromodification. *This*

> *order addresses the management measures required for the urban category*, with the exception of septic systems. Compliance with requirements specified in this Order relieves the permittees for developing a non-point source plan, for the urban category, under CZARA. The Regional Board addresses septic systems through the administration other programs. [emphasis added]
>
> Fact Sheet IV, page 6 – "In addition, there are storm water discharges from *agricultural land uses*, including farming and animal operations. However, *the CWA specifically excludes agricultural discharges from regulation under this program*." [emphasis added]

The category "irrigation water from agricultural sources" needs to be deleted from the Tentative Order and, instead, be addressed through other regulatory mechanisms.

LEGAL AUTHORITY

- **Reporting (VI. 6, page 34)**
  The Tentative Order includes a section that requires the Permittees to report threats of potential violations of the Industrial or Construction General Permits. This requirement essentially requires the Permittees to make a determination regarding the compliance status of a regulated entity with these permits. Since the Permittees do not administer or enforce those permits, the only reporting that can be provided is with regard to conformance with local codes and ordinances. The Section should be modified as follows:

  6. The Permittees shall continue to provide notification to Regional Board staff regarding stormwater related information gathered during site inspections of industrial and construction sites ~~regulated by the Statewide General Storm Water Permits and at sites that should be regulated under those Statewide General Permits~~. The notification shall include any significant ~~observed violations, or threat of potential~~ violations of the ~~General Permits~~ local codes and ordinances ~~(e.g., problematic housekeeping issues),~~ prior history of violations, any enforcement actions taken by the Permittee, and any other relevant information. (Also see notification requirements under Sections VIII, IX, and X of this Order.)

LITTER, DEBRIS AND TRASH CONTROL

- **Trash Characterization (VII. 5, page 36)**
  The Tentative Order requires each Permittee to undertake trash characterizations. The Section should be modified to identify this requirement as solely an obligation of the Principal Permittee.

MUNICIPAL INSPECTIONS OF COMMERCIAL FACILITIES

- **Types of Commercial Facilities (X.1, page 40 and 41)**

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The Tentative Order adds 11 new categories of commercial facilities that will be subject to Permittees inspection. This new requirement, which represents a significant investment of resources for the Permittees, is not supported within the Findings or Fact Sheet. Although the Permittees agree that the commercial program and related inspections need to be continued during this permit term, it is critical that any new categories of commercial facilities that are added are documented as significant source of pollutants within this region. The new categories of commercial facilities should be deleted from the Tentative Order until such a time that these types of facilities have been determined to contribute a significant pollutant load to the MS4.

Commercial facilities may include, but may not be limited to:

~~*a) Transport, storage or transfer of pre-production plastic pellets.*~~
b) Automobile mechanical repair, maintenance, fueling or cleaning;
~~*c) Airplane repair, maintenance, fueling or cleaning;*~~
~~*d) Marinas and boat repair, maintenance, fueling or cleaning;*~~
~~*e) Equipment repair, maintenance, fueling or cleaning;*~~
~~*f) Automobile impound and storage facilities;*~~
~~*g) Pest control service facilities;*~~
h) Eating or drinking establishments, including food markets and restaurants;
i) Automobile and other vehicle body repair or painting;
~~*j) Cement mixing, concrete cutting, masonry facilities;*~~
~~*k) Building materials retail and storage facilities;*~~
~~*l) Portable sanitary service facilities;*~~
m) Painting and coating;
~~*n) Animal facilities such as petting zoos and boarding and training facilities;*~~
o) Nurseries and greenhouses;
p) Landscape and hardscape installation;
q) Pool, lake and fountain cleaning;
~~*r) Golf courses;*~~
s) Other commercial sites/sources that the permittee determines may contribute a significant pollutant load to the MS4; and,
t) Any commercial sites or sources that are tributary to and within 500 feet of an area defined by the Ocean Plan as an Area of Special Biological Significance.

- **Types of Commercial Facilities (X.1, page 40 and 41)**
The Tentative Order added the commercial facility category "transport, storage or transfer of pre production plastic pellets". While the Permittees understand the intent of the Regional Board in wanting to add these facilities to the program so that they are inspected, this category of facilities are better suited for the industrial program instead of the commercial program. In the Los Angeles Region, due to the types of facilities that typically handle pre-production plastic pellets, the stormwater inspection staff has inspected plastic products manufacturing facilities to determine compliance with the Industrial General Storm Water Permit. The County recommends that this category of facility be moved to the industrial program.

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- **Inspection Frequencies (X.2, page 41)**
  The Tentative Order added a new requirement that, after the Permittees prioritize the commercial facilities for inspection based on the threat to water quality (based upon established criteria such as type of facility, location, potential for discharge, history of discharges, proximity and sensitivity of receiving waters, and materials used and generated at the site), there must be a minimum percentage allocation of the prioritized sites (10% high priority, 40% medium, and remaining % low) within the commercial facility inventory.

  There is no justification in the Findings or Fact Sheet for this designation. If the use of the prioritization system and/or criteria are viewed as problematic, then the Permittees would recommend that the Tentative Order address revisiting the existing system to fix potential flaws instead of arbitrarily assigning percentage breakdowns.

  The County recommends revising this language as follows:

  Each permittee shall conduct inspections of its commercial facilities as indicated below. To establish priorities for inspection, the permittees shall continue to prioritize commercial facilities/businesses within their jurisdiction as a high, medium or low threat to water quality based on such factors as the type, magnitude and location of the commercial activity, potential for discharge of pollutants to the MS4, any history of unauthorized, non-stormwater discharges, proximity and sensitivity of receiving waters, material used and wastes generated at the site. Within 6 months of the adoption of this Order, the permittees shall review their existing prioritization system, criteria, and results based on the inspections, and determine if any modifications are necessary. The modifications shall be completed within 6 months of the determination and reported on in the annual report. ~~*The following minimum criteria must be met: 10% of commercial sites (not including restaurants/food markets) must be ranked 'high' and these represent the greatest threat to water quality35; 40% of commercial sites (not including restaurants/food markets) must be ranked 'medium'; and, the remainder may be ranked 'low'*~~.

- **Mobile Businesses (X.8, page 42)**
  The Tentative Order adds a new requirement to develop and implement a mobile business program for four (4) categories of mobile businesses including a) mobile auto washing/detailing, b) equipment washing/cleaning, c) carpet, drape, and furniture cleaning, and d) mobile high pressure or steam cleaning. The program must include the tracking, identification of BMPs for the mobile businesses, development of an enforcement strategy, a notification effort for all businesses, and the development of an outreach and education program.

  If the Tentative Order is going require the development and implementation of a significant new element of the commercial program, the Findings and Fact Sheet must also provide a technical basis for this addition. Mobile businesses present a unique regulatory challenge in stormwater regulation for several reasons including:

- The regular, effective practice of unannounced inspections is difficult to impossible to implement;
- Identifying mobile businesses is difficult because they are often not permitted or licensed; and
- Mobile businesses are transient in nature, advertise a mobile phone number as the only means of contact and may have a geographic scope of several cities or the entire region.

The Tentative Order should include language that limits the scope of the section until the costs and benefits of the program are better understood by allowing the Permittees to identify a mobile business category that may be a significant source of pollutants and develop a pilot regulatory program. The pilot program, to be completed in the first three years of the permit, would allow the Permittees to work together on a regional basis to develop and then implement an appropriate framework for addressing mobile business over the balance of the permit term.

Within 12 months of adoption of this order, the ~~principal~~ permittees shall develop a mobile business pilot program. The pilot program will address one category of mobile business, which may include: mobile auto washing/detailing; equipment washing/cleaning; carpet, drape, furniture cleaning; or mobile high pressure or steam cleaning. The pilot program will include at least two (2) notifications of the ~~all~~ individual ~~mobile~~ businesses operating within the County concerning the minimum source control and pollution prevention measures that they must ~~develop and~~ implement. ~~For purposes of this order, mobile businesses include: mobile auto washing/detailing; equipment washing/cleaning; carpet, drape, furniture cleaning; and mobile high pressure or steam cleaning. The mobile businesses shall be required to implement appropriate control measures within 3 months of being notified by the permittees. Within 12 months of adoption of this order, the principal~~ The pilot program will also include the ~~permittee shall~~ development of an outreach and enforcement strategy to address mobile businesses. ~~Each~~ The permittees shall ~~also~~ develop and distribute ~~the~~ BMP Fact Sheets for the mobile business selected ~~es that has been developed by the permittees~~. At a minimum, the mobile business BMP Fact Sheets ~~/training program~~ should include: laws and regulations dealing with urban runoff and discharges to storm drains; appropriate BMPs and proper procedures for disposing of wastes generated ~~from each mobile business~~.

RESIDENTIAL PROGRAM

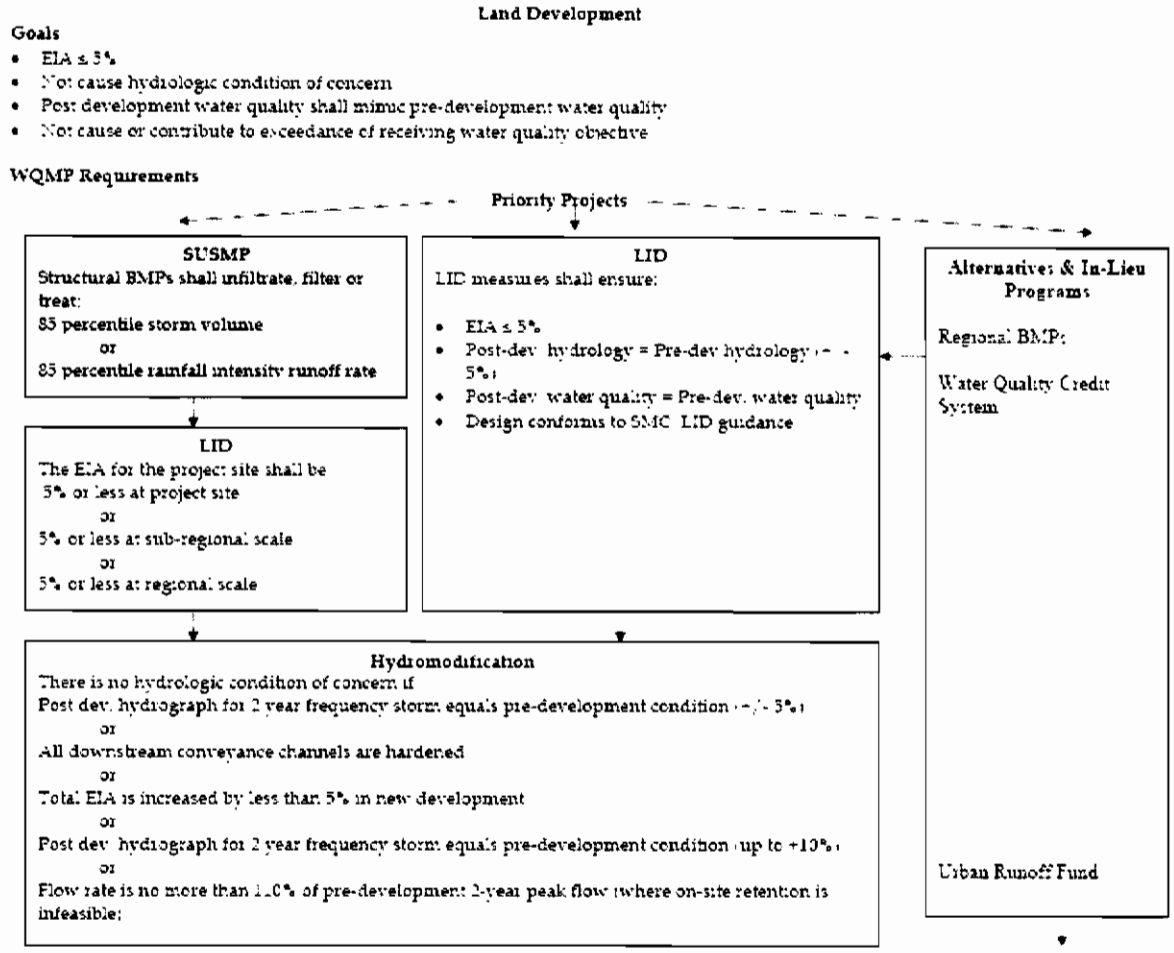
- **Pollution Prevention Measures (X.1.2, page 43)**
  The Tentative Order adds a new requirement for the development and implementation of a residential program to reduce the discharges from residential areas to the maximum extent practicable. Given the success of the Permittees' public education and outreach program – Project Pollution Prevention – which has demonstrably changed residents' awareness and behaviors in Orange County, this requirement appears duplicative of existing education and outreach efforts. However, there is also a concern that the

obligation to "require" residents to implement BMPs is contrary to current educational approaches which are striving to engender a stewardship ethic and may ultimately erode public support. If this section is retained, the County recommends that it be modified as follows:

> *2. The permittees should identify residential areas and activities that are potential sources of pollutants and develop Fact Sheets/BMPs. At a minimum, this should include: residential auto washing and maintenance activities; use and disposal of pesticides, herbicides, fertilizers and household cleaners; and collection and disposal of pet wastes. The permittees shall encourage ~~require~~ residents to implement pollution prevention measures. The permittees should work with sub-watershed groups (e.g., the Serrano Creek Conservancy) to disseminate latest research information, such as the UC Master Gardeners Program36 and USDA's Backyard Conservation Program.*

NEW DEVELOPMENT (INCLUDING SIGNIFICANT RE-DEVELOPMENT)

The New Development provisions include significant new requirements related to SUSMP, LID and Hydromodification. The flow chart provided below is an attempt to graphically represent the County's understanding of and interplay between these provisions as currently written.



For the reasons stated in the comments related to Finding 62, the County believes that there is a vital need to develop a contextual approach to the revised land development provisions of the Tentative Order. Instead of seeking to establish a Countywide performance standard for land development upon permit adoption, these new requirements need to be developed in a stakeholder driven process with the goal of producing a substantially revised Model WQMP within 12-24 months. The elements of the revised Model WQMP would include an integration of SUSMP, LID and hydromodification requirements informed by consideration, on a watershed-by-watershed basis, of the opportunities and constraints presented by the urbanized landscape, water balance within each watershed, the ecological condition of individual stream systems, and other mandates (as previously noted) for more sustainable patterns of urban and sub-urban development. Provided in the sections below are the detailed technical comments that encompass the County's vision for New Development in the Orange County area.

The County is also concerned about the provision relating to pre-approved projects (XII. J, p. 58). Requirements for LID and hydromodification will need to be considered at the earliest stages of project conception and design and so those projects that are in the middle or nearing the end of project design but do not have an approved WQMP at the time of adoption of the

permit will be required to re-design the project, placing an undue burden on project proponents. Consequently, the County strongly recommends that the "grandfathering" provision of the current permit be used to avoid major disruption and undue burden to projects that are close to completion of their design phase.

A. GENERAL REQUIRMENTS

- **WQMP Guidance (XII.A.2., page 44)**
  Section XII.A.2. requires that the Permittees, within 6 months of adoption of the Tentative Order, develop a WQMP guidance document to more effectively ensure that water quality protection, including LID principles, are considered in the earliest phases of a project. The schedule for developing this guidance does not allow sufficient time to develop and institutionalize an effective guidance document through the necessary consultative stakeholder process. The Tentative Order should also therefore be modified to allow at least 12 months for each Permittee to revise its LIP at the same time to be consistent with the WQMP guidance.

  2. Within 12 months of adoption of this order, the principal permittee, in collaboration with the permittees, shall develop a guidance document utilizing a stakeholder driven process for the preparation of conceptual or preliminary WQMPs to more effectively ensure that water quality protection, including LID principles, is considered in the earliest phases of a project. ~~The appropriate revisions to the DAMP to incorporate this guidance shall be submitted with the first annual report after adoption of this permit~~. Within ~~12~~ 18 months of adoption of this order, each permittee shall revise its LIP to be consistent with the guidance. The permittees are encouraged to require submission of a conceptual WQMP as early in the planning process as possible.

- **CEQA Document Preparation Review (XII.A.6, page 45)**
  Section XII.A.6 requires the Permittees to perform an annual review of their planning procedures and CEQA document preparation processes. Review of the planning procedures and the CEQA document preparation processes on an annual basis is unnecessary. The Tentative Order should be modified to require that a review of the planning procedures and CEQA document preparation processes should be completed concurrently with finalization of the revised land development provisions of the DAMP.

  6. The permittees shall ~~continue to~~ review their planning procedures and CEQA document preparation processes at the time of DAMP finalization and no later than 24 months after the adoption of the Order, ~~on an annual basis,~~ to ensure that urban runoff-related issues are properly considered and addressed. If necessary, these processes shall be revised to consider and mitigate impacts to stormwater quality. Should findings of the review result in changes to the above processes, the permittee shall include these changes in the LIP and submit a revised copy of the LIP to the Regional Board with the next annual report. The permittees shall ensure that the following potential impacts are considered during CEQA reviews:...

B. WATER QUALITY MANAGEMENT PLAN (WQMP) FOR URBAN RUNOFF (FOR NEW DEVELOMENT/SIGNIFICANT REDEVELOPMENT)

- **Commercial and Industrial Developments (XII.B.2.(c), page 47)**
  Section XII.B.2.(c) lowers the threshold criterion for commercial and industrial developments to comply with WQMP requirements from 100,000 square feet to 10,000 square feet. The findings and fact sheet should explain the basis for lowering the threshold criterion.

- **Streets, roads, highways** – This provision especially the proposed LID requirement is particularly difficult for linear projects. In lieu of applying the LID requirement to streets, roads and highway the County suggests that these type of projects be required to incorporate where feasible EPA's *Managing Wet Weather with Green Infrastructure: Green Streets.*

- **Retail Gasoline Outlets (XII.B.2.(j), page 47)**
  Section XII.B.2.(j) includes, as a category of priority development projects, Retail Gasoline Outlets of 5,000 or more square feet with a projected average daily traffic of 100 or more vehicles per day. However, the fact sheet does not provide any technical basis for inclusion of RGOs as a priority development project category. It should be noted that the DAMP already prescribes a suite of BMPs specific to RGOs. Subjecting RGOs to WQMP requirements imposes duplicity where it is not needed. Section XII.B.2.(j) should be removed from the Tentative Order.

- **WQMP Goals (XII.B.3., page 48)**
  Section XII.B.3. Identifies goals associated with WQMPs. However, these "goals" are currently written as specific requirements in a section that otherwise addresses project thresholds for WQMP preparation and numeric sizing criteria for treatment controls. The placement is confusing regarding how subsections a-d relate to each other and how they are to be addressed in Section XII.B.4 Treatment Control Sizing. Sections XII.B.3 (a), (b), and (c) should be relocated to a separate discussion of overall goals regarding introducing all the land development provisions of the Tentative Order.

- **Structural Infiltration BMPs (XII.B.5., page 49)**
  Section XII.B.5.(d) requires the vertical distance from the bottom of the infiltration system to seasonal high groundwater must be at least 10 feet. However, the Fact Sheet does not provide any technical basis for the distance of 10 feet. In fact, studies by NURP and Nightingale (1975; 1987a,b,c; 1989) and F. Napier (2008) have identified that pollutant removal occurs for most pollutants in the first several inches of soil. Furthermore the State Water Board is currently developing proposed regulations and waiver for onsite wastewater treatment plans (OWTS). These regulations may be relevant and provide a more technically based approach to protect groundwater from infiltration BMPs. The technical basis for the distance of 10 feet should be provided or the language should be revised to state that the vertical distance should be based on an adequate protection of groundwater defined as no impact to groundwater quality. Section

XII.B.5.(f) identifies that systems must not be used for areas of industrial or light industrial activity and areas subject to high vehicular traffic (25,000 or more daily traffic). Clarification of a definition of "light industrial" should be specified in the Tentative Order. The Fact Sheet does not provide any technical basis for the exclusion of high vehicular traffic of 25,000 or more daily traffic and thus should be removed.

- **Structural Infiltration BMPs (XII.B.7., page 50)**
  Section XII.B.7. appears to require that WQMPs are to be required for all non-priority projects. There are many types of non-priority projects, such as interior re-modeling, which do not meaningfully lend themselves to the preparation of a WQMP. The County requests that Section XII.B.7. be revised to be consistent with DAMP Section 7.6.2 which establishes the scope of project applicability with respect to WQMP requirements.

C. LOW IMPACT DEVELOMENT TO CONTROL POLLUANTS IN URBAN RUNOFF FROM NEW DEVELOPMENT/SIGNIFICANT REDEVELOPMENT

- **LID Site Design Principles (XII.C.1., page 50)**
  Section XII.C.1. identifies a list of site design BMPs that should be taken under consideration during each phase of priority development projects. However, the list provided is a confusing mix of goals, tasks, and work products which does not provide a clear basis for compliance. The list needs to be revised with thought toward a potential future checklist of required considerations. Reference to accepted or forthcoming LID guidance, such as the USEPA LID Guidance or the future SMC Technical Guidance Manual, respectively, should also be considered.

- **LID Site Design Principles (XII.C.2., page 51)**

  It is not clear why the major discussion of LID includes prescribed source control BMPs. For the purposes of clarity, Section **XII.C.2** should be deleted.

- **LID & Effective Impervious Area (XII.C.3., page 51)**
  Section XII.C.3. requires the EIA for the project site shall be limited to 5% or less. However, consistent with the comments provided regarding Finding 62, the County would submit that EIA is not an appropriate project specific performance metric for LID. The County would submit that in order to ensure feasibility of compliance as well as water quality benefits associated with an LID metric that the Permittees develop an integrated and contextual approach focused on volume retention and reduction through a stakeholder process. This process would incorporate input from LID designers, academia engaged in LID research, municipal stormwater and plan check staff, and environmental groups to develop requirements that more effectively emphasize LID, can be feasibly implemented and is protective of water quality. The development of an appropriate LID metric is anticipated to require 12 months.

The County recommends that Section XII.C.3. be rewritten to provide for the development of a contextual approach for the Orange County permit. Alternative language for Section XII.C.3. is provided below.

Within 12 months from the date of adoption of this Order, the permittees shall identify a quantitative metric for incorporation of LID-based principles, update the new development standards, and adopt the new development standards to be in compliance with the development related requirements within the Order. In order to complete this, the principal permittee shall utilize a stakeholder driven process that includes, to the extent feasible, representatives from the permittees, LID designers, academia engaged in LID research, municipal plan check staff, Regional Board staff, and environmental groups. The development metric and approach, once agreed upon by the stakeholders, will be submitted to the Regional Board Executive Officer for approval.

Section XII.C.3. (a) identifies that pervious areas should have the capacity to percolate excess runoff from a two-year storm event. Percolation is not the only method for reducing the volume of runoff from a site and the Tentative Order should recognize the option for capture and onsite reuse.

Footnote 50 and 51 in sections XII.C.3. (a) and (b) refer to Footnote 38 which refers to the "Metropolitan Water District Evaluation of the Landscape Performance Certification Program" which appears to not be the correct reference.

- **Substitution of Treatment Controls for LID Measures (XII.C.4., page 53)**
  The County presumes that the intention of Section XII.C.4. is to allow project proponents to substitute LID measures for treatment controls if certain conditions are met and not the reverse substitution option currently prescribed by this section.

D. HYDROLOGIC CONDITIONS OF CONCERN (HYDROMODIFICATION)

- **Hydrologic Conditions Assessment (XII.D.1., page 54)**
  Section XII.D.1. requires each priority development project to ascertain the impact of development on the site's hydrologic regime. This analysis should not be required if a hydrologic condition concern does not exist (i.e. downstream conveyance channels are engineered, hardened, and regularly maintained as identified in Section XII.D.2).

  Each priority development project shall be required to ascertain the impact of the development on the site's hydrologic regime and include the findings in the WQMP, including the following for a two-year frequency storm event, except those projects that do not have a hydrologic condition of concern as identified in Section 2 below:

- **Hydrologic Conditions of Concern (XII.D.2.(c), page 54)**
  Section XII.D.2. (c) identifies that a hydrologic condition of concern is not present if the total effective impervious cover on a site is increased less than 5%. With respect to the hydrologic performance of a site, any performance metrics should be expressed in terms of runoff volume reduction.

- **Hydrologic Conditions of Concern (XII.D. page 54)**
  The County recommends that an additional provision be added to Section XII.D. Certain Permittees have employed HCOC mapping efforts to assist developers in identifying areas where HCOC conditions exist. In the interim, while an appropriate LID metric is developed, the Permittees will engage in an HCOC mapping effort to identify HCOC areas in the Santa Ana Region of Orange County. This effort will provide a tool that project proponents can use to comply with the HCOC requirements as part of the Model WQMP and provide an enhanced benefit to help maintain hydrologic conditions in those areas most susceptible to water quality degradation due to new development and significant redevelopment. The proposed language for the new provision Section XII.D.5. is:

  Within 12 months from the date of adoption of this order, the principal permittee shall develop a map to identify the HCOC areas in the Santa Ana Region of Orange County. This map will identify those areas susceptible to water quality degradation including downstream erosion and adverse impacts on physical structure, aquatic and riparian habitat due changes in the volume, peak discharge, and time of concentration for runoff associated with new development and significant re-development.

PUBLIC EDUCATION AND OUTREACH

- **Outreach Activities (XIII.4, page 59)**
  The Tentative Order added a new requirement that the Permittees conduct individual or regional workshops for various business-related sectors on an annual basis. However, past experience with these types of workshops has shown that it is very difficult to garner the support of the business community and to have them attend since they are concerned about time spent away from the office. Instead of spending the resources on the development and implementation of workshops, which are very time intensive for everyone, it is suggested that the Permittees explore other, alternative methods and provide outreach to the business sector through existing mechanisms including industry related events, chamber of commerce, etc. Thus, the County recommends that the section be modified as follows:

  4. The permittees shall continue their outreach and other public education activities. Each permittee should try to reach the following sectors: manufacturing facilities; mobile service industry; commercial, distribution and retail sales industry; residential/commercial landscape construction and services industry; residential and commercial construction industry; and residential and community activities. ~~Individual workshops (or regional workshops) for each of the aforementioned elements shall be administered by each permittee (or on a countywide basis) by July 1, 2010 and on an annual basis thereafter~~. The permittees shall propose, by July 1, 2010, the mechanisms that will be used to outreach to the above mentioned business-related sectors and the frequency at which the mechanisms will be utilized. Commercial and industrial facility inspectors shall distribute developed educational information (Fact Sheets) to

these facilities during inspections. Further, for restaurant, automotive service centers and gasoline service station corporate chains, new information or that which has been previously developed shall be provided to corporate environmental managers during outreach visits that should take place twice during the permit term. The outcomes from all outreach requirements contained herein shall be reported in the applicable annual reports.

MUNICIPAL FACILITIES

- **Conveyance System Inspection (XIV, page 60)**
  The Tentative Order prescribes that stormwater conveyance systems be inspected annually. Following systematic, thorough and repeated inspection of the underground portions of the conveyance system during earlier permit terms, the County requests that the obligation to annually inspect conveyance systems apply only to the open channel portions of the system.

TRAINING

- **Training Program (XVI, page 62-63)**
  The Tentative Order prescribes that a schedule of training be delivered by the Principal Permittee an annual basis. Further to a specific ROWD commitment, the Permittees have developed a core competencies and skills based training program framework for 6 key areas of stormwater program functional responsibility predicated on a 2 year schedule for the development and delivery of a significantly revised training modules. The County requests that the training requirements be revised for consistency with this framework. In addition, the requirements should allow a Permittee to deliver its own equivalent training in lieu of receiving training from the Principal Permittee.

WATERSHED ACTION PLANS AND TMDL IMPLEMENTATION

- **Waterbodies with Technical TMDLs (B.3, page 66)**
  The Tentative Order includes a description of the selenium and nitrogen-related efforts within the watershed and describes the collaborative approach that has been utilized over the past 4 years. However, the section then goes on to describe what may occur if the stakeholders do not participate or if the collaborative approach "fails to achieve the TMDLs". Since the collaborative approach is designed to assist in addressing the rising groundwater source and the Regional Board may issue waste discharge requirements for rising groundwater if the Permittees do not attempt to mitigate this source, the County recommends that the section be modified as follows so that this direct cause and effect is more explicit:

  3. ..... Through the Nitrogen and Selenium Management Program, the watershed stakeholders are collaboratively developing comprehensive nitrogen and selenium management plans, which are expected to form the basis, at least in part, for a revised nutrient TMDL implementation plan and the selenium implementation plan. A collaborative watershed approach to implement the

nitrogen and selenium TMDLs for San Diego Creek and Newport Bay is expected to continue. ~~As long as the stakeholders are participating in and implementing the collaborative approach, if approved, they will not be in violation of this order with respect to the nitrogen and selenium TMDLs for San Diego Creek and Newport Bay~~. The stakeholders' participation in and implementation of the collaborative approach will satisfy any wasteload allocations assigned to the permittees under this permit for compliance with the nitrogen and selenium TMDLs. In the event that ~~any of the stakeholders does not participate, or if~~ the collaborative approach is not approved or ceases to exist, ~~fails to achieve the TMDLs~~, the Regional Board ~~will~~ may exercise its option to issue individual waste discharge requirements or waivers of waste discharge requirements.

- **Numeric Effluent Limits (E, page 73) [Also addressed in Attachment A]**
  Although Section XVIII discusses the requirements for TMDLs including the related targets and wasteload allocations, section XVIII E incorrectly identifies that "numeric effluent limits" are included within the Tentative Order for the TMDLs. The County contends that this language is counter to the intent of the Tentative Order for the following reasons:
    - Numeric effluent limits are monitored at the end of pipe – section XVIII recognizes in numerous places that the monitoring for the TMDLs is within the receiving waters, not end of pipe
    - Numeric effluent limits are used to assess compliance with the Permit – if the discharger exceeds the effluent limit, they are out of compliance with the Tentative Order/requirement. However, the Tentative Order identifies within the Receiving Water Limitations (Section IV.) and Section XVIII.E. that compliance will be achieved through an iterative process with the application of more effective BMPs.

  Thus, the use of the term "numeric effluent limit" is incorrectly being used and should be replaced throughout the Fact Sheet, Findings and Tentative Order with "wasteload allocation" as follows:

  Fact Sheet –V., page 13
  The proposed order includes ~~numeric effluent limits based on the~~ wasteload/load allocations developed and approved by the Regional Board, State Board, Office of Administrative Law and the EPA.

  Fact Sheet – IX., page 17

  This order recognizes the significant progress made by the permittees during the first, second and third term permits in implementing the stormwater regulations. The permit also recognizes regional and innovative solutions to such a complex problem. For these reasons, the order is somewhat less prescriptive when compared to some of the MS4 NPDES permits for urban runoff issued by other Regional Boards. However, it incorporates an integrated watershed approach in

solving urban runoff related water quality and quantity issues. The proposed permit also includes ~~numeric effluent limits based on~~ wasteload/load allocations and an emphasis on implementation of low impact development principles. With these requirements, it should achieve the same or better water quality benefits because of the programs and policies already being implemented or proposed for implementation, including regional and watershed wide solutions.

The major requirements include: (1) Discharge prohibitions; (2) Receiving water limitations; (3) Prohibition on illicit discharges and illegal connections; (4) Public and business education; (5) Adequate legal authority; (6) Programs and policies for municipal facilities and activities; (7) Inspection Activities by the municipalities; (8) A program to address runoff from residential areas; (9) New development/re-development requirements including a requirement to fully implement low impact development principles and to minimize any hydrologic conditions of concern; (10) Waste load allocations for nutrients, sediment, and fecal coliform bacteria; metals, and pesticides, ~~including numeric effluent limits~~; and (11) Monitoring and reporting requirements.

Fact Sheet – IX., page 20

The proposed order includes special sections for the protection of impaired waterbodies. The 303(d) listed watebodies fall under the following four categories:

a. 303(d) listed with no TMDLs: The permittees are required to develop and implement pollutant-specific Watershed Action Plans to control the discharge of the pollutant causing the impairment.
b. 303(d) listed with a technical TMDL (no implementation plan): If the TMDL specifies a wasteload/load allocation for urban runoff or stormwater, the proposed order includes the appropriate load allocation ~~or a numeric effluent limit derived from it~~.
c. 303(d) listed with a TMDL implementation plan that has a compliance date beyond the permit term: The permittees are required to implement control measures to reduce the pollutant causing the impairment and monitor the progress towards achieving the wasteload allocation ~~target numeric effluent limit~~.
d. 303(d) listed with a TMDL implementation plan that requires meeting the target goals within the permit term: ~~Numeric effluent limits based on the~~ wasteload allocations are included in the proposed order.

Finding 72, page 23

This order includes wasteload allocations ~~numeric effluent limits~~ for those constituents for which the Regional Board has already established TMDLs. Consistent with the federal stormwater laws and regulations, the order does not include numeric effluent limits for other potential pollutants. Federal Clean Water Act requires the permittees to have appropriate controls to reduce the

discharge of pollutants to the maximum extent practicable, including management practices, control techniques and systems, design and engineering methods, and such other sections as the Administrator or the State determines appropriate for the control of such pollutants (33 USC 1342(p)(3)(B)). MEP is a dynamic performance standard and it evolves as our knowledge of urban runoff control measures increases.

Waterbodies with Technical TMDLs (E, page 73)

1. Except for sediment TMDLs in San Diego Creek and Newport Bay, compliance determination is based on monitoring within the receiving waters. For sediment TMDLs, compliance determination is based on end-of-pipe monitoring.

2. Based on the TMDLs, wasteload allocations ~~numeric effluent limits~~ are specified for most constituents. If the monitoring results indicate an exceedance of a wasteload allocation, ~~a violation of the numeric effluent limits,~~ the permittees shall reevaluate the current control measures and propose additional BMPs/control measures. This reevaluation and proposal for revisions to the current BMPs/control measures (revised plan) shall be submitted to the Executive Officer within 12 months of determining that a violation has occurred. Upon approval, the permittees shall immediately start implementation of the revised plan.

ATTACHMENT C

MONITORING AND REPORTING ISSUES AND COMMENTS ON TENTATIVE ORDER NO. R8-2008-0030 NPDES NO. CAS618030

INTRODUCTION

Attachment C contains the principal monitoring and reporting program comments of the County of Orange (the "County") on Tentative Order No. R8-2008-0030 dated November 10, 2008 ("Tentative Order").

The County has endeavored to provide a complete set of comments on the Tentative Order. However, the County reserves the right to submit additional comments relating to Tentative Order No. R8-2008-0030 and the supporting Fact Sheet/Technical Report to the Regional Board in the future.

COMMENTS

TRANSITION THE URBAN STREAM BIOASSESSMENT PROGRAM FROM A SOLELY NPDES SEMIANNUAL PROGRAM TO AN ANNUAL HYBRID PROGRAM

The Tentative Order requires continued implementation and evaluation of the Bioassessment element of the Monitoring Program (p. 85; III.1.f.). The County requests that this element of the monitoring program be revised to allow integration with the regional bioassessment monitoring initiative being coordinated by the Southern California Stormwater Monitoring Coalition through the Southern California Coastal Water Research Project (SCCWRP). The revision would transition the existing bioasessment monitoring to a program of annual surveys using Targeted (NPDES program) and Random (Regional program) sites.

ELIMINATE THE LAND USE CORRELATION PROGRAM ELEMENT

The Tentative Order requires continued implementation and evaluation of the Land Use Correlation element of the Monitoring Program (page 85; III.1.h). The County requests that the Land Use Correlation element be eliminated from the program for the following reasons:

- The most beneficial information from the Land Use Correlation program element has already been obtained from the development of the Hines Nursery/Northwood and Quail Hill areas of Irvine.
- The current monitoring locations in the drainage channels surrounding the former Tustin air station receive significant amounts of runoff from the adjacent neighborhoods. This interference effect makes assessment of the air station redevelopment difficult to isolate from ambient conditions. Further, downstream water quality has not shown any significant changes since development of the former Tustin air station began in early 2007.

REDUCE THE INLAND CHANNEL BACTERIOLOGICAL / PATHOGEN MONITORING PROGRAM

The Tentative Order requires continued implementation and evaluation of the Bacteriological / Pathogen Monitoring element of the Monitoring Program (page 85; III.1.e). Additional sampling of Newport Bay watershed sources began in 2005 at the request of the Regional Board for increased data collection to strengthen statistical power assessments of water quality conditions. Currently weekly channel monitoring is conducted in San Diego Creek and Santa Ana-Delhi Channel by both OC Environmental Health and the Orange County Program. This intensive monitoring requirement should now be reduced since almost four years of intensive data has been obtained.

ORANGE COUNTY VECTOR CONTROL District
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Mr. Mark Brown
California Regional Water Quality Control Board
Santa Ana Region
3737 Main Street, Suite 500
Riverside, CA 92501

RE: Tentative Order No. R8-2008-0030,
NPDES No. CAS618030

Dear Mr. Brown:

Thank you for the opportunity to comment on the Waste Discharge Requirements for the County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Tentative Order No. R8-2008-0030, NPDES No. CAS618030, Areawide Urban Storm Water Runoff. We appreciate that in recent years, the Santa Ana Regional Water Quality Control Board (the Board) has recognized the relationship between structural storm water treatment control BMPs and the propensity of these features to produce disease vectors (i.e., mosquitoes). The Board's incorporation of vector control considerations into pertinent permits and guidance documents is important in initiating changes needed to better protect public health.

The Orange County Vector Control District (the District), over the course of the last two years, has worked independently with staff from Regions 8 and 9 Boards and the Orange County Stormwater Program to raise awareness and address public health concerns associated with storm water BMPs and urban runoff. It has been the District's experience that structural storm water treatment control BMPs (i.e., media filters, vault separator units, bioswales, extended detention basins, constructed wetlands, and the like) can become significant mosquito breeding sources if not properly designed and regularly maintained. Difficulty with tracking responsible party/ownership information further compounds the problem. Additionally, the year-round non-storm water nuisance flows, more commonly known as urban runoff, in the municipal separate storm sewer system (MS4) conveyance infrastructure especially poses a threat to public health during the mosquito breeding season.

Measures called for in this draft tentative order and draft tentative order No. R9-2007-0002, the Orange County Municipal Storm Water Permit for the San Diego Region, begin to help address these issues at a time when West Nile Virus (a disease transmitted by mosquitoes to humans) is making a resurgence in the County and across the State. In 2008, Orange County had the highest incidence of West Nile Virus (WNV) cases since the local introduction of the disease in 2003. There were 71 human cases reported, four of which resulted in fatalities, and 692 dead birds tested positive for WNV. Any and all measures that can be taken to ensure the inclusion of vector minimization principles in the planning, design, operation, and management of structural storm water BMPs along with efforts to reduce nuisance flows will assist the District in our joint mission to protect and serve the public.

New NPDES requirements for the wide-scale implementation of structural storm water BMPs and some Low Impact Development (LID) features coupled with the threat of West Nile Virus have further exacerbated the need for cooperative efforts to find preventative solutions and long-term management strategies. The District is already faced with many such challenges and obstacles when treating hundreds of storm water BMPs that routinely breed mosquitoes throughout Orange County. Often District staff is unaware of storm water BMP features until they are reported by the public and have already become a nuisance or hazard. Those that are problematic are either poorly designed, improperly installed, or inadequately maintained (especially lacking in regular sediment removal and vegetation management). Structural storm water BMPs require proper and timely maintenance to ensure they meet water quality objectives and minimize potential for mosquito and vector production during the seasons when urban runoff flows continually into storm water structures. Vector control agencies, under the authority of the California Health and Safety Code (Sec. 2040), have the obligation and authority to require "the person or agency claiming ownership" to remove conditions that contribute to mosquito production (California Health and Safety Code Sec. 2060)

Some storm water BMPs are less likely to produce mosquitoes than others, depending on the structural design and surrounding conditions. Incorporating vector minimization principles and, when necessary, involving the District early in the planning process would help ensure that the most effective options are implemented and that disease vector production is avoided to the maximum extent practicable. This proactive approach would save project proponents, developers, and property owners the cost of having to make required changes after the BMP is in installed. This would also allow for planning of appropriate and safe access for inspection and treatment when necessary by vector control staff.

Furthermore, the District is forced to spend disproportionate amounts of the tax-payers resources on treating the most problematic storm water BMPs (like water quality treatment wetlands/basins). Some of these features require frequent treatment (at times as much as three to four times per week during mosquito breeding season), large amounts of biorational pesticides, and hundreds of man hours are required. This sort of intensive treatment, year

after year, can be avoided if these features included vector prevention elements. Compounding the problem, under certain circumstances, neglected BMPs are eventually viewed as providing "habitat" for certain species of animals. When this occurs, any subsequent maintenance procedures can be in violation of some other state, federal or international wildlife statute. It is not uncommon for the party responsible for the BMP to be in violation of the Health and Safety Code because of mosquito production, and potentially facing a violation of the Endangered Species Act (ESA) or other laws and regulations when they take the steps necessary to curtail mosquito production.

Since September of 2007 OCVCD has worked closely with the Orange County Stormwater Program (the Program) to examine and address the public health concerns and issues associated with stormwater BMPs as detailed above. The Program has been most gracious and agreeable to exploring ways to cooperatively minimize and mitigate vector control issues through, education, data sharing and reporting.

The District would like to emphasize the need for the Board to more adequately address dry weather nuisance flows in the context of the proposed Order, as such flows tend to concentrate pollutants and are a more persistent water sources in the MS4 and the watershed as a whole, which promote mosquito production.

In light of our current challenges and in anticipation of the additional, numerous storm water BMP features and Low Impact Development features that will be implemented and/or retrofitted in the future, we ask that the Board consider the following recommendations which would help to avoid, mitigate, and manage potential vector related issues associated with structural storm water BMPs.

- All storm water treatment BMPs should be planned and designed using vector minimization principles.
- Copermittees should submit relevant Priority Projects (and any others which may have an elevated potential create a vector-borne disease risk to public health) to the Orange County Vector Control District (OCVCD) for review.
- Copermittees should provide a list of properties (public and private) and responsible operators for, at a minimum, all treatment measures implemented from the date of adoption of the proposed Order. Information on the location and ownership of all existing and proposed storm water treatment measures should be sent to OCVCD.
- All storm water treatment BMPs should be outfitted with signage that identifies the type of BMP and responsible parties contact information in clear view (when applicable).
- OCVCD would like to receive copies of all storm water BMP annual reports.
- OCVCD would like to provide all municipalities with a vector education training workshop suitable for planning, public works, and management staff.
- Vector control considerations should be added to the municipal plan check approval process.

- The OCVCD website link should be added to all municipal website's storm water page.
- A section should be included in all Water Quality Management Plans (WQMPs) and /or Standard Urban Stormwater Mitigation Plans (SUSMPs) which details the vector minimization principles incorporated into project storm water BMPs. This section should detail access provisions for vector control staff for inspection and treatment. The WQMP should also include educational materials which discuss the potential for storm water BMPs to breed mosquitoes and harbor other vectors. These materials can be acquired from the OCVCD website.
- In an effort to minimize the threat to public health and liability resulting from mosquito production, the District proposes to work cooperatively with Board staff, municipalities, and storm water program managers to identify and report malfunctioning or neglected BMPs. During the mosquito breeding season the District staff of inspectors and seasonal personnel in the field numbers approximately 60. Our staff's daily presence throughout Orange County could help to serve as an extra layer of reporting on bad BMPs to the appropriate agency.

It is the District's belief that these recommendations will help minimize many of the mosquito and vector production problems associated with storm water BMPs required for compliance with water quality regulations. We recognize that the proposed tentative Order establishes a framework for areas that will aide in addressing our concerns and provide better opportunities to work cooperatively and share data. Below are specific changes that we would like the Board to consider incorporating into Tentative Order No. R8-2008-0030 which would more adequately address and ensure minimization of vectors associated with storm water BMPs. We believe that these suggestions will accomplish the intent of Finding No. 65.

Page 13. I. Potential Pollutants in Storm Water Runoff/ Impacts on Beneficial Uses
Add underlined:

#36. Add a reference to address vectors: <u>Stagnant water trapped in trash and debris provides creates breeding conditions for disease vectors (i.e., mosquitoes).</u>

#37. Add a reference to address public health threat caused by vector production.

Page 19 L. New Development/Significant Redevelopment

#61. Vector control concerns should be addressed in the Low Impact Development Manual for Southern California.

Page 25 P. Public Education/Participation

#80 Vector control issues should be incorporated into public education outreach to bring public awareness to the association of vector production and storm water BMPs and urban runoff.

Page 48 B. Water Quality Management Plan (WQMP) for Urban Runoff (For New Development/Significant Redevelopment):

WQMPs should have section where project proponent discussed vector minimization measures designed into structural treatment control BMPs and any measures to mitigate for vectors. Additionally, specific measures for vector control should be described in the Operation and Management Plan.

Add underlined:

#5. c) Structural infiltration treatment BMPs shall not cause a nuisance (i.e., breed mosquitoes) or pollution, as defined in .....

Page 52 C. Low Impact Development to Control Pollutants in urban Runoff From New Developments/Significant Redevelopment:

3. a. In general LID measures "at the project site" will increase the amount of standing water in and around homes and businesses where they are applied if aggressive maintenance is not conducted or if they are improperly sized. Our concern with this is that these features will not percolate in less than 96 hours if they are clogged. Unlike a more regional treatment approach which is more accessible for vector control treatment, this "project site" LID is less accessible and may create numerously more mosquito breeding sources in and around where people live and work.

Page 57 I. Operation and Maintenance of Post-Construction BMPs

In general, Operation and Maintenance Plans should have a section where the the project proponent details specific vector control mitigation measures that will be conducted to avoid and/or minimize vector production for all post-construction structural treatment control BMPs and LIDs. This should also clearly state who the responsible party is and the funding mechanism and maintenance and any needed vector control treatment.

Page 62 XIV. Training Program for Storm Water Managers, Planners, Inspectors and Municipal Contractors.

OCVCD provides a free annual (or as needed) vector control workshop for municipal staff.

The District appreciates this opportunity to comment on the tentative Order and looks forward to working with the Board to ensure that vector concerns are addressed as they relate to storm water BMPs.

Sincerely,

Amber Semrow

Amber Semrow
Biologist, OCVCD

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